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A "PERFECT PICTURE" SERVICE FOR CABLE

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ABSTRACT

The American cable television system has been optimized for medium quality transmission of a very large number of television signals. It has been generally assumed that these cable systems would be ideal media for the distribution of high resolution, wide bandwidth images. This is not necessarily so. Present S/N of VSB/AM transmission of 525 line NTSC signals is barely adequate. The increased bandwidth of high resolution images implies reduced S/N in present cable systems. Bandwidth reduction techniques and/or improved noise immunity in new image transmission techniques will be required, as well as reduced cable system noise. FM video transmission, with or without improved color encoding techniques, is proposed as the best means of providing high quality transmission of 525 line video.

BACKGROUND

'QUALITY' considerations in cable systems have concerned themselves almost exclusively with noise and distortion. In common with other frequency division multiplexed (FDM) transmission systems, cable systems tread a narrow path between noise and distortion. Signal levels which are too low result in excessively low C/N and consequent S/N, while signal levels which are too high produce excessive distortion Inadequate C/N results in 'snowy' pictures. The limiting distortion in multi-channel cable systems is now third order intermodulation. This results in 'waterfall' effects in non-coherent carrier systems and 'cross-talk' in coherent carrier systems. All of these effects are, of course, objectionable.

The cable systems business has evolved in a market environment in which variety, i.e. the number of signals, is more important than image quality. Systems operate with adjacent channels to pack the most signals into the least system bandwidth. Coherent carrier techniques are used to reduce distortion both by reducing peak composite signal levels and by reducing the subjective impairment effects of intermodulation. Video signal synchronization is being used by some systems to further reduce subjective effects of transmission distortions. Manufacturers of the thin film hybrid gain modules which are almost universally used in cable television repeater amplifiers are producing gain modules with remarkably good specifications for noise, distortion and flatness of frequency response.

Notwithstanding the remarkable sophistication of the equipment and the transmission technology, cable television image transmission must be considered mediocre by the standards employed by the television production industry. The cable television industry understandably tends to stretch the capabilities of the available equipment to the utmost. The FCC rules allow C/N as low as 36 dB. C/N in cable systems is measured in a 4 MHz bandwidth. It turns out that C/N in 4 MHz bandwidth translates almost directly to video weighted S/N with only minor numerical correction. Most recently designed cable systems aim for C/N of 43 dB. Although many cable subscribers, particularly those close to the distribution 'head-end', enjoy higher C/N ratio, many accept what video professionals would consider mediocre S/N. There is a similar pressure on intermodulation distortion, cable systems pushing for maximum economic efficiency and accepting image quality compromises.

This situation has arisen because cable television systems, by and large, do not serve sophisticated viewers. Most subscribers served by mediocre cable systems have mediocre receivers - by professional standards - and would not know a really good picture if it popped out of the screen and offered to make coffee. The present cable television market judges the value of the service by the number and variety of television program services, provided practical standards of 'barely perceptible' impairment are achieved.

Cable transmission engineers have generally overlooked one major parameter which, in my view, also affects transmission quality. The effect of multiple, closely spaced reflections is not fully understood. I believe that these reflections, arising from the small impedance mismatches caused by the myriad of connectors and devices in the transmission path, and the small imperfections of the coaxial cable itself, cause a slight 'smearing' of picture detail - a loss of 'crispness'. The visual effect is that of a reduction of transmission bandwidth, even though we know that the broadband transmission system has not itself directly reduced the transmission bandwidth. Our operations engineers get complaints from subscribers who have a chance to compare good quality local television signals as received direct from a local broadcaster and as received through the cable system. There is a small but noticeable impairment in this circumstance which does not have to do with C/N, intermodulation or signal processing considerations. I attribute the impairment, as I have said, to multiple, low level reflections in the cable system.

HIGH QUALITY TRANSMISSION OF NTSC SIGNALS

I consider this a topic of major importance. I am concerned that the new DBS services will point out picture quality 'disabilities' in cable service. I am told that COMSAT is designing an 'all-digital' origination center (Las Vegas) with the objective of providing absolute state-of-the art program origination for their DBS service. I believe that DBS service will be capable of providing higher quality image transmission than the present terrestrial television broadcasting system and certainly better than present cable systems. Cable television systems must anticipate this competitive pressure and respond with significant improvements in cable distributed image quality.

HIGH DEFINITION TELEVISION (HDTV - 1125 line) has excited a great deal of interest in the professional television community and is starting to get some attention from the popular press. The present HDTV concept originated with NHK and has been implemented to the present demonstration level by several Japanese equipment manufacturers - SONY, MATSUSHITA, NEC. The May, 1983 International Television Symposium in Montreux, Switzerland had a large scale HDTV demonstration with demonstration programs taped by CBS and several European (including USSR) broadcast authorities. SONY staged an impressive HDTV demonstration at the 1983 NCTA convention in Houston.

HDTV is 'spectacular', particularly when projected onto a large screen by a good quality projector. Images approach 35mm movie quality. The HDTV screen, as proposed by NHK, has a 5:3 aspect ratio compared to the 4:3 aspect ratio of conventional 525 line systems. The 5:3 aspect ratio approximates current 'wide-screen' motion picture presentation. Frame/field rate remains 30/60. The improvement in definition results in a significant increase in video bandwidth - about 20 MHz compared to the 4.2 MHz used by present broadcast systems. The system has, of course, high-fidelity stereo sound.

All of these attributes -

- 1125 scan lines
- 5:3 aspect ratio
- increased video bandwidth
- non-NTSC color encoding
- high fidelity stereo sound

result in a serious incompatibility with present broadcast television receivers. There is general acknowledgment that it will take many years to introduce HDTV as a broadcast service.

Just before going to Montreux I read an account of Joe Flaherty's presentation on HDTV at the NAB convention earlier this year. I am sure you know Mr. Flaherty as chief engineering executive at CBS. Flaherty was complaining that there hadn't been any major improvement in television program origination quality in the last few years. HDTV was a new breakthrough in this area. This report moved me to write to Flaherty. I pointed out that 99.9% of the television audience in this country has yet to see a 'good' 525 line picture.

I believe that we will experience a 'generation' (10 years) of improved 525 line television before HDTV (1125 line) becomes a major factor in television broadcasting. It might turn out that improved 525 services actually delay introduction of 1125 line HDTV services because of the renewed investment in high quality 525 line receiving equipment. HDTV can follow as a cable service in due course. We will have to invent a new 'superlative' to market it.

Americans have a long standing reputation for not caring much about television picture quality. I believe that there is a 'quality' market in America which can be 'sold' on quality video, and that they will pay a reasonable price to get it. I believe that this 'quality' market segment subscribes to cable and that cable is the best way to reach them.

There was a similar situation in phonographs thirty years ago. CBS developed the LP microgroove record. Recording engineers were able to produce records with much better audio quality than had ever been produced before. The existing phonographs just could not reproduce the sound quality that the recording artists and engineers were putting into the new records. People had LP players but the pick-ups, the amplifiers and the loud speakers just weren't good enough. Improved phonograph components were developed and found a ready market as 'high fidelity' audio. There has been a continuing market for improvements in audio equipment over the last thirty years. We may finally have achieved the end of the technology chain in audio as PCM techniques provide 'ultimate' recordings, and amplifier and loudspeaker engineers find it increasingly difficult to wring out the last minor imperfections in audio reproducing equipment.

'HIGH FIDELITY' 525 LINE VIDEO

There are three aspects of providing high quality 525 line service -

improvement of color encoding technique,

improvement of transmission,

improvement of color decoding technique and other aspects of image display.

ENHANCED VIDEO

Cable television represents a unique opportunity to introduce new color encoding techniques. Most cable systems firmly control subscriber terminal equipment - the addressable programmable converter/descramblers which are provided to control access to cable television services. The equipment is owned by the cable system and provided to the subscriber as part of the overall cable service. Much of this equipment operates in a baseband mode, i.e. they consist of complete demodulators which presently provide a composite video output. These baseband subscriber terminal units could just as easily provide improved color decoding with RGB output to the subscriber's video monitor. This improved decoding could be improved decoding of NTSC encoded color or it could be optimum decoding of a new, more sophisticated color encoding system, such as the C-MAC component system which has been proposed.

Program originators, such as national Pay-TV networks, could originate in both conventional NTSC video and an improved 525 line mode. Cable systems could similarly distribute in both modes - most have spare channel capacity during a changeover period. When a cable system has completed a changeover of all of its subscriber terminal equipment it would distribute in the improved mode only, although program originators would have to distribute in dual mode to allow for a longer period of changeover in all of their affiliates. Alternately a cable network operator could provide head-end decoding and transcoding equipment for those affiliates who were not immediately prepared to change from NTSC distribution. Cost and complexity would be comparable to the video encyphering that some of these network operators will be providing soon.

Television broadcasters would have a more difficult conversion since they do not have the dual service transmission capability that many cable systems have. The market created by cable systems would, however, speed the introduction and acceptance of new-standard receiving equipment. Local broadcasters would, however, be under competitive pressure since the cable distributed networks would be taking advantage of the improved transmission technologies. Local broadcasters could meet this competition by setting up local area direct feeds of enhanced video to cable systems in their service area.

I am not an expert in the detail of various enhanced 525 line video systems which are being proposed, but I do perceive that they offer a significant enhancement potential and that cable systems can speed the introduction of a worthy enhanced video proposal.

IMPROVED CABLE TRANSMISSION - PERFECT PICTURE

The cable television industry is substantially committed to its present plant. It would be a very expensive and difficult task to replace amplifiers or other major components in existing or 'under-construction' cable systems. Feed-forward amplifiers, with significantly reduced distortion (at least 16 dB reduction in third order intermodulation) are on the brink of widespread acceptance and availability. Widespread retrofit of existing systems will, however, be quite expensive. Use of feed-forward amplifiers in cable system trunks would improve system C/N but would still leave the system with the problem of multiple, low level reflections.

Most new cable systems have 'spare' bandwidth available. I am proposing to several of my client systems that this bandwidth be traded for 'quality' in the traditional way, by use of frequency modulation (FM) transmission. In the first phase of an image quality improvement program the cable system would use FM transmission of ordinary NTSC video. FM transmission in a cable system would require 18 MHz of spectrum. Most new urban cable systems have enough spare spectrum to provide conventional VSB-AM transmission (6 MHz per channel) and high quality FM transmission (18 MHz per channel) at the same time. I call the service 'PERFECT PICTURE'. The FM video service would also have high quality stereo sound, probably in the form of discreet L and R subcarriers, but possibly in PCM digital format.

FM transmission would remove S/N as a quality compromise in cable system transmission. Other quality degradations in cable systems, such as intermodulation and 'reflections', have different, less visible, less objectionable manifestations in FM video transmission (intermodulation in the baseband and as small degradations in differential phase and gain).

Subscribers who opt for the 'PERFECT PICTURE' service would be provided with a special FM video receiver which would tune the desired FM video channel, demodulate and descramble it, and provide both composite and RGB outputs (as well as baseband stereo L and R sound outputs). 'PERFECT PICTURE' subscribers would be expected to have a high quality video monitor or projector in order to enjoy the benefits. It wouldn't make much sense to remodulate 'PERFECT PICTURE' to NTSC VSB/AM for an ordinary receiver. The special FM video receivers would be adapted from the DBS receivers which will now be manufactured in fair volume. The principal difference will be the tuner. The DBS receivers tune 12 GHz.

The cable version will, of course, tune cable FM video channels in the 50 - 550 MHz range.

Major cable television services are now distributed by satellite. Most broadcasting networks now (or will soon) distribute their servce by satellite as well. Another way to look at my proposal is that it 'splits' the satellite receiver. These satellite-based video transmission systems are designed to provide 'professional' grade transmission. PERFECT PICTURE places the satellite downconverter at the cable system head-end and places the rest of the receiver in the subscriber's home in order to maximize transmission quality. It puts the TVRO right in the living room!

The second phase of a transmission improvement program would introduce enhanced color encoding with compatible optimum decoding and other image display improvements in the subscriber terminal box.

HIGH DEFINITION SERVICES

HDTV creates special problems for cable transmission. 'Raw' HDTV has significantly increased video bandwidth. Transmission, even by spectrum conservative VSB-AM, will require substantially increased bandwidth compared to 525 line video. For purposes of discussion I will assume 20 MHz of bandwidth for noise calculation purposes.

It has become customary to calculate cable system noise (for NTSC transmission) in a 4 MHz bandwidth. The random 'KTB' noise in a 75 ohm system in a 4 MHz bandwidth is 1.1 microvolt or -59 dBmV. Overall transmission noise is calculated by taking into account amplifier noise figures and system operating levels. As I have said, the FCC minimum standard is 36 dB C/N. A C/N of 43 dB would be considered more usual for a 'good' cable system. This 43 dB C/N degrades by 7 dB to 36 dB C/N in the 20 MHz bandwidth of a HDTV transmission. HDTV service subscribers will probably have increased service quality expectations and the 43 dB S/N that we consider good for NTSC images might very well not be acceptable for HDTV images. I have not seen any published figures for S/N corresponding to various grades of HDTV transmission.

Frequency modulation might not be an available noise reduction option for HDTV transmission. We can realistically talk about 18 MHz transmission channels for enhanced 525 line PERFECT PICTURE service. FM for 20 MHz HDTV video would probably require at least 60 MHz per channel. This would cut our newest 500 MHz systems down to eight channels per cable. This kind of channel capacity reduction might be acceptable in Europe but is not acceptable here.

Some kind of bandwidth reduction technology would be very desirable. Feedforward amplifier technology might produce the 7 dB improvement in cable system C/N that conventional transmission would require. Some reduction in amplifier loading because of a reduction in the number of channels would also help somewhat. All in all, I fear that large scale, multi-channel HDTV service on cable will not be feasible without significant bandwidth reduction technology. I am sure that HDTV proponents are aware of this problem and that practical HDTV proposals will come forward with accompanying practical bandwidth reduction technologies.

CONCLUSION

I believe that image transmission improvement in cable will come about through a new public interest in high quality video. It will first take the form of enhanced 525 line video, which will be followed some considerable time later by HDTV services. Cable systems will lead in the introduction of enhanced 525 line transmission by providing FM transmission along with improved color encoding techniques.

A DIGITAL AUDIO SYSTEM FOR BROADCAST, CABLE, AND SATELLITE DELIVERY MEDIA

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ABSTRACT

The requirements for a digital audio system to be used for broadcast, cable, and satellite delivery media differ from those for recording in that the major economic consideration is the cost of the playback circuitry. This fact has been utilized in the digital audio system to be described. The system offers high quality sound at a relatively low data rate (on the order of 200-350 k bits/sec) and the option of audio scrambling. No precision components are required in the decoder minimizing cost. The performance, cost and data rate advantages are achieved by placing more sophisticated circuitry in the encoder. Applications being pursued include DBS, cable, pay-TV, and terrestrial broadcast systems.

INTRODUCTION

The system described in this paper (1) arose from Dolby Laboratories' continuing work on exploiting digital transmission and recording techniques without the high costs inherent in PCM. Previous papers (2) (3) concerned a proposed use of delta modulation for recording television sound on magnetic tape; a consumer VTR incorporating that system would contain both an ADC and a DAC (although much of the circuitry could be in common). In broadcasting only the DAC appears in the consumer's home. This paper describes a digital audio broadcasting system in which the DAC has been further simplified, at the expense of greater complexity in the (professional) ADC. The values assigned in the paper to various circuit constants reflect the probable first application, direct broadcasting of television sound via satellites, (525 line, 60 field/sec) but it will be apparent that the principles lend themselves to many other media.

Although much of the discussion concerns two-level differential quantizing (delta modulation) the noise reduction techniques could equally be applied to multi-level differential systems. However, this would not satisfy one of the design aims, elimination of the multi-level DAC, a component necessitating high precision in manufacturing.

PERCEIVED OBJECTIVES

We set ourselves the following goals:

A. We demanded a subjectively transparent system for delivery of the highest quality audio from the broadcast center to the consumer. The system should not introduce audible degradation to audio program material of the highest quality (not only the highest quality which is available today but the highest quality which can be expected to be available in the future).

B. The system should have a high tolerance of errors, such that only a modest degradation of audio quality shall be perceived when "worst case" error conditions occur.

C. The system should be economical. The receiving equipment should be very low in cost. The system should be efficient in usage of channel capacity since then more excess capacity will exist for flexibility to add additional channels, or revenue generating services, or more bandwidth will be available to the video signal.

D. The system should be practical in operation. The transmission equipment should not require any special attention (such as very accurate level adjustment to prevent clipping) which might exceed the capabilities of the broadcast personnel, or require the use of noncomplementary signal processing.

POSSIBLE SOLUTIONS

Considering these goals, we compared various digital encoding schemes.

A. High bit-rate linear PCM with sophisticated error corection.

This brute force approach can satisfy objectives A, B and D easily. However it falls short on objective C. It requires bit-rates of 700 kbit/s or more per audio channel, and is inherently expensive.

B. Efficient PCM with modest error correction.

Digital companding may be used to reduce the bit rate of solution A. Digital compandors resemble analog compandors in that the level of quantizing noise rises as the signal level rises; that is, digital compandors are fundamentally susceptible to noise modulation (defined as a modulation of the perceived background noise level by the audio signal). If the transmitted code has at least 10-bit resolution in the presence of full scale signals, and high frequency pre- and de-emphasis are used, then acceptable performance can be achieved. The resulting loss of high frequency headroom is acceptable with audio program material. The error correction system may be simplified if modest degradations in audio quality at high error rates are accepted and error concealment is employed to lessen the requirements for error correction. Bit rates can then be reduced to perhaps 350 kbit/s.

However the cost saving of this approach is only modest (if any) compared with solution A because the precision of the required DAC has not been reduced. The costs are dominated by the requirements for precise 14 to 16-bit D-A converters, sharp cut-off low pass filters, and the error correction circuitry.

C. Adaptive Delta-Modulation

Delta modulation has some significant virtues. The circuitry does not require any high precision components, and can be manufactured very economically with today's technology. Since all bits have essentially equal significance, isolated bit errors have a minor audible effect. One can consider operation without an error correction system, yielding a saving in bit rate and cost. However, linear delta modulation at the bit-rates under consideration (a few hundred kbit/s) has an inadequate dynamic range for high quality audio. We are therefore led to consider adaptive delta modulation (ADM).

Adaptive Delta-Modulation is a companded system so noise modulation must be considered. In contrast to companded PCM, noise modulation in an ADM system is caused not by high amplitude signals but by high slope signals. Noise modulation is worst in the presence of high frequency signals but the fact that high frequency signals effectively mask noise makes this characteristic acceptable and even preferable to that of companded PCM where high amplitude low frequency signals will produce noise modulation which may not be masked by the signals.

The usual technique for ADM involves coding into a single bit-stream both the audio information and the step-size or scaling information, so that the adaption of the delta modulator is necessarily output controlled. The significance of a bit then varies in accordance with the characteristics of the adaption algorithm, leading to a "gain blipping" effect on a small percentage of errors (which have hit "critical" gain control bits); this is the most noticeable degradation caused by errors on such a system. The effect can be reduced in magnitude by making the control signal move more sluggishly at the expense of poorer transient response. The adaption characteristic is therefore a compromise between speed of response (necessary for handling transient signals) and tolerance of errors; that is, objectives A and B above cannot be met together.

A judicious choice of fixed pre- and de-emphasis characteristic can provide a good compromise between audible noise modulation with mid frequency signals and high frequency handling capability, but is unsatisfactory when program material contains predominantly high frequency energy. The problem is not so much that the signals might overload the system, but that in this situation the de-emphasis curve in the decoder is more accurately described as a low frequency emphasis characteristic which actually increases low frequency noise (see section 7 below). Output controlled ADM with fixed emphasis may satisfy objective C, but is unlikely to meet objectives A and B.

OUTLINE OF NEW SYSTEM

During our work on digital audio for video tape we became very well acquainted with the promises and pitfalls of delta modulation.

A fundamental aspect of this new approach is that we have significantly increased the complexity and cost of the encoder (of which very few are required) in order to lower the cost of a decoder and to remove the performance limitations of a simple ADM system.

The "gain blipping" effect of a conventional ADM system has been substantially eliminated by extracting the step-size control information and then generating from it a separate low data rate bit stream. A simple algorithm is employed to convert this bit stream into a control signal of limited bandwidth and with this algorithm all bits have equal weight. It is thus impossible for an occasional bit error to cause much of a gain variation.

A low data rate control signal suggests a sluggish response which would yield poor transient performance. We have avoided degrading transient response by employing a delay line in the encoder. This technique allows a sluggish control signal to begin to rise in anticipation of an oncoming audio transient. The conventional tradeoff is not necessary and perfect transient performance is achievable with no additional cost in the decoder.

The performance compromise inherent in fixed pre-and de-emphasis is removed by the use of a variation on our proprietary "sliding band" pre-and de-emphasis. This powerful technique gives a larger improvement in noise modulation than fixed emphasis yet does not incur a penalty of reduced high frequency headroom or low frequency noise emphasis in the presence of predominantly high frequency program material.

The method of controlling the sliding band is similar to that used for the step-size. A circuit in the encoder analyzes the spectral distribution of the program material to determine the optimum placement of the sliding band. After a delay this emphasis is applied to the audio, and the control signal is encoded into a separate bit stream which is handled identically to the step-size bit stream. Again, because of the delay line, perfect dynamics are achieved by the encoding method. The decoder complexity is not affected.

Before explaining in greater detail, it is necessary to cover some theoretical points.

USE OF LIMITED BANDWIDTH CONTROL INFORMATION

In adaptive delta modulation, the step-size or unit of quantization is made variable, increasing with increasing slope of the input audio signal. The operation of the adaptive modulator is equivalent to sampling and quantizing an audio waveform which has been multiplied by a further waveform representing the variation of step-size.

When one waveform is multiplied by another, as in amplitude modulation, the output signal has an extended spectrum; in this case, each spectral line of the modulating (step-size) waveform fm adds a pair of modulation side-bands to each spectral line fa of the input audio, spaced from fa by ±fm.

Similarly the action of the adaptive demodulator is to introduce side-bands. In a perfect adaptive system, the modulation and demodulation products will have exactly equal amplitudes but opposite polarities, and will therefore cancel leaving only the desired audio. This discussion is true whether the adaptation occurs "instantaneously" that is, the step-size can change from one value to a distinctly different one between two adjacent sampling periods, or whether it occurs smoothly and is continuously variable.

In a real-world system, the encoder and decoder will not track perfectly because of component tolerances and/or transmission bit errors. In an instantaneous system, discrepancies between the encoding and decoding step-sizes leave modulation products spreading across the whole audio spectrum; if the noise and distortion of the overall system are not to be degraded audibly, the step-sizes must be defined with an accuracy comparable with the minimum resolution of the quantization.

In a continuously variable system, the modulation products resulting from mistracking are the side-bands mentioned above, attenuated by partial cancellation. The lower the bandwidth of the step-size control waveform (the smaller fm), the more tightly the modulation products are confined to the immediate vicinity of each audio spectral component.

The masking properties of any particular audio frequency are greatest near that frequency. For example, a 1 kHz signal makes low level noise and distortion components within a few hundred Hz of 1 kHz inaudible, but components at the extremes of the audio spectrum remain audible. It is this property of human hearing that makes it possible to design noise reduction systems without audible noise modulation.

Hence the narrower the bandwidth of the step-size control, the less audible will be the modulation products of mistracking, or the greater amount of mistracking can be tolerated. With the control bandwidth employed in our new system, approximately 50 Hz, mistracking of several percent remains inaudible on real program material, and component tolerances can be greatly relaxed. Furthermore error rates up to perhaps 10^{-2} in the control bit-stream can be accepted without correction.

OPTIMIZED ADAPTIVE DELTA MODULATION

The noise and distortion emerging from a complete ADM codec depends on (among other things) the nature of the audio input signal and the step-size; both these factors are varying all the time.

Consider a codec receiving and reproducing the simplest audio waveform, a constant amplitude sine-wave. As a function of step-size, the output noise and distortion will vary as shown qualitatively in figure 1.

In the region labelled a, the step-size is unnecessarily large, giving excessive quantizing noise. In region b the step-size is too small and the system is therefore in slope overload, giving high distortion. There is an optimum value of step-size for the particular input conditions, labelled c.

For each short time segment of real audio there is a curve like figure 1, and there is a best step-size. With discrete instantaneous adaptation in which the step-size can only adopt one of a limited number of values, it is clearly impossible to operate at the best values all the time, since they will inevitably lie between the available values.

With continuously variable adaptation it is possible to operate very near the best values. In a system employing limited bandwidth control information, the relevant time segment is a window related to the rise-time of the step-size control signal, in our case around 10 ms. From examination of the audio within a moving window of duration 10 or 15 ms, an optimum step-size can be generated which minimizes the noise and distortion from the codec.

Note that a conventional output controlled ADM system, in which the bit-stream carries two pieces of information, the audio and the step-size, cannot achieve optimum step-size, but remains in region a most of the time, moving into region b on signal transients. Also, of course, adequate response time for signal transients indicates that the bandwidth of the step-size adaptation must be wide (many kHz), implying a need for much greater precision.

VARIABLE PRE- AND DE-EMPHASIS

In an audio system whose noise is independent of the audio (for example, an amplifier with thermal noise or an FM broadcast system), the effects of fixed pre-and de-emphasis are easy to understand and to calculate.

The choice of emphasis characteristic is usually a compromise between noise reduction and overload characteristic, and in some applications noise reduction effect is offset by the need to reduce program level to the extent that little improvement in unweighted signal-to-noise ratio is observed. However the change in the spectrum of the noise may be audibly valuable.

In an optimized ADM system, the noise varies with the signal. At any fixed input frequency, the noise is directly proportional to the signal amplitude (that is, the instantaneous signal-to-noise ratio is constant), and at any fixed input amplitude the noise is directly proportional to signal frequency. Furthermore, unlike PCM, there is no clear system-defined maximum signal level which can be transmitted, although practical instrumentation may impose one.

The effects of fixed high frequency pre- and de-emphasis on such a codec are quite different. When the predominant audio input spectral components are at low or middle frequencies, that is in the unboosted area, emphasis does not change the demand on step-size in the ADC or DAC, the basic noise output of the demodulator is unchanged by emphasis, and hence subsequent de-emphasis reduces high frequency noise.

However, when a predominant audio input spectral component is within the area of frequencies boosted by emphasis, an increase step-size is demanded, with the result of increased noise output from the demodulator. The de-emphasis then does several things:

i) It restores the audio component to its correct (unboosted) level.

ii) It lowers the noise in the region of that component, but only back to the level it would have had without pre- and de-emphasis.

iii) It lowers the noise at frequencies above the audio component, but starting from the increased level.

iv) It has no effect on the low frequency noise, which therefore remains at its increased level.

Hence for high frequency signals, the effect of fixed pre- and de-emphasis is not primarily to degrade headroom or give distortion, but to <u>increase</u> low frequency noise, that is, the noise which is <u>least likely</u> to be masked by high frequency signals.

Consideration of the noise levels and spectra delivered by an optimized ADM codec operating at 200 or 300 kbit/s shows that there are three (overlapping) regimes to be considered if satisfactory noise shaping is to be employed.

A. When the predominant audio spectral components lie below roughly 500 Hz, a large high frequency pre- and de-emphasis will reduce noise sufficiently that audible noise modulation will not occur. An example of a practical emphasis characteristic is a 20 dB shelf starting at 800 Hz (see curve 1 on figure 2).

B. As the predominant spectral component is increased up to 2 or 3 kHz, it is necessary to slide the emphasis upwards in frequency so as to retain high frequency noise reduction <u>relative to the spectral component</u> (curves 2 and 3). <u>Low frequency noise is not yet an audible problem.</u>

C. When the predominant spectral component is above about 3 kHz, noise both at low and at very high frequencies must be reduced. An emphasis curve with a dip at the predominant component will reduce the step-size and hence the broad-band noise emerging from the codec, while the subsequent complementary de-emphasis peak will pick out the wanted signal component, while attenuating high frequency noise, and retaining the reduced low frequency noise level which resulted from the smaller step-size. For example, if the predominant signal lies at 6 kHz, curve 5 is a desirable emphasis characteristic.

This explanation has assumed that the predominant components of an audio signal at a particular moment are concentrated in a narrow region of the spectrum; such a signal is in fact the most critical case. When the spectral components are more distributed, their masking properties cover more of the noise, and the emphasis shape is less critical.

Thus a variable emphasis circuit giving a family of response curves of the form shown in figure 2 preceding the modulator, with the complementary de-emphasis following the delta demodulator, will provide efficient subjective noise reduction under all signal conditions, provided that circuitry can be designed to analyse the input audio and to give suitable instructions to the emphasis and de-emphasis.

PRACTICAL DETAILS OF THE DECODER

Figure 4 illustrates the decoder required in the consumer's home. Each audio channel of decoding receives three data bit-streams.

The audio data is at a moderately high rate, 200 kbit/s or more. The precise rate depends on the application; for television it is convenient to operate with an integral number of bits per horizontal picture line. The two control bit-streams are at much lower rates; for television a practical rate is half the television horizontal frequency.

Basic Adaptive Delta Demodulator

In order to achieve the required dynamic range from adaptive delta modulation, it is necessary to be able to adapt the step-size or unit of quantization over a range approaching 50 dB. The basic demodulator takes a step-size voltage Vss (or an equivalent current) which can vary over this range and switches it with one polarity or the reverse in accordance with the audio data to a leaky integrator. The leak time-constant corresponds to a few hundred Hz; below this frequency the system is strictly not delta but delta-sigma modulation.

Step-Size Decoder

The step-size control bit-stream contains the logarithm of the required step-size coded as delta-sigma modulation. It is therefore decoded by passage via a low-pass filter, which determines the bandwidth (and hence rise-time) and ripple of the step-size voltage, and an exponentiation or anti-logarithm. circuit (for example, a bipolar transistor, which inherently has the appropriate characteristic). If the normalized mean level of the bit-stream (or the duty-cycle measured over the rise-time of the low pass filter) is written as x, then

$Vss = Vo \exp kx$ where Vo is a constant suitable for the particular instrumentation, and $k = 10 \ln 2$

This definition gives an increase of 6 dB in step-size for every increase of 0.1 in x. Since by definition x is confined to the range 0 to 1, the resultant maximum possible range of Vss is 60 dB. Of this, about 50 dB is useful.

The transmission of step-size information in logarithmic form reduces the dynamic range conveyed in the bit-stream, in this case from about 50 dB to about 9 times, or 19 dB, and spreads the effect of bit errors more uniformly across the dynamic range. Since Vss is confined by the low-pass filter to a bandwidth of about 50 Hz, bit errors lead to slow random amplitude modulation of the output audio. The audible disturbance produced by errors in the control bit-stream is quite negligible compared with the effect of similar error rates in the audio data. The control system is so robust that uncorrected error rates up to 10^{-2} or so produce nearly imperceptible disturbance of music or speech.

Sliding-Band De-Emphasis

The requirements have been discussed in section 7; figure 3 shows a representative set of de-emphasis curves, complementary to the emphasis of figure 2.

There are obviously many ways of synthesizing responses of this nature. Figure 4 shows one practical technique; here the cut-off frequency of the high-pass filter formed by the capacitor and variable resistor should be directly proportional to the control signal decoded from the sliding-band control bit-stream.

Those familiar with Dolby noise reduction systems (such as A- or B-type) will recognize the dual-path configuration in which a main path with fixed characteristics is paralleled either with feedforward or feedback by further paths having variable characteristics. However in noise reduction the further paths constitute compressors, while in this new system the further path (the variable high-pass filter of figure 4) is ultimately controlled by the spectrum of the incoming audio; there is no systematic compression or expansion of the dynamic range.

Emphasis Control Decoder

The emphasis control decoder is substantially identical with the step-size decoder. The emphasis control bit-stream contains the logarithm of the cut-off frequency of the variable high-pass filter in the de-emphasis circuit; the virtues and benefits of a logarithm. function here are similar to those in the step-size control. The cut-off frequency follows the relationship

$f_1 = fo \exp ky$ where fo is a constant determining the scaling, $k = 10 \ln 2$, and y is the normalized mean level of the bit-stream

This definition results in a movement of one octave for every increase of 0.1 in y. The control of emphasis in the presence of errors is if anything more robust than that of step-size.

Output Filter (not shown on figure 4)

Since in delta modulation the sampling frequency is vastly greater than the minimum required by information theory, there is little probability of aliasing components in the output. Non-audio spectral components in the output are at frequencies well above the audio band, and hence only an elementary two or three pole low-pass is necessary.

REQUIREMENTS OF THE ENCODER

As will be clear from the block diagram in figure 5, the encoder is very much more elaborate and expensive than the decoder; this is not a serious objection since it does not need to be mass produced for the consumer market.

The basic requirement, of course, is to deliver bit-streams which can be interpreted correctly by the decoder.

The emphasis control block analyzes the spectrum of the input audio to determine which of the family of available emphasis and de-emphasis curves will minimize the audibility of codec noise in the presence of that signal spectrum. This information is coded into the low-bit rate emphasis control data stream. The conversion of this bit-stream back to a signal suitable for operating on the variable filters of the emphasis and de-emphasis includes limitation of the bandwidth to about 50 Hz, corresponding to a rise-time of about 10 ms. Hence the input audio is delayed by this time before entering the variable emphasis circuit.

After emphasis, the audio is passed to the step-size detection block which measures the slope of the signal to determine the optimum step-size (point c on the curve in figure 1). The logarithm of this value is coded into the step-size control data. Again conversion back to actual step-size voltage Vss restricts the rise-time, and so the emphasized audio is delayed by about 10 ms before application to the main encoding delta modulator.

Since the audio is subject to this further delay after emphasis, the emphasis control bit-stream needs delaying also so that all the data will arrive synchronously at the decoder.

ERROR CONCEALMENT

Our previous work (1) illustrated the nature of the difference between a bit error reproduced by a PCM or DM system. In the PCM case the reproduced error takes the form of a narrow impulse, the height of which depends on which bit is hit (being very large for an MSB hit). In the case of delta modulation, the error takes the form of a small step of significant length (decaying only because the integrator has a "leak" with a 0.5 msec time constant); small because there is no possibility of hitting an MSB (there isn't one - all bits are equal!). If the error rate is low (on the order of 10^{-5}) a delta modulation system is quite usable without any error correction or concealment, while a PCM system is not.

PCM systems intended for operation at moderate to high error rates (10^{-4} to 10^{3}) must (to be usable) carry some overhead for error concealment. No attempt is made to correctly reproduce the audio, but using a small amount of redundant data, bad words are identified and an interpolated value substituted. A very substantial audible improvement can be realized with a modest amount of data overhead and a reasonable amount of additional circuitry (storage of a previous sample, addition of the next sample and shift right for divide by two). The result of concealment is to greatly reduce the amplitude of the impulse which is added to the reproduced audio.

Delta modulation systems can benefit from a somewhat analogous error concealment scheme which yields a similar result with simpler circuitry. The scheme involves detection of the approximate location and polarity of the error, and the creation of an error of opposite polarity in nearly the same location. This has the effect of terminating the duration of the step the error has created yielding an impulse similar to the concealed PCM impulse.

The implementation of the scheme involves blocking the data into N bit blocks and performing a modulo 4 summation of the number of data 1's in the block. This two bit result (0, 1, 2, 3, 0, 1, 2, 3 . . .) is transmitted along with the data block as redundant information. If a single bit error occurs in the data block (for moderate error rates nearly all errors will be single errors) the number of data 1's in the received block will differ from that sent. If the same modulo 4 summation is performed in the decoder and compared to the result received from the transmitter, the presence and polarity of a single bit error is detected. If an error is detected, the concealment involves creating an error of opposite polarity in the block. Since we have only located the error to a particular block and we want our artificial error to be located as close as possible to the real error, we insert the artificial error into the center of the block. The distance between the real and artificial errors will then be between 0 and N/2 bits, with an average distance of N/4 bits. The step introduced into the audio will be (on average) this length. Note that some errors $(2/(N + 2))$ will hit the concealment data and the system may misconceal. This possibility can be virtually eliminated by carrying along a 3rd bit which is a parity on the other two, but the audible improvement doesn't really justify the added overhead unless the block size is quite small $(2/(N + 2)$ becoming large).

By way of example, suppose we block the data into 32 bit blocks and send 2 redundant bits for each block for an overhead of about 6%. For approximately 32/34 ths of all errors (94%) we correctly receive the concealment data and can conceal the error, terminating it to an average length of N/4 or 8 bit periods. For a system operating at a 250 kHz data rate, the step would have a length of 32 μsec (about the same length as an impulse in a PCM system sampled at 32 kHz). In practical sytems the data is often organized in blocks of some size (in a video application a block of data may be sent every horizontal scan interval), so these same blocks are used to implement the concealment.

CONCLUSION

This paper has described a digital audio system particularly suited to broadcasting, cable, and satellite delivery. It offers a bandwidth in excess of 15 kHz, a dynamic range potentially around 100 dB (although initial embodiments may be limited to perhaps 85 dB because of the limits of present IC technology and of the available means of producing 10 ms delays), audio scrambling, and a level of program-modulated noise better than most of the digitally-companded PCM systems proposed or in use. All this with a total bit-rate potentially less than any existing PCM system, and with a decoder having a fraction of the cost.

REFERENCE

(1) This paper, in substantially its present form, was presented at the 75th Convention of the Audio Engineering Society, Paris, March 1984 (preprint 2071 (C7)).

(2) K.J. Gundry, D.P. Robinson and C.C. Todd, "Recent developments in digital audio techniques", presented at 73rd Convention of the Audio Engineering Society, Eindhoven, March 1983 (preprint 1956).

(3) S. Forshay, K. Gundry, D. Robinson, C. Todd, "Audio Noise Reduction in Cable Systems," presented at 32nd Annual National Cable Television Association Convention, Houston, June 1983.

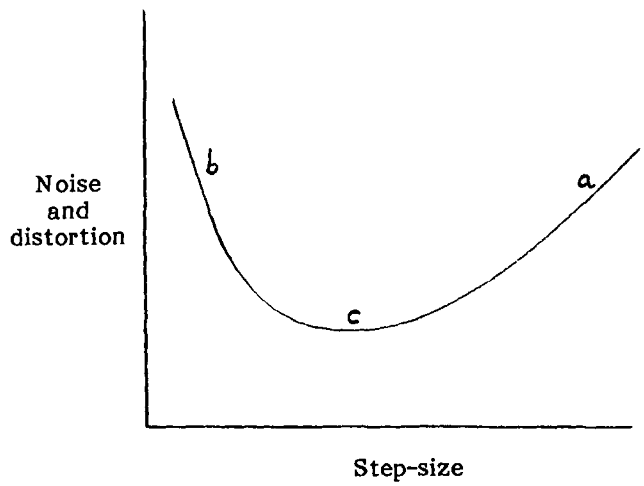

Figure 1

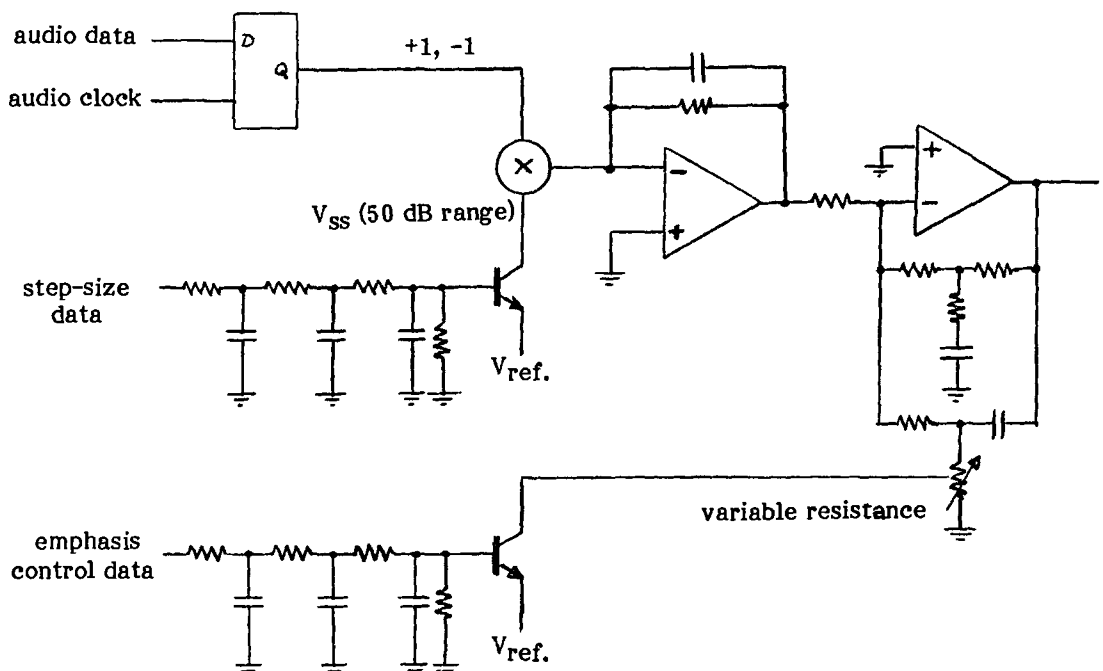

Figure 4 Consumer decoder

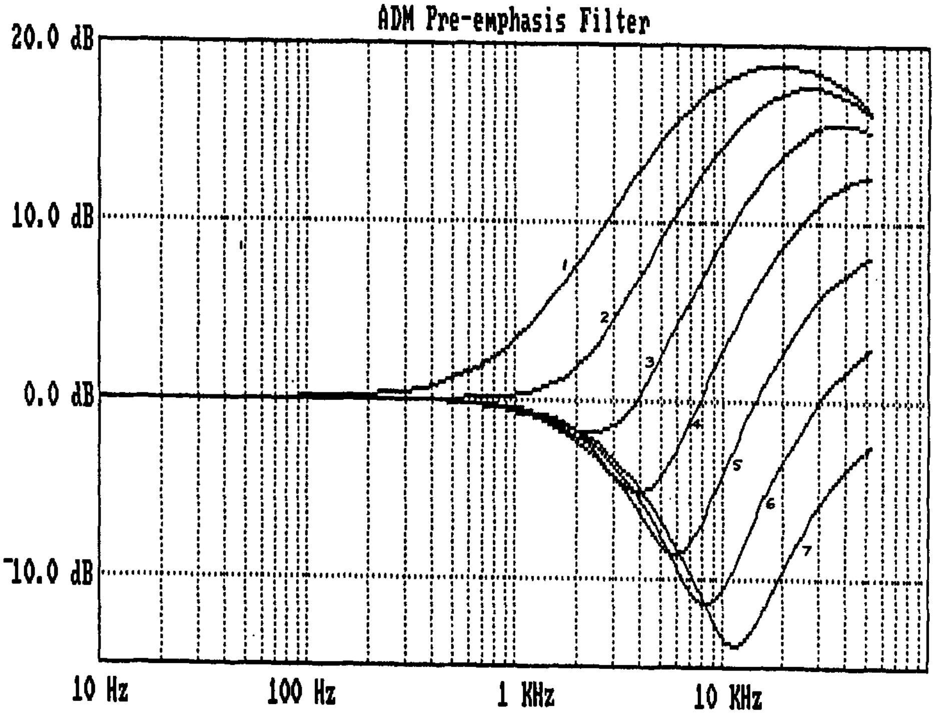

Figure 2

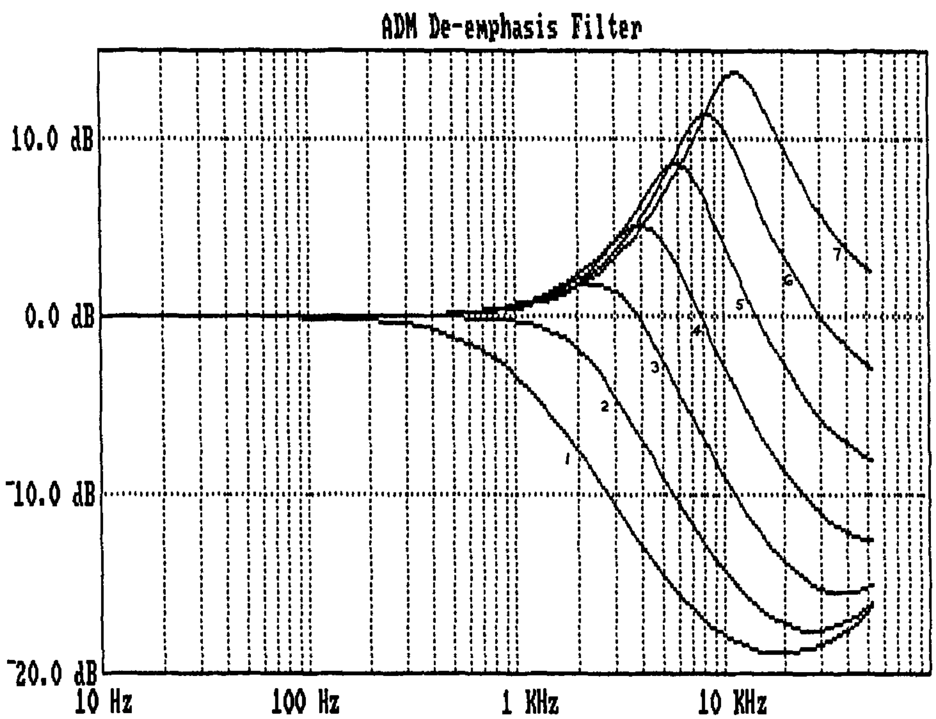

Figure 3

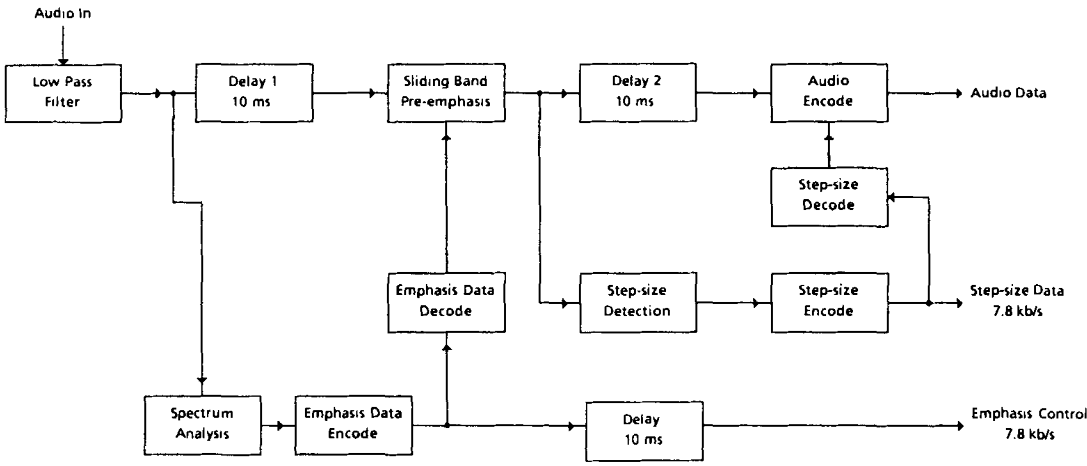

Figure 5. Professional Audio Encoder. Block Diagram

A MODEL FOR PREDICTING SURGE CHARACTERISTICS INTERNAL TO BROADBAND DISTRIBUTION EQUIPMENT

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Abstract

The characteristics of external surge waveforms and energy levels are well documented for both aerial and underground coaxial systems. The internal stresses applied to the complex electronic system of a modern broadband distribution amplifier are less known and documented. This paper presents a model which accurately predicts the magnitudes and waveshapes at certain key points in the amplifier. The results of the analysis are then used to determine proper and effective circuit design and protective device use.

1.0 INTRODUCTION

Surges and transients are a common cause of CATV failures. Ironically, major system outages can arise when the only CATV device that fails is a transient protection device. Since the surge problem can be very severe and outages are very expensive, it is important to evaluate where protection is needed in order to protect electronic equipment from whatever residual surges intrude. The following sections examine transients and surges found in CATV systems and their affect on the internal components of a broadband amplifier.

2.0 WHERE DO TRANSIENTS ORIGINATE FROM?

Transients capable of causing malfunctions are erratic in nature, come in a variety of waveforms and energy levels, and emanate from a number of sources. The transient sources most common to CATV systems are lightning and power switching.

Lightning does not need to directly strike CATV equipment to create havoc. In fact, the most frequent effect of lightning on distribution lines is longitudinally induced sheath currents. These are brought about by the inductive coupling of indirect strikes through the neutral sheath. Protection against the devastating effects of a direct lightning strike will not be considered in this paper. No matter what protection scheme and grounding measures are taken, a direct lightning strike will inflict extensive damage.

Power switching transients result when the current in an inductor is suddenly interrupted and a spike voltage proportional to Ldi/dt is generated. These can originate from either residential switching (relays, heavy machinery, etc.) or from power company faults. These surges can enter the CATV AC-to-AC power supply via the power company secondary, or be induced into the system via nearby power lines. The AC-to-AC power supply can itself generate a switching transient when the transformer primary is energized and de-energized. This particular surge is well documented and will be discussed separately at the conclusion of this paper.

3.0 WHAT DO THESE SURGE WAVEFORMS LOOK LIKE?

Although surge energies range from that of a spark of static electricity to a direct lightning hit, simplified repeatable surge standards have been designated. This is a result of extensive studies on the surge waveforms present on power grid and telecommunication networks, thus making protective circuit design both reasonable and effective. Figure 1 lists some of these surge standards.

ANSI C37.90a	IEEE C62.33
CCITT K.12	IEEE 465.1
CCITT K.17	IEEE 587
FCC 19528 Doc 68	IEEE 932
IEC 60-2	REA PE-60
IEC 255-4	REA PE-80
IEC 255-5	UL 217
IEC 255-6	UL 268
IEC 255-10	UL 943

Figure 1
SELECTED SURGE STANDARDS

Based upon actual occurrences, two representative waveforms have been designated. The first, based on indoor AC power lines, is the oscillatory waveform shown in Figure 2. These are characterized by a steep rise time and rapid decay time. The second waveform, based on outdoor power and telecom lines, is the impulse waveform shown in Figure 3. These are characterized by an undirectional, exponential rise and decay waveshape.

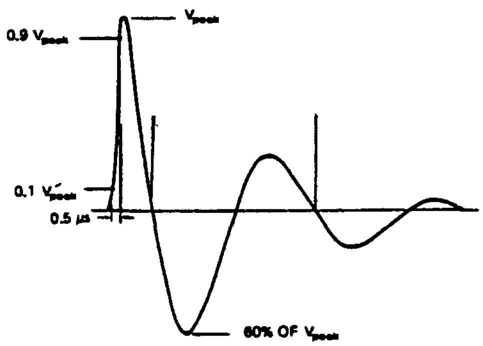


Figure 2
TYPICAL BALANCED TWO-WIRE LINE SURGE

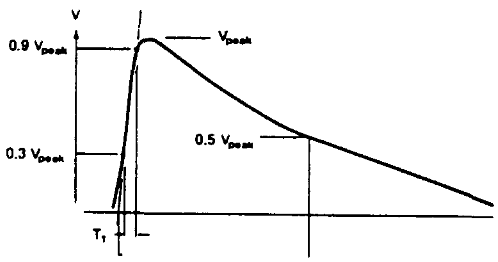


Figure 3
TYPICAL COAXIAL LINE SURGE

Most test standards show that the longer duration, uni-directional impulse wave is dominant in the communication field. This may be due to the high frequency filtering and greater shielding properties of the coaxial jacket, which tend to reduce amplitude and cause elongation of the wave. Fundamental surge data on .412 in aerial coaxial aluminum tube cable is contained in the Bell-Northern research paper on lightning surges in open wire, coaxial, and paired cable. The abstract of this paper states:

> "Oscillograms of longitudinal surge voltages occurring in open wire, paired, and coaxial cable were continuously photographed during each season using an automatic camera system especially developed for the investigation. On completion, approximately 10,000 useful surge photographs were obtained and analyzed.
>
> The results indicate that a standard test wave, with 1000 volts peak and 10 x 1000μs wave shape, simulates 99.8% of the lightning surges encountered in paired and coaxial cables."[1]

This paper also reports that "all surge protection devices were removed where possible during the investigation."

A typical coaxial cable surge is presented by Bell-Northern in Figure 4 and a distribution of surge maximum peak voltage amplitude in Figure 5.

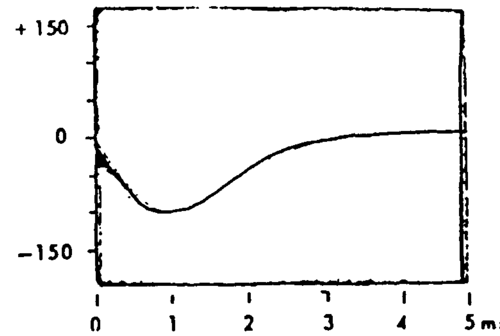


Figure 4
TYPICAL COAXIAL SURGE

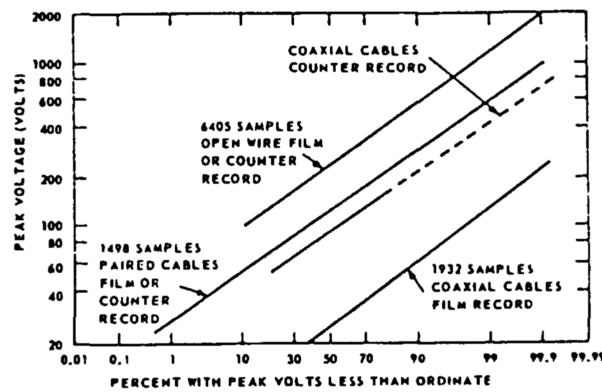


Figure 5
DISTRIBUTION OF SURGE MAXIMUM
PEAK VOLTAGE AMPLITUDE

The first step in predicting the internal surge characteristics of a CATV amplifier is to select an applicable surge standard. After evaluating the research findings and standards for telecom lines, a 1.5 kv 10 x 1000 waveform was chosen as a standard for a 'worst case' surge introduced into a CATV amplifier. An oscillatory waveform was also tested to simulate possible surges introduced through the power company secondary. No attempt was made to simulate and test for the relatively low voltage, long duration surges caused by unbalanced loading in the power grid.

4.0 WHAT INTERNAL STRESSES RESULT FROM THIS WORK?

Computer analysis on key sections of a two-way cable powered broadband trunk amplifier is useful in estimating the internal surge tolerance levels. This information can be used to help decide where protection is needed and as verification for actual lab tests.

A computer-aided transient analysis was obtained on circuit components in the baseplates, diplex filters, powered housing (power transformer and power supply), and coupling capacitors to the RF hybrids when an input port is surged by the impulse standard waveform. Key investigation points are indicated by an asterisk on the block diagram shown in Figure 6.

Along with the theoretical analysis, actual surge testing is necessary to assure the design can withstand a full-blast surge. This will assure us of an inerrant quantitative understanding of the internal surge waveforms. A KeyTek model 424 mainframe and PN241 module was used to inject our standard waveform into a conventional two-way CATV distribution amplifier. Surge photographs were taken with an HP1411 100 MHz storage oscilloscope to record surge voltage levels at key points in the amplifier. Gas-filled surge voltage protectors (SVP's) were removed from the amplifier (except where indicated) for these lab tests.

Each location lettered in Figure 6 was monitored for 20 alternating positive and negative undirectional pulses before a photograph was taken. A side-by-side comparison of lab work with the computer analysis is represented in Figures 7-12.

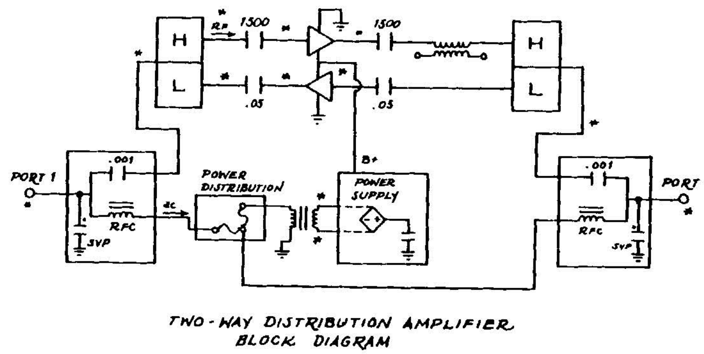
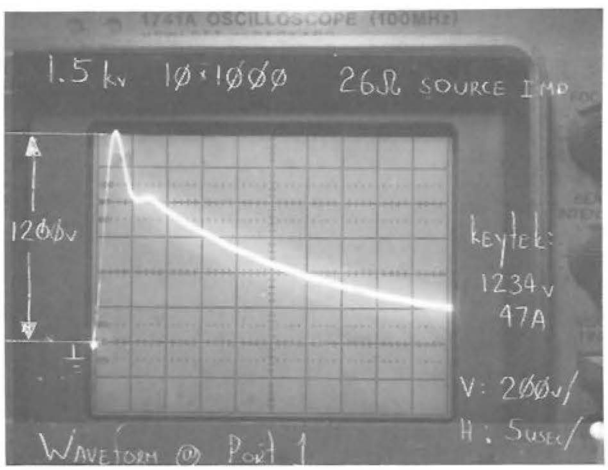


Figure 6



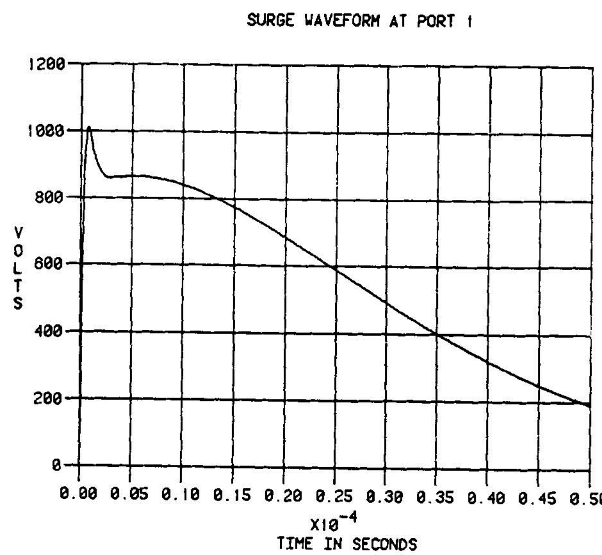
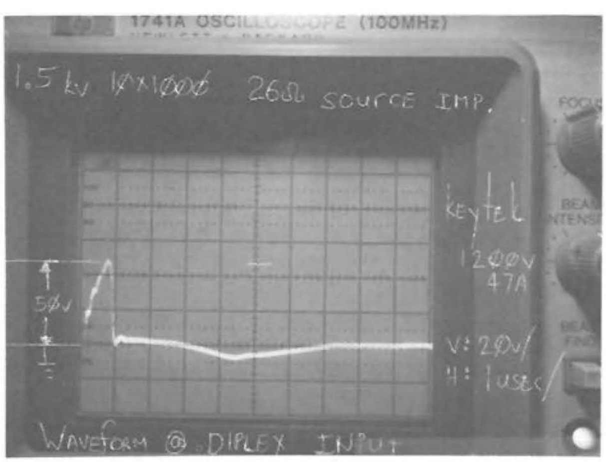


Figure 7
SURGE WAVEFORM AT Port 1



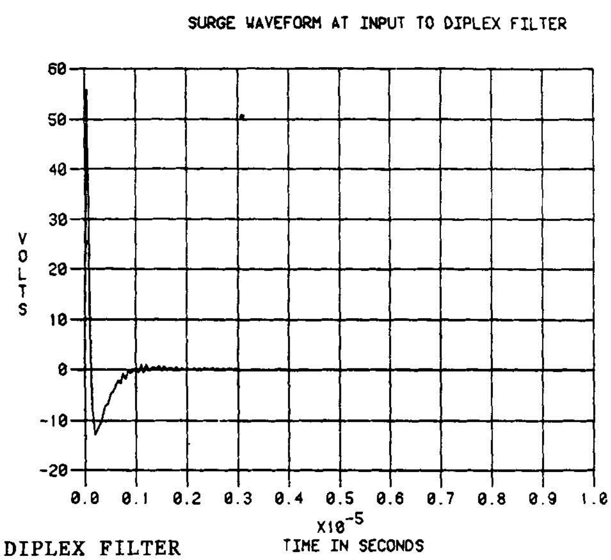


Figure 8
SURGE WAVEFORM AT INPUT TO DIPLEX FILTER

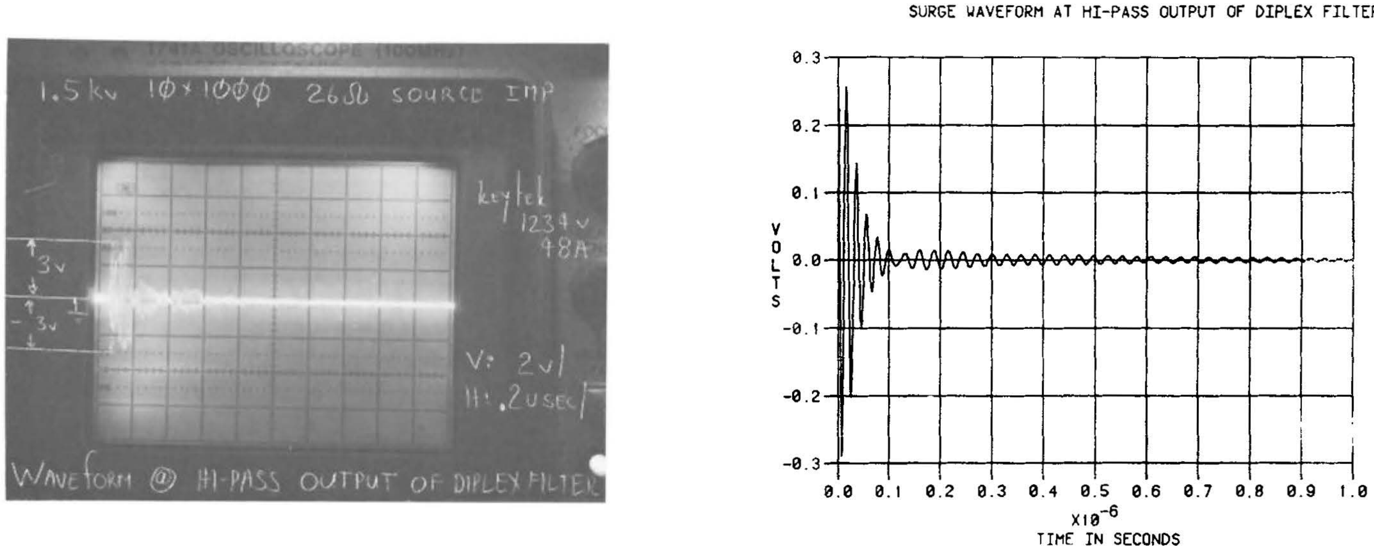


Figure 9
SURGE WAVEFORM AT HI-PASS OUTPUT OF DIPLEX FILTER

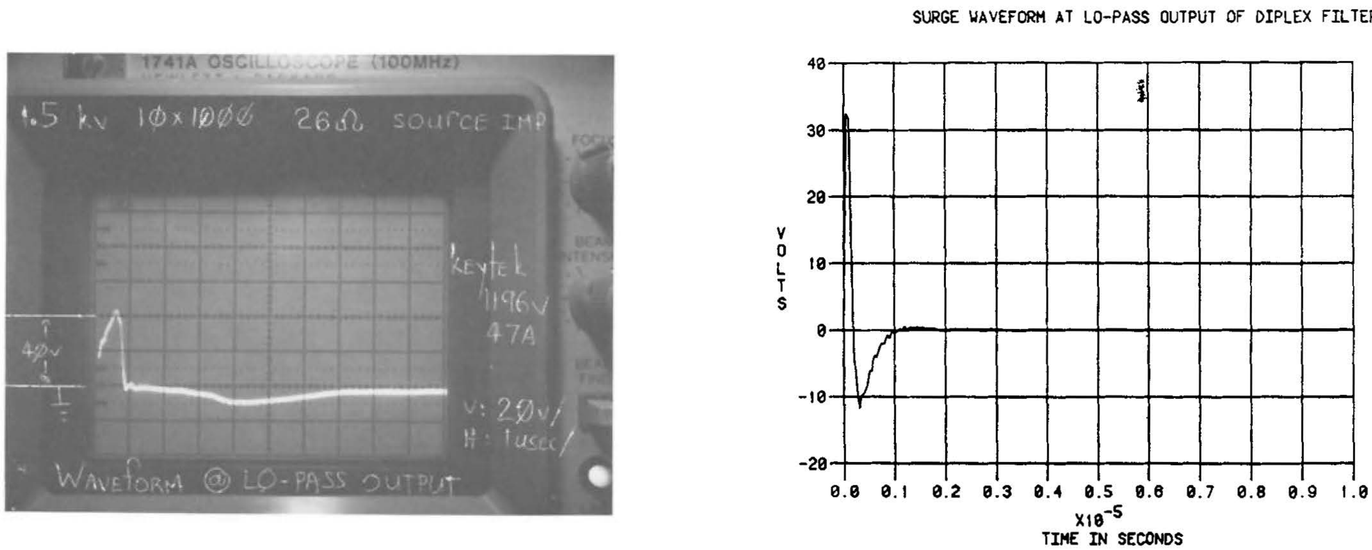


Figure 10
SURGE WAVEFORM AT LO-PASS OUTPUT OF DIPLEX FILTER

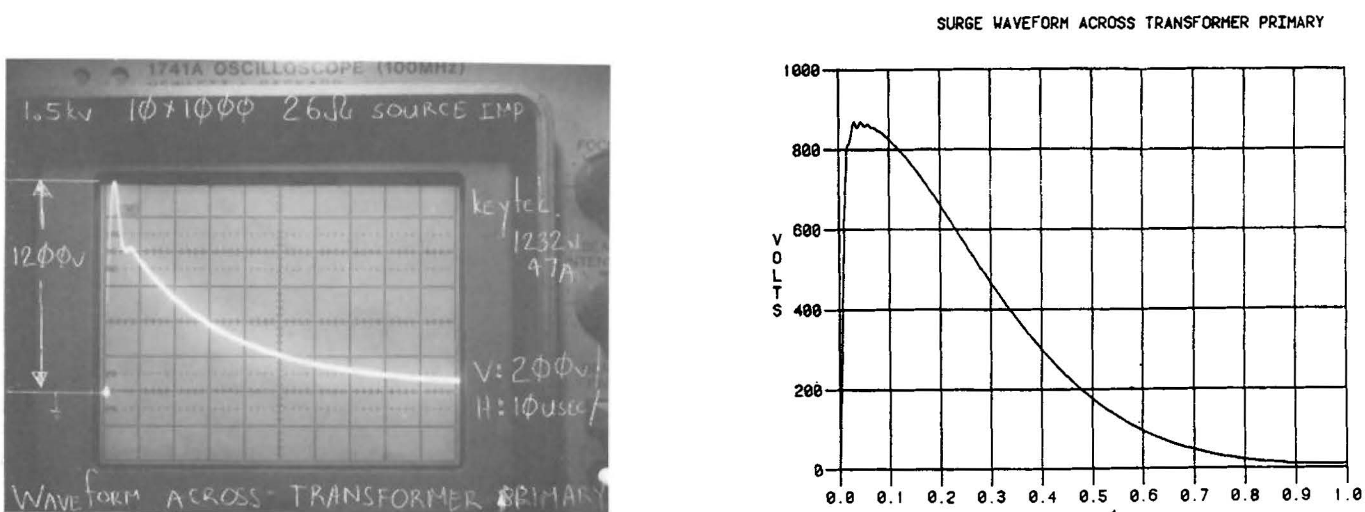
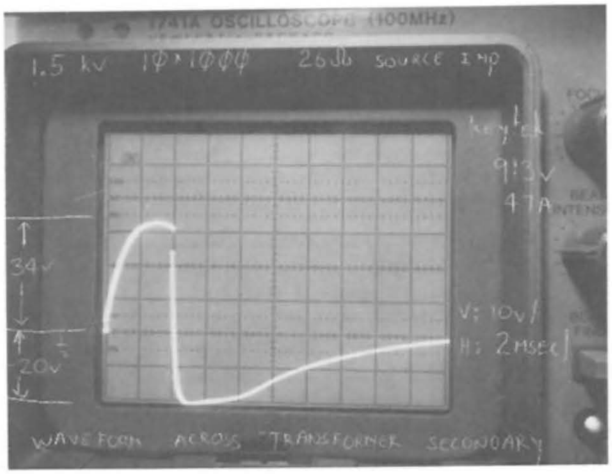


Figure 11
SURGE WAVEFORM ACROSS TRANSFORMER PRIMARY



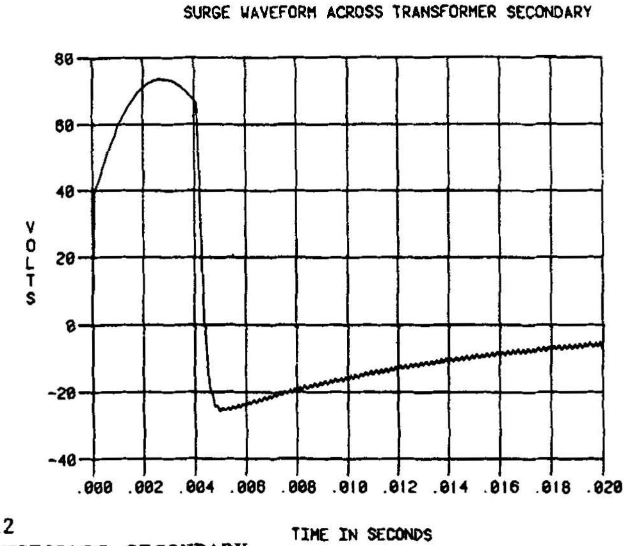
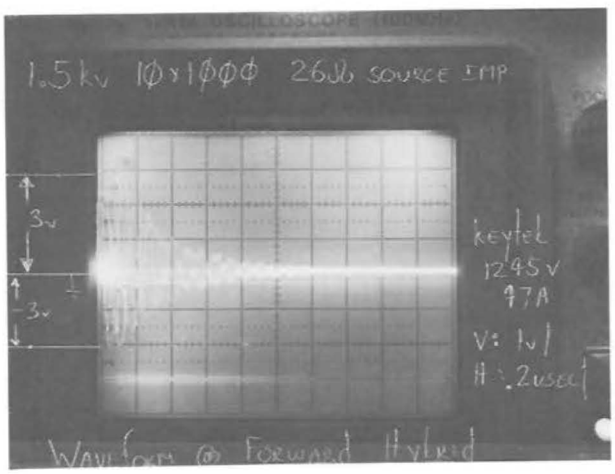
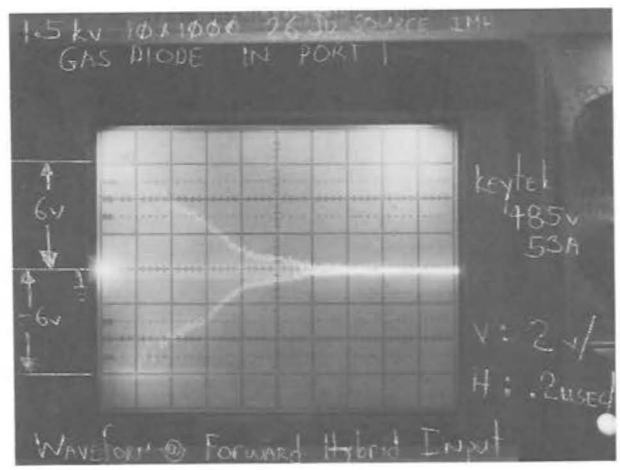


Figure 12
SURGE WAVEFORM ACROSS TRANSFORMER SECONDARY

Figures 13-15 document voltage waveforms at the RF hybrids with and without gas diodes placed at port 1. Gas diodes alter the waveform somewhat, but do not significantly reduce magnitude or duration.

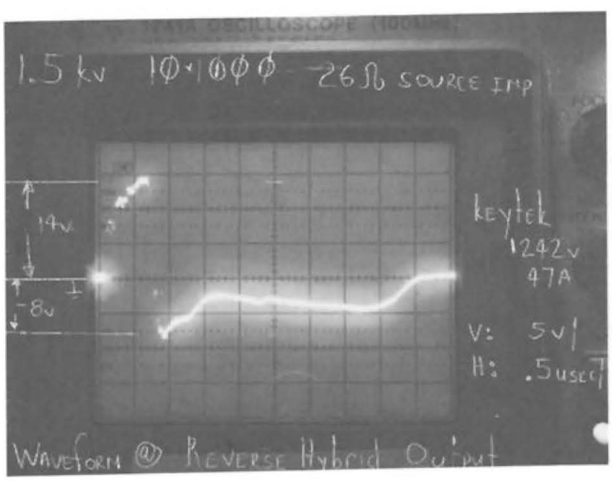


Without Gas Diode

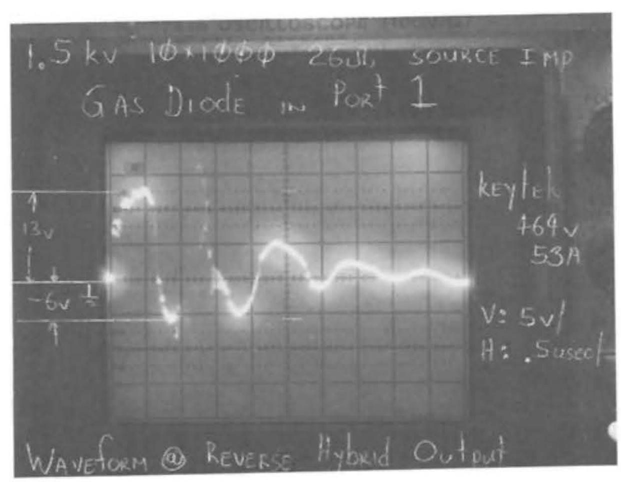


With Gas Diode

Figure 13
SURGE WAVEFORM OF FORWARD HYBRID

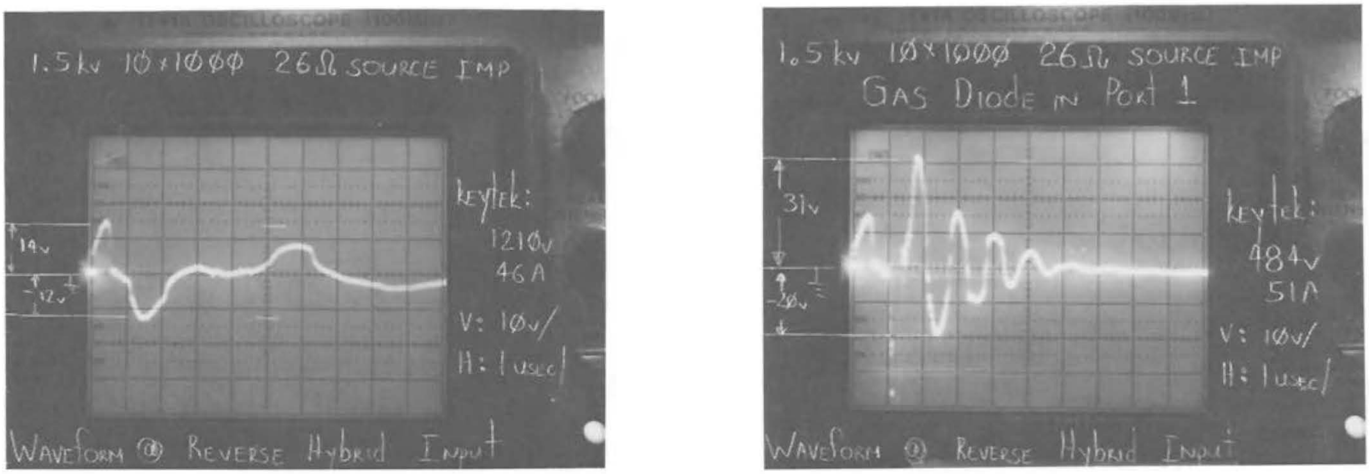


Without Gas Diode



With Gas Diode

Figure 14
SURGE WAVEFORM AT REVERSE HYBRID OUTPUT



Without Gas Diode

With Gas Diode

Figure 15
SURGE WAVEFORM AT REVERSE HYBRID INPUT

Figure 16 shows the surge remnant present on B+ when the switching regulator power supply is powered. Figures 17-18 show voltage waveforms at port 1 and across the transformer primary with gas diodes. Gas diodes reduce surge magnitude and duration to the power supply.

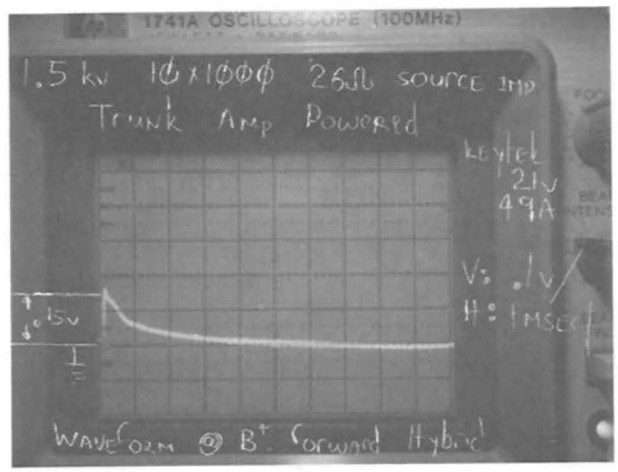


Figure 16
SURGE WAVEFORM AT B+

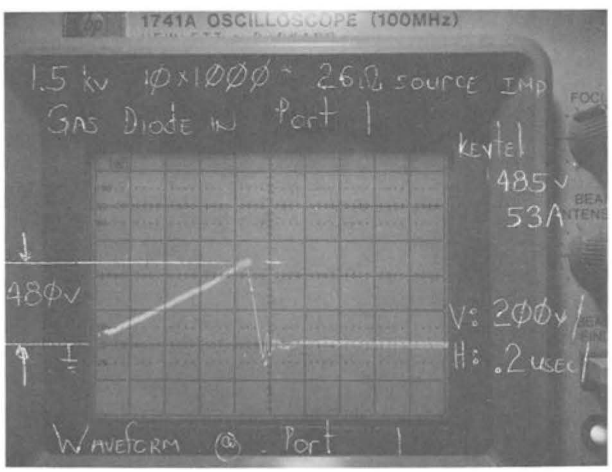


Figure 17
SURGE WAVEFORM AT PORT 1 WITH GAS DIODE

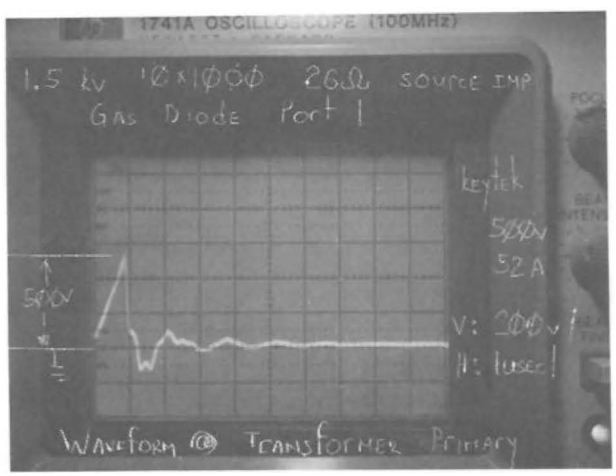


Figure 18
SURGE WAVEFORM AT TRANSFORMER PRIMARY WITH GAS DIODE

Figures 19-25 show various key points in the distribution amplifier when our standard test waveform is replaced with a 1.5 kv, .5 usec rise time, 100 KHz 'ring' wave. A KeyTek PN281LS module was used to simulate this oscillatory waveform which is typical of surges found on AC power lines.

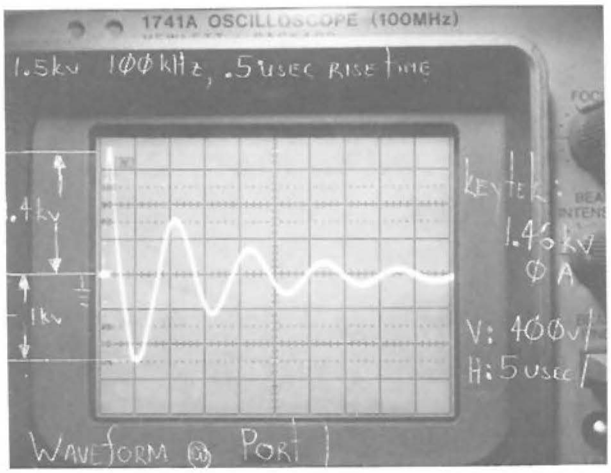


Figure 19
SURGE WAVEFORM AT PORT 1

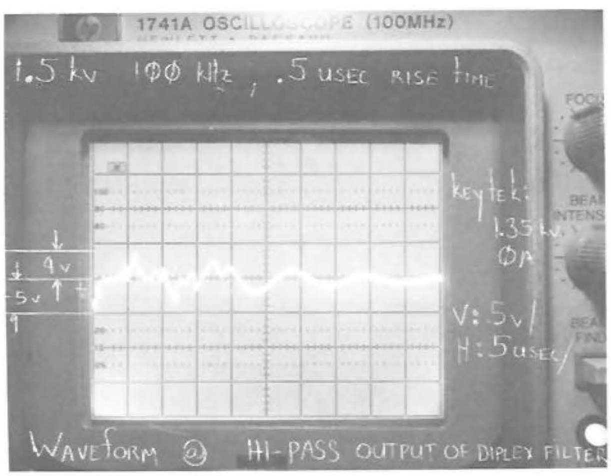


Figure 20
SURGE WAVEFORM AT HI-PASS OUTPUT OF DIPLEX FILTER

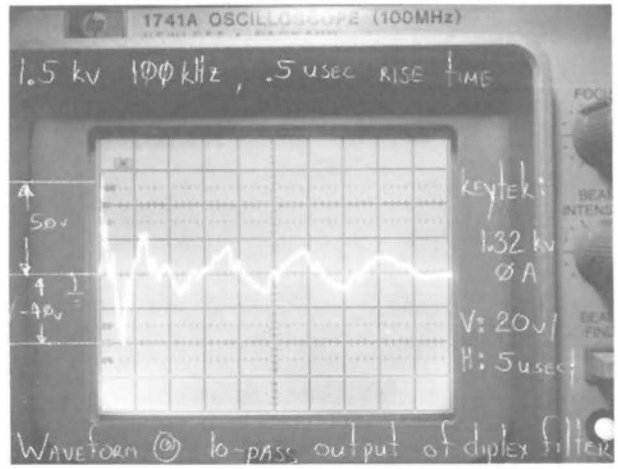


Figure 21
SURGE WAVEFORM AT LO-PASS OUTPUT OF DIPLEX FILTER

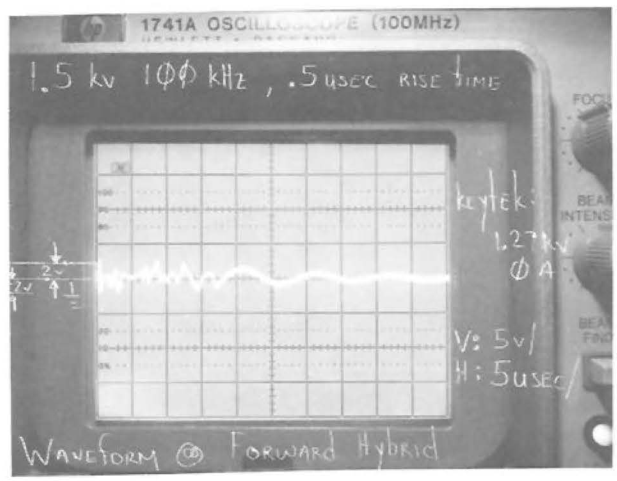


Figure 22
SURGE WAVEFORM AT FORWARD HYBRID

Figure 23
SURGE WAVEFORM AT REVERSE HYBRID OUTPUT

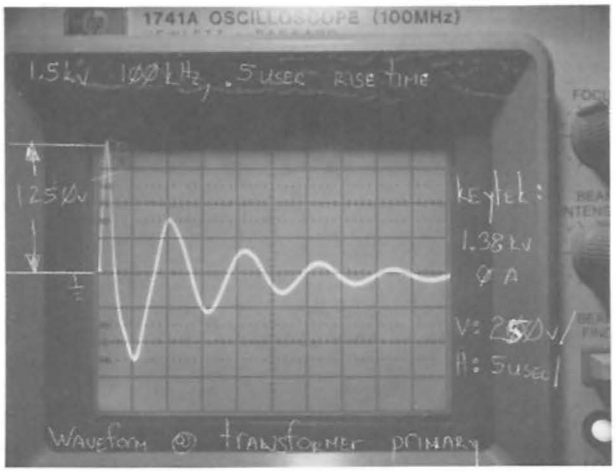


Figure 24
SURGE WAVEFORM AT TRANSFORMER PRIMARY

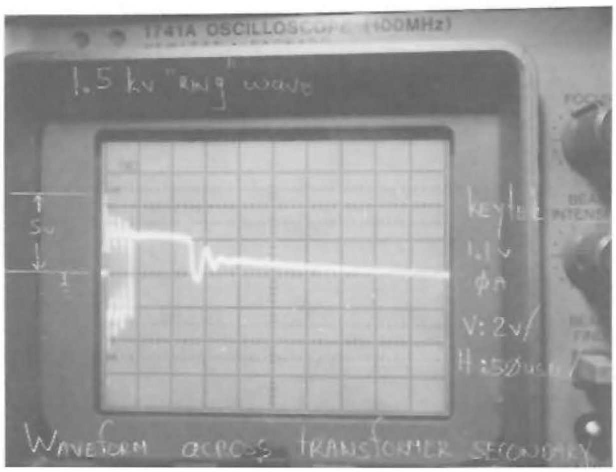


Figure 25
SURGE WAVEFORM AT TRANSFORMER SECONDARY

It is also possible to have a surge on a port where there is not a low impedance path to ground, a power supply for example. Therefore, data on a one-way trunk powered from an unsurged port will be presented here. A block diagram of such a trunk is shown in Figure 26.

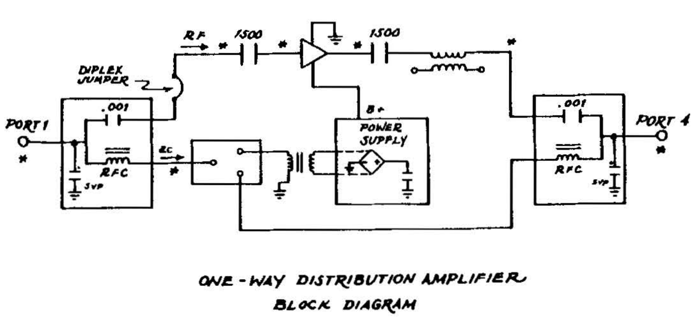


Figure 26

The lab results at Port 1, both sides of the coupling capacitor, and the hybrid input with gas diode in Port 1 are shown in Figures 27-30.

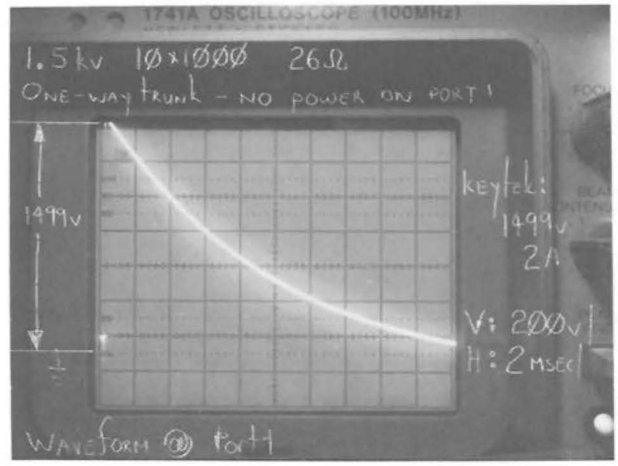


Figure 27
SURGE WAVEFORM AT PORT 1

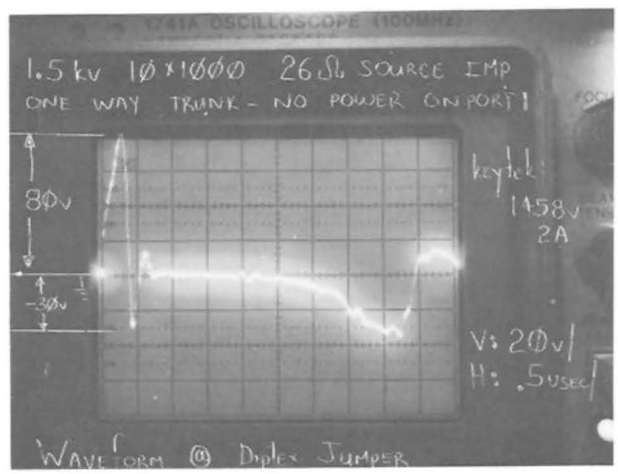


Figure 28
SURGE WAVEFORM AT DIPLEX JUMPER

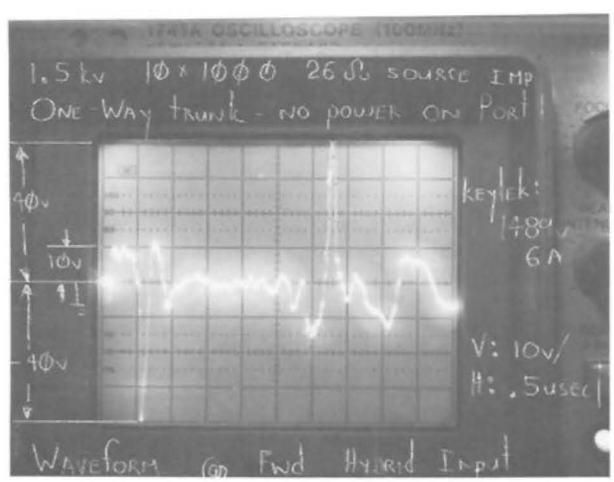


Figure 29
SURGE WAVEFORM AT FORWARD HYBRID INPUT

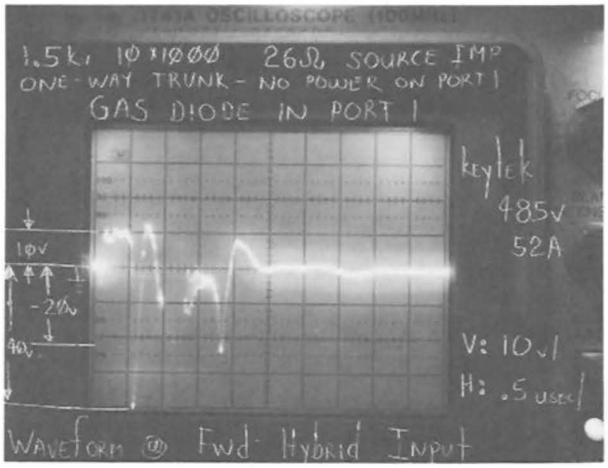


Figure 30
SURGE WAVEFORM AT FORWARD INPUT WITH GAS DIODE

5.0 WHAT NEEDS PROTECTION? (ANALYSIS OF DATA)

The preceding computer plots and lab photographs serve as excellent predictions of the internal stresses applied to a distribution amplifier when a "worst case" surge is applied. This data can now be analyzed to determine which components need protection.

Our data indicates that it is the low-pass section of the amplifier, namely, the power supply, which is most susceptable to surge damage. This is to be expected, since a Fourier analysis of our 10 x 1000 waveform will show most of the energy lies below 1 KHz. At these frequencies, the coupling impedance of our forward hi-pass section is greater than 100 K ohm and 3 K ohm for the reverse path section. We would, therefore, expect to see only remnants of the surge in the RF sections of the amplifier. The inductively coupled power supply is much more inviting for our transient (data taken for a one-way unpowered port.)

$$Z_c = \frac{1}{2\pi f(1500pF)}$$

Table 1 contains some conclusions drawn from our test results of a "worst case" surge.

3.2

Table 1

Item	Voltage Rating Required	Comments
Baseplate	All components must be able to withstand the full 1.5 kv 10 x 1000 surge	Baseplate capacitors susceptable to surge damage.
Diplex Filters	100 V components will give adequate protection	Waveform relatively "unaltered" by lo-pass section. A small remnant of the surge appears at the hi-pass output.
High & Lo RF Sections	Coupling capacitor should be a 100 V part	No surge damage through RF circuits.
RF Hybrids	No additional protection required	
Transformer	Requires a surge resistance of 1.5 kv on primary	Saturation/filtering provides excellent surge protection.
Power Supply	Normal operating voltage can dictate choice of voltage rating here when an isolating transformer is used.	Switch mode power supply damps input surges. Bridge rectifier protects electrolytics from negative surges.
SVP's	Must have a firing voltage below the rated value of the components on the baseplates.	If baseplate components can withstand a 1.5 kv surge and the above guidelines are followed, then SVP's are not needed

This table contains design guidelines for component ratings without relying on any surge limiting devices at the input to the amplifier. RF hybrid data sheets indicate that these devices can withstand a 1/40 surge of 4,410 V at the RF input, 15,624 V at the RF output, and 107-116 V on the B+ input.[2] Our hi-pass filtering, therefore, adequately protects the RF hybrids. Photographs of key points with SVP's are included to show the limitations of these devices, which are used almost without exception in the CATV industry. SVP's appear to protect only the baseplate of the amplifier.

A brief explanation for the discrepancies between the computer and lab results will be made here. When doing the computer analysis, certain factors were not taken into consideration. Saturation of the power transformer is one example. We would expect our power transformer to saturate during a test wave surge. Consequently, our secondary current will not be proportional to the turns ratio (as assumed by the computer). In addition, all filtering capacitors were assumed to be "ideal," ignoring the effects of ESR, ESL, and DC resistance. No attempt was made to take stray inductance and capacitance into consideration. Also in the 'computers circuit' we did not attempt to model the reverse RF path or RF hybrids, effecting the lo-pass section of the diplex.

In our lab work, common mode noise affected our low-voltage measurments in the hi-pass sections. To keep this to a minimum, photographs were taken in the differential mode with baluns or "co-axers" on the scope leads. This greatly reduced the problem, but at the same time the differential mode reduced the writing speed of the scope. This might have caused some additional error. Keeping in mind that the impulse was 1.5 kv, the difference between 3 V in the lab and 1.5 V for the computer analysis seems quite reasonable (see Figure 9).

6.0 WHAT ABOUT THE AC-TO-AC POWER SUPPLY TRANSIENT?

As mentioned earlier, the energizing and de-energizing of the AC-to-AC ferro-resonant power supply will produce transients in the CATV system. This transient can be as high as three times the normal operating voltage and last for two or three cycles of the operating frequency. This low frequency surge is rejected by the capacitively coupled RF circuitry, but the power supply must be protected from this type of surge. If a power transformer is used, a voltage limiting device placed across the transformer secondary can be used to protect the power supply of the amplifier from this high energy surge. This scheme has the advantage of using the impedance of the transformer in providing protection. If a transformerless supply is used, the input section of the power supply should be able to withstand the full 180 V surge.

7.0 SUMMARY

This paper described the surges and transients to be expected internal to a broadband CATV distribution amplifier. Once an understanding of the magnitudes and waveshapes of these internal stresses is obtained, proper and effective circuit protection can be accomplished. Table 1 is a chart showing design guidelines for such protection against induced overvoltages.

References

[1]Bennison E., Ghazi, A. J. and Ferland, P., "Lightning Surges in Open Wire, Coaxial, and Paired Cables," IEEE Transactions on Communications, Vol. Com-21, No. 10, October 1973.

[2]Grant, Al; Eachus, James, "Reliability Considerations in CATV Hybrids," Motorola Semiconductor Products, Inc. 1978.

[3]Palmer, James R., "Power and Lightning Surges In Coaxial Distribution Systems," C-COR Electronics, Inc., 1976-1977.

[4]"Surge Protection Test Handbook," KeyTek Instrument Corporation, Burlington, Massachusetts, 1982.

Acknowledgements

Special thanks are extended to our Vice-President of Engineering, Joseph P. Preschutti, and Hamid R. Heidary, Product Engineer, for their input to this paper.

A NEW ACTIVE CATV SYSTEM ECHO TESTING TECHNOLOGY

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ABSTRACT ONLY

Various attempts have been made to quantify the transient or "echo" performance of CATV systems. Most of the testing done to date has dealt with the echo level tolerance following the limits devised by P. Mertz. Recent subjective tests by Bell Laboratories have shown that the Mertz's curve is too simplistic to define chrominance visual degradation since the Mertz subjective tests were conducted with monchrome sources.

The recent criteria require a CATV system testing technology beyond that developed to date. The author's firm has developed apparatus capable of highly refined CATV system echo testing, which when applied to existing systems and hardware, unveils new distortion factors not previously quantified in CATV systems.

The past measurement techniques and the recently developed measurement technology are discussed, together with samples of component and system measurements taken, consistent with the latest criteria.

The importance of these parameters are discussed especially as applied to high speed data signalling in cable systems such as are associated with vertical blanking interval data. It is also shown that these same distortions can degrade picture quality in CATV systems. Remedial procedures are discussed.

A USER'S GUIDE TO HOME TERMINAL UNITS

Delbert H. Heller

VIACOM CABLEVISION

INTRODUCTION

The Home Terminal Unit (HTU), in its many varieties, has made possible the reception of a multitude of special cable-delivered programs to our subscribers. With the advent of Addressable HTUs, an entirely new approach to providing and controlling subscriber services is now available.

The additional complexity of the addressable system warrants a careful consideration of its total impact on cable system operations. The addressable product presents a new set of technical challenges, as well as inheriting some of the shortcomings of older generation HTUs.

Finally, there is on the horizon, the potential for greatly reducing the costs of addressable HTUs with the work being done on Cable Compatible Television Receivers by a joint EIA/NCTA Engineering Committee.

OUTLINE

I. SUBSCRIBER EXPECTATIONS

- A. High product reliability
  1. As the monthly bill for cable service increases, subscribers become less tolerant of product deficiencies and failures.
  2. The same caveat applies to all other aspects of plant operations.
- B. Product friendliness
  1. Entries and functions easily performed and remembered
  2. Condensed and well-written customer operation booklet
  3. Booklet may include common operating errors
- C. Product esthetics
  1. Attractive-looking
  2. Unobtrusive design, blends well with surroundings

II. OPERATOR EXPECTATIONS

- A. Product Reliability
  1. Short term and long term
- B. Historical data -- HTU Failure Rates
  1. Non-addressable HTUs -- service call percentages
  2. Addressable HTUs -- service call percentages
  3. The "hidden service calls"
- C. On-going vendor support

III. PRE-PURCHASE CHECK LIST

- A. Reliability and Field Performance Record
  1. Check with current users -- don't take the vendor's word
- B. Delivery record of vendor
  1. Order commitments -- can he meet your long term demands
  2. Production capacity
  3. Order lead times and delivery scheduling
- C. Engineering support
  1. Do they have an adequately trained technical Field Support staff
  2. What is the vendor's position on product deficiencies
  3. Are complete and understandable operating and maintenance manuals available
  4. Do they provide Field Service updates to these manuals
- D. Repair procedures
  1. In-warranty
  2. Out-of-warranty
- E. Establish product performance specifications
  1. Electrical
  2. Mechanical
  3. Failure rates

F. Addressable software

1. Is it compatible with your on-line billing system
2. If not, will they provide support in developing a software/hardware interface
3. Is software documentation available, understandable and complete

G. Compatibility

1. Is the proposed scrambling technique compatible with any existing scrambling system you may have, if you require that capability
2. Can they make it compatible

H. Security

1. Are there older vintage converters or descramblers available on either the open or black market, that are capable of compromising your new purchase
2. Is the vendor willing to discuss any security weakness of his system
3. Is there any mechanism available whereby the vendor would alert his customers of future security breaches
4. Is the security system compatible with future services such as stereo audio, videotext and cable-ready TV sets
5. Can the security system be easily reproduced by pirates or tampered with

I. Addressable control capabilities

1. Maximum number of HTUs system can support
2. Maximum addressing cycle time
3. How is pay-per-view accommodated and what are the customer access parameters
4. Expansion capabilities and cost
5. What happens when the system "crashes"
6. Special test equipment requirements
7. Is remote control feature under addressable control

J. Is special computer equipment and software available for Q.C. testing, independent of management computer

IV. POST-PURCHASE CONSIDERATIONS

A. Inventory control

1. Automated vs manual entries

B. Incoming Quality Control checks

1. Should you or shouldn't you
2. Average failure rates

C. Q.C. time comparisons

1. Standard HTUs
2. Addressable HTUs

V. FIELD PROBLEMS WITH ADDRESSABLE HTUs

A. Bad subscriber grounds/cut AC cord prongs

B. Lightning exposure and its consequences

C. HTU trouble points

1. Power supply design
2. Shielding characteristics
3. Video modulation/aural deviation on Baseband Decoders
4. AM radio and CB susceptibility

D. Subscriber drop levels

1. Too low
2. Too high

F. Cable plant ingress problems

G. High level sweep problems

H. Difficult operating procedures

1. Customer confusion
2. Customer education service calls
3. Parental control easy to use
4. Favorite channel recall feature easy to use

I. Computer problems

1. HTU deauthorizations

VI. THE CABLE COMPATIBLE TELEVISION SET -- HTU OF THE FUTURE?

A joint EIA/NCTA Engineering Committee has spent the last year and a half developing new performance specifications for a Cable Compatible Television Receiver. The efforts have been divided into three major categories.

A. Tuning standards

EIA Interim Standard No. 6(IS-6) now establishes a channelization structure for Cable Compatible Receivers that corresponds to historical cable industry channel designations for standard, incremental and harmonically related cable systems, extending from 50 MHz to 650 MHz.

This Interim Standard also includes manufacturer's labeling suggestions for receivers with varying degrees of tuning capabilities. Copies are available from the Electronic Industries Association in Washington, D.C.

B. Interface standards

Work continues on establishing electrical interface standards such as maximum and minimum input levels, spurious signal leakage and RF shielding characteristics. It is possible that most of these standards could be implemented in the 1985 model receivers.

The increased RF shielding characteristics should allow the use of cable-compatible receivers in high ambient signal conditions, without having to install a cable converter to protect the receiver from direct pick-up interference.

C. Baseband decoder interface standard

Work also continues on establishing a multi-pin connector interface at the rear of the cable-compatible receiver to facilitate the development of a less expensive cable decoder. This could reduce the cost of an addressable decoder by at least half the current price.

If complete compatibility can be achieved by the cable-compatible receiver interface and a secure scrambling system, the possibility exists for the cable customer to own his own decoder module.

The decoder interface will also support the attachment of other baseband video and audio devices such as VCRs, stereo systems, computers, etc.

Greater cable industry participation is sorely needed to develop a baseband interface that meets our operational and economic needs.

ACTIVE TRAP TECHNOLOGY
AND
ADDRESSABILITY

Ray St. Louis

PICO Products, Inc.

ACTIVE TRAP

The concept of the Active Trap is an extension of the technology used for many years in the negative trap.

The Active Trap is a two pole, phase cancelling device with one pole fixed-tuned to the video carrier of the channel and the second pole tuned by voltage applied to a varactor diode. This square wave voltage causes the varactor-tuned pole to pass through the frequency to which the fixed pole is tuned. Each time this happens (47,118 times per second), maximum attenuation of the video carrier will occur. When the poles are not tuned to the same frequency, the video carrier attenuation will be at its minimum.

The difference in attenuation of the video carrier between the electronically tuned, then de-tuned condition of the active trap results in a 99.6% AM modulation of the video carrier with the 47KHz scramble signal. This scramble causes a permanent "overwrite" of the video intelligence and sync signal on the channel.

SECURITY RATIONALE

If it is technically possible for the manufacturer of a Pay TV security system to design a decoder for their scramble scheme, one can also be designed by the Pay TV pirate.

The Pay TV pirate has a great advantage. He can produce a decoder at a lower cost than the CATV security manufacturer because he does not need to provide for addressability and perfect signal recovery. In addition, he can sell his decoders at a price higher than the CATV operator pays for his legal decoders. This results in a fantastic profit margin for the Pay TV pirate.

Pico Products, Inc. considered these factors when they formulated a scramble system for which a decoder could not be designed; by them or the Pay TV pirate. The system was designed so the encoder is turned off to unscramble the signal. Since the signal is not decoded, it can be totally destroyed.

The Addressable electronics are placed outside - subscriber tampering in the home is eliminated.

Hence, the advent of the Pico OTAS System (Outdoor Terminal Addressable Security).

SUBSCRIBER TERMINAL

The Pico OTAS subscriber module is plugged into a high security housing that can be strand, pole or pedestal mounted. This housing utilizes state of the art light weight, nickel plated, structural foam molded plastic. The terminal serves 1 to 4 subscribers and is wired between the outputs of the existing multitap and the subscriber drops with coaxial cable. Multiple dwelling terminals are mounted in security cabinets capable of handling eight (8) subscribers (Figure 1).

Fig. 1 OTAS Subscriber Terminal

Each terminal has the ability to control seven (7) premium tiers plus basic on/off service per subscriber.

Unlike other scramble methods, the action of scrambling the seven tiers literally destroys the TV signal. The signal can not be recovered by reversing the encoding process.

The scramble is accomplished with small Active Traps (patent pending) used to scramble each of the seven tiers (Figure 2). Each Active Trap is a two pole, phase cancelling trap. One pole is tuned to the visual carrier of the channel. The second pole is tuned by a voltage applied to a varactor diode. This square wave voltage causes the varactor-tuned pole to pass through the frequency to which the fixed pole is tuned. Each time this happens, (47,118 times per second, slightly less than 3 times horizontal frequency), the Active Trap will attenuate the picture carrier by 70dB (Figure 3).

1

When the poles are not tuned to the same frequency, the pix carrier is attenuated by 22dB.

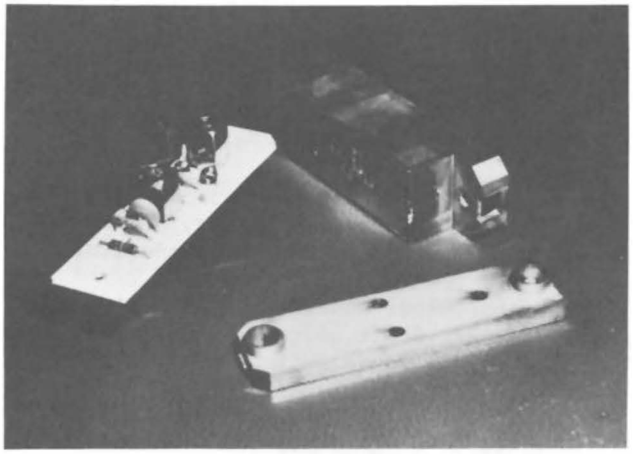

Fig. 2 Active Trap

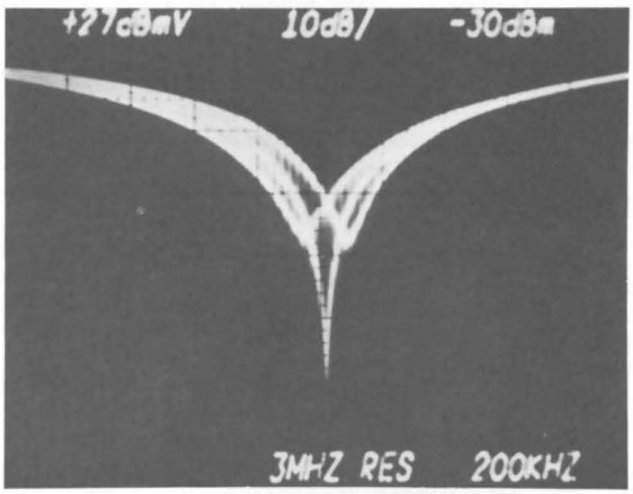

Fig. 3 Swept response of Active Trap on Spectrum Analyzer

The 48dB difference in pix carrier level between the electronically tuned, then de-tuned condition of the Active Trap results in a 99.6 percent AM modulation of the pix carrier with the 47KHz scramble signal. Interfering carrier and sync suppression scramble methods depend on the TV set to cause the scrambled picture. The OTAS scramble causes a permanent "overwrite" of the video intelligence and sync signal of the channel. Once part of the video modulation, the scramble can never be removed.

In addition to the amplitude modulation of the pix carrier, the Active Trap also phase modulates the pix carrier with 47KHz. This modulation is caused by the rapid phase changes that the Active Trap undergoes when it is tuning and de-tuning. After intercarrier detection, the TV set "sees" this phase modulation as FM modulation of the aural intercarrier signal. The 47KHz audio is above audible range and cannot be heard, so the 47KHz tone is "broken up" with a 47 KHz frequency divided by 32, 64, and 4096; tones that can be heard in the TV audio output causing an aural scramble.

The voltage that is applied to the varactor is generated by a scramble generator within the 4-subscriber addressable terminal. This 47KHz frequency is held constant through-out the CATV system by genlocking the scramble generator oscillator at each subscriber terminal to a multiple of the central computer data rate (Figures 4 & 5).

2

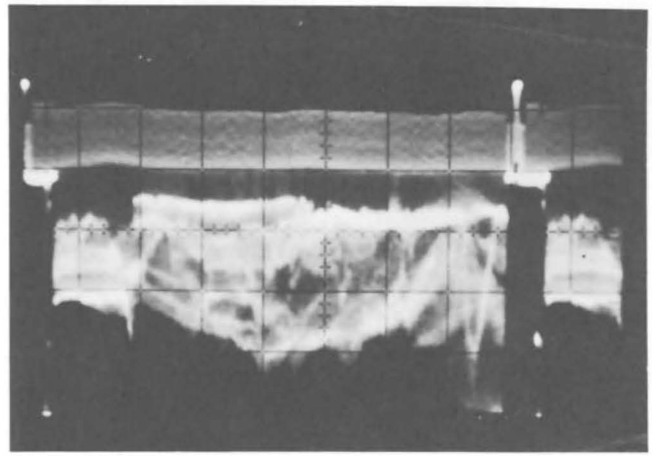

Fig. 4 Oscilloscope photo of unscrambled video

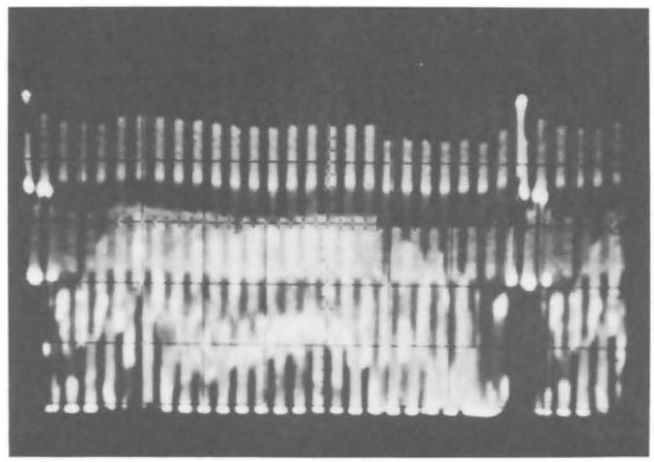

Fig. 5 Oscilloscope photo of Active Trap scrambled video

If a subscriber wants to receive a premium channel service, an order must be entered into the computer terminal. A command is then sent to the subscriber terminal to bypass the Active Trap associated with the requested premium channel. The bypass of the Active Trap is accomplished electronically with two (2) SPDT pin diode switches (Figures 6 & 7).

Subscriber terminals are addressed with a digital data stream that consists of a combination of binary and trinary bits modulated on 103.7 MHz FSK carrier. Each subscriber terminal must receive its correct address and the same command twice in succession before it will execute the command. This Double Valid Data requirement essentially eliminates data decoder errors. For example, a system that might have one error per day using the standard single valid data transmission scheme would have one error per 12,092 years using the Double Valid Data scheme.

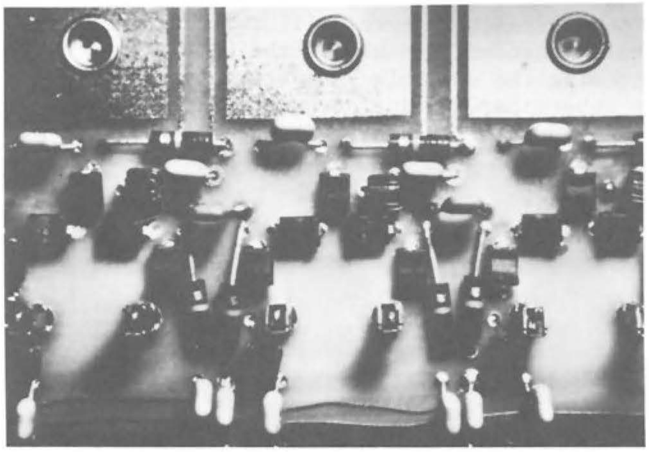

Fig. 6 Pin Diode switch on subscriber module pc board

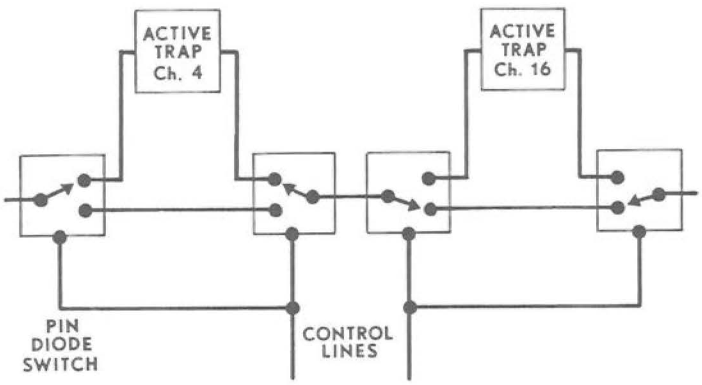

Fig. 7 Block diagram of bypass of Active Trap

The subscriber terminal electronics consists of a security housing and up to four (4) plug-in subscriber modules (Figure 8). The terminal is powered through the subscriber coaxial drop from pocket calculator size, low voltage power supplies on the subscriber premises. A four subscriber terminal is capable of being powered from a single power supply in the event that all other subscribers on the housing unplug their power supplies or have disconnected service.

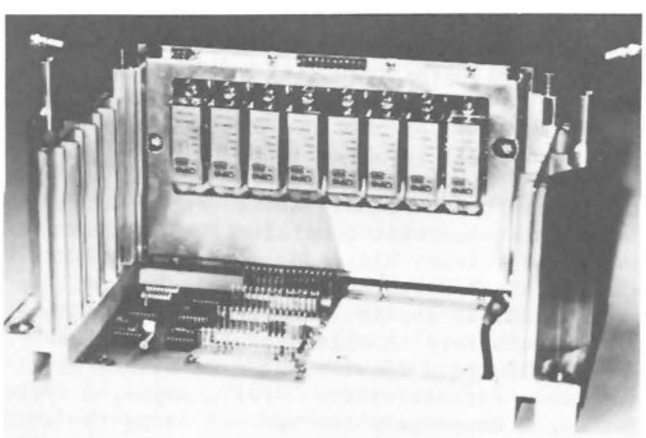

Fig. 8 Subscriber Module and Housing Modules removed from weather housing

To prevent subscribers from purposely or accidentally disconnecting their power supplies, circuitry has been provided to sense power on the subscriber drop cable and to interrupt the Basic Service latch if power is removed. Thus, if subscribers unplug their power supplies, they receive no TV signal at all. The TV signal is instantly restored when the power supply is reconnected.

The security housing contains an RF modulator-demodulator, 9 bit address decoder, 9 bit global command decoder, and the scramble generator.

Each subscriber module contains an address/command decoder, 8 bit addressable latch, 9 bit data encoder, pin diode switch driver, and eight pin diode switches.

Security housings receive a computer generated address in manufacturing. The computer blows fuses on a plug-in module and prints the housing serial number which is the same number as address. The subscriber module is not given an address in manufacturing, but receives its address upon being plugged into the housing module. This allows complete interchangeability without changing address. No knowledge of binary or trinary addressing is required by installers in the field. This prevents incorrect and/or duplicate addresses.

The OTAS subscriber terminals allow for a maximum of 314,415 subscriber addresses per system, although the standard headend Data Controllers available at this time handle up to 100,000 subscribers. The number of subscribers capable of being handled depends only upon the number of MOS Random Access Memory (RAM) IC's added to the Data Controller and the capacity of the Winchester hard disc memory used

The Data Controller addresses the subscriber terminals at the rate of 10,000 to 16,000 subscribers per minute for per view Pay TV, (a single global command turns on all pay-per-view customers on or off at once), and at a rate of 2500 subscribers per minute for continuously re-addressing subscriber terminal with service level latch commands. In a two-way CATV system, an audit program can be used which increases the number of subscribers from 2,500 to 16,000. This is possible because the subscriber terminal is only interrogated as to the status of its service latches. This data is returned to the central computer location on a crystal controlled 24.3 MHz FSK carrier. If there is a discrepancy between the service level the customer actually has and the service level indicated by the data controller, the proper service level commands are sent to that subscriber.

The Audit is also useful in locating failures in the cable plant. Subscribers failing to reply can be listed by address on the computer CRT. In one-way cable systems, the reply portion of the computer program can be disabled.

Diplexers pass 5-35 MHz around the subscriber terminal to the subscriber drop. This path is normally disconnected to prevent return path ingress from entering the CATV plant from the subscriber's premises (the greatest cause of ingress). By installing a plug-in jumper cable, customers may subscribe to a return path service not associated with the OTAS system. These jumpers can be installed without removing the Subscriber Modules from the housing.

CENTRAL COMPUTER SYSTEM

The central computer system consists of six basic parts:

1. Pico Data Controller (Figure 9)
2. Pico Communications Controller
3. IBM PC File System and hard disk Controller
4. Winchester/hard disk memory
5. Up to eight IBM PC Work Stations
6. Printer(s)

All computer equipment required for the OTAS system is off-the-shelf and unmodified, qualifying it for manufacturer's service contracts.

The Pico Data Controller is an entirely self-contained subscriber controller that operates independently of other computer equipment. The Data Controller is designed for a higher MTBF than the rest of the computer system. It uses MOS memory and an uninterruptable power supply (UPS). Its function is to continuously address the subscriber terminals with data that has been stored in its memory by the File System or the Work Station. Because the Data Controller contains a real time clock and is able to store pay-per-view turn-on information for execution at a future date, the disastrous results of a computer power failure are avoided. This works even if the Data Controller is disconnected from the rest of the equipment. In addition, it contains elaborate self-test programs that can provide automatic switch over to a backup Data Controller in case of malfunction. In the event of a failure of the Data Controller, the subscriber terminals will maintain their service levels indefinitely.

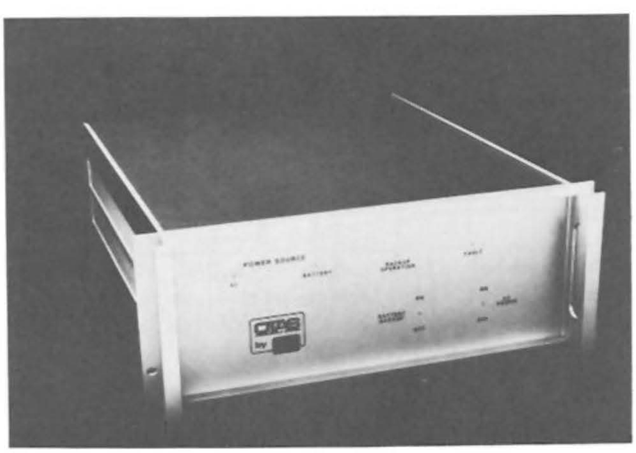

Fig. 9 Pico Data Controller

Incorporated in the Data Controller is a programmable protocal EPROM. The EPROM simplifies the downloading process from the central computer and custom software to the Data Controller itself. The downloading can be accomplished by telephone lines or satellite down link.

OTAS uses IBM Personal Computers in its system. These are used as intelligent terminals and also serve as the work stations of the system. Up to eight of these computers may be connected to the Communications Controller which is essentially the "traffic cop" of the system. The programs are on a mini disc which is loaded into the computer with a self contained mini disc drive.

The terminal operator can retrieve data from File System and change any data in the File System that he or she is authorized by password to change (eg. customer service level commands, per view turn on, billing date start, etc.). When the terminal operator has finished entries, the data is loaded into File System along with date/time, and the name of the operator making the entry. The data is then entered into the Data Controller.

The IBM PC Work Stations can also be used in the local mode with any of IBM's programs for this computer. Programs include: word processor, accounts payable, general ledger, payroll, income tax, etc. Programs can also be written on this computer that use the CATV subscriber data base stored on the File System hard disc, but the data base cannot be changed either purposely or accidentally.

FILE SYSTEM

The File System and Hard Disc are the storage areas for all subscriber statistics and contain numerous programs such as customer statistics, per view program guide, billing mailing labels, printer control, Data Controller control, trouble reporting, self monitoring, maintenance programs, etc.

The Work Stations, Hard Disc, and the File System may be turned off when not in use and the subscriber addressing will continue from the Data Controller. This greatly increases the MTBF of this equipment.

AN EQUIPMENT SCENARIO FOR DELIVERING STEREO SOUND ON CATV SYSTEMS

J. W. Wonn

Group W Cable, Inc.

ABSTRACT

NCTA studies indicate that off-air TV signals carrying stereo sound are likely to cause problems in certain CATV distribution equipment. To ignore this issue in a CATV plant may result in unacceptable picture and/or sound quality. This paper describes an alternative approach that permits delivering CATV stereo sound in a way that is advantageous to both the subscriber and the cable operator. The scenario is to simulcast stereo sound in a special off-channel frequency band. This approach permits the customer to receive stereo sound with conventional audio equipment rather than a special TV set, and is compatible with most existing set-top terminal equipment. In addition, this approach provides a systematic migration path from present CATV configurations to stereo delivery, and also could provide some attractive subscriber feature enhancements.

THE PROBLEM

It now appears almost certain that stereo sound TV signals will soon be broadcast by many TV stations. It is also likely that there will be some new problems for CATV operators when those signals start arriving at their off-air antennas. The NCTA has released a study on the proposed broadcast of stereo sound TV and its likely effects on CATV systems. Delivering stereo TV signals on cable as received off-the-air can cause several problems, including:

1. broadened audio spectrum may cause interference with upper adjacent channel video,
2. proposed stereo signal formats are likely to interfere with authorization coding that is presently transported on the audio carrier in some popular scrambling schemes,
3. reduced audio carrier level required in CATV systems could significantly compromise the quality of decoded stereo sound,
4. many present set-top terminals may not pass off-air stereo sound.

With the variety of equipment used today in head-ends, distribution, and set-top terminals, it is likely that even a small cable system operator will encounter at least one channel where direct carriage of off-air stereo sound causes subscriber dissatisfaction.

In addition, even if the cable operator is able to deliver stereo sound TV as it is broadcast, the subscriber may be forced to purchase a "stereo" TV to take advantage. The CATV operator needs to develop an equipment strategy that will permit delivering stereo sound in a way that is more attractive to the subscriber and at acceptable cost.

PROPOSED ALTERNATIVE

The proposed alternative is to simulcast, delivering two signals to the subscriber. One is the conventional TV signal incorporating monaural sound. This conventional TV signal is fully compatible with any TV set and will not suffer any of the potential problems cited in the NCTA study. This is the same signal that TV sets have always received. The other signal is the stereo sound signal which is carried 'off-channel' in a special frequency band dedicated to that service. There is considerable flexibility in delivering the stereo sound signal. One option would be to deliver it in the FM-broadcast band. This has the advantage that the subscriber needs no special equipment beyond what is likely to already exist in the home. Another means of delivering the stereo sound signal is to carry it in some special part of the cable spectrum that is presently unused. This method does result in a requirement for a special device ("stereo module") in the subscriber's home, but as will be discussed, also promises to be low-cost, user-friendly, and can include special user convenience features. Either way, this alternative delivers to the subscriber stereo sound signals that are compatible with reasonably-priced audio equipment which in many homes, already exists.

WHAT IS NEEDED TO DELIVER OFF-CHANNEL STEREO SOUND

There are two basic things that must happen to deliver off-channel stereo sound. First, the stereo sound must be removed from the incoming signal at the headend and replaced with a monaural equivalent. This will require some additional equipment at the headend that will be discussed later. Second, the stereo sound must be delivered to the subscriber. That implies the need for some additional FM-stereo modulators at the headend and some receiving and audio equipment at the subscriber's home.

SUBSCRIBER'S VIEW OF DESIRED TERMINAL CHARACTERISTICS

The subscriber is sensitive to equipment cost, convenience, and compatibility with existing home entertainment equipment. The total cost of required terminal equipment should be significantly less than a new "stereo" TV. A subscriber "stereo module" that would deliver left and right stereo audio channels, including considerable user convenience features, might cost $50 in large production quantities. Many subscribers would already own a suitable amplifier and speakers. If not, purchase of dedicated stereo equipment might cost an additional $100. So the anticipated subscriber equipment cost would be very favorable compared with the cost of a new "stereo" TV set.

The subscriber would also favor user-friendly equipment. One option is simulcasting in the FM-broadcast band and have the subscriber use a conventional FM-stereo receiver. The problem here is that the subscriber has to get up and re-tune the stereo receiver each time the TV channel is changed. It would be far better to have a "stereo module" that automatically tunes to the audio program that corresponds with the channel being viewed on the TV set.

The subscriber would also be receptive to a hand-held remote control and any other user convenience features that could be incorporated at reasonable cost.

SOME DESIGN ALTERNATIVES FOR SUBSCRIBER TERMINAL EQUIPMENT

At least three concepts have been identified for implementing the subscriber equipment described above. In each case, the primary function of the subscriber terminal or "stereo module" is to tune to the appropriate stereo sound carrier frequency, detect the left and right (L and R) stereo components, and provide L and R audio outputs.

The first concept is diagramed in Figure 1. The drop feeds signal to both the existing converter and the stereo module. To satisfy the auto-tune requirement, each channel having a corresponding stereo audio program would carry a unique 'tag' that passes through the converter and is fed back to the stereo module. This unique tag would "ride along" with each TV channel so that the tag reaching the stereo module would be the one corresponding to the channel which the converter is tuned to. Either VBI or audio tone codes might be useful for tags since both can pass through most existing converters and are essentially invisible to the TV set. This concept of Figure 1 provides for hand-held remote control of channel selection to the extent that the converter supports same.

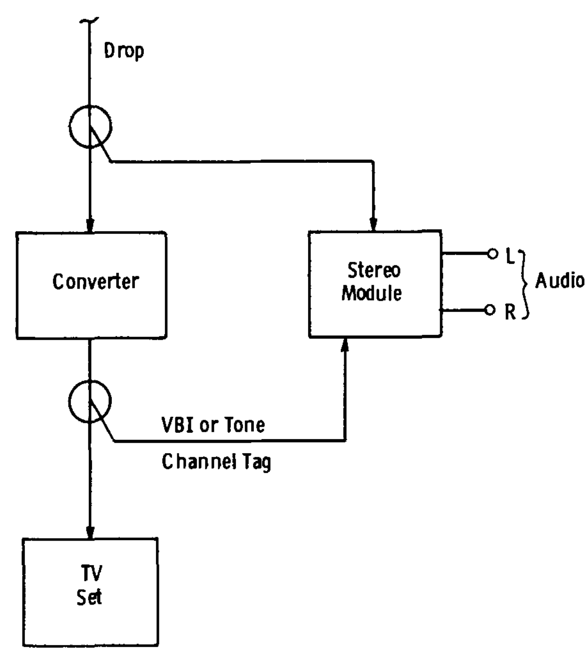

Figure 1. Stereo Module can be auto-tuned by VBI or tone 'tag' passed through converter.

In some cases, it might be necessary or desirable to not require a converter as part of the subscriber equipment. Figure 2 suggests a concept which satisfies that need. The suggested approach is to directly sense the channel that the TV is tuned to. This might be a sensor that gets installed in the TV set to detect some RF amplifier frequency. Another possibility might be for the sensor to 'listen' for some unique subaudible tone 'tag' that gets passed through the TV and is available at the speaker.

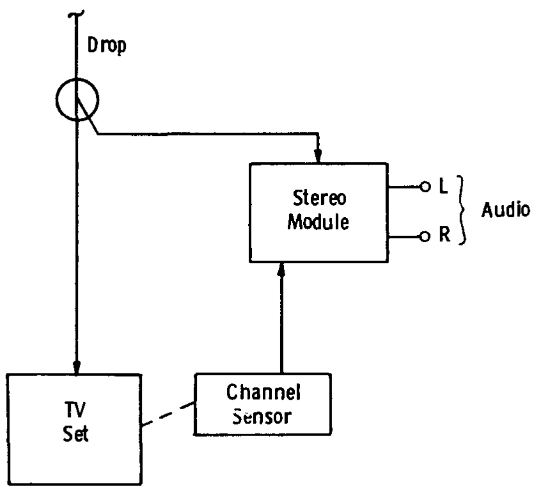

Figure 2. Stereo Module can be auto-tuned by sensing TV channel directly.

Figure 3 suggests an embodiment that is very attractive. This embodiment again does not require a converter (although does not preclude) and makes use of a hand-held remote control to tune the TV (if applicable) and also to tune the stereo module. The stereo module in Figure 3 includes an IR receiver so the hand-held remote control can communicate commands directly to it. This offers the option of remote-control volume, a feature heretofore associated with base-band converters. This approach would require some attention to dealing with the various IR remote control encoding formats now in use. It appears likely that a plug-in PROM in the stereo module might be one way of handling this variance. Another option might be to provide a special remote control that is universal.

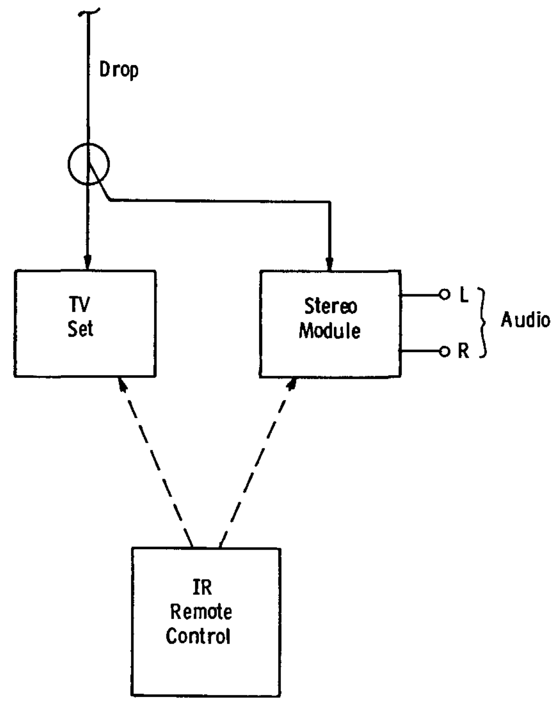

Figure 3. IR remote control tunes both TV and Stereo Module, and can offer remote-control volume.

SYSTEM IMPLICATIONS

As has been discussed, some new equipment would be required at the headend in addition to the above subscriber equipment. Operationally, it is important to understand how to go about specifying the new headend equipment. This issue has been approached by dividing headends into two categories according to the type of signal processing employed. The categories are (1) base-band types and (2) RF processing types.

Channels that employ RF processing could be modified in a number of ways. Referring to Figure 4, the solid line part of the diagram indicates the functional blocks in a single channel of RF processing headend equipment. Those functional blocks take incoming channel A and convert it to some IF frequency. Then the signal is reconverted from IF to the desired channel B for insertion onto the cable distribution system. The three circled numbers in Figure 4 indicate locations where equipment could be introduced to remove the stereo sound, and replace it with monaural sound.

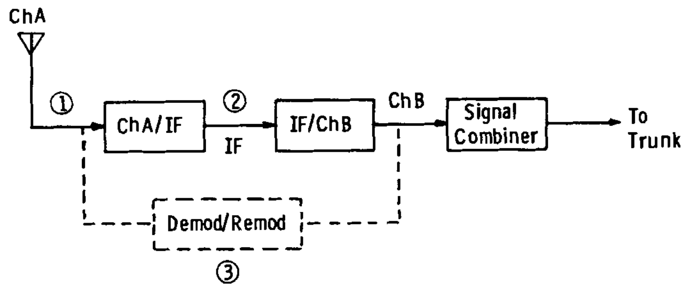

Figure 4. Alternatives for modifying RF headends.

Location 1 is where the antenna terminates at the headend equipment. A device could be defined for this location that detects and removes incoming stereo sound and replaces it with monaural sound. Such a device would deliver a conventional TV signal to the input of the headend equipment. The same device would make available L and R audio signals for delivery in the off-channel band. One potential disadvanage of this device is that it is channel-specific, probably requiring a different operating frequency for each off-air channel. The principle advantage of this approach is it is universal-- the necessary equipment will always be in the same location, is essentially independent of any other aspects of the headend, and requires no electrical/mechanical modifications to existing equipment. The correct equipment could be ordered by specifying nothing other than the channel frequency, and installation makes use of existing connectors and cables. For large MSOs, this could be a tremendous operational benefit.

Location 2 is the IF of the processor. The functional requirements of the device for location 2 is essentially the same as for location 1. The principle advantage is that most RF processors use a standard IF frequency, making it sort of a 'one-size-fits-all' device. The potential disadvantages are that the existing processor would have to be modified electronically and mechanically to break into the IF strip. In addition, ordering the required device seems to inherently require more in-depth understanding of the headend electronics.

Location 3 suggests replacing the RF processor with a demod/remod signal processor that has the functional attributes of detecting and removing the stereo signal, and replacing it with a monaural sound. While this approach is certainly feasible in a technical context, considerations of cost and available rack space might be a significant drawback.

The other category of headend equipment is base-band signal processors. Channels that use base-band headend signal processing are expected to remove the stereo from the incoming signal without any equipment changes. Presumably, these base-band devices will pass on to the subscriber some acceptable quality, non-stereo signal. But existing base-band signal processors would certainly require some modification to detect and make available the L and R audio channels. It may further be found that additional modification would be needed to replace the stereo with a higher quality mono sound for distribution over the cable. Alternatively, it should be clear that another option for base-band processed channels is the device described above for use where the antenna terminates at the headend input, further demonstrating the universal nature of that approach.

Regardless of the approach taken to remove stereo and replace it with mono sound, the final step is to take the detected L and R stereo components and modulate an FM carrier for distribution in some off-channel frequency band. The FM carrier frequencies could be in the FM-broadcast band, suggesting an FM receiver as reception equipment. Alternatively, the cable operator might dedicate some unused 6-mHz band to carriage of the FM-stereo signals, with the accompanying subscriber enhancements described above. In addition, some of the subscriber equipment options described above require 'tagging' the TV channel to provide the auto-tune feature. These headend equipments are schematically indicated in Figure 5.

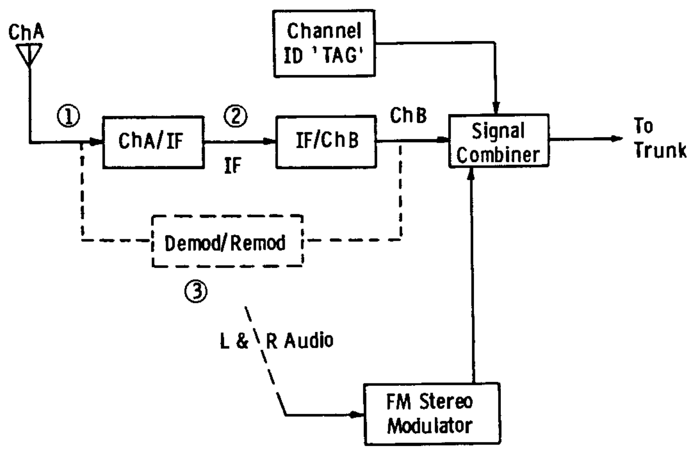

Figure 5. Full complement of equipment for modified headend.

ENHANCEMENTS

We have so far focussed on the essential equipment needed for delivering stereo to subscribers without requiring a new TV set and without requiring modification to existing set-top terminals. It should be noted that some additional features could be added to further enhance this approach.

One enhancement is that this approach plays into delivering bilingual programming. One language could be delivered over the normal TV signal, and the other language could be provided over the "stereo" band. This enhancement does not add cost to the subscriber equipment.

Another possibility would be to include in the "stereo module" some audio power amplification, permitting the module to drive stereo speakers directly. It is likely that this feature could be added to the subscriber equipment with very little additional cost.

The proposed equipment could be configured to also support some forms of 'enhanced' sound, using increased FM deviation, or might even be made to deliver digital audio.

By adding some additional circuitry to the "stereo module", it would be possible for subscribers to derive all audio, both stereo and mono sound, through the stereo speakers. This would provide 'improved' sound on all TV channels.

Finally, the utility of the hand-held remote control could possibly be expanded beyond the functions of auto-tuning and remote volume control. Other subscriber conveniences could probably be added to further enhance this equipment scenario. These possibilities are left to the imagination of the reader.

CONCLUSIONS

It is concluded that cable delivery of stereo sound TV in the same format as received off-air is not in the best interest of the subscriber, both from the standpoint of quality of delivered audio and video, and from the standpoint of subscriber equipment cost. Instead, this paper proposes and explores the equipment needed to deliver stereo-sound TV over cable in a way compatible with subscribers' home stereo equipment. It is concluded that the proposed approach is advantageous for both the customer and the cable operator. The customer would not need to purchase a "stereo" TV to take advantage of stereo broadcasts, and could be offered extra features such as remote volume control. The cable operator would not face the prospect of a massive change-out of set-top terminals. It is also concluded that nothing new needs to be invented to produce the necessary equipment and that the cost of that equipment compares very favorably with other alternatives.

APPLICATIONS OF DATA ON CABLE SYSTEMS

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ABSTRACT

The use of coaxial cable for business and municipal communications is increasing at an extremely rapid rate. It has been estimated that by 1985, three-fourths of all businesses will use non-telco services for at least part of their communication needs.(1) Many will turn to CATV technology to provide this service. Municipalities also view cable as a means to provide reliable, cost effective communications for civic needs.

Applications using cable for business and municipal communications are in operation but little documentation exists on what has been done and the reasons for its implementation. This paper will review three actual applications where CATV technology is used in the applications of: 1) Videoconferencing earth station links; 2) Municipal medical information network; and 3) Business communications.

INTRODUCTION

During 1984 an estimated $2.2B will be spent by businesses and municipalities to communicate voice and digital information in the metropolitan area. Local telephone companies will accrue 98% of these revenues while less than two percent will go to operators of private microwave systems, earth stations, Digital Termination Service, and cable networks. It is projected that by 1988, expenditures for local business communication will reach $5.9B per year with approximately 85% of this revenue being spent on telco services. The four other competitors will split the balance of the revenue cable technology accounting for three percent or $177M per year.(2),(3)

There is an endless variety of applications for which CATV technology can be used. Generally, these applications are lumped into data, voice and video. Some examples are:

Data: Business transfer of Accounts Receivable, Accounts Payable, Inventories, New Orders and Scheduling. Credit card validation at retail stores. Bank account balance status. Data base access.

Voice: PBX voice communication and voice trunking.

Video: Business videoconferencing, live video educational programming, taped presentations and seminars.

Municipalities have needs similar to those of the business community. Data transfer, voice communication and video programming to benefit education and government are needs which are taken into account when franchises are granted or refranchising occurs.

VIDEO CONFERENCING

In Fairfax County, VA, there are almost 2,000 businesses employing approximately 90,000 people. Media General Corporation operates the cable franchise which covers approximately 400 square miles west and south of Washington, D.C. To service the communication needs of the area, Media General has instituted a service called Medianet.(4)

Medianet is a cable network separate from the entertainment cable network dedicated to service the needs of business, public offices, educational institutions, and health care facilities. Medianet has readily available bandwidth, features competitive pricing and offers the inherent advantages of using cable for high speed digital transmission. After evaluating the alternatives of telco and microwave, SBS (Satellite Business Systems) decided that Medianet was the most economical choice to link its earth station to the videoconferencing facility at its McLean, VA headquarters. The initial customer utilizing this videoconferencing service was Aetna Life & Casualty Insurance Company of Hartford, Conn.

Video Conferencing System Figures 1A and 1B show the video conferencing system established by SBS and Media General Corporation for Aetna Life and Casualty Insurance Company. A video conferencing room has been built on the 9th floor of the SBS/RealCom Building in Mclean, VA.

This room can be used by Aetna executives and others in the Washington, D.C. area for conferences. In the room, video and audio signals from cameras and microphones are converted in a device called Codec (Coder Decoder) to a digital bit stream at 1.544 MBPS.

The earth station which will transmit data to the satellite transponder is located three miles away. Medianet was employed to make this link using T-1 (1.544 MBPS) broadband modems. Modems used include field trial units of Jerrold Metronet 1600 modems. All data is modulated (demodulated) to RF by the modem located in the conference room and demodulated (modulated) by the modem at the earth station. From there, the video conferencing data stream is transmitted to the satellite 23,000 miles above the earth and retransmitted to an earth station on the roof of the Aetna headquarters building in Hartford, Conn. A direct link to the Codec in the teleconferencing room is made and the digital information is reconverted to analog for audio and visual communication.(5) The entire voyage of the data is 46,000 miles and takes less than 1/4 second to complete.

Video Conferencing Benefits The video conferencing link solved a problem for Aetna in that it now can accomplish timely, cost effective business conferences between executives in two cities. The "right people" can now attend meetings and much less "wear and tear" is experienced by executives shuttling between cities.

Recent advances in satellite and communication technology have made videoconferencing an affordable and reliability means of conducting meetings. However, all this technology is of little use unless it can be distributed to the specific building where the videoconferencing room is built. Of the three alternatives available to provide this local link, 1) Dedicated telephone lines for T-1 service would not be available for 11-12 months; 2) Microwave transmission was too costly since direct line of sight could not be gained; and 3) Only Medianet was available, at competitive prices and used proven technology.

MUNICIPAL NETWORK

The cable system in Kansas City, MO and its suburbs is operated by American Cablevision a Division of ATC. The franchise area includes Jackson, Clay, and Platte counties in Missouri and parts of Johnson County in Kansas. As part of its franchise committment, American Cablevision of Kansas City (ACKC) built a 72 mile institutional network throughout the franchise costing $700,000. The Distribution System is a 330 MHz network and features Jerrold SJ Amplifiers and Passives. Four channels upstream and four channels downstream are dedicated for municipal use. The balance of the network is available for commercial applications.

The Institutional Network provides municipal communication services to four groups; hospitals, libraries, educational institutions and police. Each was allotted one TV channel on the network. When fully completed, the municipal network will service over 50 institutions including:

15 - Hospitals/Medical Centers

13 - Colleges

12 - Libraries

11 - Police Facilities

Medical Network The Kansas City Area Hospital Association (KCAHA) has 44 member organizations in the Kansas City area on both sides of the Missouri/Kansas border. The KCAHA is responsible for managing the programming of the medical channel. The KCAHA uses this channel to reduce the cost of education to member hospitals and increase the amount of health care related programming in the area.

Figure 2 shows the 14 health care facilities (3 medical centers and 11 hospitals) currently interconnected on the "I" Net. The three hub sites, linked by microwave, are also shown.

The medical network at Kansas City provides a variety of services related to health care for hospital staffs (medical and administrative) and patients.(6) These services include:

1.) National satellite video teleconferencing of health related topics.
2.) Teleconferences among the 14 health care facilities.
3.) Broadcast of prerecorded programs on health care issues.
4.) Distribution of cable health network to hospital patients and their families.

Medical Network Benefits The medical network at Kansas City has given the community health care facilities a medium over which to share information for education and training purposes. It also provides a means to demonstrate medical techniques on a consistent and more frequent basis. This medium was not previously available and the cost would have been prohibitive without a system shared by other municipal and business institutions. The availability of this network has resulted in a noticeable increase in staff participation in education. This is attributed to its convenience, broad range of programming and quality.

In the future, the medical network at Kansas City has planned to have expanded services such as data transmission, electronic mail service, credit and non-credit courses for hospital employees, uplinking of programming from Kansas City to other regional medical networks and potentially distributing live or taped health care programming to the subscriber network in Kansas City.

BUSINESS COMMUNICATION

Many cable operators are reacting positively to the need for cost effective business communications. Some are building vast institutional networks and promoting their use through active selling and marketing. For those operators outside the largest metropolitan areas, another strategy can be taken to serve the business community without the huge initial capital outlay.

Currently a cable operator in the northeast is following the strategy of first building individual systems for major businesses in its area. Later, these systems will be expanded to serve smaller businesses. As the systems grow, availability to all businesses will be achieved and an integrated institutional network will be developed. The network currently being developed will eventually serve the 9,000 businesses and 200,000 employees in the franchise area.

In one particular system developed by this cable operator, a major customer with 24 buildings is using CATV technology for a business communication system. It includes electronic mail, word processing and access to information located in the company's computer and communication center (inventory, Receivables, schedules, etc.).

Business Communication Network The architecture of the system is shown in Figure 3. The front end processor is located in the computer and communications center. This computer center is linked to the main headquarters building and a second administrative office building via cable. This link is made using broadband data modems which are predecessors of the Jerrold Metronet 1000. The modems operate at 9600 BPS and yield an RS-232 output.

At both the headquarters building and the administrative office, this RS-232 is split into four (4) separate RS-232 outputs by a device called an MSD (Modem Splitting Device). This device has four IBM #3274 controllers connected to it and 32 individual work station terminals can be connected to each controller. This means that with one 9600 BPS point-to-point connection, 128 terminals can be supported by the processor. With a total of eight such point-to-point communication paths, the system capacity is presently 1,024 user terminals.

Currently three buildings and approximately 700 users are linked to the business communication system. Future plans include a link to all 24 buildings.

Business Communication Benefits The system described is used for electronic mail, data access and word processing. This system has led to higher productivity through more efficient communication. Moreover, the system offers flexibility since any terminal in any building can be used to access information in the network, including an individual's own list of messages.

Originally the business communication system was implemented using telephone lines. The major problem with the telephone system was reliability. The user had experienced 2000-3000 errors per hour on telco lines but has experienced almost no errors with the cable system.

The user also considered cost in choosing CATV technology for its business communication system. Microwave transmission was evaluated along with telco and cable. Of the three alternatives (microwave, telco, cable), it was found that cable provided the least costly system to build and operate.

CONCLUSION

The three applications discussed in this paper are actual installations currently operating in good order. In each application, the cable system plays a key role in providing communication services to each of the users. Also, in each application cable has proven to be the most cost effective, reliable, and available alternative.

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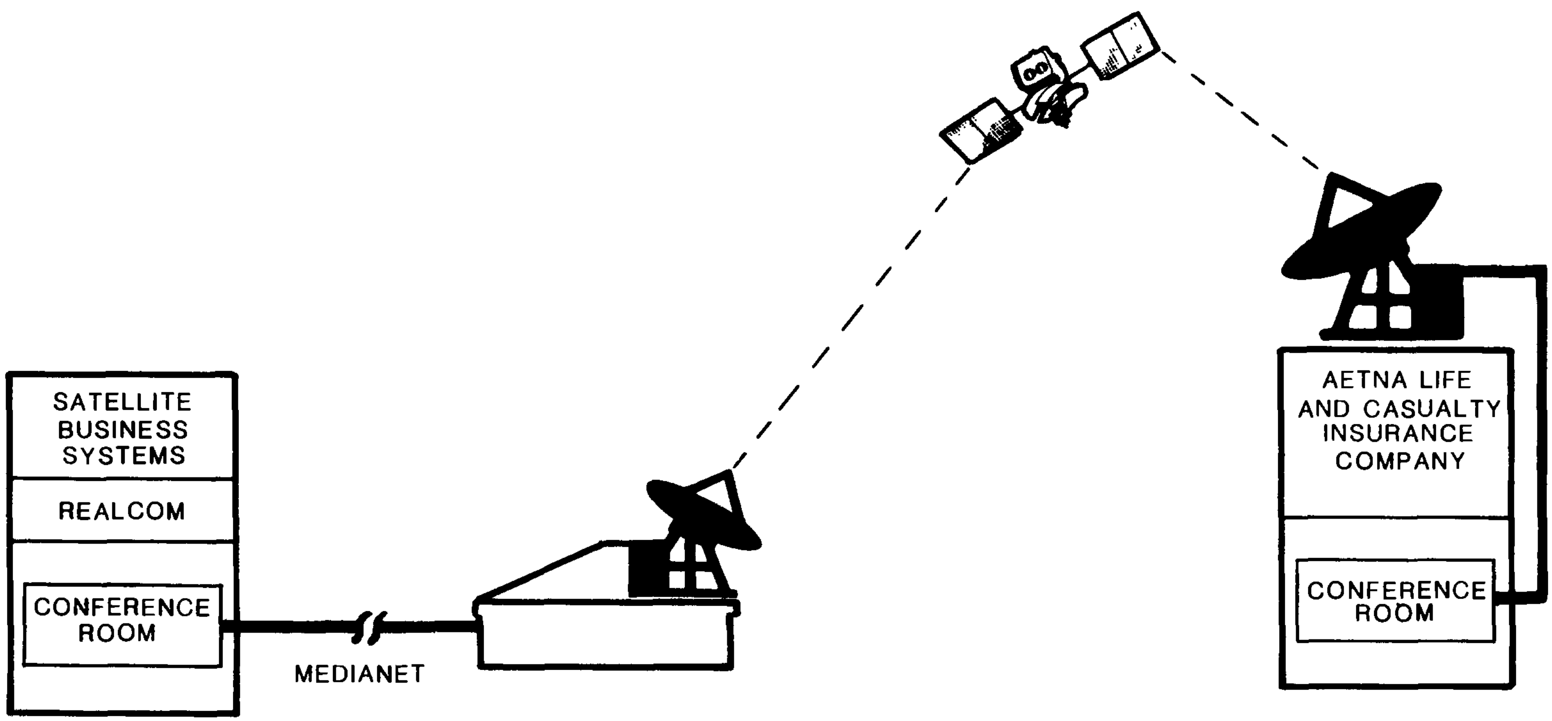

FIGURE 1A – VIDEOCONFERENCING SYSTEM

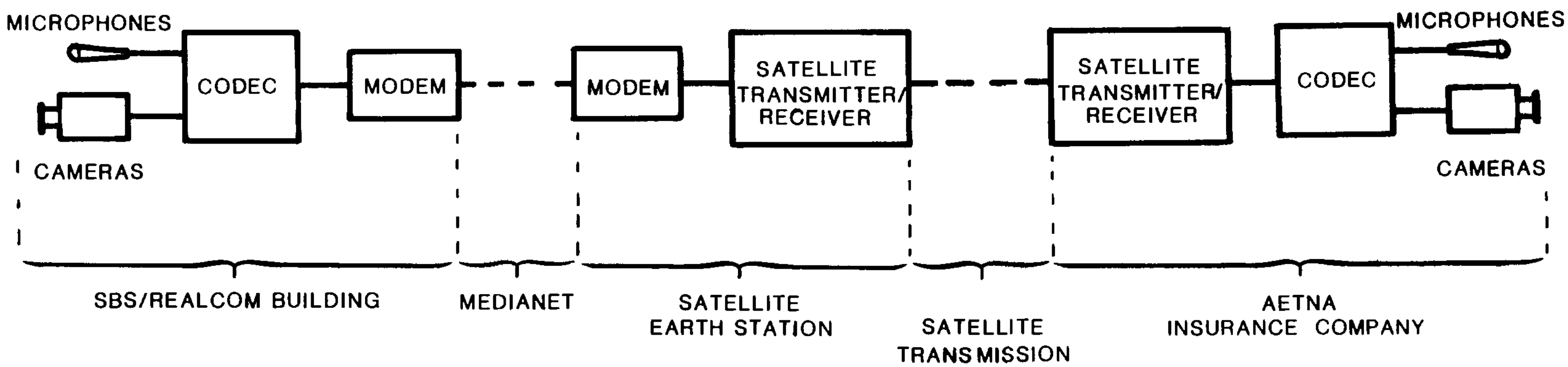

FIGURE 1B – BLOCK DIAGRAM – VIDEOCONFERENCING SYSTEM

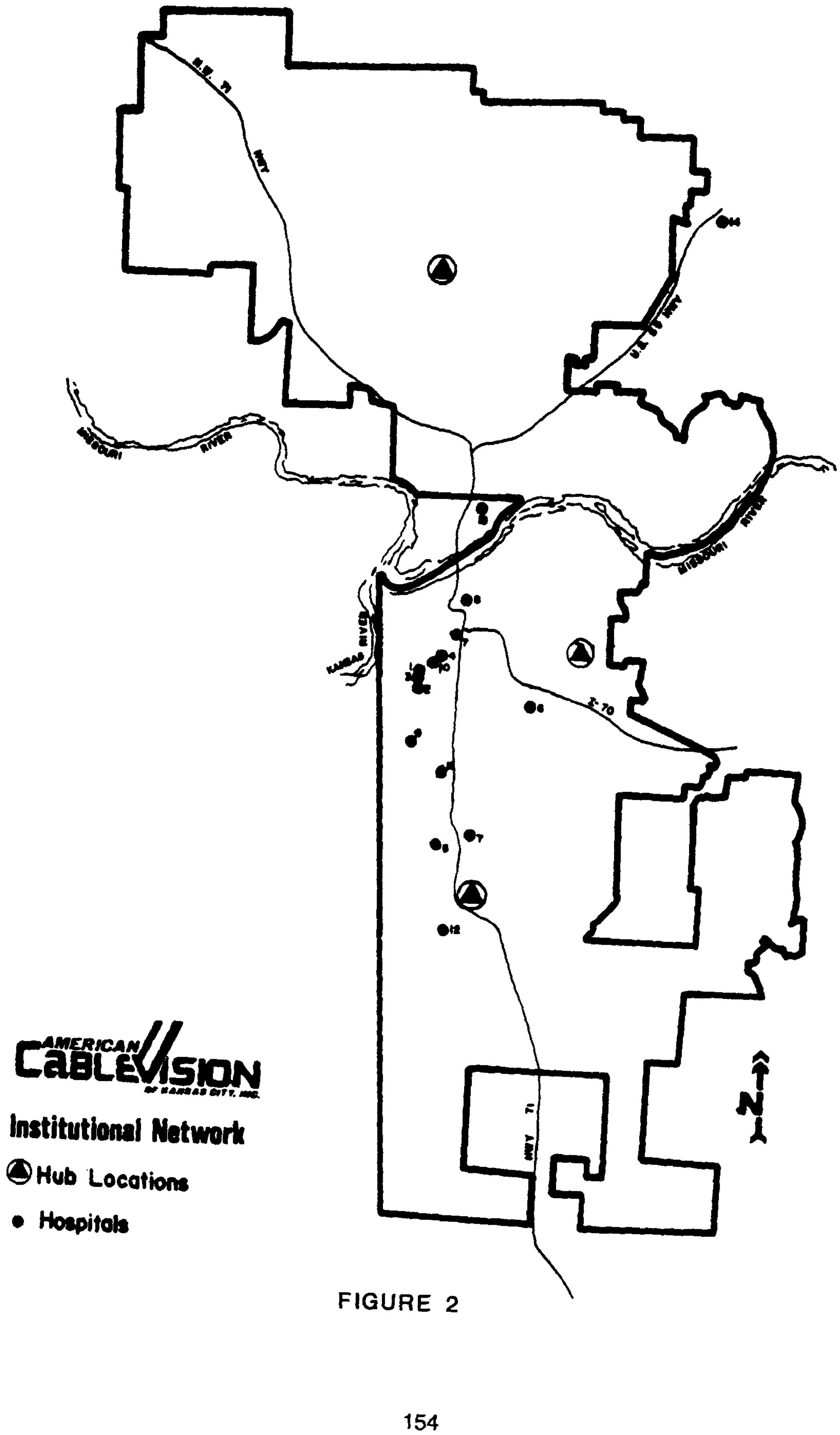
N.W. 71
HWY
U.S. 69 HWY
MISSOURI RIVER
MISSOURI RIVER
KANSAS RIVER
I-70
HWY 71
AMERICAN CABLEVISION
Institutional Network
Hub Locations
Hospitals

FIGURE 2

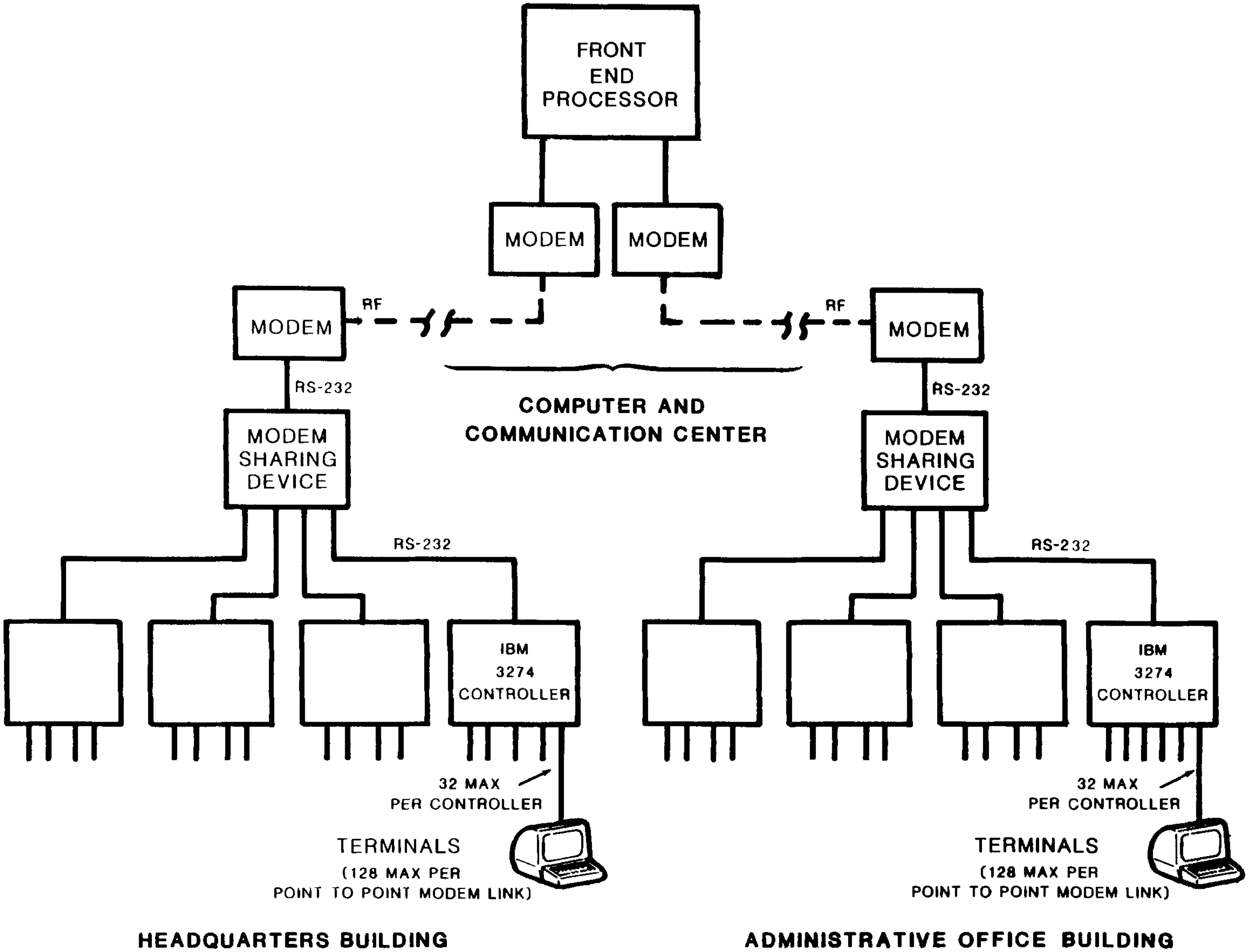

FIGURE 3 – BUSINESS COMMUNICATION NETWORK ARCHITECTURE

AUTOMATED BIT ERROR RATE TESTING

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ABSTRACT

An automated bit error rate (BER) test system has been developed for an environment that requires repetitive testing. This system acquires data by the IEEE 488 interface, performs all BER and CNR calculations, and plots and stores the results for further processing and references. An important usage of such an automated system is to monitor the receiver's performance over a prolonged period of time to record its response to the varying transmission characteristics of the channel.

INTRODUCTION

For a CATV scrambling system employing encrypted digitized audio, the live audio is first digitized and then encrypted in the encoder. The digitized audio can be transmitted through the cable system either by pulse amplitude modulation (PAM) within the horizontal blanking interval of the video or by means of other RF modulation techniques. In either case, after demodulation and detection in the CATV decoder, the digital bit stream containing audio information is recovered but not without errors. The BER after detection, but before decryption, is referred to as the raw BER. In order to provide high audio quality, the raw BER should be kept low over the range of subjectively acceptable video carrier-to-noise ratios (CNR). Thus numerous BER tests are required for quality control. A specific automated BER test system for decoders in a CATV environment will be discussed. The paper also considers some general philosophy in automating BER tests.

DIFFERENT BER TEST METHODS

A communications system can be tested by transmitting a pseudorandom bit sequence and comparing the detected bit stream bit by bit at the receiver with a locally generated replica of the transmitted sequence. For systems without explicit ports for inputting the data sequence, this method requires interfacing the pseudorandom bit sequence at both the transmitter and receiver. In many TV applications, data bit is usually inserted during the horizontal blanking intervals (HBI) or vertical blanking intervals (VBI) of each frame, making burst synchronization necessary before bit-by-bit comparisons can commence. This method is fine for accurate laboratory tests but cumbersome in the field. Furthermore, this method cannot be used to continuously monitor the performance of a system without disrupting services.

A simpler BER test method can be devised if the information bits of the system are encoded for error checking. For example, in linear block codes, a nonzero syndrome indicates an error in the received block. This error checking can be accomplished either by software or by hardware. Other techniques use the violations of signal format for error monitoring as in bipolar and correlative partial response systems. In either case, an external pulse can be generated whenever a bit error is detected. By averaging the number of error pulses per second over a sufficiently long time, the BER of the system can be estimated quite accurately. The required averaging time T is approximately given by

$$T \geq \frac{1}{\varepsilon^2 pR} \qquad (1)$$

where p is the desired bit error probability, and R is the bit rate of the system. ε is the ratio of the standard deviation of the measured probability to the desired probability. ε should be of the order 0.1 to provide a high-confidence estimate. The advantages of this method are that live information can be sent so that no disruption of services is incurred while monitoring the BER performance of the system, and it is relatively simple to implement. The shortcoming of this method is that there will be undetected bit errors, the number of which depends on the block codes being used. For example, assume that odd parity checking is used and there are 26 bits per block or word, then the probability of two random errors per block is given by $\binom{26}{2} p^2 (1-p)^{24}$ where p is the bit error rate and $\binom{n}{x}$ denotes the combination of n items taking x at a time. These double errors do not cause much sacrifice in accuracy; for example, if the true raw bit error rate is 1×10^{-4} then the probability of double errors is 6.5×10^{-6}. For systems where double errors are likely, e.g., in a differentially encoded system, counting the odd number of parity errors may underestimate the BER of the system. In essence, system-dependent errors should be considered in devising the correct BER test.

SOURCES OF BER DEGRADATION

There are system-dependent and transmission-dependent parameters that affect the BER of a communications system. Some system-dependent factors are the front-end noise figure, the bandpass filters' delay distortion, the timing jitter, etc., of the receiver. The transmission parameters are the inherent noise in the channel, the channel amplitude and delay distortion, co-channel and adjacent channel interferences, etc. In this paper only the channel characteristics and noise are considered as the factors affecting BER.

In a CATV environment, the noise is the cable noise measured at the input to the decoder. This noise can be measured by demodulating the video signal to baseband and using a Tektronix 1430 in noise insertion mode. The actual cable noise and the inserted noise are matched to within 0.5 decibel by comparing the displays on a Tektronix 1480R waveform monitor. The noise figure of the video demodulator can be factored out to get a more accurate estimate of the input video signal-to-noise ratio. The equation governing the input carrier-to-noise ratio to the output carrier-to-noise ratio, after passing through a linear device with noise figure F, is given by

$$\left(\frac{C}{N}\right)_{in} = \frac{1}{1/(C/N)_{out} - \frac{(F-1)kTB}{P_i}} \qquad (2)$$

where P_i is the input power, the product kTB is the noise power at temperature T°K, and bandwidth B.

The channel can be modelled by a two-path transfer function[1]

$$a\left[1 + be^{j\phi}e^{j(\omega-\omega_o)\tau}\right]$$

where a and b are scale and shape factors, respectively; ϕ, τ, and b are the phase, delay, and attenuation, respectively, of the second path compared to the main one. ω_o is the frequency of the fade minimum, and (1+b)/(1-b) is fade depth of the channel. In a CATV environment b can be as strong as -10 to -15 decibels and the delay T can be between 150 to 1000 nanoseconds.

Each BER test should be qualified with the attenuation b and the delay T of the second path of the channel.

AUTOMATING A BIT ERROR RATE TEST SYSTEM

In many cases numerous BER tests are required to evaluate a product. It is convenient to utilize a microcomputer to perform all the repetitive functions in BER testing. In order to ease the communications with other data acquisition equipment, the microcomputer should have the IEEE 488 interface. HP-IB is one trademark that conforms to the IEEE 488. The microcomputer's language should be simple to use and flexible enough to control and communicate with different equipment that may be required in the test. Furthermore, the whole system should be fast enough to compute mathematical functions for algorithmic branching purposes in real time.

At a minimum, the electronics counter for counting the error pulses should be able to "listen" to the IEEE 488 commands. Error pulses are then counted over a selectable duration, e.g., 1-second interval, and then averaged by repeating the trial. In monitoring the BER performance of a communications system over an extended period of time, it is important to record the input carrier power variation with time. One way to accomplish this is to sense the ALC or AGC level. An autoranging digital voltmeter with the IEEE 488 interface can acquire the ALC level and the computer stores the data for future plotting and references.

The philosophy of BER testing is to stress the system so as to produce bit errors. One way is to increase the noise power into the system by injecting noise. A noise generator with a 1-decibel step attenuator should be used so that carrier-to-noise ratio can be varied 1 decibel at a time. Attenuators programmable through IEEE 488 are available if total automation is desired. Other methods of stressing the system, like decreasing the threshold and/or jittering the bit timing of the data detector, can also be devised for BER testing.

AN AUTOMATED BER TEST SYSTEM

To efficiently test and survey the performance of a cable product, an automated BER test system has been developed at Oak. The test system's setup is shown in Figure 1. The microcomputer we have chosen is the HP 9816S. This computer has a clock rate of 8.0 megahertz and has both HP-IB and RS-232 interfaces. The RAM memory is expandable to 1024 kilobytes. It has a built-in real-time clock, essential for data logging when the time durations of tests are important. The computer language chosen is HP BASIC with extensions. It has a rich set of commands for equipment control and is simple to use. The test system further consists of an HP 9121D dual disc drive and uses 3.5-inch, semi-rigid discs with 256 kilobytes of storage per disc. This provides an additional 512 kilobytes of storage for gathering long-term statistics of the system under test. The printer used is HP 82906A. It accepts direct graphics dumping instructions and has programmable font control. Both HP and Fluke counters can be used. HP 5316A electronics counter can both "talk" and "listen" to the microcomputer through the IEEE 488 interface. The Fluke 7220A counter can only listen and requires a translator Fluke 1120A to convert codes and signals of IEEE 488 to the corresponding codes and signals compatible to the counter.

An extensive interactive, user-friendly BASIC software package has been developed at Oak for the HP 9816S microcomputer. This package has a manual for choosing test routines for both short and prolonged BER tests. These routines prompt the operator step by step for necessary inputs and information, like carrier power, filename, etc., for BER testing and allows the operator to choose what information to store, plot, and print. It also allows retrieving and previewing of stored data on the CRT before printing and plotting. Furthermore, stored BER files can be retrieved and further processed to include the noise figure of the device under test for

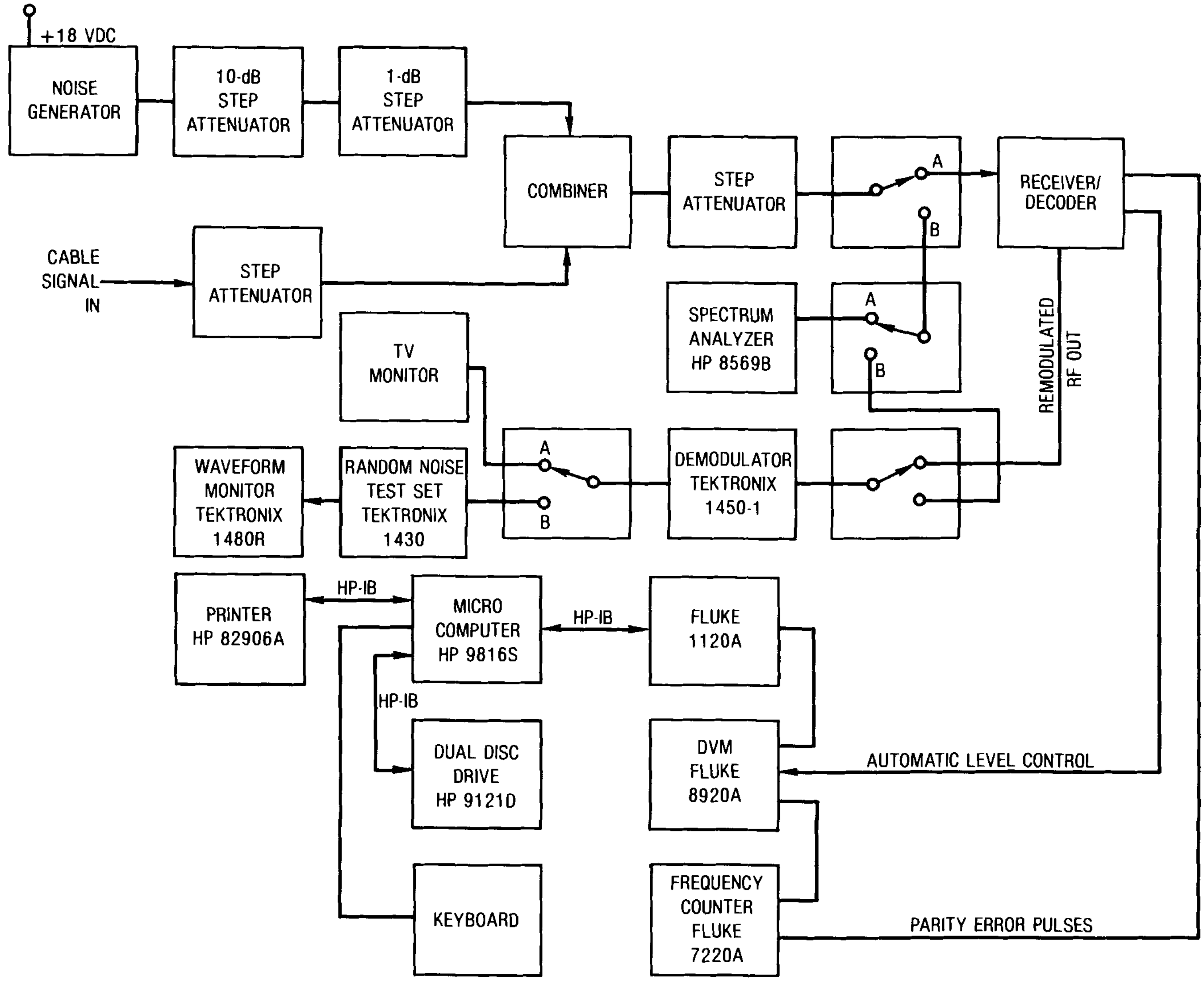


Figure 1. CATV Survey and BER Test Setup

CNR computations. In addition, a routine allows a number of BER curves from different files to be plotted together for comparison purposes.

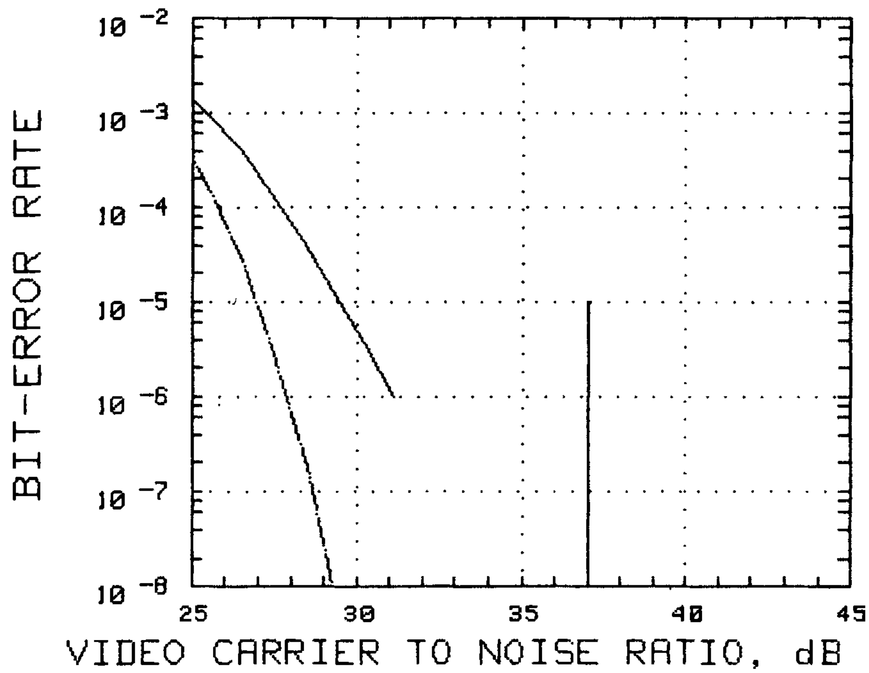
SHORT BER TEST

A single BER curve is a snapshot of the system's performance under different carrier-to-noise ratios given the transmission characteristics of the channel during the test. The noise is the sum of the thermal noise, the channel noise if measurable, and the injected noise. To run a BER test with this automated system in a CATV environment, the operator only requires the video carrier power and the cable SNR of the test channel at the site. The attenuator setting of the noise generator is then varied to change the resultant CNR.

The computer automatically sums the thermal noise, the cable noise, and the injected noise to arrive at a resultant video CNR. It continuously acquires the parity error counts every second from the HP-IB counter and averages the BER accordingly. The total averaging time is controllable by the operator and should be proportional to the bit error rate as per Equation 1 in order to form a statistically high-confidence estimate. The final averaged BER can be manually changed by the operator, if desired, and stored. The BER curve can be plotted immediately after the run so that any errors can be corrected at the site. The multipath and delay information at the site can be appended to the BER file at the users' convenience.

Figure 2 shows the printout of a typical BER run. "CNR INJ." is the CNR with the injected noise. "CNR TOT." is the resultant CNR when the cable noise is included. Figure 3 is a plot of multiple BER runs at different sites of the same amplitude modulated link (AML).

AML HE



Leftmost curve: PAM Theory for 60-IRE p-p HBI DATA. NO VIDEO, NO MULTIPATH.

SERIAL # = 115
VIDEO LEVEL AT CAL = +8.00 dBmV
ATTEN AFTER COMBINER = 14 dB
WEIGHTED CABLE SNR = 41.1 dB
TEK DEMOD NOISE FIGURE = 15.00 dB

CHANNEL # =M DISC FILE : BROOHE3
REF NOISE POWER = +1.43 dBmV(4.2 MHz)
INPUT VIDEO POWER = -6 dBmV
LIMITING CNR = 41 dB

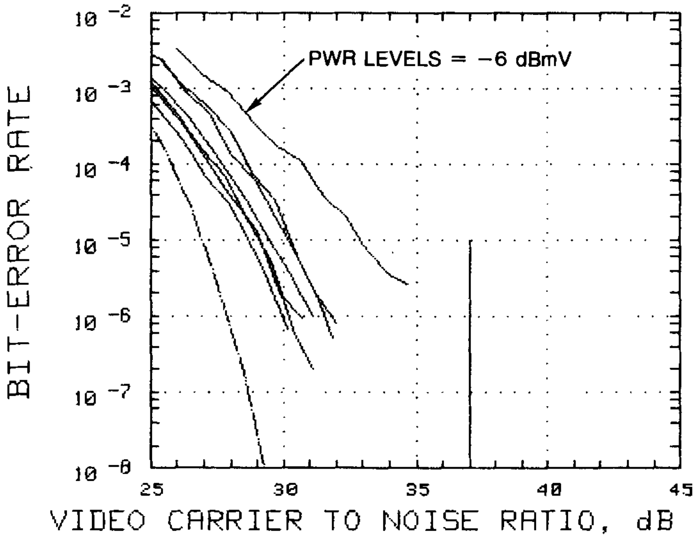
CABLE SIGMA PC FIELD BOARD, AUDIO CHANNEL TEST BY PARITY COUNTING
THE DELAY IS APPROX. 200 NS. THE ANGLE IS 180 DEG. NO GHOST OBSERVABLE
LIVE AUDIO, 5 STEP VIDEO IN SCRAMBLED MODE, DATA SWING ON, INVERT & NONINVERT

TEST BY USING C. WONG'S PROGRAM

BER DATA SUMMARY

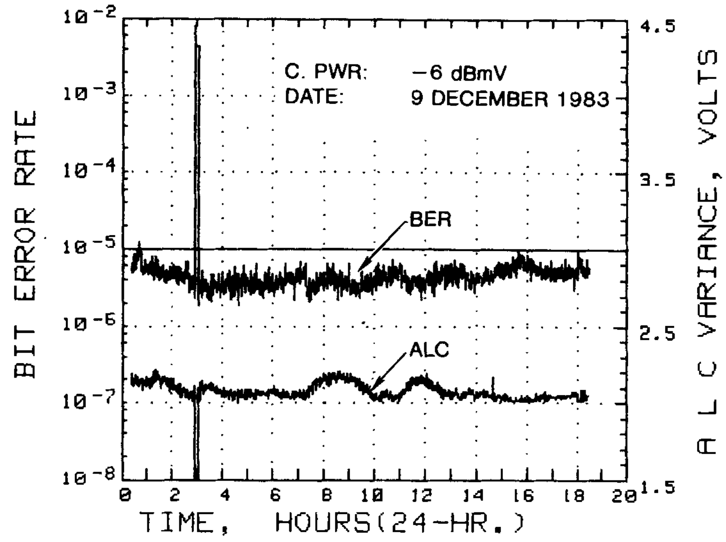
CNR	TOT:	23.5	24.5	25.5	26.4	27.4	28.3	29.3
	BER:	4.48E-03	2.10E-03	9.75E-04	4.08E-04	1.37E-04	4.42E-05	1.33E-05
	SNR:							
CNR	INJ:	23.6	24.6	25.6	26.6	27.6	28.6	29.6
CNR	TOT:	30.2	31.1					
	BER:	3.82E-06	9.89E-07					
	SNR:							
CNR	INJ:	30.6	31.6					

Figure 2. Printout of an Automated BER Run



Leftmost curve: PAM Theory for 60-IRE p-p HBI DATA. NO VIDEO, NO MULTIPATH.

Figure 3. BER Multiple Plots



PROLONGED BER TEST, C. PWR = -6.0 dBmV

Figure 4a. Prolonged BER Test

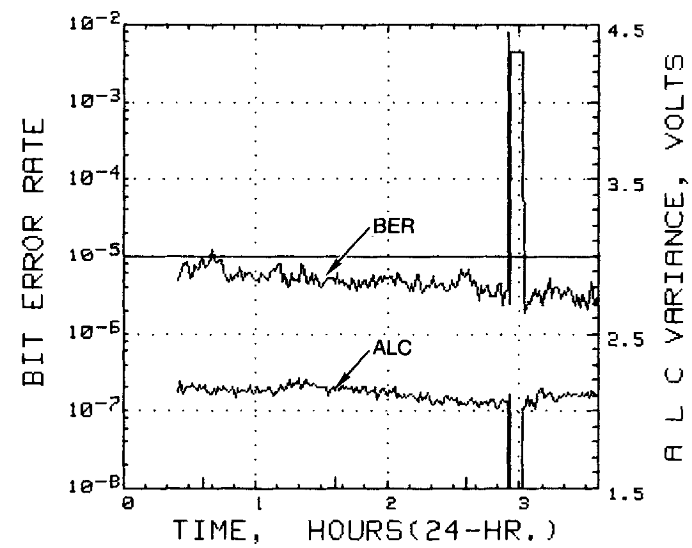


Figure 4b. Expanded View of Error Event

PROLONGED BER TEST

A prolonged BER test is performed to detect and record the duration between events which causes the BER of the receiver to increase above a preset threshold. It is a test on the varying transmission characteristics of the channel over time. It can be used to gather relevant statistics about the channel, e.g., mean time between fades and noise bursts, etc.

In this test, the operator sets up the injected noise level to attain a certain desired BER. The computer continuously logs in error counts every second so that any instantaneous BER and ALC level variations can be monitored. The ALC level is proportional to the input signal power. No operator supervision is required during the test. The program contains error traps so that minor momentary instrument malfunctions will not disrupt the operation. To conserve storage, not all the data acquired in each second are recorded. An algorithm was written so that only BER variations above a certain magnitude will be stored. This allows extended testing of 48 hours or more to be conducted easily with the present system. The program is further capable of zooming in on an error event of interest and plots an expanded view of the BER versus time for easy diagnosis. Figure 4a shows the results of a prolonged BER test. Figure 4b shows the expanded view of the error event. Both the BER and ALC values versus time are plotted. Note the simultaneous decrease in carrier power and the increase in BER. This test shows the decoder's response to the carrier power outage.

CONCLUSION

This paper discusses some aspects and problems in automatic BER tests. An automated system has been developed that utilizes a microcomputer for data acquisition and control. This system has been used extensively in cable system performance surveys.

A further enhancement of this system could be to add an intelligent spectrum analyzer with IEEE 488 interface which can tune to different channels and change resolution bandwidth under computer control. Such a system could then perform peak search for video and audio carrier power measurement, noise averaging for CNR measurement, etc., in a routine way to survey a whole cable system accurately and expeditiously.

REFERENCE

1. C. Siller, "Multipath Propagation," IEEE Communication Magazine, Vol. 22, No. 2, pp 6-15, February 1984.

AUTOMATIC COMMERCIAL INSERTION EQUIPMENT FOR THE UNATTENDED INSERTION OF LOCAL ADVERTISING

Bill Killion, President

CHANNELMATIC, INC., ALPINE, CA

BACKGROUND

Channelmatic was founded over a decade ago as a manufacturer of automatic machine control systems and accessories for the broad video industry. The first product shipped was a low-cost 3-VCR sequencer; thousands of similar systems have been produced by the company to date.

In 1979, Channelmatic produced the first automatic commercial insert system for satellite services. The initial system was installed in Hawaii; it inserted locally generated advertising into the local avail provided by NEWSTIME as part of its slowscan news service. The satellite cue tone prompted device controlled one Sony VCR on a hands-off, totally automatic basis. This product was the forerunner of all automatic commercial insert systems and was the first to use the innovative spot sequential (multiple spots per tape) approach.

Since only a few cable systems sold local advertising on NEWSTIME, the first inserter was a year or so ahead of its time. However, most of the insert systems available today from any manufacturer are utilizing the techniques proven by this initial design.

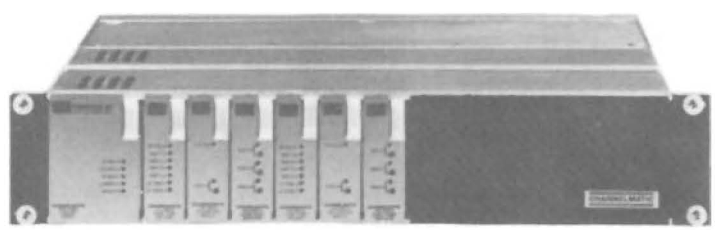
By the time CNN began offering local ad avails, thirty or so of these systems were in the field and most of them were changed over in advance to operate with the new CNN cue tones. Many of the systems inserted advertising in the very first avail offered by CNN.

This early experience has caused the manufacture of related equipment to be dominate in Channelmatic's sales. Accordingly, a constant research and development program is continuing to produce more effective and often less expensive equipment approaches to the commercial insertion problem.

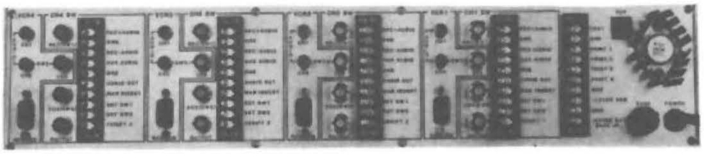
The following paper will discuss the many types of equipment and systems we manufacture for automatic insertion and related functions. Much of that described has been introduced in just the past few months. Several projects are in engineering currently, but are in very early stages and are not mentioned. Much research and software engineering time and effort has been spent on an elaborate Traffic Control and Accounting System, which is described briefly in this paper. Detailed information on all Channelmatic products is available upon request.

VCR-3004A SPOT INSERTER

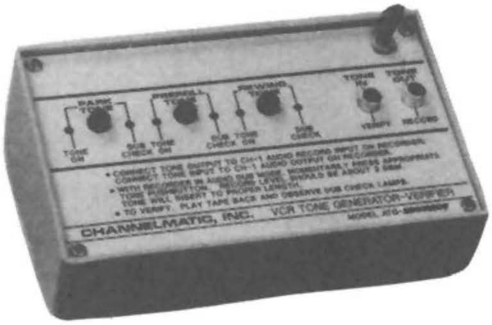
The VCR-3004A system is probably the most widely used automatic spot inserter in operation today. It is a slightly improved version of the first inserter and operates in a multiple spot mode. In a multiple spot system, all spots are recorded, in proper sequence, on a single tape. The system automatically plays back the next spot in the sequence each time a satellite insert tone is received. After the last spot on the tape has played, the VCR rewinds and additional satellite insert tones merely repeat the spots. The system, including the cue tone generator-verifier required to tone tapes, is shown in Figures 1, 2 and 3.



1. VCR-3004A Insert System, Front View

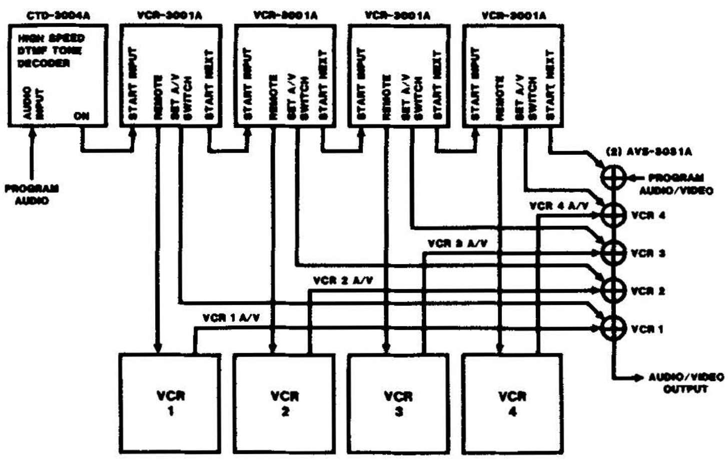


2. VCR-3004A Insert System, Rear View



3. VCR-3004A Tone Encoder

The most obvious advantage of this type of system is its relatively low cost, as it only utilizes one VCR per channel. A single channel price of approximately $4,600, with a VCR, and a four-channel price of about $10,000, with VCRs, makes it very appealing to most cable operators. Figure 4 is a simplified block diagram of a multiple spot system.

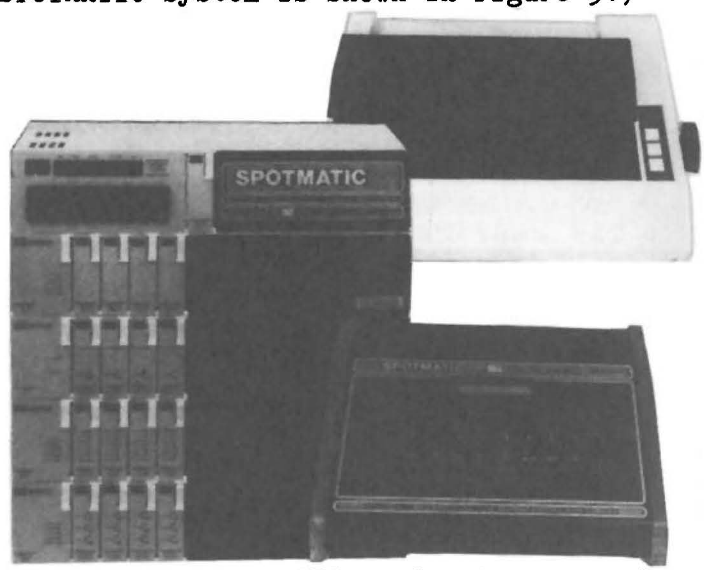


4. VCR-3004A Insert System Block Diagram

SPOTMATIC RANDOM ACCESS SYSTEM

The SPOTMATIC Random Access Commercial Insert System is designed to schedule and automatically insert local commercials into any length of available time slot on multiple channels of satellite service programming. SPOTMATIC locates, cues and inserts the proper commercials in the proper order from standard 3/4-inch videocassettes. Up to 100 randomly mixed commercial spots can be added to each cassette, greatly reducing tape and editing costs. In addition, it prints out a log of all switching functions as they occur and also prints out a daily advertiser-grouped listing identifying all spots inserted on each channel. Insertion is accomplished in a clean, broadcast-quality fashion.

The system also has the additional ability to control multiple VCR's in order to run multiple shorter spots back-to-back to fill longer satellite avails. With this feature, the cable operator may load each VCR with a duplicate of one tape and have complete freedom as to which spots are run back-to-back and in what sequence. More importantly, a commercial spot videocassette need only be edited once and no spots need to be edited back-to-back. Since editing time is cut drastically and simple machine-to-machine duping results in as many tapes as needed, the savings in time alone makes the higher price of a multiple VCR per channel random access system a worthwhile investment. (A typical SPOTMATIC system is shown in Figure 5.)



5. Typical SPOTMATIC Random Access System with Encoder and Printer

When specifying a system, it is a good rule-of-thumb to allow one VCR for each 30-second spot increment on a given channel; this will greatly minimize editing. For example, if the length of the longest avail on a particular service is 1 minute, then two VCR's should be assigned to that channel; if the longest avail is 2 minutes, then four VCR's should be utilized for the channel. Since most commercials are formatted in 30-second lengths, this approach will normally eliminate all editing required for grouping spots.

The SPOTMATIC system uses sophisticated multiple microcomputers to automatically locate an individual commercial spot on a videocassette, cue it in accordance with a satellite service's chosen preroll time and insert it upon receipt of the proper satellite cue tones. It may be configured to control from one to four VCR's per channel and to insert commercials on as many channels as desired, as long as the total number of VCR's to be controlled does not exceed 32. A built-in automatic logging feature gives the operator a hard copy printout of the times and contents of each commercial insertion.

To accomplish all of this, SPOTMATIC requires that commercial videocassettes be encoded with data which gives spot identification information and accurate spot location for automatic cueing. Included with the SPOTMATIC system is a Digital Code Generator which encodes this data on the unused audio track of a commercial videocassette. At the beginning of the tape, the DCG records a directory which lists each spot location by its control track count; the Microcomputer will later count track pulses to accurately locate each spot. Commercial and advertiser identification data is also added to the tape at the location of each spot for later printout.

The operator programs the Master Control Unit microcomputer by entering the channel number, service preroll time, insert times and the commercial numbers to be run during each insert. This is accomplished with simple front-panel keypad pushbuttons. Every entry step is prompted by a large 12-digit LED display mounted directly above the keypad on the front panel of the Master Control Unit. At the completion of programming, the entered data is routed to and stored by secondary microcomputers, each of which controls one VCR. This is accomplished by a one-pushbutton operation which also parks each VCR at the first spot for which it is programmed.

When the proper satellite cue tones are received and decoded, a commercial insert sequence begins. The VCR programmed to insert the first spot is started and, after the proper preroll time, the VCR audio and video is automatically switched on air. Video switching takes place during the vertical blanking interval of the satellite source to give a glitch-free, broadcast-quality transition.

If more than one VCR is assigned to the insert, the following VCR is started into preroll just before the prior spot ends and at the end of the spot, audio and video are automatically switched to the prerolled VCR. At the completion of the last scheduled commercial, the satellite source is automatically switched back on air and each VCR is automatically rewound, cued and parked at its next scheduled spot.

Stereo Processor Interface. The SPOTMATIC system has been designed to be totally compatible with all stereo processors on the market, enabling its use with such services as MTV and TNN.

No VCR Modification Required. The SPOTMATIC system has been designed to control all SONY Type 5 VCR's with no modification required. The HANDIMOD I is available as a simple and low-cost means of locking the VP-5000's so that vertical interval switching is possible; it merely inserts into the unused modulator cavity on the rear of the VCR.

Operational Modes. Because of program requirements, each of the satellite services schedule local avails differently. Some services adhere to a strict time schedule and provide time slots of a constant length. Some services provide constant length avails at random times. Still others, especially those offering live sports programming, vary both the time and duration of local availability periods. The SPOTMATIC system has the ability to modify its operational parameters to suit each individual channel that it controls.

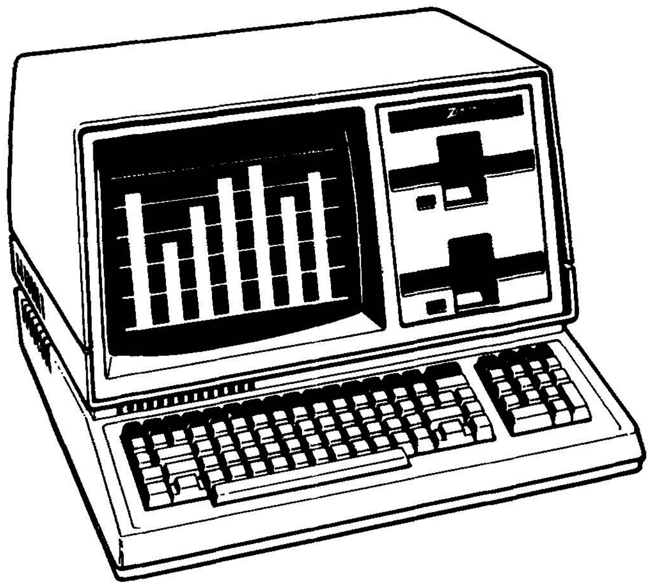
Each day, if need be, the operator may select from several operational modes (OPMODES) to fit each channel's requirements. Among other things, the OPMODE'S allow inserts on each individual channel to be performed (1) within time-blocked windows (if commercials must run at or near a specific time, or not at all); (2) in run-of-schedule (if commercials must run in a specific order regardless of time); (3) on a daily basis (if a service changes its availabilities each day); (4) on a repeating basis (if a service runs a similar schedule for more than one day). Other arrangements are possible, including almost any combination of those described.

In addition, the SPOTMATIC is operator programmed to each satellite service's allocated preroll timing. If this preroll time is ever changed by the service, a simple one-pushbutton program entry adapts SPOTMATIC to the new timing.

Spot Location Accuracy. SPOTMATIC's microcomputers locate and cue commercial spots by counting control track frame pulses. This method gives a plus-or-minus 2-frame accuracy (plus-or-minus tenth of a second) at a fraction of the cost of SMPTE Time Code methods.

NEW SPOTMATIC Z OPTION

The SPOTMATIC "Z" Computer Controlled Random Access Commercial Insert System has been designed to supplement all of the features found in the original SPOTMATIC Commercial Insert System with true computer control provided by a modified Zenith Z-100 Minicomputer. (See Figure 6.)



6. Zenith Z-100 Computer

The Z-100 offers a full, typewriter-style keyboard, twelve inch diagonal, high-resolution CRT display, and dual 5.25 inch floppy disk drives with a total disk storage of 640K bytes. The system is provided with plain english menus and displays to assist in the programming function. Communications between the commercial insert system and the computer result in quicker, easier and more complete event logging and verification. System diagnostics and malfunction logging are also included to simplify troubleshooting.

Scheduling is entered onto a floppy disk by date and retrieved automatically as needed by the SPOTMATIC system so that advance schedules are always available through the computer for inspection and editing as time sales are made.

The SPOTMATIC "Z" is available either as a complete system or as a field retrofit addition to any SPOTMATIC system now in operation. The over 100 SPOTMATIC systems now in operation will be made more effective, not obsolete, by this addition.

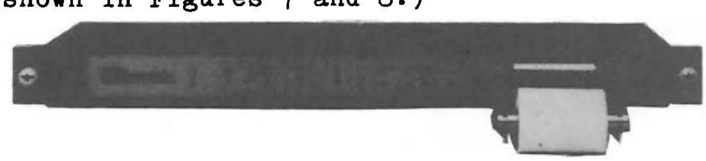
NEW FOR SMALL CABLE SYSTEMS

Since the vast majority of cable systems serve less than 5000 subscribers, Channelmatic has developed a second generation of products specifically for this market. Currently consisting of three products, the are the SPOTMATIC JR, the LOGMATIC JR and the ASS-1A Automatic Satellite Switcher. These devices are now in production and initial field reports indicate that their capabilities far exceed the expectations of most customers, particularly when price is a prime consideration. All have features far advanced of competitive systems and each is priced substantially less than its competition.

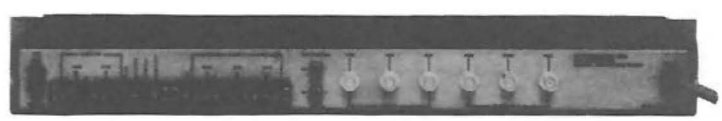
Ease of installation and operation by untrained personnel were also a primary consideration in design of the equipment. The products are all microcomputer based, withcost advantages due entirely to the larger production runs made possible by the under 5000 subscriber marketplace.

NEW SPOTMATIC JR

This unit provides a highly versatile, yet extremely cost-effective means of inserting local commercials into one channel of satellite programming. The micro-computer controlled unit performs all functions necessary to insert commercials in a broadcast fashion and is also equipped with a full-feature logging and verification printer. At $2150, it is priced far less than its nearest insert/logging competitor and has many features not found in even the most expensive systems. (The SPOTMATIC JR is shown in Figures 7 and 8.)

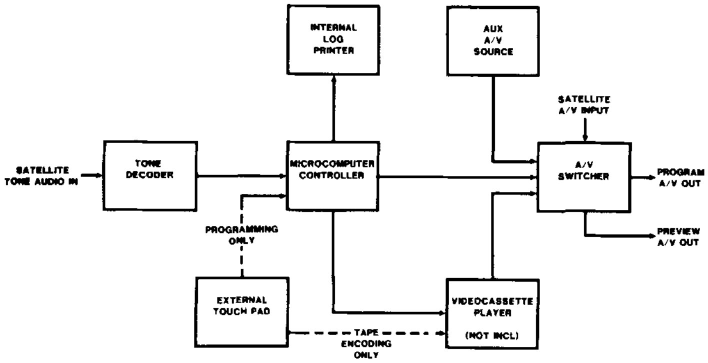


7. SPOTMATIC JR, Front View



8. SPOTMATIC JR, Rear View

In its simplest mode of operation, the unit is a basic multiple spot system and operates as previously described for the VCR-3004A system. However, since the unit is micro-processor based, by properly programming it with a tone pad it will also operate in either a "spot sequential mode" or an "automatic fill mode." Switching is performed in the vertical interval. (Figure 9 is a block diagram of the SPOTMATIC JR.)



9. SPOTMATIC JR, Block Diagram

Spot Sequental Mode. A commercial tape edited with back-to-back 30-second spots may be utilized. End of spot coding is ignored by the microcomputer and spots will be run until the satellite end of insert tones are received. The VCR will then be rewound slightly and parked at the beginning of the next spot on the tape which has not been aired. This feature allows any length of avail to be filled with the appropriate number of 30 second spots without extensive editing. A large window for error is incorporated to compensate for inaccuracies in tape editing.

Automatic Fill. If a commercial is run which is shorter than the available time slot, the system can automatically switch to an auxiliary audio/video source (such as a character generator) until the end of the time period. This allows a VCR spot to be automatically followed by a character generator spot.

Power And VCR Failure Protection. All power failures and VCR malfunctions are detected and logged, and automatic return to the satellite is always effected in event of such failures. A lithium battery maintains memory and allows the system to resume normal operation when power is restored. The battery is essentially permanent, in that it has the capacity to maintain the memory and timekeeping function for approximatelysix months without AC power applied.

Preview Feature. A preview function is included for monitoring the VCR commercial insert process without interfering with the satellite channel. When preview is selected, the satellite program remains on air and is not affected by the commercial insert function. Preview audio and video outputs are provided on the rear panel which allow monitoring of the satellite signal and the commercial insert function. This feature is particularly useful when performing system tests and for preview and test of commercial spot cassettes.

Logging And Verification. Program logging includes printouts upon receipt of cue tones with date, time and cue tone identification; switching changes with date, time and identification of input A/V source; data on the video tape identifying an advertiser and power failure ON/OFF date and time. The microcomputer can be programmed to modify the printouts to include information on satellite code setting, insert operation instructions and other information which has been programmed into the microcomputer itself. This allows the operator to verify every instruction he has given to the SPOTMATIC JR by means of hard copy printout.

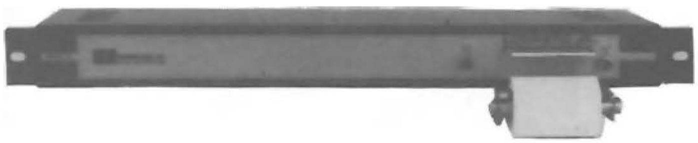
Auxiliary Functions. The system also has the capability of decoding program ON/OFF tones used by some satellite services and automatically switching to an auxiliary source for program fill during off-air periods or the replacement of services sharing the same transponder, but not used on the cable system.

The SPOTMATIC JR has a disable input which, when connected to ground, will disable the commercial insert function. This provision facilitates the connection of a programmable clock to allow insertion of commercials only during pre-programmed time blocks. A manual start input is also provided which, when taken to ground momentarily, will preroll the VCR and cause a commercial to be inserted in a normal fashion. An on air output is also provided, which goes low only during the actual time period a commercial is being inserted. These connections are also utilized to interface with stereo decoders used with some satellite services.

A satellite sync output is also provided for genlocking purposes. This signal is used to servo-lock the VCR to the satellite signal, thereby assuring vertical interval switching. A tone level indicator on the front panel facilitates proper adjustment of the satellite receiver audio output level. This feature assures that the correct satellite cue tone audio levels are applied to the SPOTMATIC JR.

NEW LOGMATIC JR

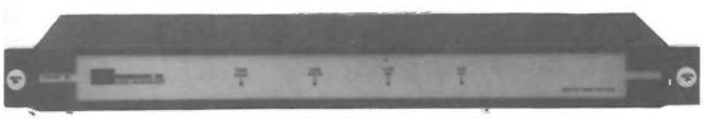
The LOGMATIC JR is a fully automatic four channel commercial insert logging system providing a printout of the time, date and channel identification of any insert along with encoded advertiser and spot information. A built-in real-time clock furnishes the time and date information, while advertiser and spot identification are read from DTMF data previously added to the unused audio channel 1 of the commercial videotapes. A portable DTMF keypad is used to both add the identification data to the tapes and to set the internal clock. LOGMATIC JR printouts are invaluable for both switch verification and billing preparation. The unit will operate with most commercial insert systems. (This unit is shown in Figure 10.)



10. LOGMATIC JR, Front View

NEW AUTOMATIC TONE SWITCHER

The ASS-1A Automatic Satellite Switcher provides a simple and inexpensive means of inserting local programming from an audio source and a character generator or other video source into satellite programming. It decodes the satellite tones which occur at the beginning and end of the satellite programming or local commercial insert period and uses the locally generated information to automatically fill the time period surrounded by the cue tones. (Figure 11 is a front view of the ASS-1A.)



11. ASS-1A Switcher, Front View

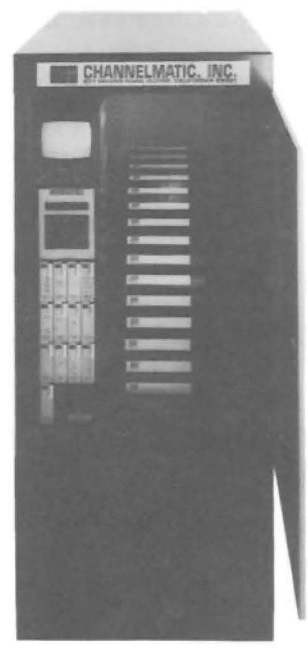
All switching is performed by integrated circuits and occurs during the vertical blanking interval for clean, broadcast-quality peformance. The microcomputerized tone decoding circuitry automatically tunes itself to the tone code of the satellite service to which it's connected. The unit is equipped with a lithium backup power supply for months of memory retention in the event of power failure.

A form-C (SPDT) contact, an open collector logic output and a reset/disable input are available from terminals on the rear panel. The reset/disable and logic output functions facilitate control by a time clock for blackout purposes and operation with stereo channels such as Nashville and Music TV. (The rear panel of the ASS-1A is shown in Figure 12.)

12. ASS-1A Switcher, Rear View

NEW BROADCASTER I

This unit is a precision 15-cassette changer mechanism which operates with one Sony Type 5 or BVU-800 VCR. It can be programmed to playback tapes in any sequence over a seven day schedule. With options, it can random access up to 100 spots on each of the 15 cassettes. Since playback can be started with an optional tone decoder or with a closure, this unit also lends itself for application as a stand alone commercial insert system. (The BROADCASTER I is shown in Figure 13.)



13. BROADCASTER I

The BROADCASTER I can also be added to a SPOTMATIC Random Access System, on one or more VCR's, to increase spot capability and flexibility. This allows any or all VCR's controlled by the SPOTMATIC to have automatic access to up to fifteen separate videocassettes.

This unit is provided with its own microcomputer and can be operator-programmed separately to allow last-minute spot changes and additions. Possibilities created by this interface include the immediate insertion of new commercials into the program schedule; furthermore, if BROADCASTER I units are added to each VCR position, almost complete freedom from tape editing is attained.

NEW FOR VCR AUDIO PROBLEMS

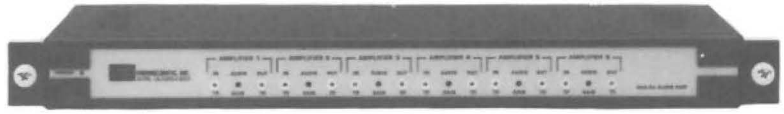
Sony VP-5000 VCR's (and others) have a high-impedance audio output and the level control is not user accessible. Each of these cause problems with level matching in a switching system. To solve these problems, Channelmatic has developed two devices: the UAA-6A Universal Audio Amplifier and the HANDIMOD I.

The UAA-6A (Figure 14) has six independent universal audio amplifiers, each with a level control; it can be used to match impedances and levels for up to six VCR's. The HANDIMOD I (patent pending) plugs into the existing modulator cavity of a VP-5000 and provides 150 or 600 ohm audio and a level control. (Figure 15 shows the HANDIMOD I installed in a Sony VP-5000 VCR.) The HANDIMOD I also adds the ability to lock the VCR to an external video signal for vertical interval switching.

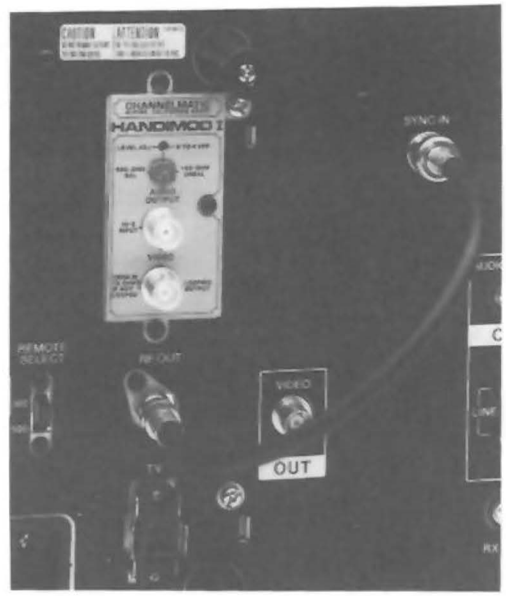
Some means of matching audio impedances and levels must be used in any VCR installation; these units offer cost effective solutions.

FUTURE TRAFFIC CONTROL SYSTEM

Channelmatic is currently developing a traffic control system specifically designed for the unique requirements of CATV. The software-based system will provide a multitude of information related to spots inserted and current availabilities as well as rates and other advertiser related data. It will also have a full accounts receivable capability, including the ability to tabulate and invoice. It is designed primarily for use with a Zenith Z-100 Computer, but can be adapted easily to certain others, such as the IBM personal computer.



14. UAA-6A Universal Audio Amplifier



15. HANDIMOD I Installed in VP-5000

Channelmatic's Traffic Control package has been in software development for several months and will be available in late 1984.

SUMMATION

The equipment required for insertion of local commercials varies radically from system to system. No single insertion package can possibly cover the cost/performance requirements for all operators. Alternate approaches are necessary, as is the ability to expand easily to meet future requirements. Unique accessory items are necessary in some cases to perform the job well. Existing broadcast equipment and garden variety VCR sequencers are not suitable. A very broad product line is required and it must be designed specifically for the market.

AVERAGE LEAKAGE INDEX

ALI

Ted Hartson

CAPITAL CITIES CABLE

ABSTRACT

The implications of signal leakage from a cable television system have changed as dramatically as the cable industry. In the earliest days a cable operator was concerned with radiation simply as it provided a mechanism for unauthorized reception. Today we have regulations which prescribe the conditions by which we may use certain frequencies and require affirmative actions to control system leakage and on-going record keeping, yet we still tend to refer to our systems by subjectively saying "a good tight system", "a lotta leakage" or so forth.

The Average Leakage Index (ALI) was developed to rank system leakage and access repair effectiveness. ALI serves as a repeatable, objective method which yields an 'executive summary' of leakage within a system.

INTRODUCTION

The Average Leakage Index is a simple, straight-forward method of determining the relation of leakage in a particular system to others in the same universe. The process is fully random, and since it is conducted under similar circumstances and not (hopefully) subject to operator interpretation, unbiased. The process conducts two measurements for each mile of plant and classifies each site as shown:

1. Unlikely to exceed FCC limit.
2. 50/50 chance of exceeding FCC limits.
3. Likely to exceed FCC limits.

The total samples in each category are then related to the overall total (100%) and expressed as a percentage.

Finally, the actual ALI for the system is determined by adding the total scores together and dividing by the number of samples. While a more statistical astute method might be applied, it is felt that the under-lying objective of ranking is met by the process. The ALI technique will provide clues to the nature of leakage problems, better focus repair efforts and evaluate the effectiveness of a repair project.

It is important to remember the ALI is only a ranking tool. It does not assure compliance with the Commission rules. Systems with very low ALI's should not forget about radiation monitoring. The Commission rules are inflexible, and any leakage can result in Commission action.

THE PROBLEM

Assume you have a leakage detector adjusted to indicate a "fail" condition when detecting a leakage source of 20 uV/M at 10 feet. Now drive down a street; a drop passes overhead, perhaps 5' from your antenna; the plant is on the other side of the street, now 30' away; or its in the back lot, 130' distant. Unless you can identify each source of leakage--no matter how small--and then evaluate it based on your distance from that source, the survey will provide misleading data. The leakage from a back lot distribution plant could be 10-12 dB above the allowed level and be seen as less than the source of a "legal" nearby drop. Any system wide survey testing will be subject to this effect. Understanding this limitation, let's look at what ALI offers.

CONDUCTING AN ALI

The total mileage of the system should be determined. A street map should be marked showing the boundaries of the plant. All test locations should be within the confines of the system.

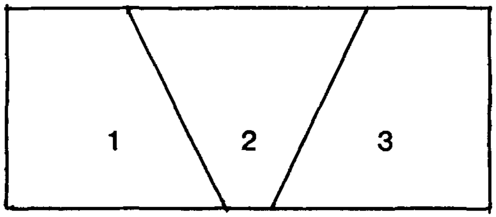
The number of test locations should be equal to twice the number of plant miles. So, a 50-mile system will have 100 test locations. The locations should be consecutively labeled and as the actual testing progresses, tests should be made about every one-half mile. On the average, about 25 to 30 tests can be made for each working hour.

The ALI testing conducted by Capital Cities personnel used the Comsonics Sniffers operating in the vicinity of 108 MHZ. Other units could be used, however, unless the meter display of the substitute unit followed the same sensitivity curve, the comparison between these ALI's and others would be distorted. The 'Sniffer' is essentially linear to mid scale and compresses toward the upper end. If a system were employed which were linear the resultant ALI samples would be higher.

The following procedure relates to the

calibration of the sniffer:

The equipment should be calibrated to the Internal Standard so 20 uV/M at 10 feet equals mid scale. At this point the calibration dot will be near the 12 o'clock position. Install the monopole antenna on the roof of the test vehicle so as to be away from other antennas, lights and ladder racks. Install the clear overlay on the face of the Sniffer.



ALI METER OVERLAY

The test vehicle should be driven to the reference point and stopped without any attempt to optimize or diminish the reading of the detector. This would be best accomplished by turning down the testing device's audio and covering the meter. This is very important.

When the vehicle is fully stopped, the relative indication of the meter (1, 2, or 3) should be logged along with the location number (See Figure 1) which is also marked on the survey map. This provides a method of returning to locations displaying high leakage indications. When the survey is complete, the Average Index may be calculated. Total the value of all measurements and divide it by the total number of measurements actually made (See Figure 2).

Newer well maintained systems will be capable of ALI values very close to 1.0 (i.e. 1.005 1.01 etc.). In our experience a value of 1.2 is not uncommon in a 5 year old aluminum cable system with casual maintenance. ALI's of 2.05 have been recorded in 15 year old systems using foil type trunk and distribution cables. After an extensive maintenance effort the particular system demonstrating 2.05 was reduced to below 1.1. This proves the effectiveness of the repair process. As a practical matter, in a system with severe leakage it may be very difficult to isolate individual leak sources. A technique of trapping out the radiation transmitter from down stream amplifiers may be employed to control the amount of system 'illuminated'.

Capital Cities has been using the ALI test since July, 1983, and to date conducted approximately 100 full ALI's on its 55 systems.

AUTOMATED ALI

After using ALI for a few months we found that while it was a quantum leap over the old emotional 'good system' or 'leaky' expression, the present system has some shortcomings in the area of testing convenience and the use of a single spot frequency for measurements. This paper will conclude with the concept of Automatic ALI which is presently under evaluation by a major CATV Equipment Manufacturer.

The process utilizes several techniques which are new to leakage measurements. The principle features of this technique include:

- Non-Additive Multi-Frequency Leakage Detection.

- Automated Logging of Measurement Samples.

The nature of leakage sources within coaxial cable inherently create highly reactive networks. Because of the large reactive component, a leakage point may offer a low radiation resistance at certain frequencies and a high resistance at others. Because of this effect, a leakage source may generate substantial fields at frequencies removed from the survey frequency yet present virtually no fields at the survey frequency itself. This disparity can cause major leakage sources to be missed. The reactive component of a leak is controlled by mechanical variables. As physical cable plant conditions change due to movement such as vibration, wind sway or temperature, points of grounding between the cable and strand can change. These changes and other effects alter the nature of the reactance at the leakage source and consequently its frequency selectivity. This effect may account for the heretofor unexplained appearance of 'new leaks' on a system just repaired. Simply stated, the leaks were always there but were simply hidden from the single frequency detection equipment.

The proposed system utilizes three frequencies which due to their harmonic relationship, increase the probability that any leakage source will present a low radiation resistance at one of these frequencies. The actual frequencies may differ slightly to accommodate on-going cable signals and regulatory considerations.

When a signal is detected by the appropriate antenna, the output of the respective receiver increases. It is further believed that multi-frequency techniques will tend to smooth out the cyclical (grating lobe) effect experienced while passing a leakage source with a single frequency detector. This improvement is due to the contribution from the other two frequencies effectively filling the propogational nulls of any single frequency. Each of the three receivers and its respective antenna is reconciled to some nominal field sensitivity. This is accomplished considerate of the differential in path loss to the leak due to frequency and the gain of the individual antennas.

The display meter shows an indication of the amount of signal received from the predominant receiver. The vehicle is equipped with a 'Fifth Wheel' and at predetermined intervals loads the measurement into memory.

Concurrent with the sync and data packets being loaded two other components are present. A voice operated microphone is mixed with a continuing audio sample of the output of all three receivers. The mike circuit allows for noting significant reference points along the survey route. The audio component of the receivers identifies the particular receiver dominant in the audio summation as the three source transmitters having distinctively different audio tones.

The magnitude of every sample may be determined by inspection of the record. The Average Leakage Index is determined by dividing the total of all recorded levels by the total samples. An operator knowing the distances between samples, survey path and reference points, can identify the approximate distance from a reference point to any sample point.

While some enhancement is bound to occur when this system is prototyped and eventually used in the field, it is felt the essential features of the system will prove to be a valuable contribution to continued CATV plant maintenance.

CONCLUSION

A logical relation exists between the regulatory environment and ALI. A process like or similar to ALI could serve as the gateway for the utilization of more sensitive frequencies in a "closed system". The operator who through diligence maintains a nearly perfect closed system should be rewarded for this effort by the right to re-use critical frequencies. Those who ignore the consequence of operating leakage-prone or poorly maintained systems should bear the brunt of Commission's Enforcement actions. Until some economic reward fuels leakage management, it is likely to remain an 'also ran'.

It is our belief that a measurement system that makes the distinction between good and bad plants will be at least useful and in all probability pivotal in future years.

Example of field log

fig. 1

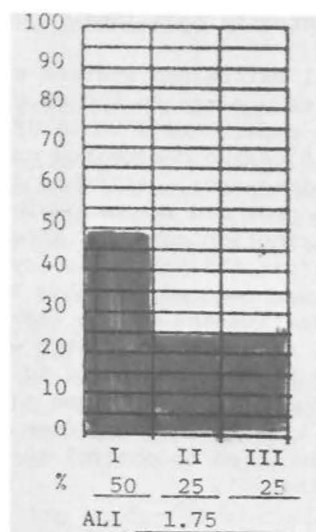
LOCATION	LEVEL
1	3
2	1
3	2
4	1

Total of Levels - 7
Number of Samples - 4

$\frac{7}{4}$ = ALI 1.75

Example of test results

fig. 2



BASEBAND TERMINALS APPLIED TO CATV

John D. Schilling

GENERAL INSTRUMENT CORPORATION

The possibilities with baseband CATV terminals are significant, but implementation must be tempered with caution. While the advantages are certainly attractive, implementation is not problem free and before one considers the advantages it is wise to reflect on the fundamental purpose, define the criteria for that purpose and insure that the purpose is met.

THE FUNDAMENTAL PURPOSE IS ACCEPTABLE TELEVISION ENTERTAINMENT. CRITERIA IS THAT A BASEBAND TERMINAL SHALL NOT CREATE ANY SUBSCRIBER DETECTABLE DEGRADATION WHEN COMPARED TO A TRADITIONAL RF TERMINAL.

The above definition may appear vague. The intent is not to demonstrate that a baseband terminal does not create additional degradation. But, the additional degradation is controllable within acceptable limits and is transparent to the subscriber.

INTRODUCTION

Although the reason for implementing a baseband system is to allow for enhanced features, this paper will concentrate on the signal path, categorize and rank distortions relative to functional blocks, analyze the cause of the distortions and present methods of controlling these distortions within acceptable limits.

TYPES OF DISTORTION

Within a CATV converter there are three (3) basic categories of signal degradation or interference. For the purpose of this paper the degradations will be referred to as Type One (1), Two (2) and Three (3) ranked in order of threshold of perception. One being most critical, and Three being least critical. Refer to Figure 1.

Type 1

Multiple Signal Interference: a degradation of a desired signal due to the presence of other signals in a non-ideal system.

This is the most objectionable, as it adds continuous undesired distracting information to the desired information. The level of perception is typically between Ø.1% and Ø.2%.

Type 2

Random Interference: thermal noise degradation of the desired signal. This interference is spectrally evenly distributed, and the brain acting as a correlator rejects substantial amounts of random noise. Acceptable interference levels are typically 1%.

Type 3

Single Signal Distortion: change in the desired signal due to non-ideal processing.

This distortion does not present additional extraneous information to the desired signal. It is entirely synchronous with the desired information and, as a result, distortions from 1Ø% to 2Ø% are not readily perceived as a degradation.

In the above three types of distortion, Type One and Two are inherent to both RF and baseband terminals, while Type Three is typically inherent to baseband only. It is the utilization of the basic fact that Type Three distortion is two orders of magnitude less severe than Type One, and that Type Three distortion can be maintained well within these limits which allows the criterion to be met within the limits of a consumer product.

FIGURE 1

DISTORTION TYPE BY FUNCTION

RF TUNER	
DISTORTION	**TYPE**
SPURIOUS SIGNALS	1
CROSS MODULATION	1
THIRD ORDER	1
SECOND ORDER	1
NOISE FIGURE	2
FREQUENCY RESPONSE	3
IF DEMOD VIDEO	
VIDEO FREQ. RESPONSE	3
920 KHz BEAT	1
DIFFERENTIAL GAIN	3
DIFFERENTIAL PHASE	3
TRANSIENT RESPONSE	3
CHROMA DELAY	3
CHROMA LUMINANCE INTER-MODULATION	3
SIGNAL TO NOISE	2
IF DEMOD AUDIO	
FREQUENCY RESPONSE	3
INTERCARRIER BUZZ	3
HARMONIC DISTORTION	3
SIGNAL TO NOISE	2
VIDEO MODULATOR	
FREQUENCY RESPONSE	3
920 KHz BEAT	1
DIFFERENTIAL GAIN	3
DIFFERENTIAL PHASE	3
TRANSIENT RESPONSE	3
CHROMA DELAY	3
CHROMA LUMINANCE INTER-MODULATION	3
SIGNAL TO NOISE	2
MODULATION DEPTH	3
FREQUENCY ACCURACY	3
AUDIO MODULATOR	
FREQUENCY RESPONSE	3
HARMONIC DISTORTION	3
SIGNAL TO NOISE	2

SIGNAL PATH

Baseband converters are really RF converters with demod/remod systems attached. This can be seen by comparing the signal path block diagrams of Figure 2 (RF) and Figure 3 (Baseband). The major differences between the tuner sections is the addition of a low noise broadband AGCed RF amplifier and a variable AFCed second local oscillator.

While there is no technical reason for not implementing these features in an RF terminal, a baseband terminal inherently has all the drive signals available and the incremental cost is justifiable, while in an RF terminal it is not.

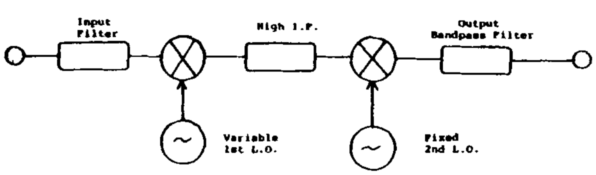


Figure 2 RF

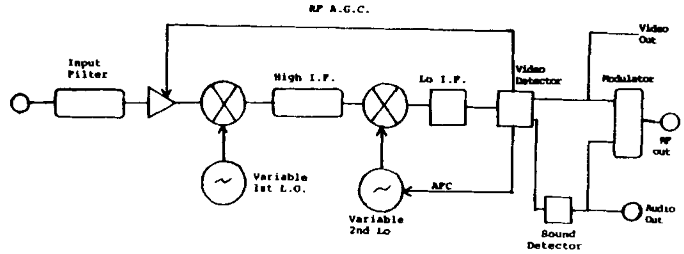


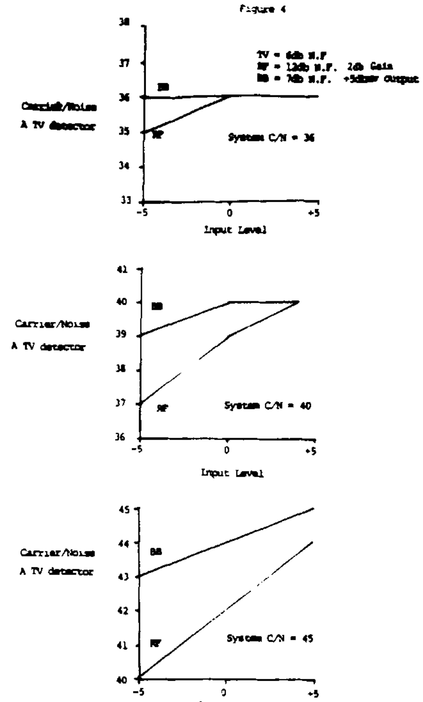
Figure 3 Baseband

TUNER

With careful design, RF AGC can be used to increase the usable input operating range. RF terminals typically have a 12 dB noise figure and small net gain, while a baseband terminal typically has a 7 dB noise figure and fixed output level. At low input levels and high C/N this will result in a direct decrease in Type Two distortions. Refer to Figure 4.

While the above is possible, a reduction in random noise must not be offset by an increase in Type One distortion. If the addition of an RF amplifier reduces the maximum input level for acceptable Type One distortion by 5 dB, while improving the C/N by 2 dB, the dynamic range has not been increased. If this condition occurs, this feature is best left out since the problems it will create will negate any performance improvement. However, by careful design techniques, utilizing today's manufacturing technological and strict process control, it can be reliably accomplished.

Figure 4



IF DEMOD

While the tuner is an integral part of the sytem and careful attention must be taken, especially in the areas of dynamic range and frequency control, it is this section that is either going to make the terminal a success or a failure. The areas that particular care must be taken are:

- Adjacent Channel Rejection
- 92Ø KHz Beat
- Dynamic Range
- Frequency Response
- Transient Response
- Differential Gain
- Differential Phase
- Chroma Delay

Also, one should remember that with the exception of 92Ø KHz beat, the above are Type Three (3) distortions and significantly more distortion can be tolerated.

Adjacent Channel Rejection

Adjacent channels must be carefully filtered out to prevent this interference from becoming Type One interference. This is accomplished by tightly controlling the frequency accuracy of the double conversion tuner to ensure the adjacent channels fall within the traps located in the tuner and SAW filter. With commercially available SAW filters and proper frequency control, only 1Ø dB of additional rejection is required in the tuner itself to ensure that no unwanted signals reach the detector. This requirement is easily met with present technology.

Dynamic Range

In a baseband converter, the low IF section must amplify the desired signal to a fixed level for demodulation. If, at any point along the signal path, the signal falls within 1Ø dB of the input level, then the amplifier may have a significant contribution to the total system noise figure. Also, if the desired signal exceeds the signal handling capacity of the IF amplifiers, Type One distortion occurs. This distortion, commonly called "92Ø KHz beat" is caused by intermodulation between video, chroma, and aural carriers. The balance between noise and overload is additionally aggravated by high loss in the IF SAW filter.

The 92Ø KHz beat is overcome by use of a SAW filter that reduces the sound carrier approximately 18 dB, in conjunction with heavy negative feedback in the pre-amp, preceeding the SAW and differential drive to the AGCed IF amplifier.

The low end noise problem is solved simply by maintaining proper signal level to the detector, however, implementation is not so simple. The area where particular care must be taken is again in the pre-amp prior to the SAW filter. This amplifier must have high gain, low noise and wide dynamic range, therefore, particular attention must be paid to this area of design. Once the basic design is achieved, performance can be very repeatable over an input dynamic range of -1Ø dBmV to +15 dBmV, while maintaining proper noise performance and less than Ø.1% 92Ø KHz beat.

Frequency Response

A change in video frequency response is inherent in all baseband systems. The RF tuner passband contributes to this type distortion. The major changes are caused by the IF SAW filter. The SAW filters used are TV receiver Nyquist filters with sound carrier shelves, approximately 18 dB below the passband maximum. Due to the finite slope of the SAW filter response, 3.58 MHz and 4.2 MHz video is attenuated. Attenuation at 3.58 MHz is typically 3 dB and is easily corrected by the color AGC of the TV receiver or monitor connected to the converter. 4.2 MHz is significantly attenuated and for all practical purposes not present. This particular parameter cannot be corrected economically. It is my contention that it need not be. For all practical purposes it can be viewed as not being part of the video spectrum. I realize that this point can be debated at length, but I contend that the absence of 4.2 MHz video signal does not now, nor will in the future, present information a subscriber can discern. Therefore, it does not violate the original criterion.

Transient Response

Transient response distortion is also a result of the IF SAW filter. However, by careful selection and specification of the SAW itself and particular care taken in proper matching between input pre-amp and IF amp, this type distortion can be maintained well below 1Ø%. This is significantly better than the typical TV receiver.

Differential Phase Gain and Luminance Non-Linearity

This type of distortion is the result of imperfect demodulation and possible non-linear IF and video amplification. While this distortion cannot be eliminated, it has been shown that distortion can reliably be maintained below 5 percent and 5 degrees. This performance is accomplished by optimizing the AFC, setting the detector input level for optimum linearity, and compromising between limiter and detector bias adjustment for optimum performance. This is not the normal method of aligning demodulator systems, but experience has shown that careful alignment of these parameters results in a substantial performance improvement over the typical TV receiver.

Chroma Delay

Chroma delay is an incorrect time alignment of the luminance and chrominance portion of the displayed video. Since chrominance and luminance are both part of the same picture, it may be considered Type Three distortion. But, in reality, its visual effect more closely resembles Type One in terms of threshold of perception. Tests have indicated that Ø.3% of the active video scan line is visible on typical video. Therefore, of all baseband video degradation, chroma delay is the most important to minimize.

Chroma delay results from filtering in two places, the IF SAW and 4.5 MHz sound carrier trap. Fortunately, both are very consistent by the nature of their construction, and proper design results in a very close compensating match with the FCC standard pre-distortion curve.

AUDIO DEMODULATION

Ignoring the stereo issue, sound detection systems in all baseband converters are typically intercarrier types with adequate performance, which do not add noticeable additional distortion. In fact, given today's performance in sound detection systems (and assuming that baseband outputs are connected to Hi Fi audio equipment), sound quality is impaired to a much greater extent by TV network transmission than by the baseband converter. If stereo is addressed, all baseband terminals will require redesign; the redesign will entail more than implemention of a demux system, but also requires a complete redesign to the video and audio demodulator. Since the presently approved system employs an AM subcarrier system, true high fidelity can only be achieved by implementing a quasi-parallel detection system. While implementation of this system adds significant cost, it improves both video and audio performance.

While Quasi-parallel solves the performance issue, volume control remains a dilemma. Since implementation of a stereo modulator is cost prohibitive, stereo compatibility will most likely be accomplished by passing the 4.5 MHz aural carrier directly to the modulator and volume control will only be available via the baseband outputs. This may seem a poor compromise, but present indications are that stereo compatible TV receivers will also include baseband interfaces for use with external high quality audio equipment. If this, indeed, turns out to be the case, then the dilemma is solved.

REMODULATOR

Up to this point, we have dealt with the tuning path and demodulation process. If the interface to the television set was at baseband, there would indeed be a performance increase over the standard RF terminal. The reason for this is that baseband CATV terminals typically outperform even the best TV receivers and an additional conversion process has been eliminated. However, we are not yet at the point where the whole world is using component video equipment. The majority of receivers require an RF input, therefore, an additional modulation process must be included. While all the same Type Three distortions must be dealt with, the solutions are more straightforward since we are starting with baseband.

TYPES OF MODULATORS

Today there are two modulators in use. The first uses a 4.5 Mhz audio modulator whose output is summed with the video. The composite signal is used to AM modulate the video carrier. The second modulates the video separately and mixes the 4.5 MHz modulated audio with the unmodulated video carrier. The first modulator is prone to 92Ø KHz beats, while the second is not. Since this is Type One distortion, good design practice mandates implementation of Type Two.

Frequency Response

Video frequency response can be essentially perfect (Ø.5 dB ripple) because filtering, if used, is channel filtering; this does not separate video and audio as required in the demodulation process.

Signal to Noise

This parameter is insignificant due to high signal level. However, if an output SAW filter is used to provide vestigal sideband - rather than a double sideband output - care must be taken to prevent the RF level from dropping below the output to prevent noise addition.

Differential Gain, Phase and Chroma Luminance Intermodulation

While modulators add differential phase and gain, this distortion is usually less than that of the demodulator, because the carrier is generated rather than recovered. The only critical parameter is depth of modulation, which can be easily controlled if the demodulation is done correctly and the input video constant.

Chroma Delay

As with the demodulator, this parameter is most critical in the modulator also. Typical modulators do not include standard FCC 17Øns group delay pre-distortion. Therefore, if the baseband video is correct the RF output will be off by 17Øns, visible to the trained eye. To correct this, pre-distortion should be added, preferrably in the output channel SAW filter for repeatability.

Audio Modulator

As with the demodulator, audio performance of all modulators is well within required performance. Since the percentage of deviation from center frequency is very small less than 1% total harmonic distortionn is easily achieved. While distortion or noise performance is not a problem, volume control may be.

Reduction of deviation of the sound carrier is the method of volume control used in baseband converters. This method is effective; however, decreases the signal to "buzz" ratio in the TV receiver since the buzz level remains constant. Best performance is obtained by deviating more than the standard +/-25 KHz and operating the unit near the top of its volume control range. This can be quite effective, but requires education of the subscriber to insure the subscriber sets his TV receiver at the optimum point.

CONCLUSION

If the reader agrees with the given criterion and the ranking of distortion presented, it is obvious that with proper care the baseband terminal can effectively perform equivalent to the traditional RF terminal and even improve Type Two distortion performance to the subscriber.

Now you can start adding features, letting your imagination and pocketbook be your guide. It is all possible once the signal path is designed correctly.

CABLE OR HOME POWER FOR OFF-PREMISES ADDRESSABLES

by

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Introduction

In the saga of addressable pay TV services the inevitable problem of increasing theft of service is now in full bloom. One of the most effective approaches toward limiting theft of service has been the development of pay TV control equipment which is mounted outside the subscribers residence where tampering is extremely difficult. Authorizations are transmitted to these off-premises units from the headend while communications from the home are implemented with a low cost keypad unit. The off-premises units are, in many cases, simply "pole mounted converters". These units consume a considerable amount of power, typically in the range of 15 to 35 watts per converter. Other off-premises premium TV security equipments include addressable jammers and/or taps which require less power per drop however this requirement is not insignificant. Some manufacturers are offering off-premises equipment powered from the cable distribution power supplies and others utilize power from the home via the drop cable. Powering of these off-premises devices in either case provokes a number of technical and economic considerations.

Technical Considerations

The amount of powering required for off-premises addressables is a primary factor. A few numbers to illustrate the magnitude of the situation are appropriate. In a system with 75 homes per mile and an average of 1.5 TV sets per household, where 15 watts is required for each off-premises addressable (OPA) almost 1700 watts of extra power is required for each mile of distribution. Looking at what perhaps is the low side of 1 watt per subscriber drop this still amounts to over 100 watts per mile. Taking the high end number of 35 watts per OPA almost 4 kilowatts per mile is required.

These numbers are significant in terms of power costs, however the current handling capacity of other system components must be considered. Some amplifiers and passives are designed to pass a maximum of 4 amps. This limitation complicates the powering design for line extenders and OPAs.

Cable powering is a matter that is quite well understood by the cable industry. In the past serious problems were encounter due to the idiosyncrasies of cable powering but these have been overcome by the equipment manufacturers so that cable powering is quite reliable and universal today.

One of the more difficult problems was involved with what has been labeled "longitudinal sheath currents" [1,2]. Longitudinal sheath currents are those currents which flow on the sheath of the CATV distribution cable due to the cable system's close association with the public power system. Since the CATV cable is bonded frequently to the power company three phase neutral leg the power company neutral current is shared by the CATV cable in a manner determined by the relative resistances in these two members. If all loads on the public power system were balanced no current would flow in the neutral. This, however, is far from the practical case. Power company neutral currents can be in the tens or hundreds of amperes and often a significant part of this current is diverted to the cable system distribution cable sheath.

Since the CATV amplifiers are powered using the coaxial cable conductors for the power circuit, voltage drops occurring along the cable sheath add vectorially to the power supply voltages delivered to the equipment. This vectorial addition can increase or decrease the voltages delivered. In addition the power line components may inject other functions such as transients and power frequency harmonics.

These longitudinal sheath currents vary throughout the day depending upon the power system loads. It is possible for amplifier power supplies to be overdriven when the sheath currents result in a voltage increase causing failures due to overvoltage or heat. Power supplies may also be underdriven causing malfunction or extraneous ripples and transients. In certain cases operators have found amplifiers that would continue to run when the CATV power supply was shut off simply as the result of the power company contribution through longitudinal sheath current. Realization of these conditions has caused amplifier manufactures to more conservatively rate their units and to employ switching supplies that will accept wider ranges of input voltages.

Off-premises addressables powered from the cable system are also subject to these same problems, however solutions are well within the state-of-the art.

When considering powering from the home it would appear, at first glance, that these problems are less important. This may not always be true. The drop cable mechanism equivalent to longitudinal sheath current has somewhat different parameters. The drop cable may shunt some of the power company neutral current to ground through whatever CATV grounding configuration is employed. This is usually a secondary effect. The unbalanced currents in the ground side of the residential power system are not from three phase leads but largely the currents occurring in the ground leg of the 220 volt center tapped service. This means that 220 volt loads such as water heaters, air conditioners, etc., will not cause current to flow in the ground leg, however the return for all 110 volt circuits is through this leg where the components again add vectorially. The CATV drop cable shares current with the power company ground leg in a ratio based upon the relative resistances (including the respective ground resistances). This magnitude of this current changes as a result of varying electrical power usage within the residence.

There are some further differences. The resistance of a 3/4" CATV hard cable sheath is less than 1/2 ohm per thousand feet while the resistance of the sheath of RF-59 drop cable may be as high as 20 ohms per thousand feet. As in the case of strand mounted amplifiers power voltage to drive the off-premises converter is applied to the drop in the home and is also affected by the vectorial addition of the voltage developed by the current on the drop cable outer conductor. Transients and harmonics can also be present. These currents which can be many amperes at times which must also flow through the F connector crimp joints as well as the threaded contacts. Poor contacts, corrosion, etc., can increase these resistances thereby increasing the contribution of the sheath current as well as the normal IR voltage drop.

There is one other subtle factor. The power supply voltage fed to the off-premises device is probably in the order of 30 volts or less rather than the 60 volts used on the cable distribution system. This means that any effects caused by sheath currents will be magnified in their percentage effect since the basic voltage is lower.

Measurements have been made simply by using a clamp-on meter to find the typical values of power company current flowing on the drop. These values vary greatly with the area of the country, power company grounding system, CATV house grounding technique, time of day and year and other factors. For purposes of discussion let us assume that a home powered OPA requires 15 watts, utilizes a 30 volt AC supply, the drop cable sheath resistance equals 1 ohm and the loop resistance equals 15 ohms (RG59 cable is typically 50 - 70 ohms per thousand feet center conductor resistance). The converter will require 1/2 amp of current at 30 volts assuming that the power factor is unity (this is unlikely, particularly with capacitive input filters).

The first problem is that 1/2 amp must flow through the 16 ohms drop cable resistance producing a voltage drop of 8 volts. In order to work with a line voltage 10 percent low (-3 volts) the minimum voltage supply will be 30 - 8 - 3 or 19 volts. Assume now a constant 4 amps of sheath current in a phase which subtracts from the power supply voltage (-4 volts) which now lowers the minimum voltage to 15 volts. Throw in an occasional 10 amp transient and the minimum voltage on a short term basis could be as low as 5 volts. If the power supply does not have the filter capacity to supply power over the duration of the transient the addressable may lose its memory and require reinitialization and cause an interruption of customer services. With 15 volts at 1/2 amp. only 7.5 watts is delivered to the OPA so we must supply more input voltage or more current to power the device. If the phases of the sheath current and transients add it will help maintain the voltage at the off-premises device, however. In some cases excess voltages will be present increasing the range over which the device must operate. The numbers used in the above example are much closer to being typicals than extremes so that one may well see that there are potentially serious power supply problems in powering from the home. Even if DC is employed the same effects are present plus the threat of electrolytic problems at contact points.

The whole matter of grounding a CATV system is an enigma in itself. The electrical codes try to establish a good ground to which the drop cable is connected as it enters the house through the grounding block. Under these conditions, when a failure occurs in the power company ground conductor, extreme currents can flow on the CATV drop. In such a case the CATV drop cable becomes the only power company ground return path and all the current must flow in that path. These currents can reach levels over 100 amperes and have, in some cases, heated the drop cable to the point where a fire was caused and structural damage was done.

The other side of the coin in seeking a technical solution to these grounding problems is not to ground the cable at all. In the case of a falling power line which touches the drop cable and pulls it from the tap, high voltages can be present and become extremely hazardous. It seems to boil down to the choice between fire and electrocution. The various safety organizations such as the National Electrical Code and the National Electrical Safety Code seem to have opted for fires by selecting good grounds.

As a result of this conflict, there have been various suggestions for devices that would in some way ameliorate the problem. One approach which is being worked on by at least two manufacturers, interrupts the drop cable for the power line frequencies. This device is essentially a capacitor in series with the sheath. This capacitor is small enough to be a high impedance at 60 Hertz. Such a device, when perfected, may be widely used in the industry. This type of device, however, is totally incompatible with providing DC or 60 Hertz power to off-premises devices through the drop cable.

Power supplies used in off-premises devices generally rectify AC to supply the DC requirements of the circuitry. Operation of these power supplies from the normal 60 volt quasi-squarewave cable system supplies is easily accomplished since the amount of filtering required is minimal due to the square voltage waveform. On the other hand, supplying power from the drop generally assumes sinewave power, therefore larger capacitors and some increases in size and cost are necessary to achieve adequate filtering. Extra capacity is also required to protect against the short term interruptions previously mentioned in connection with sheath current transients.

Last but not least in the technical considerations, it appears that off-premises powering from the home may require UL approval whereas powering from the cable does not invoke this requirement since it is not a residential device.

Economic Considerations

The first economic consideration that draws the attention of the cable operator is the cost of power. Traditionally converters have been powered from the residence and have not been an expense to the cable operator. Powering of off-premises addressables from the cable system immediately incurs two economic disadvantages. The first is the cost of the power and the second is the cost of the additional power supplies which will probably be required due to the significant extra load. (The following approximations ignore the fact that certain OPAs serve multiple sets on a single drop). A 15 watt off-premises converter will consume (ignoring efficiency, etc.) approximately 130 kilowatt hours of electricity per year which, at 5 cents per kilowatt hour, is about $6.50 per year. Using the figures before of 75 homes per mile and 1.5 TV sets per home this amounts to about $740 per mile per year in power cost. This is not insignificant. In a device consuming an average of 2 watts per drop which is about $0.87 per drop or $100 per mile.

Assuming a standard CATV power supply delivers 800 watts and costs $400 the additional cost of power supplies will be 50 cents per watt or $7.50 for the 15 watt unit and $1.00 for a 2 watt unit. The biggest factor then is the power cost which will vary in different parts of the country. Unfortunately this cost goes on forever.

There another penalty for in-home power. Let's say that a 15 watt supply costs $15 and a 2 watt supply costs $7.50 then the fixed cost of installing an OPA system with home power is greater than installing one with cable power. If the power for the converter is picked up in the basement, there will be many cases where an outlet is not readily available and additional wiring expense will be incurred.

The biggest disadvantage to home power, however, seems to be the intangible matter of service calls. It is likely that there will be many situations where the plug is inadvertantly removed or some local power failure within the residence disables the OPA and generates a service call. If a service call costs $30, one service call can be traded off for a good deal of power (600 KWH which is 5 years for a 15 watt OPA or 34 years for 2 watts consumption). Refer to Table 1 for a summary of these economic factors.

Conclusions

Off-premises addressables are fairly new in the CATV field so that there is not a broad background of experience on which to base conclusions. It does appear, however, that there are a number of subtle problems inherent in home powering which should be carefully considered by the cable operator. The economics of cable powering can be somewhat disturbing, however, a realistic evaluation of the contingent costs relative to home powering, such as service calls, have considerable weight. Cable powering of the higher power off-premises addressables seems to be self defeating by virtue of the very magnitude of additional power supplies and power costs, perhaps forcing the decision to home power. Cable powering of the lower power devices on the other hand, may well be the optimum decision and already seems to be the preference of many in the field .

FOOTNOTES

1 James C. Herman, Jacob Shekel, "Longitudinal Sheath Currents in CATV Systems", presented at the 24th Annual NCTA Convention, April 1975.

2 Norm Everhart, "Protecting CATV Equipment against the Effects of Longitudinal Sheath Currents", presented at the 24th Annual NCTA Convention, April 1975.

	Cable Power		Home Power	
	2 W	15 W	2 W	15 W
1. Consumption per yr./drop	17.5 KWH	131 KWH	--	--
2. Power cost per yr./drop @ $.05/KWH $.87	$.87	$6.50	--	--
3. Consumption per yr./mile	2025 KWH	14738 KWH	--	--
4. Power cost per yr./mile	$98	$740	--	--
5. Power supply cost/drop	$1.00	$7.50	$7.50	$15.00
6. Period of cable powered operation equivalent to cost of in-home power supply	--	--	8.5 yrs.	2.3 yrs.
7. Period of cable powered operation equivalent to one $30 service call	33 yrs.	7.6 yrs.		

TABLE 1

SUMMARY OF ECONOMIC FACTORS

COMPOSITE SECOND ORDER DISTORTIONS

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ABSTRACT

The last few years have seen cable television technology leap from 300 MHz, thirty-five channel capacity to 450 MHz, sixty channel capacity and beyond. New technologies which use two amplifiers in the post amplifier stage are now being used to reduce the level of composite triple beat in extended bandwidth systems. The two amplifiers are arranged in parallel or in a feedforward configuration and reduce post-amplifier composite triple beat levels by 5 dB and 18 dB respectively.

Test results are presented which show that second order distortion can be the limiting distortion in a system carrying more than fifty channels.

An analysis is then performed to confirm that second order distortion should be of very real concern to designers of both amplifiers and systems. This analysis also shows that active equipment using parallel or feedforward post amplifiers give a disappointing improvement in second order distortion performance.

INTRODUCTION

Many cable television systems are now rebuilding or upgrading their networks in order to have the capacity to carry extra channels. These extra channels may have to be carried in order to meet franchise commitments, or in order to generate greater revenue for the system.

Carrying more channels on a system causes two basic technical problems: an increase in intermodulation distortion and greater cable loss because the added channels are usually carried at higher frequencies. Due to the large economic advantages obtained by reusing existing cable, amplifiers with high gain and high output capability are desirable. In order to meet these two requirements new amplifier technologies such as feedforward and parallel-hybrid amplifiers have been developed. In addition, various new headend technologies are sometimes used to improve system performance. Two commonly used examples of these are incrementally related carrier (IRC) frequency assignments and scrambling systems which as a side benefit reduce distortion levels in the system.

These technologies are all designed to reduce the level or the effects of composite triple beat (CTB), the generally accepted limiting distortion in a cable television system.[1] Feedforward and parallel-hybrid technologies are typically used in post-amplifiers and provide some 18 dB and 5 dB improvement respectively in post-amplifier CTB. In an IRC system, CTB falls precisely on the video carrier frequency. The subjective degradation of picture quality is reduced, although the CTB level is unchanged. It is generally considered that IRC technology permits a 3 to 5 dB increase in amplifier output levels.[1] Scrambling systems used to provide security for pay channels or for tiered channels often use techniques such as suppression of synchronization pulses, or alteration of video levels. One such technique, called sync suppression and active video inversion (SSAVI), reduces the CTB level by at least 10 dB if all channels are scrambled, and by a lesser amount if only some channels are scrambled.[2]

Cablesystems Engineering has performed subjective and objective tests on cascades of amplifiers fed by an operating system which uses IRC and has 30 out of 52 channels SSAVI scrambled. Cascades of 16 feedforward trunk amplifiers, 16 conventional trunk amplifiers and a combination of both cascades were all tested. The limiting distortion with various system configurations is shown in Exhibit 1, where it can be seen that CTB was not always the limiting distortion and that composite second order beats (CSB) tended to be the limiting distortion in many cases. This paper will examine why the technologies which give a significant improvement in CTB give a somewhat disappointing improvement in CSB and will propose possible solutions to CSB problems.

CTB IMPROVEMENTS WITH NEW TECHNOLOGIES

Improvements in CTB achieved with new technologies have been well researched and documented. This section will briefly summarize previous work in this area in order to highlight the differences between improvements in CTB and CSB.

EXHIBIT 1: LIMITING NON-LINEAR DISTORTION USING VARIOUS HEADEND TECHNIQUES AND AMPLIFIER TECHNOLOGIES AS TESTED BY CABLESYSTEMS ENGINEERING USING 52 CHANNEL (400 MHz) LOADING

Amplifier Technology	IRC Comb	Modulation	Limiting Distortion
Feedforward (6dB O/P slope)	off	NTSC	CSB
	off	NTSC/SSAVI	CSB
	on	NTSC	CSB
	on	NTSC/SSAVI	CSB
Conventional (flat O/P)	off	NTSC	CTB
	off	NTSC/SSAVI	CTB
	on	NTSC	CTB
	on	NTSC/SSAVI	CTB
Feedforward and Conventional	off	NTSC	CSB
	off	NTSC/SSAVI	CTB
	on	NTSC	CSB
	on	NTSC/SSAVI	CSB

Feedforward and parallel-hybrid technology is analyzed first. A conventional station with a single hybrid post-amplifier is used to determine reference distortion levels. Stations which have the same gain as the conventional station but which have parallel-hybrid or feedforward post-amplifiers can then be analyzed to determine CTB improvements by comparing their CTB performance with the reference conventional station performance. Block diagram models of these three amplifier types are shown in Exhibit 2. Output levels of preamplifier and post-amplifier hybrids are shown in Exhibit 3.

EXHIBIT 2: TYPICAL GAINS AND LOSSES INTERNAL TO A CONVENTIONAL, FEEDFORWARD AND PARALLEL-HYBRID STATION

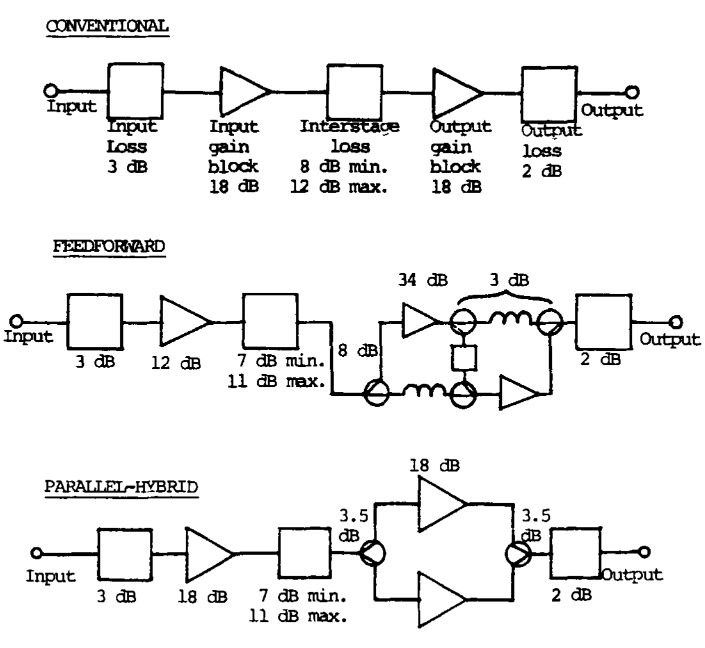


EXHIBIT 3: OUTPUT LEVELS IN dBmV OF THE HYBRID AMPLIFIERS IN EXHIBIT 2 FOR A STATION OUTPUT LEVEL OF 34 dBmV

Station Type	I/P Hybrid Level AGC @ max	AGC @ min	O/P Hybrid Level
feedforward	20	24	39
conventional	26	30	36
parallel-hybrid	26	30	33.5

If a standard hybrid amplifier CTB spec of -86 dBc at a flat output level of +34 dBmV for 52 channels is assumed then the performance of the three stations can be compared by calculating CTB levels generated by the input and output amplifiers as is shown in Exhibit 4. It should be noted that the CTB level for the output hybrid amplifier has been improved to take into account its sloped output level. The CTB contribution of the input hybrid amplifier has been calculated twice, at the two extremes of a 4 dB range in station input level.

EXHIBIT 4: CTB RATIOS FOR THE THREE STATIONS IN EXHIBIT 2

Amplifier	AGC gain	CTB (dBc) I/P	O/P	Station
feedforward	max	-114	-103	-100.8
	min	-106	-103	- 98.4
conventional	max	-102	- 85	- 83.9
	min	- 94	- 85	- 82.4
parallel-hybrid	max	-102	- 90	- 88.1
	min	- 94	- 90	- 85.8

Significant station CTB improvements are achieved using feedforward and parallel-hybrid technologies. These improvements are in the order of 16 dB and 4 dB respectively.

In a rebuild situation, the great appeal of parallel-hybrid and feedforward stations is that they can be configured with higher gains and higher output levels than can conventional stations while still delivering the same CTB performance. Stations with gains of 26 and 30 dB can be constructed using amplifier stages with higher gain. If a preamplifier with greater gain is used, then for a given station output level the CTB level will remain constant. If a post-amplifier with greater gain is used then the preamplifier will contribute less CTB for a given station output level.

Frequency assignment techniques such as IRC do not effect the level of CTB but are designed to make most third order beats caused by offending video carriers fall precisely on the video carrier frequency of the victim channel.[3] This can alter the victim channel's video carrier level by a small amount, but the effect of this on picture quality is negligible. Another similar frequency assignment technique is harmonically related carriers (HRC). With HRC, all in-band beats formed by video carriers fall precisely on the video carrier frequency of a channel. An HRC system however, can not usually be used in a rebuild as HRC frequency assignments are non-standard and are incompatible with many television sets and converters.

The SSAVI scrambling system is comprised of two elements. First, the horizontal synchronization pulses are suppressed and second, the video information is inverted when its average level is less than 50 IRE units. Both of these elements reduce the average RF level in a channel and thus reduce the average level of a beat created by one or more scrambled channels.

In a system which is undergoing a rebuild in order to increase its channel capacity, there are likely already a large number of channels which are non-scrambled. These unscrambled channels form part of a basic service offering. In a rebuild it may be unwise from a marketing viewpoint to scramble these channels, but there is no reason why extra channels could not be scrambled, as they would likely form part of a pay service, or at least part of a more expensive tier of service.

If all channels on the system were SSAVI scrambled, approximately a 10 dB reduction in CTB level should be expected. Significant reductions in CTB level should also be expected even if less channels are scrambled. For example, if all channels from 54 MHz to 260 MHz are unscrambled and all channels from 260 MHz to 400 MHz are scrambled, greater than 5 dB reduction in CTB can be expected.

SYSTEM TEST RESULTS

As briefly described in the introduction, a test was conducted to determine the effects of low distortion post-amplifiers, IRC and SSAVI.

The conventional, feedforward and combined cascades were tested with the four combinations of IRC on and off and SSAVI scrambling on and off. Selected victim channels were viewed as amplifier output levels were adjusted until it was determined that barely perceptible distortion was visible on the victim channel. Objective tests were then made at that level. CSB was the distortion which limited output levels in the cascade under several conditions.

The test results have been examined in an attempt to determine why CSB was predominant. First, the reduction in beat level achieved by using a feedforward post-amplifier was examined. The reduction in CTB and CSB achieved by using a feedforward post-amplifier is shown in Exhibit 5, where it can be noted that for any signal format, significantly less feedforward improvement is obtained for CSB than for CTB.

The effect of an IRC frequency assignment as compared to a standard assignment where output frequencies are not locked to a comb was subjectively analyzed. The addition or removal of IRC from the system did change the pictures when

EXHIBIT 5: IMPROVEMENT IN CTB AND CSB OF A FEED-FORWARD STATION OVER A CONVENTIONAL STATION

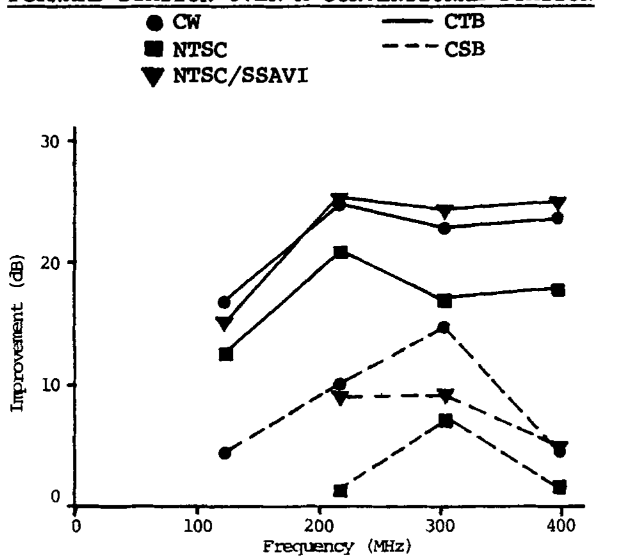
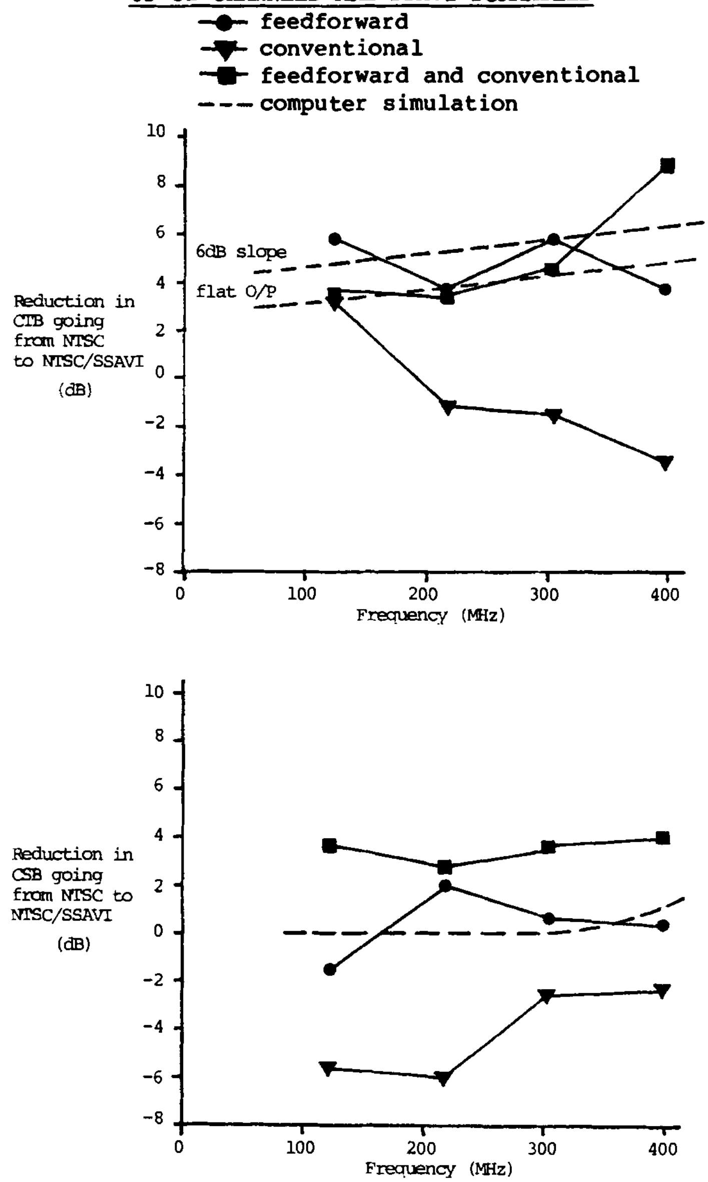


EXHIBIT 6: IMROVEMENTS IN CTB AND CSB WHEN 30 OUT OF 52 CHANNELS ARE SSAVI SCRAMBLED



distortion, particularily CTB, was present. However, no significant improvement in picture quality was evident when IRC was added to the system. This result conflicts with previously published work and may be due to some peculiarity in the operating system, such as the large number of character generator channels.

The effect of signal format on CTB and CSB was analyzed by comparing the difference in beat levels on a system with NTSC signals and on the system with 30 of the signals SSAVI scrambled. Differences in CTB and CSB levels are shown in Exhibit 6, where it is clear that less improvement due to SSAVI scrambling was measured for CSB than for CTB. The reason for anomalous test results in the conventional cascade is unknown.

CSB IMPROVEMENTS WITH NEW TECHNOLOGIES

The tests results in the previous section indicate that new technologies give a disappointing improvement in CSB compared with the improvement in CTB. It is interesting to examine why these technologies give less improvement in CSB when compared to CTB.

Using the station models used to compare the effect of different post-amplifier technologies on CTB (see Exhibit 2), an analysis of the effect of these technologies on CSB was conducted. Due to a lack of CSB specifications for hybrids an assumed specification must be used. A CSB specification of -66 dBc at a flat output level of +34 dBmV for 52 channels was considered reasonable. CSB levels for preamplifiers and post-amplifiers are calculated and shown in Exhibit 7, where it is clear that the preamplifier is a major contributor of CSB, especially with a feedforward post-amplifier.

EXHIBIT 7: CSB RATIOS FOR THE STATIONS IN EXHIBIT 2

Amplifier Type	AGC Gain	CSB (dBc) I/P	O/P	Station
feedforward	max	-80	-92	-79.7
	min	-76	-92	-75.9
conventional	max	-74	-71	-69.2
	min	-70	-71	-67.5
parallel-hybrid	max	-74	-73.5	-70.7
	min	-70	-73.5	-68.4

EXHIBIT 8: IMPROVEMENTS IN CTB AND CSB TO BE EXPECTED BY USING A FEEDFORWARD OR PARALLEL-HYBRID OUTPUT STAGE INSTEAD OF A CONVENTIONAL OUTPUT STAGE

Amplifier Type	AGC Gain	CTB	CSB
feedforward	max	16.9	10.5
	min	16.0	8.4
parallel-hybrid	max	4.2	1.5
	min	3.4	0.9

Improvements in both CSB and CTB achieved by using feedforward and parallel-hybrid post-amplifiers compared to conventional post-amplifiers are shown in Exhibit 8. It is clear that improvement in CSB is much less than that in CTB, due to the significant contribution of the preamplifier hybrid.

As mentioned earlier, in a system with an IRC frequency assignment, most third order video carrier beats fall precisely on the victim channel video carrier frequency. However, no change should be expected in CSB due to the addition of IRC to a system.

If all channels in a system have the same signal format, the effect of a change in signal format on the levels of CTB and CSB can be analyzed fairly simply. Since three channels combine to form a third order beat and only two channels combine to form a second order beat, the change in CSB level would be expected to be two-thirds of the change in CTB level.

In most systems, however, only certain bands of channels would be scrambled. An analysis of CTB and CSB levels under these conditions was conducted. Television channels modulated with an average video level of 30 IRE units were modelled. The levels of individual third order and second order beats were predicted as the relative phases of the video information were varied randomly. Time average discrete beat levels were then established. All individual third order and second order beats falling on selected victim channels were classified according to offending channel signal format and level. Expected CTB and CSB levels were then determined by adding individual beats on a power basis. Using this method, improvements in CTB and CSB levels were predicted for the channel line-up described earlier, where all channels from 260 MHz to 400 MHz were SSAVI scrambled. Predicted reductions in CTB and CSB are shown in Exhibit 6, where it is clear that significant CTB improvements can be expected with SSAVI scrambling, while very little CSB improvement can be expected. It should be noted that this analysis assumed that the relative phase of the video information on offending channels was random. If many, but not all channels have common sync pulse sources, then the effects on beat levels and picture quality may be detrimental.

POSSIBLE SOLUTIONS TO CSB PROBLEMS

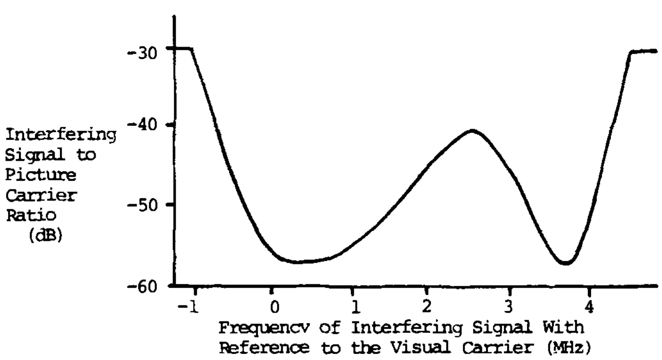
An improvement in post-amplifier technology can achieve excellent improvement in CTB levels because the post-amplifier in a conventional amplifier is the major contributor to CTB. However, when considering CSB, the preamplifier can be a major contributor, especially when low distortion post-amplifiers are used.

In order to reduce the CSB level from the preamplifier, three approaches could be taken. First, hybrid amplifiers with better CSB performance could be used as preamplifiers. Second, preamplifier hybrids could be arranged in a parallel-hybrid or feedforward configuration to reduce their CSB contribution. Third, hybrids could be tested for critical parameters such as noise figure, CSB and CTB levels and selected for various uses. For example, in feedforward amplifiers, preamplifier hybrids with good noise figure and CSB characteristics could be used, post-amplifier hybrids with good CTB characteristics could be used and other hybrids could be used as error amplifiers.

Amplifier output slope has a significant effect on CSB levels. The CSB high frequency levels of an amplifier operating with 6 dB output slope will be approximately 7 dB lower than the CSB levels of a similar amplifier with flat output levels.[4] At the low end of the frequency band, CSB levels will be higher with sloped outputs than with flat outputs. However, this may not be a problem because hybrid amplifiers have better second order distortion performance at lower frequencies.

The IRC frequency assignment was designed to mask the effect of CTB by making it fall precisely at a video carrier frequency. Using this frequency assignment or even with a standard unlocked frequency assignment, second order beats formed by the summation of offending carrier frequencies fall 1.25 MHz above a victim video carrier frequency. As can be seen from Exhibit 9, this is a critical area of a video channel.

EXHIBIT 9: CURVE SHOWING THE RELATIVE SENSITIVITY OF A VICTIM CHANNEL TO AN INTERFERING SIGNAL AS A FUNCTION OF FREQUENCY



It would be more desirable to have these beats fall 2 to 3 MHz above the video carrier frequency. In order to accomplish this, a non-standard frequency assignment could be used. For example, channels above 300 MHz could be lowered by 1 MHz from their standard frequency assignment, while all channels below 300 MHz would remain on their standard frequencies. This would sacrifice one channel which would only have 5 MHz of spectrum from 300 MHz to 305 MHz. This spectrum could be used for other purposes such as modified video transmission or data transmission. The frequencies of various second and third order beats generated using this non-standard frequency assignment have been analyzed and compared to the frequencies of beats generated using a standard frequency assignment. The results of this analysis are shown in Exhibit 10.

EXHIBIT 10: NUMBER OF SECOND AND THIRD ORDER BEATS FALLING ON SAMPLE VICTIM CHANNELS WITH AND WITHOUT FREQUENCY OFFSETS (400 MHz SYSTEM)

Frequency Assignment	Carrier Frequency	CTB 0MHz*	CSB 1.25MHz*	CSB 2.25MHz*
Standard	397.25	565	16	-
	301.25	806	8	-
	217.25	827	3	-
Offset	396.25	401	3	13
	306.25	401	0	9
	217.25	567	3	0

*NOTE: These frequencies refer to the beat frequency relative to the victim channel frequency.

Note that on the highest channel, 16 second order beats fall 1.25 MHz above the video carrier frequency with a standard assignment, while with a non-standard assignment only 3 beats fall on the same frequency. The other 13 beats fall at a less critical frequency 2.25 MHz above the video carrier frequency. Assuming power addition of beats and neglecting the beats falling 2.25 MHz above the video carrier frequency, then a 7.3 dB improvement in CSB level can be achieved using this non-standard frequency assignment. This was accomplished at the cost of one lost video channel and possible tuning problems with existing converters. In a rebuild situation these tuning problems may be minor, as existing converters may not tune beyond 300 MHz in any case.

It should also be noted in Exhibit 10 that the non-standard frequency assignment will give a minor improvement in CTB level. If all third order beats not falling on the video carrier frequency are neglected, than a 1.5 dB improvement on the highest channel could be expected using this non-standard frequency assignment.

The frequency offset of channels between 300 MHz and 400 MHz should be viewed only as an illustration of the potential benefits which could be realized with frequency offsets. No attempt was made to determine an optimum frequency assignment, and the effect of changing the frequencies of beats falling at the low end of the frequency spectrum may be unacceptable. However, it does appear that non-standard frequency assignments may provide a significant improvement in CSB levels and some improvement in CTB level as well.

CONCLUSIONS

A number of new technologies have been developed in order to reduce the level or the effects of CTB. Test results have been presented which indicate that feedforward post-amplifiers, power doubling post-amplifiers and SSAVI scrambling do in fact reduce CTB levels as expected. The expected improvement in picture quality obtained by using IRC frequency assignments was not observed during these tests.

Test results have been presented which demonstrate that CSB can be the limiting intermodulation distortion in cable systems carrying over 50 channels. This is in large part due to the fact that the technologies which have been developed to improve CTB performance provide much less CSB improvement. Further work should be done in an effort to reduce the levels or the effects of CSB.

Promising areas of development include improving preamplifier CSB performance to reduce station CSB levels and further investigating non-standard frequency assignments in an effort to reduce the impairment caused by CSB.

ACKNOWLEDGEMENTS

The authors would like to express their thanks to the CTRI for their support of the research documented in this paper.

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DATA ON CABLE FOR PROFIT

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The paper reviews the technical standards for international packet switching networks as well as the bus access methods applicable to Local Area Networks (LAN) and Cable Television Wide Band Area Networks (WAN).

The LANTEC^{TM} 8400 token passing, packet switching data communication system for residential and institutional cable sytems permits the interconnection to the outside world at any point along the cable system and enables the operator to transform his coaxial cable network into a telephone bypass and Teleport delivery network for the transmission of high speed data.

Automated network control, automated coaxial cable maintenance and automated billing systems are presented as necessary ingredients to assure profitable operation.

1. Evolutionary Developments

Some of you may recall the blue sky dreams of our industry in the early 70's.

The broadband capabilities of the CATV coaxial cable were to provide all these wonderful services like home banking, home shopping, energy management, security and data communication.

Here it is 1984 and we are finally on the right track. It is my prediction that data communication on CATV will become, in the very near future, a revenue producer for every cable operator.

If we look at the evolutionary development of data communication in general, we find that in the early 70's the ideas were present, but there were also too many questions seeking solutions.

In retrospect, it was clearly too early then to transmit data on cable in a cost-effective manner.

As early as 1976 we saw the first CCITT standards developed for packet switching. At about the same time, Xerox developed a baseband high speed data transfer system called Ethernet.

EVOLUTIONARY QUESTIONS IN THE 1970's

- WHAT KIND OF TRANSMISSION PROTOCOLS?
- WHAT TRANSMISSION STANDARDS?
- WHAT TYPES OF MICROCHIPS?
- WHAT STANDARDS FOR SPECTRUM UTILIZATION?
- HOW DO WE INTERCONNECT?

These baseband systems are working; they fulfill a need, but are restricted to short intra-plant installations.

So what about broadband? Since about 1978 we see the evolution taking a faster pace. Without standards for transmission and protocol, we would not be able to interconnect to the world around us.

TRANSMISSION STANDARDS OF THE 1980's

- POINT-TO-POINT DATA TRANSMISSION PROTOCOLS
  - INTERNATIONAL CCITT V.35
- PACKET SWITCHING DATA TRANSMISSION PROTOCOLS
  - INTERNATIONAL CCITT X.25
- IEEE STANDARD 802
  - POLLING SYSTEMS
  - COLLISION DETECTION SYSTEMS 802.3
  - TOKEN PASSING SYSTEM 802.4

Now, that standards have been set, we can build the equipment.

2. Comparison of Standard Bus Access Methods

A brief look at the three standard Bus Access Methods should be taken to identify which method appears most suitable in a CATV network.

2.1 Polling System

A polling system requires a centralized controller. This controller would select the sequence of transmission of any associated terminal along the system. The controller would address each terminal modem, verify its readiness to transmit, go through a formal handshake and then listen to the transmission from the terminal modem. After completion of transmission, the controller would select the next terminal.

Polling systems are identical to this panel of people that all want to speak. But as long as I have the floor, as directed by our panel moderator, the others are not permited to say anything.

POLLING SYSTEMS

- CENTRAL CONTROLLER
- DIRECTED SEQUENCE
- HANDSHAKE DELAY
- PRIORITY TO LONG "TALKERS"
- THROUGHPUT A FUNCTION OF TRAFFIC LOAD
- LIMITED USE FOR HIGH DATA RATES

The deficiencies of a polling system are quite apparent. The terminal modems with a lot of data will "talk" for a long time. In other words, the priority is given to whoever has a lot to "say" and short urgent messages from others might be delayed.

Another deficiency is the centralized controller itself. In case of a failure, a redundant unit must be available which increases the front end cost of the system.

Tele-Engineering Corporation's Tele-Dat II was a polling system and we have learned from our mistakes.

It may be interesting to note that all proposed two-way converter systems are polling systems. This is fine for low speed data and opinion polling, but does not permit the data transfer at high rates with a high throughput.

2.2 Collision Detection Systems

The term Carrier Sense Multiple Access/Collision Detection (CSMA/CD) is well known in the world of LAN (Local Area Networks). Collision Detection is used by most baseband and broadband high speed data transfer systems.

Collision Detection is used by Ungermann-Bass and Sytek to name just two.

Tele-Engineering is designing and installing broadband LAN systems in-plant, inter-plant and in campus environments all over the U.S. and in every case Collision Detection Equipment has been applied.

CSMA/CD uses the principle "listen before you talk" or "listen before transmitting, listen while transmitting" to gain access to the network. All stations listen to the medium and stay silent if it is in use. When silence occurs, then any and all stations may jump in and transmit.

This method is very similar to the rule that we use when we are in a meeting. We let one person finish. Then, when there is silence, anyone may speak. When multiple speakers attempt to talk simultaneously, they usually detect the "collision" and stop talking. So if you now picture a meeting where everyone has something important to say and barely waits for silence to occur, there will be many collisions and interruptions.

COLLISION DETECTION SYSTEMS (IEEE 802.3)

- CARRIER SENSE MULTIPLE ACCESS/COLLISION DETECTION (CSMA/CD)
- LISTEN BEFORE YOU TALK
- MANY INTERRUPTIONS
- THROUGHPUT A FUNCTION OF CABLE DELAY
- THROUGHPUT DECREASES WHEN TRAFFIC LOAD INCREASES
- PRIORITY TO LOUD "TALKERS"
- IDEAL FOR SMALL SIZE BROADBAND SYSTEMS

Conversely, in a CSMA/CD system, a high traffic load will cause many collisions and interruptions. This tends to restrict the throughput of the network. The network throughput is decreased rapidly as the traffic load increases.

The length of the cable system also plays an important role in the network throughput. Picture our group of people a mile apart. It would take time for the sound to travel the distance. During this time, another speaker may talk and the transmissions will collide.

CATV systems are by nature longer and more extensive than broadband LAN systems and cable transmission delays will reduce the throughput even further.

There is also a level consideration in Collision Detection systems. Unintended priorities are produced any time the levels of the RF signal are different at the various receivers. The stronger signal may "capture" the receiver and no collision is detected. Although one message has gotten through, a new problem has established itself. A transmitter with a higher signal level has a better probability of gaining access to the medium than lower level transmitters.

With tap steppings of 3 dB, which is our industry standard, it is imperative that the LAN designer has exact distance measurements of every cable length between taps and that the drop wire lengths are identical.

Collisions also have the potential to cause frequency "splatter" on broadband systems, introducing additional interference components that may show up in other TV channels on the system.

2.3 Token Passing Systems

This bus access method has been standardized by IEEE 802.4 and offers a real alternative to Collision Detection Systems, Token Passing is the distributed version of polling.

If we picture our group of people again. Instead of the meeting chairman passing the go ahead to the next person, a token is passed from one person to the next.

Possession of the token allows a terminal modem to transmit. After sending data, or in the case that there is no data to be sent, the terminal modem will send the token to the next station. The token is then passed around a logical ring. Every terminal is given the same priority and collisions do not occur.

Since the station that has the token does not have to listen to the system to determine whether the medium is silent, there are no interruptions. An increase in traffic load therefore does not decrease the throughput. Only the cycle time of the network may slightly increase.

Since the Token Passing System does not wait for collisions, cable delay on long systems will not decrease the throughput either. Systems up to 25 miles of cable length become practical.

There are also no priority problems. RF level variations between transmitters can be substantial before errors would occur.

TOKEN PASSING SYSTEMS (IEEE 802.4)

- DISTRIBUTED VERSION OF POLLING
- TOKEN PASSED AROUND A LOGICAL RING
- INDEPENDENT OF CABLE DELAY
- INDEPENDENT OF LEVEL VARIATIONS
- SYSTEMS UP TO 25 MILES
- THROUGHPUT NOT A FUNCTION OF TRAFFIC LOAD
- 4 LEVELS OF PRIORITY
- IDEAL FOR CATV SYSTEMS

A Token Passing System operates without a mandate for minimum message length. The IEEE token access standard foresees four (4) levels of priority. Transmissions of lower priority are deferred when the network is heavily loaded. Each station computes network loading by measuring the time between token passes. When there is no traffic load the token is passed around very quickly and the cycle time of the network is very short.

As loading on the system increases, the time to return to the station increases. If the time exceeds a pre-determined threshold value, then low priority traffic is deferred until the traffic load decreases.
Each of the three lower priority levels have separate threshold levels, which helps to maintain minimum cycle times even in high traffic periods.

As we will see later, this concept of priority selection can be used for service categories and revenue structuring.

In summary, it appears that the Token Passing Bus Access Method has clear advantages for CATV systems and is considered the best vehicle to establish high and low speed data communication on our cable systems in the very near future.

3. Packet Switching

Affiliates with the United Nations, the Consultive Committee of International Telephony and Telegraphy (CCITT) is a branch of the International Telecommunications Union (ITU).

CCITT deals mostly with telecommunications to establish world wide system interconnections. The V-series standards for point to point traffic and the X-series for switched and distributed systems are important and considered mandatory in any networking involving the telephone systems.

CCITT recommendation X.25 covers the standards for packet switching system that will apply throughout the world.

Needless to say, any distributed packet switching data system working on twisted pair, baseband or broadband will be designed to the X.25 standard if it is to be interconnected to the world.

Interconnection with AT&T, SBS, MCI, DTS services, uplinks etc. is exactly what must happen to establish CATV as a data communication medium. Interconnection is the key to home banking, shopping, energy management, security, electronic mail and all the other blue sky services that we are talking about.

PACKET SWITCHING (CCITT X.25)

- INTERNATIONAL STANDARD FOR INTERCONNECTION OF DATA SYSTEMS
- INTEGRATED SERVICES DIGITAL NETWORK (ISDN) ARCHITECTURE
- PACKETIZING OF DATA
- FORMATTING OF DATA PACKETS
- ORDERLY TRANSFER OF DATA PACKETS FOR PUBLIC NETWORK INTERCONNECTION

And we know already that any one of these services cannot be profitable by itself. So the most logical solution appears to be to establish a data transfer network on the cable that first provides for business data communications, then integrates P.C. traffic and then adds all the other categories to it.

So, now, without further delay I can now introduce to you the advanced packet switching, token passing data communication system for the cable industry - the LANTEC™ 8400 System.

The LANTEC™ 8400 product line has just been introduced for the first time, here in Las Vegas, at this NCTA convention.

4. LANTEC 8400™ Data Communication System

4.1 LANTEC 8400™ Token Passing Packet Switching Equipment

LANTEC™ 8400 System utilizes self starting, token passing, random access addressing, which permits communication between any number of modem terminals.

LANTEC™ 8400 equipment design conforms to the international standard of CCITT X.25 and to the latest IEEE standards 802.4 for token passing bus access method.

LANTEC™ 8400 DATA COMMUNICATION SYSTEM

- PACKET SWITCHING TOKEN PASSING (CCITT X.25/IEEE 802.4)
- RESIDENTIAL SYSTEM (SUB-LOW)
- INSTITUTIONAL SYSTEM (MID-SPLIT AND HIGH-SPLIT)
- DISTRIBUTED TOPOLOGY
- 1 BIT/Hz SPECTRAL EFFICIENCY
- 4 SYSTEMS PER 6 MHz CHANNEL AT 1.5 MHz EACH
- USER SELECTABLE SPEED SETTINGS FROM 300 TO 19,200 bps.
- NETWORK MANAGEMENT
- STATUS MONITORING AND REDUNDANCY SWITCHING
- AUTOMATIC UNIT RATE BILLING SYSTEM

LANTEC™ 8400 is a local area network, wideband area network and CATV network communications system designed to meet the needs of multiple data users in a local or extended area coaxial cable network.

4.2 Application

LANTEC™ 8400 is designed to accommodate transmission on standard sub-low residential CATV systems as well as on institutional mid-split or high-split systems, Local Area Networks (LAN) and Wideband Area Networks (WAN).

4.3 Frequencies

On sub-low residential networks, the LANTEC™ 8400 system works on channels A-2 or A-1 in the forward direction on T7, T8, T9 or T10 in the return direction.

On mid-split systems the return frequencies are maintained as T7-T10 and the forward frequencies varied to Ch. 7, I or H.

On high-split systems, the return frequencies are maintained as T7-T10 and the forward frequencies changed to Ch. M (234 MHz) through Ch. P (252 MHz).

4.4 Spectrum Utilization

IEEE Standard 802.4 addresses the various physical signalling techniques and media defined for Local Area Networks (LAN) and CATV systems.

Using a multi-level duo-binary AM/FSK modulation, channel bandwidths of 1.5, 6 and 12 MHz are recommended by the IEEE standard.

LANTEC™ 8400 operates in any 1.5 MHz band within the above mentioned TV channel assignments. This means that 4 independent systems can operate in a TV channel assignment.

Data rates of over 1 Mbps are used in a 1.5 MHz band, permitting an approximate bit to Hertz rate of 1.0 as prescribed by the IEEE 802.4 standard.

Equipment operating at data rates of 5 Mbps and occupying a 6 MHz channel are in design to satisfy multiple high speed users.

4.5 Distributed Topology

In the Token Passing system, all modem terminals transmit on the same frequency on the return (low) channel and receive on the same frequency in the forward (high) channel.

At the headend, a simple frequency translator is used to re-transmit all low return transmissions into the high forward band. In this manner each modem "listens" to every other modem on the system, inclusive of its own transmission.

The token or the permission to transmit is passed from one modem terminal to the next in accordance with a sequential address number system. Each modem terminal knows the address of the previous and following modem. The token is therefore passed around a logical ring.

Addresses and sub-addresses can be developed to identify groups of modem terminals that always talk together. In the same manner, using sub-addresses, a group of modems can be interconnected with the modem that represents the gateway port for a particular service category.

Flexible topology permits gateways to occur at any point along the CATV or LAN system. Examples of gateways are Up-links, MCI, SBS, DTS services, AT&T, security boards, branch bank offices, computer data bases, electronic mail points and any other data service carriers that you may find located in your service area or that may be interconnected by telephone, microwaves, satellite up-links or coaxial regional interconnect networks.

The LANTEC™ 8400 system, for the first time, enables the cable operator to approach business and home computer data traffic within and outside of his franchise area in complete disregard of the cable system layout. The only remaining consideration that the cable operator must make is to assure that the CATV cable, whether residential or institutional is in front of the potential user.

5. LANTEC™ 8400 Components

The components of the LANTEC™ 8400 system have been conceived to permit automated maintenance, computerized network management and automatic unit rate billing.

The product line consists of the following:

LANTEC™ 8400 BUILDING BLOCKS

LANTEC 8401	Single Port Modem
LANTEC 8404	Four Port Modem
LANTEC 8408	Eight Port Modem
LANTEC 8412	Twelve Port Modem
LANTEC 8441	Headend Translator
LANTEC 8442	Network Control Unit (NCU)
LANTEC 8451	Status Monitoring Module (indoor)
LANTEC 8452	Status Monitoring Module (outdoor)
LANTEC 8453	RF Redundancy Switch
LANTEC 8460	Automatic Maintenance System Computer
LANTEC 8470	Automatic Unit Rate Billing System Computer
LANTEC 8481	5-30 MHz Drop Trap
LANTEC 8482	5-30 MHz Feeder Trap

5.1 LANTEC™ 8401 Single Port Modem Terminal

The LANTEC™ 8401 modem terminal consists of four basic modules, i.e., the transmitter module, the receiver module, the power supply board and the communications board.

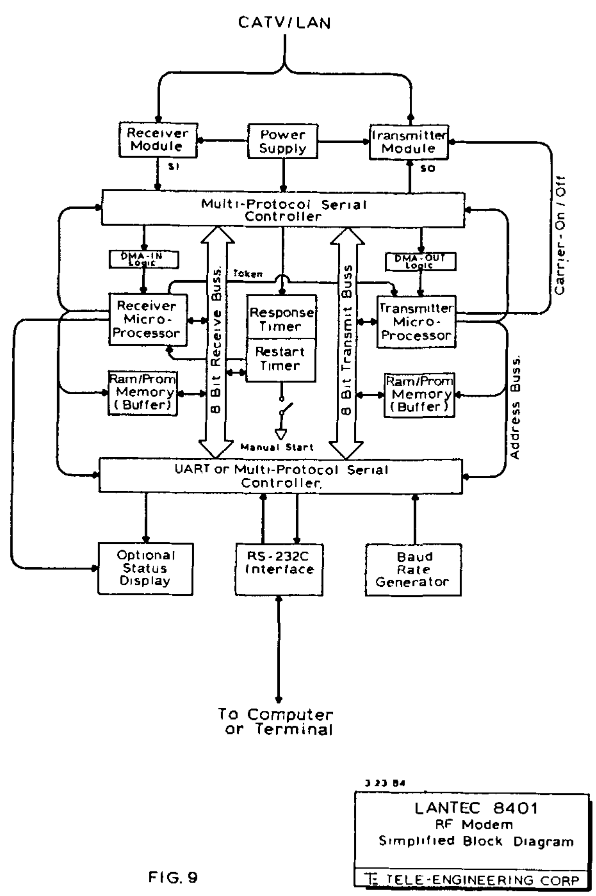

FIG. 9

The transmitter and receiver modules are shielded. Output levels are adjustable from + 35 to 50 dBmV to permit operation in the standard CATV distribution system environment.

The transmitter module contains harmonic suppression filters to provide interference free transmission characteristics.

The operating frequency of the unit is changed by replacing the transmitter and receiver modules or by utilizing the optional frequency agile modules.

The RF modules assume 1 bit/cycle modulation. To increase the spectral efficiency to 2 bits/cycle of bandwidth, the transmitter/receiver modules can be replaced with quadrature amplitude modulation and detection which would permit 8 LANTEC™ 8400 systems to operate on one 6 MHz video channel assignment.

Optionally, the modem can be provided with a status display that would indicate the set-up status of various handshake conditions. For instance, the busy condition of an addressed modem is immediately displayed.

The communications board combines separate microprocessors for the transmitter and receiver sections. It includes the multi-protocol serial controller chip, the DMA control logic, the interrupt logic, two RAM/PROM memories, a digital clock, a response timer, a re-start timer as well as RS-232C drivers, baud rate generator and optional status indicators.

Speed selections can be made by the user for 300, 600, 1200, 2400, 4800, 9600 and 19,200 bps.

5.2 LANTEC™ 8404, 8408, 8412 Multi-port Modem Terminals

To accommodate multi terminal users we have developed multi-port modems for 4, 8 and 12 ports. All ports are serial RS-232C and can be selected by the user as to the desired speed.

Multi-port units require the inclusion of additional communication boards, and a larger power supply module. The communication boards are stacked which increases the height of the unit and the price.

5.3 LANTEC™ 8400 Distributed Topology and Loading

As mentioned previously, distributed topology is one of the benefits of the token passing bus access method.

Figure 10 indicates a number of terminals interfacing with a computer on a different trunk of the residential CATV system. In addition, the computer delivers data to an SBS up-link location and to a local Digital Termination Service (DTS) both at different locations on the system.

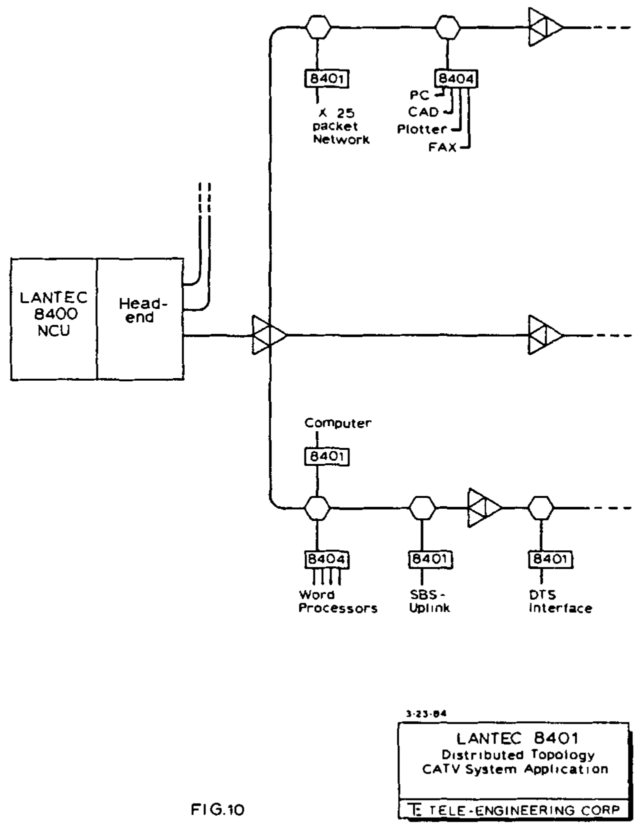

FIG.10

Most of you have spent the money to satisfy the license requirement for an institutional network. And now this capital sits idle except for some limited point-to-point connections.

Figure 11 indicates that direct interconnections with in-plant LAN networks are possible. The in-plant LAN is a mid-split network used for factory automation, computer aided design, accounting, word processors, etc. By interconnection with your idle mid-split institutional network you can provide data transmission to other branch locations, to satellite up-links, to DTS and provide communications to the outside world.

There is a lot of talk about Teleports. You may just be able to convert your idle institutional system to become the Teleport transportation or collection system.

The LANTEC™ 8400 packet switching, token passing data communication system permits flexible extension of your institutional system for business data communication. Closer investigation of businesses within your franchise area may well show you that with slight routing modifications and additions, your institutional system can become the best telephone bypass network in the area and a great revenue producer.

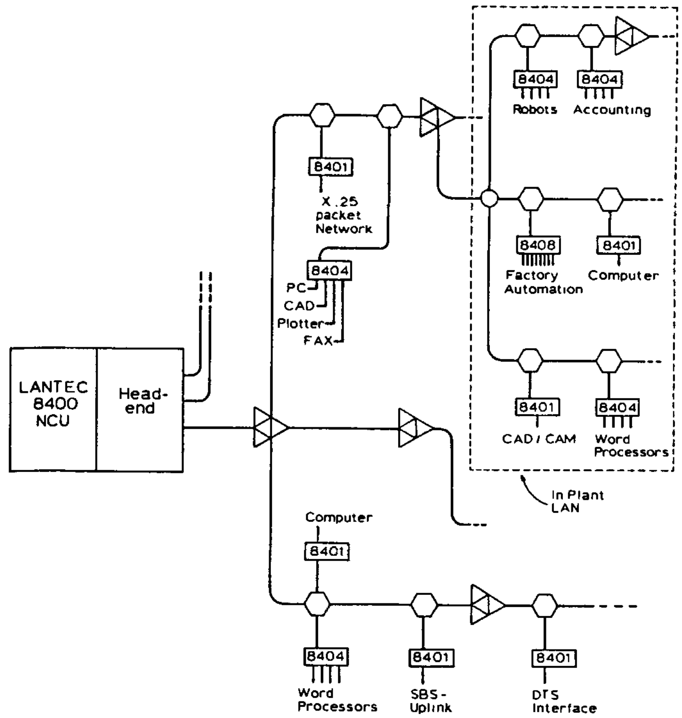

FIG. 11

3 23 84

LANTEC 8401
Business LAN Interface
CATV Institutional System
TE TELE-ENGINEERING CORP

Assuming standard traffic engineering principles, a LANTEC™ 8400 system can support 250 terminal modems operating at 19,200 bps or about 16,000 terminal modems operating at 300 bps.

There can be a mixture of baud rates throughout the system and, as I said before, the baud rates are selectable by the user.

Let us suppose then that you have connected 5,000 modem terminals to the system and they are all working at high data speeds, the system will not experience a breakdown. All that is going to happen is that the token does not get around to all terminals within the design cycle time of one second.

In other words the communications rate of the high speed users will slow down a little. In addition low priority users will be passed over and may have to wait a second or two until the peak load traffic period is over.

You may want to use this occurrence to up-grade a particular complaining low priority user for higher revenues and you may start thinking about deployment of a second LANTEC™ 8400 system to accommodate the increasing usage on your system.

Again, it should be recognized that four LANTEC™ 8400 systems can operate on only one 6 MHz channel spectrum. Considering the number of unused channels on your institutional system, the expansion possibilities are indeed unlimited.

5.4 LANTEC™ 8452 Status Monitoring Module

CATV systems lack status monitoring. Our industry has always relied on the subscribers to call in to report system or amplifier problems. This method cannot be used when you transport business data communication on your system.

As a matter of fact your serving telephone company can always point to the fact that there is discrete hard wire going to every telephone which does not contain any active elements.

So, it is my firm belief that your institutional system cannot become the telephone bypass instrument and compete with the telephone company without having status monitoring, automated maintenance and possibly automatic redundancy switching.

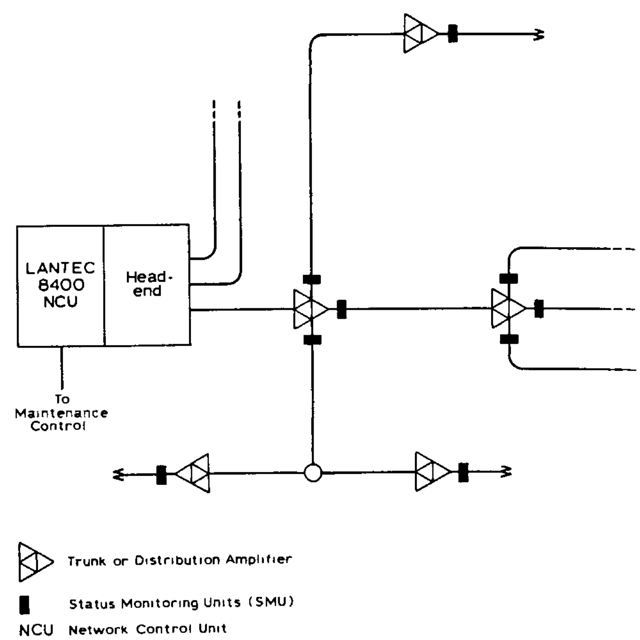

FIG.12

LANTEC 8400
Advanced LAN / CATV
Topology
Status Monitoring
TE TELE-ENGINEERING CORP

Figure 12 indicates a trunk and feeder protected institutional system with status monitoring modules.

The LANTEC™ 8452 outdoor status monitoring modules can be installed external to the line amplifier. They do not communicate on a fixed data rate, but rather respond to a polling modem. This polling modem is one of the token passing modems and is installed at the headend or the system maintenance location.

When asked to respond, the status monitoring module (SMM) communicates up to 128 bits of data per poll.

The polling modem does not hold its token longer than any other modem terminal on the system. Therefore only a few SMMs will be polled at a time during the one second cycle time of the sytem. Yet there can be many hundreds of SMMs connected without decreasing the data communication capability of the LANTEC™ 8400 system.

Status monitoring is then handled as a separate subsystem of the LANTEC™ 8400 that collects the information from the SMMs during a period of say 10 seconds.

The same principal of subsystem architecture can be used for other low speed services, like energy management, security, polling etc., without affecting the data throughput of the system.

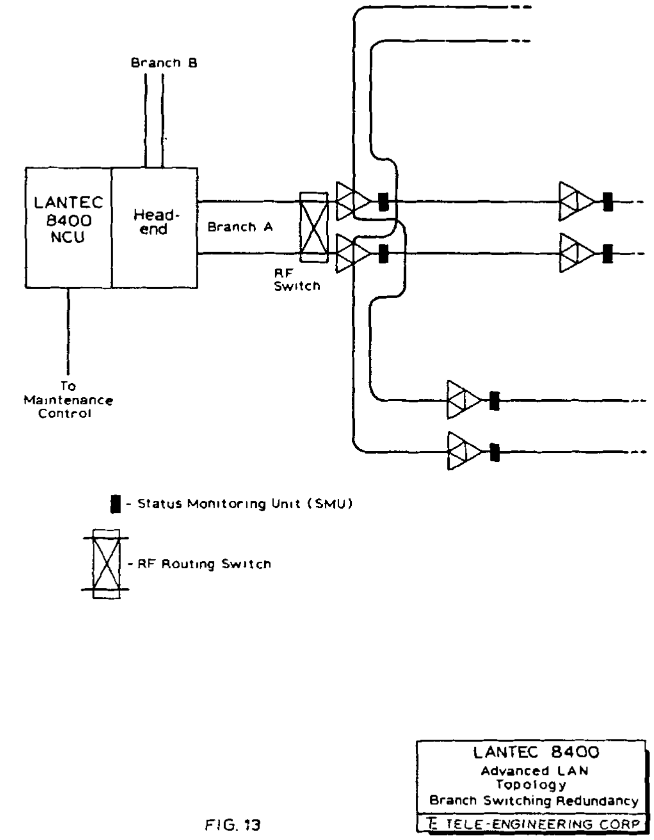

FIG. 13

5.5 LANTEC™ 8453 RF Redundancy Switch

Suppose you are ready to transport high speed data on your institutional system and you are asked by your potential customer about the outage time or the availability of your system.

What are you going to tell him?

You cannot really tell this sensitive prospective customer that you have a status monitoring system that lets you see which amplifier is not performing right and that you are sending a technician out to fix the problem.

Your customer will say "thanks, but no thanks" if you cannot give him 100% availability, 24 hours a day.

Figure 13 shows an example of Branch Switching Redundancy using the LANTEC™ 8453 RF Redundancy Switch.

Your institutional system is simply duplicated to protect the traffic of this sensitive customer along the branch of the system that he uses, i.e., between his data locations and the gateway point.

Another form of redundancy is provided by the Segment Switching Redundancy shown in the example of Figure 14.

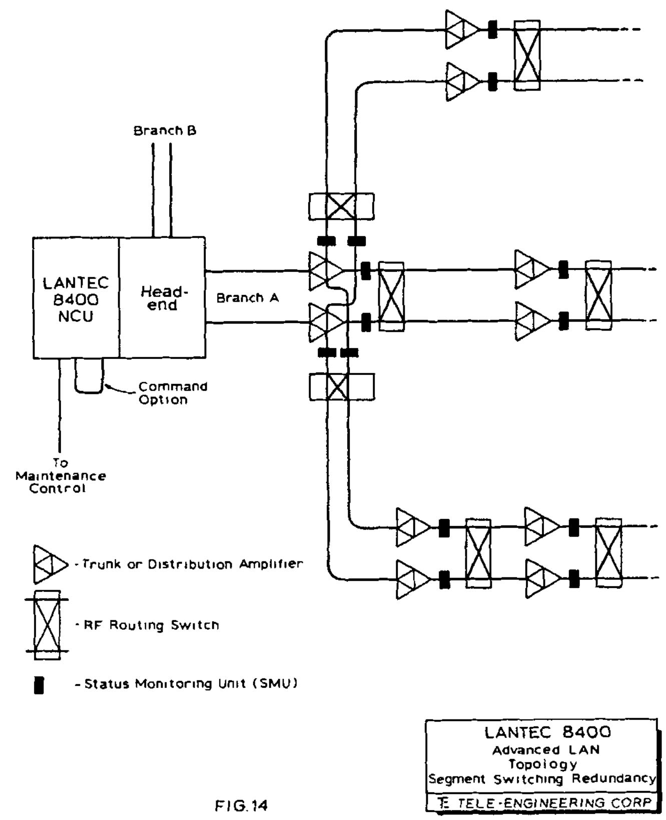

FIG. 14

Here, LANTEC™ 8453 RF Switching modules have been placed at every amplifier. In case of any amplifier failure, indicated by the status monitoring system, you simply command the particular module to switch to the redundant segment and then send your technician out the next day to fix the amplifier.

With segment switching redundancy you have achieved 100% availability provided there is somebody there 24 hours to push the right button.

5.6 LANTEC™ 8460 Automatic Maintenance System Computer

Revenues of data communications are measured at a unit rate per kilobits transmitted. If you have many customers sending data at rates of 19,200 bits per second, the pennies are starting to add up.

You may want to have 24 hour personnel to protect your revenue stream.

In case you don't, the alternative is the LANTEC™ 8460 Automatic Maintenance System Computer. A standard IBM PC with Tele-Engineering software can be used to fully automate your system maintenance.

The LANTEC™ 8460 system software is designed to function independently of multi-vendor terminal equipment. It utilizes forward and return pilot frequencies to access the spectrum performance of the system.

The controller at the headend is initialized by programming the system topology of your system by sequential inputting of trunk branches, amplifiers and feeder amplifiers.

The SMMs provide information on level variations of + 3 dBmV. Alarm indications are provided for level variations of over ± 6 dBmV.

Figure 15 shows a typical screen layout for two amplifiers on different branches.

It is obvious that trouble shooting can be reduced to reading the printout and implementing the steps as outlined. The maintenance software allows immediate restoration of the system by switching to the redundant segment, pinpointing the problem to the faulty network device and instructing the technician in the proper fault clearing sequence.

The LANTEC™ 8460 maintenance system has a thirty day continuous memory to store performance data. The performance data can be printed locally or transmitted remotely, on a demand basis.

LANTEC™ 8460 AUTOMATIC MAINTENANCE SYSTEM

ITEM	BRANCH	TRUNK	AMP. NO.	CRITERIA ± 3	± 6	REDUNDANT
1	2	4	4015A	over	under	NO

Forward module OK
Check return module
Set output level to + 32 dBmV
Check flatness
Restore station to complete

ITEM	BRANCH	TRUNK	AMP. NO.	CRITERIA ± 3	± 6	REDUNDANT
2	1	3	3008A	over	over	YES

Outage of forward module
Return module OK before switching
Redundant segment ok
Replace forward module
Set output level to + 33 dBmV
Set pad value to 6 dB
Set equalizer to 9.5 dB
Check flatness
Restore station to complete

Figure 15

5.7 LANTEC™ 8442 Network Control Unit (NCU)

Where the LANTEC™ 8460 computer system concerns itself only with the availability of the transmission media, the LANTEC™ 8442 Network Control Unit concerns itself with the proper functioning of all connected LANTEC modem terminals.

At the headend or maintenance center of the system, a LANTEC™ 8442 NCU is installed and constantly monitors the addressing, the token passing sequence, the handshake protocols, the packets transmitted and received at every modem terminal.

During initialization of the NCU, it is important to program all addresses of all participating terminals into the memory. The token passing traffic is compared against this memory and any anomalies will be reported. Priority levels of the various customer categories are set in accordance with the type of service desired.

The NCU software permits the pinpointing of modem terminal problems to the board or module level so that expedient maintenance procedures can be effected before the customer registers the outage.

Figure 16 indicates a typical screen layout on the CRT connected to the Network Control Unit.

LANTEC™ 8442 NETWORK CONTROL SYSTEM

TERM #	ADDRESS #	Tx STATUS	Rx STATUS	COMM. BOARD
25	203568	no	ok	ok

unit does not pass token
Tx level low

TERM #	ADDRESS #	Tx STATUS	Rx STATUS	COMM. BOARD
38	203589	ok	ok	no

unit responds irregular
check response timer/re-start timer

TERM #	ADDRESS #	Tx STATUS	Rx STATUS	COMM. BOARD
45	203678	no	no	no

check power and RF connections

FIGURE 16

The screen information can be printed and given to the technician who will be on his way to change the unit.

The third failure listed may be a disconnected unit. Terminal 45 may be disconnected from power or RF. A telephone call seems appropriate to find out the status before sending a technician.

5.8 LANTEC™ 8470 Automatic Unit Rate Billing System

It was mentioned earlier that every modem terminal on the system listens to the traffic on the system and can be placed anywhere on the system.

By installing a LANTEC™ 8401 modem terminal at the headend or office location, a traffic count can be made in megabits per second. The LANTEC™ 8470 combines the traffic count with the senders' addresses, priority level, sub-addresses, date and time of transmission as well as address of the number called.

The LANTEC™ 8470 computer then sorts the data in transaction files that permit the collection of data by customer and by priority rate level to record the number and length of calls made in megabits per second.

The LANTEC™ 8470 software includes a billing program for automatic billing of all data traffic as well as balances, past dues and standard account maintenance routines.

A billing summary program provides an instantaneous overview over all completed and invoiced transactions.

LANTEC™ 8470 DATA TRAFFIC BILLING SYSTEM

NAME: TELE-ENGINEERING CORPORATION

ADDRESS: 2 CENTRAL STREET, FRAMINGHAM, MA 01701

TERM #: 203568

DATE	TIME	DESTINATION	RATE	Mbps	AMOUNT
3-05-84	6:27 pm	30546	0.005	6.450	$ 32.25
3-28-84	11:07 am	30555	0.009	8.502	76.52
3-30-84	10:16 am	20654	0.009	3.600	32.40
				Total Amount:	$141.17

FIGURE 17

6. SUMMARY

Token passing, packet switching systems are in existence now and can form the basis for additional revenues for every cable operator.

The LANTEC™ 8400 token passing, packet switching data transfer system has been developed to provide a total range of services to the operator. The system provides for status monitoring, automatic transmission system maintenance, network control, account maintenance and automatic billing.

The development of data transmission on cable systems is considered the most important factor in the search for additional revenues.

Institutional systems have been left idle and are especially suited to provide multiport distributed data communication services.

The equipment, the LANTEC™ 8400 can help to develop a new revenue stream of data transfer speeds that cannot easily be supported by the twisted pairs of the telephone company.

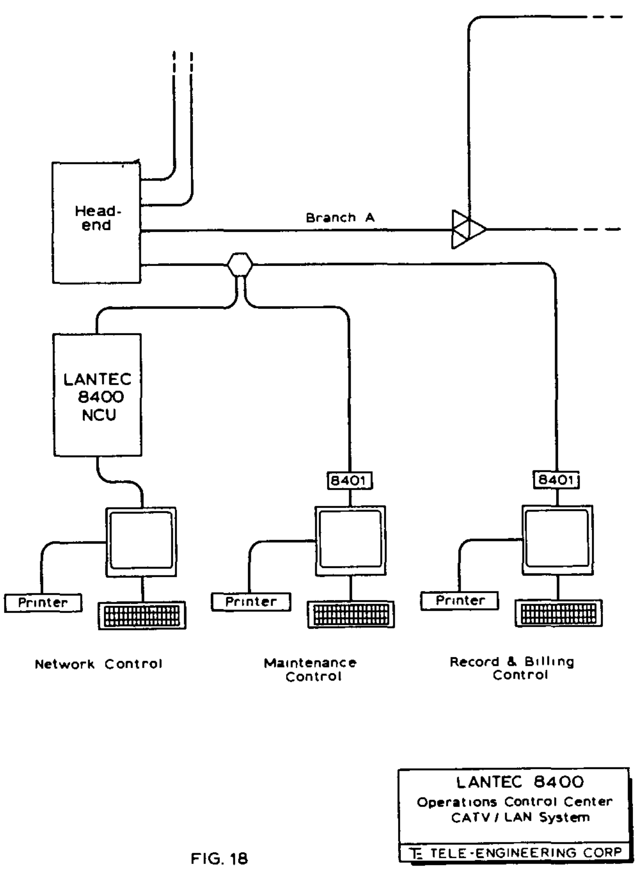

FIG. 18

The coaxial cable is a powerful tool. Even though your experience has been such that the distribution of entertainment television is all you can handle in your daily operations, have an open mind. Research the data transfer requirements in your franchise area. Start with a few LANTEC™ 8401 modem terminals and experiment. Then build a new business communication network and a Teleport transportation system with minimum capital expenditures and gradually build up a new revenue base from business data communications that may soon exceed your revenues from entertainment.

Tele-Engineering Corporation has an experienced staff of system engineering that is available for consultation on matters such as:

- ingress on residential sub-low
- return activation
- extension of institutional system
- redundancy considerations of institutional system

Tele-Engineering Corporation can also provide your business data communication system on a turnkey basis to give you the necessary assurances that everything works flawlessly.

Whatever your approach may be is not important. What is important is that you recognize the fact that the window of time for data communication on cable is open wide and that you must act soon or be bypassed by other more enterprising organizations.

DIGITAL AUDIO AND DATA TRANSMISSION SYSTEM FOR CATV LINE

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Tokyo, Japan

ABSTRACT

There is an increasing need for digital data transmission system using CATV line today. With the above in mind, we have developed a system which is able to transmit digital data of approximately 7.4 MBPS using a frequency bandwidth of 6 MHz (equivalent to one arbitrary TV channel), and which can also be connected to currently used CATV system without any alteration.

2-level VSB transmission method is employed for this system because of its suitability for the various characteristics of CATV system and simplicity of instrumentation in paticular at the receiving side. The system is also provided with a very flexible data format, enabling a wide application in designing the system.

The system enables to simultaneously transmit four ultra-high-fidelity stereo audio programs, as well as computer and game software, facsimile data, still picture, etc. to all or specified subscribers.

1. INTRODUCTION

A system that enables to offer a wide menu of new services by use of current CATV line is in demand.

Time division multiplex digital data transmission can be considered as one of the method well-responding to the above. The method is advantageous because of its flexibility in multiplexing various kinds of signals. It is also advantageous because the signals are seldom degraded by noise or distortion. This method is therefore well-suited for the multi-channel-broadcast of ultra-high-fidelity digital audio programs when a large amount of transmission capacity can be obtained.
Some of the data transmission method for CATV system has already been considered. However, most of them, for example, the method which uses blanking period of TV signal, are difficult to get large capacity and have only a restricted application.

Taking the above conditions into consideration, we have developed a wholly new style of data transmission system for the current CATV.
In this system a frequency bandwidth of 6 MHz which is equivalent to one arbitrary TV channel is used for data transmission, and digital data of approximately 7.4 MBPS can be transmitted by use of a flexible data format which can effectively process both audio and non-audio data and realize addressable function. The system has been prudently considered about the suitability for various characteristics of CATV, and is able to use in currently used CATV without any alteration. The receiver unit can be reasonably implimented concerning both the cost and the hardware size.

2. SYSTEM STRUCTURE

The captioned system is composed of a transmitter with a system control computer and home receiver-converters.
The transmitter, which are connected to Head End of the current CATV system, also includes, a modulator, a frequency converter, and A/D converters if necessary.
Although the level of the system control computer will depend on the contents of application, micro-computer can be generally used, giving sufficient performance.
The receiver is connected to drop-line from a tap-off of CATV line at each subscriber-sites.

Figure 1 and 2 show a photograph of the experimental system and an illustration of the system concept, respectively.

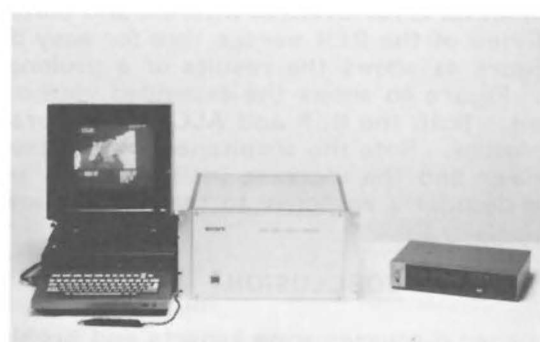

Fig. 1 : EXPERIMENTAL SYSTEM

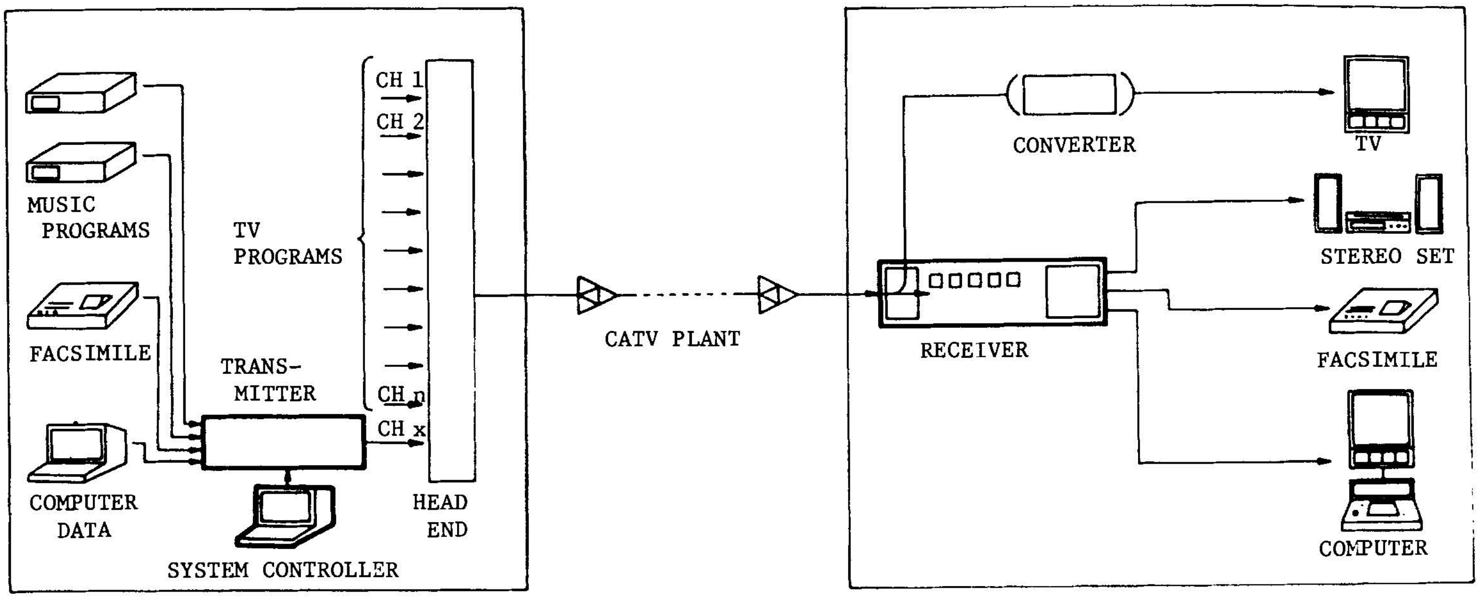

Fig. 2 : SYSTEM CONCEPT

3. TRANSMISSION METHOD

Some of the modulation methods used for digital data transmission are FSK(Frequency Shift Keying), PSK(Phase Shift Keying), and SSB(Single Side-Band AM) and VSB (Vestigial Side-Band AM).

FSK and PSK, however, require a more complicated demodulator compared to AM in order to get a large capacity using a restricted bandwidth of 6 MHz, which results in the cost increase of the receiver.
SSB and VSB are possible method for AM. SSB has an advantage of getting a large transmission capacity using a restricted band. However, it is not a practical method for data transmission because its filter requires an extremely strict accuracy in order to accomplish distortionless transmission. Consequently, considerations like the above lead us to select VSB for the captioned system.

In our system, the implementation of the above method becomes as follows:
The modulation depth is max. 50%. Envelope detection is applied at the receiver, taking advantage of the good C/N of the line; the current CATV line in use maintains C/N of min. 36 dB, providing sufficiently large carrier. Consequently, this method, in which outstanding waveform distortion seldom occurs, shows sufficient noise performance for digital data transmission.
Figure 3 shows the spectrum of this method. This method requires no alteration of current equipment, such as Head End, line, repeater, etc. because a position of the carrier and the bandwidth can be adjusted to those of current TV signals.

This method is also advantageous in economical implementation of the receiver because mass-produced TV parts, such as VIF IC, SWF, tuner, etc., can be used as hardwares of the receiver.

In order to suppress intersymbol interference, an accurate sinusoidal roll-off bandwidth restriction must be done at the baseband. The roll-off factor concerns both transmission capacity and amount of intersymbol interference.
In this system 21% roll-off is applied by LPF and BTF(Bynary Transversal Filter).
In this case the Nyquist frequency is, as shown in Figure 4, approximately 3.7 MHz, and the transmission capacity becomes approximately 7.4 MBPS.
Figure 5 shows the eye-pattern of the detected baseband signals.

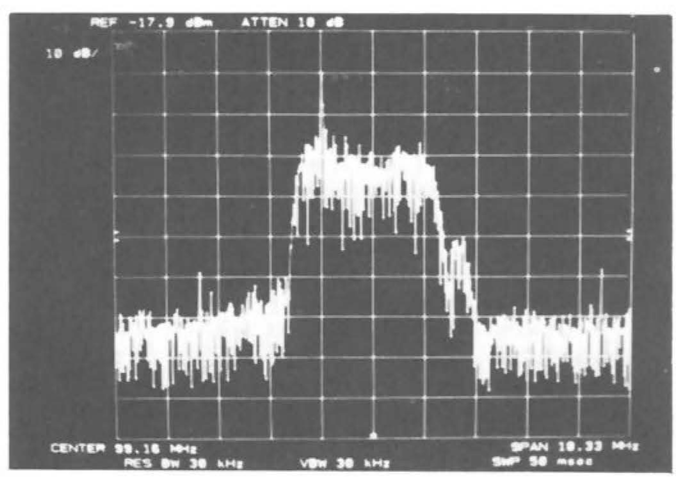

Fig. 3 : VSB SPECTRUM OF THIS SYSTEM

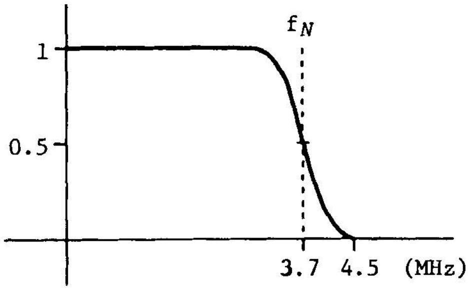

Fig. 4 : BANDWIDTH RESTRICTION

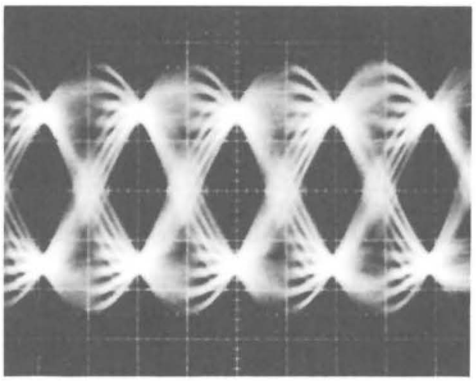

Fig. 5 : EYE PATTERN

4. DATA FORMAT

Various kinds of data must be processed in this system, responding to the respective demands of CATV operators. Therefore, it is indispensable for this system to provide a flexible data format, enabling a wide application in designing the system.

One of the main purposes of this system is, as mentioned before, to transmit data of ultra-high-fidelity audio programs, and the audio signal must be real-time-processed in general.
Taking the above into consideration, the minimum unit of this format, which is called q-unit, has been settled as shown in Figure 6. The q-unit consists of 32 information bits and 7 check bits, and is processed in approximately 22.7 μsec (= 1/44.1 kHz), i.e. one ultra-high-fidelity stereo audio program (16-bit quantization, 44.1 kHz sampling frequency) can be processed using a q-unit.
The format provides four independent q-unit, enabling simultaneous transmission of four ultra-high-fidelity audio programs.
Transmission format which is called "frame" is shown in Figure 7.
4 bits of service bit which are used to realize addressable function and 8 bits of synchronization data are attached to 4 q-units of data which are time division multiplexed for each and every bit, forming a frame consisting of 168 bits.
Therefore, the bit rate in the above process becomes;

$$168(\text{bits}) \times 44.1(\text{kHz}) = 7.4(\text{MBPS})$$

In order to facilitate the management of the service bits, a larger unit named "super frame" has been defined. One super frame consists of 256 frames and one super frame sync is attached to every 256 frames.
In order to answer to the various demands, the q-unit has four different modes as shown in Figure 8.
Mode A is used for transmitting the aforementioned ultra-high-fidelity stereo audio program. Mode B can transmit two stereo audio programs (8-bit quantization, 44.1 kHz sampling frequency) using one q-unit. In this case, high quality, which is better than current FM, is obtained when the noise reduction is applied. Mode C enables to transmit 8 monaural audio programs (8-bit quantization, 22.05 kHz sampling frequency) for BGM and announcement. Mode D is a combination of Modes B and C. Consequently, three quality-levels of audio programs can be transmitted by use of the above format. As for the non-audio data, each mode may be used depending on the data rate, using a certain interface if necessary.

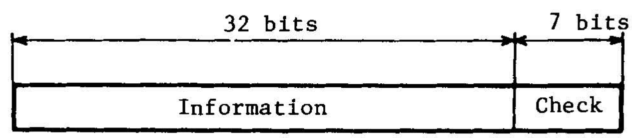

Fig. 6 : Q-UNIT

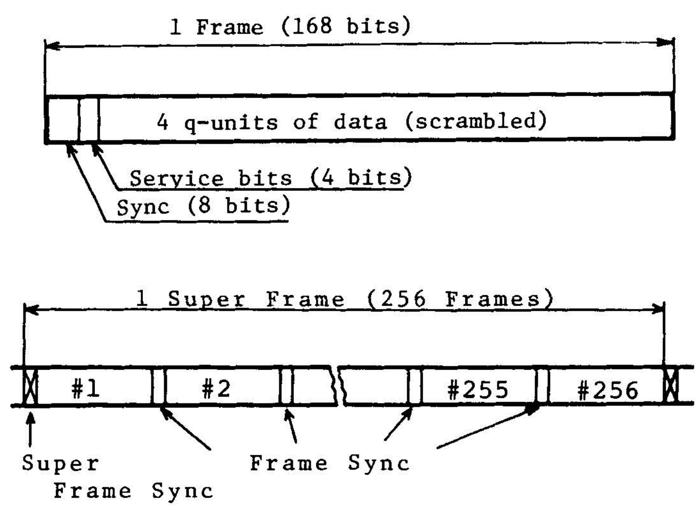

Fig. 7 : FRAME STRUCTURE

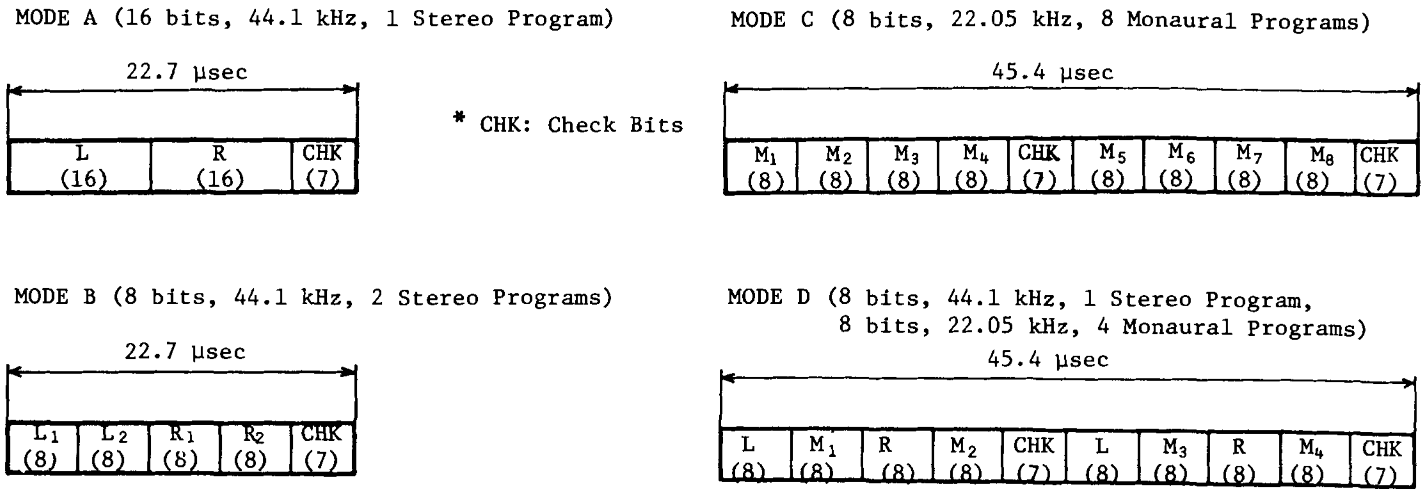

Fig. 8 : Q-UNIT MODE

5. SIGNAL PROCESSING

Figures 9 and 10 show the block diagrams of the transmission side and the receiving side of the system, respectively.

At the transmission side, input digital data are first converted into a serial data, and then sent through an encoding circuit where check bits are generated and attached. [63, 56] Extended Hamming Code is used in a shortened form, as shown in Figure 11. This code is capable of correcting single error in any digit, and detecting all patterns of double errors and some of the triple errors, owing to the shortening effect. Figure 12 indicates the theoretical performance of this code. The encoded data is then time division multiplexed and scrambled by use of an M-sequence in order to ease the bit-clock-recovery, while sync and service bits which are sent from the system control computer are attached to them, forming one data stream. Afterwards, the data stream is sent through a BTF and a LPF, at which 21% roll-off bandwidth restriction are accomplished. Output signal of the LPF is AM modulated, passed through a VSB filter, frequency-converted, and sent to the Head End.

At the receiving side, signal which is fed from a tap-off of CATV line is detected after going through the Front End and VIF circuit which are currently used in TV sets. Digital data and clock are recovered at the level-comparator and clock recovery circuit, respectively, and then sent through digital signal processing circuits. In these circuits synchronization data and service bits are separated from the data stream and sent to the built-in micro computer. The computer processes these data according to the data format and the instruction given by the subscriber, and generates some control signals. The data is descrambled by use of an M-sequence, and error controlled, and finally sent out in various forms according to the control signals.

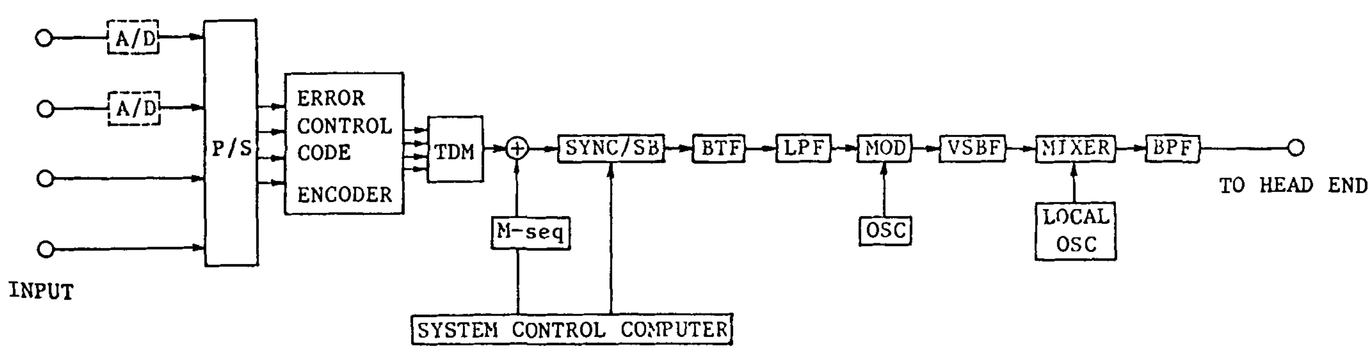

Fig. 9 : BLOCK DIAGRAM OF TRANSMISSION SIDE

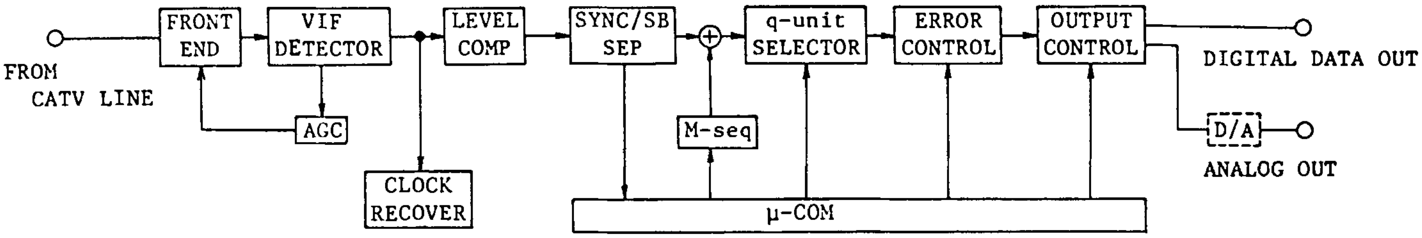

Fig. 10 : BLOCK DIAGRAM OF RECEIVING SIDE

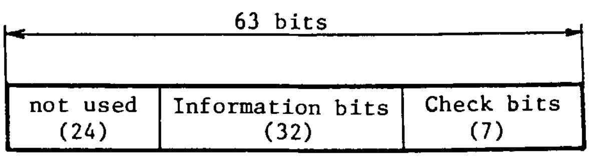

Fig. 11 : ERROR CONTROL CODE

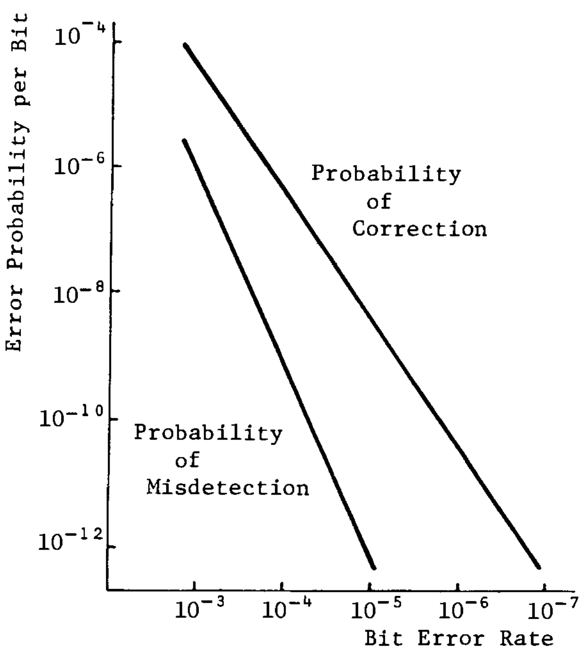

Fig. 12 : PERFORMANCE OF ERROR CONTROL

6. APPLICATION

As is already stated at the beginning of this paper, many applications are possible in designing this system depending on the various mode-selection of q-unit and handling of service bits.

The system is able to transmit three quality-levels of audio programs, as well as computer and game software, and facimile data, etc. Still pictures can be transmitted as well, provided that frame memory is applied to the transmitter and receiver. A certain application of the service bit leads to addressable function which enables, for example, specified announcement and facimile transmission. Furthermore, various pay service system can be designed when addressable function is effectively combined to the technique of scrambling and encription.

7. CONCLUSION

The system reported in this paper has proven to be effective in our North American and Japanese CATV system transmission experiments.

We believe the system is totally suitable to transmit various digital data using CATV, and will be used in the near future to offer various new services.

ACKNOWLEDGEMENT

The authors would like to express their deep appreciation to Dr. H.Nakajima, former Director, Dr. S.Miyaoka, Director, and T.Waku, Manager, Audio/Video Technology Center, Sony Corporation, for their kind support and valuable advice in developing this system.

DOMESTIC SATELLITE COMMUNICATIONS
-The Impact of Recent Advances-

Dom Stasi

Warner Amex Satellite Entertainment Company

Cable television embraced communication satellites as a distribution method as early as 1975. In the ensuing years sweeping changes have altered both mediums, and as with most emerging technology based businesses, many of the changes were revolutionary. The ruling, following a body of cable industry research, which allowed use of small aperture (4.5m) receive antennas is an example of one such revolutionary change.

Today both cable TV and satellite communication are mature industries, and as is characteristic of mature industries, what changes do occur are usually of the more subtle evolutionary nature.

Developments of the last year however, have belied that reasoning, and a considerable degree of radical alteration of our delivery medium is again in the offing.

Consider for example that higher power and solid state transponders are already on orbit.

Several encryption schemes have been developed, some or all of which will be deployed on cable oriented services.

New modulation formats such as multiplexed analogue component (MAC) or video FDMA are under serious consideration by programmers, and satellite delivery is the medium which will no doubt be first to convey extended or high definition television.

Interleaved with these developments comes the use at 'C' band of very small aperture, very low cost receive systems designed to operate at carrier to noise levels reduced well beyond those considered feasable as recently as one year ago.

This paper will review these developments from an observers perspective and attempt some objective evaluations of their performance from a largely imperical point of view.

BACKGROUND

More than any single factor, the landmark decision to routinely license small (<9m) receive antennas was responsible for the exponential growth of CATV.

At that juncture the now well known (32-25 log ϕ) expression for antenna sidelobe performance predicated antenna apertures as small as 4.5 meters yielding sufficient off axis discrimination. This, of course, assumed a 4 degree adjacent transmitter environment.

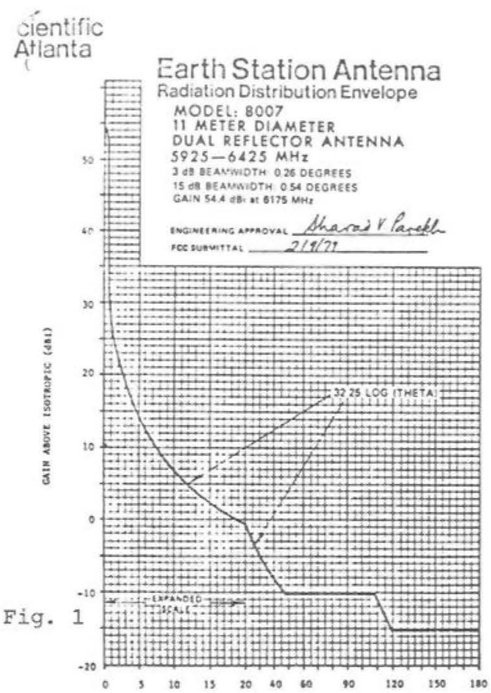

Fig. 1

That same popular acceptance of CATV via satellite was however enjoyed by many other communicators. This resulted in an extraordinary demand for transponders. The supply of which was limited, largely by the 4 degree adjacency rule.

The commission responded by approving a plan of reduced satellite spacing (2 degrees) in 1983. To facilitate such density the performance expectation for receive antennas, was altered accordingly. A more stringent (29-25 log ϕ) envelope was mandated along with other operating practices and a compromised but workable situation anticipated.

One factor expected to complicate matters is the new generation of communication satellites likely to constitute the reduced spacing constellation. Significantly more powerful transmitters than their extant neighbors, the potential for interference they represent is considerable.

Space craft such as advanced Satcom or Galaxy are flying with 8 to 9 watt power amplifiers. The former (Satcom) employing the first of a new generation of solid state output devices. A departure from conventional traveling wave tubes the considerable advantages of S.S.P.A.'s* will be discussed later in this paper.

While higher power adjacencies would be expected to result in a move toward conservative station design utilizing larger aperture more discriminate antennas, current trends are quite the contrary.

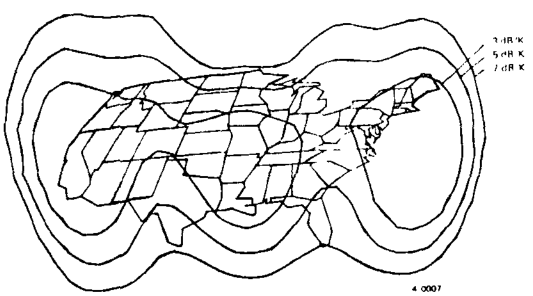

Figure 2 Measured G/T Contours - Satcom IIR

Rather than concern over higher power outputs, users are tending toward exploitation of those EIRP values, which now approach 40dBw. Through lower noise front ends, as well as manipulation of IF bandwidth and aural carriage, antenna apertures have been tested, albeit with varying degrees of success, down to 1.3 meters, at 'C' band.

If such experiments prove successful 'C' band Earth stations could be reduced in cost to a few hundred dollars and installed virtually anywhere.

EVALUATION

Considerable study and information dissemination has accompanied the commissions alteration of the space and Earth segments of the domestic network. The (29-25 log ϕ) specification was the product of much deliberation.

Whether or not to employ very small aperture (<3m) devices will be a free enterprise decision however, and to date little or no definitive data has been forthcoming. No similar restraint has contained the appearance of hardware. Since none of these devices meet anything approaching (29-25 log ϕ), tacit disapproval must be assumed from the commissions refusal to protect them by license.

At this juncture then a closer examination of performance expected from such systems under such conditions is appropriate.

As a starting point reference let's assume a 1.8 meter antenna of 60% efficiency.

The analysis will be for five geo-stationary satellites 2 degrees apart, the satellite of interest being of the advanced class, (8.5 Watts).

The parameters of interest will be limited to those of carrier to noise (c/n) performance and interference immunity (c/i).

The method used is an abreviation of that developed by Golin & Kolsun[1] in 1976, which is considered the definitive analysis.

In the interest of brevity all angles are geocentric.

C/N THERMAL

Conventional TVRO systems for CATV video reception utilize full transponder (36 MHz) bandwidth. Carrier to noise as the aggregate product of uplink and downlink propagation is:

$$C/N = \psi + Ai + G/Tsat - K - 10 \log B$$

Where:
ψ=Saturation flux density for satellite

G/T sat=Figure of merit for satellite.

Ai =Area of isotropic reference antenna

*Solid State Power Amplifiers

Then:
UPLINK C/N:
C/Nu =-82+(-37)+(-3dB/K)+(-228.6) -75.6
= 31dB
DOWNLINK C/N:
C/Nd=EIRP+G/T-Lp-K-B

=36+(15.33)-196-(-228.6)-75.6
=8.32dB

UPLINK C/I:

$$C/Iu=EIRP(es)=-\sum_{i=1}^{4}[EIRPi-Gi+G(i)+Pi]$$

Where:
EIRP(es)=EIRP of wanted transmitter=83dBW

EIRP(i)(1)=EIRP of 1st unwanted E.S.=83dBW

(2)=EIRP of 1st unwanted E.S.=83dBW

(3)=EIRP of 1st unwanted E.S.=83dBW

(4)=EIRP of 1st unwanted E.S.=83dBW

Gi(1)=Tx gain (on axis) of 1st, unwanted antenna = 54 dBi

(2)=Tx gain (on axis) of 2nd unwanted antenna = 54 dBi

(3)=Tx gain (on axis) of 3rd unwanted antenna = 54 dBi

(4)=Tx gain (on axis) of 4th unwanted antenna = 54 dBi

i(1)=Tx gain (2° off axis) of 1st, unwanted antenna = 22dBi

(2)=Tx gain (2° off axis) of 2nd, unwanted antenna = 22dBi

(3)=Tx gain (4° off axis) of 3rd, unwanted antenna = 16dBi

(4)=Tx gain (4° off axis) of 4th, unwanted antenna = 16dBi

Pi = Polarization discrimination for i satellite system. Earth station antennas offer approximately 6dB of off axis polarization discrimination.

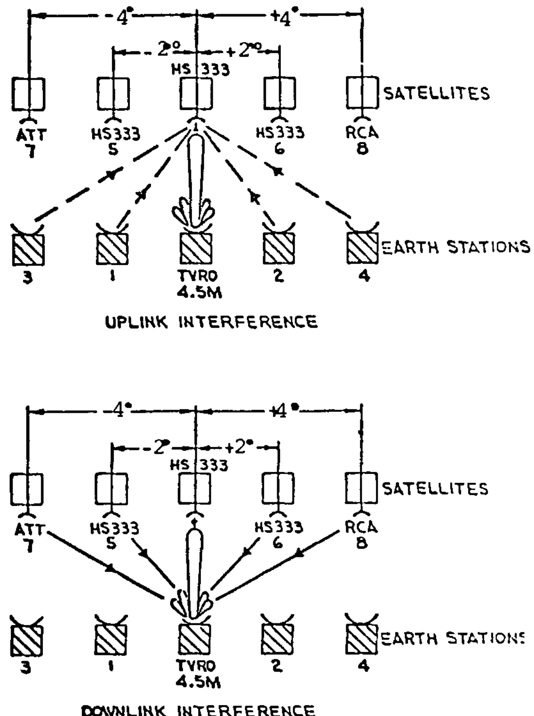

Figure 3

Then:

C/Iu=83-[(83-54+29-25log2-6)]
*(+)[(83-54+29-25log2-6)]
(+)[(83-54+29-25log4-6)]
(+)[(83-54+29-25log4-6)]
=83-48.2

C/Iu=34.8dB

*Indicates Power Summation

At this point, a serious departure from definitive analysis takes place. The parameter of downlink carrier to interference (C/Id) appears incalcuable. Therefore, all interference calculations have been verified by actual field tests.

Tests were conducted by Warner Amex utilizing a system identical to that described here. Findings failed to produce the expected results. Under all conditions, including no carrier of interest, no evidence of descernable adjacent satellite interference was observed.

Typically a six foot (1.3m) antenna exhibits a three degree (3°) beamwidth. At 2° off axis, the point of most likely interference, the best available 1.3 meter antenna offers no more than 6dB of discrimination.

Using that number and abandoning ($32-25 \log \phi$) the downlink C/Id calculates as follows:

C/Id=

$$EIRP(sat)+G(es)-\Sigma[EIRP(sat/i)+Ges(i)+Pi]$$
$$=36+35.5-[36+(30-6)]$$
$$(+)[36+(30-6)]$$
$$(+)[34+(28-6)]$$
$$(+)[36+(30-6)]$$
$$=71.5-64.9$$

C/Id = 6.6dB

Despite that 6.6dB appears an abhorently low margin, considering this number against that of C/Nd=+8.3dB the interference energy would be sufficiently below the already marginal carrier level to be indiscernible in the noise. This was supported by the field test results.

Ignoring interference contributions from cross transponder causes and the unknown effects of terrestrial ingress the effective carrier to noise ratio becomes:

C/N (eff)=C/Nu(+)C/Nd(+)C/Iu(+)C/Id
=4.35dB

4.35dB is clearly an unacceptable level of performance. This is, of course a worst case scenario and several improvements can be introduced. It does However serve to indicate the inadequacy of the fundamental system.

OPTIMIZATION

As stated several improvements, however subjective, may be imparted, and, since the only application thus far considered for very small aperture stations has been direct reception, no margin for distribution (as via cable) need be considered.

Reduction of I.F. bandwidth can provide significant C/N improvement.

A reduction to 18 MHz (from 36 MHz) provides an improvement to C/N performance of +3dB.

This is a considerable improvement but does impose a penalty. In order to so drastically reduce IFBW, modulation deviation of the carrier must be reduced accordingly. Signal to noise FM improvement reduction results in a random noise performance penalty of approximately 3dB

or:

$$S/N\ p/p=C/N(eff)+(20\log\Delta FV/Fvm)+(10\log B/Fvm)+10\log 6+ew$$

Where:

ΔFv=video deviation
Fvm=Max modulating frequency
ew =weighting & pre emph advantage

Thus, reducing the parameters of ΔFv, & B imposes a corresponding decrease in signal to random noise ratio through loss of FM improvement. An increase in carrier to noise (C/N) of 3dB however reduces the $\Delta S/N$ to only -3dB.

Thus:

$$S/N=7.35+20\log(7/4.2)+10\log(18/4.2)+7.78+13$$
$$=38.9dB$$

Removal of subcarrier, and component processing such as MAC, can contribute an additional 3dB of subjective improvemnt to the picture raising the S/N to ≈42dB

Therefore provided an alternate means of aural carriage is available as with most scrambling systems and provided no additional distribution is anticipated and the user is able to reduce deviations and/or IF bandwidth, a 1.8 meter very low cost Earth terminal is capable of yielding passable performance.

Reduction in aperture below 1.8 meters (G/T ≈15dB/°K) however exhibited rapid and pronounced degradations, even under optimum conditions.

High levels of impulse noise were apparent and pointing accuracy proved too precise to be practical.

VIDEO FDMA

Since its inception, conventional domestic satellite video service has been characterized by full transponder (36 MHz) bandwidth.

Despite the robust performance such allocation provides, it quickly exhausts the finite transponder resource.

Until very recently, the demand for transponders on certain satellites far exceeded the supply. In addition the cost of full transponder allocation is often such an inordinate proportion of a programmers operating expense as to prove prohibitive.

Consequently, efforts to imporve video throughput are frequently launched. To date, successful programs have been undertaken by Comsat Corp. & RCA, wherein two (2) and four (4) channels of video respectively are routinely delivered within the bandwidth constraints of a single (36 MHz) transponder,with program audio relegated to a separate delivery source.

The limitation faced by such users however, has been the inability to reach any but the most sensitive Earth stations. This being due primarily to the well known shortcomings of traveling wave tube amplifiers, flown aboard conventional communications satellites, in the presence of multiple carriers. (Abbott, Beakly, Rowse)[2]

A brief review of FDMA deficiencies is in order before proceeding.

REVIEW

Conventional satellite modulation, optimized for video transmission, is distributed across the 36 MHz of available transponder bandwidth as follows:

$$\Delta F=[\Delta fv+(\Delta fe)^2+\Sigma(\chi/fsl\cdot fsi)^2]^{1/2}$$

fv=Deviation of main carrier by video
fe=Deviation of main carrier by E.D.U
χ=Deviation of main carrier by aural Subcarrier
fsi=Frequency of aural subcarrier.
fsn=Frequency of additional aural subcarrier

For the single subcarrier case composite deviations are equal to:

$$[(10.75^2+1^2)+(2/6.8\cdot 6.8)^2]^{1/2}=10.98$$

Then: Δf=10.98MHz
fm=6.8MHz+237KHz

BW=[2(10.95)+2(7.037)]=36.03MHz

LIMITATIONS

Even in the most cursory consideration of a two (FM) carrier per unit bandwidth scheme, the designer will assume deminished performance for a number of expected reasons. The most apparent, of course, being degraded signal to noise performance due to reduced carrier deviations necessary to accommodate bandwidth restrictions, more simply stated:

$$BW=(2\Delta F)+(2FM)$$

Where:

ΔF=Peak composite deviation
FM=Maximum instantaneous modulating frequency.

Results of earlier testing by RCA laboratories verified limitations to 2:1 video transmission to extend well beyond those of power sharing and reduced FM improvement function. The most pronounced of these unfortunately being satellite borne and clearly outside the control fo 2 for 1 aspirants.

For example, conventional satellite transponders utilize high frequency, large output travelling wave tubes as power amplifiers[3]. If nominal EIRP levels are to be expected satellite TWT/P.A.'s must be operated at the region of "saturation". Saturation is characterized by a non-linear input/output power relationship or; as the input power is raised beyond low level (fig. 4) the output power increased in direct proportion, then non-linearly unitil a point is reached where the output will decrease with any additional input.

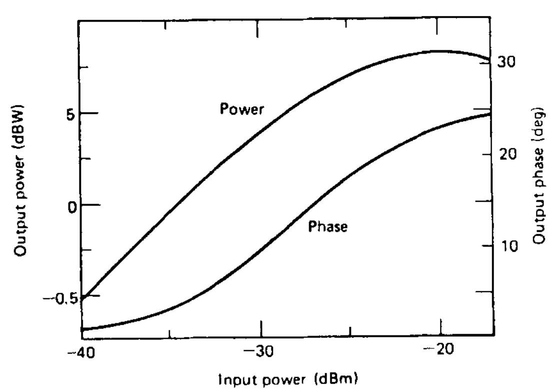

Figure 4 INTELSAT IV single-carrier TWT curves.

Departure from linear operation is manifest as an AM/PM conversion which generally follows input envelope fluxation, and AM/AM conversion hearing a non linear relationship to input flux.

In single carrier operation, considering direct FM modulation, input amplitude levels are constant thus introducing no substantial erroneous output effects.

In the case of multiple carriers, however, a number of degrading effects occur:

1. Non-linearities cause intermodulation products which may fall back into the passband and interfere with one or the other signals and cause disproportionate power sharing.

2. Since two carriers, displaced in frequency are contained within the T.W.T., large excursions of the amplitute envelope will occur. This will translate to phase modulation of the output (AM/PM) resulting in crossmod visible in both reproduced video channels.

In order to minimize these effects operation must be limited to the linear portion of the T.W.T. characteristic curve. The dual carrier power transfer curve developed by RCA experimentation, is considerably reduced over that of single carrier operation.

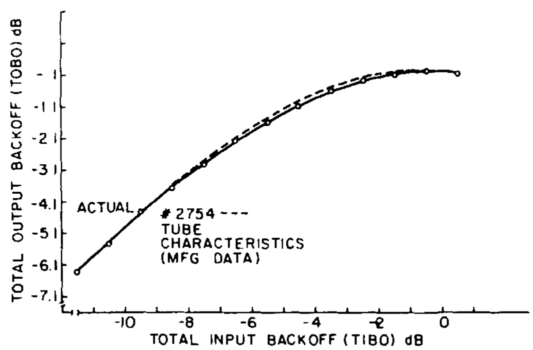

Fig. 5—Single carrier backoff characteristics.

In actual practice input back-off levels are held at approximately -8dB from saturation. This results in a proportionate reduction in satellite EIRP and consequent carrier to noise performance.

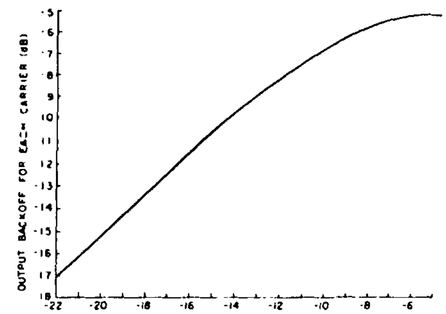

Fig. 6—Two-carrier input versus output backoff relative to single-carrier saturation Carriers at ±9 5 MHz from transponder center (composite from 8/25/76 and 9/1/76, includes HPA)

Reduction in FM improvement ratios, imposed by the narrow (17 MHz) IFBW necessary to accommodate two channels in 36 MHz, dictated operation be limited to Earth stations of typically 33 dB/°K G/T. Or at least 13 meters aperture. Such systems clearly hold no potential for cable reception and have found application primarily in thin route traffic.

EXPERIMENTS WITH ADVANCED SATCOM

In August, 1983 following the launch of RCA's first advanced Satcom satellite a joint experiment was carried out. Engineers from Scientific Atlanta and Warner Amex Satellite Entertainment Company, with the cooperation and assistance of RCA American Communications, undertook to distribute 2:1 video through a single transponder aboard this satellite.

This series of tests differed from previous efforts in three significant areas:

1. This would be the first attempt at video FDMA through a satellite utilizing solid state (non-TWT) power amplifiers, hence referred to as S.S.P.A.'s.

2. Four channels of 15KHz program audio would accompany its associated video within the transponder.

3. Reception would be by a cable grade, seven meter Earth station of 28 dB/°K, G/T.

In order to determine feasibility an ideal system is assumed. Performance assumptions to be verified in practice are as follows:

Video (S/N) Objective =50dB
Channel BW =20 MHz
Guard Band =1 MHz
Satellite EIRP=(Gant+Log^{-1}8.5w/10)=37dBw

Thus to maintain BW=19 MHz, a corresponding reduction in FM deviation equals:

BW=2Δf + 2FM
or:
2fm=8.4 - 19 = 10.6 MHz

Then:ΔF = 5.3 MHz

Using this figure (5.3MHz) to determine receiver transfer function will allow us to determine the necessary C/N ratio which will yield 50 dB S/N as follows:

50=C/N+RTF
=C/N+[20log(Δf/Fvm)+10log(BW/FM)+W]

Where:
ΔF=FM deviation
FVM=Top modulating Frequency
W =Weighting & pre-emph advantage

Then:
50=C/N+[20log(5.3/4.2)+10log(19/4.2)+20.8]

And
50dB=C/N+29.41

Thus: C/N must equal at least 20.58dB

We can now determine the minumum Earth station figure of merit which will yield such performance to hals transponder video modulation:

G/T(min)=C/N-EIRP+Lp+K+BW

Where: 1
Lp=Path Loss at 4GHz
K=Boltzmans Constant

Then: 20.58-37+196+(-228.6)+75.6
Thus: G/T(min)=26.5dB/K

Substituting system parameters and solving for G/T will yield actual equipment configurations necessary to meet our performance objectives:

G/T=G(a)-10 log T(sys)

Where:
G(a)= Antenna gain 7 meter
T(sys)= System noise temperature 90K LNA

Then:
G/T = 26.2dB/°K

This is sufficently close to our ideal figure of merit (26.5). That we may then assume a system so configured will yield our performance objectives of S/N=50dB

TEST RESULTS

Results of field tests utilizing a seven meter, 90°K/LNA receive Earth station exceeded predicitons.

Contrary to expectations, the superior linearity of the SSPA aboard Satcom V allowed operation very near saturation. Thus no degradation for input back off was experienced.

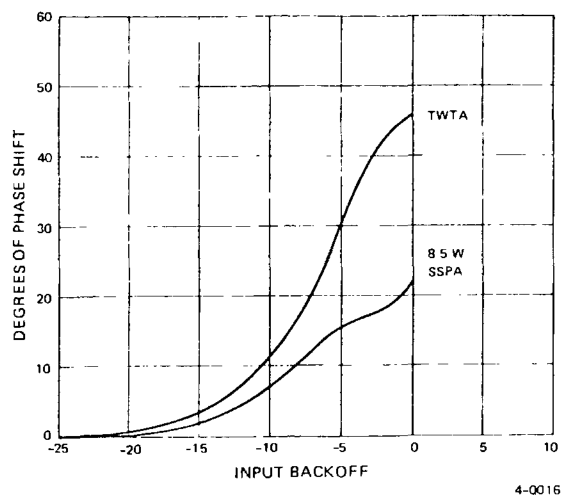

Figure 7 . Phase Shift as a Function of Drive - SSPA vs. TWTA

Power sharing, not included in the previous calculations contributed 3 dB of C/N reduction.

Various configurations yielded the following nominal parameters at Warner-Amex, Long Island, NY facility:

Sat EIRP	37dBW
Antenna S/A	7 meter

LNA Avantek	90K
Exciters S/A 461	18MHz
Frequency Offset	9MHz
High Power Amp's., Varian	3.3KW
Nominal IFBW	17 MHz
IF Filters, Cherychev Slope	17.5MHz
Subcarriers 5.8, 6.2 MHz	-19dB/2MHz

In practice, it was found that video deviations could be increased to 7.5 MHz without discernable overdeviation.

Interference was observed on color bar signals as black dots into lower half of transponder and white dots into upper signal band.

Reduction of subcarrier injection leves from -17 to -19dB, and phase locking of syncronizing pulse generators alleviated all discernable interference.

CONCLUSIONS

Routine operation of 2:1 video can be acheived from advanced Satcom series and presumably future SSPA equipped satellites into what may be described as cable grade earth stations.

The affotmentioned experiments yielded:

S/N = 47.5dB, CCIR weighted.

Notably these signals were accompanied by four (4) robust audio channels of:

15KHz, S/N = 60dB.

It is assumed that video baseband processing would yield additional subjective improvements raising S/N ratios above 50 dB.

Acknowledgements:

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R.C.A. Review, September 1980

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Wiley Interscience, 1981

"EVOLUTION: A Rational Way to Achene Hybrid Network Implementations"

Steve Westall

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Hartford, Connecticut

Cable Television had it's beginning with an antenna system perched on the highest accessible location and with coaxial cable runs to town residents below. There were few at that time who envisioned this business network would evolve into a multi-media communications system.

Early implementations utilized available cable and electronic equipment to receive and distribute broadcast (off-air) signals to populated areas with poor reception. This quickly evolved into a business opportunity for entrepreneurs who would eventually change American T.V. Both equipment suppliers and cable operators responded to the opportunity at hand providing more sophisticated equipment, cable and services. Soon in-home equipment began to emerge as a complement to installed headend and cable plant electronics. Converters first expanded available channels then were used to decode scrambled signals for pay service security; finally new sophisticated addressable converters were created to provide subscriber specific service authorization under computer control.

The evolution which has occurred in Cable Television distribution systems has been running on a converging course with the Computer and Communications industries. This is evidenced by the myriad of new products and services we see at this 1983 NCTA Show. The triad, Cable/Computers/Communications, opens new revenue producing potential for both entertainment and service related programming; these are the opportunities of the 80's.

Cable Television: System-Architecture

Since many definitions are appended to today's technical terms the following is our reference for System Architecture:

> "The composite design which results from using physical structure to interconnect with and enable (logical) devices used to perform systems operations." --S. Westall, 1983 NCTA

This reference applies to many device structures in electronics, construction and many other fields. For example, reservoir and water distribution systems employ an architectural design to deliver service to residential and business consumers.

Traditional Cable TV Networks

The early pioneers in Cable Television utilized a system architecture which satisfied their objectives efficiently and economically; a cable plant which was installed at minimum cost and was extendable. This network implementation was a tree-branch structure and supported cable broadcast services.

The first and second generation cable television systems utilized this structure to build increasingly complex cable operations. Even today this architectural approach remains viable for broadcast services which do not require future sophisticated control or service capabilities.

Services and Control: Requirements Variables

The evolution occurring in cable television is not driven by new techniques engineered in the many development labs represented here today. Rather, our engineering is driven by emerging revenue producing opportunities available to cable television; to be successful we must respond with cost effective, expandable, production solutions. The design variables seem simple: Services and Control.

Control

Early systems had little requirement for network control. The physical installation (on the pole) was seen as enough of an impediment to service theft. Quickly we learned the entire country was getting smart in the electronics field and there were many who would tap into the cable plant to pirate service. The industry's problem awareness in this area ultimately resulted in opening the door for computer/communications technologies to be applied in cable television control application; at this juncture cable television networks satisfied the fundamental criteria qualifying them as computer communications systems architectures: The physical and logical functions were separate/discrete network elements; physical facilities fell under logical device control; network electronics were active and functionally interdependent. With this development, system design rules had to be expanded to accomodate computer control; the basic tree-branch guide lines no longer applied.

Services

Initially, cable television services were comprised of off-air signals distributed via a quality carrier. This quickly led to inclusion of FM radio, distant TV stations and finally pay oriented events or services. For over two decades these services have been successfully delivered via tree-branch structures.

During the mid-to-late 70's the computer/communications fields enjoyed an explosive growth in system applications. Software based products were developed to address numerous commercial and service based applications. As previously noted, this growth first crossed into cable television in the system control area. The cable industry also began to recognize the potential these new control capabilities offered. They quickly translated the potential into new categories of service which could be offered via their existing cable plants.

Two major service types have been focused on since that time.

Enhanced video - Examples include:

Pay movie channels; teletext; videotext; interactive services for shopping, banking, etc.; video games; impulse purchase for video, services or goods.

Enhanced network - Examples include: Business data transmission; home security, fire, energy management, utility meter reading, telephone; cable plant management; interface subscribers to network services such as Dow Jones, Source, New York Times, etc.

System control considerations have satisfied basic computer/communications architectural criteria. New complex emerging services are resulting in expanded use of these structures. These factors require the design engineer to revisit basic network design rules and the methods for computer applications within them.

The Designers Tool Kit

The Cable Television design engineer has a more complex problem today than ever before. In new builds: Whats the most effective implementation with future expandability?

In rebuilds: How do we make use of the existing main plant and retrofit new technology to it? To answer these questions we must take stock of the tools at our disposal and various methods for applying them.

Central Equipment - Electronics located at the main operations center (Headend); for signal and data processing.

1) Headend - Various signal processing, encoding, control and transmission equipment.

2) Ancillary Controllers - Mini/micro computer equipment programmed to communicate with and control remote subscriber support electronics.

3) Data Processors - Various computer equipment used to process subscriber or network data; to support customer billing, viewer statistics or provide management reports.

4) Service Processors - Computer equipment used to provide subscriber services (fire, security).

Network Equipment - Electronics located at various points within the network; used for either signal or data processing.

1) Distribution Electronics - Amplifiers, taps, splitters, power supplies, etc., used to provide quality signals throughout the network (may be active or passive).

2) Hub Equipment - May include combinations of central equipment, network distribution and customer support or electronics.

Customer Support Equipment - Electronics located near or within the subscribers premises and which serves as the user interface to the network.

1) Converter Devices - Signal processing and/or digital control equipment which outputs appropriate T.V. signals.

2) Service Devices - Security, fire, energy management or interactive devices which support enhanced services and interface to network equipment.

3) Remote Controllers - Mini/micro computer equipment and/or any combination of converter or service devices; used to centralize functions, access and provide enhanced network operations.

Applications/Methods - To build an effective/expandable cable system architecture we must view the design problem in a layered approach. There are three major layers: Local distribution, plant distribution and network control, each layer has multiple secondary layers.

1) Network Control - The combined effect resulting from central computer to remote customer support equipment interactions. This layer is the most complex in the system design; depending on selected control methods it will exert major influence on both the local and plant distribution scheme. The over-riding concern in network control is to minimize message traffic congestion while reliably servicing all active terminations. Architecturally this leads to a decision on whether the control will be centralized or decentralized. Once this decision is made, options for operational control, device protocol, interfacing to customer support equipment and external environments can be selected.

2) Local Distribution - Connectivity from the main plant system to a subscribers premises. Two options exist: 1) Plant extension via main plant tapping or a loop through cable. 2) Plant extension via star (point-point) distribution; with supportive electronic devices for both options. Having selected the Network Control scheme to be used the decision on which option to use is relatively straight forward. The greater the requirement for enhanced services and their resultant increase in message traffic, the more applicable a star distribution becomes.

3) Plant Distribution - Connectivity from main signal source equipment to local distribution. Plant trunk cable and electronics options exist to provide quality signal source in varying applications; requirements are driven by local distribution interconnection parameters.

Centralized control methods are pervasive in today's cable television equipment marketplace; this is an outgrowth of continued development efforts which began in the early 70's. At that time, computer networks accessed terminals sequentially (polled) for information interchange. Industry vendors applied this technique in their systems to control rising concerns in service theft. The headend-located controller maintains an active device list and associated authorization data which is continually transmitted to remote devices. Early systems were extremely vulnerable to controller failures but are becoming more reliable with the remote terminals which retain program authorizations if the central controller fails. Even with their increased reliability centralized systems do not readily lend themselves to future evolution to support emerging services. This is due to their inherent requirement for transaction/control data to be funneled through the central controller.

Decentralized control is now making its way into the cable television equipment marketplace. This is resulting from applying computer/communications industry networking concepts to the CATV plant. The best current example is inclusion of non-volitile memory in centralized systems as an improvement to converter and system reliability; this is the essence of decentralization. However, when the remote equipment is sufficiently intelligent to control access and retain authorization without central controller interactions then why continue polling them? Following this through further, remote subscriber support equipment can be designed to have certain functions currently housed within the central controller. Further, new functions can be added to remote equipment which enables communications for emerging services.

Emerging Cable Television Systems Architecture

The elements at work in our technological evolution are:

1) Computers and communications for control and to support services.

2) Services to make new uses of the cable plant and increase per-subscriber revenue on multiple service levels.

3) Existing technology which we must accomodate until it has exceeded its useful life.

4) Equipment availability for production models which incorporate enabling technology.

As we have seen in our own industry as well as automotive, petroleum and many others, only an approach which embraces old methods while evolving to new ones can be successful. While it is feasible to implement a fully decentralized switched cable television system today most applications have existing technological constraints; only new builds can be designed with the most advanced techniques throughout. On the other hand, we must begin to evolve toward network structures which are expandable to meet the demands we already see on our horizon.

Currently, the major network component being developed by numerous cable industry suppliers is the remote controller device. Both on and off premises devices are taking on a Controller versus Converter profile: Digital electronic control, one/two way communications, local authorizations, impulse purchase and support for other emerging services. In their stand-alone application (set-tops) they provide increased reliability and enhanced services. When carried to the next logical step the electronics are housed in a common (Hub) location wherein support becomes less cumbersome. The more expensive electronics are shared by multiple subscribers and ultimate security is attained, without scrambling, because only authorized signals are outputted to subscriber receiving equipment.

Our industry, Cable Television, is entering a period of rebirth. A restructuring is occurring; in the way we operate, the systems which support our business, new programming methods and alternative services. All these focus on one objective: increase the revenue per network termination. With these ambitious goals, we are likely not to see a stabilization in equipment or services but rather a continued evolution to new ways of competing in the communications marketplace. Design engineers must turn to hybrid network implementations which employ advanced technology while accommodating their previous local distribution equipment.

Editor's Note: The author, then with Times-Fiber, completed this presentation too late to be printed in the 1983 NCTA TECHNICAL PAPERS--it is included here with the author's permission and his new address and affiliation.

FIBER OPTIC VIDEO SUPERTRUNKING
FM VS. DIGITAL TRANSMISSION

Robert J. Hoss, F. Ray McDevitt

WARNER AMEX CABLE COMMUNICATIONS INC.

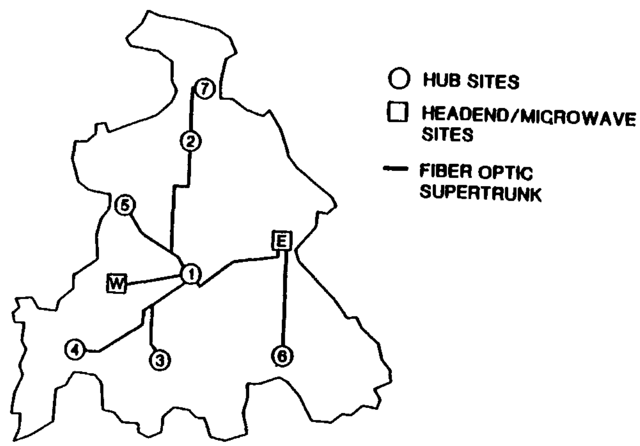
ABSTRACT

The rapidly evolving technology of fiber optics is providing many new options to the CATV systems integrator. For many years within the broadcast and CATV industry, fiber optics has provided short, single channel per fiber links for interference-free broadcast quality transmission. Not until recently has fiber optics become economical for video supertrunking. The ability to frequency and wavelength multiplex large groups of channels on a single fiber for repeaterless transmission beyond 10 miles has made fiber cost-competitive with coaxial supertrunk in certain systems. Advances in the fiber technology, with the introduction of low-cost single mode fiber, provide new cost and capacity advantages to the service provider. Although FM transmission on fiber is the lowest cost near-term approach, the projected introduction of low-cost digital encoders may make PCM transmission the future choice, particularly for long haul transmission.

The cost and performance of FM video transmission over multimode and single mode fibers is compared. Comparison with digital transmission is made. Test data will be presented to confirm analytical results.

THE PROBLEM

In today's larger metropolitan areas, a trunked hub architecture is generally employed for CATV video transmission. Such an architecture is shown in Figure 1 as conceived for the City of Dallas. Operationally, video programming originates from the headend(s) and is delivered to the hubs via microwave, coaxial, or fiber optic supertrunks. From the hubs, it is distributed to the subscriber over a conventional coaxial network. This supertrunk distance is generally on the order of 8 to 12 miles. As separate systems within a metropolitan area begin to merge through acquisition or business venture, a need for even longer, higher quality supertrunks arises for intersystems interconnect. Interest in data interconnect along with video is rapidly emerging. Fiber optics is evaluated here as a supertrunking means.



Fiber Optic Supertrunk Routing
Figure 1

APPROACHES

Three approaches to video supertrunking are evaluated:

a) Frequency modulated, frequency multiplexed, wavelength multiplexed (FM/FDM/WDM) transmission on multimode fiber;

b) FM/FDM/WDM transmission over single mode fiber; and

c) Pulse code modulated, time division multiplexed, wavelength multiplexed transmission (PCM/TDM/WDM) over single mode fiber.

The three approaches are illustrated in Figures 2 and 3.

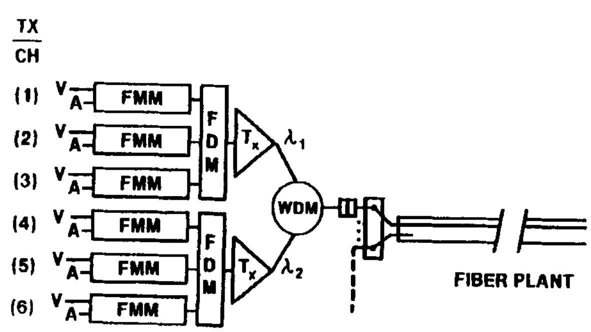


Figure 2

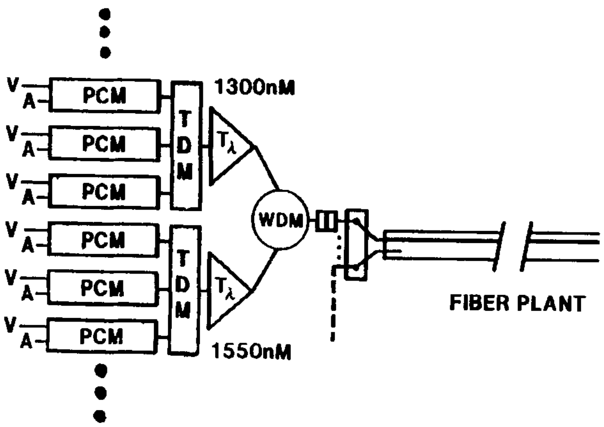


Figure 3

PERFORMANCE

Performance of a fiber optics link is a function of the received, detected carrier to noise (CNR_R) vs. the CNR required to achieve demodulated weighted video signal to noise (SNR_W). Received CNR_R is a function of received optical power (P_R) vs. noise introduced in the optical link by the source (modal noise) and the receiver. In general, therefore, SNR_W is affected by P_R. Since optical power margins are usually small (30 to 40 dB), encoding must be used to improve the CNR to SNR relationship.

FM/FDM

For FM modulation, wide deviation (8 to 10 MHz) is used to reduce the required CNR_R. FM improvement factors of 32 to 38 dB have been demonstrated. A CNR_R of 21 dB, for example, is shown to achieve a 55 dB CCIR weighted video SNR. Allowing for guardband, a 36 to 40 MHz passband is required. Optical receiver sensitivity (required P_R) at 21 dB CNR_R is the range of -36 to -32 dBm. FDM divides the available optical source power by the number of channels transmitted per wavelength and utilizes a transmission bandwidth which is, as a minimum, N x Bc, where N is the number of channels and Bc is the passband per channel. A 10-channel per wavelength system, therefore, requires 400 MHz BW.

Multimode vs. Single Mode Performance For FM/FDM

Multimode fiber has the following performance disadvantages over single mode:

Attenuation: .9 to 1.2 dB/km vs. 0.5 to 0.6 dB/km for single mode

Bandwidth: ≤ 1.6 GHz-km vs. multiple GHz for single mode

Noise: Multimode lasers and their interaction with multimode fibers creates a noise component which becomes a limiting factor; optical power penalties of typically 3 to 4 dB can be attributed to modal noise.

Intermod: Although single mode sources have linearity limitations, they are inherently more linear than multimode since stability of one mode is easier to control than that of multiple modes. Source screening may prove a low yield, high cost operation for multimode.

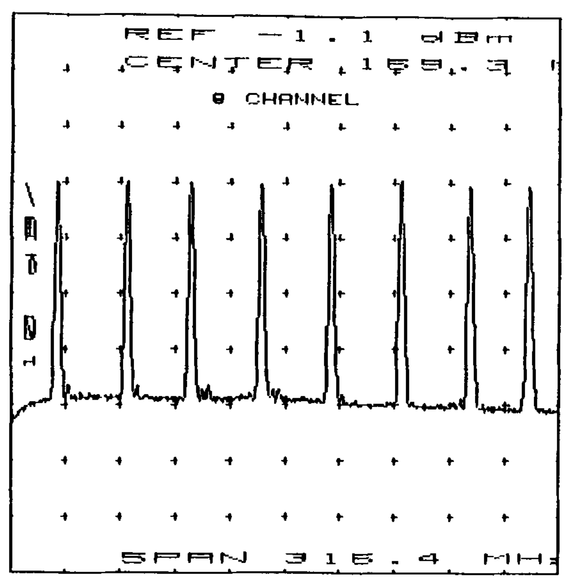
Table 1 gives the results of tests performed at Warner Amex which compares the performance of FM/FDM video trunking over multimode and single mode fibers. Multimode tests were performed over 16 and 22 km, and single mode over 20 km of cabled fiber.

Figure 4 shows the spectrum analyzer printout for 8 channels per wavelength FM/FDM over a 20-km distance.

Parameter	Multimode		Single Mode	
Mod/Mux	FM/FDM/WDM		FM/FDM	
FM Deviation	10 MHz		10 MHz	
Wavelength	1200, 1300 nm		1300 nm	
No. Ch/Fiber	4	6	6	8
Tx BW (MHz)	90	130	250	330
Tx Distance (km)	22	16	20	20
Tx Loss (dB)	25.6	21.1	11.5	11.5
Coupled Power (dBm)	-5	-5	-6.2	-6.2
Rcvd. CNR_e/Ch.	21	24	26	24
Typ. Intermod (dBc)	-30	-30	-42	-40
Video SNR_W (dB)	55	58	59*	59*

*Limited by FMM/FMD

Tests Comparing Single Mode To Multimode FM/FDM Transmission (Typical Values Shown)
Table 1



8 Channels Per Wavelength
Figure 4

PCM/TDM

The relationship between video SNR_W and number of PCM bits required is:

$$SNR_N = 6n + 10 \log \frac{fs}{b} + W$$

Where: n = Number of bits per sample
fs = Sampling rate
b = Video BW
W = Weighting factor

Note: $fs \approx 1.25 \times$ Nyquist Rate = 1.25(2b) to account for practical filtering

The data rate per channel is as a minimum:

$$Rc = Nfs$$

For a 4.2 MHz video bandwidth, therefore:

fs = 10.5 MHz (10.74 often used as multiple of color subcarrier)
N = 8
$Rc \approx 86$ Mb/s

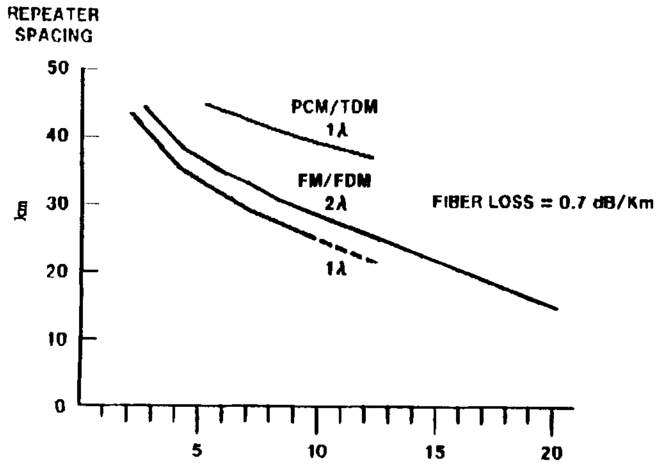
For TDM, the transmission rate is:

$$R_T = N(2nBb)(1 + \gamma)$$

Where: N = Number of channels
γ = An efficiency factor reflecting added frame bits for multiplexer and endcoder overhead and synchronization

If a 5% frame overhead factor (12/256) is assumed, the rate per channel is 90 Mb/s. If we assume scrambled NRZ encoding, then the minimum transmission bandwidth is $\approx R/2$. Bandwidth utilization per channel is, therefore, approximately 45 MHz or only slightly greater than that required for FM/FDM.

A key difference between FM and PCM is that for PCM, assuming few bit errors (10^{-7} to 10^{-9} BER), video SNR is a function of the encoding and not the transmission quality. The received peak signal to RMS noise to achieve a 10^{-9} BER is approximately 21 dB (or 15 dB average signal to RMS noise). This is a 3 dB optical power advantage over FM/FDM. PCM offers an additional advantage at repeaters where, with signal regeneration, degradation is negligible. With FM/FDM, approximately 3 dB optical power penalty per repeater can be assumed since video SNR is a direct function of received CNR above the FM threshold. Considering the above, intermod penalty, modulation depth, and noise bandwidth differences, the performance comparison is shown in Figure 5. Single mode fiber is assumed.



No. Of Video Channels Per Fiber
Figure 5

COST ANALYSIS

The analysis compares equipment cost only, assuming labor and construction are equal. Cost projections incorporated the following assumptions:

a) Current costs were based on actual quantity quotations or recent experience;

b) Projections were based on today's pricing for similar components where volume or maturity has influenced cost;

c) Transmission assumes video only: one video with companion audio per channel;

d) Fiber optics cost projections assumed:

- Fiber @ 35¢/m
- Tx/Rx @ $4,500/pr. multimode, $5,000/pr. single mode

e) FM/FDM assumes actual costs for existing hardware;

f) PCM/TDM projected costs assume:

- Encoder costs (video vs. audio) will achieve same price levels as FM
- High speed TDM will reach the $4,000 to $6,000 per pair range (includes shelf and power supply)

The results are shown in Figures 6 through 9. Route lengths of 16 km (10 miles) and 32 km (20 miles) are compared as to total cost vs. channel capacity.

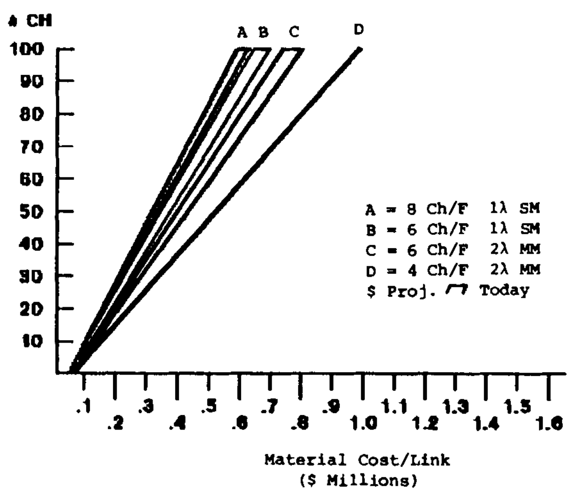
OBSERVATIONS

FM/FDM (FIGURES 6 AND 8)

For a 16 km route length, transmission on multimode is in practice limited to 3 channels per wavelength, i.e., 6 channels per fiber. Single mode transmission can achieve over 8 to 10 channels per wavelength at this distance. At only 8 channels per fiber, one wavelength, the single mode approach is 20% less than the best multimode approach (6 channels per fiber). In addition to the cost advantage, even at 8 channels per fiber, the single mode approach is not limited to 16 km repeater spacing. The excess optical power, the total absence of modal noise, and the low intermod of single mode results in much higher video performance, more capacity and longer repeaterless distance.

At 32 km spacing, the multimode system requires at least one repeater, while the single mode system does not. This results in a cost advantage for single mode of 40% at 8 channels per fiber (as compared with 6 channel per fiber, 2 wavelength, multimode).

Of interest to note is that multiple wavelength operation over single mode only has significant cost advantage for longer trunk distances. The logistic problems of maintaining two transmitter types may outweigh any small cost advantage for shorter distances.

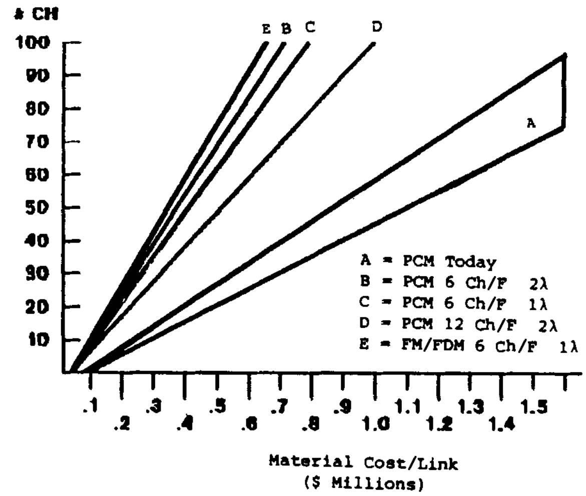


Single Mode vs. Multimode
FM/FDM 16 km Hub Spacing
Figure 6

PCM MODULATION (FIGURES 7, 8, AND 9)

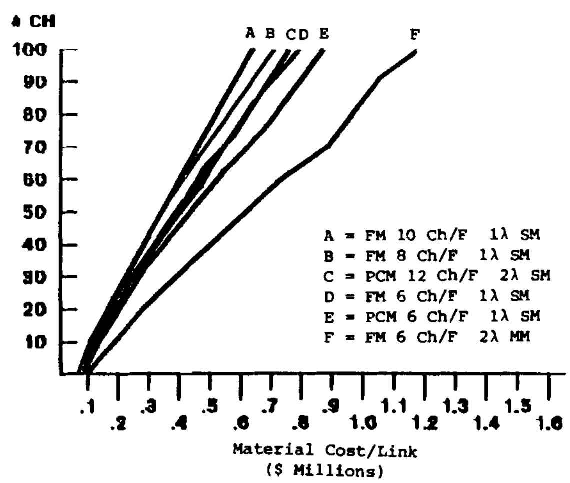
Figures 7, 8, and 9 illustrate the projected cost of PCM/TDM/WDM in comparison to FM/FDM. For PCM, today's cost is also reflected. Today's cost reflects linear encoding, single channel per wavelength operations as the lowest cost architecture available in product form.

What the figure shows is that for short trunks (10 miles), PCM at today's product costs is at best 2 1/2 times higher in cost than what can be achieved today with 8 channel FM/FDM. If we project PCM encoder cost to be equivalent to FM modem costs, 6 channels per fiber PCM/TDM becomes cost equivalent to only 4 channels per fiber FM/FDM. The difference is the TDM multiplexer cost.



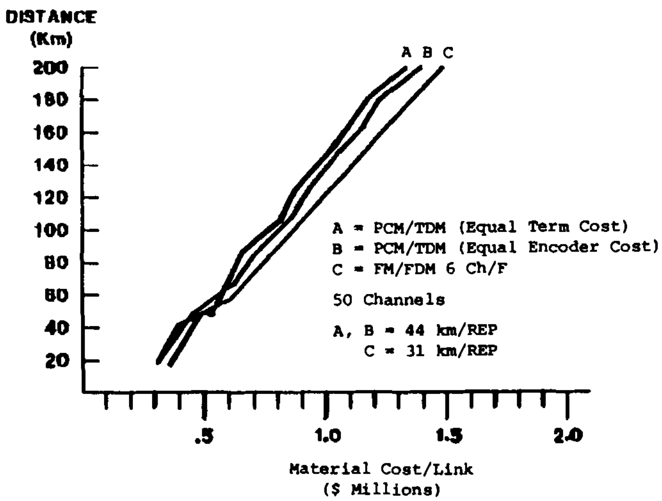
FM/FDM vs. PCM/TDM
16 km Hub Spacing
Figure 7

For PCM/TDM to compete with FM/FDM in metropolitan CATV networks, for example, the cost of a 6 channel video plus audio encoder/mux terminal end must be in the $10,000 to $14,000 range (excluding optics). This is true of the 16 and 32 km trunk distances. These costs are possible but not anticipated in the near term.



FM/FDM vs. PCM/TDM
32 km Hub Spacing
Figure 8

Addressing inter-LATA supertrunk distances beyond the 32 km range (Figure 9), PCM has a distinct performance advantage in its ability to be repeated with negligible degradation. The convenience of digital encoding and its ability to handle mixed service (video and data) makes it the preferred choice if and when costs come in line with FM. Figure 10 compares PCM to FM costs for long distance trunking at the 6 channel per fiber multiplexing density. Two PCM cost scenarios are presented: (a) equal encoder costs to FM modems, and (b) equal total terminal costs to FM/FDM. Using these assumptions, PCM is 5% to 10% lower in cost than FM/FDM, primarily due to longer repeater spacings assumed.



Long Haul Trunking
Figure 9

CONCLUSIONS

Where fiber optics is employed for supertrunking, FM/FDM incorporating single mode fiber, operating at 6 to 10 (or more) channels per fiber, appears the optimum solution for metropolitan area CATV video trunking. In order to be competitive, a PCM/TDM terminal pair with optics must achieve a cost below $4,000 per channel.

PCM is more advantageous for long haul trunking beyond 20 miles (32 km), although even here, today's costs render it non-competitive with FM.

FIBEROPTIC TRUNKING
THE REALITIES OF ACTIVATION, OPERATION, AND MAINTENANCE

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ABSTRACT

Lightwave transmission has been touted as a ready-made solution to many of the characteristic shortcomings of traditional RF networks. Immunity from EMI and RFI, signal theft resistance, extended bandwidths, high transmission quality, and lower active parts counts are among the virtues of fiberoptic systems.

This paper will show that through an understanding of fiberoptic's concomitant "unknowns" this type of system is no more difficult to operate and maintain. Actual operating data will be used to substantiate conclusions.

I. THE SELECTION PROCESS

Fiberoptics has been heralded as the answer to the future demands of broadband distribution. Few are unfamiliar with the advantages of lightwave transmission, but they bear repeating to persuade the remaining non-believers.

The most popular quality among interference-weary operators is fiber's inherent RFI , EMI and crosstalk immunity. It's totally dielectric (with the exception of metallic strength members, if any), thereby eliminating ground loops and various electrical code problems. Fiber lists tremendous bandwidth, low loss, easy upgradabilty and small physical size and weight among its attributes. It's impervious to corrosion and oxidation, doesn't require pressurization, needs fewer splices and active electronics. Needless to say, it's giving competing technologies a run for the money.

Obtaining frequency and path authorizations for a microwave link is becoming increasingly difficult, particularly in urban areas. Competition for spectrum in the previously exclusive CARS band has eliminated microwave as an option in many cases. FCC interaction is required, often delaying installation and activation of a microwave hop even if path coordination is achieved. Zoning, FAA, and building code restrictions may preclude placement of towers or antennas. If approvals are obtained, towers and leased antenna space are expensive and will involve other factors such as lighting, painting and accessibility problems.

CAFM is the other option available to the interconnect designer. Over short runs, involving few channels, conventional FM coaxial systems are very cost effective. However, a longer cascade may destroy the original logic. With an amplifier spacing of 2200 feet (2.4 amps/mile or 1.4 amps/km), 72 amps would be required to span 30 miles (50 km). Conversely, an equivalent fiberoptic system with "amplifiers" required only every 19,000 feet (0.28 "amps"/mile or 0.17 "amps"/km) would yield an 800% reduction in active line electronics; 9 "amplifiers" would do the job. The proportional increase in reliability brought about by reducing the number of potential failure points is a key argument. Additionally, conventional cascaded amplifier calculations can be applied to quantify the improved performance.

Granted, one coaxial cable could accomadate 10 CAFM channels, whereas 3 optical fibers are necessary to achieve the same capacity. But not all signals in the optical system would pass through the same amplifier as they would in the CAFM link; separate repeater modules are required for each fiber. This in itself also adds to the system's reliability; a failure of one repeater would not affect all the channels on the interconnect.

With all of these qualities and more, why has the CATV industry not totally embraced fiber? To be sure, lightwave transmission is an emerging "sci-art". There are many revolutions yet to occur in laser, detector, and fiber technology.

There are many lessons yet to be learned at the School of Hard Knocks by suppliers and appliers alike.

Designing and purchasing the optical system are only a few of the engineering manager's concerns. He's obligated to make it work day after day, beginning the day after the stuff is installed! And besides, they're ONLY a cable company, not a bunch of scientists. Where are they going to find the talent to maintain the system? Who can afford to hire MIT graduates for technicians?

In reality, optical transmission is no different from RF transmission. Most of the animosity towards fiber stems from "fear of flying"! The majority of the industry's technical cadre has not been exposed to optical technology--thereby breeding a dread of the unknown.

Many fiberoptics systems have frequency-division multiplexed RF as their input to the laser transmitter. Once modulated onto the light carrier, the signal is simply another form of electromagnetic energy and behaves similarly to RF. Light power loss and repeater spacing are still quoted in dB; carrier frequency and bandwidth in Mhz. It is well within the ability of most CATV operators to operate and maintain an optical system utilizing existing technical personnel. A well thought-out training program, good system documentation, and a minimum of additional test equipment complete the requirements.

II. BACKGROUND INFORMATION

Caltec Cablevision of Baltimore County, Maryland has, for the past eighteen months, been operating a fifty-kilometer optical trunking system. Over that period, a realistic approach to the operation and maintenance of the optical link has evolved. Designed in concert with Times Fiber Communications, the lightwave network links together four equipment sites. Figure 1 illustrates the routing and present channel loading of the system. An eighteen-channel FM microwave system provides the overwater tie-in between the West and East portions of Caltec's network.

Referring to figure 2, four wideband FM video carriers with subcarriers are frequency-multiplexed and applied to each fiber's optical transmitter. The transmitter intensity (amplitude) modulates a laser diode, its output being light in the near-infrared region, with a wavelength of 820 nanometers (nm) and a power level of no less than 100 mW (20 dBm). This energy is coupled into a 125 micron O.D. graded-index fiber with a

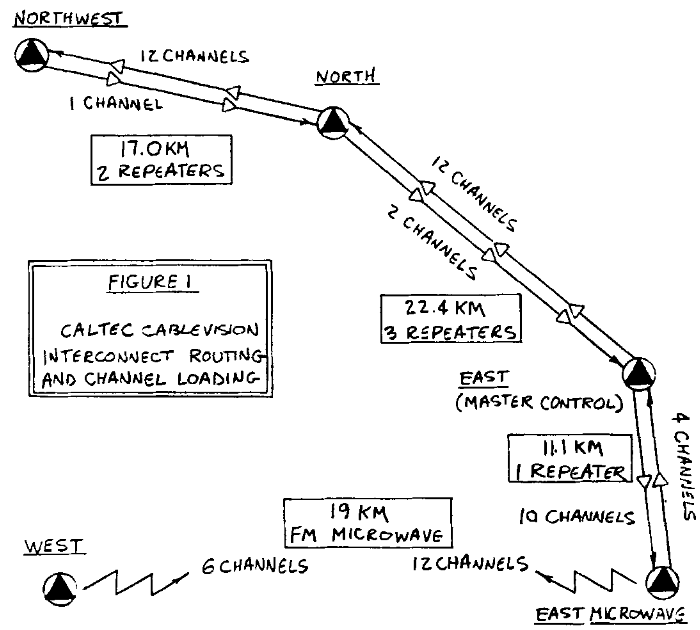

FIGURE 1
CALTEC CABLEVISION INTERCONNECT ROUTING AND CHANNEL LOADING

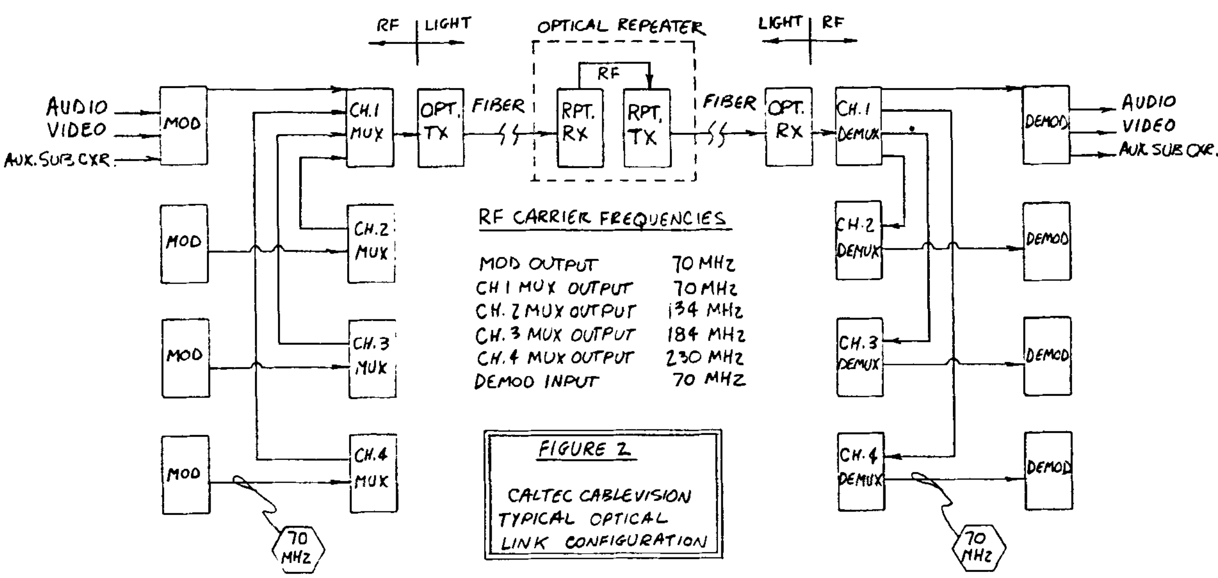

FIGURE 2
CALTEC CABLEVISION TYPICAL OPTICAL LINK CONFIGURATION

characteristic loss of 2.5 dB/kilometer (about 0.8 dB/1000 ft.). As in a traditional RF system "line amplifiers" or repeaters are required approximately every 22 dB of fiber (with allowances for splice losses and system margin), yielding a repeater every 6 kilometers.

Repeaters are essentially demod-remod stations; the light energy is brought back down to its original FDM-FM form, amplified, and reapplied to the input of another optical transmitter. This process continues until a terminal point of the system is reached. Here the signals are again "bumped down" to RF, demultiplexed and demodulated. Signals continuing on to the next site undergo the process again.

III. DESIGN CONSIDERATIONS

For the purposes of this discussion we will assume that the egg preceded the chicken. As such, no system should be specified until the requirements of that system have been determined.

A key parameter of any transmission link is it's insertion distortion. By what factor will a transported signal be degraded? What is the tolerable limit? For example, if the CATV system has a minimum video signal to noise spec at the end of it's longest cascade, what is the minimum required S/N at the input of the system (or the output of the interconnect)? Quality of transmission does not come without accompanying expense; it may be wise not to over-specify the system.

Cost tradeoffs can be made in the original design by including FM mods/demods that provide only the required improvement factors. Each channel's transmission bandwidth can be tailored to meet the target performance. Narrowband FM mods/demods could also be used for non-entertainment channels such as teleconferencing and monitoring.

The second consideration is channel capacity, both at present and in the forseeable future. No one has the foresight to predict channel demands with total precision. Fiber's relative ease of expansion can help soften the expense later. Initial installation of a spare fiber or two may be a prudent decision. Upstream channel requirements must be determined also. Provisions for additional remote feeds, monitoring channels and return data paths should be made.

Most optical fibers have two operational "windows" available. While present technology favors the shorter 850 nm components, cost-reducing developments in 1300 nm lasers, detectors and passives are occurring. Wavelength division multiplexing could be accomplished on existing systems using optical diplexors and two "colors" of laser light. The longer wavelength laser energy experiences a lower loss through the same fiber, thereby necessitating even fewer repeaters than the 850 nm links. The controlling factor at 1300 nm becomes one of available bandwidth; as wavelength increases, bandwidth decreases.

The fiber supplied by Times has a loss of 2.5 dB/km and 1.5 dB/km at 850 nm and 1300 nm respectively, while the passband narrows from roughly 800 Mhz/km to 500 Mhz/km. To determine the actual available bandwidth for a given length of fiber, apply this formula:

$$F_t = F_1 / 1+(N-1)^{0.5}$$

Where F_t = Total system bandwidth
F_1 = Bandwidth of 1 km of fiber
N = Fiber length (km)

The important concept to keep in mind is that the optical system possesses inherent expandability by virtue of its physical characteristics.

A package of spare equipment is part of any complex system. Each major component should have its counterpart held in reserve to permit rapid service restoration in event of a failure. Minimizing downtime of the network is paramount, particularly where revenue generating services are concerned. Determining quantities of spare equipment requires a careful analysis of the proposed system. Common elements in a link (those that effect all services on a particular fiber--laser transmitters, optical receivers, power supplies) should be stocked on-site in sufficient numbers.

Ask for the manufacturer's calculated reliability of the various components. Better yet, request factory service histories for actual in-service failure rates. Inquire about the turnaround time for such repairs, and other warranty information. Don't cut corners on spares! Their availability (or lack thereof) when needed will separate success from failure.

One proposed method of applying spare equipment involves installation of a spare fiber and "hot standby" optical components (laser, repeaters, receiver) on critical sections of an interconnect. This may seem frivolous, but service restoration after an optical failure becomes a matter of simply re-patching inputs and outputs at the terminal ends of a fiber hop. This may save time when compared to poleline troubleshooting.

IV. CONSTRUCTION AND ACTIVATION

One of the greatest areas for potential error is the physical construction of the system. While the techniques involved are straightforward and traditional, hanging and/or burying the optical waveguide and turning up the electronics involves careful planning.

Before the first centimeter of fiber is ordered, a diligent walkoff of the proposed route is mandatory. Hopefully, the manufacturer will have specified the number and spacing of repeater stations. Make every effort to situate repeaters in accessible locations! Just as trunk amplifiers are spared residence in backyard easements or on "suicide" poles that attract more vehicles than most, a repeater must be protected and reachable. If possible, avoid routing along roads that may preclude maintenance during specific hours. State and local authorities frown on a string of cones occupying a lane of roadway in the thick of rush hour. At the very least, insure that service vehicles can be positioned sufficiently out of traffic (perhaps on the shoulder or sidewalk) to guarantee the safety of service personnel.

Positioning of splice points is also very important. The splicing procedure is relatively time consuming and demands conditions other than mid-span over a busy intersection. If the system is to be installed in telco-type ducts with manhole access, and fusion (electric arc melting) splicing is employed, leave sufficient excess fiber to permit splicing above ground. Safety dictates that electric arcs are not discharged in potentially explosive environments! Once fused, the fiber can be coiled and placed in the manhole.

To allow optimum placement of repeaters and splices, varying continuous fiber lengths are assigned unique places in the link so their ends fall at predetermined locations. Taking the time to judiciously lay out the system will provide for easier installation and future servicing.

Actual installation of the fiber does not require special crews, and is within the ability of any conscientious crew using due care. The longer length of many pulls (averaging about 1 km each) is perhaps the largest difference. Fiber is not practically limited by the number of 90^{o} turns in any given pull. Due to its integral strength members, fiber is resistant to deformation by reasonable pulling forces. Its flexibility far exceeds that of any mainline coaxial cable. Aerial runs can be overlashed to existing lines; direct burial fiber is also available.

One form of insurance during the construction phase involves obtaining pre and post-installation optical TDR (OTDR) signatures. Similar to coaxial fault location, any initially defective fiber will be discovered. After installation, the absence of damage can be verified to everyone's satisfaction. System management should insist that manufacturer's representatives perform these tests.

Once on the poles or in the ground, splicing and connectorization can occur. The optical TDR is usually employed again to give a real-time indication of splice quality. Figure 3, a photo of an OTDR display, shows the signature of a typical 3700 meter section of fiber, after splicing. The "steps" on the trace indicate the loss of each fusion splice. There are four splices on this segment, with losses of 1.0, 0.3, 0.3 and 0.4 dB respectively. Design allowances for splice losses should not be exceeded. Fusion splices attenuate light energy an average of 0.5 dB per junction. The 1.0 dB splice in this fiber segment could be improved.

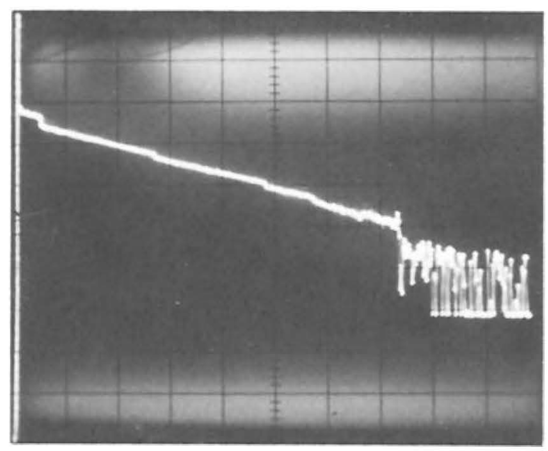

Figure 3

Figures 4 and 5 show two parallel fibers over a 2800 meter span. In figure 4, note the splice at 750 meters; it exhibits a 0.8 dB loss. The pip on the trace at 2550 meters indicates the presence of an air bubble created during splicing. In contrast, figure 5's splices at 750 and 2550 meters are practically invisible.

Splice points , once completed, are generally trouble-free and require no maintenance. Photos of each fiber's loss signature should be obtained and held on file for future reference. Connectors at fiber-to-equipment interfaces require special tooling to install; the skills are

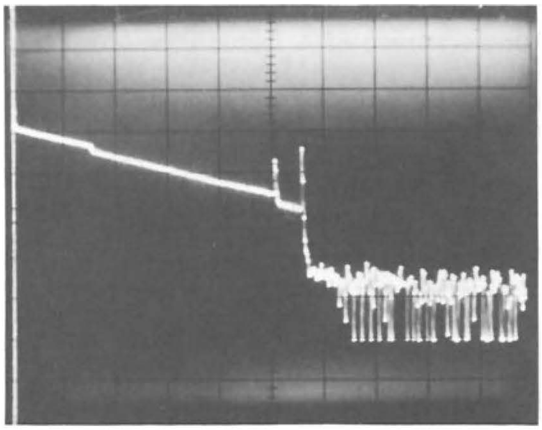

Figure 4

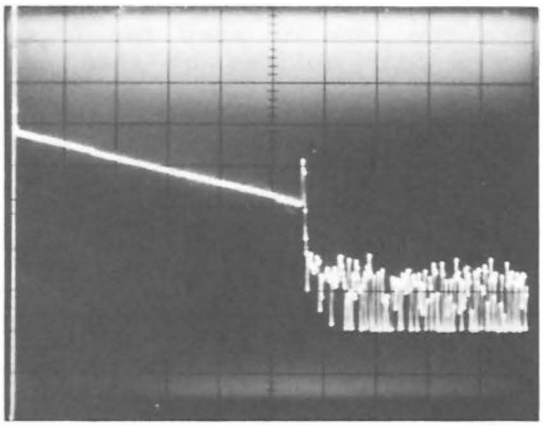

Figure 5

easily learned. System technicians should develop facility in connector attachment.

Once the fiber is spliced, the next step is the installation and activation of the system's electronics. Prior to placing any active component in the field, it is strongly suggested that each module be thoroughly bench-tested. Back-to-back tests of all components under laboratory conditions will save many an hour later. Aside from weeding out the few units that won't work, subtle departures from factory specs can be more accurately detected. Parameters such as optical, RF, and baseband level capabilities should be examined.

Another advantage of this pre-installation shakedown is that it allows most key operating adjustments to be made in advance. Prime examples of this are a modulator's deviation setting and demodulator output levels. Of course, thorough documentation of all tests is strongly advised.

In a large system, turn-up of the link's electronics will be largely the equipment manufacturer's responsibility. In theory, lighting up each link should be a matter of applying predetermined methods and getting predetermined results. Hopefully the vendor's field personnel will have the benefit of experience in dealing with the many unforseen problems that crop up in any technical undertaking. However, this is also the ideal time for the system's owner to get his technicians involved; the best lessons are learned through observation. Throughout the entire activation procedure, complete records should be maintained. This would include in-service spectral photographs of the various RF portions of a link as well as outgoing and incoming optical power levels.

Once in place and operating, each link should be proof-tested to verify compliance with manufacturer's and accepted industry specifications. Of primary concern are the link's video and audio transmission quality. Standard tests for gain vs. frequency, signal-to-noise, chrominance-to-luminance gain/delay inequalities, differential phase and gain, line and field rate anomalies, and general subjective quality should be conducted and documented. This information will prove invaluable as an index of system performance over an extended period. To reiterate, document the entire installation process from start to finish. Include summaries of various problems encountered, delays (if any), time and man-hours expended on each portion of the project (including fiber placement), and notes on procedures employed. After all, history is being made!

V. EQUIPMENT AND PERSONNEL

One statement from the outset--it's not necessary for optical technicians to have a degree in electro-optics. That would be helpful, and maybe with time key personnel will obtain such accolades. The technical manager will have to educate himself in the salient points of the system. But again, the optical trunk is nothing more than a souped-up RF system; many of the same principles are applied.

In all likelihood maintenance of the network will occur utilizing existing technicians. Usually, these people will have line or headend upkeep experience and will suffice quite nicely. What is required of these techs is an ability to grasp new concepts and master the use of a few new pieces of test equipment. Fundamental qualities should also include a good attitude and perseverance. Being assigned to work on a lightwave link should, and will be, viewed as a promotion and a new challenge.

So--what about training? There will be some new concepts involved. The laser transmitters, receivers and optical connectors will be the most notable items. It's incumbent on the technical manager to be familiar with these devices. By doing so, he can teach by example and anticipate the anxieties and questions of his staff. Proper instruction must be given in the fundamentals. Demonstrate how to attach fiber connectors, handle optical fibers, and set-up the various components. Develop their familiarity with the system's channelization and routing.

To assist these ends, it's recommended that either the vendor or technical manager prepare a Field Operations Manual that pertains specifically to the system as installed. Topics might include:

1. A system overview.
2. Safety considerations.
3. Step-by-step setup procedures.
4. Summaries of key specifications.
5. Reference charts and block diagrams.
6. A system map showing repeater locations.
7. A link summary listing pole numbers and locations of splice points and repeaters.
8. Emergency and preventive maintenance procedures.
9. The system's initial performance documentation.
10. Examples of any forms used for maintenance.

This type of document is infinitely more valuable to the field tech than the often highly technical manufacturer's equipment manuals. True, they will be a main source of information during compilation of the Field Operations Manual. Their relevance to the particulars of the system as it exists in operation are questionable. Each equipment manual usually covers a discrete component's circuit specifics and is of little value to the technician with system-oriented concerns.

Uppermost in management's mind should be the safety of its personnel. Low power solid-state lasers as used in communications systems are not inherently dangerous. The Times Fiber laser transmitters have all optical sources enclosed under normal operating conditions; no laser energy will escape with a fiber connected to the output.

As mentioned earlier, these devices are not necessarily harmful to humans. They won't burn through plate steel, much less skin. One should not tempt fate, however. The eye is not the proper test instrument to determine the presence or absence of laser light. The near-infrared energy will be visible as a reddish glow, and could potentially cause damage to the retina of the eye with prolonged or focused exposure.

No optical instrument (magnifying glass or microscope) should ever be used to view the laser in operation or the end of a laser-active fiber. Infrared viewers are available that convert the IR radiation to eyesafe visible light. These devices are relatively inexpensive (less than $1000) but not absolutely essential for maintenance.

To protect both the company and its lightwave technicians it is advised that all personnel directly connected with the operation or maintenance of the system have a complete eye checkup. This would include an ocular history, a visual acuity test, and an ocular fundus examination. The ocular fundus portion should record the specific qualities and pre-existing condition of the interior and light-sensitive tissues of the eye.

These tests should be conducted upon initial assignment, immediately after any suspected eye damage, and again after transfer to other duties. Records should be maintained for an extended period, possibly no less than 20 years.

Many states have laser safety regulations either on the books or under legislation. State occupational safety agencies will be able to "shed light" on the pertinent rules. Stress to each person associated with the system that all the rules in the world don't automatically create safe conditions. The employee must accept as much, if not most of, the responsibility for his on-the-job safety. It is management's role to educate their people about potential occupational hazards. It is the employee's duty to observe safety practices and report all injuries, actual or suspected.

Fiberoptic links require some additional tools and equipment to permit proper maintenance. They can generally be divided into two categories: the "would like to have" and the "must have".

The former classification would include the high-dollar instruments--fusion splicers and optical TDR's. Depending on the size of the network, it may be beneficial to have a splicer and OTDR handy for rapid restoration after a fiber break. However, this usually happens when motor vehicle and fiber-bearing pole or pedestal meet by accident! These types of fiber faults are easy to localize and can be restored more rapidly by installing mechanical connectors and a fiber "patch" until conditions are conducive to permanent splicing. Fusion splicing is an art and proficiency is rapidly lost if not done regularly.

In the event that the fiber does have to be fault-localized and/or re-fused, short term rental of the required instruments will be a more cost-effective solution. The system supplier should also have the resources to locate and repair fiber discontinuities available on an emergency basis. Charges covering per diem fees and expenses will no doubt be levied. Still, this beats tying up capital with purchases of seldom-used equipment.

Equipment in the "must have" category will be an RF spectrum analyzer, optical power meter, digital voltmeter, and connector installation tool(s). Remember, the lightwave system is fundamentally an RF system. A good spectrum analyzer will be the primary test instrument. There are several units available in the $7K to $10K range that will suffice. Most CATV systems have already found them to be invaluable for maintenance of existing plant and probably already own one.

Without an optical power meter all the tech can do is guess what his light levels are. True, some laser transmitters and companion receivers may contain built-in test points that provide a DC voltage indication of light power levels. These are prone to potential error, and do not necessarily guarantee that all the energy being developed by a laser is leaving the output port or reaching the receiver.

The optical revolution has spawned the appearance of many low-cost and easy to use instruments. A good optical power meter with input adapters and jumpers can be obtained for about $500. These usually provide indications in microwatts or dBu and may be ordered with detectors tailored to the wavelength of the system's lasers.

A digital voltmeter will be necessary to accurately measure various test point voltages, including power supplies. This meter should also preferably have dBm readout capabilities, which will facilitate setting baseband audio levels. Several manufacturers offer instruments with this feature.

Lastly, providing the necessary tooling to attach the optical connectors will complete the hardware requisites. Today's connector is distant from those of yesterday that demanded precision polishing and epoxy to affix. The connector selected by Times requires only a single tool to cleave the fiber end at the proper length. It may be prudent to purchase a spare tool in the event that one is misplaced or damaged. The optical connector is perhaps one of the most frequently replaced items in a system; to be tool-less is to be vulnerable!

VI. OPERATIONAL PROCEDURES AND DATA

After the system is installed, activated and tooled, emphasis shifts to the long-term concerns of maintenance, both routine and emergency. Routine service is comprised of equipment set-up and preventive maintenance procedures. Emergency or outage restoration techniques must also be addressed.

The Field Operations Manual will be where these procedures are detailed. The manufacturer's equipment manuals will be a good reference here, but the accent is on short, clear, concise no-frills directions. During compilation of the manual, include only the information necessary to perform each operation. Define nominal test point values, alarm light indications and operation of controls.

The value of preventive maintenance has long been recognized in CATV. It certainly applies to a complex interconnect network, regardless of the mode of transmission--but it especially applies to the optical system. Conducting routine PM checks is one of the best ways to guarantee the longevity of the system's performance as well as educate technical personnel in its care and feeding.

Determine what parameters should be checked on a cyclic basis. RF and light levels, test point voltages and dynamic standby power tests (if any) should be logged on prepared forms. Data from each set of tests must be compared to help detect any changes in performance. An initial test interval of every two weeks is suggested until familiar with the system's idiosyncrasies. After that, dropping back to every three or four weeks will probably be acceptable.

Service restoration after an outage is largely a matter of common sense and traditional troubleshooting techniques. The technician must be aware of the system's channelization and routing so as to be able to interpret the clues of a system failure. If status monitoring is part of the network, fault location is made even more clear-cut. Procedures to be followed during an outage should be included as part of the Field Operations Manual. A periodic review of all procedures, both routine and emergency, will keep them relevant as more experience is gained.

The question on everyone's mind is one of reliability. It's evident that over longer distances fiberoptic systems require fewer active components. But does this translate into a higher level of dependability? Unfortunately, it's difficult to make an apples-to-apples comparison between a true RF supertrunk and its hybrid RF-optical counterpart. There are many differences, not only in the total number of electronics "on the pole", but in the number of channels affected by each failure of the system.

Caltec has tracked system outages informally since the network was activated. In October 1983 a formal procedure was initiated whereby a System Failure Report (SFR) is generated whenever an outage occurs. Using these SFR's for a representative 160 day period, the following analysis was made regarding the fiberoptic trunk.

There were a total of 17 failures summing 40.5 hours during this 3840 hour span. This yielded a total system availability factor (when the optical interconnect was functioning 100%) of 98.95%. The mean time before failure (MTBF) of any component was 225.9 hours. The mean time to repair (MTTR) any outage was 2.4 hours. Outage duration ranged from 15 minutes to 8.5 hours, depending on the time of day and severity of the failure. The tech's location on the "learning curve" also influenced this statistic.

The optical components (laser transmitters, repeaters, optical receivers) failed twice, for a total of 9.5 hours. This resulted in an optical availability factor of 99.75%, an MTBF of 1920 hours, and an MTTR of 4.8 hours. Again, the average duration of each of these outages can be attributed to time of day, location of failure, and technician's skill. Considering that these two failures represent the total of all outside plant problems, this is an acceptable figure.

Surprisingly, the so-called tried and true RF components turned in the lowest availability factor; 99.47%. These devices, however, are the most numerous in the system. A total of 9 RF outages (20.3 hours) produced a 426.7 hour MTBF and a 2.3 hour MTTR.

The other major category of equipment is power supplies and connectors. Here, 6 failures totalling 9.1 hours gave an availability factor of 99.72%. The MTBF and MTTR were 640 hours and 1.5 hours respectively.

A total of 41 channels are carried between the four sites served by the optical trunk. Figure 6 shows the distribution of the number of channels affected by each outage. Outages disabling 1 and 2 channels were the most numerous; 6 each. Failures affecting 4, 6, or 8 channels numbered 1 each. Finally, 9-channel outages were 2 in number. A typical outage on the fiber will affect fewer channels; not all channels pass through the same active device as they would in an RF trunk.

Across the extensive nine-site Caltec headend complex, the fiberoptic system accounted for 13.9% of the total outages. Total preventive maintenance time on the light-net during the 160 day period was 128 hours. This, added to the 40.5 hours that the system was "outage-afflicted" resulted in a total manpower commitment of 168.5 hours, or a little over 1 hour per day.

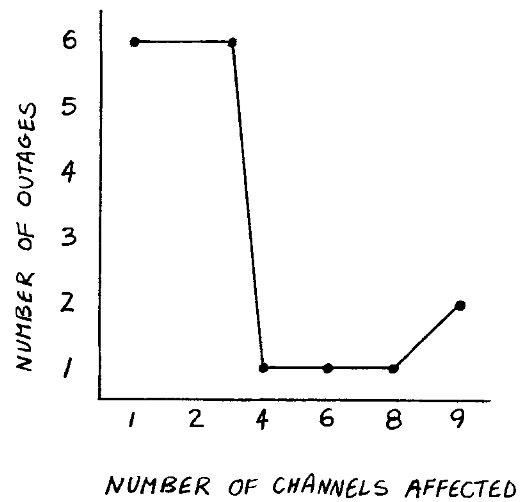

Figure 6

VII. SUMMARY

The fiberoptic system is not an unmanageable entity. It is not bred of strange and exotic stock. Any CATV operator able to make the commitment to personnel development, test equipment, and assiduous maintenance techniques will be successful with fiberoptics.

The future is here now! Gain experience with optical systems. Read up on advances in technology and applications. Light is indeed communication's "new wave".

GUIDE TO PLANT ANALYSIS
INCREASING CHANNEL CAPACITY OF A C.A.T.V. SYSTEM

Paul D. Brooks

GENERAL ELECTRIC CABLEVISION CORPORATION

ABSTRACT

The major technical considerations of increasing channel capacity are outlined. Priorities are indicated with respect to performance and cost factors, and a guide to decision making is presented. This discussion is limited to the section of the plant between the headend and the subscribers tap port.

INTRODUCTION

The reasons to increase channel carriage of a C.A.T.V. system are well known in the industry. Reasons such as franchise requirements, desire to add revenue-producing programming, or simple modernization of outdated and expensive to maintain plant. To increase capacity, must all the plant be replaced? If not, then what portion should be retained? To find the answers, we must keep in mind two prime considerations: delivery of a reliable quality product, and keeping required investment and operating costs to a minimum. Other important issues are compliance with franchise and FCC regulations, and service to the community.

OBJECTIVES

The most expensive item in a rebuild is cable materials and labor. If existing cable can be used, it will result in significant cost savings. It is also a big advantage to retain existing trunk amplifier locations, so that channel capacity can be increased with a minimum of service interruption to the subscriber. Picture quality, of course, must be maintained at the worst case subscriber. With any type of service upgrade, this is the first consideration. A retrofit is often the most cost-effective way to increase channel carriage while retaining picture quality.

METHOD OF ANALYSIS

To determine if some type of retrofit is practical, it is necessary to take a careful look at the plant. This is best accomplished through separate analysis of four main catagories:

1. Cable Evaluation: type, age, and condition of existing cables need to be examined first because of the large cost impact.

2. Trunk Evaluation: distances, cascades, amplifier spacings - these factors will set the limits on performance.

3. Distribution Evaluation: intimately related to trunk evaluation, this catagory is important because of cost and ease of maintenance.

4. Existing Equipment: often a first priority, usability of existing equipment is best determined after analysis of the previous three items as presented here in logical flow chart form.

CABLE EVALUATION

The first chart (Fig. 1 - Cable Evaluation), will help to answer three main questions:

1. Does existing cable make a retrofit a poor choice?

2. Will existing cable limit usable bandwidth?

3. If cable types and ages are mixed, will some cable need to be replaced?

To evaluate existing cable, first it is necessary to determine the ages, types, and the manufacturers specifications. What is the history of replacement? Each type of cable needs to be looked at separately.

If a significant or increasing percentage of a given type has been replaced, does the type being replaced still comprise a majority of the plant? If so, a rebuild is indicated. If not, replacement of the remainder would be proposed. If the replacement history is spotty and amounts to a low percentage, the type of cable involved should be considered. If this type is outdated (i.e. styrene foam dielectric, corrugated or braided sheath), replacement would be proposed, or if this is the majority of plant, a rebuild would be called for.

If very little or no cable of a given type has been replaced, it is then necessary to look at the age of the cable. Older types, with solid polyethylene or chemically-foamed polyethylene dielectrics, are probably usable to about 35 channel capacity. Cable of medium age, with gas-injected polyethylene or earlier air dielectrics, can typically be used up to about 40 channels. More recent types, such as low-loss versions of gas-injected polyethylene and improved air dielectric cable, will have capacities in excess of 40 channels. If all cable for which replacement has not been proposed is one of these recent types, the cable evaluation is completed. If not, then does the existing cable meet the bandwidth requirements? If not, a rebuild is indicated.

If the needed bandwidth seems attainable with existing cable, this cable should then be tested in the field. To accomplish this, select several long; uninterrupted samples of each age and type to be retained. Each sample is then tested for attenuation and structural return loss across the proposed bandwidth. If the samples show substantially higher loss than the manufacturers specs., then a rebuild may be required. If the samples do not exhibit acceptable return loss across the required bandwidth, then perhaps the proposed bandwidth can be reduced, or if it cannot, a rebuild is indicated. If samples pass both attenuation and return loss testing, the cable evaluation is complete.

TRUNK EVALUATION

The second chart (Fig. 2 - Trunk Evaluation) addresses three issues:

1. Are additional hubs required?

2. Can existing trunk cable be used?

3. What are the optimum operating levels?

To evaluate the trunk layout, it is first necessary to determine the service area boundaries. Expected growth areas within the period of the franchise and plant lifetime should be included. Then it is possible to determine the maximum trunkline mileage from existing headend or hubs along potential trunk routes to the extremities of the service area. With this distance in mind, can practical trunks be built to serve these areas and meet the required end of line specifications at the proposed bandwidth? A negative answer to this general question will quickly indicate the need for additional hub sites with attendant high-performance coaxial, fiber optic, or microwave interties. If service area extremities are within potential trunk reach, a map of the existing trunk layout needs to be examined. In many cases it will be necessary to create such a map. The trunk map and information previously determined about cable types will allow the trunk spacing to be determined at the highest existing operating or design frequency. In cases where spacings are difficult to determine, or if determined spacings appear to be erratic, then some field work is required. A technique that answers the spacing question and can also yield a lot of other valuable information is to measure the inputs and outputs at each trunk amplifier in the system. The results of such a study can be used to check the trunk map, indicate bad cable and equipment, and spot bad design and construction. Sometimes it also makes sense to set amplifier output levels as system technicians measure their way out into the trunklines.

Once existing spacings are determined, they can be converted to dB at the highest frequency needed to pass the proposed bandwidth. Now it is possible to examine the option of use of existing trunk amplifier locations. Determine maximum trunk cascade using the trunk layout map. Be sure to include growth areas. Establish the required distribution cascade. Use manufacturers performance specs to optimize equipment operating levels for maximum system reach at existing trunk spacings and required end-of-line performance. Is the worst case trunk cascade within system reach? If not, perhaps lower loss cable can be installed to shorten trunk spacings and improve system reach. The operating levels again need to be optimized to find out if this technique will work. If changing trunk cable is not pracitcal, can trunk cascades be shortened through re-routing or use of "interceptor" trunks? Here again, levels must be optimized at the proposed shorter maximum trunk cascade to determine if this is a viable alternative. If neither of these options alone or in combination will work, then it is necessary to start over again by selecting proposed hub sites and repeating the trunk evaluation. When the final choices have been made, the operating levels can be re-optimized to result in the best performance at the worst case subscriber.

DISTRIBUTION EVALUATION

The third chart (Fig. 3 - Distribution Evaluation) will help to answer three questions:

1. Can line extenders and passives remain in their present locations?

2. Is additional trunking required?

3. Is additional distribution cable required?

To evaluate the distribution section of the plant, first select several trunk amplifiers as samples. Use a sufficient number of samples to represent a cross section of different subscriber densities, trunk depths, design specs/philosophies, and system ages. Redesign each sample at the proposed bandwidth. Use existing line extender and passive locations, changing only levels, gains and tap values. Can sufficient signal be provided to all subscribers? If so, the distribution evaluation is complete. If not, redesign samples using new equipment locations and additional cables if necessary. If the samples can be fed without excessive use of new cable, again the evaluation is complete. If not, can new trunks be built into these areas without creating spacing problems in the "backbone" trunk? If spacing problems come up, return to the trunk evaluation and see if spacing problems can be resolved through use of larger or lower loss cables. When a method of new trunking has been established, the following comparison can be made. Redesign samples using additional distribution cables, and redesign the samples using new trunks. Estimate the cost of each option. If new trunking is cheaper, then it becomes the method of choice. If additional distribution cabling is cheaper, does it result in a complex and hard to maintain layout? If so, new trunks should be used. Analysis of each sample can result in a different conclusion, and the preferred solutions may vary in each situation.

EXISTING EQUIPMENT

At this point, cable has been looked at, design problems have been worked out, and operating levels, spacings, and required equipment performances are known. Now choices can be made regarding replacement, upgrade, and retention of the components of the outside plant.

1. Actives. Trunk amplifiers, bridgers, and line extenders are of principal importance. In general, existing actives are not adequate for increased channel loading. If the gear is of recent vintage, many manufacturers offer replacement plug-in modules with improved performance and higher gain ratings. Modification kits are available in the aftermarket to upgrade performance and increase gain of existing modules. If the highest performance is a must, then feedforeward technology or power doubling amplifiers could be the answer.

2. Passives. The existing splitters and directional couplers must be able to pass the required number of channels. The original manufacturers spec. sheets will indicate the bandwidth of these passives. Directional taps must also be able to pass the required number of channels. Many modern taps are of modular construction, and will allow the tap value to be changed without re-splicing. Some manufacturers offer replacement modular plates designed to pass wider bandwidths.

3. Connectors. Existing connectors must be mechanically sound, and have sufficient shielding to prevent signal leakage. They must also have high enough return loss to reduce reflections. If connectors need to be changed, the additional splicing labor may negate the cost advantages of retaining existing passives and taps, particularly if these devices are of borderline or questionable performance.

4. Powering. Existing power supplies must have adequate current ratings. If selected amplifiers require more power, or if greater numbers of amplifiers will be used, the powering layout should be checked. Replacement or conversion of 30 volt supplies to 60 volts will often eliminate the need for more supplies at new locations.

PERFORMANCE CALCULATIONS

The practical mathematics of performance prediction, although not overly complex, can be difficult for non-engineering personnel in management and technical positions at the system operations level. Fortunately, many electronics manufacturers are happy to provide assistance in operating level selection and determination of end-of-line performance.

SUMMARY

Hopefully this guide will help to sort out the technical and economic issues of channel expansion. Attention to a few simple rules will result in better allocation of financial resources and produce a cable system with dependable performance that will be a good revenue producer for years to come.

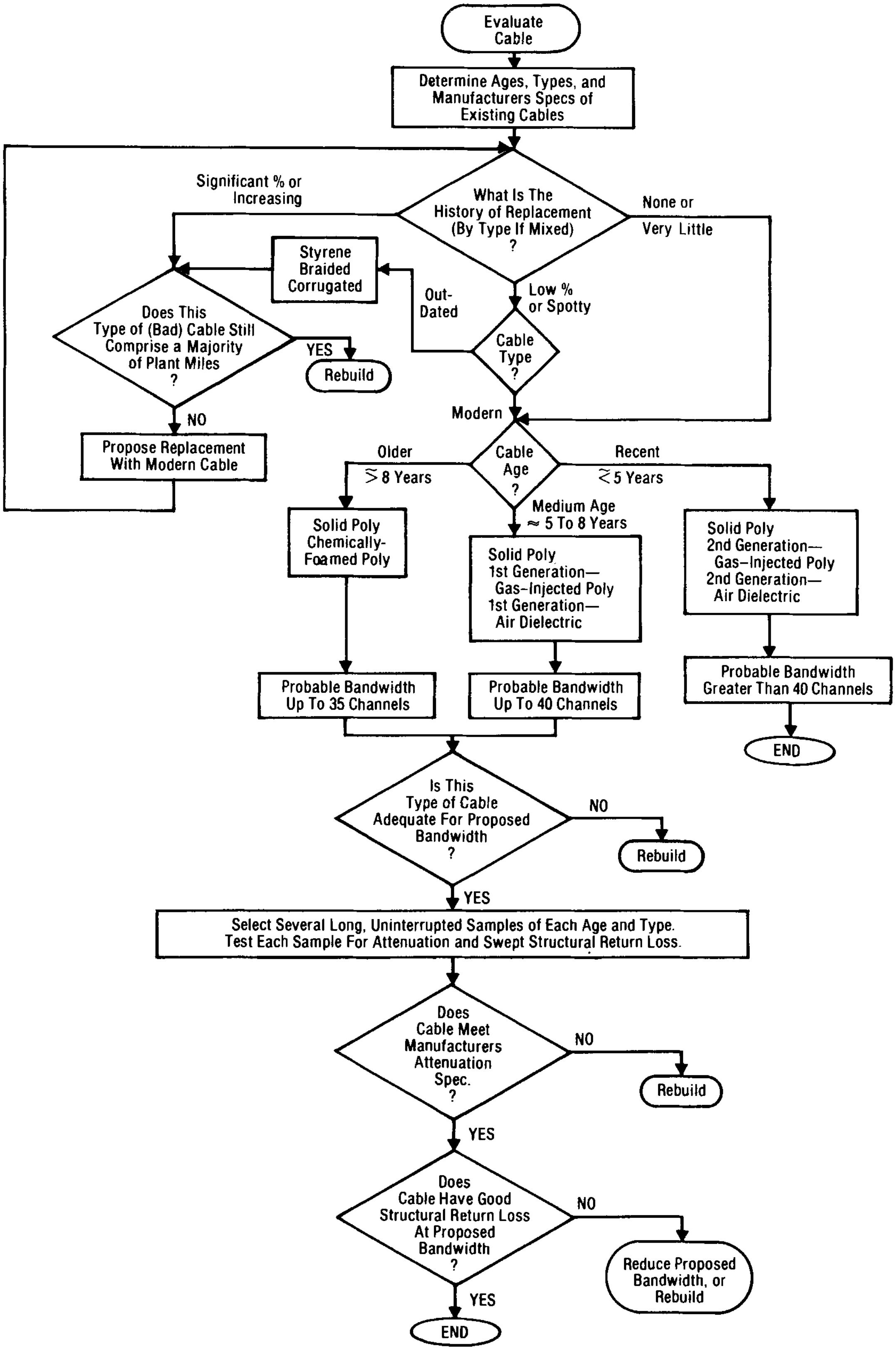

FIGURE I. **CABLE EVALUATION**

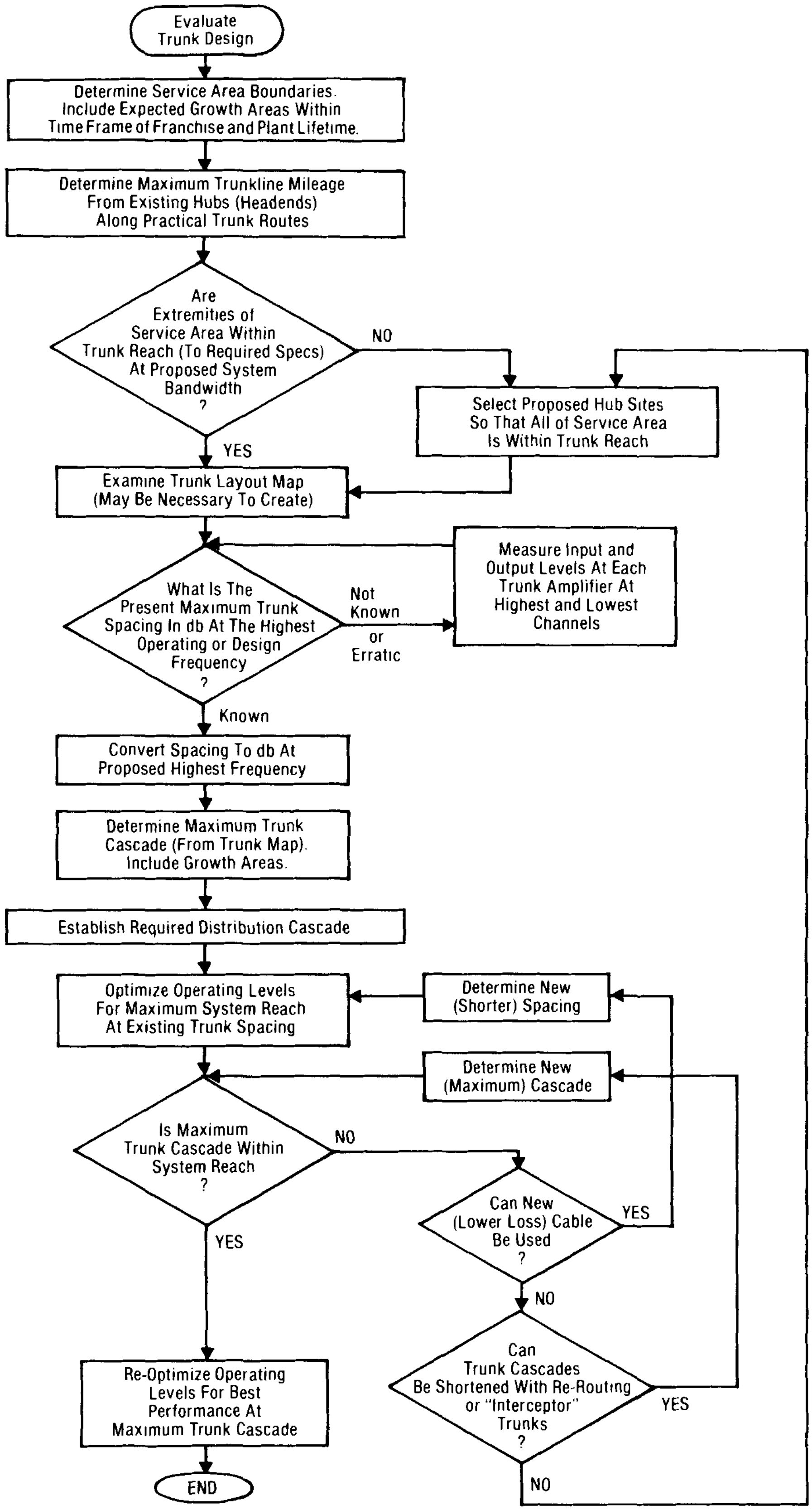

FIGURE 2. **TRUNK EVALUATION**

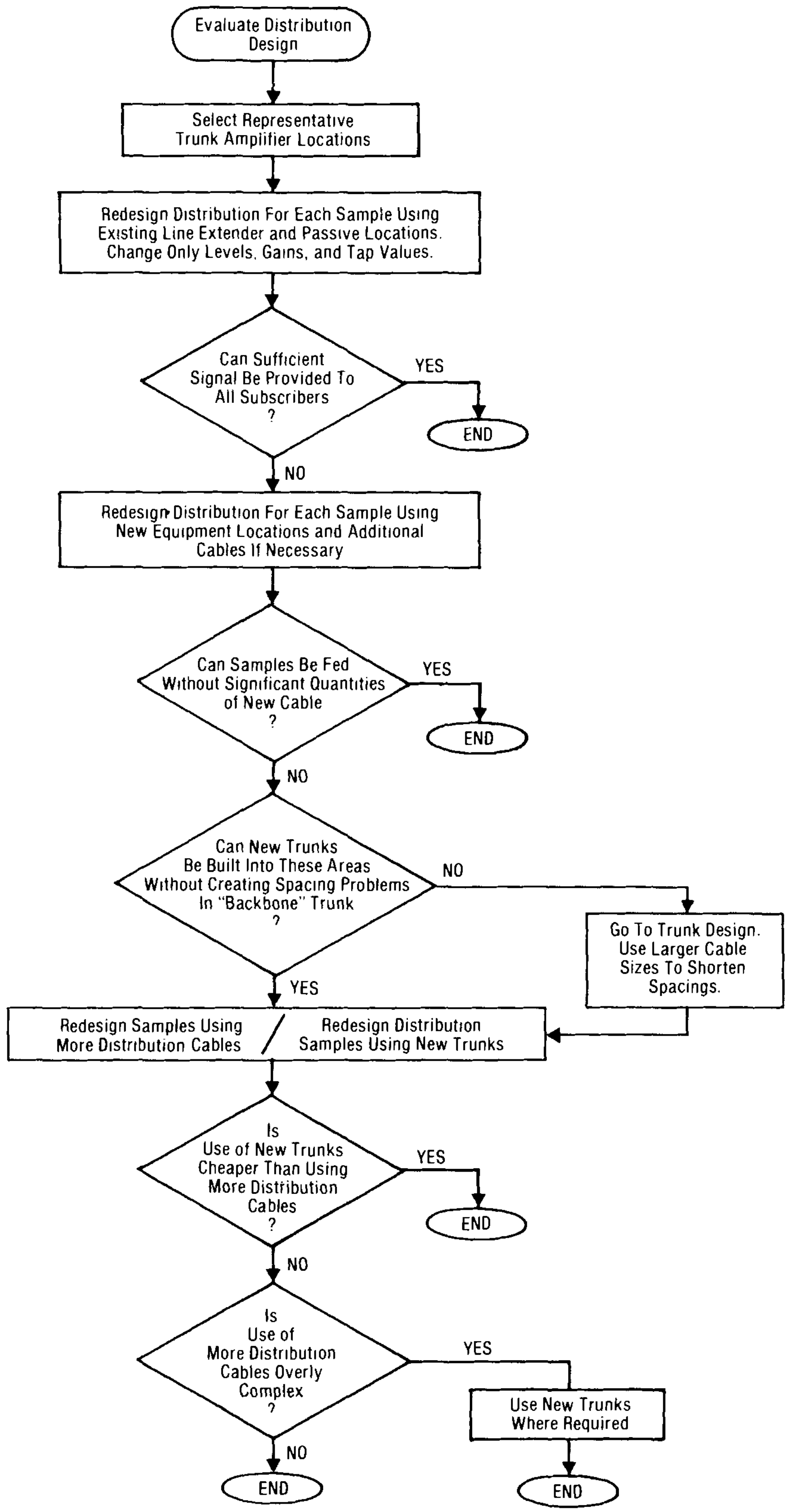

FIGURE 3. **DISTRIBUTION EVALUATION**

HYBRID ADDRESSABILITY -- A HYBRID COMBINATION OF OFF-PREMISES AND SET-TOP ADDRESSABLE EQUIPMENT

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ABSTRACT

Cable systems in metropolitan areas require addressable technology which satisfies the requirements for secure distribution of pay-TV signals simultaneously to both high-density areas and to individual residences. To date these differing needs have been filled separately by off-premises equipment (for high-density areas) and addressable home terminals (for individual residences).

This paper describes the system considerations for a hybrid addressable system optimized for both environments. Several alternative hybrid system arrangements are described, and based on discussion of their relative merits, a specific hybrid system is proposed. The proposed system merges the best operational and security features of both home-terminal and off-premises systems.

INTRODUCTION

Addressable technology is now firmly established as the means of delivering multi-tiered pay television services to cable television subscribers. There have been two recurring themes in discussions of the technology employed for addressability: security and in-home versus remote equipment.

Security

Security has become of paramount concern as the industry has found itself deprived of revenues by organized piracy - the marketing to the public of every conceivable way of circumventing existing control systems. Operators and equipment manufacturers have recently joined forces to specify and develop a level of security to thwart even the most technically sophisticated would-be pirate. The state of the art in highly secure scrambling methods is represented in the encrypted digital-audio technique employed in the Oak Sigma™ system (Figure 1).

Scrambled video is employed in the Sigma system, wherein complete horizontal and vertical synchronous pulse removal (as opposed to synchronized pulse suppression) is performed. Two channels of audio are digitized, encrypted, and embedded in the video. Two separate control channels are used: 1) a global FSK-modulated channel which all decoders continuously monitor and 2) an in-channel vertical blanking interval (VBI) data path which is channel-specific. The first contains general authorization and system-oriented control data, the second, program-specific data relevant to a given channel and time.

Separate service encryption keys are used for each channel and the keys are continuously varied. A multi-level key distribution system is employed in which

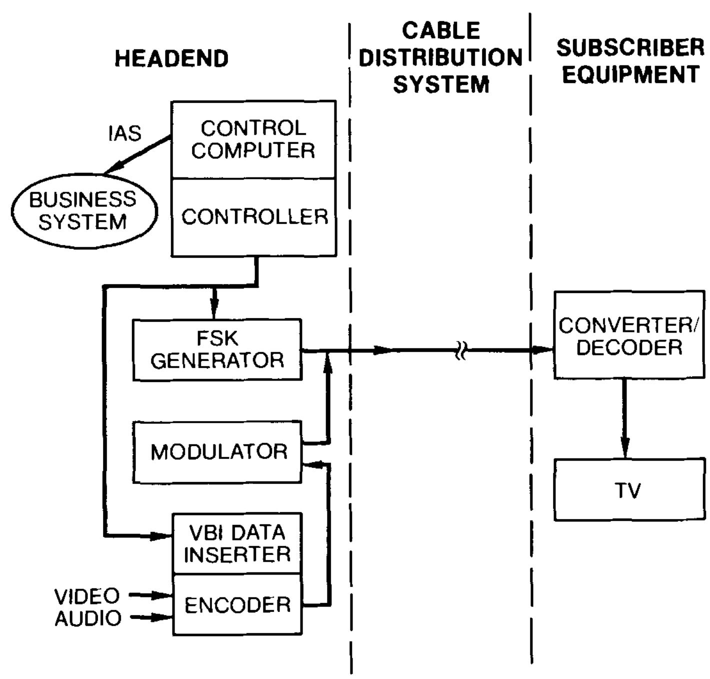

Figure 1. Sigma Home-Terminal System

three key variables are used. These include a box-specific key which is secret and unique to each box (unknown even to the system operator); a variable, second-level key common to all legitimate subscribers; and the service keys. Solid-state nonvolatile memory is used in the Sigma decoder to store key and authorization information (encrypted while stored). Each box also has a non-secret box address which is its addressing identification used by the headend computer to communicate to the box.

Off-Premises Versus Home-Terminal Equipment

Off-premises versus home-terminal equipment (HTU) for addressable control has been widely discussed. Off-premises systems have been developed to remove decoding equipment from the subscriber's home and to control availability of premium channels prior to delivery to the subscriber's premises. The Times Fiber Mini-Hub™ II (Figure 2) is an off-premises addressable converter system which secures pay programming by denying all but a subscriber-selected (and system-authorized) channel from entering the subscriber's home. Mini-Hub is a microcomputer-controlled local distribution system designed to provide cable television and other services for high-density urban areas.

Flexibility is provided in the Mini-Hub II off-premises switching unit through its capability of using a single drop cable to feed multiple television sets, each with its own subscriber interface unit (SIU).

Until recently no single comprehensive solution has been available to address the need for secure delivery of pay signals to the mix of multiple- and single-dwelling construction encountered in most metropolitan areas. This paper examines several alternative methods of satisfying this need, and proposes a specific hybrid system architecture.

ALTERNATIVES FOR THE OVER-ALL HYBRID ADDRESSABLE SYSTEM

The criteria considered in evaluating alternatives for a hybrid addressable system are:

- Number of distribution cables required
- Ease of control and business computer operation
- Capacity for premium channels
- Degree of security
- Cost

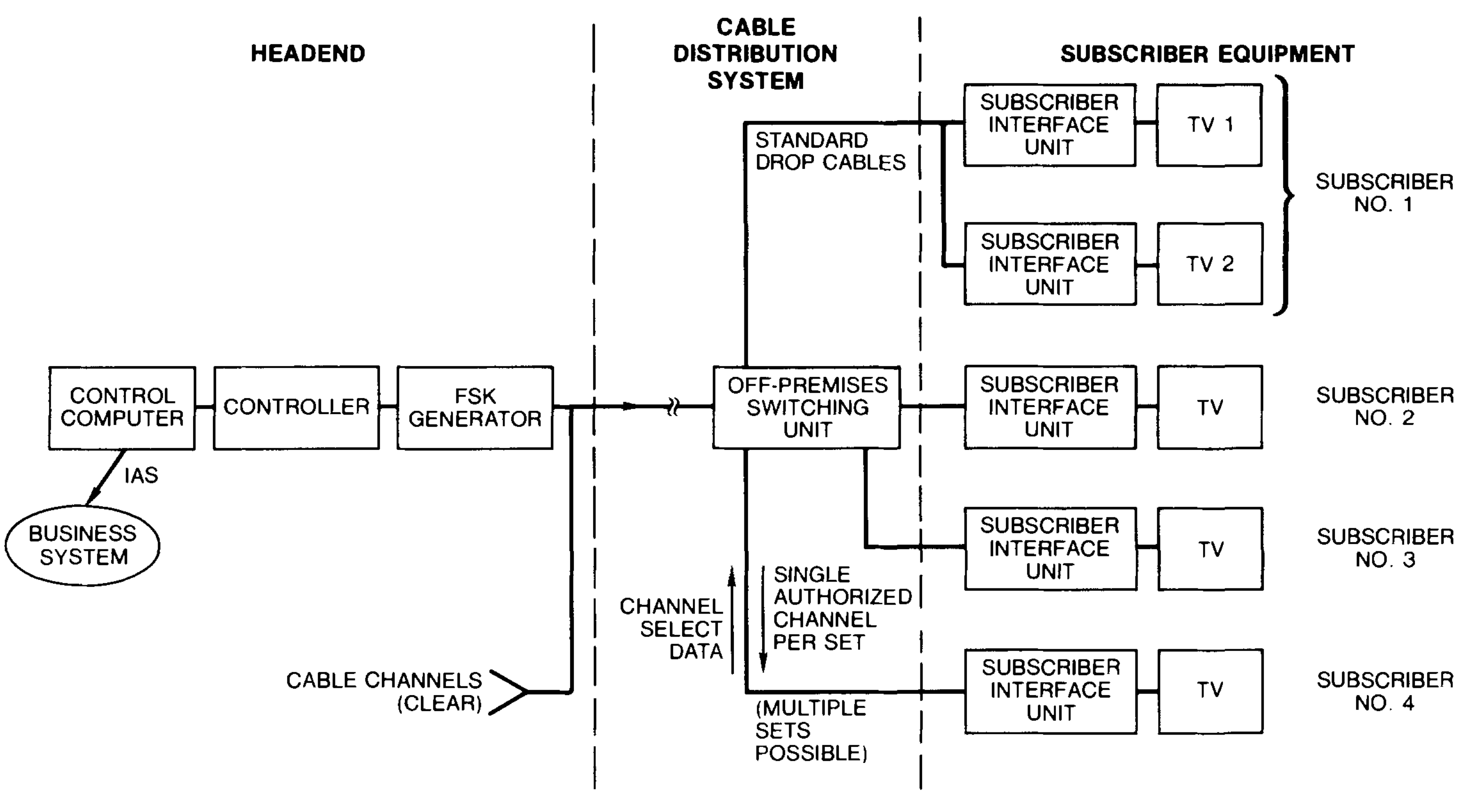

Figure 2. Mini-Hub Star-Switched Off-Premises System

The simplest way, conceptually, to employ both off-premises and home-terminal addressable methods would be to provide two independent systems using dual cable and separate control computers (Figure 3). A system of this type is clearly feasible, but would present operational difficulties because of the complete separation of computer functions.

An alternative is to provide a common control computer (linked to a common business system) controlling off-premises and home-terminal equipment fed by separate cables (Figure 4). In this case the first cable would carry all channels in the clear to the off-premises equipment; a second cable would carry clear basic-service channels and scrambled premium channels to single dwellings. This system is very secure as long as both cables are free from tampering. If the cable that feeds Mini-Hub is restricted in geographical coverage this system can be cost effective; if both cables must cover most of the cable system area this technique may be prohibitively expensive.

A system could be designed using a single cable carrying both clear and scrambled premium channels (Figure 5). In this alternative the clear premium channels must be eliminated by means of traps

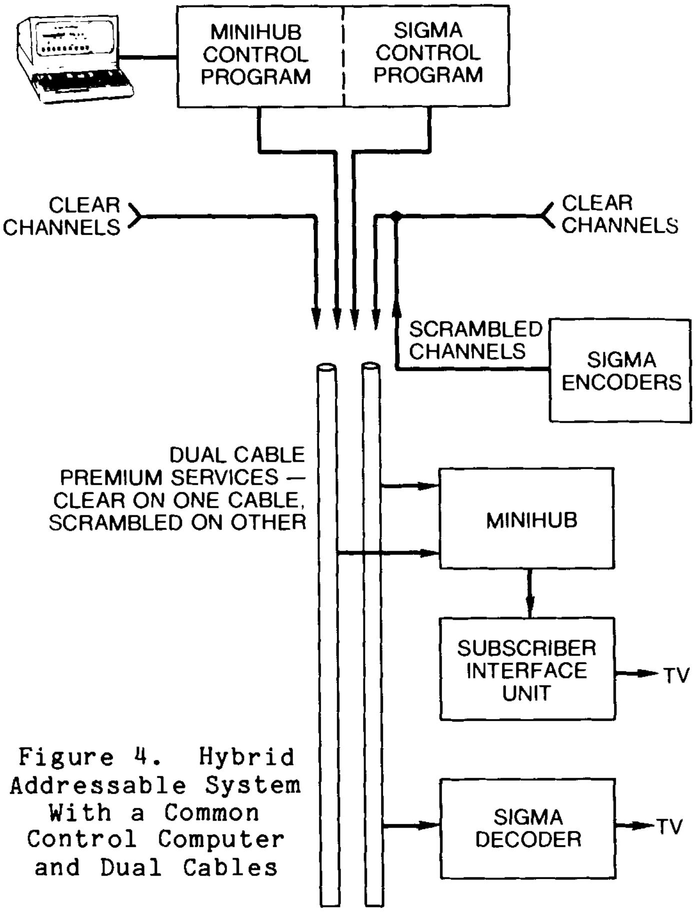

Figure 4. Hybrid Addressable System With a Common Control Computer and Dual Cables

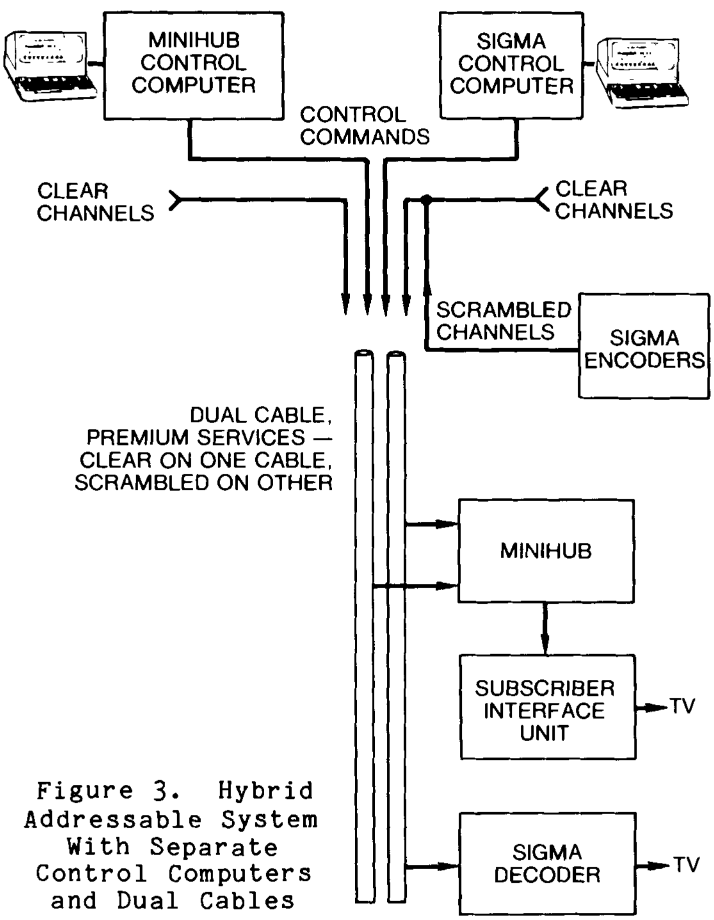

Figure 3. Hybrid Addressable System With Separate Control Computers and Dual Cables

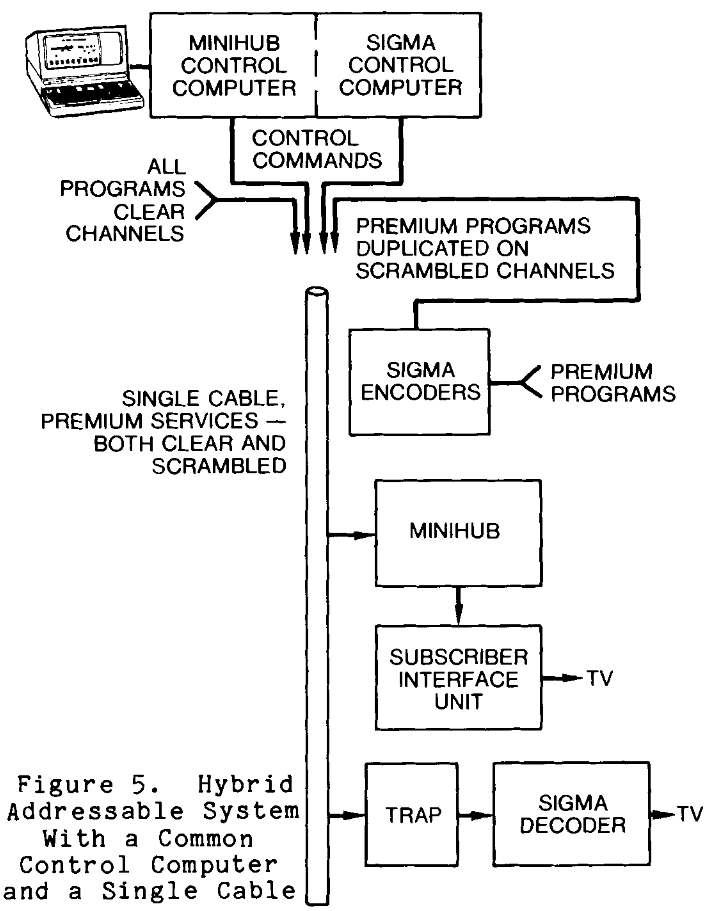

Figure 5. Hybrid Addressable System With a Common Control Computer and a Single Cable

before being fed to homes destined to receive the scrambled channels. This system must be rated poor for over-all security. In addition, duplication of premium channels seriously reduces the total channel capacity.

To provide complete flexibility of premium channel assignments without reducing channel capacity, a hybrid system could provide a Mini-Hub with a descrambler for each subscriber drop (Figure 6). A block diagram of a descrambler-equipped Mini-Hub is shown in Figure 7. Although this system has complete flexibility of channel assignment and excellent security, it is high in cost and consumes the most power.

The preferred system described in this paper is a single-cable system, in which the premium channels are all scrambled but which does not require descramblers in each Mini-Hub (Figure 8). Signals are delivered to the subscriber by means of either an individual Sigma converter/

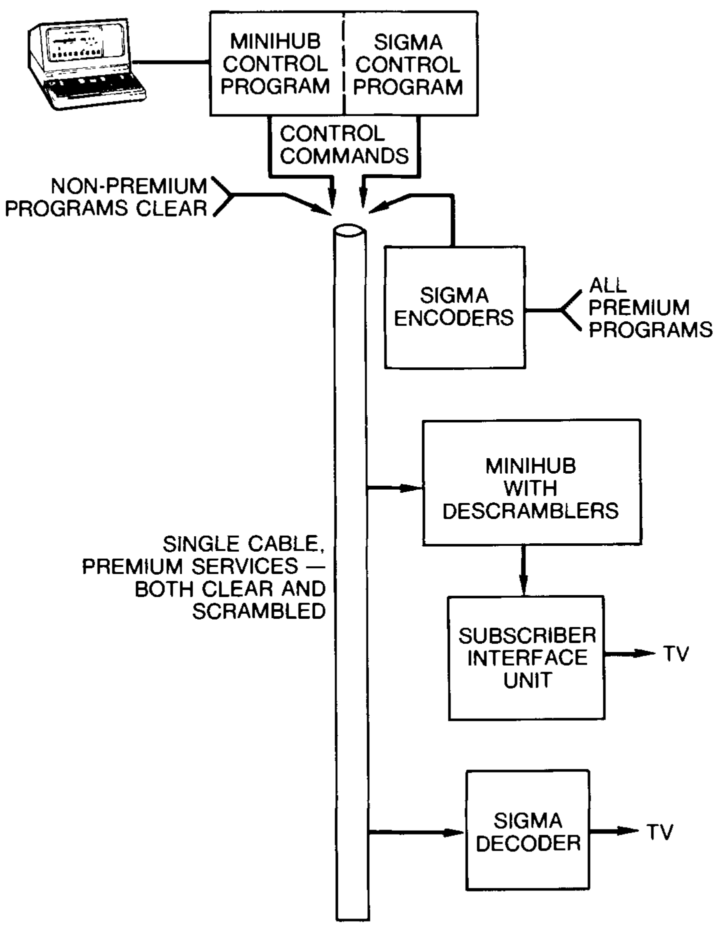

Figure 6. Hybrid Addressable System With a Mini-Hub for Each Subscriber

decoder, or, in the case of multiple-dwelling locations, through Mini-Hub units. A master decoder, installed between the trunk cable and a group of Mini-Hubs, descrambles the premium channels and reconverts each to an otherwise unoccupied frequency. In the Mini-Hub itself, these channels are converted and switched to the subscriber in the same manner as non-premium channels. Additional control signals do, however, direct frequency agility of the converters in the master decoder, permitting flexibility of premium channel assignments. Any number of scrambled premium channels can be accommodated and converted to frequencies above 450 megahertz for local distribution to Mini-Hubs. In order to satisfy filtering requirements, alternate channels would be employed at the output of the master decoder.

Table 1 summarizes the factors considered in evaluating these five alternate approaches to a hybrid addressable system

COMPUTER SYSTEMS - ALTERNATIVES

A typical computer architecture for an addressable pay-TV system includes:

- Business system
- Standard communications interface
- Control computer
- Controller which delivers a serial control data stream

There are variations of this architecture, depending on whether the business software is resident in the "control" computer or in a separate business machine. Assuming that the cable operator already has a business computer, either on-site or provided through a service bureau, a communication link and a separate control computer are required to operate the system.

Integrating the overall system allows both operation of the business functions and commands for addressing subscriber equipment to be done from the same business computer terminal. Subscriber status information contained in the business system data base is used to formulate control commands and the business data base, in turn, is updated in real time as changes occur. Thus, the business system's interface must contain all the necessary information to control the subscriber decoders. The interfaceable addressable system (IAS) link is shown connecting the business and control computers in Figures 1 and 2.

Control functions for the Sigma home-terminal systems and the control functions needed for Mini-Hub off-premises systems have some similarities and differences.

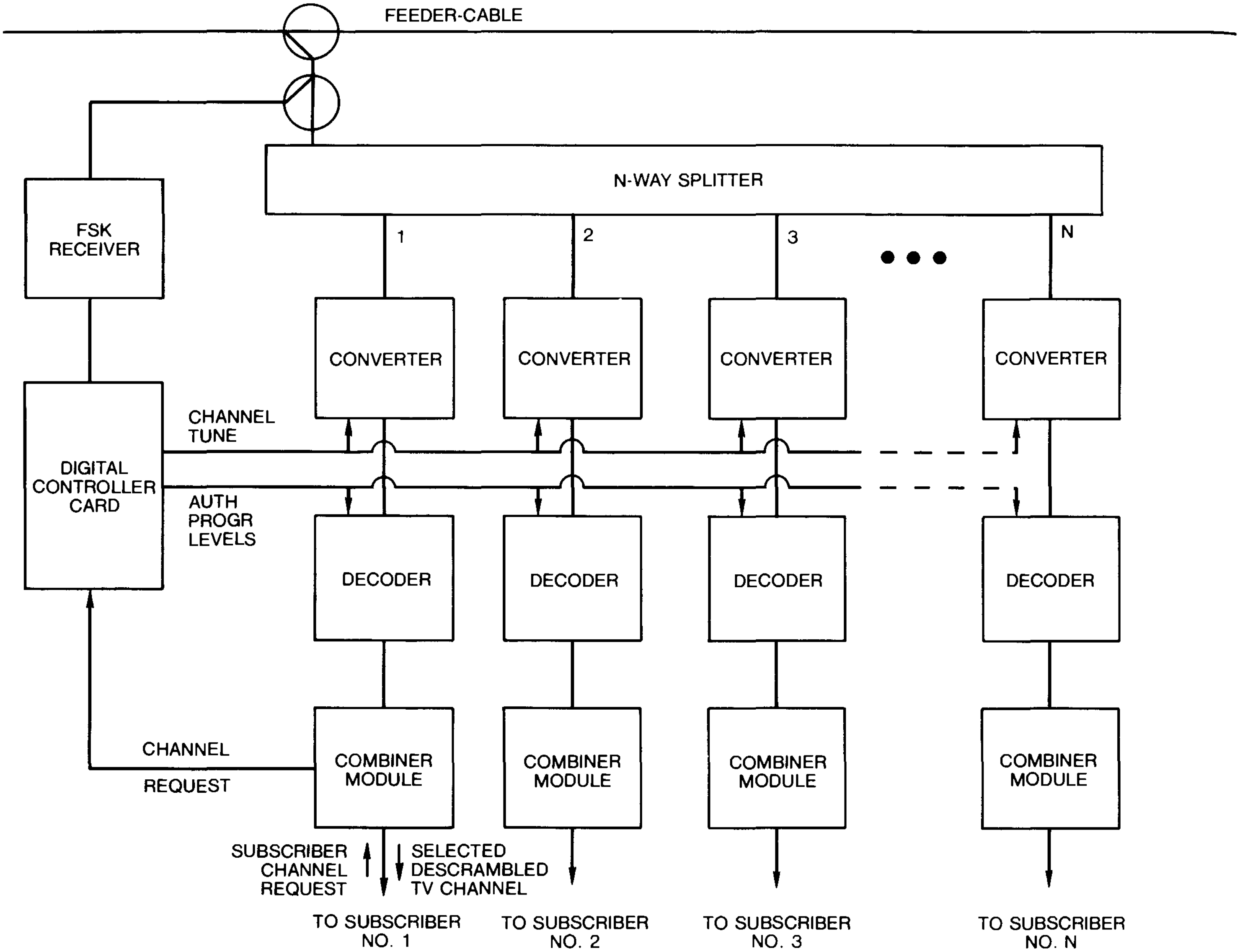

Figure 7. Descrambler-Equipped Mini-Hub Block Diagram

Each control system contains the following form of data files:

- Customer
- Converter or decoder
- Site location
- Special event
- System parameters

The control systems organize this data differently, however. The home-terminal communication system relies on a single address per decoder, whereas the off-premises system uses three forms of address: site, local distribution unit, and subscriber control. The Sigma home-terminal systems also use preauthorization and "data tag" matching for control, while Mini-Hub off-premises systems use downloaded mapping of authorized channels.

Despite these differences, and although home-terminal and off-premises systems have been developed independently, the computer system architectures are quite similar. For example both systems are multi-user/multi-tasking, allowing many terminal users to address decoders or off-premises converters, and to perform file inquiries on the installed customer base. This similarity makes it possible ultimately to develop a single computer system to control both kinds of hardware.

Conceptually the easiest way to control the set-top subsystem and the off-premises system in the same CATV operation would be to provide two dedicated control computers (Figure 9).

This system concept results in some rather onerous disadvantages. All control

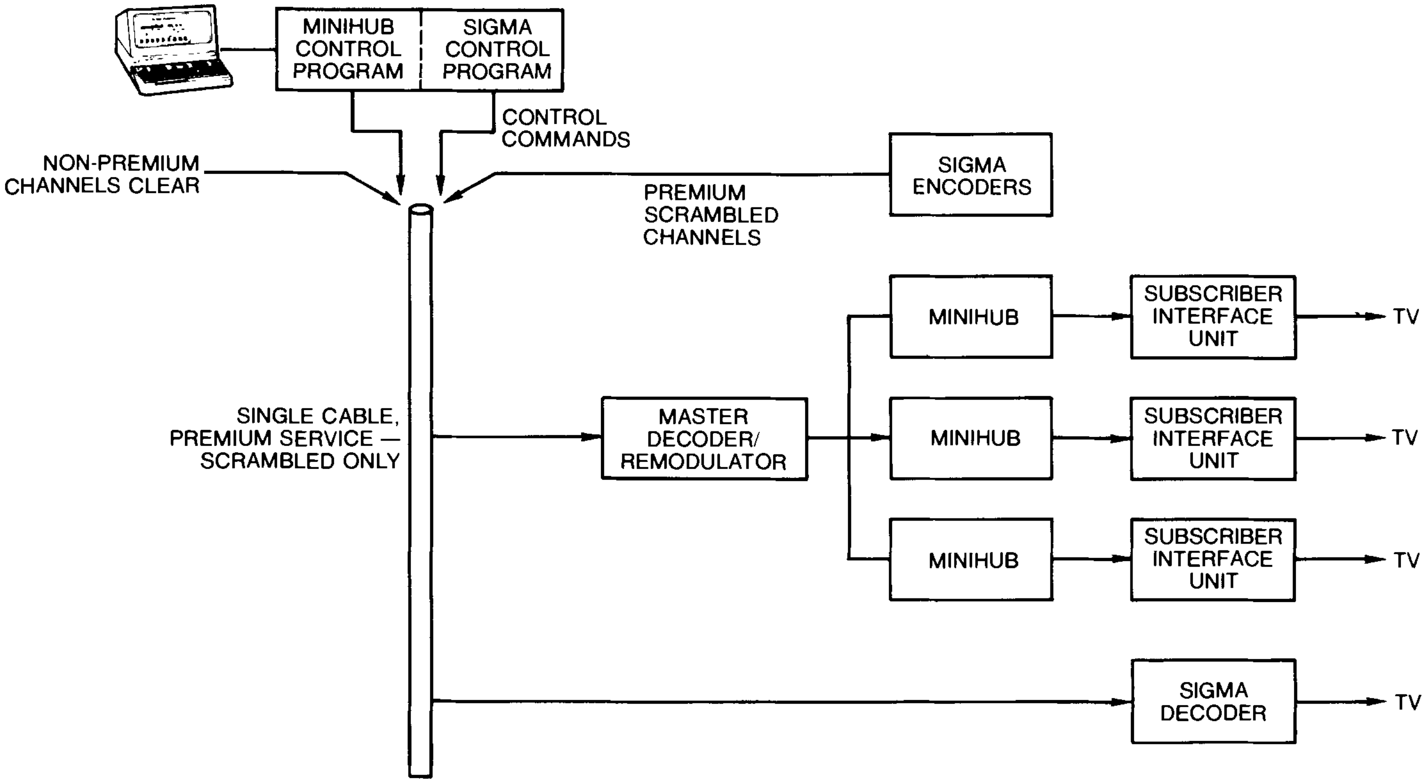

Figure 8. Preferred Hybrid Addressable System

Table 1. Hybrid Addressable Systems - Comparison of Configurations

System Configuration	No. of Cables	Operational Factors	Channel Capacity Factors	Security Factors	Cost Factors
Separate computers, separate cables (Figure 3)	2	Business system interfaces to separate computers/independent control systems	Two cables; but premium channels must be duplicated on both cables	High if Mini-Hub feeds are physically secure	Dual cable/two computers
Common computer, separate cables (Figure 4)	2	Consolidated business and control system	Two cables, but premium channels must be duplicated on both cables	High if Mini-Hub feeds are physically secure	Dual cable
Traps in cable drops (Figure 5)	1	Consolidated business and control system	Premium channels duplicated on one cable	Poor - traps easily circumvented	Potentially lowest cost
Descrambler per drop in each Mini-Hub (Figure 6)	1	Consolidated business/control system	Complete flexibility for premium channels	Very high	Potentially highest cost
Master Descrambler feeding multiple Mini-Hubs (Figure 7)	1	Consolidated business/control system	Restriction on number of premium channels	Very high if Mini-Hub feeds are physically secure	Cost effective if master decoders shared between multiple Mini-Hubs

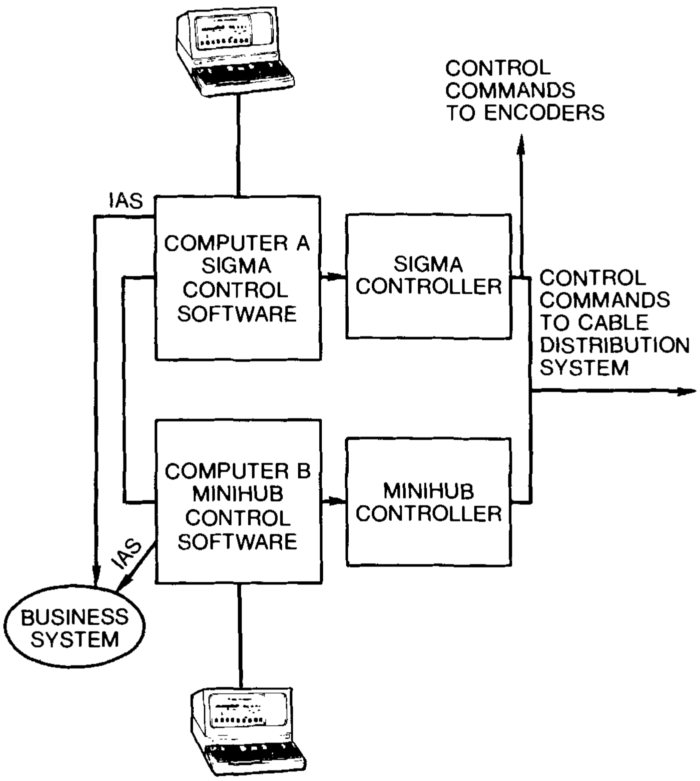

Figure 9. Separate Computer Configuration

and communication hardware must be duplicated; hardware and software maintenance, training, and operational costs are all significantly increased over a single machine system. Furthermore, if the customer and/or decoder data bases are on separate machines, the operational side of the business is less efficient.

A more attractive approach is to combine both control systems on one machine. This simplifies headend maintainability and conserves equipment dollars for both terminals and the control processor. However, just placing an assortment of control programs on one machine is not sufficient to achieve economies of scale.

Let's look at two alternative control software configurations in which a single control machine is used for the entire hybrid system.

The simplest means of merging two control software systems onto a single CPU is to allow the operating system to be the only common element between the two systems (Figure 10). For example, the Sigma control programs could reside side by side with the Mini-Hub control programs operating under a single operating system, such as VMS or RSX11M+ on the Digital Equipment Corporation's VAX or PDP-11 computer families. In this scheme, the design of each control program can be kept separate and the system is thus easy to implement. A common log-on menu is provided and both control software programs are accessed from any terminal in the control system. There are several disadvantages to this arrangement, however, including the lack of software integration which results in a higher maintenance cost; redundancy of code for such functions as screen handling, report generation, and transactions; and perhaps most important, the need to provide two data bases for user information.

A fully integrated system is shown in Figure 11. In this option, all user

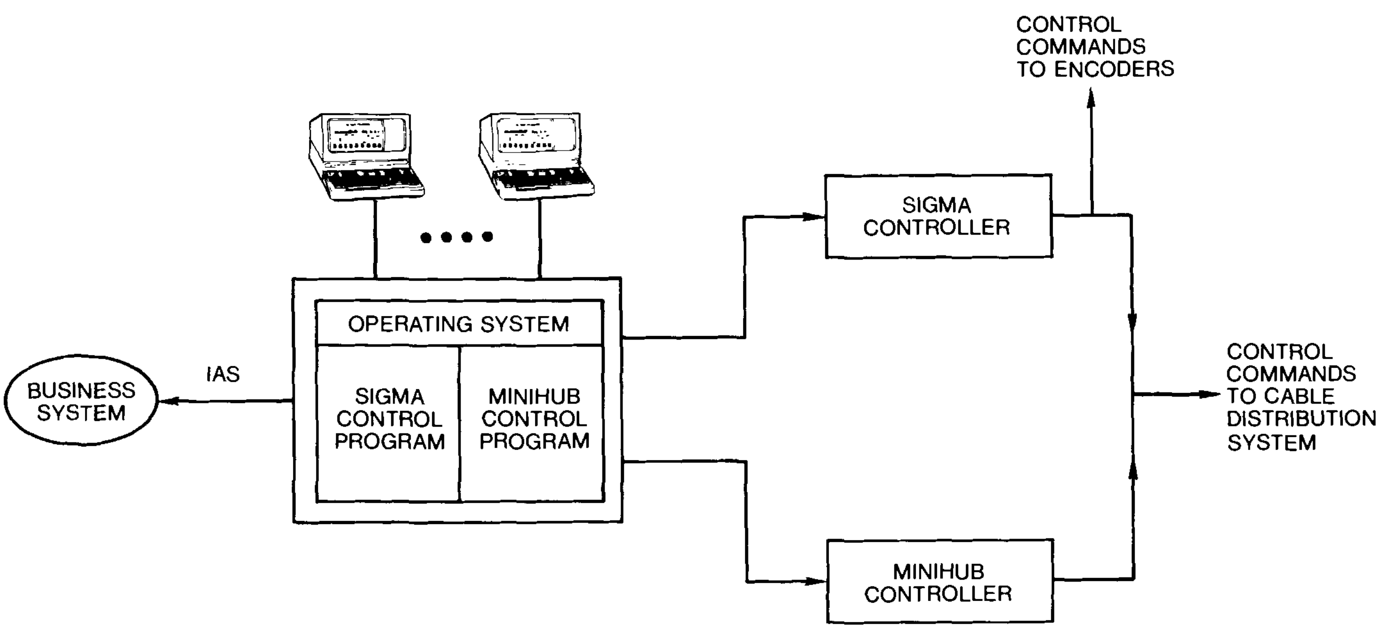

Figure 10. Common Computer - Separate Control Programs

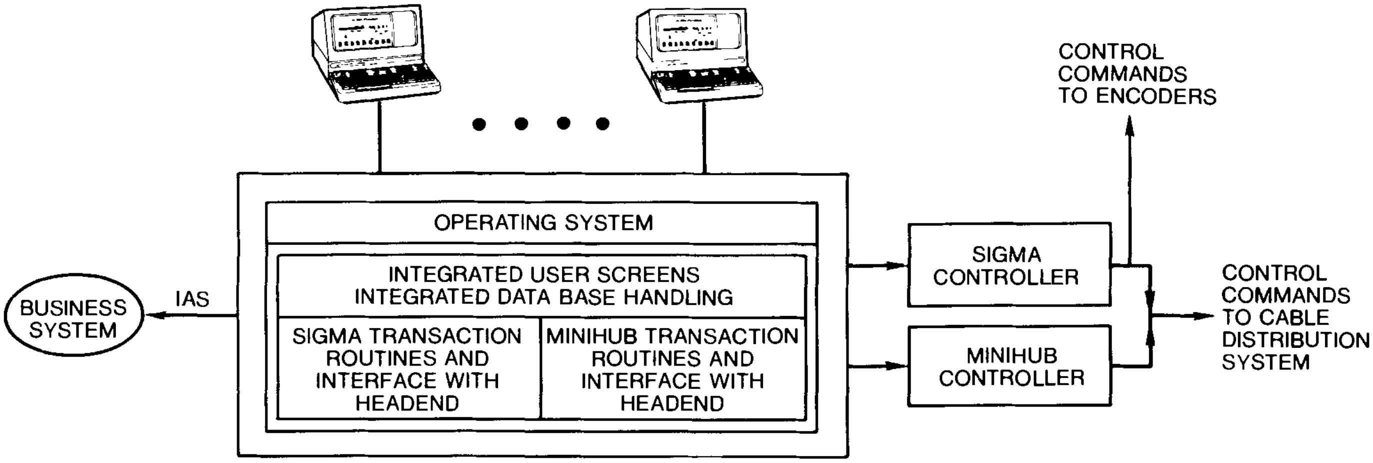

Figure 11. Common Computer - Integrated Screens and Data Base

screens are integrated as well as all of the customer and decoder information data bases. This provides for efficiency of maintenance, optimum terminal response time, and reduced data storage requirements. The integrated system is also much easier to use, since the equipment used to deliver the TV signals (whether off-premises or in-home) is transparent to the terminal operator. This is the preferred architecture described in the proposed hybrid addressable system.

A RECOMMENDED HYBRID ADDRESSABLE SYSTEM

The preferred system (Figure 12) provides Sigma-level security for all premium channels. Although the example of Figure 12 shows only five premium channels, any number of the cable system's channels could be encoded. At the headend the scrambled channels are combined with other, non-premium, services and system control signals. A common computer feeds separate control data channels, each individually optimized for data communication throughput based on the differing message requirements of Sigma home terminals and Mini-Hub off-premises equipment.

Conventional trunk and feeder lines distribute premium and non-premium channels to both master decoders and individual decoders. Each master decoder feeds descrambled signals locally to the Mini-Hub units. The master decoder (Figure 13) selects each scrambled channel, descrambles and decrypts video and audio content, and modulates/upconverts each signal to an otherwise unoccupied frequency. The master decoder is modular, each tuner/converter / descrambler / upconverter being self-contained and including its own digital control receiver. The tuners are frequency agile, tunable to any cable channel as directed by the control data channel from the headend. Similarly the upconverters are frequency agile, although their tuning range is more limited.

Each descrambler has the encryption security features of the Sigma home-terminal unit. The Mini-Hub units tune the descrambled and upconverted premium channels as well as the clear channels carried throughout the cable system. The subscriber requests channels by means of the SIU located in his home. For each subscriber an authorized channel map is down-loaded to the logic system of the Mini-Hub. Only if there is a match between the requested channel and the channel map does the subscriber receive the program.

CONCLUSION

No longer is the cable operator faced with the choice of exclusively off-premises or exclusively in-home equipment for his addressable system. Cable systems are not constructed in cities or towns which consist entirely of single-family homes or entirely of high-rise apartments. What is needed is an architecture tailored to cable systems serving a variety of population densities and types of dwellings.

The recommended hybrid addressable system satisfies this need without compromise to signal security. Integration of the control system has been achieved allowing business system operation without regard to the type of hardware used to deliver premium programs to the subscriber. The system hardware configuration is designed for economy and flexibility of channel assignments.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of the technical staffs of Oak Communications Inc. and Times Fiber Communications, Inc.

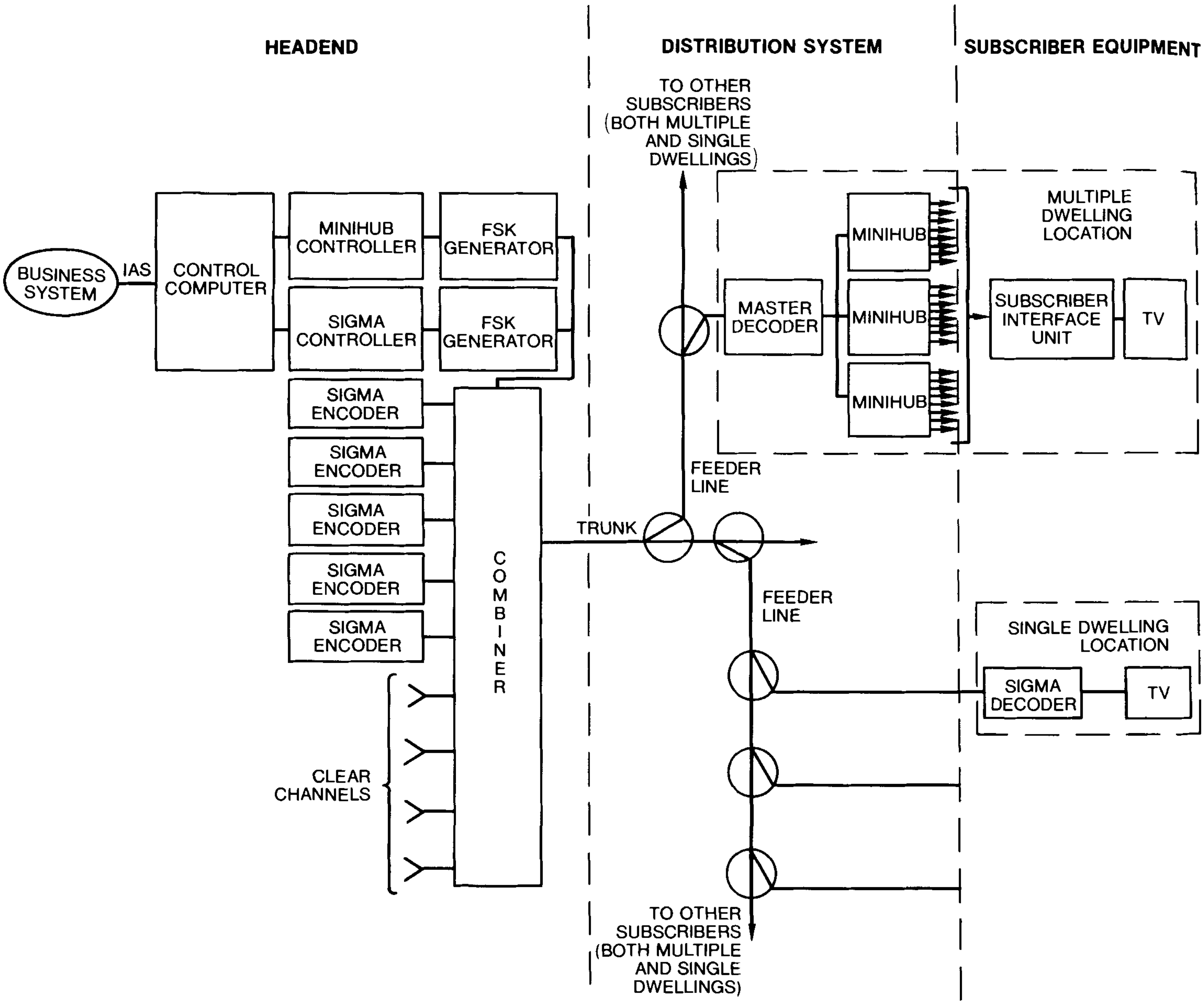

Figure 12. Hybrid Addressable System With Master Decoders

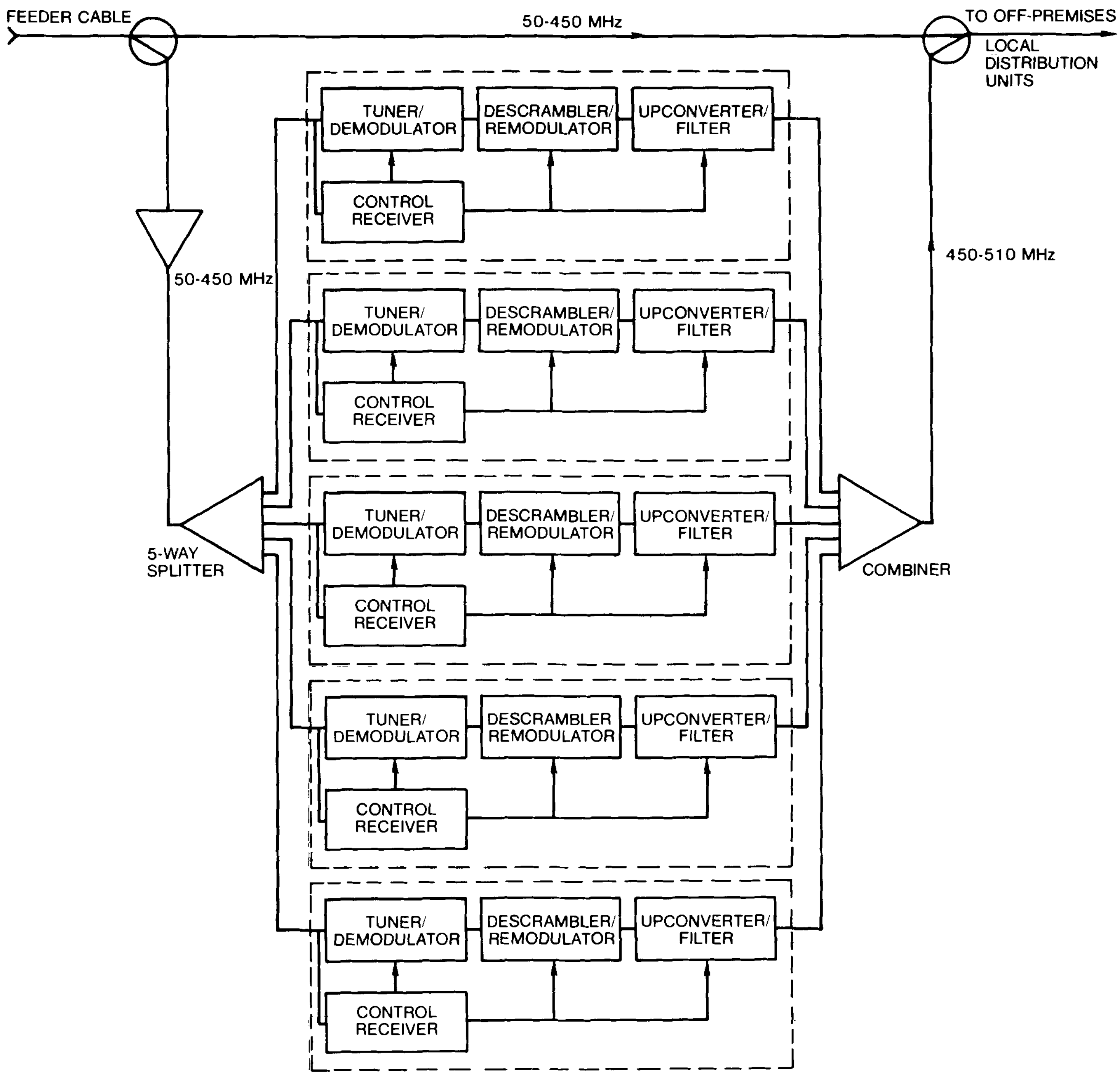

Figure 13. Master Decoder Block Diagram

LIMITATIONS AND CHARACTERISTICS OF BROADBAND FEEDFORWARD AMPLIFIERS

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Abstract

The nature of critical multi-channel broadband system design parameters using Feedforward technology is strikingly different from previously existing technologies. Several system design procedures taken for granted prior to using Feedforward circuits must be re-evaluated. The unique characteristics and limitations of Feedforward circuits regarding output capability, gain compression, temperature stability, noise figure, flatness, cross modulation and delay line technology are presented. The effects of these on system design considerations are discussed.

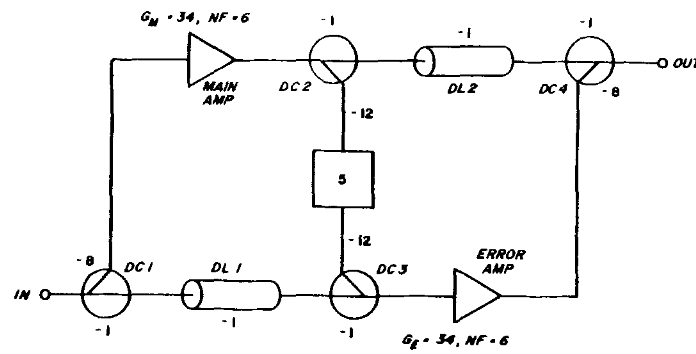
1.0 Introduction

The distortion reduction provided by the Feedforward circuit configuration makes this circuit very attractive for use in broadband distribution equipment.[1] However, several unique characteristics of the Feedforward circuit are strikingly different from existing technologies. The system designer must then become familiar with the nature of the Feedforward circuit in order to understand the limitations of these devices.

This paper presents an analysis of the characteristics of the Feedforward circuit and defines limitations to be used by the system designer. Analytical means are emphasized rather than empirical methods commonly used prior to widespread Feedforward circuit use. Output capability, gain compression, temperature stability, noise figure, flatness, cross modulation and delay line technology are discussed.

2.0 What is Feedforward?

Feedforward is a distortion reduction technique. Since cancellation circuits are used twice in the Feedforward circuit, understanding the characteristics and limitations of cancellation provides the basis for analyzing the characteristics and limitations of a Feedforward circuit. The internal operation of the Feedforward circuit is discussed in this section.



GAIN = 23 dB
OUTPUT CAPABILITY IMPROVEMENT = 9 dB
NOISE FIGURE = 9 dB
POWER = 16.3 W

FIGURE 1
FEEDFORWARD FUNCTIONAL BLOCK DIAGRAM

Figure 1 is a functional block diagram of a Feedforward amplifier. Two push-pull cascode hybrid integrated RF amplifiers are required, the first is the main amplifier, the second is the error amplifier. There are two cancellation loops, the first isolates noise and distortion generated by the main amplifier and the second produces the distortion cancellation phenomena.

2.1 First Loop Cancellation

The first loop isolates the noise and distortion created by the main amplifier. This technique is shown in Figure 2 with the signal flow indicated by the dotted lines. A signal (S) is applied to the input of the circuit and is sent in two directions by DC1. At the output of the main amplifier not only is the original signal (S) present, but also the errors involved in the amplification process; namely, noise and distortion (indicated by N and D respectively).

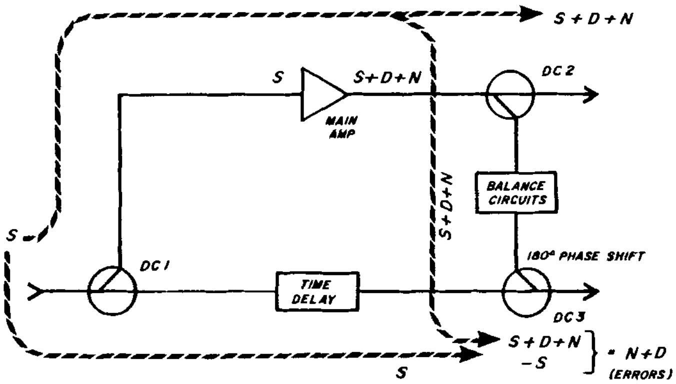


FIGURE 2

FIRST LOOP CANCELATION

Most of the output signal of the main amplifier is directed towards the output of the Feedforward circuit through DC2, however, some of that signal is siphoned off and brought down to DC3 where it is combined out of phase with the original input signal. Equation 1 indicates the cancellation process if the cancellation were ideal.

$$\underbrace{S + D + N}_{\text{main amp output}} - \underbrace{S}_{\text{input signal}} = \underbrace{D + N}_{\text{errors in the amplification process}} \qquad (1)$$

2.2 Second Loop Cancellation

The cancellation of the second loop reduces noise and distortion. This second loop is shown in Figure 3. In this figure the N plus D term isolated by the first loop cancellation is amplified by the error amplifier and reinjected out of phase with the signal coming from the main amplifier at DC4. The end result is shown in Equation 2. If the cancellation process were ideal, then the output signal would be an exact replica of the input signal without the noise and distortion created by the main amplifier.

$$\underbrace{S + D + N}_{\text{main amp output}} - \underbrace{(D + N)}_{\text{distortion and noise}} = \underbrace{S}_{\text{clean output signal}} \qquad (2)$$

3.0 Cancellation

Ideally, the Feedforward circuit would provide a perfect replica of the input signal without any distortion. In fact, the Feedforward circuit relies on cancellation to provide distortion reduction and the limitations of cancellation define several of the limitations of the Feed-forward amplifier; output capability, flatness, temperature stability, and long term stability.

Cancellation involves the combination of two signals which are of equal amplitude and opposite phase. The state of the art for broadband circuits over the temperature range -40° C to +60°C is on the order of 22 to 26 dB cancellation. We will use 24 dB cancellation as a basis for the rest of the analysis presented in this paper. Improvements in second order distortion of push-pull hybrid IC's and typical passive and tap output-to-output isolation specifications can be cited as good examples of this 24 dB cancellation figure.

4.0 A New Phenomenon; Third Order Nonuniformity

Modern multichannel broadband systems are being specified with third order distortions being the main output limiting factor. This is still the case with Feedforward amplifiers. However, the nature of this parameter has changed dramatically. RF hybrid IC's with a push-pull cascode circuit were the main gain blocks used in broadband distribution amplifiers prior to the use of Feedforward. The third order performance of these circuits did not rely on cancellation, but rather depended on the performance of the transistor die. Because of this, the third order performance of the individual transistors, the hybrids; and therefore, the distribution amplifiers themselves was a relatively fixed value. Unit-to-unit and lot-to-lot variations in third order performance were very small. The amplifier performance was then very predictable and orderly. System performance calculations based on individual amplifier tests were also predictable, orderly and practical.

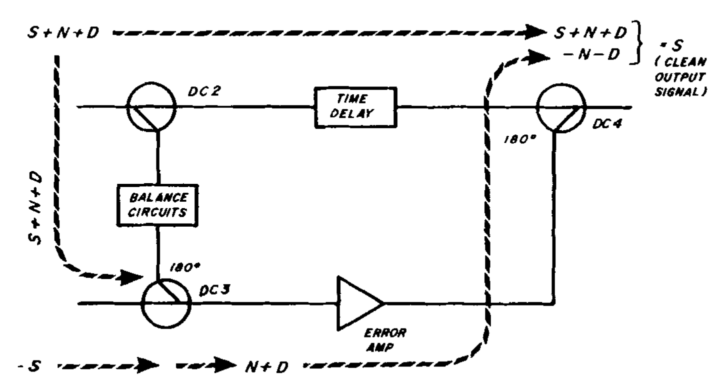


FIGURE 3

SECOND LOOP CANCELATION

System designers relied on this uniform product to predict system performance by using empirical techniques. That is, one could measure the performance of the single trunk amplifier and then predict the performance of a cascade of these amplifiers or predict system performance based on data accumulated from amplifier performance. With Feedforward circuits, this is no longer the case. A discussion of the specification of the output capability of the Feedforward amplifier follows.

4.1 Cancellation And Distortion Reduction

The distortion of the Feedforward circuit compared with the distortion performance of the main amplifier will be considered. The second loop (Figure 3) produces 24 dB cancellation. We are concerned with third order distortions being the limiting system design factor and these, if the main amplifier is operating in a well behaved mode, will derate on a two for one basis. That is, if the output signal level is increased by 1 dB, the carrier to composite triple beat ratio will be degraded by 2 dB. A 24 dB cancellation would then result in a basic 24 dB reduction in distortion. However, a 3 dB loss exists between the main amplifier output and the Feedforward circuit output (see Figure 1). This loss reduces the output capability, so we should subtract 6 dB from the 24 dB reduction in distortion. The result is an 18 dB reduction in distortion with this Feedforward circuit.

4.2 Cancellation Measurements

As was stated earlier, third order distortion performance of non-Feedforward type amplifiers was uniform from unit to unit. Examine Figure 4 which is a photograph of a swept display of the cancellation of the second loop of a Feedforward gain block versus frequency. This photo was taken at room temperature. Notice that the cancellation is generally better than 24 to 26 dB with the high frequency cancellation having two nulls where the distortion is substantially better than 30 dB. Also note that the cancellation is not uniform across the entire bandwidth. These cancellation characteristics will not be uniform from unit to unit. The nulls will be displaced in frequency from one unit to the next. In a typical production run, some units will align to better than 28 or 30 dB across the band while others may have no nulls at all and will be relatively uniform in the 24 to 26 dB range.

The result is that the third order distortion performance of several Feedforward amplifiers will naturally be remarkably different from one another. Empirical tests on individual amplifiers must then be basically unreliable in and of themselves as an evaluation and specification process.

5.0 Temperature Stability

The cancellation shown in Figure 4 involves a delicate balance of amplitude and time delay along two different signal paths. When the temperature changes, the gain and delay of the main amplifier as well as the insertion loss and delay characteristics of the directional couplers and delay lines will change slightly with temperature. It is impractical to assume that the precise balance needed to maintain 30 or 35 dB cancellation can be maintained over the temperature range. Figure 5 shows the cancellation of the circuit in Figure 4 at +60° C temperature. Figure 6 shows the cancellation at -40° C.

The key point here is that the equipment manufacturer and system designer must deal with specifications based on the analysis of the limitations of the cancellation process and not rely upon empirical data taken on one or even several units. Generally speaking, 16 to 18 dB cancellation would be a poorly designed circuit, while 22 to 26 dB cancellation is a well designed state of the art circuit. However, 26 to 30 dB cancellation is impractical to achieve over the temperature range and across the entire spectrum.

6.0 Cascade Test Results

Cascade tests of 20 Feedforward trunk stations were conducted. The amplifiers had 26 dB spacing and were operated at 36 dBmV output signal level at the highest channel with a 7 dB linear tilt between the highest and lowest channel. Without providing the details,[1] the assumption of 24 dB cancellation on the Feedforward circuit plus the minimum performance specifications of the hybrids used in these amplifiers indicated an individual amplifier carrier-to-composite triple beat ratio (CCTB) performance of 89 dB. Assuming in-phase addition of CCTB, the cascade of 20 trunks would produce 20 Log N or 26 dB worse CCTB than an individual amplifier. This results in an expected CCTB of 63 dB for the cascade.

The CCTB of each amplifier was measrued individually. The minimum CCTB was 92 dB, while the mean value was 95.2 dB. Cascade test results are shown in Table 1. Clearly, the minimum performance of an individual amplifier should not be used to predict cascade performance. This results in an overly pessimistic performance prediction of 63 dB for the cascade. The mean value of 95.2 dB could be used to make cascade preditions, with a calculated performance being 69.2 dB.

TABLE 1

	Calc	25° C	-20° C	55° C
Carrier-to-Composite Triple Beat	63	72	70	69

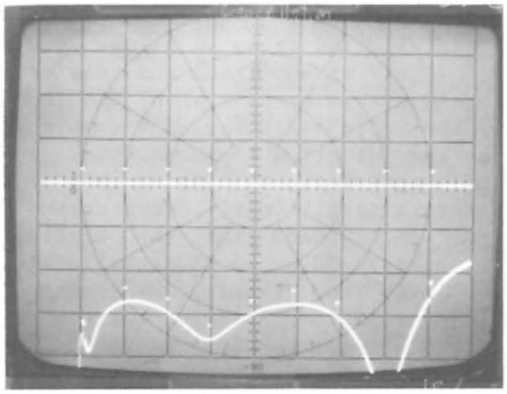


FIGURE 4

CANCELLATION AT
ROOM TEMPERATURE

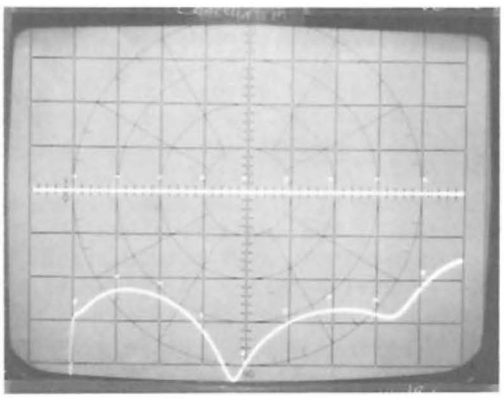


FIGURE 5

CANCELLATION AT 60° C

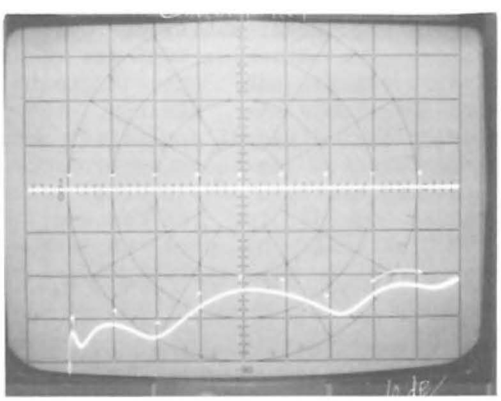


FIGURE 6

CANCELLATION AT -40° C

Two points should be considered. First, individual minimum amplifier performance should be specified along with typical amplifier performance in a Feedforward circuit if meaningful cascade performance calculations are to be attempted. Secondly, will the typical performance of the system, which clearly depends upon better than 24 dB cancellation, be maintained with time? This author believes that some consideration to an ultimate softening of the cancellation characteristics with time and temperature ought to be considered in system designs with Feedforward circuits.

7.0 Gain Flatness

There are two parameters which affect the basic flatness of the Feedforward gain block. One is relatively straight forward, understandable, and controllable. The other is more subtle, insidious, and out of control. The more controllable parameter is the fact that 34 dB gain hybrid IC's are used in the Feedforward amplifier instead of the commonly used 18 dB gain blocks. The higher gain combined with basic limitations of the packaging technology result in reduced gain flatness in amplifiers utilizing 34 dB gain blocks. This, however, is controllable by a slight increase in the complexity of the flatness circuits provided with the trunk-line equipment.

The new and unusual phenomenon associated with a Feedforward circuit is understood by looking at Figure 7. This figure shows that the output signal is in reality a combination of the desired output signal derived from the main amplifier plus an undesired output signal provided by the error amplifier. The undesired signal is below the desired signal by an amount equal to the cancellation achieved in DC3, the coupler before the error amplifier. This phenomenon does not exist in trunk stations of the non-Feedforward type. This phenomenon has two effects, one concerns the equipment designer and the other concerns the system designer. The equipment designer must add further complexity to his interstage flatness circuits in a trunk station to overcome the results of the flatness degradation caused by the undesired output signal at room temperature.

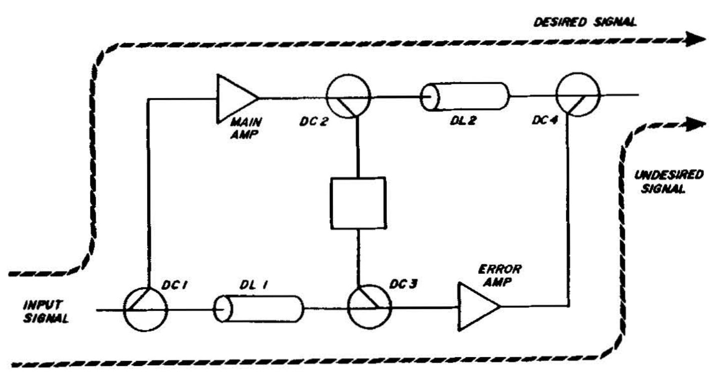


FIGURE 7

UNDESIRED OUTPUT SIGNAL WITH A FEEDFORWARD CIRCUIT

The system designer must realize that the flatness of the Feedforward circuit is dependent on the cancellation of the first loop and that the cancellation profile will change with temperature, thus producing a small gain change. For example, a null might exist at room temperature so that essentially no undesired signal is present at the output. At the temperature extremes, the null may disappear and the undesired signal at the output could be 24 dB below the original signal. This is still well within expected performance for cancellation. However, the change in cancellation from 35 dB to 24 dB at that particular frequency will cause a gain change of approximately 0.1 dB.

The net result is that trunk-line cascade flatness will change more with temperature with Feedforward equipment than it will with non-Feedforward equipment. This flatness change is due primarily to changes in cancellation of the first loop of the Feedforward circuit. In a 20 amplifier cascade, a gain change caused by this phenomenon of 0.1 dB per amplifier could result in 2 dB flatness degradation different from and not normally seen on previous equipment. Very long supertrunk cascades may require seasonal balancing if these gain changes cause significant changes in cascade flatness.

8.0 Noise Figure

Although the Feedforward circuit has excellent properties for using it as an output amplifier on a trunk station, its use on the input or preamplifier stage of a trunk station is restricted.

The noise figure of the Feedforward amplifier can be analyzed by considering the fact that the noise generated in the main amplifier is cancelled by the first loop so that the noise at the output of the Feedforward amplifier is primarily due to the noise created by the error amplifier. Noise is not usually considered to be a cancellable phenomenon, however, in this case the noise being cancelled is correlated. That is, the noise output of the main amp is contained in both signal paths and, therefore, is correlated and cancellable. The noise generated by the error amplifier is not in both signal paths, is not correlated and not cancelled.

Where does the noise come from? In Figure 1 it can be seen that the gain of the Feedforward amplifier is equal to the gain of the main amplifier minus those losses incurred through DC1, DC2, DL2, and DC4 (Equation 3). A general characteristic of the Feedforward circuit is that if we neglect the effect of the cancellation of the first loop, the gain from input to output through DC1, DL1, DC3, the error amplifier, and DC4 is also equal to 23 dB (Equation 4). The noise at the output is due to error amplifier noise. Therefore, the noise figure of the Feedforward amplifier is equal to the noise figure of the error amplifier plus those losses incurred between the Feedforward circuit input and the error amplifier input. In this case the noise figure would be equal to 9 dB.

$$-DC1 + G_M - DC2 - DL2 - DC4 = \text{Gain}$$

$$-8 + 34 - 1 - 1 - 1 = 23 \text{ dB} \quad \text{main path gain} \quad (3)$$

$$-DC1 - DL1 - DC3 + G_E - DC4 = \text{Gain}$$

$$-1 - 1 - 1 + 34 - 8 = 23 \text{ dB} \quad \text{error path gain} \quad (4)$$

Generally, this Feedforward circuit will always have a worse noise figure than an equivalent RF Hybrid amplifier. It follows then that the use of a more complex Feedforward circuit on the input or preamp of a trunk station would have to improve the distortion of the trunk station enough to overcome the deleterious effect of reducing the dynamic range by increasing the noise figure.

9.0 Gain Compression

Feedforward circuitry does not improve the power handling capability of the amplifier, rather it simply reduces the distortions created by the main amplifier. Figure 8 presents the CCTB ratio versus output levels for a 450 MHz 60 channel system operating with output levels having a 6 dB linear tilt between the highest and lowest channel on the system.

Note the performance of the single hybrid. At levels below 45 dBmV, the third order distortions behave in a well-mannered fashion and follow the two for one slope lines indicated on the chart. Above this, higher order terms such as 5th, 7th, and 9th order terms, start coming into play and the distortion performance departs from the well behaved performance.

The other two performances indicated on the chart, the parallel hybrid and Feedforward performance, are determined by using the single hybrid performance as a reference and then constructing the other two charts according to the following rules.

The parallel hybrid performance is obtained by shifting the single hybrid performance to the right 3 dB at each point.

The Feedforward curve is constructed by taking any point on the single hybrid line, shifting to the left 3 dB to allow for Feedforward circuit output losses, and then shifting downwards 24 dB to allow for cancellation of the second loop.

Figure 8 presents an analytical approach to determining the expected performance of the Feedforward feeder amplifier at the higher output levels required for bridger and line extender functions in the distribution system. Empirical data taken on individual units can and will vary considerably. Note that at 51.5 dBmV out the Feedforward amplifier performance is identical to the parallel hybrid performance. Also note that if the lines were extended further, that at 54 dBmV out, the single hybrid performance would be better than the Feedforward circuit performance.

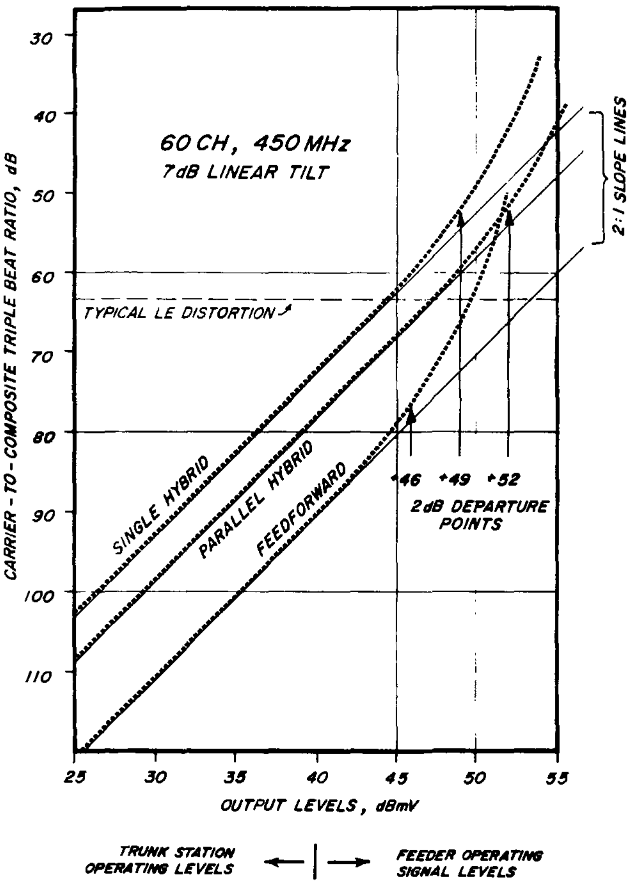


FIGURE 8

OUTPUT CAPABILITY COMPARISON

This unique behavior, that is, poor derating at elevated signal levels complicates the task of the system designer when selecting and specifying the output signal level for Feedforward distribution amplifiers in bridger and line extender applications.

This analysis indicates that if a 3 dB safety margin were required in the system design that equivalent performance between parallel hybrids and Feedforward circuits would be achieved at 48.5 dBmV output levels. At this point, a parallel hybrid device would have 60 dB CCTB while a Feedforward device would have 67 dB CCTB. However, if the output levels of each were increased by 3 dB, each would have a 55 dB CCTB.

There is some question then as to whether a parallel hybrid circuit would be preferrable to a Feedforward circuit in bridgers and line extenders. The Feedforward circuit is substantially more complex and consumes more power than a parallel hybrid circuit.

11.0 Delay Line Selection

The selection of the proper delay line approach affects the ability to maintain, repair, and upgrade equipment. Two types of delay lines are presently being used in feedforward circuits. The first is a lumped element delay line utilizing a low pass filter circuit. These delay lines are generally 10 branch circuits with 20 or more components.

The lumped element delay lines have several drawbacks. They are costly, requiring many components and requiring time-consuming alignment. Furthermore, a unique delay line must be used for each type of hybrid. When changing hybrids from one vendor to another or if a hybrid vendor changes his manufacturing process in such a way as to change the delay of the circuit, a redesign of delay lines might be required. The history of the broadband amplifier business has been such that this type of change occurs every 18 months to two years. Repair of existing equipment using future hybrids can require redesign of the delay lines. Changing the hybrid vendor can require redesign of the delay lines.

Furthermore, technician training related to alignment and balance procedures for equipment using Feedforward circuits with lumped element delay lines is complex.

Another type of delay line is useable in these circuits, that is a fixed delay line utilizing microstrip technology. It has several distinct advantanges over its lumped element counterpart. The use of a plug-in fixed delay line allows a change in the time delay without redesign. A series of several time delay values can be configured in a common package which can plug into a Feedforward circuit. Thus, if the hybrid vendor or hybrid process is changed, the delay line can be easily changed.

The microstrip delay line has a constant impedance with an inherently broad bandpass, generally greater than 1.2 GHz. The lumped element counterpart is inherently a low pass filter with band limiting characteristics. Also, the fixed impedance of the microstrip delay line requires no alignment, therefore, no training for maintenance purposes.

The cost differences for these delay lines are near an order of magnitude, the micrcostrip delay line being dramatically lower in cost than its lumped element counterpart.

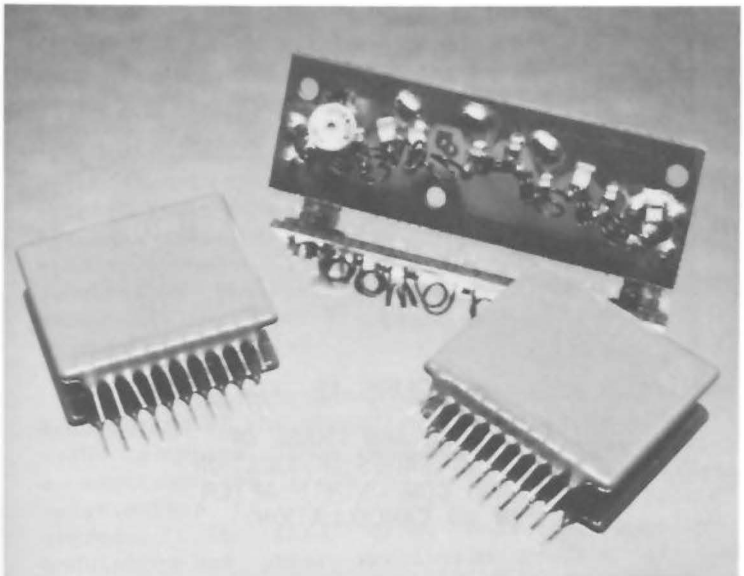


FIGURE 9

PHOTO SHOWING MICROSTRIP AND LUMPED-CONSTANT DELAY LINES

12.0 Power Consumption and Heat

A disadvantage of the Feedforward circuit over the RF hybrid counterpart is the increased power consumption and heat generated within the package. This increased power consumption requires the use of an efficient switching regulator power supply, and attention to the thermal characteristics of the amplifier package. In many instances, repackaging of standard broadband product lines will be necessary to allow for switching power supplies and lower thermal resistance packages in order to maintain reliability and avoid excessive overheating of critical amplifier components.

13.0 Cross Modulation in Broadband Feedforward Circuits

The feedforward circuit configuration provides significant improvement in the intermodulation distortion performance of a broadband amplifier. However, amplitude cross modulation reduction at high frequencies does not necessarily occur to the same extent in a feedforward circuit. This will be shown after first discussing cross modulation in push-pull cascode amplifiers.

The nature and behavior of cross modulation at high frequencies in multichannel broadband amplifiers is well known and documented. Gumm[7] and Luettgenau[5] have described, documented and characterized phase cross modulation at high frequencies. Simply stated, the predominant energy of the cross modulation sidebands occurs as phase modulation instead of amplitude modulation of the carrier at higher frequencies.

Furthermore, the visual effect of the phase cross modulation occurs at levels which make composite triple beat noise the limiting factor in broadband systems which carry 50 or more channels. Even in systems which use harmonically related or phase-lock carrier techniques, the triple beat mechanism is of prime importance, while cross modulation was deemed incidental.[3,6]

The cancellation phenomenon of the Feedforward circuit introduces yet another degree of complexity in analyzing high frequency cross modulation. The following analysis shows the effect of cancellation on cross modulation sidebands and predicts the resultant effect on amplitude cross modulation.

Jeffers used the classical rotating vector representation of narrowband FM to describe the phase cross modulation phenomenon at low levels of nonlinearity. This approach will be used to describe the effect of Feedforward circuit cancellation on the cross modulation sidebands.

Figure 10 shows a carrier vector with the double sideband cross modulation vectors having a resultant vector whose phase is 90 degrees out of phase with the carrier vector. This represents pure narrowband FM or phase modulation. Detection of the envelope of this signal would result in no amplitude modulation.

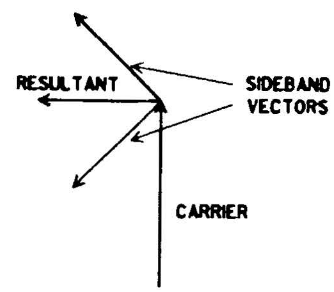


FIGURE 10

NARROW BAND FM MODULATION VECTOR REPRESENTATION

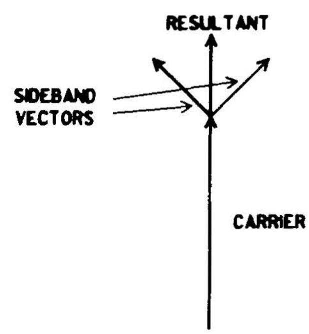


FIGURE 11

AM MODULATION VECTOR REPRESENTATION

Figure 11 shows a similar representation for the case of pure amplitude modulation. In this case the resultant vector of the sideband components is shown in phase with the carrier vector and therefore provides pure amplitude modulation, with no phase modulation.

Experiments were conducted to define the extent of this effect on push-pull cascode RF hybrids. The magnitude of the phase difference between the carrier and cross-mod sideband components can be calculated by first measuring the magnitude of the cross modulation sidebands on a spectrum analyzer and then comparing the results to the measurement of amplitude cross modulation by standard NCTA techniques.

Experiments on 450 MHz, 60 channel RF hybrids indicate a typical phase angle of 80 degrees for the resultant of the sidebands at the high frequencies. This is very close to pure phase modulation as shown in Figure 10.

Figure 12 shows the general tendency of the phase modulation to produce a discrepancy between the amplitude of cross modulation sidebands as measured on a spectrum analyzer and cross modulation measured by NCTA methods.

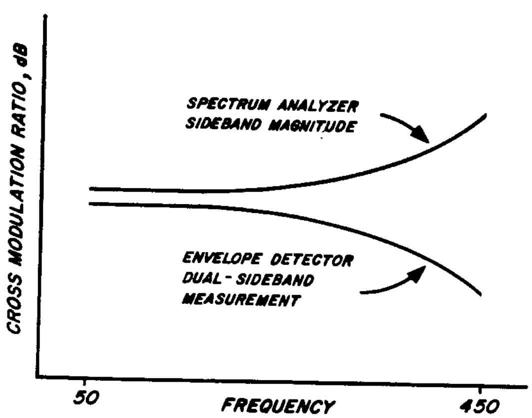


FIGURE 12

CROSS MODULATION OF RF HYBRID IC USING TWO MEASUREMENT TECHNIQUES

This beneficial phase relationship can be destroyed by the cancellation process in a feedforward circuit. For instance, the high frequency cross mod component generated by the main amplifier will have a phase characteristic similar to that shown in Figure 10 with characteristicaly low amplitude cross mod. The cancellation process of the error loop involves the combination of the sideband with another signal of nearly equal amplitude and nearly opposite phase to provide an output signal with substantially reduced sideband magnitude. However the phase of the resultant sideband can take on any value between 0 and 360 degrees. This is shown in Figure 13.

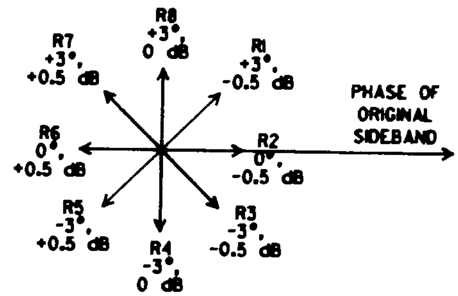


FIGURE 13

MAGNITUDE AND PHASE OF RESULTANT CROSS MODULATION SIDEBAND COMPONENTS AFTER 26 dB CANCELLATION

There are several resultant vectors R1 through R8, plotted in Figure 13. Each of the possible resultant components has a magnitude 26 dB below the original distortion sideband, corresponding to a cancellation signal having a magnitude within 0.5 dB and a phase within 3 degrees of 180 degrees with respect to the original sideband. Clearly, the resultant can take on any phase value.

What then is a reasonable expectation for amplitude cross-modulation performance for feedforward circuits? The answer to this question involves first recognizing the magnitude of the original cross modulation sideband and then analyzing the results of the cancellation process.

Hybrid vendors now specify both composite triple beat and amplitude cross modulation on their 450 MHz parts. Typical performance numbers for both distortions with 60 channel loading at +46 dBmV output levels at all channels is 60 dB. Yet, these same devices exhibit cross mod sideband magnitudes of typically 45 dB referenced to the sideband of a 100% square wave modulated signal for the same test conditions. That is, the sideband magnitude for cross mod components is 15 dB worse than the composite triple beat. But again, this is predominantly phase modulation and not amplitude modulation. Using this information, the amplitude of the cross mod sidebands of a feedforward circuit can now be calculated.

Refering to Section 4.1, which presumes 24 dB cancellation and 3 dB in output losses for the feedforward circuit, one could expect a reduction in the magnitude of the cross mod sidebands of 18 dB relative to the performance of a single hybrid. So, if we start with a predominatly phase modulated sideband component of 45 dB and improve this by 18 dB, the result is a cross mod sideband component 63 dB below reference. This takes care of the magnitude of the component. Now, we must look at the phase.

Figure 13 shows the phase of the resultant component after cancellation. If the resultant is either R2 or R6, the original beneficial phase relationship will be maintained. If the resultant is either R4 or R8, the opposite is true, with complete PM to AM conversion taking place. Note that this condition occurs at perfect amplitude balance of the Feedforward circuit while the extreme limit of delay balance is being reached. Assuming that all points in this circuit are equally probable, the typical or average phase will intuitively be between these extremes. That is, either R1, R3, R5 or R7 on Figure 13 represents average performance.

Combining this assumption with the amplitude information of the preceding paragraphs we are left with the typical cross modulation sidebands having a magnitude of 63 dB and a resultant whose phase relationship to the carrier of typically 45 degrees. In this case, both the amplitude modulation and phase modulation content of the sidebands are assumed to be equal with a corresponding value 3 dB below the magnitude of the resultant component. This assumption is shown graphically in Figure 14 and results in a prediction of typical amplitude cross modulation of 66 dB for the case being considered.

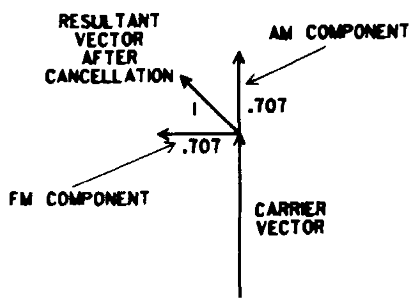


FIGURE 14

ASSUMED TYPICAL PHASE RELATIONSHIP OF THE CROSS MODULATION SIDEBAND RESULTANTS AFTER CANCELLATION

Summarizing and comparing cross modulation and composite triple beat performance predictions for the Feedforward circuit; a hybrid with 46 dBmV output at 60 channels ha 60 dB CTB, 60 dB AM cross modulation, and 45 dB cross modulation sidebands. A Feedforward circuit with the same output level will have 78 dB CTB with 66 dB AM cross modulation. The key point is that this analysis predicts the probability of PM to AM cross modulation conversion by the cancellation process of the Feedforward circuit. Therefore, AM cross modulation should not be specified at levels equal to CTB in a Feedforward amplifier.

Experiments on individual circuits confirm the existence of this process.[4] Room temperature performance of Feedforward circuits can be aligned to minimize this effect, however, the effects of time and temperature can and will produce AM cross modulation in a balanced Feedforward circuit at levels well above the CTB.

14.0 Summary and Conclusions

Feedforward amplifiers have attractive advantages, but specification of equipment performance and system performance must be done on an analytical basis rather than empirical basis. Critical third order distortion performance is not uniform, but is rather dependent on a cancellation phenomena which can change with frequency, temperature, and time.

450 MHz, 60 channel composite triple beat for a Feedforward gain block should be specified at no better than an 18 dB improvement over existing hybrid integrated circuit technology distortion performance.

Use of Feedforward circuits for trunk station pre-amplifiers is not normally advisable due to the decrease in dynamic range associated with higher noise figures of Feedforward circuits.

System designers must expect cascade flatness at temperature extremes to be measureably less than previous non-Feedforward systems.

Poor Feedforward circuit derating should be considered in specifying amplifiers which operate at high output levels, such as bridgers and line extenders.

Cross modulation performance should be specified at levels worse than the composite triple beat.

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LNAs FOR MULTICHANNEL MICROWAVE RECEIVERS

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ABSTRACT

The fade margin of any microwave path can be extended by reducing the noise figure of the receiver. Low noise Ku Band gallium arsenide FET amplifiers and image reject filters have been developed specifically for multichannel microwave receiver application in the 12.7 - 13.2 GHz band. Incorporation of the the amplifier into such receivers either as a retrofit or in new designs generally requires built-in AGC circuitry to control the signal level and optimize performance. Without AGC ahead of the LNA, the third order distortions can build up to unacceptably large levels during unfaded conditions. Performance tradeoffs of various typical system configurations are examined. These tradeoffs illustrate the regimes in which AGC utilization is required.

INTRODUCTION

Steady improvements in GaAs FET technology has led to the development of amplifiers with noise figure on the order of 3 dB in the 12.7 - 13.2 GHz band. This type of LNA, if properly employed, can be incorporated into a multichannel microwave receiver with substantial system benefits. On newly installed paths, the improved receiver noise figure can be traded off against increased antenna diameter. Alternatively, longer path distances are feasible with acceptable system performance. For existing paths, the retrofit of a low noise amplifier and image noise rejection filter into a receiver will lead to increased path margin to overcome rain and multi-path fades. However, the retrofit usually must utilize an AGC to avoid the generation of excessive composite triple beat and other distortions.

LNA WITHIN RECEIVER

As a point of comparison consider first a standard multichannel CARS band receiver operating without an LNA. The receiver is designed to maintain a constant signal level not only at its output, but also at the input to all circuits within the receiver capable of generating any third order distortion. Figure 1 is a simplified block diagram of such a receiver. Its noise figure is specified to be less than 10 dB. The AGC can maintain the VHF output constant over a 35 dB range of microwave input. Throughout this region, both S/N and third order distortion are constant. One can be traded off against the other by adjustment of the AGC level. For instance, the 54 channel carrier to composite triple beat ratio is 81 dB for a S/N of 53 dB. At 56 dB S/N composite triple beat degrades 6 dB to 75 dB. Alternatively, at 50 dB S/N the composite triple beat is 87 dB. In any practical path, the maximum signal available at the input of the receiver is limited by fixed path losses. The difference between this maximum signal and the signal at which the output signal starts to fall is the available AGC range. If rain or multipath attenuation exceeds this range S/N at the output of the microwave receiver will be degraded.

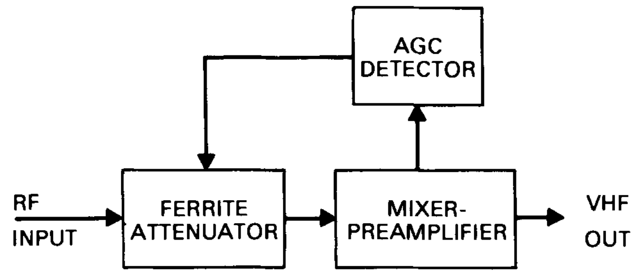

Fig. 1. Multichannel AML receiver simplified block diagram.

This drop in S/N at low input levels is illustrated in Figure 2. The figure also shows the extension of the AGC range to 3.5 dB lower input level by utilization of an LNA between the ferrite attenuator and the mixer as shown in Figure 3. The 3.5 dB improvement in available AGC range also shows itself as a 3.5 dB improvement in fade margin to an "outage level" S/N of 35 dB. The typical 3.5 dB improvements should not be confused with the 3.5 dB noise figure specification of the single stage LNA. The receiver fade margin improvement, ΔF, is a function of both LNA noise figure and gain, G, as well as the receiver noise figure before installation of the LNA. The higher the LNA gain, the greater, up to a point, the improvement in fade margin. However, in order to maintain the S/N within the AGC range at 53 dB, the AGC operating point must be raised by $(G - \Delta F)$ dB. This establishes the correct input level at the LNA. Note however the mixer-preamp is driven harder than before. As a result the C/CTB is degraded by just $2 \times (G - \Delta F)$ dB. For single stage LNAs the gain, less filter loss, is typically 7.5 dB.

A dual stage LNA with 15 dB of gain would further increase ΔF by 1-1/2 dB to 5 dB. At a S/N of 53 dB the 54-channel C/CTB would then by on the order of 61 dB, a value too low for most cable system applications. This is the reason why the LNA gain must be restricted in this configuration. On the other hand for 21 channel applications the C/CTB would be approximately 72 dB and the

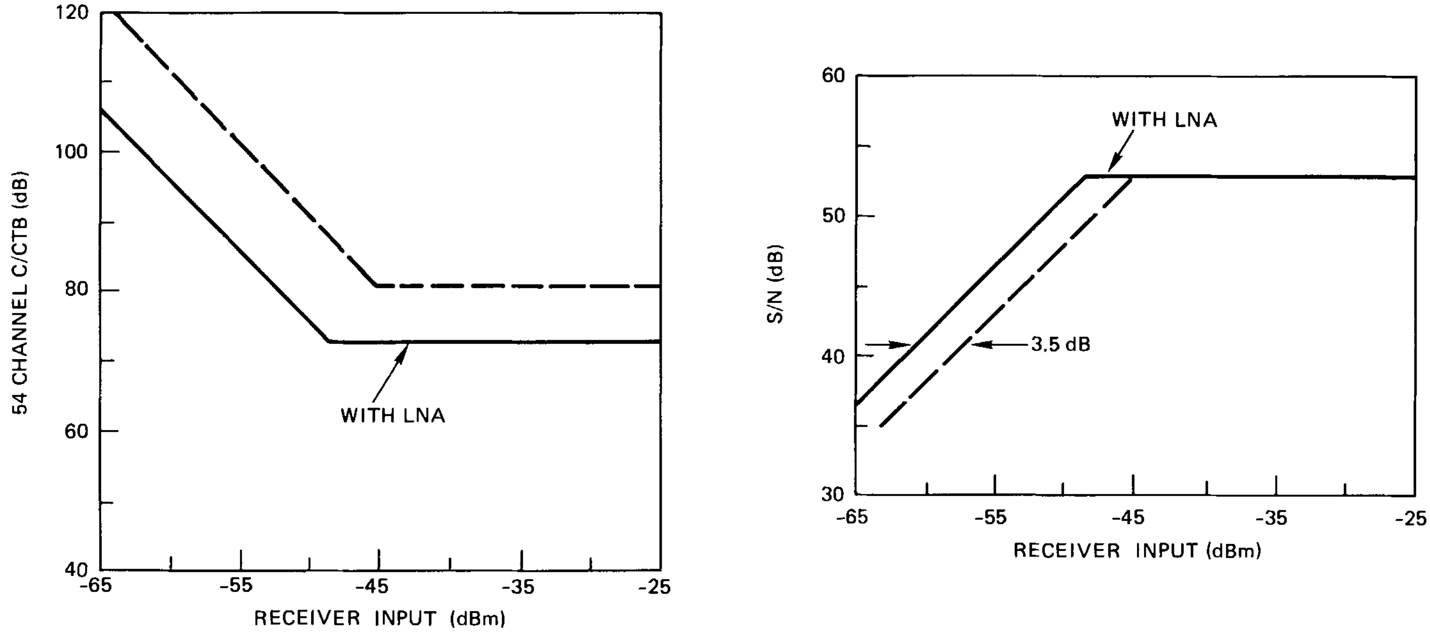

Fig. 2. Receiver S/N and C/CTB with and without built-in LNA.

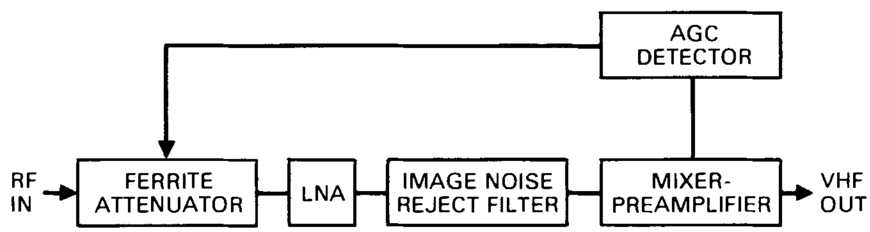

Fig. 3. AML receiver with integrated LNA.

built-in dual stage LNA would therefore become a viable candidate.

Note that in all of the above cases the LNA contributes negligibly to the composite triple beat. This is due to its high 3 IM intercept point, +21 dBm in the case of the single stage LNA and +24 dBm for the dual stage LNA. This high intercept point is achieved by means of a balanced design. A close examination of Figure 4 shows how this design is implemented in the MIC hardware. It should also be pointed out that full advantage of the LNA low-noise performance can only be obtained by providing an image noise reject filter as shown. This is particularly true with high LNA gain since the LNA is then by far the dominant source of noise at the output of the receiver. Since the LNA is a broadband device typically having full gain at the image frequencies, deletion of the filter would degrade the receiver sensitivity by as much as 3 dB.

EXTERNAL LNA CONFIGURATIONS

In contrast to the arrangement shown in Figure 3, CATV systems have often installed an LNA preceding the broadband microwave receiver, either with or without an image reject filter. The generalized arrangement is shown in Figure 5. The deleterious consequence of working without a filter has already been discussed so it will be assumed that the filter has been installed to obtain the largest possible fade margin improvement. Any waveguide loss between the LNA and the receiver is represented by the loss, L, in Figure 5. This arrangement permits mounting of the LNA directly behind the antenna while the bulkier receiver can be more readily serviced at ground level. If then one were to compare the fade margin performance of such a ground-mounted receiver with and without the antenna-mounted LNA, the improvement would be very dramatic particularly if the waveguide loss is substantial. This is illustrated by Figure 6 which assumes the existance of 5 dB of waveguide loss. The improvement in fade margin is 9.4 dB. Naturally, this improvement would be less if L were smaller, but a part of the improved fade margin is also due to the fact that the LNA now preceeds the ferrite attenuator and its unavoidable minimum insertion loss. Thus, this configuration yields the largest fade-margin improvement. The receiver AGC threshold is again set for 53 dB S/N at an antenna input of -40 dBm (corresponding to -45 dBm at the receiver input in the absence of the LNA) but the S/N is not constant in the AGC range. As the signal level increases, S/N at first improves dB for dB until the receiver AGC sets in. In this example, the AGC is set only 1/2 dB higher than usual with respect to the mixer-preamp input level. With this setting, the S/N rises to 53 dB at -40 dBm antenna input. The gradual rise in S/N is due to the fact that while the signal is kept constant

Fig. 4. Balanced LNA design implementation.

after the -53.8 dBm antenna input threshold, the LNA's contribution to noise is increasingly attenuated by the ferrite attenuator. Ultimately preamp noise predominates and the S/N flattens out at high signal level.

Third order distortion at low signal levels is primarily due to the mixer preamp. However, at -49 dBm antenna input the contribution from the LNA equals that of the mixer preamp whose distortion remains constant above the AGC threshold. As the antenna signal continues to increase the LNA's contribution to 3rd order distortion dominates. The actual number depends on both the LNA gain and 3 IM intercept point. The lower the gain and higher the intercept, the better the C/CTB at the high signal levels. Nevertheless, despite the high +24 dBm intercept specification for the 2-stage LNA, it is evident that 3rd order distortion is unacceptably high for LNA input levels in excess of -40 dBm. Even 62 dB C/CTB would hardly be "transparent" when added to the cable system were it not for the fact that LNA caused intermodulation is likely to add on a power basis rather than a voltage basis to that of the cable system. In phase voltage addition is probable only when like devices are generating the distortion products. Power addition of composite triple beat generated by a microwave FET amplifier and a VHF hybrid amplifier has been verified in the laboratory.

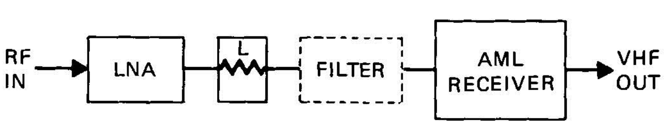

Fig. 5. External LNA arrangement.

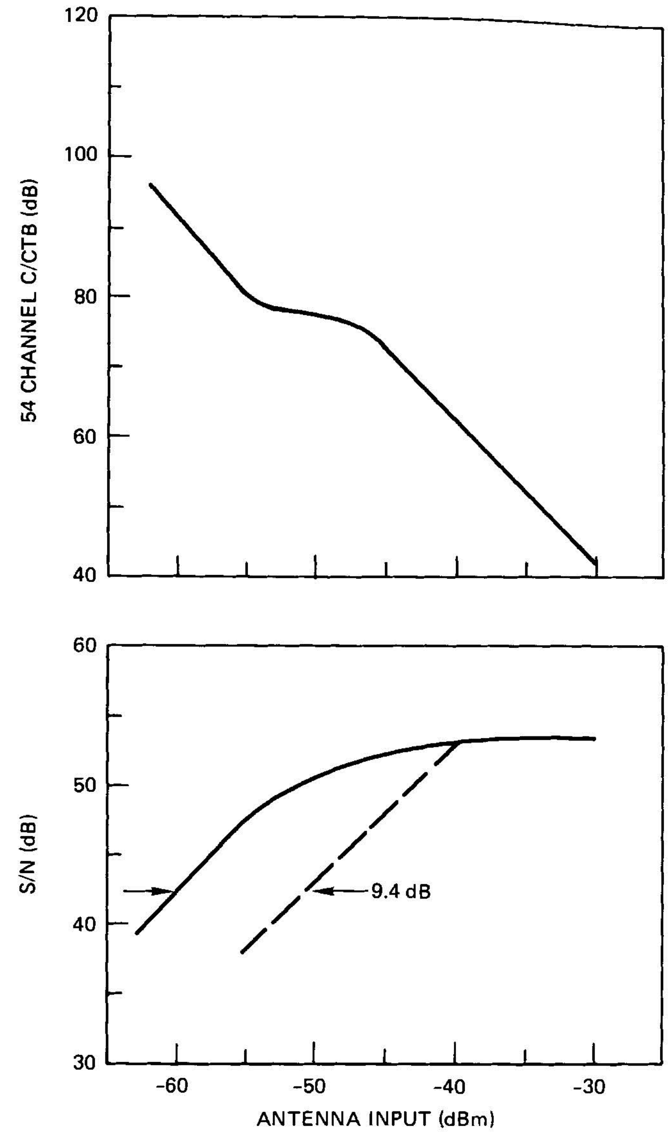

Fig. 6. Tower mount dual stage LNA (5 dB waveguide loss).

EXTERNAL AGC

To extend the useful range of application for the tower-mounted LNA it is necessary to place the AGC function in front of the LNA as in the previous configuration. This is conceptually achievable by removing the ferrite attenuator from the AML receiver and mounting it instead in front of the LNA. Figure 7 shows the performance obtained. The fade margin improvement is 0.7 dB less for the same LNA and waveguide as in Figure 6 because the small signal insertion loss of the ferrite attenuator is now in front of the LNA instead of following it. The 8.7 dB fade margin improvement dictates that the AGC commence at -48.7 dBm at the antenna input. This translates to 5.6 dB higher than normal signal level at the mixer preamp input to achieve the 53 dB S/N. As in Figure 2, C/CTB is dominated by the mixer-preamp.

Even better performance could be obtained with a dual AGC control. In this case the ferrite attenuator remains inside the AML receiver but an additional ferrite attenuator is added in front of the LNA. At very low signal levels neither AGC is activated. At threshold, the attenuator internal to the receiver becomes active and maintains constant input level to the mixer-preamp. As the antenna signal level continues to increase, this attenuator takes on a fixed value and control shifts to the pole-mounted attenuator. Thereafter, a constant signal level is maintained throughout the remaining AGC range at the LNA as well as at the mixer. Despite the added complexity that this concept embodies, improvement in C/CTB is a modest 3.5 dB relative to the case illustrated in Figure 7. A more fruitful approach to further improving intermodulation would seem to be a direct improvement of the linearity of the mixer-preamp. In any case the performance indicated by Figure 7 should be satisfactory for most cable systems.

SUMMARY

In conclusion, LNAs can be used to increase fade margin on a microwave path. However, care must be taken to avoid excessive generation of third-order distortion products. This is best done with AGC which maintains both S/N and C/CTB constant as with standard multichannel broadband receivers. If LNAs are used without AGC the range of permissable applications is severely limited. In any case it is important to specify a high LNA 3-IM intercept point and to utilize an image-noise reject filter to achieve the best possible performance.

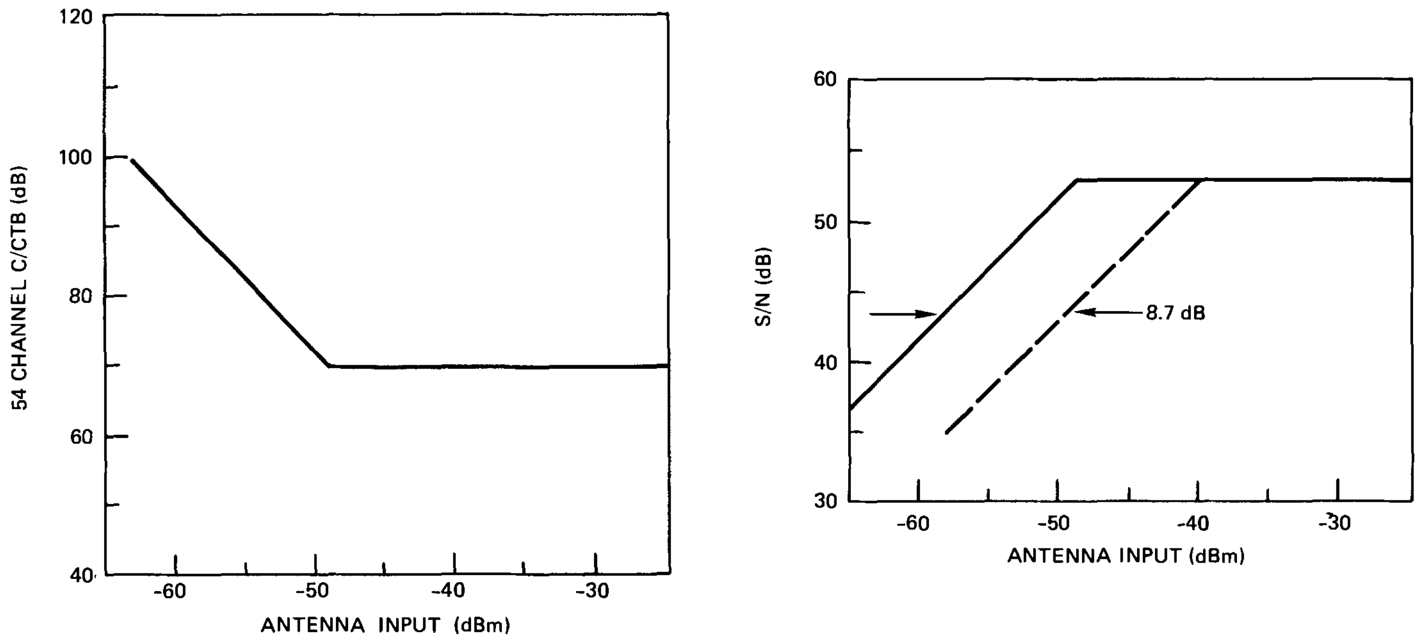

Fig. 7. Tower mount LNA with AGC (5 dB waveguide loss).

LOCAL COMMERCIAL INSERTION: A PARTNERSHIP
CABLE OPERATOR, PROGRAMMING SERVICE AND MANUFACTURER

Paul E. Olivier

American Television and Communications Corporation

Local commercial insertion is becoming an increasingly important revenue resource for the cable operator. Program services, cable operators and equipment manufacturers must work together in coordinating the development of commercial insertion equipment, program services signaling procedures and methods to ensure continued growth in local advertising sales. Procedures and guidelines for signaling methods, pre-roll times and signal measuring must be established. Local availabilities are important to the cable operator, and the lack of sensitivity by some program suppliers and manufacturers is of paramount concern. Operators are sometimes forced into buying automated equipment not capable of handling the task at hand. The challenge of handling the problems inherent in local commercial insertion touches all of those involved in our industry. A close examination of these problems, discussions and solutions will ensure the success of cable operators, program services and the equipment manufacturers.

Selling advertising on local cable has not been as easy as some operators were led to believe. The new revenue stream flowing from local advertising spot availabilities on satellite network programming very often started as a trickle. System operators have been faced with significant capital expenditures to develop reliable commercial insertion equipment, but instead they have encountered problems with scheduling, signaling and malfunctioning equipment.

The Cabletelevision Advertising Bureau says more than 800 cable systems have local advertising sales capabilities. It is important to note that more than 100 of these systems are of the smaller category, serving 5,000 or less subscribers. At present, more than 1,000 cable systems can accommodate local cable advertising through the use of of data channels, alphanumeric and graphic displays.

Cable advertising is fast becoming an increasingly important revenue source for the cable operator.

LOCAL ADVERTISING REVENUE PROJECTIONS

* Year	Dollar Projections	
1983	$ 50.4	million
1984	80	million
1985	128	million
1990	672	million
1994	1.3	billion

* from Cabletelevision Advertising Bureau

The industry has launched an aggressive campaign documenting the growth of cable. The Cabletelevision Advertising Bureau, rep firms and systems are helping to inform advertisers and major agencies about the effectiveness of cable advertising. By now, most of us have seen CAB's, Einstein campaign, $E=mc^2$. The formula, "Effectiveness Equals More Cable," should help increase both cable programming services and local advertising revenues.

On June 13, 1983, in Houston, Texas, the CAB board of directors unanimously approved the recommendation that a Local Sales Advisory board be formed. This board would be would be responsible for:

1. Identifying key issues affecting the development of local cable advertising, and

2. Reporting to CAB on the role it should play in dealing with those issues.

I have had an opportunity to assist the Local Sales Advisory Board and work as a member of the ad hoc technical subcommittee. The role of the subcommittee was to deal with technical problems in coordinating systems' commercial insertion equipment with network transmission procedures.

Our goal was to survey systems and determine the exact problems that occur in commercial insertion procedures. The technical committee's immediate concern was to work with the cable networks and equipment manufacturers to improve their support of local commercial insertion operations.

SATELLITE TONE SIGNALING

An objective was set to establish, if economically viable, a unified cue tone system which could be utilized by all programming services. At the time, we found that there were a number of signaling methods used.

1. DTMF tones (Dual Tone Multi-Frequency): These tones are most common on ESPN, CNN, CBN, ARTS and Entertainment, Nickelodeon and SPN, just to name a few.

2. DTMF tones placed on a separate audio subcarrier from the program audio. This is being used on USA Cable Network.

3. VITS (Vertical Interval Test Signal): Such as that being used for signaling of local availabilities on The Weather Channel.

4. MTV "pilot" tone cue method: A 19 KHz sub audible tone transmitted on the 5.8 MHz audio subcarrier. It is used by MTV in conjunction with the Wegener or Leaming stereo audio system. The pilot tone starts the pre-roll five seconds prior to the commercial break and stays on for the duration of the break. The tone drives a contact closure on the back of the stereo audio system which, in turn, remotely controls automated switching and machine control of VTRs.

   Another 19 KHz tone is transmitted on the 6.62 MHz audio subcarrier to switch audio from the network to the local source.

During 1983, a fifth method of signaling was also being used within the industry. An inaudible digital signal was used by SNC. Sat-A-Dat devices were used in the headend to decode the digital signals sent by the network. The Sat-A-Dat device provided contact closure to activate automation equipment.

The signaling cue tones utilized by satellite services consist of four DTMF tone pairs. The overall duration of the burst is approximately 1/4 second for the group of four tones. The fourth digit of the code is used to differentiate between the start and finish of an availability. Star (*) indicates the beginning and pound (#) indicates the end of the spot.

Most satellite services place a great deal of attention on the reliability and location of the cue tones. However, there have been numerous mistakes in cue tone transmission. In order to achieve a high degree of reliability with automated commercial insertion equipment, the proper audio level during DTMF tone transmission is extremely important.

One of the major problems with automated insertion equipment is the proper maintenance of audio levels as they apply to satellite tone decoders in the system. NCTA has recommended that during DTMF tone transmission, subcarrier deviation shall be 12 dB below peak deviation for that subcarrier. A convenient method must be developed and documented to measure the amplitude.

In order for the tone decoders to operate reliably, the amplitude range must be within a specific area. These amplitudes are very difficult for most cable technicians to accurately interpolate. Program signals vary radically, depending on the nature of a given program.

Tones are only transmitted several times an hour and few systems have the necessary equipment to check levels from the satellite receiver. There has been a lack of industry coordination and standardization concerning tone controls. Since the tones facilitate the automated insertion of locally generated material by the cable affiliate, it is necessary that satellite services place a high level of concern on the audibility of tones and their relationship to the program audio.

It has been proposed that the tone and space duration be not less than 35 ms and not more than 45 ms, with a 35-45 ms silence between tones. It is also proposed that there be a 40 ms pre-tone silence before each sequence of tone burst.

During September 1983, the Local Sales Advisory Board agreed to have its local advertising divisions closely monitor DTMF network tone performance during a two week period. During this period, commercial insertion operators kept a log of every problem caused by network signaling, equipment malfunctions, and operator error.

Documentation also included local breaks not running as scheduled, network's failure to send tones, erratic tones running in the middle of programs and scheduling errors. Erroneous tones may have been caused by cross talk in VCR audio channels but some were actual tone burst.

It was found, for instance, that during live coverage of a news event on CNN on September 6, tone signaling information ran at 15:55:56 EST during the Nigerian ambassador's presentation to the UN Security Council. The tones caused automated equipment to be activated, causing a break from the network. The reoccurrence of cue tones during live news coverage occurred again on September 7 at 14:28:00 EST, September 12 at 14:56:00 EST, and again on September 12 at 15:56:00 EST.

It was also found during the two week period that during scheduled local availabilities occurring during live sporting events on ESPN and USA Cable Network that DTMF tones and schedule information were sometimes erratic. It was also noticed during this time period that many of the video cassette players being used throughout the industry would not cue and lock within the prescribed pre-roll times for various networks. More than 75% of all units being used for automated commercial insertion required more than 5 seconds pre-roll time. Most of ATC's automated 3/4 inch video cassette players required more than 5 seconds pre-roll time, for instance.

When all the variables concerning method of signaling, length of pre-roll time, fluctuation of schedule and operator error are combined, the reliability of automated commercial insertion becomes suspect.

PRE-ROLL TIME

The Cabletelevision Advertising Bureau's technical subcommittee proposes an eight (8) second pre-roll time for both manual and automated insertion systems. Since most video cassette players and recorders are servo-locked through the use of a TBC or simply by receiving a reference from the satellite signal, sufficient time must be required for servo-lock and pre-roll.

MODE OF OPERATION

Some important considerations for the operator when purchasing equipment for commercial insertion is the mode of operation, i.e. how the spots are sold, will the control system be manual or automated, will the system accommodate only "Run Of Station" (ROS) schedule, random access, sequential access or will it be a combination of manual and automated insertion. When making the selection for the type of equipment needed, the operator must take into consideration who the competition is and where the cable advertising revenue will come from. There are generally two attitudes in developing the cable advertising business.

1. Small Market

   The cable operator may be creating an advertising medium that does not already exist in the market the cable system serves. This is most common in smaller communities where the majority of local advertising is handled through print and radio. The lack of local television provides the cable operator with a new form of advertising in the market served. In this scenario, the cable operator has a greater equipment selection to choose from to accommodate the insertion of commercials. The cable operator may select to purchase equipment which is operated manually or automated equipment. The operator must examine the staffing required for either operation.

2. Large Market

   In a larger market, most commonly in the top 50 ADI, cable advertising is being compared to television advertising. The competition in this market is the broadcaster. The cable operator must be far more selective in choosing equipment which is capable of performing competitively with the scheduling standards, operational techniques and technical standards of the broadcaster. The switches from satellite services to local commercials and back to satellite service must be transparent. Switching must take place in the vertical interval and local equipment must be phased with the signals from the satellite feed.

   Extremely close attention must be given to the adjustment of audio and video levels to coincide with those of the satellite service. Time base correctors and audio signal processing should be considered when developing a commercial insertion system to serve a large market.

   Equipment must be flexible enough to accommodate program changes and commercial position changes. Optional log verification systems may be needed to certify the actual positioning and play times of commercials. These systems are generally staffed during the hours of operation to allow for manual operation or override of the automated system.

EDITING COMMERCIAL REELS

The formatting of commercials is extremely important when selecting a mode of operation. Attention should be given to the amount of time required to edit commercial reels. It may be necessary with some automated systems to tone tapes, digitially encode information, or carefully note the control track or SMPTE time code of the tapes.

Editing commercials can be very time consuming. With some systems, an operator can opt to edit commercials back to back on a videotape. This technique is most common when scheduling a Run Of Station schedule (ROS).

An operator can select the technique of building spot reels by carefully studying the schedule of the various satellite services. A tape can be built which consists of individual breaks which will be run in 30, 60, 90 or 120 second commercial segments. This tape can then be programmed manually or through an automated system. The operator must be aware that this technique is not flexible when dealing with program schedule changes.

Another common method is editing "pods." Tapes are edited to accommodate groupings of commercials. These groupings are then programmed as a commercial pod. The positioning of various commercials are selected prior to the editing process. This technique is most commonly used in semi-automated systems.

The single spot tape is the least common used by cable operators with manual or automated commercial systems. A tape with one single commercial may contain identification and signaling information. The tape is most commonly used in a sequential automated system and can easily be played in a manual sequential operation.

Regardless which editing format is used, the operator must always pay close attention to the details involved in the editing process. The operator must time the commercials carefully, must place toning or digital information at precise locations and must not overlook the importance of proper video and audio levels.

EQUIPMENT

Selecting the proper equipment to meet the mode of operation the cable system has chosen may be the most important step in designing your commercial insertion system. During the period from August 1983 to April 1984, I have been able to identify 30 hardware manufacturers all claiming to design and build automated commercial insertion equipment for the cable industry. Many of these operators are familiar with the satellite programming services which provide local commercial insertion availabilities, as well as the needs of the cable operator. Other manufacturers have never been on the premises of a cable system, nor have they seen any of the satellite services with which their system is designed to work. Much of the equipment has never been tested in a field environment. Cable operators are being told that the automation systems are so reliable that the equipment can be set up in a headend and operated for seven days at a time totally unattended. Some manufacturers lack the sensitivity to understand the operational needs of the cable system. Sometimes a cable system finds itself with equipment that cannot perform the requirements of the advertising sales department. Other times, the equipment is designed with software that cannot accommodate operator errors, satellite signaling errors or last minute program changes. Manufacturers must understand cable, the business of commercial advertising on cable and the satellite programming with which their equipment is designed to interface. A manufacturer that does not know the difference between the DTMF signaling on CNN and the tone signaling on MTV should not be telling the operator that his system is fail proof, and all tones are the same. Too often, the cable operator has been touted in ordering equipment which he thinks and has been told will serve his needs only to find that it does not perform as expected. It is the responsibility of the cable industry, hardware manufacturers and the programming services to work together to provide information which allows the manufacturers to design and build equipment suited to fill the needs of the end user.

Many manufacturers perceived the cable industry as the new frontier—an opportunity for increased sales and a new source of revenue. Manufacturers should not take advantage of the cable operator by rolling out product which is not ready for field distribution. Too many cable operators have spent too much time attempting to de-bug insertion systems, spent time replacing components and returning equipment which has been recalled by the manufacturer. Recently, one noted manufacturer of commercial insertion equipment recalled to the factory the first 75 devices delivered to the field. Cable systems are in the business of selling commercial avails, not being test locations for various manufacturers.

There are a number of manufacturers that have excelled in the design, development and rollout of commercial insertion equipment. They have taken the time to evaluate cable's needs, and the method in which cable operators would like to insert commercials. They have studied the individual programming services and signaling techniques, and they have been in the field to see what works and what doesn't.

Cable operators must take the time to question the manufacturers and seek out other end users that are using the products proposed. Also, the cable system should check the integrity of the manufacturers and vendors when seeking out commercial insertion equipment. The manufacturer and vendors must be financially stable to stay in business long enough to complete the project and to provide the necessary service and support after the hardware has been sold.

DESIGN AND DEVELOPMENT OF COMMERCIAL INSERTION SYSTEMS

When designing a commercial insertion system, one should take into consideration the entire scope of the project.

1. The mode of operation
2. The number of channels
3. The programming services on which the availabilities will be inserted
4. Network signaling methods
5. Physical requirements
   (a) Space
   (b) Electrical
   (c) HVAC

A design and development phase should allow for the gathering of all the necessary data pursuant to the engineering design phase of the project. The objectives and design parameters should be identified, reviewed, discussed and prioritized. All mechanical and electrical criteria must be evaluated pursuant to the performance of engineering and final design of the commercial insertion system.

Manufacturers and turnkey vendors should produce documentation necessary and incidental to effect application. Documentation should be further defined as providing hardware descriptions including block diagrams, schematics, system wiring diagrams and control diagrams.

The design should be reviewed to ensure that optional interfaces with the headend are included. These could include stereo processors similar to the ones used with The Nashville Network and MTV. Those most commonly used are the Leaming, Wegener and Catel. Some of these processors will require optional VCR cards. If an operator is planning to insert commercials on a stereo service and has unanswered questions, it is best to contact the manufacturer or the particular satellite service for assistance.

THE TIME IS NOW

Cable operators, programmers and manufacturers must work together and concentrate efforts to ensure the industry's overall chances of success with local advertising sales. Generally recommended practices must be established for all areas. The time is now to settle on pre-roll times that manufacturers, programmers and cable operators can live with.

The first step has been taken. All parties now realize the need to work closely in establishing guidelines for the technical development of commercial insertion. We must work together to develop economically viable methods to accomplish local commercial insertion. We must study the problems of commercial insertion involving multiple headends and system interconnects.

Programmers and manufacturers alike must not forget the needs of the small system operator. We must afford these systems the same support and concern that we offer the large MSOs. The intent is to bring the program services, local operators and manufacturers together to avoid the many, many horrendous problems that we have encountered.

Cable advertising is fast becoming an important part of the cable industry, however, without major attention to the problems inherent in local advertising, the operators, the program services, and the manufacturers can expect major dissatisfaction. In order for local commercial sales to be successful, a cooperative effort must be made between cable operators, program services and equipment manufacturers to develop reliable methods of commercial insertion.

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MEASUREMENT OF INTERMODULATION PRODUCTS GENERATED BY CORRODED OR LOOSE CONNECTIONS IN CATV SYSTEMS

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ABSTRACT

Metal-to-metal junctions can exhibit non-linear characteristics as a result of corrosion or low contact pressure. The non-linearity can be seen on a V-I curve tracer and has been implicated in causing intermodulation interference, especially in the 5-30 MHz band. The junction behavior at RF under actual operating conditions cannot be accurately predicted from the low frequency V-I curve, however.

Measurements have been made of the actual level of 3rd order Intermodulation Products generated at RF by a variety of connections. The results are reported here, with a description of the factors found to influence the junction's behavior.

INTRODUCTION

Junction non-linearity is receiving increased attention as a possible cause of excess noise in the troublesome 5-30 MHz upstream band. Lovern and Butler [1] have presented an extensive theoretical analysis of the effect in CATV systems, while reporting only one measurement at 60Hz, 0.5 volts A.C. and 0.15 Amps. Other researchers [2], [3] have measured the generation of 3rd order intermodulation products at microwave frequencies with incident RF power of approximately 3 watts. This paper reports the results of measurements made at typical Cable Television frequencies and power levels, with and without 60 Hz power on the junction.

A junction is linear if it obeys Ohm's Law over the range of interest (R=V/I=constant). A curve tracer will display this V-I characteristic as a straight line with slope m=1/R (dashed traces in Figure 1). Some junctions exhibit V-I characteristics more like the solid trace, however. The curvature is caused by electron tunnelling through thin Oxide or other corrosion films separating the metal contacts [4]. This is easily seen on Aluminum contacts under low contact pressure, for Aluminum is known to grow a uniform insulating layer of Al_2O_3 ranging from 30 to 100 Angstroms thick upon exposure to air.

Generally speaking, a junction with non-linear V-I characteristics will cause Intermodulation Products (IP's) to be generated when two or more different frequencies are incident upon it. The most commonly encountered IP is the 3rd order $(2f_1-f_2)$, followed by the 5th order $(3f_1-2f_2)$. In systems transmitting a range of frequencies, many IP's could fall in the 5-30 MHz band [1].

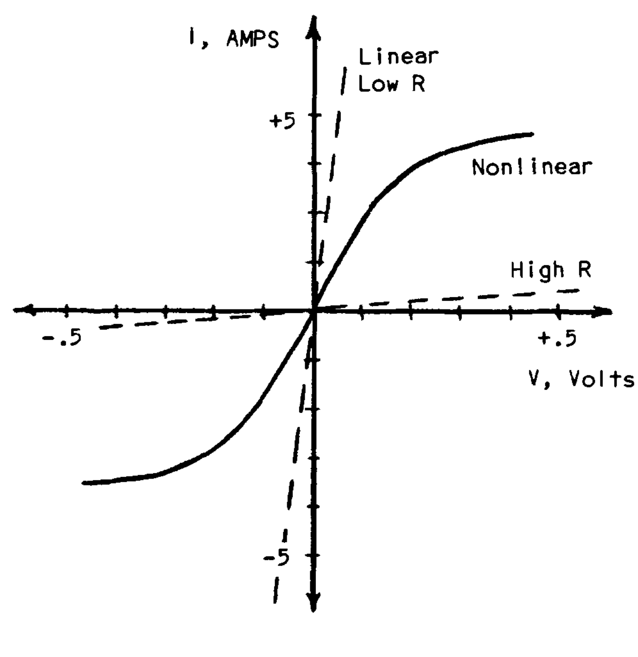

Figure 1) V-I Characteristics

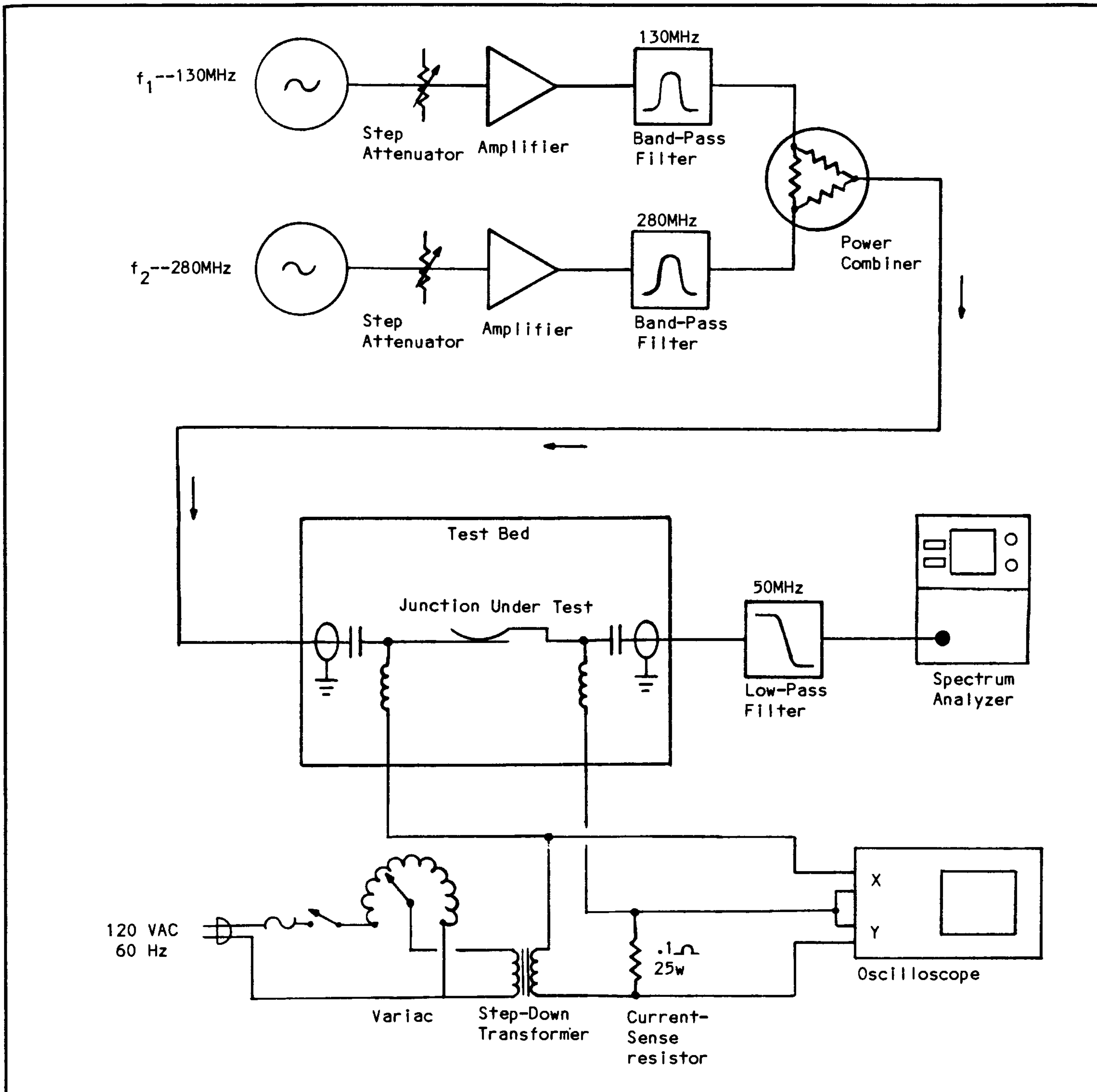

Figure 2--Test Equipment Configuration

MEASUREMENT CONFIGURATION

The actual generation of IP's was measured with the equipment set-up shown in Figure 2. 50 Ohm RF hardware was used throughout, due to availability. The fundamental signal frequencies f_1=130 MHz and f_2=280 MHz were chosen to produce a 3rd order IP at 20 MHz. The signal levels were controlled by step attenuators, then boosted by a pair of Amplifier Research 5 watt power amplifiers so that the level of f_1 reaching the sample could be varied from -20 dBm to +20 dBm and f_2 from -20 dBm to 0 dBm. The amplifiers were followed by multiple-section passive bandpass filters (BPF's) to remove any harmonic distortion from the signals and to prevent power from flowing between sources. The signals were then combined via a resistive "delta", resulting in a 6dB drop, and fed to the test bed.

The test bed was constructed by mounting two type-N connectors and a decoupling network on a copper-clad ground plane. The samples under test were secured at the ends to plexiglass support blocks, and when possible, soldered into place.

The output signal from the test bed was then fed through a 50 MHz 4-section low-pass filter (LPF) to block the high amplitude fundamental signals. If these are not blocked, the over-loaded front end of the spectrum analyzer can generate its own 3rd order IP's, indistinguishable from the ones generated by the junction under test..

The curve-tracer section of the set-up consisted of a Variac, step-down transformer, current-sense resistor, and an oscilloscope in x-y mode. The x-deflection displayed the voltage drop across the sample, while the y-deflection in volts times 10 equalled the current in amps.

Verification of the set up was accomplished by soldering a wire across the test bed in place of the sample under test and measuring the fundamental signal levels transmitted to the spectrum analyzer with the LPF removed (f_1=-20 to +20 dBm, f_2= -20 to 0 dBm). Replacing the LPF, residual 3rd order IP's were searched for. None were found down to the noise floor of -80 dBm. This performance is adequate for the testing described in this paper.

MEASUREMENTS

Experimental Al-Al Junction The first junction that was tested was comprised of two pieces of Aluminum outer conductor that were cut from cable that had been in the field for several years. The surface appearance was gray-white with almost no metallic luster. The samples were simply rested against each other, under no external mechanical load. With no R.F. signal applied it was observed that the junction's V-I charactistic varied significantly as a function of the applied voltage. For V= 0.1 volt peak-to-peak (p-p), the V-I characteristic looked very linear with a resistance of approximately 1 Ohm. As V was increased to 0.3 volts p-p, the V-I characteristic assumed the "S" shape of Figure 1. When V approached 1 volt p-p, the junction produced an audible crackling noise, and the V-I characteristic became linear with a resistance of 50 milli-ohms. As the voltage was reduced, the junction remained linear with the same moderately low resistance. Because the junction was under no mechanical load, it was very sensitive to vibration and tapping, which showed up as broken, noisy traces on the oscilloscope. Tapping disturbed the low-resistance connection, essentially returning the junction to it's original state. The observations are summarized in Table 1.

With the curve tracer turned off, RF signals were applied to the junction, and the 3rd order IP level was recorded. The results are presented in Table 2. Again, vibration and tapping were very evident on this loose connection, with levels jumping 10 to 30 dB and broadband noise appearing during vibration.

One very important result is noticeable. Even for this very poor junction, it takes relatively high signal levels (from a CATV standpoint) to generate appreciable 3rd order IP's. This supports the curve tracer observation that for low voltages, the junction is linear.

The next experiment with the Al-Al junction was to observe simultaneously the low frequency V-I curve and the 3rd order IP's. For low curve tracer voltage (0.1 volt), the RF performance of the junction was identical to the results in Table 2. As the voltage was increased to 0.3 volts, the spectrum analyzer displayed high though intermittent levels of broadband noise, and the 3rd order IP signal fluctuated wildly. With 1 volt applied, the IP signal disappeared completely, though some broadband noise from the poor connection was still visible.

TABLE 1] V-I Characteristics of Al-Al Junction Under no Mechanical Load

Step	Applied Voltage (p-p, 60 Hz)	V-I Curve Shape	Resistance
1	0.1V	Linear	1 OHM
2	Increased to 0.3V	"S" Shaped	Non-Linear
3	Increased to 1V	Linear	.05 OHM
4	Decreased to 0.3V	Linear	.05 OHM
5	Decreased to 0.1V	Linear	.05 OHM
6	0.1V, Junction Tapped	Linear	1 OHM

TABLE 2] 3rd Order Intermodulation Product Generation
Al-Al Junction Under no Mechanical Load

f_2 Level, dBm					
0	<-80 (1) <-80 (2)	-50 <-80	-25 -55	-20 -40	-25 -50
-10	-60 <-80	-60 <-80	-50 <-80	-40 -60	-30 -60
-20	<-80 <-80	-60 <-80	-40 <-80	-30 -70	-30 -60
	-20	-10	0	+10	+20
	f_1 Level, dBm (3)				

NOTES:
1) Maximum level of $2f_1-f_2$ in dBm observed during tapping. Always intermittent and accompanied by broadband static.
2) Maximum level of $2f_1-f_2$ in dBm observed with junction at rest. The actual level from junction at rest varied from this level to <-80 dBm in depending on tapping.
3) To convert the level in dBm in a 50 Ohm system to dBmV, add 47.

The explanation for the observed change in junction characteristics with applied voltage lies in a phenomena called "fritting" [4]. This is basically a breakdown of the thin Al_2O_3 film due to extremely high local electric field intensities. If a 100 Angstrom Al_2O_3 film has 1 volt potential applied to it, the electric field intensity is 10^8 volts/meter, enough to cause break down. Continued current flow tends to widen the conduction path, reducing the junction's overall resistance. Reference 4 contains extensive details of fritting.

The final experiment with the Al-Al junction was to intentionally frit the junction. The curve tracer voltage was set to 5 volts, but disconnected from the circuit. High levels of RF were applied to the junction, and the 3rd order IP observed. Immediately upon applying the 5 volt power, the 3rd order IP disappeared entirely. No amount of vibration made it reappear, as the junction had been fritted. Removing the 5 volt power, no 3rd order IP was visible until tapping once again disturbed the junction.

<u>Tap Box Set Screw-Center Conductor Connection</u> Most tap boxes contain an Aluminum contact block with a plated steel set screw to establish contact with the center conductor. One of these assemblies was removed from a tap box and mounted in the test bed to evaluate the effect of low contact pressure. The center conductor used in this experiment was new Copper-clad Aluminum from a polyethylene-foam (PE) type cable. It had been scraped with a knife, though a very thin layer of PE still adhered to it. This is the way craftsmen often prepare the cable.

It was much more difficult to obtain the "S" shaped curve with this sample. With the set screw completely loose, the curve tracer indicated an open circuit for V=0 to 15 volts A.C. It appears that tunneling does not occur through the residual PE. Tightening the screw very gently by hand, just until contact was established, produced an immediate jump of the V-I curve to a linear low resistance state, regardless of applied voltage. The "S" shaped curve could only be produced by gently tapping the assembly with approximately 0.3 volts applied until the assembly loosened. Then the curve was unstable, tending to jump to either the short-or open-circuit condition.

The RF characteristics with no A.C. power applied were also better than with the Al-Al sample. See Table 3. The maximum $2f_1-f_2$ levels observed during tapping were more short-lived and noisy than those reported in Table 2, and it was generally more difficult to produce a stable 3rd order IP.

The behavior of this junction under simultaneous RF and 60 Hz power was similar to that reported for the Al-Al junction. Again, fritting occurred with approximately 1 volt applied to the junction, completely preventing 3rd order IP generation. Interestingly, when the curve tracer indicated an open-circuit condition, the level of fundamental signals f_1 and f_2 had only dropped by about 10 dB. Apparently there was a substantial parasitic RF coupling across the otherwise open junction.

The copper clad center conductor used for this series of tests was replaced by a Tin-plated Brass pin cut from a pin-type connector. The curve tracer generally indicated either an open-circuit or a short-circuit condition with the set screw loose --no stable "S" shaped curve was observed. An intermittent "S" shaped curve could be seen during tapping on a very loose connection. It is reasonable to assume very low 3rd order IP generation from this configuration. Regardless of the center conductor material, tightening the set screw with a screwdriver prevented any 3rd order IP generation.

<u>Pin-Type Connector Center Conductor Seizure</u> Pin-type connectors rely on some internal arrangement to press the fingers of a "pin-basket" down on the cable's center conductor to grip it and establish contact. A Tin plated Brass pin basket was removed from a connector and mounted on the test bed to simulate the worst-case condition of no externally applied contact pressure. A new Copper-clad Al center conductor (with some residual PE) completed the circuit.

The curve tracer indicated either an open-circuit or short-circuit condition, with no stable "S" shaped curve. This is not surprising, since clean Tin and Copper are excellent contact materials, and PE, when present, is a good insulator. Under RF power, this junction generated no 3rd order IP's.

A severely tarnished section of Copper-clad Al center conductor was recovered from a Styrene-foam cable that had been in the field for many years. The foam was not bonded to the center conductor so consequently water had tracked down the cable. The tarnish was black and shiny, and was determined to be Copper Oxide.

A junction consisting of this tarnished Copper conductor and the loose Tin plated Brass pin basket was mounted on the test bed. The curve tracer showed the junction to be initially non-conductive, but after some wiggling, a stable "S" shaped V-I characteristic was observed (V=0.3 volts). The non-linear characteristic was very similar to that seen with the Al-Al junction, pictured as the solid trace in Figure 1. Again, increasing the voltage across the junction to 1 volt broke down the oxide layer, resulting in a linear, low resistance

TABLE 3] 3rd Order Intermodulation Product Generation
Loose Tap Box Set Screw/C.C. Connection

f_2 Level, dBm					
0	<-80 (1) <-80 (2)	-65 -80	-40 -60	-30 -40	-40 -40
-10	<-80 <-80	<-80 <-80	-60 <-80	-50 -60	-60 -60
-20	<-80 <-80	<-80 <-80	-60 -80	-50 -60	-80 <-80
	-20	-10	0	+10	+20

f_1 Level. dBm (3)

TABLE 4] 3rd Order Intermodulation Product Generation
Tarnished Copper - Tinned Brass Junction

F2 level, dBm					
0	<-80 (1) <-80 (2)	-80 <-80	-60 -70	-50 -60	-45 -60
-10	<-80 <-80	<-80 <-80	-65 <-80	-55 -70	-65 -70
-20	<-80 <-80	<-80 <-80	-75 <-80	-60 -70	<-80 <-80
	-20	-10	0	+10	+20

F_1 level, dBm (3)

NOTES: See notes to TABLE 2

connection. The 3rd order IP levels from this junction before fritting are listed in Table 4. No IP's were found after fritting.

Aluminum Outer Conductor-To-Connector Junction Raychem, Gilbert, and LRC 1/2" pin type connectors were installed to connect Aluminum coaxial cable to taps in accordance with manufacturer's instructions. No connection demonstrated visible non-linearity on the curve tracer when new. The samples were then corroded by two month's submersion in a salt bath with daily airing. The samples built up a thick layer of salt, and the Aluminum cable developed lines of small holes shot through to the PE. When reconnected to the curve tracer, again no sample showed non-linearity, and the junction resistances were low. It appears that the original connections remained intact, perhaps protected by a surrounding Al_2O_3 film.

DISCUSSION OF RESULTS

The results reported here agree with the conclusions by Bayrak and Benson [2], who reported that the highest 3rd order IP's were generated by Al-Al and Steel-Steel contacts, the lowest by Copper and Brass contacts, with intermediate levels produced by Aluminum -Copper contacts. They also reported that the highest level IP's were produced by junctions under minimum mechanical load, with IP level falling rapidly as load is applied. Finally, they confirmed that a thin insulating film of plastic (in their work, Teflon) prevented IP generation.

This paper's observation of film breakdown by fritting is strongly supported in reference 4. Anyone interested in further study of electrical contacts should locate this book. Especially relevant is the description of "applied fritting" from the telephone world, where an EMF of 48 to 60 volts with equivalent source resistance of 100,000 Ohms is maintained on relay circuits to frit the contacts for reliable connections.

The level of the 3rd order IP generation reported here is low in all but worst cases. A connection really has to be pretty poor to generate 3rd order IP's, and poor connections generate a host of other problems -- 'static', varying signal levels, voltage drops, intermittence, RFI, etc. No connection studied here generated solid 3rd order IP's without showing some of the other symptoms of poor connections.

SUMMARY

1.) Intermodulation Products (IP's) can be generated by corroded, tarnished, or loose connections under low contact pressure.

2.) Signal levels must be high to generate significant IP's. For signals at -20dBm (50 Ohm system), 3rd order IP's were below -80dBm for all connections. Signals at -10dBm produced 3rd order IP's below -80dBm in all but the worst case of Al-Al under zero load; here they reached -60dBm intermittenly. Signals at 0dBm (+47dBmV) produced 3rd order IP's of -55dBm to -70dBm in loose connections.

3.) Junctions with more than 1 volt of 60 Hz power applied generated no IP's due to contact fritting.

4.) When observed, the IP's were always jumpy and accompanied by broadband static from the loose connection.

5.) Any reasonable amount of contact pressure prevented IP generation.

6.) Based on these observations, it is unlikely that problems in the 5-30 MHz upstream band are due to IP generation at loose connections. A more likely explanation is RF ingress, as described in [5].

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METROPOLITAN DATA NETWORK STANDARDS

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Abstract

The CATV system holds great potential for high-speed data communication. Equipment standards in this area will accelerate development, lower costs, and will make interconnection of franchises much easier Such standards are now evolving under the IEEE Project 802, originally formed to standardize local area networks on a smaller geographic scale. Participation by cable operators and users is needed in order to insure that the standards will provide the equipment and services that customers want.

Introduction

The idea of sending data on CATV systems is a hard one to resist. The situation is similar to the early days of computers, when telephone lines were used because they were available. The telegraph was designed as a digital system, but the analog telephone lines had the advantage of universal availability.

Now we are approaching availability of CATV cables in every city, at a time when the requirements of data traffic in speed and volume are beginning to overflow the telephone system. The fit of data to CATV is in many ways a natural one, but there are several problems to be overcome.

The first is that the CATV system is much more fragmented than the telephone system. The economies of modern electronics are highly dependent on large-quantity production, and the demand created by one franchise or MSO cannot drive costs down far enough to be competitive with telephone-based transmission. In addition, passing data from one franchise to another is not necessarily a trivial task. Uniformity of implementation is needed.

The economics of data transmission look favorable, in the sense that the cables have already been installed for entertainment purposes or to meet institutional requirements of the franchise contract. The next largest expense, the network access units, can be borne by the users via purchase of equipment or fixed-term leases. This leaves reverse amplifiers and head-end equipment as costs that the franchise operator must incur before providing data services.

The Role of IEEE 802

One of the most significant developments in the data communications area has been the advent of high-speed local networks utilizing a shared medium, usually coaxial cable. The IEEE has set up a standardization effort (Project 802) for such networks, driven principally by the cost reductions possible with high-volume integrated circuits. The advent of desk-top computers and other distributed computing devices has created a demand for data transmission within buildings that is well beyond the capabilities of conventional telephone circuits and modems.

Several different protocols have been standardized under the IEEE 802 umbrella, optimized for different applications. CSMA/CD, for example, represents an evolution of early work in packet radio, and provides very fast response under light load but tends to degrade under heavy load. Token-passing systems behave well under load but have larger delays than CSMA/CD under light load. They also require complex recovery procedures when one unit fails.

Expansion of the charter of the IEEE group to larger networks, 50 km in diameter, made it possible to add metropolitan networks to the set of standards, with all the same benefits. The focus of technical development in a few directions rather than many is likely to provide faster improvements in the technology than dozens of independent corporate efforts.

The best protocols for metropolitan data networks are not necessarily the same as for local area networks, which are optimized for distances of a mile or two in cable length. The longer propagation time of signals in a 50-km system means that a price must be paid in data rate or efficiency if other considerations are unchanged.

In the case of CSMA/CD, collision detection depends upon a collision existing everywhere on a cable if it happens at all; this requires that the packet transmission time be at least twice the maximum cable propagation time. Unless the packet size is made excessively long, an extension of the system size by a factor of 10 results in a speed reduction of a factor of 10.

Similarly, a token bus system that requires tokens to circulate to all units on the system, whether they have anything to send or not, will spend far too much time in token propagation relative to data transmission.

An additional difference between local area networks and metropolitan systems is that local area networks are owned by the same organizations that use them. There is no billing and control issue. Shared systems operated by a third party need centralized control of the network for maintenance and billing purposes. This is not provided by the peer protocols used by the strictly local area networks. An additional advantage in the case of large networks is that it is more economical to concentrate the intelligence of the network in one place--with redundancy-- than to put highly complex logic in each access point.

The result of these considerations is that new protocols are needed for metropolitan networks. Initially it was assumed that the metropolitan area networks working group (known officially as 802.6) would work out a standard for TDMA. Since then, some of the initial proponents of TDMA have fallen by the wayside, and the proposal that has received the most attention has been one based on polling.

Participation

The participants in the standards effort have mostly been equipment manufacturers. Some of these have been computer manufacturers, others have been radio and cable equipment companies, and others have been in more traditional data communications. In addition, there has been a heavy degree of participation by the telephone industry, mainly Bell Laboratories and its various successors.

We have not seen a high degree of participation by the cable operators. A few individuals have attended, but the work of the committee has not been driven by the expressed needs of the CATV industry and its customers. Rather, it has been secondhand perceptions on the part of the manufacturers that have provided most of the impetus thus far.

End users have been scarce also. This seems to be normal in standards committees: users don't get involved until they have actual equipment to consider buying. The conclusion seems obvious enough: those who put their two cents in early will stand a better chance of seeing the standards they want.

Work to Date

Once the immediate pressure to produce a TDMA standard had dissipated, the committee took the opportunity to consider the basic question: what kind of applications did we expect to serve? This would dictate the properties of the protocols chosen for standardization. Figure 1 shows the results of the deliberation. From a lengthy list of particular applications we abstracted the most significant properties: overall rate and burstiness. We can assume that some applications such as interconnection of local area networks can afford relatively complex protocols in order to achieve high performance. Others, such as small business and home access, will require simpler protocols in order to meet price goals comparable with inexpensive telephone modems.

Digital voice and video, will also require high performance and will support higher-price interfaces, at least where multiplexed voice is generated by a PBX. In the future, digital compressed video may be a factor, but at the present it is cheaper just to provide analog bandwidth for video.

It is quite possible that two or more standards will emerge to support the application matrix of Fig. 1. In the case of a fixed-bandwidth service like voice, TDMA is ideal. A contention mechanism is needed to permit requests for time slots, but once established, a time slot will be allocated to the same source until it is released. Connections from one source to multiple destinations are possible; the source unit simply includes an address in each data packet that it sends in its time slot. Assignment of time slots and system housekeeping functions are performed by a computer at the head end; the user interface unit requires a microprocessor to request and release the time slots.

For lower cost systems, polling has an advantage in cost. In particular, the user-end interface is quite simple, being required simply to respond when addressed. Such systems have been in use for years in various computer-terminal clusters. The problem of delays while the poll propagates up and down the cable can be handled by polling in order of increasing distance from the head end. So long as the time per response is no less than the time per poll, responses from different units will not pile up at the head end and garble the data. At the end of the polling sequence, or when shifting from one priority list to another, the cable is allowed to run down.

To support digital voice in such a scheme, a maximum priority polling class is established with guaranteed polling interval driven by a real-time clock. On clock interrupt, perhaps every 50 milliseconds, the current polling list is suspended and the fixed-bandwidth list is polled. Since each side of a telephone conversation is polled separately, demand channel assignment (know as TASI in the telephone industry) follows automatically. The overhead to allow all responses to come back in is only about 1% of the capacity.

Calculations assuming reasonable parameters for packet size and distribution of active and inactive users indicate that cable efficiency of about 55% is achievable.

Other protocols have been proposed but not as yet examined thoroughly. These include a cellular form of CSMA/CD and a high-speed token system which requires a non-branching cable.

Interconnect Issues

If we look at the businesses that might be served by metropolitan networks, we see that some are concentrated in center cities and others tend to be located in suburban areas. Financial industries such as banking and insurance are usually located downtown and could take good advantage of a network provided within a city franchise. However, most high-tech industry has located in suburban areas, and it is quite common for a company's facilities to exist in a number of different CATV serving areas. Likewise retail chains are distributed throughout suburban areas.

In order to serve customers that are located in multiple franchises, data must move freely from one cable system to another. In the telephone area, the equivalent problem is solved by a hierarchy of switching offices, but nothing of the sort exists for institutional TV networks.

The simplest way to interconnect the franchises for data purposes is to establish bridges that pick up data packets on the boundary between two franchises and put it down on another system. This can be accomplished readily if the same protocols are used in the two franchises.

However, if the protocols are different, the problem becomes very difficult to solve. There are too many possibilities for arbitrary data formats for anyone to produce a system that will convert between them automatically.

With the present fluidity in the telecommunications business, it is possible that some carrier will step forward with a system designed to provide interconnection of franchises. This would be a natural extension of the long-haul carriers' interest in cable systems as the "last mile" of their satellite and microwave systems. Once again, the use of standardized protocols within the franchises makes interconnecting them very much easier.

Where favorable terrain permits, DTS systems may also serve as CATV data interconnection media. Although DTS has been designed to go directly to the end user, many applications will not be able to support the expense of a dedicated installation, or there will be no available rooftop. Here the CATV system can provide the connection to the customer's building, and the link between head ends can be done via DTS. For longer haul systems, satellites can serve a similar function, with two-way earth stations located where receive-only antennas now pick up TV programming.

In the Future

In the IEEE 802 metropolitan area networks committee, we expect to have our first draft of at least one protocol by the end of this year. We would encourage more participation by cable operators to make sure that the standards meet the cable industry's needs. Additional interest on the part of the cable operators, in turn, will encourage additional manufacturers to participate.

As a result, the users, the CATV operators, and the manufacturers will all benefit.

		SPEED: LOW	SPEED: HIGH
BURSTINESS	LOW	CONVENTIONAL DATA COMMUNICATION	BULK DATA, VIDEO, MULTIPLEXED VOICE
	HIGH	INTERACTIVE TRANSACTIONS	LOCAL AREA NETWORK INTERCONNECT

Figure 1. Metropolitan network parameters for different applications.

MODIFICATION TO SATELLITE MODULATION

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The NCTA has recently completed extensive testing to determine the worst usable C/I ratio for cable television TVRO receivers. With the modulation techniques used in cable-oriented video services today, the acceptable limits appear to be 18 db. This paper proposes a possible modification to the modulation techniques which may improve the TVRO's tolerance to poor C/I ratios.

Thirty-six thousand (36,000) F9 modulation of microwave satellite carriers indicates the carrier is deviated by a number of things including video sync pulses, wideband video information, any number of subcarriers, and an energy dispersal waveform (EDW). This proposal concerns two of these: video sync pulses and EDW. After de-emphasis, video sync pulses cause approximately 2-3 MHz of deviation. During video, EDW normally causes 0.5 to 1 MHz of deviation.

This recommendation would require that a nationwide and joint-corporate venture of satellite operators and users "genlock" these two signals on all transponders as follows:

1. Each satellite uplink would require a full field frame storer as the last video device before the exciter. This frame storer would be genlocked to a given transponder (on the same satellite and polarity used by that uplink) by use of an additional downlink receiver.

2. One transponder on each polarity of each satellite would be designated as "satellite masters". These masters would be selected by their uplink's ability to receive and genlock to a signal from the transponder designated as an "arc master".

3. Each frame storer's vertical and horizontal phases would need to be adjused so that its downlink video sync would be in-phase with its master's downlink video sync.

4. Next, the 30 Hz dispersal waveforms would be sync'd with the video field.

Syncronizing the deviation of all transponders in this manner would result in fewer cases of two adjacent carriers occupying the same spectral segment simultaneously--a major cause of cross-pole interference.

The first sign of crosspole interference is the appearance of sync bars on the screen. Genlocking the video's in this manner would make a given level of crosspole interference much more acceptable since the interfering sync bars would be off the screen and virtually invisible. However, it should be noted that this advantage is only realized if the interference is from the same satellite as the desired signal. Geometry, the velosity of radio waves, and the very short time of a horizontal scan line, make it impossible for satellites in different geometric positions to provide genlocked video to downlinks in different geographic locations on the earth.

However, the energy dispersal waveform is a much lower frequency; therefore, syncronization of adjacent satellites would be realized by downlinks everywhere.

The actual overall improvement of this system would depend on many things, including the receiver I.D. bandwidth and the type of detector used. Manufacturer engineers indicate that their detectors would perform somewhat better if the desired carriers were at the high end of its I.F. spectrum when the interfering carrier appeared at the low end. However, none could be certain to what degree the output would be improved.

Another advantage to the cable industry would be improvement in the intermodulation of their distribution systems. All their videos from a given satellite would be genlocked--something only the richest cablevisions have been able to afford to do themselves.

NEW DEVELOPMENTS IN SATELLITE TELEVISION SCRAMBLING

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ABSTRACT

Satellite delivery of television signals to cable affiliates is now the industry norm. To protect these signals from unauthorized reception, an extremely secure scrambling system is needed that provides high quality audio and video at an affordable cost. In fact, the need for such a scrambling system has increased significantly with the dramatic growth in private TVRO installations.

M/A-COM is meeting this need with its line of VideoCipher[tm] satellite television scrambling systems. VideoCipher systems use the Data Encryption Standard (DES) algorithm of the National Bureau of Standards for the highest level of security protection. VideoCipher produces a descrambled signal that is indistinguishable from the original, even at low C/N. Stereo digital audio, as well as reliable, flexible addressing and control of large numbers of descramblers in seconds, are also key features. Since the audio and control information is transmitted during the horizontal sync interval, the need for subcarriers with their accompanying degradation is eliminated. VideoCipher descramblers interface easily to existing CATV satellite receivers. A single spare descrambler can serve as a backup for multiple VideoCipher scrambled television feeds. The system is extremely robust and reliable, and can be configured as fully redundant with automatic switchover to hot spares.

VideoCipher I descramblers are designed with discrete components for use in CATV headends. They are currently in production and are being extensively tested over satellite. This deployment is fully proving the basic technology in the VideoCipher product line.

VideoCipher II is a direct extension of the initial VideoCipher I system and uses the same stereo digital audio and DES encryption. VideoCipher II descramblers use custom LSI circuit components and high volume manufacturing techniques to significantly reduce their cost. By the end of 1984, production versions will be available for both CATV and private TVRO applications. They will incorporate consumer features not found in VideoCipher I, such as a flexible subscriber interface with an on-screen display, a credit register for impulse pay-per-view, a parental lockout control, and a versatile text capability for messages, program guides, and other information. Of course, since all VideoCipher descramblers must be individually authorized to receive programming, the consumer units will be under the program provider's direct control.

In summary, the VideoCipher II satellite television scrambling system is a natural evolution of field-proven technology. It will give program providers an extremely secure and very high quality system for the controlled delivery of programming to CATV affiliates and/or private individuals, all at a dramatic reduction in cost relative to earlier scrambling systems.

NEW TECHNOLOGY FOR CABLE TELEVISION

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Abstract

Four new technologies are presented. They are: Digital Television, Multiplexed Analog Components, High Definition Television and CCD Cameras. Each of these new technologies is explained and its application to cable television is described.

INTRODUCTION

A number of new technologies are emerging that will make profound changes in cable television. These changes range from entirely new kinds of television to new methods of signal processing to improved television signal sources. They will be found in the subscriber's home, in the cable head-end and at the point of original picture production. Four new technologies have been selected for this discussion: namely, digital television, multiplexed analog components, high definition television and CCD cameras.

DIGITAL TELEVISION

Digital television includes more than just the use of digital circuitry in television equipment. We are all familiar with the digital processing in TV receivers and set top converters for remote control, for on-screen display, and for frequency synthesized tuning. However, these are not digital television. Digital television refers to the representation of a television waveform as a series of discrete digital words called pixels, rather than as a continuous analog waveform.

The advantages of digital over analog processing in television are the same as those that led to the use of digital processing in other fields. For example, digital circuits have smaller parts counts because they do not require passive resistors, capacitors and coils. Moreover, adjustments for gain, level, bandwidth and so on can be eliminated and performance does not gradually degrade as parts age. Software can be used to conveniently test subsystems during and after manufacture; control of digital television processors by other digital equipment is natural; and computer-aided design can be applied to digital integrated circuit design. Finally, new functions can be done digitally that could not be done at all in analog.

The growth of digital television is driven by advances in three kinds of semi-conductors. A/D converters, memories, and very large scale integrated circuits [VLSI] High speed A/D converters capable of digitizing real time television signals have dropped in price from $15,000 in 1975 to about $50 today. They are expected to drop by another order of magnitude within the next two years. Semi-conductor memories have dropped in price from a penny per bit with 4K dynamic rams in 1976 to about 10^{-2} cents per bit with 64K dynamic rams today. With further improvements in semi-conductor density, a single chip will be capable of storing an entire television frame. VLSI has advanced to the stage where vast amounts of logic can be built on a single chip. High-speed gate arrays with more than 10,000 gates per chip are presently available to the digital television designer. Use of such large gate arrays combined with sophisticated logic simulation techniques permit complex digital television IC's to be developed reliably and within a reasonable time frame.

Digital television will bear on cable in a number of ways. New high definition television services will depend on digital processing for their operation. In addition, picture improvement methods such as noise reduction and ghost cancellation can be done digitally. However, the most important impact of digital television on cable will be in advanced video encryption. It is possible with digital processing to design encryption systems that cannot be broken by pirates. These encryption systems will not depend on hardware that must be physically protected from a subscriber, but rather they will

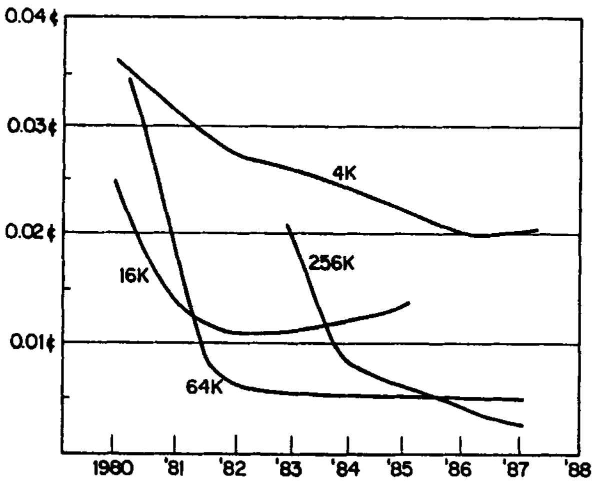

Fig. 1. The price per bit of memory of dynamic RAMs has been driven down sharply by each fourfold increase in memory size. By mid-1985, the price per bit of 256K RAMs is expected to drop below that of 64K RAMs (Fortune Magazine, May 26, 1983, page 154).

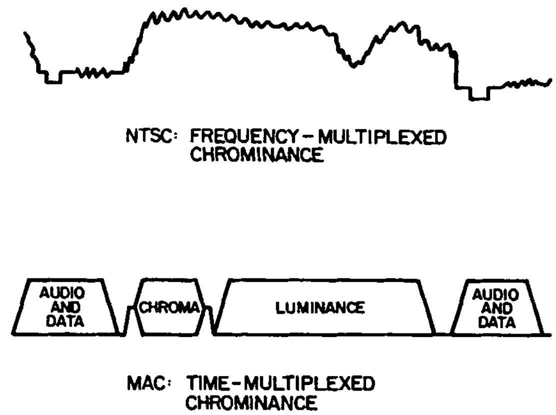

Fig. 2

depend on software that can only be received by authorized subscribers. The authorization of subscribers is also controlled by encrypted software. In short, digital processing can lead to that elusive ideal: a foolproof method of controlling pay TV revenues for the system operator.

MULTIPLEXED ANALOG COMPONENTS

Multiplexed Analog Components (often abbreviated MAC) refers to a new kind of television signal that uses a different method of encoding color from NTSC. As we know, NTSC uses a subcarrier at 3.58 MHz to encode color. MAC on the other hand does not use a subcarrier, but instead the chrominance and luminance components for each line are compressed in time and transmitted serially during each line time. Another difference between MAC and NTSC is in the way audio is encoded. For the MAC signals likely to be used on cable, audio will be encoded digitally with pulses in the horizontal blanking interval. In the event that the MAC signal is encrypted, addressability data to control subscribers' access will also be included in the horizontal and vertical blanking intervals. In the MAC systems, sync would also be digitally encoded and included in the blanking intervals along with the audio and addressability data.

MAC has a number of advantages as a signal format. Since a subcarrier is not used to encode color, none of the effects of the subcarrier that are visible in NTSC are visible on a MAC picture. In particular, there is no dot crawl, there are no hanging dots and there is no luminance/chrominance crosstalk. Because luminance and chrominance are not combined in MAC, but rather transmitted separately (time-multiplexed) the picture is completely clean and free from any color subcarrier visible artifacts. The second advantage of MAC for cable use is that the digital audio provides multiple channels of high fidelity sound. The third advantage of MAC applies to transmission over an FM channel such as a satellite used for distribution of programs to cable headends. Because the satellite's FM noise spectrum increases with higher frequencies, the lack of color subcarrier in a MAC signal results in a lower chrominance signal-to-noise for MAC than for NTSC, thus producing a quieter picture.

MAC can be part of the cable delivery chain, either over the satellite or on the cable itself. In direct broadcast by satellite on K-band, some companies have already announced the use of the MAC signal format. A possible business scenario for cable operators would be to receive DBS signals and redistribute them on the cable. In this case, the MAC signal format would be used both over the satellite and on the cable. MAC could also be used for C-band satellite distribution and indeed may be the format selected by some satellite channel distributors for scrambled service. On the cable, the MAC signal, which has neither sound nor chrominance subcarriers, will be less susceptible to intermodulation with the carriers of other channels. In addition, because MAC has no analog sync, the full dynamic range will be available for the picture and audio parts of the signal.

In summary, the MAC signal format offers a higher quality picture, multiple channels of high fidelity sound, compatibility with encryption of both video and audio, fewer intermodulation problems and better use of the dynamic range.

HIGH DEFINITION TELEVISION

There is no single definition of high definition television. Many HDTV systems have been proposed. They work in different ways, are designed for different purposes and have differing amounts of improvement in picture quality. Furthermore, some HDTV systems require more bandwidth than others and some require more complex processing circuitry than others do.

Although HDTV cannot be precisely defined, certain characteristics can be expected. For example, the NTSC sub-carrier artifacts such as dot crawl, hanging dots and luminance/chrominance crosstalk could be removed from the picture. A method of removing these artifacts would be the use of the MAC signal format as described above. In addition, line crawl and 30 Hz interlace flicker caused by 2-to-1 raster interlace could be removed by use of progressive scan in the display. Another improvment in the picture that high definition could yield, would be elimination of vertical aliasing caused by the discrete nature of the 525 scanning lines in the camera. This aliasing could be removed by the use of more scanning lines in the camera followed by interpolation down to 525 lines. A number of methods hve been proposed to increase both horizontal and vertical resolution including use of more than one channel for each transmitted program. Still another aspect of HDTV would be wider display aspect ratio, from 4-to-3 to 5-to-3 or perhaps even higher.

An important aspect of any high definition television system is the degree to which it is compatible with NTSC. There are three levels of compatibility. The first is HDTV that is fully compatible with NTSC. By fully compatible is meant that both a HDTV receiver and an NTSC receiver could display pictures from the same signal. Of course the HDTV picture would have a better quality picture. An example of such a fully compatible HDTV method would be the use of a sophisticated frame store NTSC decoder in a TV receiver. The second level of compatibility is HDTV that is easily transcodable into NTSC. A good example of this level of compatibility would be the MAC signal format, which has the same number of scanning lines as NTSC has and differs only in how chrominance and audio are encoded. The third level of compatibility is HDTV that is not easily transcoded to NTSC. This generally refers to HDTV systems that employ more than 525 lines for transmission and display. HDTV systems of this type would be costly in terms of bandwidth and are therefore expected to be limited in use to video production.

One interesting possibility for HDTV on cable is the use of extra bandwidth for signal transmission. Unlike the TV broadcaster, who is confined to a 6 MHz channel, a cable operator is in principle free to use as much bandwidth per channel as he desires. Future cable HDTV systems are conceivable that use more than 6 MHz for improved resolution and wider aspect ratio. Another possibility is the use of FM modulation so that a cable operator can distribute scrambled HDTV signals from a satellite directly to the subscribers' home without decoding or remodulating.

Although it is not now clear which of the many HDTV possibilities will emerge first, it is clear that the cable TV industry will soon have the technology to deliver pictures that are superior to those that we are now watching.

CCD CAMERA

A number of new all solid state TV cameras have recently been introduced to both the consumer and the broadcast markets. The broadcast CCD camera has three silicon CCD imagers instead of three photoconductive pick-up tubes. Each solid state imager has discrete pixels on each line which are read out serially in a manner analogous to beam scanning in a camera tube.

A CCD camera is more flexible than a tube camera because it is smaller in size, lighter in weight and consumes less power. It is physically rugged and has no microphonic distortion due to vibration of delicate electrodes. There are no components inside a CCD camera that require periodic adjustment or replacement. In addition to these practical advantages, the CCD camera has better dynamic resolution. Dynamic resolution refers to the ability to see detail in objects that are moving rapidly. In tube-type television cameras there is partial retention (called lag) of previous images mixing with and blurring new images falling on the tube surface. The CCD on the other hand, retains no memory of the previous image, so as in a film camera, each exposed frame is independent of the previous frame. Because the CCD inherently has no lag, a scene consisting of a moving bright light on a dark background will not leave a trailing smear. Furthermore, the camera can be pointed at a light of any brightness without causing either permanent or temporary burn-in or damage of any kind. And finally, the CCD camera has a greater dynamic range than that of any tube camera. Consequently, it can be used to shoot scenes under very low-light conditions.

The features of a CCD camera will offer the cable operator many advantages. The camera itself is less sensitive to mis-handling, can make good quality pictures under less critical lighting conditions, it requires less frequent maintenance and lower skill levels for maintenance that is required. In short it will offer the cable operator a versatile camera for a wide variety of cable production needs.

CONCLUSION

In conclusion we have looked at four new technologies that will provide for cable TV better quality pictures, more reliable equipment in the home and in the studio, multi-channel high-fidelity audio and secure scrambling. All of these new technologies add up to making our product more desirable to our customers.

NOISE FIGURE MEASUREMENTS ON DISTRIBUTION SYSTEMS

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GENERAL INSTRUMENT JERROLD DIVISION

ABSTRACT

A technique for measuring the noise figure of a CATV distribution system is discussed, as an alternative to conventional methods of determining carrier to noise ratio. The advantages and disadvantages of both types of measurement are discussed. Suitable instrumentation for noise figure measurement is considered, as well as calibration techniques. Some possible sources of error are identified and analyzed.

INTRODUCTION

As in any communication system, the signal to noise ratio in a CATV system is an important parameter. Due to the complex nature of the television signal, it is common practice to speak in terms of the carrier to noise ratio, to simplify the analysis. The carrier level is taken to be the power of the peak carrier, occuring during the synchronization pulse of the TV signal. Measurements are frequently made with a CW signal of amplitude equal to that of the sync tip.

The corresponding noise power is that delivered by the system over a specified bandwidth. The NCTA standard refers to a 4 MHz bandwidth, although other standards refer to bandwidths as high as 6 MHz.

The ratio of these two powers is the carrier to noise ratio, which is conceptually simple and direct. The carrier power measurement is straightforward, but the noise power measurement can be troublesome. In the CATV industry, a 4 MHz bandwidth is generally used, but it is somewhat arbitrary. The bandwidth must be related to the effective noise bandwidth of the measuring device, which may not be the same as its indicated bandwidth. The detector characteristic is normally defined for coherent signals, and may be somewhat different for noise input. In addition, in a typical situation the system noise power is not much greater than the measuring receiver's noise level. Noise power measurements commonly depend on correction factors supplied by the manufacturer of the measuring equipment, notably its effective noise bandwidth, and the detector noise characteristic. These are seldom independently verified.

It is the intent of this paper to consider the removal of several arbitrary factors from these measurements, by measuring the noise figure of the complete distribution system. We will first review some definitions and techniques.

NOISE FIGURE

Noise figure is a measure of the noise added to a communication system by an amplifier or other system component. At the risk of over-simplification, we will use the terminology of Figure 1 for this discussion.

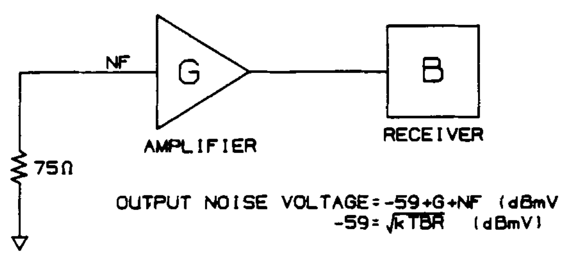

FIGURE 1.

Here G represents the gain of the amplifier and NF its noise figure, both in dB. The familiar -59 figure derives from the Boltzmann constant k, an absolute temperature of 290 K, a receiver bandwidth of 4 MHz, and a 75 ohm impedance.

This glosses over a great deal of important background in noise figure measurement. We assume that all system interfaces are well matched 75 ohm impedances, and that temperature variations (in Kelvin) are not very significant. Practically speaking, these assumptions are justifiable.

In some fields such as satellite communications, the concept of noise temperature is used, wherein a good (low) noise figure is related to a low noise temperature. We will use noise figure here.

An important variation of Figure 1 relates the output carrier to noise ratio C/N to the carrier input level I (dBmV) and the noise figure NF;

$$C/N = 59 - NF + I$$

This is true whether the equation refers to a transistor stage, a trunk amplifier, or a cascade of trunks plus bridger and line extenders. It is a statement of the impact of input level on carrier to noise ratio.

There are a number of ways to measure noise figure. One simple way is to measure the gain of the amplifier, then measure the noise power output, and calculate the noise figure. A similar way is to perform a carrier to noise measurement as described above, and work back to noise figure.

The preferred way to measure noise figure is by reference to a noise generator of known output level. The technique consists fundamentally of adding noise to the system input to the point where the system noise output increases by some measurable amount. By comparing the increase in noise output to the corresponding noise power added, the system noise figure can be determined. Such a measurement can be made with no reference to receiver bandwidth, although the frequency of measurement is a parameter.

Precisely calibrated noise sources are available from a number of suppliers. A diode operated in the reverse avalanche mode is a common mechanism for noise generation, and can be used into the microwave region. Noise output level is calibrated by comparison to a precisely known noise source, typically an actual resistor operated at extremes of temperature. The source may be calibrated in terms of its effective noise temperature in degrees Kelvin, or in Excess Noise Ratio (ENR, dB). The ENR is a measure of how much the noise exceeds the theoretical Johnson noise level, e.g. -59 dBmV.

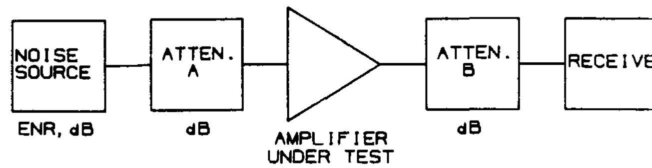

FIGURE 2.

Referring to Figure 2, a noise figure measurement is made by injecting noise into the amplifier input and measuring the resultant increase in amplifier noise output. Several variations are possible:

1. Add the noise and measure the resultant increase in noise power at the receiver.

2. Add the noise and increase the output attenuator at B to produce the original indication on the receiver. This removes the receiver's characteristics from the test.

3. Add noise by adjusting the input attenuator at A until a 3 dB increase in output power occurs.

4. Increase the output attenuator at B by 3 dB, then add noise by adjusting the input attenuator at A until original receiver indication is reached.

These four methods are all variations on what is called the Y factor method. In each case, the formula

$$NF = ENR - A - 10 \log (Y-1)$$

where

$$Y = 10^{B/10} \quad \text{or} \quad B = 10 \log Y$$

applies. Here A is the dB attenuation following the noise source, and Y is the linear power ratio of the output attenuator or detector change. If one of the 3 dB methods is chosen, the factor 10 log (Y-1) disappears. The formula points up the fact that an attenuator at the input to the amplifier degrades the noise figure of that system in like amount. Note that a small change in output power, for a given additive input noise power, is indicative of a high system noise figure rather than a low one.

It is preferable that the ENR of the source be in the same general range as the noise figure being measured. Precision suffers if ENR is less than NF. If ENR is more than about 6 dB greater than NF, the receiver dynamic range may become a factor, and there is no substantial increase in precision.

Noise figure meters automate this measurement process. The current generation of microprocessor based instruments are very sophisticated devices. In addition to being bus controllable, they can calibrate themselves, account for various losses in the device, and simultaneously measure gain. But they all perform Y factor measurements, and are directly dependent on the calibration of the noise source used.

DISTRIBUTION SYSTEM NOISE FIGURE

It is common to describe the carrier to noise of n trunk amplifiers in cascade by the formula:

$$C/N = 59 - NF - 10 \log n + I$$

Generally, the contribution of the bridger and line extenders is minimal, so this formula is approximately true of the entire system. It can be seen that the effect of the cascade is to make the effective noise figure of the cascade equal to

$$NF + 10 \log n$$

relative to the input of the first trunk amplifier. Of course, there is usually a span of cable preceding this first amplifier but this is easily dealt with.

There is no reason not to characterize the total system in terms of its noise figure, from the headend to the last tap. By determining the input levels to the system so defined, the carrier to noise contribution of the distribution system may be precisely determined. This may seem a bit abstract, but it is valid. It should be kept in mind that the noise figure measurement is involved with the system gain, and that the C/N calculation in terms of input levels is closely related to the resulting output levels. Of course, the overall requirement on system carrier to noise is the delivery of a quality signal to the subscriber, and this depends on the signal entering the distribution system as well as the system's noise contribution.

The automatic noise figure meter unfortunately cannot be used if the amplifier output is 10 miles from the input. But the Y factor technique is applicable, and an automatic system for measuring noise figure in this case is certainly feasible.

The proposed method is simple: inject noise into the system from the headend and measure the resulting increase in noise at the system output. Compute the system noise figure by any of the 4 methods indicated above, measure the corresponding system input levels, and determine the carrier to noise ratio. Or, since the system levels at the headend should be tightly controlled, the noise figure itself might become the fundamental performance characteristic. In this way, the arbitrary 4 MHz bandwidth might be kept out of the picture. This may be of increasing value as CATV systems carry other than NTSC video signals.

PREDICTED NOISE FIGURE

What value of noise figure might be expected of a distribution system? If a carrier to noise ratio of 46 dB is expected, and the input level to the distribution system is 32 dBmV, then NF = 59 - C/N + I = 45 dB. This number may seem startingly high, but is consistent with the definitions. The loss of the first span of cable is a major contributor to the value of the system noise figure, as is the 10 log n cascade factor. Note that the typical noise figure of measuring instruments, such as a spectrum analyzer, is about 30 dB.

Some systems have a trunk amplifier as the first element of the system, before the first cable span. In such a case, the system input levels would be lower, corresponding to trunk inputs, and the noise figure would be accordingly better.

If the system is operated with tilted trunk signals, then the low frequency noise figure should ideally be better than that at high frequency by an amount equal to the system tilt, e.g. 6 dB.*

*A note on terminology: this paper observes the NCTA's preferred convention on the use of SLOPE and TILT; TILT refers to signal levels as a function of frequency, whereas SLOPE refers to system gain and loss as a function of frequency. The terms are sometimes used interchangeably, with resultant confusion. Signals are tilted; gains are sloped.

As a practical matter, a test point should be included in these calculations. It is common practice to provide test points, typically a 12 dB coupler, at the headend. So the noise figure viewed through the test point loss will be typically 51 to 57 dB, for low to high frequencies.

NOISE SOURCES

The ENR of the noise source for system noise figure testing should be in the 60 dB range. The sources used with automatic noise figure meters are typically in the 15 dB range, although diode sources up to about 30 dB ENR are readily available. To get to the 60 dB range, amplification must be provided. This is straightforward, for if the ENR of the source is more than about 10 dB greater than the noise figure of the amplifier used, the ENR is simply increased by the gain of the amplifier. Of course, the gain must be known, and the amplifier's frequency response (slope) will modify the output level (tilt) of the noise source. There need be little concern for this amplifier's output capability, since a 60 dB ENR amounts to only a few microwatts of power in a 500 MHz bandwidth. Due caution must be exercised, however, to avoid pickup of extraneous signals.

The ENR of such a boosted source may be measured by direct measurement of its output, or more precisely, by putting the output through a precision attenuator and comparing to the output of a known noise source.

PROCEDURE

The procedure consists of injecting a known level of noise into the system, and measuring the resulting increase in system noise output. As such, it is subject to the same cautions as is the conventional method of measuring carrier to noise ratio. Of course, a signal free area of the spectrum must be used to measure noise output. The receiving instrument must have adequate sensitivity to sense system noise above its own internal noise. Preamplification may be necessary to make the receiver's noise figure sufficiently low. Selectivity may be required to avoid receiver or preamplifier overload. The output attenuator substitution technique is preferable, as it minimizes errors from unknown detector characteristics or insufficient sensitivity.

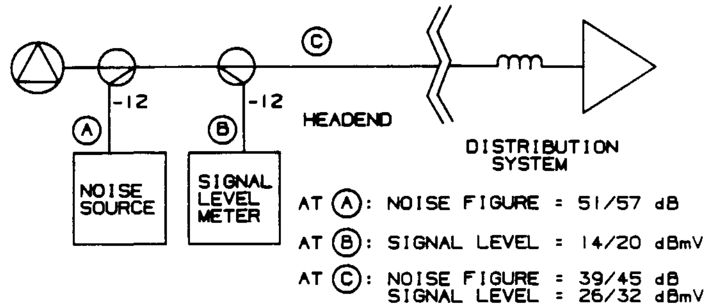

FIGURE 3.

The important point here is that the only field measurement to be made is a difference in system noise output, over a limited dynamic range. This will typically be from 3 to 10 dB. There is no concern for receiver bandwidth, apart from the selectivity which may be needed to avoid receiver overload if heavy channel loading is present. Input mixer overload is a hazard which must be avoided, since the goal is to measure system noise, rather than beats generated in the measuring receiver.

The resolution of this noise output differential impacts the accuracy of the overall measurement. Analysis of the Y factor equation will show that if the noise output difference is 3 dB, then a 0.1 dB error in its measurement will result in a 0.2 dB error in noise figure. At a 6 dB difference, a 0.1 dB error only results in a 0.14 overall error.

Any error in ENR, of course, adds directly to the overall noise figure error. But the ENR of the noise source can be determined with considerable precision, and should not be subject to very much drift, in its headend location. The carrier level error of course also adds directly to the C/N error.

REFINEMENTS

Automatic noise figure meters function by turning the noise source on and off at a rapid rate and measuring the resulting modulation in amplifier noise output. This type of approach might be done at say a 1 Hz rate for system measurements. Some deft manipulation would be required to use the attenuator substitution method. In addition, the ENR of the source might be tilted to track the expected noise figure of the system, so that the differential noise output might be relatively constant across frequency.

It is quite possible that an automatic system could be developed to perform this sort of measurement. All that is really lacking relative to conventional instruments is a means of synchronizing the receiver with the switched noise source.

SOME RESULTS

The figures of Table 1 indicate the results of measurements made on a test cascade of 16 trunk amplifiers plus a bridger. The setup was that of Figure 3. An experimental noise source was used. Its ENR (2) was determined by comparison to an HP 346B noise source, with the aid of the 9870A Noise Figure Meter.

For this test, a Wavetek 3003 signal generator was used as a test carrier source. Its level was adjusted to give a constant carrier to noise ratio at the system output at each frequency (9).

A SAM-I signal level meter was used to measure carrier levels (5), and an HP 8554B spectrum analyzer was used as the noise receiver. Measured carrier to noise data (9) was also obtained from the 8554B.

Noise figures (4) were calculated from ENR's (2) and measured increases in noise output (3) using the Y factor equation described above.

Measured characteristics of the directional coupler test points were used to determine the values of the carrier level and noise figure on the trunk relative to those at the test points (4 / 6 and 5 / 7).

1.	Frequency	55	200	300	400	MHz
2.	ENR	56.5	56.7	56.8	55.9	dB
3.	Increase in Noise Output	10.0	7.5	6.0	4.0	dB
4.	Noise Figure at Test Point	47.0	50.0	52.1	54.1	dB
5.	Carrier Level at Test Point	7.5	11.5	13.5	16.0	dBmV
6.	Noise Figure on Trunk	34.4	37.4	39.5	41.5	dB
7.	Carrier Level on Trunk	19.3	23.3	25.3	27.8	dBmV
8.	Calculated Carrier/Noise	43.9	44.9	44.8	45.3	dB
9.	Measured Carrier/Noise	44.0	44.0	44.0	44.0	dB

Table 1

The values of carrier to noise determined by the conventional measurement technique (9) are in reasonable agreement with the values calculated from system noise figure (8). The maximum difference between the two is 1.3 dB, which is in line with the accuracy of the measuring equipment.

CONCLUSIONS

System noise figure measurement allows the noise contribution of the distribution system to be isolated and analyzed. The portion of the measurement made in the field is relatively simple, and is made over a small dynamic range. Precise level measurements such as ENR and carrier level may be confined to the headend. The technique might be automated. The technique might also be applicable to reverse systems, where carriers are not very predictable.

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OPERATIONAL CHARACTERISTICS OF MODERN SET-TOP TERMINALS

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INTRODUCTION

A brief history of set-top converters is presented, along with notation of the techniques commonly employed in modern terminals. The digital architecture of a modern terminal is shown. Key RF characteristics are presented, followed by cursory exploration of one class of scrambling techniques. Finally, some information concerning the compatibility between scrambling and stereo is presented. Most of the material is intended to be generic, but where particular techniques are referred to the system described is that used by the Scientific-Atlanta Series 8500 set-top terminal.

EARLY CONVERTERS

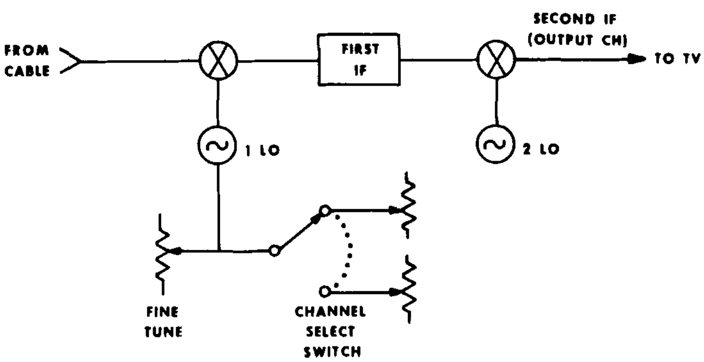


FIG 1 SET-TOP CONVERTER

Since set-top converters were first developed the architecture employed has been as shown in figure 1. Signals from the cable were applied through a low pass filter (not shown) to a balanced mixer. Here they were mixed with signals from a local oscillator whose frequency was higher than that of the incoming signal. The resultant first IF was at some conveniently high frequency, usually in the lower portion of the UHF spectrum (which officially extends from 300 MHz to 3 GHz). This high IF frequency was chosen in preference to the much lower IF used in TV receivers, in order to simplify design of the input filter and in order to prevent the possibility of L.O. radiation in-band.

The first IF signal, after amplification and filtering, was mixed with a fixed tuned second local oscillator to produce a second IF frequency which was the same as the frequency of channel 2, 3, or 4. In recent times, many people have stopped using channel 2 as an output because that is the second harmonic of the citizens band.

The first local oscillator was frequency controlled by a varactor diode. The varactor received its bias from one of a number of potentiometers, one for each channel. Because of the instability of the two local oscillators and the potentiometer voltages, a fine tuning control also had to be provided. This fine tuning voltage was added to the control voltage selected by the channel select switch.

Even today this architecture is utilized in economy lines of set-top converters. However, it exhibits several shortcomings that have driven manufacturers to develop new architectures. For example, the voltage to the varactor must be controlled very carefully. This requires good regulation. In the case of a wired remote control unit, the variability of contact resistance precludes use of plug-in cords.. Adjusting the fine tuning is difficult for some subscribers. Although descrambling has been added to this architecture, the security available is marginal, because descrambler authorization must be mechanically coupled with the channel select switch.

These shortcomings have prompted manufacturers to develop new architectures for set-top converters. The differences are sufficiently great that a new name for the box has been coined: the set-top terminal.

ENTER THE TERMINAL

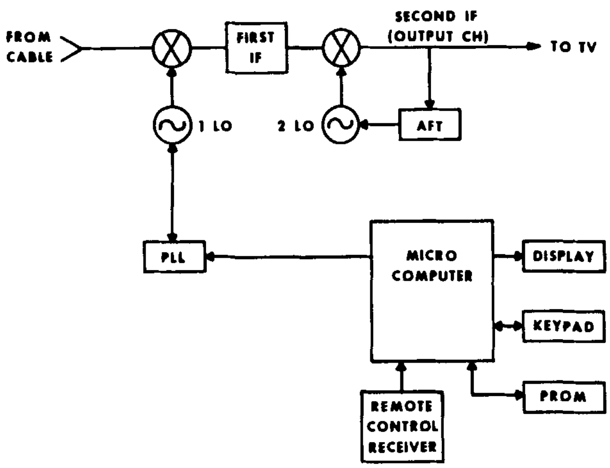


FIG 2 SET-TOP TERMINAL

Figure 2 shows the basic architecture of the new terminals, which are microprocessor controlled. The basic RF path remains much the same as before, except that first IF frequencies are going up for reasons that will be explained shortly. Better set-top terminals have replaced the manual fine tuning with automatic fine tuning to relieve the subscriber of this burden. Some set-tops have also added adjacent carrier traps, as explained below.

As the maximum number of channels went from 35 to 54 and more, most manufacturers abandoned potentiometer tuning of the first local oscillator. Phaselocked loop (PLL) tuning is now almost universal in terminals. In a phaselocked system, the local oscillator frequency is divided to a low frequency, which is then compared to a reference frequency. If the two differ even in phase (the integral of frequency), a correction voltage is sent to the local oscillator, forcing it to the correct frequency. By changing the division ratio ("modulus" of the counter), the local oscillator is forced to tune to the desired frequency. Long time stability is as good as that of the reference frequency, which is crystal controlled.

Thus, each time the tuned channel is changed, a new tuning word must be supplied to the PLL. This is generally supplied from a single chip microcomputer, which performs several other functions. Lighted channel displays (usually LED) are utilized, and are controlled by the microcomputer. The keypad used for channel entry and other functions is also scanned by the microcomputer. Wireless remote control using infrared signaling is a common option. The microprocessor accepts the modulated signal from the remote control receiver and interprets it.

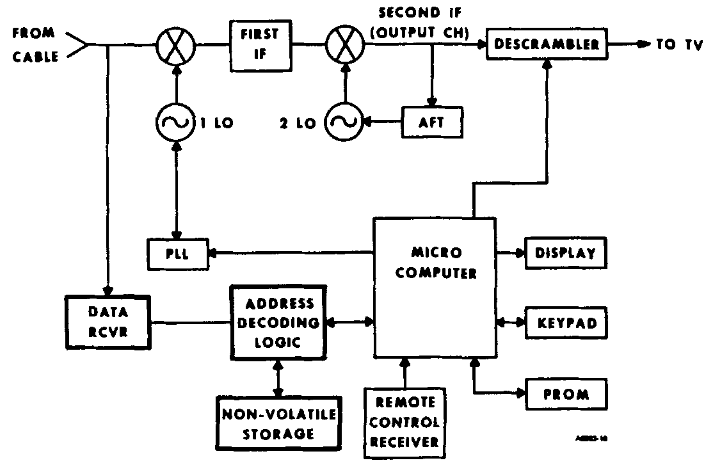


FIG 3 ADDRESSABLE TERMINAL

Figure 3 shows the same set-top terminal except that now we have added descrambling and addressability functions. No additional RF connections are necessary for descrambling, as virtually all current scrambling systems utilize in-band timing to permit an unlimited number of scrambled channels at no incremental cost per channel. The descrambler must be authorized from the microcomputer in such a way as to preclude tampering to force the descrambler on.

A data carrier on the cable is frequency shift keyed (FSK) with data representing a box address and information intended for that box, or with information intended for all boxes (a global command). The data receiver is lightly coupled to the incoming cable. This receiver is constructed similarly to a single channel FM radio through the discriminator, except that a crystal oscillator is employed for long term stability and special techniques are used to reduce local oscillator emission. After the discriminator, a low pass filter and comparator are used to convert the demodulated signal to logic levels. The logic level encoded signal from the receiver is supplied to the address decoding logic. This circuit, under microcomputer control, determines whether or not the incoming information is intended for this terminal. If so, the updated information transmitted is stored in non-volatile memory. The non-volatile memory is an electrically alterable read-only memory, which is able to retain its memory even under power-off conditions. This is important because neither the subscriber nor the cable operator should be bothered with having to initiate a memory update after every power loss.

ADDRESSABLE DIGITAL ARCHITECTURE

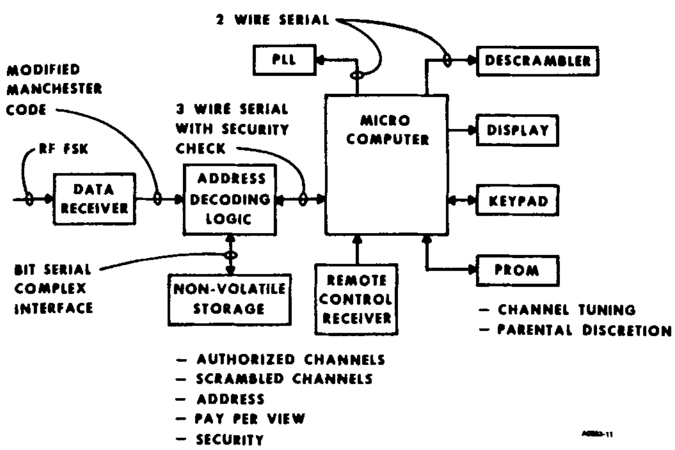


FIG 4 ADDRESSABLE DIGITAL ARCHITECTURE

The digital architecture of an addressable terminal is shown in Figure 4. At the headend the data for all terminals is formated into a modified Manchester code, in which information is carried as a logic transition for each clock pulse. If a 1 is to be transmitted an extra transition is inserted between clock pulses. A longer period with no transition indicates a start of message pulse. This format is inherently self-clocking and exhibits high tolerance for both noise and timing errors.

The Manchester encoded data is frequency shift keyed (FSK - a digital form of FM) onto a carrier. At the terminal, this carrier is demodulated in a receiver not too unlike an FM radio, whose output is applied to a custom IC in the address decoding logic. This chip translates the Manchester encoded information into parallel bytes, which are shifted into a microcomputer for interpretation.

Error detection techniques are utilized in order to prevent the reception of erroneous data. When the decoding logic interprets that it has received valid information (e.g., an updated list of authorized channels), this information is loaded into non-volatile memory. If it affects the current status of the terminal (e.g., channel tuned to) then the terminal immediately makes a change in its status.

Pay-per-view functions are also stored in non-volatile memory, in the form of a table containing pre-authorized channel and program numbers. Each pay-per-view program is pre-assigned a channel number and within that channel, a program number. When a subscriber requests a certain program, it is entered into the table in his non-volatile memory, via the headend computer. This entry is made at the time of the request, which may be hours, weeks or even months before the event. When the event begins, a global command is sent with the channel and program numbers contained within it. Upon receipt of this command, each terminal will search its non-volatile memory. If a match is found, the program is authorized. At the end of the program, another command cancels the authorization. A comprehensive set of commands generated at the headend permit the non-volatile memory in each terminal to be maintained with current requests only, and allow old and cancelled requests to be purged.

A series of commands and responses are provided to ensure that a subscriber or third party will encounter excessive difficulty in using an unauthorized terminal, while ensuring that an authorized terminal stays active.

Serial communications are utilized between different elements within the terminal. The microcomputer shown interfaces with the address decoding logic through a non-standard three wire serial interface with security check. The logic is such that no line can be tied high or low to "trick" the system. Interface between the address decoding logic and the non-volatile memory is via a very complex serial format that would be difficult for a pirate to duplicate. Again, both logic 1 and 0 levels are required for a successful transaction.

Other features of the digital architecture are shown in figure 4. The microcomputer reads commands inserted via the keypad or remote control receiver. A programmable read-only memory (PROM) stores channel tuning data to permit customization of channel lineups, and parental discretion information. All communications between integrated circuits is via serial ports, and valid communications require a series of 1s and 0s. This eliminates the possibility of tying a line high or low to force unauthorized operation.

REMOTE CONTROL

A mandatory option today is wireless remote control. An earlier generation of TV remote control, and one or two set-top units, utilized ultrasonic remote control. However, ultrasonic remote control suffered from blockage and false triggering due to high frequency noises such as keys jingling. Also, ultrasonic waves tended to be very non-discriminating in where they went, sometimes activating a TV in the wrong room. Most modern remote control systems utilize infrared remote control.

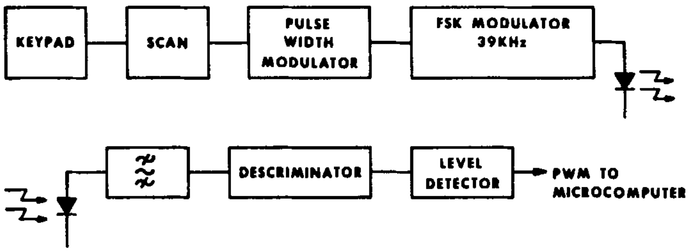


FIG 5 REMOTE CONTROL SYSTEM

Figure 5 shows a block diagram of the transmitter and receiver system. A circuit in the transmitter IC scans the remote transmitter keypad. When a key is depressed a five bit code representing the key is generated. This code is pulse width modulated (PWM) meaning that a series of pulses is generated, a long pulse representing a logic 0 and short pulse representing a logic 1. This train of pulses then frequency modulates a 39KHz carrier. This carrier then on/off (AM) modulates an infrared light emitting diode.

In the receiver, a photo transistor converts the light pulses back to the FM'd carrier. This carrier is then demodulated by a discrimator, and the resultant PWM pulses are shaped by a level detector. The pulses are then supplied to the microcomputer on an interrupt input. The microprocessor decodes the pulses to determine which key was depressed.

Since many TV receivers today utilize infrared remote control, a clear danger exists that interference will develop between the terminal and TV remote controls. Unfortunately, no clearinghouse has existed where one can obtain technical parameters of all present and planned remote control systems, so some chance exits that one will discover a conflict sooner or later. However, many TV remote control systems do exhibit some common elements. A system was developed in cooperation with a large manufacturer of remote controls, which is reasonably safe from overlap with a TV system.

With reference again to figure 5, many remote control systems utilize an FSK carrier at about 39 KHz. By changing the carrier frequency to 42KHz, some discrimination is obtained. Further security is obtained by transmitting both true and complement representation of the button pressed, with the order of the bits different from that known to be used in TV receivers. None of these counter measures will guarantee that interference will never occur, but they do move the odds in our favor.

TUNING TECHNIQUES

An almost universal attribute of set-top terminals today is control of the first local oscillator frequency by a phaselocked loop (PLL). A typical terminal which tunes from 54 to 450 MHz will have its first local oscillator frequency range from 668 to 1058 MHz (an IF of 608-614 MHz is used, as this band is reserved for radio astronomy, precluding licensing of UHF transmitters at channel 37). To control this oscillator to an accuracy of 10 KHz or so, its frequency is usually divided by 256 then compared to a reference in a CMOS phaselocked loop. In some cases, the phaselocked loop is integral to the microcomputer. Tuning is accomplished by changing the modulus of the counter fed by the prescaler. The tuning word required is often stored in PROM, to permit customization of the channel lineup for each cable system. The PLL reference is generated by a crystal oscillator, which also serves as the clock for the microcomputer.

The PLL technique is excellent for providing high stability on a multiplicity of frequencies. On the other hand, PLLs have some drawbacks. As one attempts to tune in successively smaller steps, he discovers that two undesirable things happen. First, he must store more information about each tuned frequency (i.e., the number of bits in the variable modulus counter increases) raising costs. Secondly, he must set the loop bandwith lower, resulting in longer acquisition time (e.g., from one channel to another) and potential problems with uncorrected low frequency noise.

Thus, the loop designer is forced to trade off tuning increment for storage requirement and acquisition time. We have found that a good trade-off exists for a 1 MHz tuning increment, but this leaves the problem of accomodating HRC systems, in which the frequency of each picture carrier is 0.25 MHz deviant from the nearest 1 MHz increment of a normally configured system. (A fixed 0.25 MHz offset, e.g., 55.25 MHz, is taken care of in selection of the IF frequency. But then what do we do in HRC where this is 0.25 MHz offset goes away?)

Also, how may we handle the case of a system which has offset a few tens or hundreds of KHz on one or more channels to avoid a troublesome aviation frequency ? In the days of pot-tuned set-tops, we would reajust a few pots, or let the poor subscriber fine tune every time he came to an offset channel. With PLL's and the desire for no fine tuning, we must solve this problem another way. One answer is to enclose the second local oscillator within an automatic fine tuning (AFT) loop. This technique applies the output picture carrier to a discriminator whose output is a voltage proportional to frequency error. This voltage is amplified and applied to the second local oscillator to control its frequency.

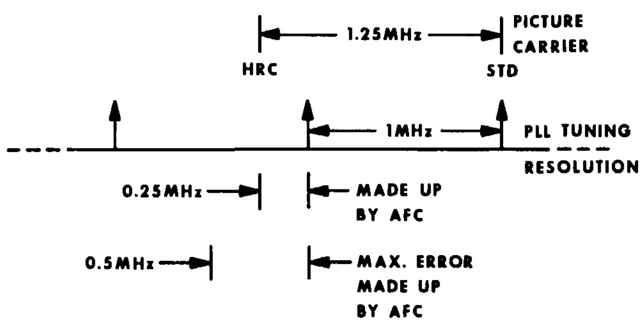


FIG 6 ACCOMMODATING HRC

Thus, the PLL tunes the first local oscillator to the nearest MHz, ensuring that the signal at the first IF is within ±0.5 MHz of nominal. The AFC is then designed with adequate acquisition range to ensure that it will take out the remaining frequency error. Perhaps figure 6 will help illustrate. This is portion of a spectrum plot of two cable systems - one having standard carriers (on the right), and the other having HRC carriers, spaced 1.25 MHz lower in frequency. Shown below these two frequencies are the equivalent STT tuning frequencies. For the standard case we can tune to the "exact" frequency. However, in the HRC case we find ourselves with a 0.25 MHz error we can't get rid of due to the 1 MHz tuning resolution. We then turn to the AFC circuit, which is more than able to make up for this error in the conversion to output channel.

Before leaving this subject we should observe that implementation of such an AFT loop is not a job for the faint of heart. Should the second local oscillator drift or be pulled too far, then the AFT may lock to the on-channel or lower adjacent sound carriers. Should the frequency pulling range become too low, then the unit could drift to the point of not locking on frequency. And, of course, AFT discriminators have calibration errors associated with them. All of these conditions must be controlled in design and production if the AFT techniques is to be successful.

KEY RF CHARACTERISTICS

No discussion of set-top terminals would be complete without a discussion of RF specifications and their relationship to system performance. Rather than plod through the long list of specifications that are normally a part of any converter discussion, we choose to concentrate here on a few things that either have developed as issues in recent years or that continue to confound many systems engineers as to their importance or effect on system performance.

1. Frequency Response

We all know that a terminal should exhibit flat frequency response across the channel in question. But what about on adjacent channels? Ideally, the terminal should have zero response at the adjacent channel, but this would yield a more expensive terminal without offsetting technical merit. Most older generation converters relied on the passband response of the first IF to provide the entire converter response. This yields little attenuation to the adjacent channels. Many modern TV sets are designed with adequate adjacent channel rejection, so that this response is acceptable. However, some sets have insufficient adjacent channel rejection, resulting in complaints of picture quality when CATV service is installed.

To ease the adjacent channel problem some manufacturers of modern set-top terminals have added adjacent carrier traps to the output circuitry of the set-top. A typical response is shown in figure 7, which shows 12dB trap depth. A trap depth of 8 to 12 dB has been found adequate to improve the performance of marginal TV receivers, without adding excessive complexity or group delay to the terminal.

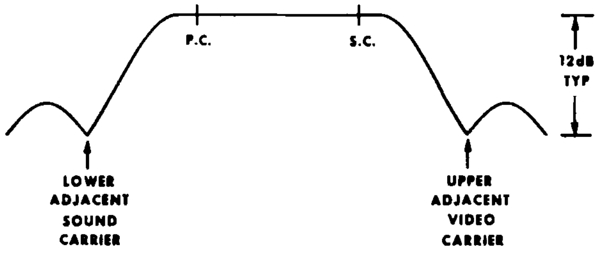


FIG 7 BANDPASS CHARACTERISTIC

Since nothing is free, however, specified frequency response may suffer slightly. The FCC specifies frequency response as from 0.75 MHz to 5MHz above the lower channel boundary (P.C. -0.5 to P.C. + 3.75 MHz). Most manufacturers have specified frequency over a broader range, to cover the sound carrier. One can see from figure 7 that the lower adjacent trap, which is 1 MHz from the FCC minimum frequency, has the potential to pull down the response in the specified region. However, the FCC frequency response can still be met or exceeded with the adjacent traps. Experience has shown that having the traps is much more important than getting the last tenth of a decibel in response flatness.

2. Backtalk

Here is an interesting specification that is relatively unknown within the industry. Under certain conditions a signal may be developed on the terminal input due to the presence of untuned signals. This spurious signal may appear on the input of another terminal, producing a beat. Until CATV systems went to extended bandwiths, this problem could be eliminated by proper choice of IF frequency. However, when frequencies above 330 MHz came into use, selection of an IF frequency to avoid this problem became impractical.

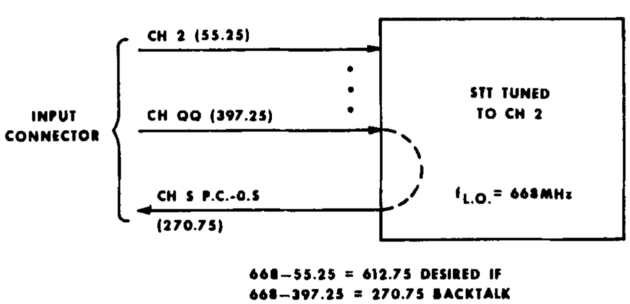


FIG 8 BACKTALK SOURCE

Figure 8 illustrates generation of backtalk by example. We have a terminal tuned to channel 2, 55.25 MHz. Among other incoming signals is channel QQ, at 397.25 MHz. Because the terminal is tuned to channel 2, the first local oscillator is oscillating at 668 MHz (668-55.25 = 612.75). Channel QQ energy is also converted by the local oscillator, to 270.75 MHz. Now this energy is ideally dissipated in losses in the mixer and IF filter, but due to incomplete balance in the mixer, some of the energy appears at the input connector. This signal is 0.5 MHz below channel S picture carrier.

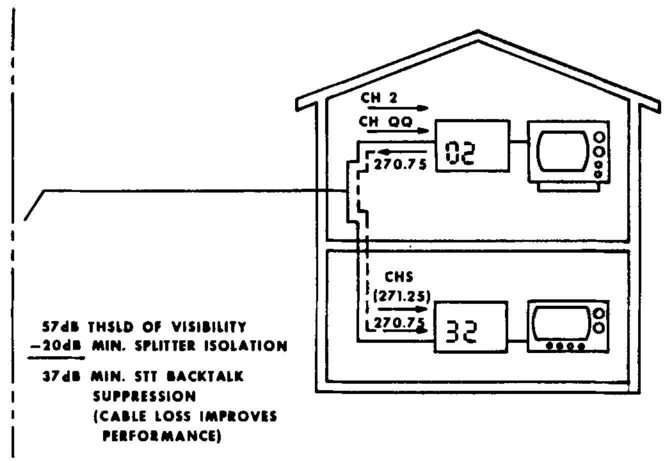
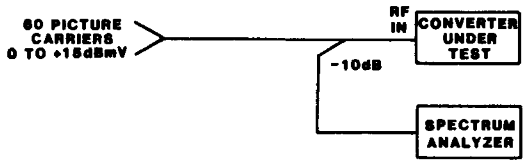


FIG 9 BACKTALK INTERFERENCE

To see how the backtalk signal can affect another TV set, see figure 9. The backtalk is generated in the terminal tuned to Channel 2 and propagates back toward a splitter. Due to imperfect isolation in the splitter, a portion of the backtalk arrives at the second set, tuned to Channel 32 (S). Here the backtalk signal shows up as a 0.5 MHz beat. Also shown on Figure 5.3 is the error budget we have used in determining what a backtalk specification should be. We assume that a backtalk signal should be -57dB from a viewed signal to be invisible. We further make the conservative assumption of 20dB isolation at the tap to arrive at a backtalk specification of -37dB from an incident carrier. We don't make allowance for frequency offset imrovement, so that we don't get trapped with an offset channel that doesn't work.



1. MEASURE SIGNAL LEVEL ENTERING CONVERTER.
2. MEASURE ANY SIGNALS FROM DIRECTIONAL COUPLER OTHER THAN INPUT SIGNALS.
3. SPURIOUS SIGNALS MUST BE -37dB FROM INPUT LEVEL, TAKING INTO ACCOUNT THE ACTUAL LOSS OF THE DIRECTIONAL COUPLER.

FIG. 10 BACKTALK MEASUREMENT

Backtalk may be measured by connnecting a 10dB directional coupler to a set-top in a direction so as to transfer backtalk energy to a spectrum analyzer. This is shown in figure 10. To allow backtalk to be seen, unmodulated carriers must be used. Calibration of this set-up is a bit tedious and should not be attempted except by someone who knows the technique well.

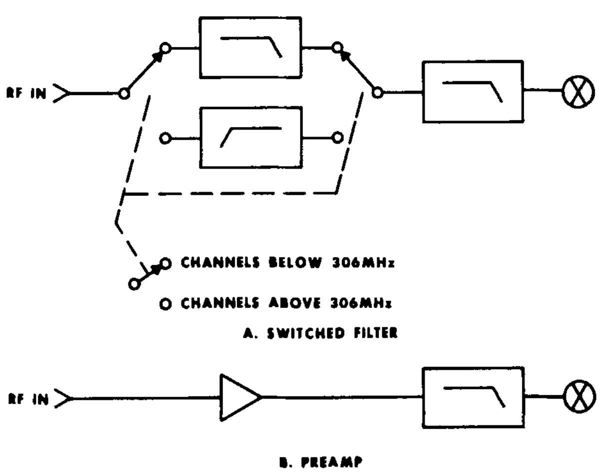


FIG 11 BACKTALK COUNTERMEASURES

If countermeasures are not taken against backtalk, normal circuit techniques will yield attenuation in the mid 20's. At least two viable countermeasures are available as shown in figure 11. In A we show the application of switched low-and high-pass filters. When tuning below 306 MHz in this case, the low pass section is switched in, attenuating the higher frequencies that cause backtalk. When the terminal is tuned above 306 MHz, we can show that backtalk doesn't occur, but we switch in a highpass filter anyway. This reduces mixed loading, reducing intermodulation distortion.

The second countermeasure available is a pre-amplifier used ahead of the mixer, as shown in figure 11B. This works because the amplifier exhibits gain in the forward direction and loss in the reverse direction. Superficially, this seems to be the way to go because the amplifier can also improve broadband input return loss and can improve noise figure. Unfortunately, these benefits come at a price, as illustrated in figure 12.

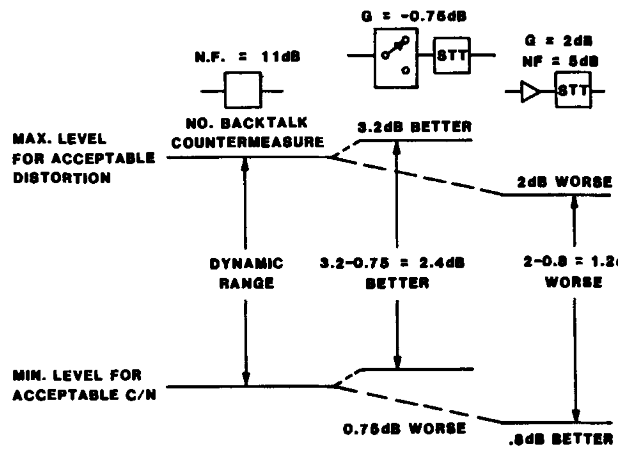


FIG. 12 EFFECT ON DYNAMIC RANGE

Figure 12 is divided into three parts. To the left is represented the dynamic range of a particular converter having neither backtalk countermeasure applied. Dynamic range is simply the window of input level which yields an acceptable picture. On the low end it is limited by noise figure, and on the high end by distortion. For the present purpose, we won't argue about the definition of where the picture becomes unacceptable, because we merely want to explore the change in dynamic range with backtalk countermeasures.

Returning to figure 12 we have on the left portion the dynamic range of a conventional converter. In the center we have added a switched filter having 0.75 dB of flat loss. To the right, we have added an amplifier to the basic converter. We compare what happens to the dynamic range of our basic converter when we add either the switched filter or the amplifier (but not both). We'll base our comparison on a 440 MHz system.

When we added the switched filter the signal hitting the mixer dropped by the filter's 0.75dB loss, so our minimum acceptable carrier level got worse by 0.75dB. However, we improved our situation on the high side. Empirically, we have determined that as more signals hit a mixer, the worst case composit triple beat increases by about

24.5LOG(NUMBER OF SIGNALS)(1)

A fully loaded 440 MHz system has 60 carriers on it. When the backtalk filter is in the lowpass position it will allow perhaps 38 carriers to the mixer, decreasing worst case CTB by about 4.86dB. Since CTB goes about 2:1 with level, this means we can increase signal level by half this, or 2.43dB before we reach maximum level. To this we add 0.75dB loss of the filter, permitting about 3.2dB increase in signal level. Thus, with the filter we improve high end acceptable level by 3.2dB while giving up 0.75dB on the low end. We now find that the terminal is 2.4dB more forgiving on input level as a result of adding the switched backtalk filter.

Now consider what would hapen if we had added the amplifier rather than the switched filter. We'll assume gains and noise figure as shown on figure 12. We calculate an overall noise figure of 10.2dB, an improvement of 0.8dB over the converter alone. This means that we can reduce the level at the low end by .8dB. On the other hand, the 2dB gain means that we must drop the maximum signal level by this much to avoid overloading the mixer (we assume that the amplifier doesn't add distortion). Thus, after adding the amplifier, the converter is 1.2dB less forgiving of signal level errors that it was previously. The difference in dynamic range between the switched filter and the amplifier is 3.6dB.

3. Noise Figure

We observed above a circumstance in which we improved dynamic range but at the expense of noise figure. Let us take a closer look at noise figure and the real effect it has on CATV system performance. The reader will recall that, by definition, noise figure (NF) is the excess noise introduced by an amplifier or other circuit element. Excess compared to what ? Every real resistance, including the 75 ohm source resistance that our distribution systems look like, generates noise as a result of random electron movement. But real electronic circuits exhibit even more noise than this, and we call the measure of extra noise generated noise figure. If an amplifier were perfect in this respect, it would have a NF of 0dB. A set-top with an 11dB NF contributes 11dB more noise than does an ideal terminal.

If we know the NF of a set-top and the incoming signal level, we can compute the resultant carrier to excess noise (C/N) ratio. If further we know the incoming C/N, we can compute the C/N ratio out of the terminal. If we also know the TV NF we can compute the C/N at the detector of the TV, the actual C/N seen by the subscriber.

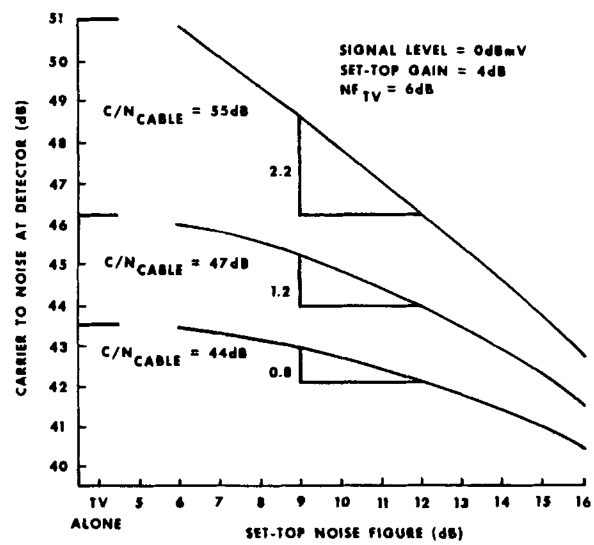


FIG 13 CARRIER TO NOISE RATIO vs. SET-TOP NOISE FIGURE

We have done all of this for several conditions, and show the result in figure 13. Here we plot C/N seen by the subscriber, v.s. set-top N.F., for three different cable C/N's. Other conditions assumed are shown. We now focus on cable C/N=44dB, representative of the end of a modern system. If the TV is directly connected to the cable, then the subscriber sees a 43.6dB C/N. If a set-top having a 9dB NF is inserted, the C/N becomes 43dB, while a 12dB NF terminal produces a 42.2dB C/N. Thus, improving the NF by 3dB in this case resulted in a C/N improvement of only 0.8dB seen by the subscriber.

From these curves, we can see that as noise figure is improved, pictures will improve, but not as fast as one

(1) CTB increases with the number of channels through two mechanisms: increased mixer voltage loading which goes as 20LOG(NUMBER OF CHANNELS), and additionally increases due to the larger number of CTB products on each channel. As the number of channels is increased, the channel of greatest CTB changes.

might hope. The reason is that we are partially limited by cable C/N and partially by TV N.F.

4. Input Return Loss

Finally, let's look for a moment at the effect of input return loss to the terminal. Return loss is defined as the ratio of incident signal to reflectetd signal. Compare waves on a pond which strike a piece of wood and bounce back. The ratio of the incoming (incident) wave to the reflected wave amplitude is the return loss. A return loss of 0 dB means all the signal is reflected (hence none is transmitted). An infinite return loss means that none of the signal is reflected, hence it must all be transmitted into the set-top.

What happens when signal is reflected from an input to a set-top ? It bounces back to the other end of the drop. If everything were perfect it would either be dissipated in the coupler resistor or the output impedance of the last amplifier, and nothing would happen. But taps and amplifiers also have finite return losses, so some of the signal is reflected again toward the set-top terminal. Or, due to limited isolation, the reflected signal may find itself on another drop, enroute to another set-top. Since the signal, wherever it arrives, will arrive later than the direct signal, it will produce that well known phenomenon known as a ghost.

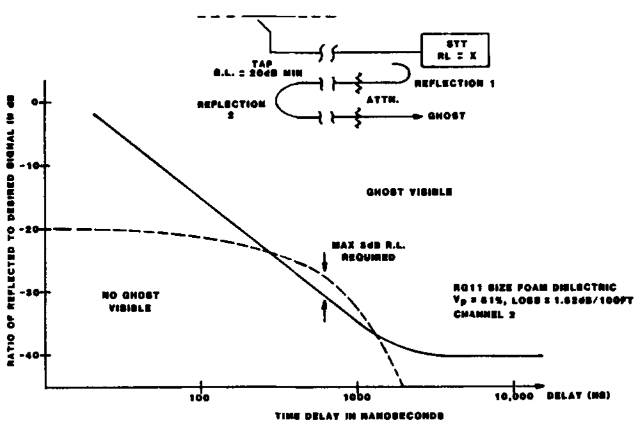


FIG 14 EFFECT OF ECHO

To analyze the severity of the ghost, we must determine the amplitude of the echo as it arrives at the set-top, plus its delay. To help, we invoke the standard Mertz curve, which defines the threshold of visibility of a ghost, as a function of its amplitude and delay. Figure 14 shows a popular incarnation of the Mertz curve. To utilize this information, Mr. R. Pidgeon of our staff has superimposed a curve showing round-trip attenuation and delay of an echo. The curve shown assumes a 20dB return loss at the last splitter (or tap). If we are analyzing the effect on a second set-top, we take this to represent a 20dB tap-to-tap isolation. Thus, Mr. Pidgeon has plotted delay vs amplitude for a particular cable, whose length is a parameter which shows only indirectly.

The curve shown is for an RG11 size cable having a loss of 1.62dB per hundred feet and a velocity factor of 81%. The cable characteristic plot invades the "ghost visible" area of the Mertz curve for a small region around 600nS delay. We can force the curve below the "visible" threshold by reducing the reflection by 3 dB. This may be achieved by using a terminal with a 3dB minimum return loss. Smaller sizes of cable will generally require even lower return loss to render the ghost invisible. Thus, we can see that a minimal set-top return loss will render ghosts invisible. Typical worst case return loss for current terminals range from about 6 to 8dB.

Another potential problem is that the reflection can affect frequency response, but calculation shows the effect to be negligible.

SCRAMBLING

No portion of a set-top terminal receives more attention than does the scrambling system. Virtually all of the popular scrambling systems in use today are based on rendering sync information indistinguishable from video. This is done variously by suppressing the sync pulses (horizontal and/or vertical) by attenuating the RF envelope, or shifting the baseband level prior to modulation. Descrambling is achieved by reversing the process. Synchronizing signals are inserted either within the vertical interval or as AM information on the sound carrier.

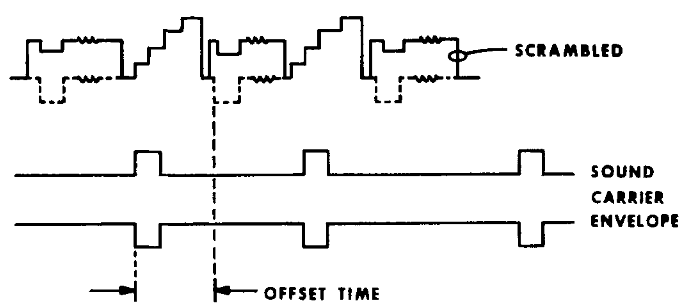


FIG 15 OFFSET SCRAMBLING TIMING

Figure 15 illustrates one such system. Shown at the top is a video waveform, which represents the bottom of a modulated RF envelope, this being an RF system. As shown, an attenuator is switched into the video IF path, reducing the amplitude by nominally 6dB during the horizontal and vertical blanking intervals. In this system pulses are placed on the sound carrier for synchronization, but they lead the horizontal blanking interval which they will decode, by a discrete length of time. Furthermore, this offset time is varied randomly from one field to the next, to make recovery by common pirate decoder boxes difficult. Extra pulses buried within a field are used to communicate timing information, which sets up a variable delay in a crystal controlled counter. For a pirate to duplicate this circuitry, he would need a rather large number of standard ICs. The manufacturer can accomplish the same end more economically because he has the volume to develop a custom IC.

Use of offset timing was developed as an improved security measure, but it has been found to offer further advantages. For example, when the video sync is restored by amplifying the RF, the sound carrier is also amplified, again by 6dB nominal. If the sound carrier has a 6dB pulse already at this time, then effectively the sound carrier is amplified 12dB from its nominal level during sync times. The sound carrier is thus more likely to crosstalk into the picture channel, creating ringing around the leading edge of sync. This effect has been observed, but the severity with different equipment is unknown. Also, with stereo this presents a problem because AM to PM conversion can cause errors in pilot amplitude and phase.

A particularly vexing problem with early realizations of scrambling systems using sound carrier synchronization was that the sound carrier had to be accurately tuned to recover pulses. Tuned radio frequency (TRF) receivers were used, and filtering was difficult due to the frequencies used.

A patented improvement makes use of the intercarrier technique to develop a 4.5 MHz sound (and sync) IF by mixing picture and sound carriers. This eliminates the critical tuning requirement of the earlier TRF approaches. By doing the filtering at 4.5 MHz, the filtering can be improved dramatically.

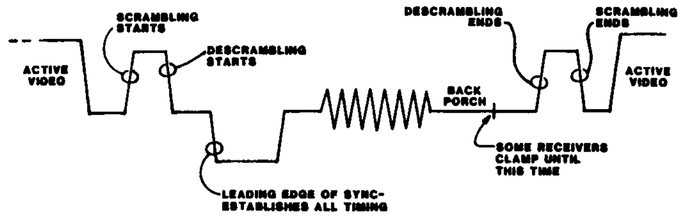


FIG. 16 DESCRAMBLED VIDEO

A compromise that must be made in descrambling is that the transition time of the descrambler must be controlled. Figure 16 shows this. The scrambling and descrambling processes must start and end in the order shown, without invading viewable picture area, clamp time or the leading edge of sync. When descrambling starts, the transition must be fast to complete itself before start of sync. On the other hand, if it is too fast, components beyond the bandwidth of the receiver are generated. In this case the receiver will generate Gibbs ringing which can overlap the leading edge of sync and cause timing errors.

Also, the scrambler must control its transition times to prevent ringing, though this is generally not as critical.

The scrambler must also follow a rather onerous set of standards for the sound carrier pulses. If the pulse transition times are too slow then timing errors can develop. If too fast, then spectrum overlap with on-or adjacent-channel video can occur.

A final requirement on the scrambler is that it should ensure that energy content on the video doesn't fall around the sound carrier, as this would result in timing errors. This is controlled by the insertion of a phase equalized lowpass filter in the scrambler baseband video loop. Characteristics of this filter should be checked when evaluating scramblers.

STEREO

A leading question in the industry today concerns the compatibility between scrambling systems and the stereo TV system. The format is nearly identical to the FM stereo format that has been with us for 25 years or so. Differences between the two can be summarized briefly.

1. TV stereo transmits a pilot at 15.734KHz (locked to the horizontal rate), rather than at 19KHz as in FM stereo.

2. TV stereo transmits a secondary audio program (SAP), FMd onto a carrier at 5 times the horizontal rate (78.67KHz). FM stereo may transmit an SCA on a 57KHz subcarrier.

3. TV stereo also transmits a low grade "professional channel" by FMing a subcarrier at 6.5 times the horizontal rate. This is intended to be used by a TV station for low rate data (e.g. telemetry from transmitter to studio) or intercom quality voice.

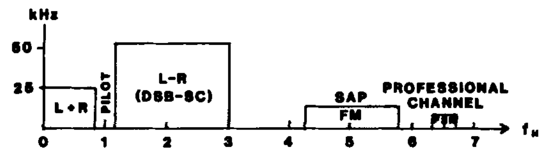


FIG. 17 MULTICHANNEL SOUND BASEBAND FORMAT

Refer to figure 17 for a spectrum of the proposed TV stereo baseband format (before modulation). As in FM stereo, a sum (L+R) signal is transmitted at its normal baseband frequency. Above this, the difference signal (L-R), is transmitted. In order to shift its spectrum, it is double sideband suppressed carrier (DSB-SC) modulated onto a carrier at twice the horizontal rate ($2f_h$). In order to recover the L-R signal the suppressed carrier must first be recovered. To do this, a pilot is transmitted at the horizontal rate. This pilot is doubled (usually in a phaselocked loop) and synchronously detects the L-R signal. The figure shows the SAP and professional channels, but let us cease our digression prior to talking about them. We have adequate background for the present purpose if we note that phase errors in the pilot result in phase errors in the L-R signal, and this causes separation errors.

Interaction between a scrambling system and stereo basically breaks down into two problems: what we do to them and what they do to us. We'll take the problems in reverse order.

What They Do To Us

The problem here is that we put amplitude modulation on signals that have been FMd with a deviation of $\pm$25KHz, and now we find ourselves facing a deviation nearly three times as great! What is bothering us is that in the signal path to recover our AM for synthronization, we have necessarily placed bandpass filters. Now bandpass filters by definition are not flat outside their passband, and they may not be totally flat within their passband. Thus, as the sound carrier's frequency is changed by the imposed frequency modulation, it may ride up and down a filter response, turning FM into AM (FM/AM). Filters that worked allright with 25KHz FM may have a problem with nearly 75KHz deviation. This could be conjectured to be a particularly onerous problem for systems that use sinewave modulation in a linear feedback loop, as the FM/AM component, now increased, is directly transferred to the video signal. Switched systems tend to be somewhat less susceptible as a result of their employment of a threshold at which a decision is made. Of course FM/AM can distort the decision point, resulting in the eventual collapse of switched systems as a result of switching time jitter.

What We Do To Them

Look back to figure 17 momentarily and observe the pilot signal, having a deviation of only 5KHz. Remember that the pilot is used to detect presence of a stereo telecast, switching in the stereo decoder. Now recall that many common RF scrambling schemes put AM on the sound carrier locked to the horizontal rate. Just as FM can get converted to AM, AM can get converted to FM. The mechanisms for doing this are legion, and include limiter errors and asymmetrically tuned bandpass filters. The more AM we put on the sound carrier the more spurious FM will get generated.

When this FM sound carrier, now contaminated with spurious FM modulation is detected, the resultant signal will have excess energy at f_h. If enough energy is present, the stereo pilot detector may falsely trigger on a monaural signal. Also, the artifact energy generated by the scrambling processs is at a random phase with respect to the pilot during a stereo broadcast. This causes a phase shift in the pilot carrier (now contaminated), which in turn results in a phase shift of the reinserted carrier. Finally, this results in loss of separation.

In summary, it is essential that AM/FM conversion be controlled to permit good quality audio on a scrambled stereo telecast. A portion of the responsibility for controlling AM/FM resides within the TV receiver or stereo adaptor. Obviously, the more AM that exists on the sound carrier, the more severe will be the problem. Recall that, by the time the receiver gets the audio signal, the signal has been amplitude modulated not only by the scrambling process, but by the descrambling process as well. The greater the scrambling depth the greater AM on the sound carrier. Also, if timing pulses are put on the sound carrier coincident with the horizontal blanking interval, then the pulse amplitude seen by the TV is the sum of the scrambling and descrambling pulse amplitudes. A particularly worrisome case is an on-time descrambling system having extra scrambling depth (e.g. 10dB suppression). With 6dB timing pulses, the audio carrier has pulses of 16dB seen by the TV audio system. This could give rise to considerable AM/FM conversion.

As of this writing, the above caveats remain speculative. Quantitatively the severity of the effects discussed is not known. Early tests tend to support conjectures made above, but more testing is needed before definitive statements can be made.

CONCLUSION

Even though this has been a cursory examination of the current state of the art in set-top terminals, the author has had to beg forgiveness for an excessively long paper. Many subjects were omitted or given only limited coverage. The role of data communications to and within addressable terminals merits much more attention (a slightly less cursory examination published previously by the author is available in the Winter '83 Addressability supplement published by CED, or from the writer.) Headend computer support systems are an integral part of addressability technology. One could write volumes concerning tradeoffs between security, cost, reliability and ease of use of addressable systems, including the role of various legal activities. Even the relatively comfortable area of RF specification needs much more work to determine the true optimum in cost vs performance tradeoffs.

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PREVENTIVE MAINTENANCE: LITTLE THINGS MEAN A LOT

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In a cable TV world filled with the excitement of new and developing technologies, it is sometimes easy to forget the simple, little, unglamorous things that keep systems running. A practical preventive maintenance program is filled with these little things.

They will never draw national headlines. They will never receive deafening applause. But these little things done properly, done at the right time, done as part of an overall preventive maintenance program, will keep a cable TV system running well. Subscribers like systems like that. I hope you do too.

INTRODUCTION

Imagine a newly-built cable television system in your town. The aluminum gleams as it spans from pole to pole; and where it goes underground, the pedestals stand straight and true. The amp cases hang majestically on the strand, never ceasing in their signal passing duties. Messengered droplines glide into each house and proudly carry "more choices than you ever dreamed possible."

Meanwhile back at the office, the calls are still coming in from people eager to subscribe to the service or from subscribers wishing to thank the cable TV firm for such good service. The installers (the only outside-working employees at this system) scurry from house to house hanging new wires and installing new converters.

The cable system runs flawlessly day after day, month after month, year after year. The owner and manager are left only to address such questions as: "Should we be 80% invested in the stock market and 20% in the bond market? Or should we be starting to put our excess cash into Jumbo C.D.'s and T-bills?"

And now open your mouth, insert your index fingers, and bite down hard. It is time to abandon our dream and come back to reality, to the cable system that really exists in your town. The system that sometimes has technicians scurrying from house to house instead of installers. The system that sometimes has the owner and the manager going nuts trying to figure out where the money is going to come from to keep everything repaired and operating.

Let's face it. Real cable TV systems have real problems. Some are big problems; many are small. But the main issue I want to address is this: some systems have fewer problems or service calls per subscriber than other systems.

Is this just luck? Well, luck might have a bit to do with it. Is it because some systems are newer than others? That would certainly have some bearing on the matter. But two things more than anything else will affect this issue: PREVENTIVE MAINTENANCE and PROPER MAINTENANCE.

It is my opinion (and I hope a few others will agree) that these two things, done with care will save untold ulcers and headaches, and make life easier for all involved in cable. What follows hereafter are some thoughts and ramblings on the two P's of maintenance.

A BAD EXAMPLE

In 1973 a state-of-the-art cable television system was built in Seymour, Indiana. It was constructed in a top quality manner with P1 aluminum and spliced using non-cored fittings. The C-COR 400 series trunk and distribution amplifiers were capable of passing 24 channels and were professionally balanced and swept for peak performance.

Waterproofing compound (RTV) was applied to all aluminum fittings and splices to insure that corrosion would not develop in the passives and the amp cases. In short, as the system lived through its first few weeks of active life, it might have resembled to a certain degree the "dream" system mentioned at the start of this paper.

However, between 1973 and June 3,

1981, when I came here, something went wrong. The dream turned into a nightmare. What was once gleaming aluminum spanning from pole to pole had turned into disaster on strand held together by corrosion, tape and short pieces of mangled lashing wire.

This did not come about by total neglect of maintenance. Nor did it happen in one year. I truly believe that the different technicians working here during that time span worked very hard and thought they were keeping up. And, I doubt that they ever realized the picture quality and the cable plant as a whole were slowly getting in worse shape.

Near the end of this eight year period, certain conditions became accepted as normal. When it rained, all cable employees knew that certain feederlines would soon be blowing fuses. Other specific feederlines always shut down during lightening storms. There were "bad" parts of town where installers hated to go because the pictures were always grainy or had lines and interference.

One technician spent his whole day doing nothing but service calls for this system of then 3500 subscribers. No one was able to keep his signal leakage monitor turned on because it never would have shut off. There seemed to be more signals on the outside of the cable than on the inside.

What has been done at Seymour in the past three years? What could have been done to prevent these problems? What is currently being done at Seymour and other Cardinal Communications systems to insure optimum operating efficiency and prevent problems like these from arising?

THE SOLUTION

Trunkline Integrity

The backbone of a CATV system is its trunkline. The tower site may be situated at the ideal location for picking up off-air signals. The earth station may be more than adequate. And, the signal processing equipment may deliver crisp, clean, broadcast-quality pictures. But if all these lovely signals are dumped on to a trunkline with moisture ingress, breaks, signal leaking splices and passives, the subscribers may think the headend gear was purchased at a garage sale.

The integrity of the trunkline must be maintained to have any chance at delivering good pictures to subscribers. Thus when the battle to restore Seymour's cable TV system to better health was begun, the trunkline was attacked first. Starting at the headend, the trunkline was inspected from amp to amp.

Particular attention was given to the number of splices in each span. One or two splices in an 1,800'---2,400' trunk cable seems very acceptable. Three or four splices could even be accepted. However, when there are five, six, or more (heavy emphasis on more), the integrity of that particular section must be questioned.

Today's splices with their radiation sleeves and high RF shielding do a very wonderful job, in my opinion. When splices are installed properly, they are almost as good as an unbroken piece of cable. And yet it seems that sage, Murphy, has warped my thinking about so many things in cable. I cannot keep myself from seeing each splice as a potential suck out, a potential short or open, or some other terrible CATV disaster.

We replaced several sections of trunkline in Seymour just to be rid of splices. We will do it again in the future as the need arises. It is good insurance. Insurance against what? Against having half your system go off on Super Bowl afternoon for two or three hours as your technicians frantically search for the offending splice.

It is insurance against problems that flare up just as a new, critically acclaimed program was about to be watched by 75% of your subscribers. Granted, these splice-induced outages may not happen often in most systems. But odds are every system's personnel could relate horror stories concerning outages of this type.

Think now about your system. Can you pinpoint any areas of above normal trouble? Could this be related to excessive numbers of splices?

Most definitely, splices are the cheapest and often the best way of repairing a trunkline. But cheapest (and easiest) is not always best and cheapest for the long haul. There can be no hard and fast rules in this area, but each system must decide for itself what the splicing limits can be.

Also, just because your system now has no heavily spliced sections in it does not mean they will never develop. They will. Electric and telephone utilities (with their pole change-outs) and drunk drivers love nothing better it seems than making sure your trunklines are 2,000 splices connected with 1,000 six inch pieces of cable.

Heavily spliced sections usually do

not grow overnight. They slowly take form over many months or years. This means that trunkline sections must periodically be inspected. Every six months seems like a good time period. However, each system's technicians should go with whatever they think will meet its needs. In any case, as the saying goes (sort of): see your trunk now, or see it later. The choice is yours.

While scanning the system for splices, do not overlook the splitters, directional couplers, and amp cases. Do the fittings seem to be in good shape? Maybe a small random sampling can give some clues about the majority of trunk fittings in your system. Check the amp cases for moisture ingress. Soggy amplifiers do funny things.

Do not be afraid to look at all these things with a critical eye. Save the trunkline!

Employees: Friends or Foes?

Before June of 1981, the cable TV system at Seymour was battling against many enemies. The natural aging process of the equipment, the weather, public utilities and drunk drivers were taking their toll. But by far the biggest enemy that the cable system faced was its own outside employees. Their work methods and "maintenance" contributed more to the system's deterioration than all other things combined.

This problem is not something that was unique to Seymour either. I think a good survey would show that many systems in any part of the country have experienced this problem. Moreover, many systems are still experiencing this problem.

Why? Lack of education! I truly believe that most times these employees are sincere in their desire to perform maintenance or do installs properly. It is just that they have never been told what really are the proper methods.

Proper Methods

Goop has got to be one of the cable system's best friends. What is it? It is the gooey, grease-like stuff that is squirted into dropline fittings on all outside connections. It is the stuff squirted on all threads of feederline and trunkline fittings. It is squirted onto the threads of the cylinder traps or coil-type traps. Goop can be used almost anywhere.

I am using "goop" as a generic name. There are a variety of products on the market which will work as goop. Oxiban, Blackburn, No-lox are some that we have used with great success here at Seymour and other Cardinal Communications systems.

The greatest advertisement for using goop has to be the effects of not using goop. At Seymour for instance no dropline fittings or trap fittings had it applied before 1981. Any droplines that had been hooked up a while had to be taken off almost entirely by a wrench. Putting them back on was just as bad.

It was not uncommon to have fittings that could not be removed from taps because they were corroded so badly. If someone got adventurous and worked hard to remove a stuck fitting, a broken tap port usually resulted.

In the same way, traps and dropline fittings were oftentimes "welded" together. Splice and groundblock fittings became hotspots for trouble. Even feederline and trunkline fittings were not immune to the problem. Corrosion was rampant and lack of goop was partially to blame. Signals leaked everywhere.

It is hard to believe, but many cable TV systems still use no goop and still fight a never-ending battle with corrosion. It is a battle they are doomed to lose. It is a battle where the cable TV subscribers are the victims.

A final thought on goop: make sure your outside employees use it without failing. If they use it on 95% of their fittings, then the remaining 5% will do you in. No percentage less than 100 is acceptable. It is that important.

Here at Seymour if an installer forgets to take his goop bottle up a pole, he will not hesitate to climb down to get it, even if it is highly inconvenient. The people here know what life is like without goop. They never want to live that way again.

Heat shrink tubing and waterproof sealants such as RTV have proven invaluable at Seymour in the past few years. These fight corrosion just as the goop does. As stated earlier in this report, Seymour's cable system was RTV'd at each trunkline and feederline connection when the system was built. However as new sections were built, taps were changed out or added, or splices were cut in, little, if any, RTV'ing was done.

Just like the goopless fittings, the unsealed trunkline and feederline connections did no immediate harm. The damage came several years later as passives and amplifier cases filled with water. Corroded fittings, especially on feederlines, led to signal leakage. Corroded fittings lead to dramatic irregularities in frequency responses of trunk and feederlines.

It has been a long, slow process to rid Seymour's cable TV system of this problem. Great amounts of time have been spent driving out feederlines looking for nonprotected connections. Hundreds of fittings have been changed, along with dozens of water-logged passives. None of this was cheap, and none of this should have happened.

We currently use heat shrink tubing on all trunk and feederline connections. It seems to be more effective at stopping moisture ingress. But the key again is this. Whether heat shrink tubing or other sealants are used, use them faithfully. Use them 100% of the time. Murphy says the exceptions will be a system's downfall, and he knows whereof he speaks.

Install in employees' minds the urgency of sealing connections at the time they are made. Many is the time I have heard the phrase: "I'll come back and seal the heat shrink tubing tomorrow." Only, tomorrow finds that technician working on the other side of town, and that unsealed connection is quickly forgotten. And then, two years later.....Disaster!

(That other well-known phrase: I'll come back and goop the fittings tomorrow" usually brings the same results.)

I know that the majority of systems are already doing these things. And yet I also know many that are not. Within the last two years at least two cable TV systems in this area alone were built with no goop, no RTV, or no heat shrink tubing. Undoubtedly the owners saved a bit of money up front. However, their future looks expensive.

<u>The Eyes Have It</u>

Because of the size of Seymour's cable TV system, I am unfortunately not able to drive out all the feederlines and trunklines each day. I feel lucky to drive my system out once every six months. But, thank goodness, I do not have to monitor the system alone. No one should have to (unless of course it is a small, one-man system).

Each system has installers and technicians who have very useful sets of eyes. If these eyes can be put to work in the preventive maintenance area, great things can be done. Or, put another way, horrible things can be prevented.

It pays for each outside employee (and even CSR's and other office personnel to a certain degree) to develop "educated eyeballs." What in the world are "educated eyeballs?"

They are eyes that see cable problems before they happen or as they are beginning to happen. They are eyes that notice little things out of place. They are eyes connected to a brain constantly in tune with seeking out trouble spots or preventing trouble spots from appearing.

Educated eyeballs are not something some cable people are born with and others are not. They are not innate. They are developed. They cannot be developed in one day, however, but must be nurtured and acquired over a period of time.

Educated eyeballs may come easier to some than others. Any skill is that way. Yet I am convinced anyone can develop them to a certain degree. Once acquired, they are an invaluable asset to any employee and to any cable TV company.

Why? They save money! They prevent trouble! They save the chief tech from exhaustion!

Most systems' installers and technicians will log many more on-job driving miles each week than the chief tech or engineer. Many of these miles will take them by or underneath the cable plant. Thus the opportunity is there for them to spot trouble, if they know what they are looking for and look for it.

What should they be looking for? The following is just a partial list: broken lashing wire, tree limbs growing heavily into the cable, low-hanging drops, expansion loops dangerously near or even rubbing J-hooks and telephone bolts, splitters hanging from taps, surprise pole change-outs, and more.

The list really is limitless. The idea is to keep the mind tuned for potential problems. When the mind is tuned in, the eyes will not be far behind.

<u>Open Ears</u>

In my thinking, any discussion about educated eyeballs would not be complete without some talk about ears. Of particular importance are the chief tech's ears.

Office personnel, installers, and technicians can spot all the potential trouble they want. But if the person who needs to be notified will not listen or take them seriously, the cable system is no better off. In fact, it is worse off because employees will soon become discouraged.

Listening is of great importance in any preventive maintenance plan. Write down employees' tips and check them out. Ask them if they saw anything out of the ordinary on the cable plant. Ask them about the picture quality at some of the houses they visited. Then stand back and listen. As a wise man once said, "Installers say the darndest things."

Ears can be important in another sense also. They can listen for signal leakage. Several signal leakage detection systems are currently made which make use of FM receivers mounted in company vehicles. When a vehicle is driven close to a leak of sufficient magnitude, the monitor goes off, alerting the driver to the leak. With the FAA, the amateur radio operators, and the FCC all hollering about signal leakage, it seems a good thing to be concerned about.

Once again it is advantageous to use the employees' on-job driving to help with preventive maintenance. Here at Seymour and at all other Cardinal Communications systems, each company vehicle is equipped with a signal leakage detector. It is amazing at what the installers, technicians, and sometimes even the managers find as they drive. But more amazing still are the problems prevented by good listening habits.

Signal leakage detectors for every vehicle may sound expensive; but have you noticed the increased amounts of FCC fines lately? I would rather hear about signal leakage from my fellow employees than from the FCC. It is much cheaper in the long run.

<u>Neatness: Is It Worthwhile?</u>

No matter where I go, I find myself spending a great deal of time looking at the cable TV lines. As I come into a city or town my eyes are instinctively drawn upwards to the aluminum spanning from pole to pole. But what my eyes really study most are the taps.

What is their overall appearance? Are the droplines coiled up neatly along with the traps? Or do great lengths of droplines and traps dangle below the taps? Do the areas around the taps look orderly to the eye, or do they look like chaos?

Although the following rule may not apply in all systems, it will apply in most. As the taps go, so goes the rest of the system.

I have found that systems with messy or chaotic taps tend to look that way in other respects. Pole change-outs are done haphazardly. Installs may be sub par. Normal plant maintenance is done with just enough effort to get by.

All of this has something to do with system pride. If employees love their system and take pride in it, then they will do their best to make it look good, even down to the taps. But I believe low employee moral and lack of pride will soon show up at the taps and then in other places.

Also, in general, it seems that messiness breeds problems. There is something about a messy tap that invites trouble. Things just seem to go wrong more frequently. I am not sure why exactly, but I know it is true. Diligent attention to plant neatness has a direct correlation to service calls and should be an integral part of any preventive maintenance program.

<u>Record Keeping</u>

At first thought maybe, record keeping would seem to have very little bearing on preventive maintenance. However, it can make all the difference in the world. Good records can help spot problems or potential problems and help prevent them.

Among the best and most invaluable records of any CATV system are the system's own yearly FCC proof testings. These tests were actually not designed by the FCC to keep technicians busy doing worthless things for several weeks every year, as some cable TV operators think. They are a forced maintenance and preventive maintenance tool.

Not a year has gone by at any of our Cardinal Communications systems that we have not uncovered problems or developing problems during our FCC testing. For that reason then, we do not skimp on our testing or treat it lightly. We work hard at it, we dig deeply, and we are richly rewarded for the effort. I think our subscribers are rewarded also.

By keeping detailed records of our FCC proofs, we can see what trunklines or feederlines have caused the most problems over the years. By analysing these records, we can see what sections are candidates for a rebuild or at least some intensive work.

Other records of great importance are input, output and voltage levels from all of our amplifiers. As routine maintenance or periodic balancing is performed on the amplifiers, we can tell if these parameters have changed and how much they have changed. We can then quickly start looking for why they have changed.

Up-to-date amplifier readings eliminate the guess-work that goes on at many systems. It is surprising how often exchanges like this really happen: "It seems like the input was a lot higher last year."----"No, I'm sure it was the same."----"O well, I think I can make it set up."

Do not neglect to keep records on stand-by power supply maintenance (battery water levels, etc.), headend equipment, tower lighting, signal leakage and more. Some records may be of more value than others in different systems, but the main thing is to decide what will be useful at your system and then record it.

CONCLUSION

So often in cable TV we are bombarded with the new technologies currently being put into practice or that are coming soon. That is exciting and one of the reasons cable TV is a good field to be involved in.

Yet, like so many other industries, cable TV is dependent on lots of little, unexciting things. It would have been nice to present a paper full of great, new discoveries in the field of preventive maintenance, and I am sure there are some coming someday.

But for now I can only tell you about some of the little things we are doing. Putting goop in a dropline fitting does not seem glamorous. Nor does having "educated eyeballs" sound beautiful. These little things, along with others, however, CAN make a difference.

They may not win systems awards for great thoughts and ideas, but I hope they will save systems some money and help keep subscribers happy. As someone once said, "Little things mean a lot."

PROSPECTS FOR STANDARDIZATION IN CABLE AUDIO

Dennis P. Waters

WATERS & CO.

ABSTRACT

Several forces are converging to swing the attention of the cable industry toward high quality stereo audio. These include tv multichannel sound, digital audio as an encryption technique, the new pay audio services, and Compact Disc digital audio in the consumer marketplace. Several incompatible systems have been proposed for transmitting high quality stereo audio over cable plants. Since each has been optimized for its own particular purposes, selecting one as a standard involves a complex set of trade-offs.

BACKGROUND

Audio has always been a stepchild of the CATV industry. This is because cable has been -- and remains -- a television business. But the attention of the cable industry is starting to swing in the direction of audio. There are a variety of reasons for this, and there are also a variety of questions to be answered before cable can take advantage of its potential as an audio medium. One of these questions is standardization.

Standardization has not been a significant problem in the video domain. There is NTSC video and that's about that. True, there are a number of scrambling techniques in use, and different cable plants tend to be subject to different technical constraints. But there has been very little argument about the basic format for carrying video information. As we shall see, however, in the audio domain there is very little but argument.

This question of standardization is never clear cut. Some argue that imposition of standards stifles development, constricts the free marketplace, and condemns the state of the art to the Dark Ages. Others insist that failure to agree on standards delays development, creates chaos, and frightens away investors. Our purpose here is not to settle this ancient argument, only to outline some issues involved in transmission standards for high quality stereo audio over cable systems.

FORCES

Why is audio drawing attention after being a throwaway for so long? We have identified four principal reasons. First is stereo television, particularly the question of what to do about multichannel sound in broadcast tv. Second is digital audio encryption, which some believe to be the ultimate weapon against theft of service. Third is pay audio services -- which may turn into a tidy profit center at some systems. Finally there is the Compact Disc, a technological innovation in the consumer hi-fi market that offers interesting opportunities to a broadband medium like cable.

Multichannel Sound

Now that the FCC has given the green light to television broadcasters to begin transmitting stereo and second language audio, what will the cable business do about it? We already know that many systems cannot carry the BTSC multichannel format. We also know that cable will face strong marketplace pressure to provide stereo service to its subscribers.

To ignore multichannel sound in the face of heavy promotion by broadcasters and set manufacturers carries a definite risk for cable operators -- the risk of being perceived by subscribers as offering low quality, less than state of the art service. Ironically, an aggressive approach by cable operators could actually depress the market for new stereo tv sets by giving subscribers stereo tv sound through their existing hi-fi equipment. But whether cable is an active or passive carrier of stereo tv sound, it faces the same problem -- how to get the sound into the subscriber's home.

Digital Encryption

Because audio can be digitized, it

can be encrypted, providing the 'hardest' possible security for a premium video signal. Use of digital audio for this purpose was pioneered in the satellite business, but now there is a cable product, with more likely to follow. There are some who believe that digital encryption is the last best hope of the cable business to protect itself against video piracy.

Pay Audio

During the past year, a handful of cable operators have begun to offer pay audio in one form or another. Most pay audio tiers combine stereo program audio for cable networks like MTV or The Nashville Network with several of the dozen or more audio services now available by satellite. These packages are either bundled into a top of the line multipay package or sold as a separate tier. Many large MSOs are taking a hard look at pay audio, and plan to begin serious market tests in the near future.

Compact Disc

The consumer hi-fi business and the pre-recorded music business are very excited about Compact Disc (CD) digital audio, the new high quality format for the consumer market. During 1983, high prices and a limited supply of software held CD player sales in the U-S to about 35,000 units. The 1984 forecast is for about 200,000 units as prices fall to the $300-$400 range and over 1,000 software titles become available. Industry optimists predict that the Compact Disc and the vinyl LP will reach parity sometime in the early 1990s.

What is interesting about the CD for the cable business is that broadcast FM radio does not have the bandwidth to transmit full fidelity digital audio into the home of the consumer. About 1.5 MHz is needed for every CD stereo pair, and FM radio has only 200 kHz. As a broadband medium, cable is one of the few ways of transmitting high-quality digital audio directly into the home. It may be useful to think of digital as 'high definition audio' -- an analogy to high definition television, which traditional broadcasters can't transmit either.

SYSTEMS

Several different systems have been proposed for transmitting high quality stereo audio over cable plants. Some of these are in use, while others are still in the prototype stage. Each has been optimized for a particular application. Here are seven system types:

FM Multiplex Systems

The ordinary broadcast FM standard is the most common means of transmitting stereo audio over a cable plant. Carriers are typically placed either in the 88-108 MHz FM band, or just above it in the aircraft navigation band. In the latter case, a block converter is used to convert the signals to a frequency that the subscriber can receive. Catel, Leaming, and Pioneer are among the companies manufacturing audio block converters.

Video-Dependent Analog Systems

Video-dependent analog systems transmit stereo audio in analog form within the video bandwidth. They tend to be proprietary, and hence incompatible with existing video transmission methods. This means a total retrofit of headend and subscriber equipment. An example is the MAAST system marketed by Telease, which can incorporate several channels of audio into each video channel.

Video-Independent 'Afterburner' Systems

Video-independent systems transmit stereo audio in-band, but in NTSC-compatible form. Stereo decoding is accomplished by an 'afterburner' device inserted in the line between the converter box and the subscriber's set. Without the device, the subscriber gets regular mono audio. With the device, he can retrieve stereo. The 'afterburner' is designed as a premium option that can be self-installed. An example is the TPM system marketed by Cable TV Supply.

Video-Dependent Digital Systems

Like their analog cousins, video-dependent digital systems transmit stereo audio in-band using proprietary technology. The audio is digitized and can be encrypted for 'hard' security of premium video services. A example is the Oak Sigma system.

Integrated Analog Systems

Integrated analog systems transmit stereo audio out-of-band in proprietary analog formats. Their audio-only converter boxes can include features normally associated with video boxes, features like discrete channel tuning, addressability, and remote control. An example is the Studioline/Leaming system.

Integrated Digital Systems

Integrated digital systems resemble integrated analog systems, but digitize the audio, thereby permitting encryption.

They can offer CD quality -- either 16-bit linear PCM or a close equivalent. An example is the Sony CADA system.

It can be seen that we are far from any consensus on how audio should best be carried on a cable system. The reason for this is simple. Each of the available systems has been optimized for a different purpose. The block converter is optimized for straightforward, low cost technology. The Oak Sigma is optimized for digital encryption. The Studioline system is optimized for pay audio tiering. TPM is optimized for NTSC compatibility. Sony's CADA is optimized for Compact Disc quality. And so on.

TRADE-OFFS

Is it possible to make any sense out of this confusion? Only partially. There are trade-offs involved, trade-offs that overlap and interlock in curious ways. Here are a few:

Analog vs. Digital

Will cable eventually be a digital audio medium, or is digital more trouble than it is worth? In digital's favor are the fact that it can be encrypted, that it can match the quality of the state-of-the-art in consumer hi-fi, the Compact Disc, and the fact that it can be blended with other types of digital data or digital services. But digital is also more expensive, for the moment at least, and is a tremendous hog when it comes to bandwidth. Analog is less expensive, more spectrum-efficient, and can approach the quality level of digital audio.

In-band vs. Out-of-band

Some systems propose to transmit stereo audio with video, while others propose to transmit audio somewhere else on the system. Putting audio with video has several advantages. First, audio and video can be tuned together, eliminating subscriber frustration with the so-called 'dual-tuning' problem. Second, in-band audio means one box. But in-band transmission limits audio offerings to stereo program audio -- leaving no room for stand-alone pay audio services. It also imposes an upper limit on quality. 16-bit linear PCM is just not going to fit in-band.

Video vs. Audio

Should cable continue to think of itself as a video medium as when it comes to audio? In other words, is stereo program audio for video services the be-all and end-all of audio on cable? Or will there be room for audio by itself, in whatever form? If both program audio and stand-alone audio are to be part of cable's plan, should they share a common transmission system or be handled individually? Should one be optimized for stereo tv sets and the other for stereo systems, or will the merging of component video and component audio blur the distinction?

Short-term vs. Long-term

The cable industry has not yet made a large investment in audio transmission systems. But it seems like it is about to. Will we see several generations? Or will the first generation be flexible enough to endure? Is the object of the game to find a 'quick fix' for the multichannel sound problem, or to view cable as an audio medium in its own right?

CONCLUSION

There are many reasons for cable operators to be in the audio business, and the industry appears on the threshold of getting into high-quality stereo for the first time. Various suppliers have their own incompatible ideas about what stereo audio means to cable, and have therefore designed incompatible systems optimized to suit these ideas. But the big question remains. What is cable's vision of itself as an audio medium? It is the answer to this question that will set tomorrow's standards.

QUANTIFYING SIGNAL LEAKAGE - HOW DO CURRENT METHODS MEASURE UP?

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ABSTRACT

Signal leakage continues to be a critical issue for systems operators and hardware manufacturers alike. The FCC's viewpoint and their actions surrounding this issue have been well documented in the past several months, as have been the opinions of several major MSO's. The viewpoint of the manufacturer, however, has been noticeably absent from recent publications documenting the issue. This paper will attempt to make the viewpoint of at least one manufacturer known, as well as discuss and analyze several different methods for measuring RFI isolation.

INTRODUCTION

As mentioned above, the viewpoint of the CATV equipment manufacturer has yet to be revealed to the rest of the cable industry. This silence can be attributed in part to conflicting signals received by the manufacturers from systems operators. On one hand, operators are demanding RF tight equipment; on the other hand, the operators are extremely price sensitive and are not willing to incur the additional cost required to improve the RF integrity of the product. This problem is especially prevalent in the area of subscriber passives, historically significant offenders relative to leakage levels, as approximately 65% of all signal leakage occurs in the drop section of the cable.[1] Little attention has been focused on improving the integrity of these products primarily due to the fractional percentage of dollars invested in the subpassive line as compared with the active and passive lines.

The majority of operators and manufacturers are finally beginning to realize that the RFI issue is a critical one as the fines levied by the FCC continue to increase in both amount and frequency. This realization is providing manufacturers the motivation and impetus to commit themselves to the manufacturing of an RF tight product line. The problem that manufacturers now face is of a different nature: by what process can they measure the leakage levels of their new products to insure that FCC radiation specifications are met and/or exceeded? How, in addition, can they correlate their results with those achieved by systems operators using either the same or different measurement methods?

In order to answer these questions, analysis and testing of several of the more "common" methods has been initiated. All tests were conducted using the same subpassive splitters in order to determine if correlation was possible. The methods analyzed include:

1. An FCC approved open air site
2. A transverse electromagnetic cell (TEM cell)
3. An RFI chamber

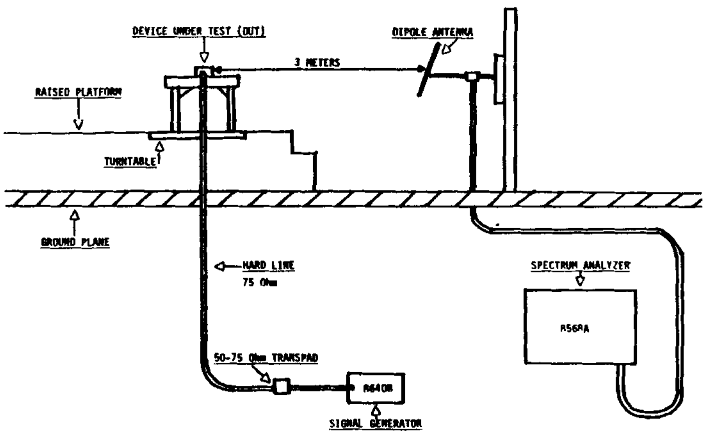
A brief description, as well as measurement results, correlational information, advantages/disadvantages and cost requirements will be included for each method outlined above.

FCC APPROVED OPEN AIR SITE

Description: The open air site is a method in which the device under test (DUT) is placed on a turntable 3 meters (10 feet) from a horizontal calibrated dipole antenna. A signal generator is used to pump a given level of signal into the DUT. The radiated field from the DUT is then measured off the dipole antenna at the far field distance using a spectrum analyzer, field strength meter, or other approved receiver. Because the length of the dipole antenna must be varied with each frequency tested, several discrete points accross the frequency band must be tested in order to create an accurate picture of the leakage levels. The turntable on which the DUT rests should then be rotated and field strength measurements repeated, until a "worst case" view is found and the discrete measurements are recorded. (See open air site measurement.)

A level terrain free of metal objects within 50 yards of the site must be selected in order to construct an accurate and effective outdoor site. Once a suitable location is found, a survey of ambient RF signals from 5-1000 MHz must be taken, and the orientation of the facility should be adjusted accordingly. These ambient signals should then be plotted and analyzed against the frequency in which most of the testing will be done. A metal ground plane (often bonded wire mesh) must cover the entire surface of the radiation site to act as a ground plane, and the engineer, field strength meter and other equipment should be located below this plane on a platform which allows the engineer an eye level view of the DUT.[2] A support tower constructed from wood and fiber glass is used to vary the height of the receiving antenna. This tower often has a chain assembly used to raise or lower the antenna depending on the height of the DUT.[3]

OPEN SITE TEST



Measurements:

1. Field strength is measured in microvolts per meter.

2. This measurement is then multipled by a correction factor which includes both an antenna correction factor and cable factor. A chart of the antenna correction factors (ACF), the loss or gain factor of the antenna used, is supplied with the antenna at the time of purchase. The cable factor (CAF) accounts for the length and type of cable used.

3. The resulting number is transposed to microvolts, then to dBmV via the formula:

$$\text{dBmV} = 20 \log_{10} \text{EmV}$$

4. The input level (dBmV) is subtracted from the above result.

You will note in the chart that the input levels are varied in this example due to leakage in the hard line cable at certain frequencies. To determine the input level used, the level was increased until leakage on the terminated cable was seen at each of the above frequencies. This input level was then used for the actual test at each of the frequencies.

Unit: ML-4DR #7

Frequency	Field Strength v/M(CAF+ACF)	Reading (dBmV)	Input Level (dBmV)	Isolation (dB)
30	3.40	-49.35	54.65	104
54	9.16	-40.76	64.25	105
125	11.37	-38.35	54.15	> 93
135	12.49	-38.05	56.95	> 95
185	.05	-85.25	54.75	>140
200	.07	-82.05	63.95	146
216	.10	-80.35	65.65	146
330	.12	-78.25	>64.75	>143
450	.18	-74.85	58.15	133
500	.24	-72.55	64.45	>137

Advantages:

1. The open air site is the approved FCC test method.

2. Test measurements are highly repeatable.

3. The open air site provides an absolute standard.

4. The open air site can be a useful diagnostic tool.

Disadvantages:

1. The open air site cannot discriminate between an egress signal and one that is normal to the external electromagnetic environment.

2. Space requirements are large.

3. The time needed to test one product at several points over the usable bandwidth is extremely high, up to one hour per unit depending on the number of frequencies tested.

4. Weather conditions will effect measurements.

Cost Requirements: The cost for materials needed to construct an outdoor site may run as low as $2000. Test equipment needed includes a signal generator, spectrum analyzer or RF meter and dipole antenna set. Final cost for an outdoor site, then, may be as low as $32,000.

The cost for materials required for an indoor site begins at approximately $70,000, not including test equipment. It should be noted here that most organizations interested in measuring RFI will already own most of the test equipment needed to operate the open air site.

TRANSVERSE ELECTROMAGNETIC CELL (TEM CELL)

Description: The Transverse Electromagnetic Cell (TEM cell) is a shielded two cell chamber used to measure either signal ingress or egress. The two cells, mirror images of each other, are designed to minimize reflections through the use of anechoic material. They are separated by a metal plate (septum) which acts as a center conductor. The cell is typically constructed of

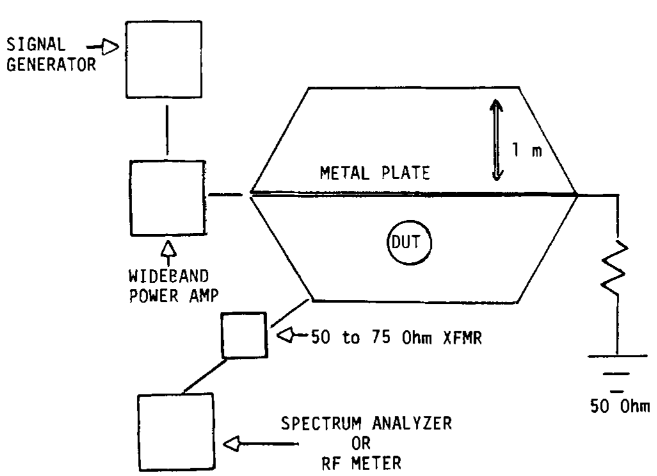
.090 aluminum with vertical delron support rods connected to the septum.

To measure signal ingress in the TEM cell, the DUT is placed in the lower cell, and is connected to the edge of the cell via 75 Ohm hard line cable. A signal generator and power amplifier are used to generate an RF field of 5 volts in the chamber. The ingress levels are then measured off the hard line connection by either an RF meter or spectrum analyzer. It should be noted that while a spectrum analyzer will display peak voltage levels across the entire bandwidth, the RF meter will display RMS values. The FCC uses an Ailtech 37/57 RF meter for their final inspections.

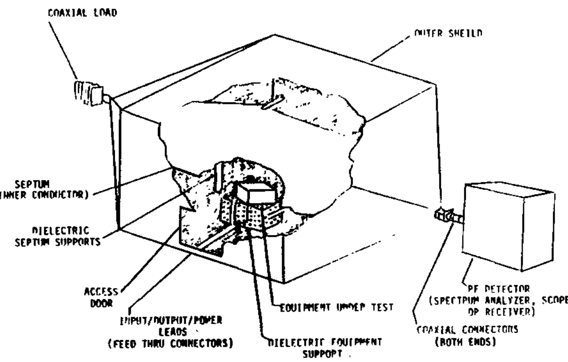
To measure signal egress, the DUT is placed inside the cell in the desired orientation and test configuration. The cell then operates as a transducer to detect emissions from the operating DUT. Energy emitted from the DUT is coupled via the TEM mode of the cell to the cell's terminals where it is measured by a calibrated receiver.[4]

TEM cell size requirements vary depending upon the size of the units to be tested. A general rule of thumb states that the largest product to be tested should never occupy more than one third the total volume of the lower test cell. Reducing the size of the TEM cell will serve to both increase the usable bandwidth and decrease the cost. For example, this particular study utilized a TEM cell large enough to test new televisions. The usable bandwidth of this cell, consequently, is limited to 216 MHz by resonance and multimodes. A TEM cell used for testing expressly subpassive units, conversely, could conceivably have an upper limit of 1 GHz. In addition, the cost of this cell would be much less costly than the above mentioned cell.

TEM CELL



CUTAWAY VIEW OF TEM CELL



Measurements:

1. Measure ingress level of empty chamber to establish noise floor (.15 μv at all frequencies).
2. Repeat measurement with DUT in lower cell (microvolts).
3. Transform to dB using the formula:

$$\text{dB Isolation} = 20 \log \frac{\text{Reading } (\mu v)}{\text{Input } (\mu v)}$$

Example (using Ailtech 37/57 RF meter)

Unit: ML-4DR #7

Frequency	Reading (μv)	Isolation (dB)
30	.223	>147
54	.251	146
125	.345	143
135	.345	143
185	.251	146
200	.397	142
216	.629	138

A spectrum analyzer may also be used to sweep the unit across the entire usable bandwidth.

Correlation With Open Air Site: Absolute correlation between the open air site and TEM cell is discussed in Appendix I. For general purposes, however, a correlation factor can usually be found to equate measurements made of the same device by both methods. In the case above, a correlation factor is difficult to find due to the fact that the leakage levels of the DUT are so low that the level of the noise floor is recorded rather than the level of the DUT.

Advantages:

1. The TEM cell has the ability to correlate with both theoretical and open cell measurements.[5] (See Appendix I.)
2. Either automated or sweep testing may be used in taking measurements.

3. The chamber itself is shielded, and may be used for other purposes in which a shielded chamber is required.

4. TEM cell RFI measurements are highly repeatable.

5. The TEM cell may also be used for EMI susceptiblity testing.

6. The TEM cell provides an excellent means for making relative measurements.

Disadvantages:

1. Resonance frequencies and wave guide modes may be encountered in the TEM cell which will negate measurements taken at those frequencies.

2. The TEM cell is not recognized by the FCC as an approved method of measuring RFI; therefore, only relative measurements are presently suggested.

Cost Requirements: The cost of the cell will vary tremendously depending on the size configuration needed. To reproduce the cell used in this study would cost upwards of $60,000; a TEM cell built for subpassive testing would cost as little at $500 once the design is finalized. Test equipment needed includes a signal generator, power amplifier and either a spectrum analyzer or RF meter. A limited number of sources for TEM cells exist at the present time; it is probable, therefore, that lead times may be lengthy.

RFI CHAMBER

Description: The RFI chamber is essentially a 4 foot long piece of 50 Ohm coaxial cable used to make relative RFI isolation measurements. This chamber was developed from a device called the "SEED" (Shield Effectiveness Evaluation Device) designed by Belden Cable in their Technical Research Center to evaluate RFI isolation of their shielded cable. The "SEED" provides consistently repeatable RFI test results - generally within 1 to 2 dB from test to test and like sample to like sample. Variations in test location, cable placement, ambient noise, etc. have no significant effect on repeatability. Belden's catalog states that "the SEED system uses a special 5 foot long coaxial fixture....consisting of two concentric copper tubes (outer diameter is 3.125" O.D.; inner tube is 1.315" O.D.) which can provide a 50 Ohm characteristic impedance. A 3 foot cable sample length is centered within the inner tube during testing, assuring that all radiated energy is absorbed. One end of the fixture is terminated; the other end is capped with a removable plate containing feedthroughs for sample and fixture test leads. For multiple tests a signal generator is required to power the cable sample, and a tuned RF voltmeter or field strength meter is needed to measure signal strength".[6]

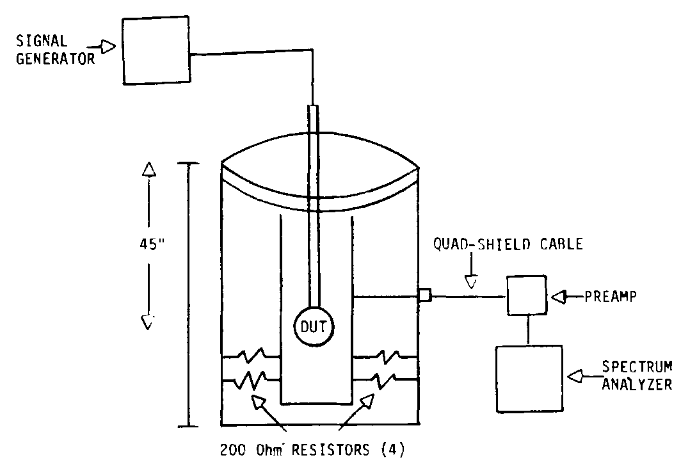
The RFI chamber is merely an adaptation of the "SEED" which allows larger units to be tested. The impedance of the chamber is 50 Ohms, chosen because the dimensions of the inner chamber are larger than that of a 75 Ohm chamber, thus allowing units as large as mainstations to be tested.

During testing a given level of signal (often 49 dBmV) is pumped into the chamber via a tracking generator. The signal level is then measured off the center conductor with a 30 dB gain low noise preamp and a spectrum analyzer. Levels into the spectrum analyzer of 112 dB down from the tracking generator can be measured.

To establish the noise floor of the chamber and the cable, the level is measured using only a terminator on the connector used to hold the DUT. This reference level is graphed. (In our case this level is approximately 112 dB down.) The DUT is then connected and leakage levels are measured.

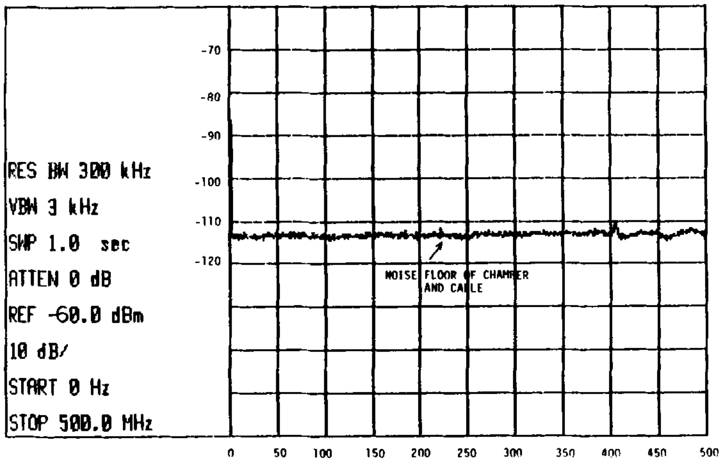
It should be emphasized that at this point in time the RFI chamber provides only a relative measurement when used in this manner; one can say with certain restrictions that one subpassive splitter is 10 dB better than another, and that in our particular chamber the isolation level is -110 dB. We can also correlate one chamber with another (for example a manufacturer correlating with an MSO) to insure that MSO requirements are fulfilled, but one cannot say that the isolation level is absolute at -110 dB when the chamber is used in this method.

RFI CHAMBER

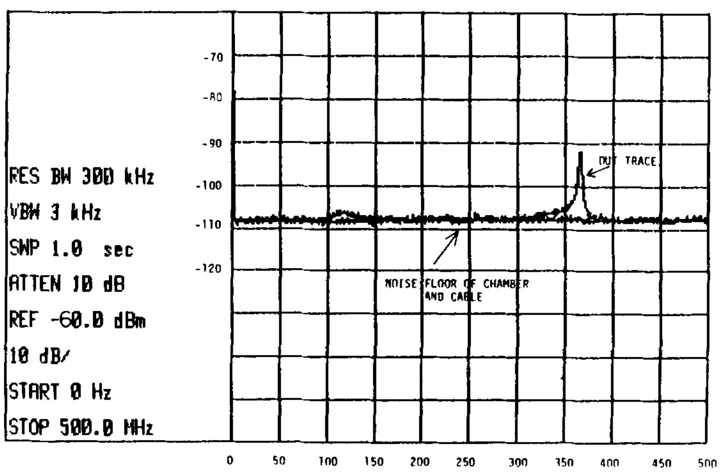


Measurements:

1. The output of the inside connection is terminated; no DUT is present at this time. Measurement is taken off the center conductor, and this level passes through a low noise preamplifier with known gain. A spectrum analyzer then measures and plots this level, which represents the noise floor of the RFI chamber and cable. This noise floor will be the lowest level of isolation that can be detected; in this particular chamber the noise (or reference) level ranges from -108 dB to -112 dB.



2. The above procedure is repeated with a properly terminated DUT. Both the reference trace and DUT are plotted on the same graph.



3. The isolation level at worst case will be the highest point on the plot. In the above example, the worst case reading (-92 dB) is taken at 365 MHz, which happens to correspond to a resonance frequency in the chamber.

Advantages:

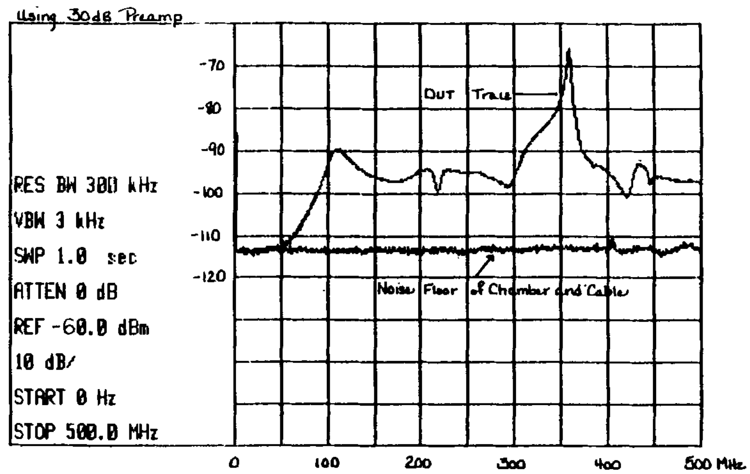
1. The chamber's small size (48" by 28.5") is convenient for the manufacturer or MSO with little space.

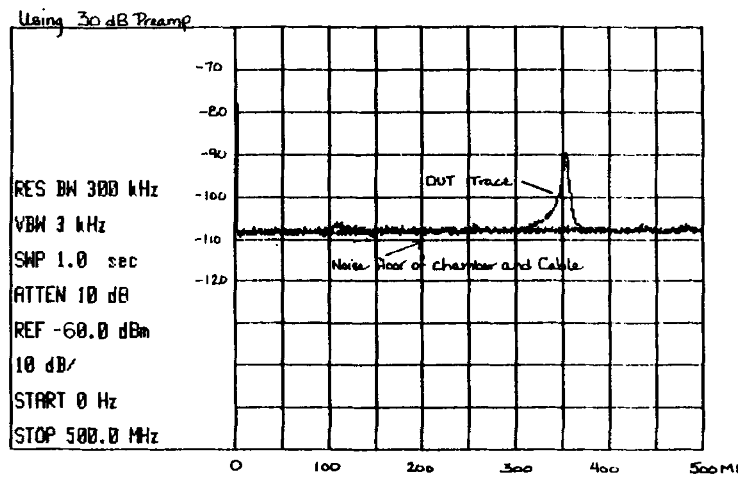
2. The chamber is lightweight and mobile.

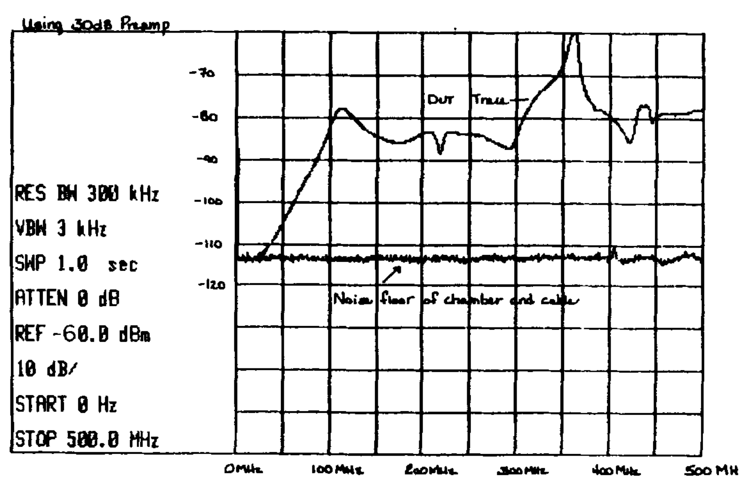
3. The simple design of the RFI chamber allows the unit to be built in-house.

4. The chamber provides a quick and easy method for comparing isolation levels of like products. The great majority of RFI chambers in the CATV marketplace today are used for this purpose. An MSO or manufacturer will typically gather together as many competitive samples as can be found, run them through the chamber and analyze the results. For example, a quick study of this kind performed recently at Magnavox yielded the following results:

3-WAY SPLITTERS







As can be seen, the difference in the isolation levels of like products can vary tremendously.

Disadvantages:

1. The noise floor of the chamber will vary depending on the connector used; therefore, several connectors should be tried to establish the lowest possible noise floor.

2. The measurement is a relative measurement, not absolute.

3. Resonance frequencies may be present in the chamber, making actual readings at those frequencies somewhat questionable.

4. The chamber is relatively fragile, and should be moved with care.

Cost Requirements: The RFI chamber is an extremely economical method of measuring RFI. The chamber itself costs only a few hundred dollars: the cost of the can itself, double shielded cable, resistors, hard line cable and connectors. The cost of test equipment will begin at approximately $30,000, but as mentioned before, in most situations the organization will already own some or all of the equipment needed.

Correlation Between Open Air Site and the RFI Chamber: Correlation between an open air site and an RFI chamber is precluded by one important detail: the measurement field. To illustrate this one needs only to compare the methods of measurement in the two cases.

An open air site is designed to measure device field strength levels located in a specific circumferential arc about the vertical axis of the device. The rotation of the device on its axis or the rotation of the axis itself can have significant effects upon the detected field strength levels. This is attributable to the fact that most devices will exhibit varying field strength levels as the device is rotated about any particular circumferential path. For example: A four way tap will display vastly differing detected egress levels when the f-ports are turned away from the detector. Thus, the device orientation is critical in achieving egress measurement accuracy and repeatability.

The RFI chamber is designed to measure device field strength levels located in a specific cylindrical area about the vertical axis of the device. The rotation of the device on its axis will have no effect on the detected field strength levels. While rotation of the device's axis will effect the detected field strength level, the magnitude of these effects will be far below the variance seen at the open air site. Therefore, with the RFI chamber, device orientation is far less critical in achieving egress measurement accuracy and repeatability.

Based on this analysis it is logical to assume that detected egress levels from an open air site will be significantly lower than those levels detected from an identical device in an RFI chamber. Also, because the fields from a circumferential arc are detected in one case and that fields from a cylindrical area are detected in the other, correlation of the two measurements is impossible.

It is possible, however, for an organization to use the RFI chamber in a manner by which adherence to FCC specifications may be recognized. To accomplish this, a pinpoint unidirectional source is used as a worst case device. Measurement of this device in an open air site can be directly compared to an RFI chamber measurement. This measurement should be made with the unidirectional source's emission calibrated at FCC regulations. It can then be inferred that any omni directional radiator having a detected level at or below the standard will meet or exceed FCC requirements.

SUMMARY

Of the RFI measurement methods discussed above, only the open air site is approved by the FCC for use in determining whether FCC isolation requirements are met. Correlation with the open air site is critical for any MSO or manufacturer using an alternate method of making RFI measurements. Methods in which to correlate the RFI chamber and TEM cell with the open air site as they now exist are somewhat cumbersome. With additional research these methods may be refined to provide the MSO or manufacturer the ability to make absolute measurements quickly and inexpensively in a TEM cell or RFI chamber.

APPENDIX I

Correlation Between Open Air Site and TEM Cell

Significant research has been done by the National Bureau of Standards to provide a means for correlating open air and TEM cell measurements. To insure significant results, NBS suggests using as the DUT a spherical dipole because its radiation characterictics can be analytically determined. The theoretical value may then be compared with actual test results to provide a correlation between actual test fixtures.

To relate the field measurement from the open air site (μV/m) to the TEM cell measurement, one must first convert the radiated field to the equivalent free space or direct path field (E_d) via the formula:

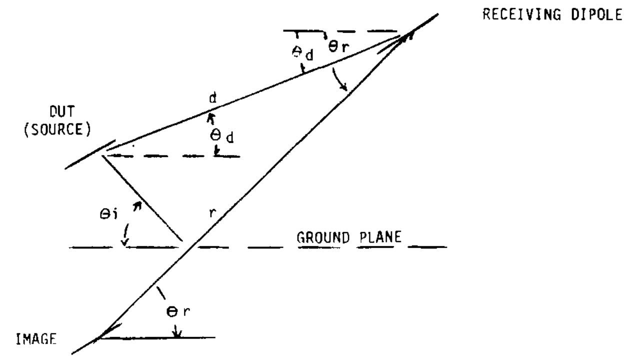
$$|E_d| = \frac{|E_m|}{1 + B^2 + 2B \cos\alpha}$$

Where:

$$B = p\frac{d}{r},$$

$$\alpha = \frac{2\pi(r-d)}{\lambda} + \phi, \text{ and}$$

$p + \phi$ are the magnitude and phase of the ground screens reflection coefficient. λ is the wave length in meters, and the parameters d and r are shown in the following:



Likewise, the measurements taken in the TEM cell are related to equivalent free space radiated field, E_d via the formula:

$$E_d = \frac{b n_o V_m}{\lambda_o \, d \, Z_o \, K(I) \, \tilde{E} \cos\theta} \sqrt{\frac{2G}{3}}$$

Where:

- b = separation distance in meters between septum and the cell floor.
- n_o = intrinsic wave impedance = 377 Ohms.
- V_m = RMS voltage (volts) measured at one port terminated into 50 ohms.
- λ_o = wavelength at measurement frequency in meters.
- d = separation distance in meters between spherical dipole and measurement point in free space.
- Z_o = characteristic impedance of TEM cell as a transmission line, 50 Ohms.
- $K(I)$ = change in equipment under test (DUT) radiation current caused by enclosing the DUT inside the TEM cell.
- $\tilde{E}$ = normalized electric field at any location inside the cell, relative to the field strength at the center of the test region of the cell.
- $\cos\theta$ = polarization of radiated field from DUT relative to the TEM mode electric field of the cell.
- G = gain characteristics of the cell.

The results obtained from the above procedures are compared to the theoretical value computed, and studies indicate that, at least for the DUT used, results between the 3 measurements correlated within a few dB at those frequencies below mode resonances in the cell. At higher frequencies, larger differences (up to 12 dB) exist due to cell multimoding.[7]

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RF MODEM SPECIFICATIONS
. . . testing between the lines

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Abstract

The RF modem, used for both voice and data communications on CATV systems, is becoming an important tool for increasing cable operators' revenues. However, any new device added to the network must be tested to see that it meets its specifications. It also must meet certain unwritten specifications that guarantee that it reliably operate under a variety of real world impairments known to exist; such as mechanical shock, frequency translator drift, and intermodulation distortion. Simple tests are presented that help identify a potentially poor performing device and keep it from eroding into those higher revenues gained by offering voice and data communications services.

Introduction

Until recently the primary application of RF modems for voice and data communication over coaxial cable broadband systems has been on private industrial and government cable systems or specialized office automation systems for centralized computer data bases. This technology is now spreading to metropolitan CATV systems where more stringent requirements must be observed. A cable operator can only add data and voice capability to his system if it does not interfere with existing services. The RF modem hardware must also be reliable and inexpensive to install and maintain.

Rigorous testing is necessary --but what are the crital parameters to test? How do you know when a modem works but is on the brink of erratic behavior or catastrophic failure?

RF Modem, What is it?

Before exploring the details of RF modem testing and answering the questions raised, a general definition of the term RF modem is necessary and consideration of its place in the CATV system.

The term "RF modem" is a series of contractions. RF stands for "Radio Frequency" and means simply that its channel of communication is in the radio frequency spectrum. For CATV that usually means from about 5 MHz to 500 MHz. The term modem is a contraction of "modulator-demodulator" and is synonymous with "transmitter-receiver" or "transceiver".

The RF modem sends and receives voice and/or data over CATV facilities. The bandwidth required is dependent on data rate in the case of data transmission and fidelity in the case of voice or music transmission. Higher data rates or better fidelity require greater bandwidth.

The modulation technique also has a bearing on spectral usage and efficiency. Frequency modulation is both noise immune and inexpensive to receive. It is also one of the least bandwidth efficient modulation techniques. Amplitude modulation is more efficient spectrally but is more likely to be impaired by noise. Phase modulation is spectrally efficient and more noise immune but is more expensive to implement.

Various forms of modulation coding are also used to achieve higher bandwidth efficiencies. QPSK (quadraphase shift keying) is a good example. The increased efficiency is gained at the expense of less noise immunity and increased hardware cost.

The RF modem is usually used in conjuction with a block frequency translator at the head end of the cable system. The translator, due to its central location in the network topology, can receive all reverse channel signals. The reverse channel usually occupies the lower frequency portion of the cable frequency spectrum for signals travelling upstream to the head end.

The translator retransmits a block of spectrum back downstream on the cable system on a forward channel. The forward channel usually occupies the higher portion of the frequency spectrum. Because the retransmission takes place at the central head end, all RF modems on the system receive the translated spectrum signal. This allows any RF modem to communicate with any other RF modem on the system. In effect, the translator serves the same function as a satellite transponder in microwave communications systems.

Although RF modems can be configured to operate without a translator, the translator is preferred for large tree topologies where single coax two way transmission is used. The translator gives the added advantage of allowing any location visibility to the reverse channel frequency spectrum. This allows maintenance facilities to be located anywhere on the cable system.

The Published Specifications

The typical specifications that RF modem manufactures publish fall into five main categories:

1. Interface (digital or analog)
2. Modulator
3. Demodulator
4. Environmental
5. General

1. Interface

The interface specifications deal with the connection to the terminal equipment. In the case of voice RF modems the specifications are mostly analog and deal with signal levels, frequency response, group delay, impedance levels, and connector types.

The omission of specification in voice modem interface usually involves voice quality and overmodulation characteristics. The tests for these are usually subjective and involve human ear judgement. Background hum or hiss are frequent problems in addition to adjacent channel cross-talk. The overmodulation is usually caused by a loud talker or the touch tone pad if a telephone set is used. Amplitude compression is often used to overcome these difficulties.

The digital RF modem interface is most often a generic type and typically cites an industry standard such as the E.I.A RS-232C interface. The standard gives most of the details of the interface. The data rates of the interface are not usually covered by the standard and must be specified for the particular modem. Also, the RTS/CTS delay must be specified. Synchronous as well as asynchronous capabilities often must be called out separately.

The omissions of note in data interface specifications are of various kinds. The transmit clock frequency accuracy for synchronous modems is usually omitted. The ability to provide external transmit clock or derive clock on data is often not mentioned in the specifications. The response of the modem to a prolonged break (space state) in asynchronous mode should be checked. The loop-back capabilities should be tested to see that terminal echo as well as data regeneration (retransmitting what is received) work for both synchronous and asynchronous if that is required. Also, some multiplexers require a single system clock from the modem pair. This capability should be investigated if needed.

It should be noted that the interface omissions are done intentionally in the interest of brevity. The installation manual often answers these questions. Be aware that interfaces are a frequent source of problems during installation. Wiring errors in cables that connect terminal equipment to modems are common.

2. Modulator

The modulator specification is the easiest of all to test. Most often the spectrum analyzer tells all! Look for various spurious signals (spurs) around the carrier frequency as well as at harmonic multiples. Close-in signals when the carrier is not modulated indicate phase noise and are often sidebands spaced at the power line frequency. A good transmitter should deliver a clean signal with spurs down 50 dB from the carrier regardless of power setting.

If the modem is frequency agile, try different frequencies, including different receiver frequencies to see if the receiver local oscillators are leaking out to the cable.

Another modulator specification to check is the carrier disable leakage. When Request to Send is dropped the carrier should be down at least 50 dB. High leakage causes problems in single frequency multi-drop applications where the leakage signals can add up to a detectable signal level.

The frequency accuracy is associated with the temperature specification. This specification becomes more critical the closer the carrier frequencies are spaced. Transmitters usually hold tighter at low frequencies so plan your spectrum to have the narrow spaced RF modems in the lower channels if this is possible. Avoid spacing carriers any closer than 20 kHz, regardless of modulating bandwidth.

3. Demodulator

The demodulator performance is more difficult to test. Carrier detect threshold should be checked on a variety of frequencies if the modem is frequency agile. Certain subchannels may be unusable due to mixing products.

Two tone tests should be performed to check the receiver's front end for intermodulation products. A good way to do this is to generate two adjacent signals both at the maximum rated receiver input level. Apply these signals to the receiver input and see if the receiver detects the next adjacent channel which is the $2f_1-f_2$ third order intermodulation product. A measure of quality is to exceed the maximum level rating until the third order is detected. More is not better in the case of RF modem received signal strength. Third order intermods are a serious consequence of receiver overloading that can degrade modem performance dramatically.

Image rejection is another important specification to test. The manufacturer probably has not volunteered the IF frequencies in the specifications. Find out and apply a signal at the image and determine if it can be detected. The image rejection should be 50 dB in a good receiver design.

The receiver dynamic range is important. Make sure the modem can operate error free (data modems) or distortion free (voice modems) over the full range of rated signal strengths. Check with the manufacturer for the preferred receiver input level. Typical narrow band RF modems operate in the range of -20 dBmV to +10 dBmV and should normally see signal levels of around -10 dBmV.

A specification most often not specified for RF modems is tolerance to frequency translation errors. It is a very real impairment and gives a good measure of the quality of the RF modem. What happens in a system is that the head end frequency translator drifts so that the retransmitted forward channel signals are off frequency. A simulation of this will allow a measure of how many kHz a translator may be mistuned before the modems begin to operate erratically. Temperature affects frequency drift so test translation margins over temperature for a really rigorous test. A good headend frequency translator should be expected to hold within 750 Hz. RF modems should tolerate at least 2 kHz of translator drift with more margin very desirable.

Bit error rate under poor signal to noise conditions can also be tested. However, it should be noted that RF modems are not normally subject to the same kinds of noise that telephone modems experience. A properly maintained cable system has carrier to noise ratios well in excess of 30 dB. The bigger source of noise to the modem may well be the phase noise of the headend frequency translator! So beware not of amplitude related noise sources but the frequency/phase types of distortion. They are more subtle and have a far greater effect on the performance of the RF modem.

4. Environmental

Most RF modems are specified for a rather benign commercial temperature range. The biggest effect temperature has is causing the local osillators to drift in frequency. This can cause poor performance if the margin of frequency translation is narrow.

Low temperature can create problems with oscillator start-up. Test the modem for cold start. You may be surprised!

FM frequency discriminators sometimes become nonlinear under temperature extremes. This may cause distortion in voice modems or bit errors in data modems.

An environmental specification that is almost never specified in commercial equipment is mechanical shock. Your RF modems may not be flying in a high G force aircraft, but vibration is a very definite impairment to proper operation. The best test is the "slam test". Some modems, particularily those with poorly designed frequency synthesizers, are so sensitive to microphonics that the slightest tap of a pencil will cause a string of bit errors. Make sure the modem is slammed and keeps on working without errors. Of course, keep those slams reasonable or you may be slammed yourself!

5. General

The general specifications group are concerned with left over details such as power, size, and weight. The power specification usually gives a tolerance to line voltage variations. This should be checked with a variac while observing transmitted frequency and bit error performance.

The Unpublished Specifications

What you don't know may either hurt you or help you. There is often a fine line drawn between important specifications and trivial detail. Experience is usually the best judge. Below is a summary of important specifications that are often found "between the lines" of the specification sheet:

1. User test points.
2. User adjustments.
3. Intermodulation products
4. Frequency translation margin.
5. Mechanical shock tolerance.

Be certain to check these details. A good RF modem needs test points to support field testing and adjustments for various parameters such as transmitter power, receiver carrier detect level, and RTS/CTS delay.

Give every modem a frequency translation and shock test before installing at the user's location. Most problems show up with just these two simple tests. It takes ten seconds and could save days!

Don't forget to test the frequency translator for the same kinds of impairments. Frequency drift and third order intermodulation products are a real problem with poor translators. And of course, give it a good slam test too!

Conclusion

RF modems for CATV are here today. Test the specifications, written and unwritten, and participate in the booming data and voice communications business now happening on metropolitan cable television systems.

RF SHIELDING MEASUREMENTS USING THE UACC RF CHAMBER

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ABSTRACT

Due to the increasing concern for RF shielding, UACC Engineering sought some means of shielding evaluation of the products used in the field. Devices are available to make these measurements in a lab environment on aluminum and drop cables, such as the Belden SEED, but similar devices to test other CATV system components including amplifiers, subscriber taps, system passives, and drop passives are not commercially available at a reasonable price.

Therefore, UACC Engineering designed and built a device very similar to but much larger than the Belden SEED to measure the RF shielding of CATV components other than cable. The original purpose of the chamber was to determine relative values of RF shielding from product to product. However, it has also revealed great differences in RF shielding between various models of CATV components allowing UACC to set minimum RF shielding specifications for approved products. Additional research has been done to determine correlation factors of RF shielding measurement to signal leakage levels measured in actual operating conditions.

A DEFINITION OF RF SHIELDING

Over the past several years, the terms "RF shielding", "shielding effectiveness", and "shielding isolation" have been used interchangeably as the electrical characteristic of an electronic device which impedes signal egress (leakage) and ingress. In greater detail, Belden defines shielding effectiveness for use with their SEED as the ratio in decibels between a reference signal applied to a sample cable length and the signal radiated by that cable. The value of the radiated signal is determined by direct measurements from the SEED output.

UACC Engineering defines "RF shielding" by a slightly different method in order to be capable of correlation with field measurements. At UACC, it is defined as the ratio in decibels between a reference signal applied to a sample device and the input signal available to a leakage antenna due to the shielding characteristic of the sample device. If the leakage antenna is assumed to be either an isotopic or a dipole radiator, fairly accurate correlation has resulted between Belden SEED and UACC chamber type measurements and field measurements using known antennas at known distances from the device under test.

RF CHAMBER DESIGN

The development of the UACC RF shielding measurement chamber is directly attributable to a need by UACC approximately three years ago for shielding effectiveness data on CATV components other than aluminum and drop cable. All components of a CATV system can contribute to egress and ingress problems; therefore, UACC Engineering decided to develop a shielding measurement method for devices such as drop and distribution passives, amplifiers, converters, and other CATV components.

The idea for the UACC RF chamber came from that of the Belden SEED. The Belden SEED is essentially a five foot long 50-ohm coaxial cable with a tubular center conductor and air dielectric. Sample lengths of drop cable are placed inside the tubular center conductor, a reference signal is applied to the sample, and leakage is picked up by the SEED center conductor to be measured. The Belden SEED has become an industry standard with its ease of operation, repeatability of results, and compatibility with common CATV test equipment. For these reasons, UACC Engineering chose to build its shielding chamber similar to, but larger than, the SEED. The purpose of the larger size was for measuring shielding on larger CATV components.

The UACC RF shielding measurement system, which is shown in Figure (1) has been operational for approximately three years. The original version of the

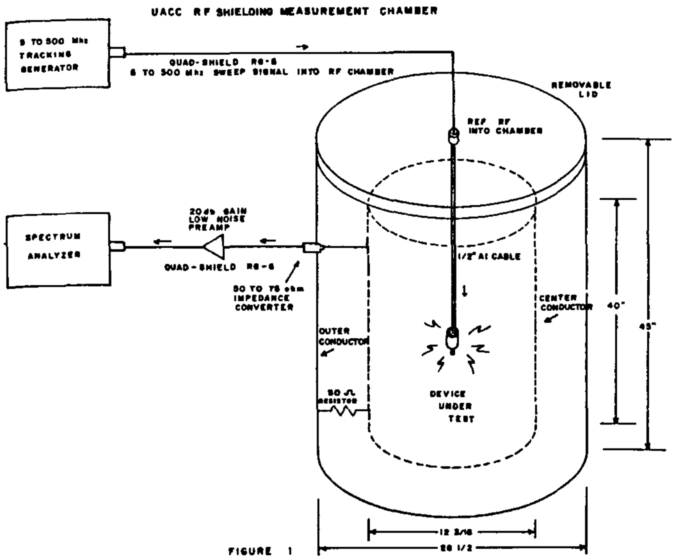

FIGURE 1

chamber was a 75-ohm device, but later it was changed to 50-ohms to allow for larger test devices to be placed inside the larger center conductor of the 50-ohm system. It was undesirable to make the original 75-ohm chamber larger because of space limitations in the UACC Lab. The dimensions of the RF chamber were determined by the following formula for the characteristic impedance of a coaxial cable.

$$Z = [138 \log(D/d)]/\sqrt{K} \qquad (1)$$

where

Z = characteristic impedance of a coaxial cable
D = inside diameter of the outer conductor
d = outside diameter of the center conductor
K = dielectric constant = 1.0 for air

From equation (1), the ratio D/d is approximately 2.3 for a 50-ohm coax with air dielectric. The UACC chamber dimensions were determined by using this ratio in conjunction with the maximum useable diameter of the outer conductor due to space limitations. The overall height or length of the 50-ohm chamber was determined strictly on a practical, workable basis.

RF CHAMBER CONSTRUCTION

Having determined the physical dimensions of the test chamber, the next step was to have the device built. It was decided to build the chamber out of sheetmetal due to cost factors. Removable lids or end covers were built for the large coaxial chamber to work with the outer conductor in maintaining an interference-free measurement system. One of the lids was made to be easily removable for purposes of placing test samples inside the center conductor for shielding measurements. This same lid is also used to support the hard line cable which supports the test sample in the center of the chamber and feeds the reference signal to the sample. To finish the chamber construction, one end of the center conductor was terminated with a 50-ohm resistor to the outer conductor and the other end of the center conductor was wired directly to the center pin of the chamber 50-ohm output N-connector. A 50/75-ohm impedance converter was attached to the output connector to allow 75-ohm shielded cables to be used in the measurement process.

RF CHAMBER OUTPUT RETURN LOSS

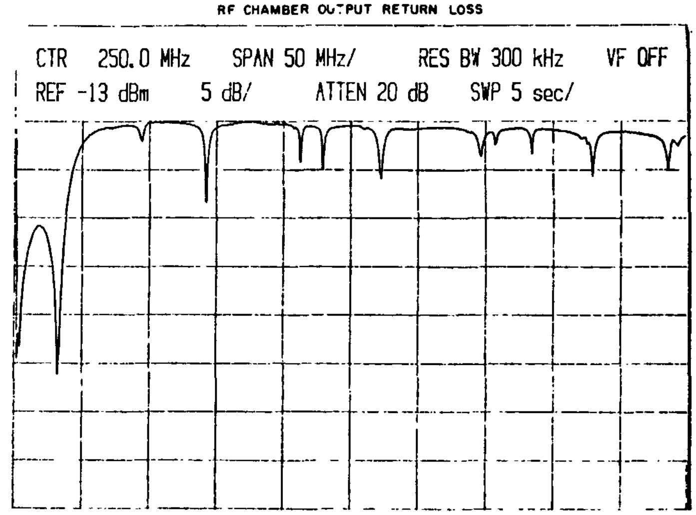

FIGURE 2

RF CHAMBER TESTING

A return loss measurement from 10 to 500 MHz of the 50-ohm system was done after the RF chamber was constructed to determine the extent of the mismatches in the chamber and to determine the resonant frequencies of the RF chamber. The return loss plot, which is shown in Figure (2), reveals that the chamber is a poor 50 ohm broadband system; however, certain resonant frequencies did show a respectable match indicating the "antenna system" was tuned at some frequencies. Some of these frequencies are used later in this paper to determine the RF shielding of the test sample. The overall poor return loss of the coaxial chamber has not been explained, but could possibly be due to the methods of terminating the coax with only a simple 50-ohm resistor and wiring the coax center conductor to the output with little concern for match. Again, this RF chamber was originally built only for relative measurements between similar sample components and its cost, ease of operation, and repeatability of results were the only major design concerns.

RF CHAMBER OPERATION

Obtaining RF shielding results from the chamber is a fairly straight-forward procedure. The first step is to establish a reference leakage noise floor of the system. This is accomplished by feeding the reference signal into a known, well shielded terminator inside the RF chamber and checking for no chamber output leakage levels above the noise floor of the receiving measurement system. The reference signal in the UACC Lab is usually a zero dBm (48.75 dBmV), 10 to 500 MHz sweep signal and the receiving measurement system consists of a broadband 20 dB gain, low noise figure preamplifier and a 300 KHz bandwidth spectrum analyzer. The preamplifier greatly increases the sensitivity of the system yielding a receive system noise floor which is approximately 110 dB down from the reference level which is supplied to the test component. This difference between the reference level and the system noise level is the maximum value of RF shielding that can be measured with this system. Decreasing spectrum analyzer bandwidth can extend the range a little more, but measurements of 110 dB have been sufficient in the past.

Figures (3) and (4) show plots of the RF shielding as given by the RF chamber on two different drop two-way splitters. UACC Engineering has always used the maximum peak on the frequency/shielding plot to determine the RF shielding of a particular component. For example, the shielding of the unit plotted in Figure (3) would be -54 dB because the highest peak at 355 MHz is that value. Likewise, the component plotted on Figure (4) would have an RF shielding of -46 dB.

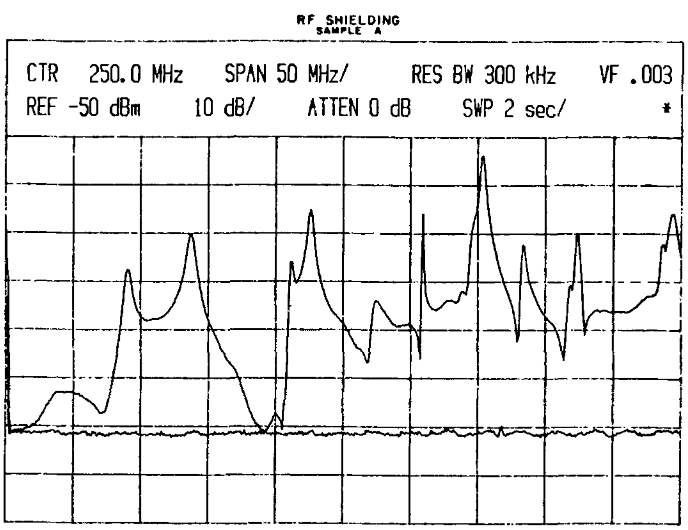

FIGURE 3

A comparison of both plots will show similar responses with the RF shielding showing definite resonant frequencies.

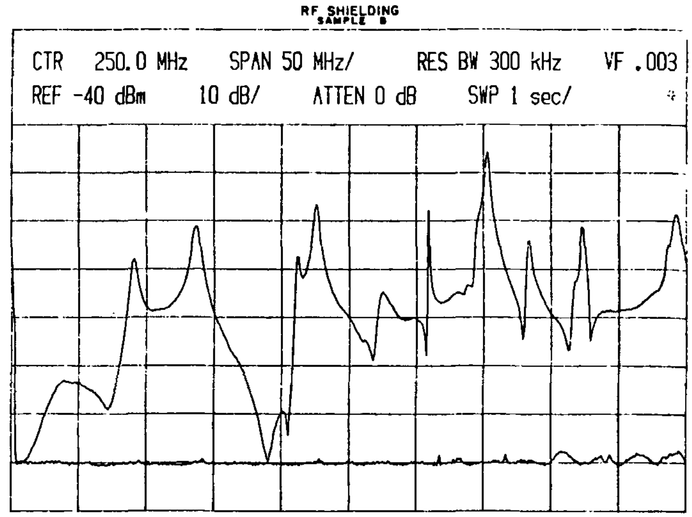

FIGURE 4

These resonant frequencies coincide similarly with the resonant frequencies shown by the return loss plot of the chamber given in Figure (2). Therefore, the chamber is only yielding RF shielding data at certain frequencies. Normally, this type of measurement is sufficient, but if an approximation is needed for other frequencies, a line connecting the major shielding peaks can be used to yield the necessary data. This has been done in figures (5) and (6).

Another interesting point shown by the plots is that of decreased RF shielding as the frequency increases from approximately 90 MHz to 355 MHz. This does not seem surprising due to the fact that drop two-way splitters radiate from slots around the back plate. This would essentially radiate similar to a slot antenna, which typically has a radiation efficiency that increases with frequency.

One last interesting point of the shielding plots is that the major peak at 355 MHz is possibly due to the fact that the chamber center conductor is approximately one wavelength long at 355 MHz. Also, the peak at 89 MHz corresponds to a quarter-wavelength chamber center conductor at that frequency. It will be shown later that the 89 MHz peak yields the best correlation to field type measurements. This may imply that the chamber type measurement approximates that of a quarter-wave antenna.

The absolute RF shielding levels at different frequencies yielded by the chamber measurements may seem somewhat vague at this point in the paper. Correlation to some actual field measurements of signal leakage from these sample components may help the reader's response to the chamber measurements. This will be discussed in the following section.

EXTRAPOLATED RF SHIELDING
SAMPLE A

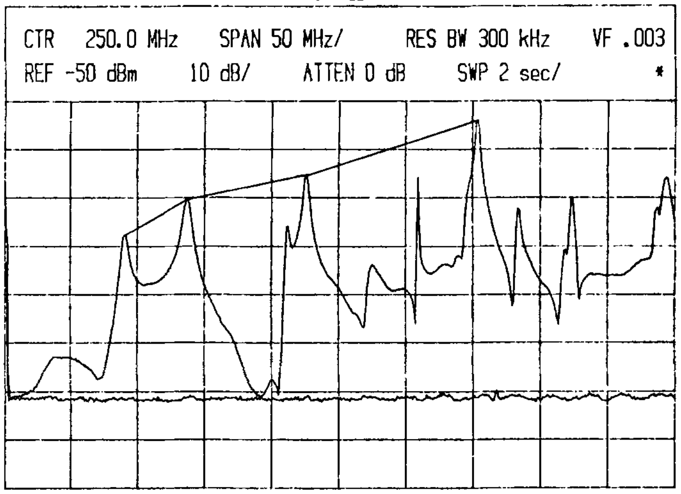

FIGURE 5

EXTRAPOLATED RF SHIELDING
SAMPLE B

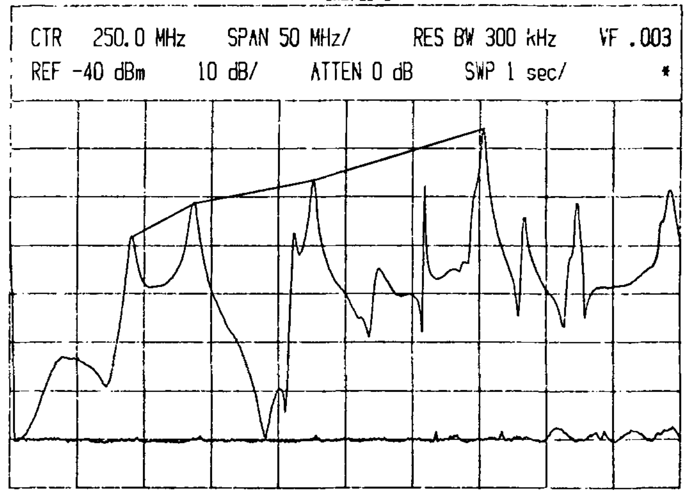

FIGURE 6

CORRELATION TO FIELD MEASUREMENTS

Over the past few years, UACC Engineering has operated the RF chamber as a relative measurement device only. When sample components of one type were shown to have better shielding than another type in the RF chamber, measurements in the field would show the same results. However, no work was previously done to determine whether or not the RF chamber could be used to predict actual egress or ingress levels from chamber tested components. The next few paragraphs will describe the testing done to show that correlation does exist and that the correlation is frequency dependent. The approach taken to determine correlation between chamber and field measurements was to take the two two-way splitters tested in the chamber and measure the leakage levels at three different frequencies with a tuned dipole antenna at known distances from the two-way splitter. The measured levels would then be compared to predicted levels calculated by using the chamber shielding data and standard antenna gain and path loss formulas.

The three frequencies used were resonant frequencies of the chamber and the distance used from the splitter sample to the measurement dipole was 20 feet. Some measurements were taken at ten feet, but near field interactions at lower frequencies forced the distance to be 20 feet. The splitter was elevated approximately seven feet off the ground by a non-conductive pole and the splitter was fed its reference signal by well-shielded drop cable with properly installed F-fittings. The test was set up to insure that all leakage measured originated from the sample splitter.

An accurate c.w. frequency generator was used to feed the test splitters with 56 dBmV of RF level at the following frequencies: 89 MHz, 226 MHz and 355 MHz. All of these are resonant frequencies of the RF chamber. The receive measurement system consisted of a tuned dipole antenna, tunable bandpass filter, preamplifier, and a spectrum analyzer. The bandpass filter was necessary to prevent the analyzer from overloading due to random off-air pickup by the dipole. The preamplifier was used to increase the sensitivity of the measuring system. The losses and gains of these devices were accounted for in the measurement process. The receive levels at the antenna output were obtained by recording the maximum levels observed while peaking the main radiation lobe and the polarization of the dipole antenna. These recorded levels were the ones used for comparison to the predicted antenna levels.

Predicting antenna receive levels involves use of the following formula found in the Radio Engineers Handbook:

$$Pr = Pt\ Gr\ Gt\ \lambda^2 / (4\pi R) \qquad (2)$$

where

Pr = receive antenna output power in watts
Pt = transmit antenna input power in watts
Gr = receive antenna gain over isotopic
Gt = transmit antenna gain over isotopic
λ = wavelength in meters
R = path distance in meters

In this case, Gr = 1.64 for a dipole antenna and R = 6.1 meters for a path distance of 20 feet. Also past experience with leakage calculations at UACC have shown that Gt (gain of leakage antenna) may equal 1 or 1.64 for field calculations. For the purposes of this paper, it seems reasonable to approximate the actual leak as an isotopic antenna with Gt = 1. There is only a 2 dB difference in gain between an isotopic and dipole antenna.

Using this given information the formula becomes

$$Pr/Pt = 0.00028\lambda^2 \quad (3)$$

which is a formula for the overall gains and losses of the antennas and the 20 foot path. This formula may then be written in decibel terms to produce the following:

$$Pr(dBmV) = Pt(dBmV) + [10\log(0.00028\lambda^2)]dB \quad (4)$$

Next, the RF shielding term S obtained from the RF chamber plots may be added to the above formula to create the final formula for predicting antenna receive levels.

$$Pr(dBmV) = Pt(dBmV) + [10\log(0.00028\lambda^2)]\ (dB) + S(dB) \quad (5)$$

The term S will be a negative number directly attainable from the shielding plots for the particular frequency in consideration. From the above formula, the predicted antenna receive level can be calculated by knowing the reference level Pt, the wavelength and the RF shielding S.

Comparison of actual measured receive levels and predicted receive levels yielded some reasonably satisfactory results. The results revealed correlation of 1 dB or better at 89 MHz, 2 to 4 dB at 226 MHz and 7 to 9 dB at 355 MHz. Since there always seems to be a few dB of error with any field type antenna measurement, the results just given seem to be very reasonable. Based on these results, the RF chamber seems to be a fairly accurate method of measuring absolute values of RF shielding.

SETTING STANDARDS

UACC has a minimum RF shielding specification of -100 dB for all CATV components to be placed in UACC systems. UACC Engineering has accepted products with -90 dB shielding because alternatives were not available. This specification is based on worse case calculations of interference based on CATV plant egress and ingress. Without devices such as the Belden SEED and the UACC RF chamber, these specifications would be very difficult to verify and enforce.

CONCLUSION

The UACC RF chamber is a proven, low cost, easy to operate, and repeatable method of obtaining RF shielding performance on almost any type of CATV equipment. For a few years, the RF chamber has been considered only a relative measurement of RF shielding. The testing presented in this paper show that the chamber can be used fairly accurately as an absolute measure of RF shielding. The CATV industry as a whole needs to realize the importance of RF shielding and become more involved in the selection of components to be placed in CATV systems.

ACKNOWLEDGEMENTS

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SPECIAL ACKNOWLEDGEMENT

A very special appreciation of the late George Fishman who was employed by UACC from 1972 to 1981. George was instrumental in the development of the original RF chamber.

SIGNAL PURITY CONSIDERATIONS FOR FREQUENCY SYNTHESIZED HEADEND EQUIPMENT

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ABSTRACT

As cable television system bandwidths increase and frequency plans proliferate, more manufacturers are turning to synthesized frequency agile headend channel converters. With this new approach using phased locked loops and dual conversion come spurious signals and noise sources not encountered before in crystal controlled channel converters.

Important characteristics of these headend converters including phase noise, spurious signals generated by the comparison frequency, and residual frequency and phase modulation, are evaluated for their subjective impact on the output signal to the cable. Data is presented which shows the correlation between subjective picture degradation and measured headend synthesizer noise contribution.

INTRODUCTION

In the past, designers of cable system headend equipment hardly concerned themselves with phase noise. This is because most systems relied on crystal oscillators where the phase noise is not a major concern due to the inherent low noise and stability of such circuitry. The current trend is toward greater use of frequency synthesis and phase-locked loop controlled conversion processes. This is due to the attractiveness to both the manufacturer and use of frequency programmability in the multichannel environment and is further driven by the decreasing cost of associated components.

Noise is influenced by each section of the phase-locked loop system and adequate performance is obtained only by careful design of all circuits. Both product and system designer must determine the phase noise performance level that is required for subjectively acceptable signal quality in the intended application.

BASIC OVERVIEW OF THE PLL

Before we evaluate the system for its noise performance, let us first review the basic operation of a phase-locked loop. A simple phase-locked loop consists of a voltage controlled oscillator, or VCO, a digital divider, a phase detector, a reference frequency source, and an integrator or loop filter. Figure 1 represents such a system.

These system components function as a servo loop such that when the VCO is phase-locked to the reference, the output frequency and phase of the digital divider is equal to the frequency and phase of the reference. This makes the average output of the phase detector zero and, therefore, the output of the loop filter remains unchanged. Should a disturbance cause the VCO oscillating at "N" times the reference to shift frequency or phase, the digital divider output would not be coherent with the reference. This makes the output of the phase detector nonzero causing the loop filter to change its average DC output voltage, which forces the VCO back to the proper frequency and phase (REF. 1).

NOISE SOURCES IN A PHASE-LOCKED LOOP

Now let us take a look at the mechanisms that can produce noise within the phase-locked loop. Signals that are integer multiples of the reference frequency will inevitably be present at the output of the phase detector. These reference frequency components can cause spurious outputs by modulating the VCO. Optimum phase detector characteristics and the loop filter design can reduce these signals to an acceptable level. (REF. 2, 6, 8.)

Loop Filter Noise

Since the loop filter drives the VCO tuning line, any noise at the output of the loop filter produces phase noise on the oscillator output. Furthermore, any noise on the phase detector output is

C4APC OUTPUT PLL SYSTEM (SIMPLIFIED)

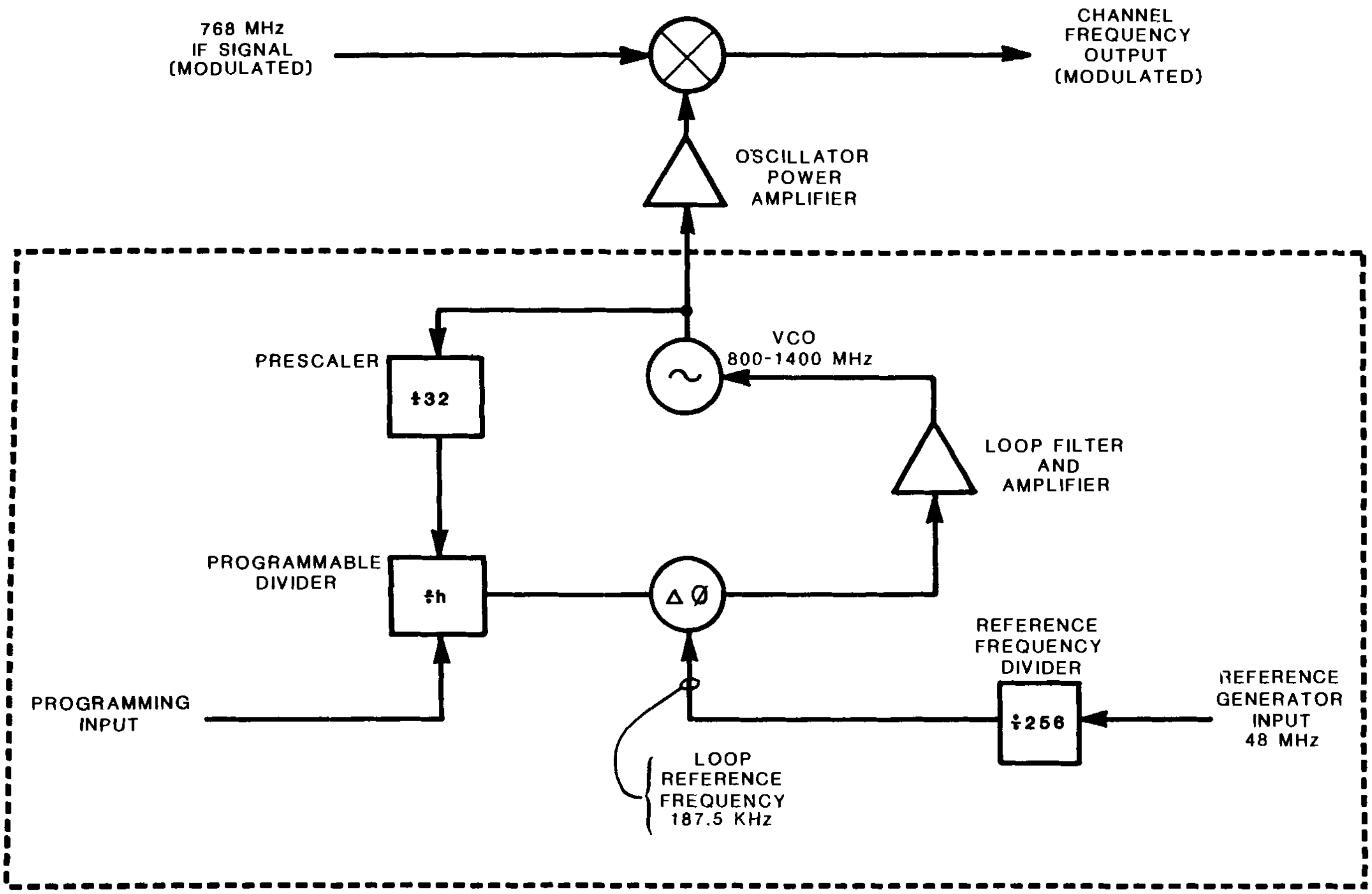


FIGURE 1

modified by the filter transfer function, added to the loop filter output, and modulated onto the VCO. The amount of oscillator phase noise is a function of the tuning sensitivity, Kv, and the amount of noise reaching the VCO's tuning port.

For example, let's look at a VCO with a sensitivity of +35 MHz per volt and assume that the VCO output frequency is 1000 MHz with 0 volts on the control line. At this sensitivity, a positive 1 volt dc average value on the control line would give an output frequency of:

F out = F nominal + (Vdc times Kv)

F out = 1000 MHz + (1 volt times 35 MHz / volt)

F out = 1035 MHz

If the 1 volt signal had been 1 volt RMS random noise then the output would have been 1000 MHz plus and minus 35 MHz RMS of residual phase and frequency noise modulation. (REF. 8)

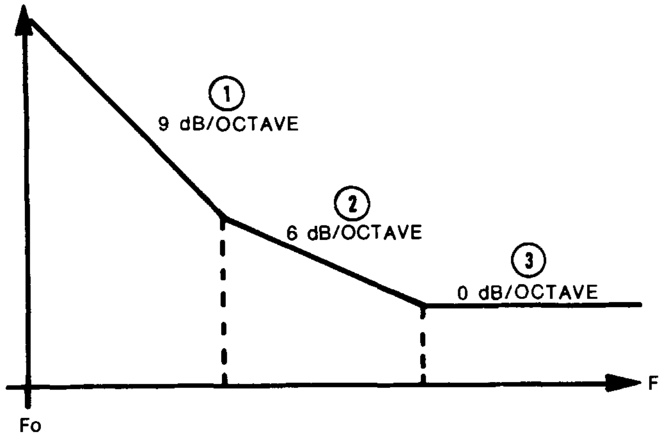
VCO Noise

One of the more significant contributors to output noise is the VCO itself, although all of the phase-locked loop components add noise to the output spectrum. The noise analysis of oscillators is difficult because the active device is operating in its nonlinear region. However, if we examine the oscillator as an amplifier that has as much gain as the feedback network has loss, we will be able to get a reasonable approximation of the phase noise performance. Using the basic relationship for thermal noise, we note that: kTB = -174 dBm/Hz (decibels relative to 1 milliwatt per hertz) is the noise floor of any amplifier input. For a 1 Hz bandwidth, adding the amplifier noise figure, and adding the gain gives the corresponding amplifier output noise floor. This will be the oscillator noise floor far removed from the carrier. The phase noise performance close into the carrier will depend upon whether it is a bipolar or field effect transistor. Rather than give a rigorous mathematical description here, let us take a look at some measured phase noise characteristics. Figure 2 shows that there are 3 basic areas of phase noise:

1) The close in portion, where the oscillator phase noise is proportional to the transistor's low frequency noise characteristic.

2) A region that is a little farther removed from the carrier where the noise is related to the Q of the frequency determining circuit.

OPEN LOOP VCO PHASE NOISE



FOR REGION:

① $\left(\frac{Fo}{2Q}\right)^2 \left(\frac{a}{Fm^3}\right)$

② $\left(\frac{Fo}{2Q}\right)^2 \left(\frac{Fosc\ kT}{2Ps\ Fm^2}\right)$

③ $\frac{Fosc\ kT}{2\ Ps}$

Fo = AVERAGE OSCILLATOR FREQUENCY
Q = LOADED QUALITY FACTOR OF OSCILLATOR'S RESONATOR
a = A CONSTANT WHICH IS PROPORTIONAL TO THE FLICKER NOISE AMPLITUDE
Fm = F - Fo
Fosc = EFFECTIVE NOISE FIGURE OF THE AMPLIFIER USED IN THE OSCILLATOR CIRCUIT
k = BOLTZMAN'S CONSTANT
T = TEMPERATURE IN DEGREES KELVIN
Ps = RF OUTPUT POWER OF THE OSCILLATOR

FIGURE 2

3) The far removed noise floor of the oscillator.

The second item is significant because a VCO that has a wide tuning range necessarily has a lower "Q" and therefore, has more phase noise.

Also, all three regions are related to frequency. This means that the higher the frequency of operation in an oscillator, the higher the phase noise, all other parameters being the same. (REF. 4, 5, 7, 10)

Divider Noise

Increasing the output frequency of the VCO inherently leads to a larger frequency divider which, of course, means higher divider noise. Generally speaking, the output phase noise of a digital divider is equal to the input phase noise divided by the circuit divisor plus the inherent divider noise. This manifests itself as a minimum attainable noise floor. The practical noise limits are -170 dBc/KHz (decibels relative to the carrier per kilohertz) for TTL types and -155 dBc/KHz for ECL dividers. CMOS dividers, working up to a frequency of about 10 MHz are similar to TTL devices, except that they have slightly higher noise between the carrier frequency and about 10 Hz away from the carrier. (REF. 3)

Unfortunately, digital circuits have another side effect, crosstalk. This causes the input signal to appear at the output as both feedthru and stray pickup. Most synthesizer systems are limited by other factors and this effect adds less than 1 dB to the noise level. (REF. 3)

Phase Detector Noise Response

In most synthesizer applications, the phase detector is chosen for reasons other than noise performance, such as acquisition and hold-in range. This is because the synthesizer phase detector does not normally operate near its noise threshold. For this reason, phase detectors are evaluated for their noise response and not as a noise source themselves. (REF. 9, 11, 12, 13)

Reference Signal Noise

Finally, we should consider the phaselock reference signal and realize that the output signal can be no more stable than the reference frequency stability times the digital divider ratio. Generally, we can dismiss this as a problem, by recognizing that the reference frequency in a synthesizer system is fixed. This allows us to use a high stability, low phase noise circuit such as a crystal controlled source.

SYSTEM IMPACT

In order to discuss how we expect the perceived signal to be degraded in the presence of phase noise, we must consider how the receiver circuits respond to this type of noise. First, we will determine what common effects receivers will experience. Second, we will take a look at the video and sound demodulators. It is necessary to evaluate the video and sound signals separately, because the difference in the modulation type for the two carriers will cause their respective demodulators to respond differently to phase noise. Finally, we will look at the effect of a signal with phase noise on broadband system distortion.

Nyquist Filtering

All television receivers have a Nyquist IF filter in front of their video detector circuits for proper demodulation of the vestigial side band video signal. The slope of this filter will translate the residual FM noise into an amplitude modulation. The video demodulator circuit will then detect this AM noise just as any other portion of the video signal. Assuming a carrier to noise ratio objective of 60 dB and using the ideal Nyquist filter slope, we can perform a simple calculation of the allowable residual FM at the input of the Nyquist filter. The ideal Nyquist filter slope starts at 45.00 MHz with 0 dB attenuation and has infinite attenuation at 46.5 MHz. This represents 100% amplitude modulation as the result of an FM input signal with 750 KHz deviation. A noise level of 60 dBc on the detector output would then correspond to AM modulation of 0.1%. To find the residual FM input necessary to produce this amount of AM, use the following equation:

$$\text{RFM} = (\text{Residual FM}) = \frac{(750{,}000\ \text{Hz})\ (\%\ \text{AM on filter output})}{100} = 750\ \text{Hz}$$

Thus, a synthesizer design objective might be to obtain 750 Hz RMS of FM noise or better.

CLOSED LOOP OUTPUT PHASE NOISE

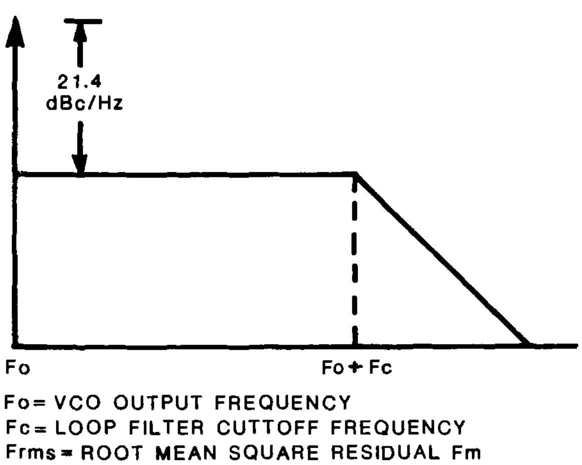


FIGURE 3

We can derive an equation for the signal to phase noise ratio of a carrier by defining F1 and F2 as the lowest and highest frequency offsets of interest with respect to the carrier. From this we will make the assumption that between frequencies F1 and F2 the slope of the noise power versus frequency is a straight line. Next, we will let F1 = 0 and F2 = Fc, the phase-locked loop cutoff frequency. In looking at Figure 3, we notice that the synthesizer has a white noise characteristic below the loop cutoff frequency of 500 Hz, i.e., the slope is 0. This is typical of a closed loop phase-locked system. (REF. 14) Our derivation leads us to the following equation from which we calculate the phase noise floor.

$$\text{NP} = 10\ \text{LOG}\ \frac{3(\text{Frms})(\text{Frms})}{2(\text{Fc})(\text{Fc})(\text{Fc})} = \frac{3\ (750)(750)}{2\ (500)(500)(500)} = -\ 21.4\ \text{dBc/Hz}$$

Although this noise floor seems to be very high, we must remember that this is phase noise and will not be directly demodulated by the video detector.

VECTOR DIAGRAM OF CARRIER, VIDEO AND PHASE NOISE

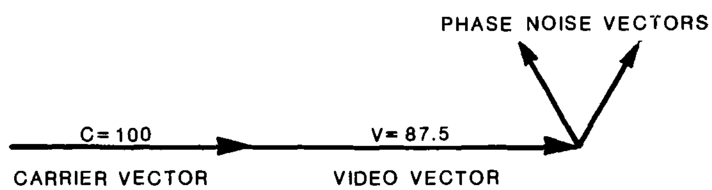


FIGURE 4A

Envelope Demodulation

We would expect an envelope demodulator to be the most sensitive type of detector to phase noise because it will detect the video amplitude noise caused by the phase noise spectrum plus the Nyquist slope converted AM noise. Figure 4a shows the complete vector diagram of the carrier, video, and phase noise. We will let the carrier amplitude be 100 units and the video equal to 87.5 units.

Next, we will take the phase noise level of -21.4 dBc/Hz and convert it to a linear form, remembering to multiply by the signal level. This is done in the following equation.

$$Rpn = \left(10^{(Np/20)}\right)(87.5) = 7.45 \text{ units}$$

Figure 4c shows, by application of the Pythagorian theorem, that the detected level of the noise is:

$$No = 20 \text{ LOG} \left(\frac{R1 - R2}{R2} \right) = -48.7 \text{ dBc}$$

where R1 = square root ((Rpn)(Rpn)+(V)(V)) and R2 = V.

PHASE NOISE RESULTANT

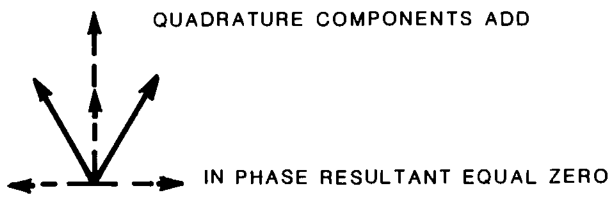


FIGURE 4B

This shows that the main contributor to picture degradation in an envelope detector is the directly detected component of the phase noise, and not the Nyquist FM to AM noise at - 60 dBc. Moreover, noting that the phase noise is predominently low frequency due to the phased locked loop in the headend synthesizer, the detected noise will be of low frequency. This suggests that the subjective video degradation for the envelope detector will be in the form of horizontally streaked noise.

PHASE NOISE INDUCED AMPLITUDE ERROR

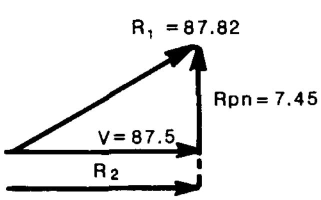


FIGURE 4C

Synchronous Detection

In theory, we would expect the synchronous detector to be better in noise performance than the envelope detector because it will track out the residual FM. In looking at the vector diagram of Figure 5b, we see that the synchronous detector only responds to the modulation vector which is in phase with the carrier: however, the detector follows the angle produced by the phase noise component as well. The phase noise directly contributes nothing to the amplitude component; therefore, none of the phase noise is directly detected.

Unlike the envelope detector, the synchronous detector has a threshold which determines the level of noise induced phase - frequency deviation it can track. This threshold is determined by parameters within its own phase or frequency locked loop. At noise levels below this threshold, we would expect the subjective effect of FM noise to be similar to that of the envelope detector, but to a lesser degree. This is because the detector doesn't actually hold zero phase to the carrier as the FM noise approaches the hold-in threshold, but instead has a small offset. This offset allows the detection of a small amount of the phase noise, which increases toward the threshold. Exactly at the hold-in threshold, the synchronous detector will jump in and out of lock following the peak noise induced FM. The result will be cycle slipping, an effect which should be familiar to anyone who has operated a satellite receiver under poor signal to noise conditions. This appears as random tearing of the picture horizontally, associated with random loss of vertical sync.

Serious degradation should occur at a lower input phase noise level than that of the envelope detector because of the dependence of the synchronous demodulation loop on the ability to follow the FM noise as a result of the synchronous demodulator threshold.

SYNCRONOUS DEMODULATION

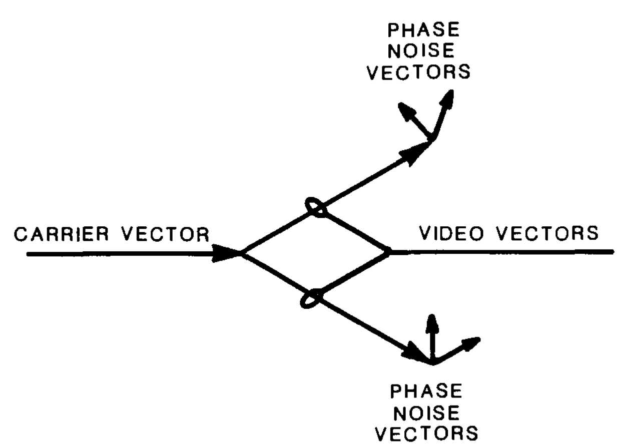


FIGURE 5A

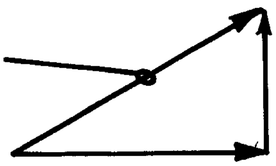


FIGURE 5B

Sound Degradation

Considering that phase noise produces a noise related FM deviation and that the sound carrier is FM modulated, we expect that the perceptibility of the noise will depend on its spectrum. The noise spectrum of the sound carrier will be the same as that of the video carrier. This makes the level of perceptibility mostly dependent upon whether a split or an intercarrier sound detection scheme is used.

Split Sound

In a split sound system, the sound carrier is detected independently from the video, therefore demodulating all the noise on the sound carrier. The noise spectrum at the output of the detector, will have a parabolic spectral shape. After deemphasis, the noise spectrum is relatively constant at the low frequencies, falling off at the mid audio frequencies at approximately 20 dB per decade. This noise response is similar to pink noise which sounds like the rushing noise made by a running shower.

Intercarrier Sound

In the intercarrier sound demodulator, the phase noise spectrum is cancelled by mixing the sound carrier with the video carrier, both of which have the same phase noise modulation. Indeed, the singular advantage of the intercarrier process is the cancellation of frequency and phase modulations common to picture and sound carriers. The degree of cancellation will be reduced by processes that independently modify the phase or frequency modulations of each carrier.

Reduction of Intermodulation Benefits of Coherent Carriers

It was anticipated that the presence of phase noise would reduce the beneficial effects of HRC operation on the visibility of system intermodulation. The improvement factor results from "hiding" the carrier intermodulation products behind a given picture carrier by causing the distortion to be coherent with the carrier. To the extent that this coherency is modified by phase noise, it was expected that the subjective intermodulation improvement would be degraded. As with the other phase noise effects, this should appear as horizontally streaked low frequency noise.

Summary of Phase Noise Effects

When signals with phase noise are introduced to a cable system, the receivers exhibit perceptible video and sound degradation depending on the types of demodulation circuits employed in any particular receiver. The video and sound signals were presented separately because of the difference in modulation processes. Both envelope and synchronous video detectors, along with split and intercarrier sound detection schemes were considered with their perceptual appearances. Also, the problems of Nyquist residual FM to AM conversion and system triple beat reduction were covered. Now let's see the results of our testing.

TEST RESULTS

The video and audio tests were performed using a phase-locked modulator to produce controlled phase noise conditions. A synthesized signal generator provided the phaselock reference signal. The generator was frequency modulated by a continuously variable white noise signal. The noise level control was calibrated for root mean square FM noise deviation by using a modulation analyzer. The subjective test results are the average of 10 expert and non-expert viewers randomly selected from laboratory personnel.

System testing for intermodulation distortion and triple beat performance was done using a "typical" cascade of 17 trunk amplifiers, followed by one line extender amplifier. The cascade was loaded with 52 HRC phase-locked channels. Phase noise was added to the carriers of the channel selected for viewing. This was done by injecting the calibrated noise source directly into the phase-locked loop of the associated IF to channel converter. The program material on the channels not being viewed included both live video and a standard color bar pattern.

Video Test Results

As predicted, the two envelope detectors tested were the least sensitive to phase noise. A residual FM of 1565 Hz RMS was the average level of perceptibility for both envelope detectors tested. This corresponds to a demodulated signal to noise ratio of 36.7 dB, as calculated by the formulas presented.

A precision demodulator was used to perform the synchronous detector testing. It was operated in three different phase-locked loop sampling modes and with two loop bandwidths. The results presented below are the average for these different operating conditions. The synchronous detector displayed the same subjective noise characteristic as the envelope detector, but perceptibility occured at a lower residual FM level. Also, as suspected, the synchronous detector lost lock very quickly after the appearance of noise in the picture due to the failure of its phase-locked loop to remain stable. The results of the video tests are tabulated below.

Residual FM for Definitely Perceptible Noise

env. det. 1	env. det. 2	synchronous
1347 Hz RMS	1783 Hz RMS	306 Hz RMS

As we can see from the table, the envelope detectors can withstand the greatest amount of phase noise before the picture is perceptually degraded.

Sound Test Results

An audio output signal to noise ratio criterion of 50 dB was used as the basis for the phase noise analysis. The phase noise level required to produce this signal to noise ratio was found to be 126 Hz RMS and 1530 Hz RMS for split and intercarrier sound detection, respectively. This was done by modulating a 1 KHz tone onto a channel with phase noise added as previously done for the video test. The aural carrier deviation was set to 25 KHz peak, demodulated using a precision detector, and a reference set on an audio voltmeter. The 1 KHz tone was then removed and the signal to noise ratio measured. The noise modulation was increased until a 50 dB ratio was achieved. The residual FM noise level was then recorded.

Listening tests confirmed that the subjective quality is one of random noise predominated by low frequencies. The sound has a "rain falling on a drum" characteristic.

System Testing for Intermodulation Performance Reduction

After setting the amplifier cascade signal level at a point where the intermodulation distortion was not a factor, phase noise was added to give a definitely perceptible degradation in picture quality. The resulting FM noise deviation was measured at 876 Hz RMS. The cascade signal level was then increased until intermodulation distortion was just perceptible. The effect of the phase noise was seen to increase as a result of increasing the cascade signal level; however, no new types of degradation appeared. In order to reduce the picture degradation due to the phase noise back to the previous perceptibility, it was necessary to reduce the residual FM to 349 Hz RMS. This brings us to the conclusion that additional degradation does occur when phase noise interferes with the coherent carrier intermodulation process. Furthermore, this degradation is on the order of 60% of the tolerable phase noise with no intermodulation distortion.

SUMMARY AND CONCLUSIONS

The phenomenom of phase noise in synthesized headend equipment has been discussed and shown to be a problem if not properly attended to early in the design stage of such equipment. A brief overview of the phase-locked loop and the major contributors to phase noise within the loop have been presented.

Perceptibility tests were performed for a video color bar pattern and tests show that the envelope detector was most insensitive to phase noise for video. These tests illustrate that a residual noise related FM of 750 Hz RMS should be subjectively acceptable when receiver envelope detection is used.

Sound testing was performed for a 50 dB signal to noise ratio and showed, as expected, that the split sound detector was inferior to the intercarrier detector. Furthermore, the type of noise heard was listened to and described.

System cascade testing to determine the impact on intermodulation performance in an HRC situation was also performed. Although not specifically proven, our expectations of a reduction in coherent carrier system advantage were partially fulfilled by the apparent increase in the level of phase noise observed; the absence of new distortion products was not expected.

Since the data presented here represents only a limited number of tests, and was obtained from a limited number of viewers, the results must be taken as preliminary. However, these results can serve as a relative basis for the evaluation of synthesized headend equipment.

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Staffing Performance Standards for Metropolitan Cable TV Operations

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Warner Amex Cable Communications, Inc.

ABSTRACT

Demand maintenance, customer service and preventative maintenance are examples of operation areas where the staffing levels are a function of plant miles, number of subscribers and the ability of the operations staff to achieve various levels of efficiency in performing their tasks. This paper reviews these areas and others to define the staffing and performance criteria for determining the size of the operating group in cable TV systems.

INTRODUCTION

Providing cable T.V. to the larger Metropolitan cities presents a new set of challenges to the cable operator, due to the larger number of subscribers, additional complexities of multiple local studios and access facilities, and an increased region for maintenance support. This paper addresses the technical operations' staffing and productivity for the three different configurations of two-way addressable one-way addressable, and trapped/programmable converter systems. A typical organizational structure is defined for each of the three system configurations, and by using staffing productivity standards the number of employees needed are defined as a function of phone load, system size, and churn.

METROPOLITAN CABLE SYSTEM DESCRIPTION

Before a meaningful review can be made of productivity standards and operations results, it is necessary to define the types of Cable T.V. systems being analyzed. For this paper we will define a Metropolitan cable system as having over two-hundred thousand homes in an area that can be contiguously cabled by the cable company. Three types of cable systems will be compared in this paper, as shown in Table 1.0.

The system denoted as a "trapped" system utilizes negative traps for the three lowest churn pays, and these three pays are made available to both the tier I and tier II subscribers. The tier I subscribers have a conventional 22 channel standard converter that does not descramble. The tier II converter is a programmable converter that has an internal read-only memory (ROM) that can be set to allow the converter to descramble from one to three additional pay channels, depending on subscriber choice. Thus when a subscriber changes service,either a pole-action to reconfigure traps, and/or a home visit to change out the converter is required.

The system denoted as a One Way Addressable (OWA) system provides the same 6 pays except that all pays are scrambled and made available to the OWA (Tier II) subscribers only. The tier II subscriber receives 22 channels consisting of off-airs, several independent T.V. channels, local orgination, and community action/access channels. The tier II subscribers receive up to 6 pay channels, with each pay selection authorized or enabled by cable T.V. head control of the descrambling in that subscriber's converter. Thus in this system pay upgrades and downgrades are handled without truck trips being required, except for those cases where a tier change is involved.

The two way addressable system (TWA) provides the same 6 pays with a converter and plant design that allows for two-way operation. In this system trunk and feeder electronics have a return amplifier installed, and a transmit modem in each two-way subscribers' converter allows upstream transmission from each home. Pay Per View channels are offered and the system for this has easy Pay Per Event capability as well. For the tier I subscribers, a non-descrambling 22 channel conventional converter is utilized, with the same programming assumptions as the OWA system.

Each system design will be single cable 360MHz bandwidth, with 42 channel capacity, assuming allowance for channel loss due to FAA and off-air interference. The systems will be assumed to have been constructed over a period of 4 years. Table 2.0 shows the system build/extension rate, total miles of plant, penetration assumption, and total subscribers. These assumptions will be utilized throughout this paper.

We will assume a local origination capability, with at least 5 municipal access channels, creating the need for an operational studio, video tape playback, and a master control facility for program switching and routing. The office will be a stand-alone office in the areas of accounts payable and receivables,

Table 1.0 Metropolitan Cable System Configurations

	SYSTEM CONFIGURATION		
	Trapped System	OWA System	TWA System
Number of Channels/ Cables	42 channels, Single cable	42 channels, Single cable	42 channels, Single cable
Plant Miles (By Year 7)	1,200	1,200	1,200
# Homes Passed (By Year 7)	195,000	195,000	195,000
# Tiers # Pays	2 3 Trapped 3 Programmed	2 6 Addressable	2 6 Addressable 2 Pay Per View
Converters	Tier I - 22 Ch. Standard Tier II - 42 Ch. Programmable with Wireless Remote	Tier I - 22 Ch. Standard Tier II - OWA, 42 Ch., with Wireless Remote	Tier I - 22 Ch. Standard Tier II - 2-way, 42 Ch., with Wireless Remote
Aux. Outlet	22 Ch. Standard or 42 Ch. Prog.	22 Ch. Standard or 42 Ch. OWA	22 Ch. Standard or 42 Ch. TWA
% Tier I Subs % Tier II Subs	50 50	15 85	15 85

TABLE 2.0 COMPUTER MODEL INPUT FORMAT

Trapped System, Programmable Converters

NCTA84A NCTA PAPER
4/7/1984 System 1

MASTER	YEAR1	YEAR2	YEAR3	YEAR4	YEAR5	YEAR6	YEAR7	YEAR8	YEAR9	YEAR10
YEARLY CONSTRUCTED MILES	30	450	450	220	50	50	50	50	50	50
YEAR END MILES	30	480	930	1150	1200	1250	1300	1350	1400	1450
DENSITY, HOMES/Mi	150	150	150	150	150	150	150	150	150	150
YEAR END HOMES PASSED	4500	72000	139500	172500	180000	187500	195000	202500	210000	217500
% PENETRATION	0.30	0.35	0.40	0.45	0.48	0.50	0.50	0.50	0.50	0.50
YEAR END SUBSCRIBERS	1350	25200	55800	77625	86400	93750	97500	101250	105000	108750
BASIC CHURN/YEAR	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
PAY CHURN/YEAR	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
CONST. NEW SUBS	1350	23625	27000	14850	3600	3750	3750	3750	3750	3750
YEARLY TOTAL DISCONNECTS	324	6048	13392	18630	20736	22500	23400	24300	25200	26100
RECONNECT % OLD SUBS	0.00	0.00	0.00	0.50	0.50	0.50	0.75	0.75	0.75	0.75
YEARLY NEW CONNECTS	1674	29673	40392	24165	13968	15000	9600	9825	10050	10275
YEARLY RECONNECTS	0	0	0	9315	10368	11250	17550	18225	18900	19575
YEARLY UPGRADES	486	9072	20088	27945	31104	33750	35100	36450	37800	39150
YEARLY DOWNGRADES	486	9072	20088	27945	31104	33750	35100	36450	37800	39150
MKTG/CHURN REL. CALLS/MO	247.5	4488.7	7830	9000	8940	9687.5	10062.	10437.	10812.	11187.
% CALLS OF SUB BASE-OTHER	0.70	0.70	0.70	0.60	0.50	0.30	0.30	0.30	0.30	0.30
# PHONE CALLS/MONTH	1192.5	22128.	46890	55575	52140	37812.	39312.	40812.	42312.	43812.

and payroll. A billing and customer support system such as Cable Data or First Data Resources is assumed for primary data base and billing purposes. A mixture of direct sales and telephone sales will be assumed for marketing, and the system will offer a guide for sale.

It should be noted that the relative revenue generating capabilities of these systems are different, since the OWA system has a revenue opportunity of supplying Pay Per Event programs such as sports events, concerts, etc. Likewise, the TWA system offers Pay Per View events routinely, and thus offers wider viewer choice of programming plus the Pay Per Event programs. Also, the capitalization of the systems are different, since the converters, distribution and head-end facilities are different. Thus the absolute comparison of operating expenses or employee head-counts is not meaningful. However, as we will see in later sections, relative operations expense and head-count, as a function of employee productivity and churn, is very meaningful.

METROPOLITAN CABLE SYSTEM ORGANIZATION

The staffing organization for the baseline system is shown in Figure 1.0. The company is organized along functional lines, as shown, with the major areas of Marketing, Technical Operations, Finance, and Broadcast Operations reporting to the local general management. The general manager has a support staff of Legal, Human Resources, and Government Affairs that are combined and referred to as General and Administrative (G&A) Operations.

The Marketing organization is comprised of Direct Sales, Telephone Sales, Marketing, and Guide Production. Although the Customer Service Group can exist in marketing or operations, for this paper we will assume Customer Service to be in Operations.

The Finance organization is made up of accounts payable, payroll, subscriber billing resolution, and capital and expense accounting.

The Broadcast Operations organization consists of "Above the Line" and "Below the Line" programming staff, video support engineers, and management staff. There is also staff provided to support access studios and local origination.

For each of the three system configurations described above, there will be differences in the Marketing, Finance, and Broadcast Operations groups. For instance, in a Pay Per Event or Pay Per View system, some additional Finance operations cost is necessary to handle the billing and billing adjustments for the programs. This cost can be handled by the billing company, in-house, or a mixture of both. Clearly the incremental revenue should be compared with the incremental capital and operating expense in this and all areas, to determine the relative business advantages of each configuration. However, to limit the scope of this paper, we will only evaluate operations costs in technical operations, which we have found by experience to comprise well over 80 percent of the incremental operating expenses.

TECHNICAL OPERATIONS DESCRIPTION

Since the Technical Operations area is the focus of this paper, the group's organization is further defined as shown in Figure 2.0, with summary job descriptions given below.

Installers - This group installs all drops for new subscribers, reconnects for previously cabled homes, and disconnects for subscribers dropping service. For a system with traps or different converters for different levels of service, the installers also perform upgrades and downgrades of service. Past the initial construction period the installers are assumed to have completed a course in installation, and are company employees. Installers are managed by supervisors who provide quality control and problem solving.

Demand Maintenance Technicians - This group is responsible for responding to all trouble calls, and are trained to diagnose and resolve problems in the home, and the drop up to, and including, the tap. Demand Maintenance technicians have had installer training and Demand Maintenance training.

Preventative Maintenance Technicians -This group is responsible for continuous monitoring of the outside plant, to assure that the plant is tight from signal egress or ingress, and meets trunk end of line performance tests for such technical performance parameters as carrier to noise, bandpass flatness, and distortion products. This group repairs all trunk and feeder outages down to the tap.

Work in Process (WIPS) - The WIPS group is the support group for the installers. They process work orders, prepare installation kits for new installs, upgrades and downgrades, and close out work orders. They are provided inputs by the Data Base management system and provide daily activity summaries back to the data base.

Dispatch - The Dispatch group controls the field fleet for installs and Demand Maintenance Technicians. They monitor plant operation, and direct the P.M.'s to problem areas if outages occur. The installers and P.M.'s call in their activity to Dispatch, and Dispatch handles priority decisions each day.

Warehouse - The warehouse group handles all technical operations' inventory and distribution. This includes drop materials and converters, extension plant materials, and spares for all electronic and plant passives.

Figure 1.0 Metropolitan Cable System Organization

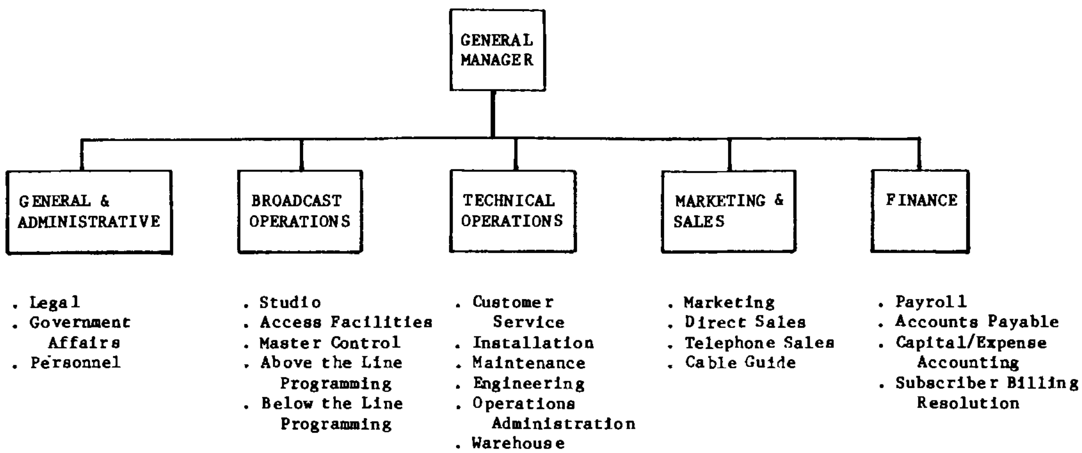
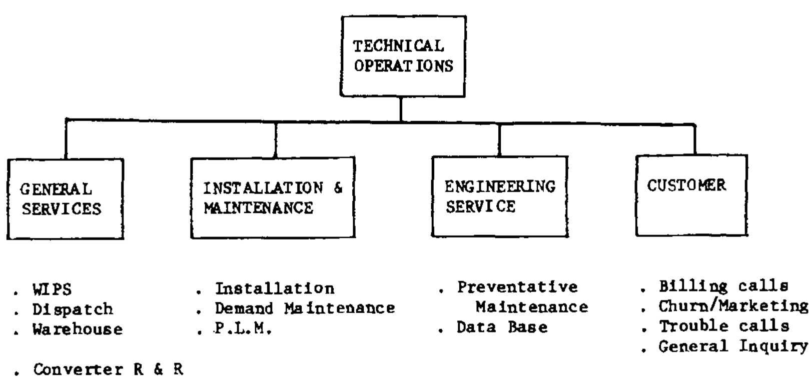


Figure 2.0 Technical Operations Organization



Engineering - The engineering group consists of the headend/master control engineer, the outside plant chief engineer, and the non-R.F. return engineer in two-way systems.

Pole-Line Maintenance - The PLM group is responsible for all pole adjustments, resolving clearance problems, and plant reconfiguration for pole moves and replacements.

Converter Refurbishment and Repair - This group is responsible for repair and refurbishment of all subscriber converters. Refurbishment includes cosmetic correction of returned converters, replacement of worn/used cords, etc. Repair consists of determining converter failure, and then returning the unit to the supplier for repair if justified. For repairing the more complex OWA and TWA converters, module fault isolation is assumed, with module or unit return to the supplier as warrented.

Customer Service - Customer service consists of telephone operators to handle all incoming phone calls for trouble calls, upgrades and downgrades, new installation requests, and reconnects and disconnects of service. This group also handles all general inquiry requests such as general information, and all billing resolution calls.

Finally, the Technical Operations organization and fixed overhead staffing is shown in Figure 2.0. This organization assumes districting, which is used for larger systems.

PRODUCTIVITY STANDARDS IN CATV TECHNICAL OPERATIONS

To define productivity standards in some areas, it is valuable to define a work standard to use as a guage. In this paper this work standard is the work unit (W.U.) defined as a 15-minute period. Thus 4 W.U.'s equal one hour and there are 32 W.U.'s in an eight-hour day. Also, 22 work days will be assumed as an average month.

Based on experience for well organized and trained operations' personnel, it is possible to define the number of work units required per technical operations' function, as shown in Table 3.0.

For the installation group, the amount of time for a new connect is higher for a two-way addressable system because the return path must be checked by a computer program link with the head end. The complexity of confirming a downstream configuration for the OWA is approximately balanced by the need to correctly install traps for the trapped system. Thus the amount of time needed to install a trapped system and a OWA are equal, with the TWA system requiring a slightly longer time. When second sets are considered at approximately 25 percent of the subscriber base, these productivity standards result in about 6 new installs per day for the trapped and OWA systems, and 5 per day for the TWA system.

Likewise, for pay upgrades and downgrades, the installer productivity is a function of system configuration and action. For the trapped system, a pay pole-only upgrade or downgrade takes one unit, thus 32 subscribers can be handled in an 8 hour work day. For tier changes or pay unit changes, which require customer access and converter change-out or modification, the average productivity is 2 work units per subscriber, or 16 subscribers per 8-hour work day. If we assume an even split of actions, then 24 subscribers per day are handled by each technician. For the addressable systems, all pay upgrades and downgrades are handled without truck calls and house calls are needed only for tier churn, to change out the converter. This action is only required in about one-fifth of the upgrades and downgrades, thus the number of install technicians needed for pay churn in addressable systems is about one-fifth the trapped system case.

For disconnects, we assume that the drop is disconnected at the pole in all systems, and the converter retrieved. There is no difference in three systems in this area. This assumption tends to penalize addressable systems, but is assumed due to the present inadequacy of scrambling systems.

For the trapped system, reconnects require a pole climb for trap reconfiguration, and a subscriber's house entry for converter installation. This can be done in two units, but when a 25 percent second set assumption is made, we can actually achieve 11 - 12 reconnects per 8 work hour day. For the OWA and TWA, we also have assumed pole climbs to reconnect the drop, and thus the same 2 work units are required. In addition, the TWA system requires return path confirmation, and thus the total reconnects per day for the OWA and TWA are 12 and 10, respectively. Again, it should be noted here that if signal piracy is not a serious threat due to scrambling security, the addressable systems would not be disconnected at the pole, and thus their productivity in disconnects would be higher. Finally, it should be stated that these work unit estimates per technician function take into account windshield time, set-up, etc., and can obviously vary from system to system depending on how spread-out the city is and the relative weather conditions during winter times.

For customer service calls, the productivity will be measured on the number of resolved phone calls handled per day per operator. By resolved we mean, if the purpose of the call was an upgrade, then the upgrade was handled by the CSO, with the subscriber on the phone. Also, trouble calls would result in a "talk down" approach to initially try to resolve the difficulty on the phone, with a work order scheduled if the "talk down" fails. Customer Service productivity for resolved calls, is shown in Table 3.0.

Trouble calls are from subscribers with T.V. reception problems. Billing calls are calls concerning billing expenses, procedures, and explanations. General Inquiry calls are all general purpose phone calls for information, future events, etc. Change of service calls are all calls for upgrades, downgrades, new service, and disconnects. The productivity for the TWA Systems is somewhat less due to the need to diagnose return path trouble symptoms, additional billing calls for Pay Per View, and additional Marketing (Subscriber retention) time needed to explain Pay Per View programming and options.

Finally, for the converter refurbishment and repair area, we assume the more complex addressable converters will be tested to the module/subassembly level, and faulty modules returned for repair. Also, the refurbishment of the two-way unit involves resetting a new address block, and slightly more cosmetic work, hence the lower number of units processed per day as shown in Table 3.0.

OPERATING RESULTS AND COMPARISONS

By using the three system configuration descriptions, Tables 2.0 and 3.0, and the organization and productivity assumptions, it is possible to compute the operations staffing and yearly expense, by assuming conventional overheads and salary structures. This approach is readily computer programmed to allow sensitivity studies of productivity variation impact on operations expense.

Tables 2.0 and 4.0 show the form of the computer program, and its output. For this paper we elected to determine the impact of subscriber churn on the operating expense of each type of system, and then the effect of reductions in productivity on operating expense and churn. An example of some of these results are shown in Table 5.0, with year 7 chosen as the comparison year since the system is built, has reached full penetration, and has stabilized operationally.

In Table 5.0, we see marked the "baseline" configuration for each type of system for a 2 percent per month basic churn (.24 of subscriber base per year), and a 3 percent per month pay churn (.36 of subscriber base per year). Note that since the TWA system has a return path and more complicated converters, the assumption is that 6 trouble calls (truck rolls) per 100 subscribers is the normal operating condition, where 4 trouble calls per 100 subscribers is the normal operating condition for the trapped and OWA systems. We should note that these trouble calls are actual field trouble calls, and should represent about one-third of the total trouble calls made per month.

By assuming the productivity defined in Table 3.0, we can evaluate the impact on staffing and expense of basic and pay churn. Figures 3 and 4 show these results for the total technical operations staffing, and shows the expected sensitivity of the trapped system to pay churn. Since the staffing levels and expense track each other very well, we will only plot staffing levels. Note that the technical operations staffing and expense of a trapped system exceeds the one-way levels, and approaches that of the more complex two-way system, for the case where there is increasing pay churn for a stable basic churn. In fact, as the pay churn goes up as shown, the installation group cannot keep up with the rate, and a disconnect backlog normally occurs. This causes additional phone calls, rescheduling, etc. such that the trapped system staffing impact and expense is in practice actually worse than that shown.

By varying productivity as shown in Table 3.0, it is possible to compare the three system types on staff and expense. Due to the relatively high number of install staff, even after the system is built, and the need to equip this staff with vehicles, etc., we have found that the install group's productivity variation has the highest single impact on staff and expense, with the Demand Maintenance group second. For instance, Figure 5 shows the staff impact as a function of 20, 40, and 60 percent reductions in installer productivity. Again note that as the productivity lowers the trapped system is proportionally worse than either addressable system.

Although installer productivity has a big impact on technical operations, we have found that if the plant is not well maintained, a "snowball" effect occurs that greatly increases technical operation's costs, and also greatly increases the work of other groups.

Recent studies of subscriber retention done for Warner Amex by external consultants, confirmed by internal staff, shows that customer dissatisfaction is heavily effected by system outages and equipment problems, and can easily effect overall churn by one percent per month or more. In our model we show this effect by assuming that if the system is not maintained, the trouble calls per 100 subscribers increases, and then the churn will increase as well. This effect is shown in Figures 6 and 7, and shows increase in one percent in basic/pay churn for a 2 unit increase in trouble calls per 100 subscribers. As the trouble calls per 100 subscribers increases still further, disconnects and downgrades increase also, creating the "snowball" effect. In Figures 6 and 7 the curves marked "XXXX/PROD." are the curves that show the "snowball" effect for each type of system, and the curves marked without the "PROD." label represent the staff impact without the "snowball" effect. Note the addressable systems are less sensitive to a reduction in maintenance than the trapped system, with the trapped system expense increase exceeding even the TWA system increase.

In conclusion, our experiences have shown that plant maintenance is the single most important factor in determining Technical Operations staffing levels and expense, for a particular type of system. The installation group productivity also has a substantial effect, with the trapped system in general being much more sensitive to both basic and pay service churn. As shown in the figures, a few percent change in churn can cause a large impact in technical operations staffing, and for increases beyond 10-20% of normal staffing, the operation typically cannot keep up with the rate of churn. In this case the back-logs increase, and this further increase needs, unless contractors are used. Finally, if the plant maintenance degrades, disconnects and down-grades increase, and a "snowball" effect occurs, further impacting the staffing and expense.

Table 3.0 Productivity Comparison of Three System Configurations

Group	Typical Parameter Ranges	Units Work Unit = W.U.	Baseline System Assumption Trapped System	OWA System	TWA System
1. Installation					
New Install	4 - 8	W.U./Install	4	4	4-1/2
Reconnect, Home Conn.	2 - 4	W.U./Recon.	2	2	2-1/2
Upgrade, Pole Only	1 - 2	W.U./Upgd.	1	N/A	N/A
Upgrade, Tier Chan.	2 - 4	W.U./Upgd.	2	2	2
Downgrade, Pole Only	1 - 2	W.U./Downgd.	1	N/A	N/A
Downgrade, Tier Chan.	2 - 4	W.U./Downgd.	2	2	2
Disconnect, Home Conn.	2 - 3	W.U./Disc.	2	2	2
2. Demand Maintenance					
Trouble Call	2 - 4	W.U./Call	2	2	2-1/2
3. Preventative Maintenance					
P.M. Staffing	80 - 120	Miles/P.M.	150	150	110
4. Dispatch Operator					
Staffing	Total Techs/12	Dispatchers/ Test	See Model	See Model	See Model
5. Work in Process					
WIPS Staffing	80 - 150	W.O.'s/Day	125	125	125
6. Customer Services					
Billing Operators	50 - 90	Calls/Op./Day	70	70	60
Trouble Call Operators	50 - 90	Calls/Op./Day	80	80	70
Churn/Mktg Operators	60 - 100	Calls/Op./Day	70	70	65
General Inquiry Operators	70 - 120	Calls/Op./Day	100	100	90
7. Converter Refurb. & Repair					
Refurb. Staff	50 - 90	Units Refurb./Day	80	80	70
Repair Staff	30 - 50	Units Repaired/Day	50	40	30

TABLE 4.0 COMPUTER MODEL OUTPUT

'NCTA PAPER SYSTEM 1 (TRAPS,PROGRAMMABLE CONVERTERS)

MASTER

TECH. OPS. SUMMARY	YEAR1	YEAR2	YEAR3	YEAR4	YEAR5	YEAR6	YEAR7	YEAR8	YEAR9	YEAR10
INSTALLERS	2	26	40	35	31	33	35	35	35	35
DEMAND MAINTENANCE	1	4	8	11	12	13	13	14	14	15
PREVENTATIVE MAINTENANCE	1	5	8	10	10	10	12	12	12	13
CUSTOMER SERVICE	0	14	27	32	32	23	25	26	26	26
POLE LINE MAINTENANCE	5	5	5	5	5	5	5	5	5	5
WORK IN PROCESS	1	3	4	4	4	5	5	5	5	5
DISPATCH	2	2	3	3	3	3	3	4	4	4
CONVERTER REFURB & REPAIR	1	1	3	3	3	3	3	3	3	3
DATA BASE	1	3	3	2	1	1	1	1	1	1
WAREHOUSE	3	5	5	4	3	3	3	3	3	3
ENGINEERING	3	3	3	3	3	3	3	3	3	3
TOTAL STAFF	20	71	109	112	107	102	108	111	111	113
TOTAL EXPENSE (000'S)	632.1	1891.5	2814.7	2920.2	2803.8	2752.4	2933.5	3003.6	3003.6	3086.1

Table 5.0
Comparison of Year 7 Staff and Expense for Technical Operations as a Function of Average Yearly Churn

Yearly Churn	Trouble Calls/ I.O.	Trapped System Staff	Trapped System Exp. ($K)	OWA System Staff	OWA System Exp.	TWA System Staff	TWA System Exp. E
.24/.36							
	4	108	2934	96	2641	109	3041
	6	117	3197	105	2905	116	3216
	8	124	3413	112	3120	125	3510
	10	130	3601	118	3308	134	3788
.36/.48							
	4	121	3235	105	2884	121	3318
	6	130	3499	114	3108	129	3543
	8	137	3714	121	3324	138	3807
	10	143	3902	127	3511		
.48/.60							
	4	138	3633	121	3224	138	3715
	6	148	3918	131	3509	145	3920
	8	155	4133	138	3724	154	4183
	10	161	4321	144	3912	163	4462
.60/.72							
	4	158	4103	135	3546	152	3938
	6	167	4367	144	3810	159	4243
	8	174	4582	151	4025	168	4506
	10	180	4870	157	4213	177	4785
	12					184	5010

Legend

x/y = x% basic churn/yr.
y% pay churn/yr.

Exp $ = $ (000's)

Figure 3.0

STAFFING AS A FUNCTION OF BASIC CHURN

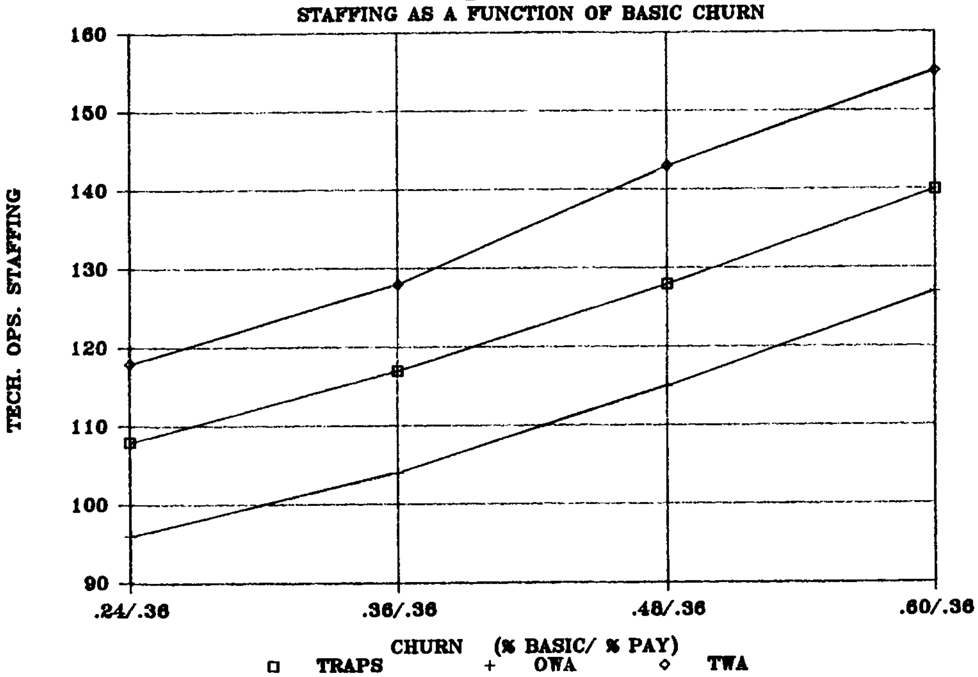


Figure 4.0

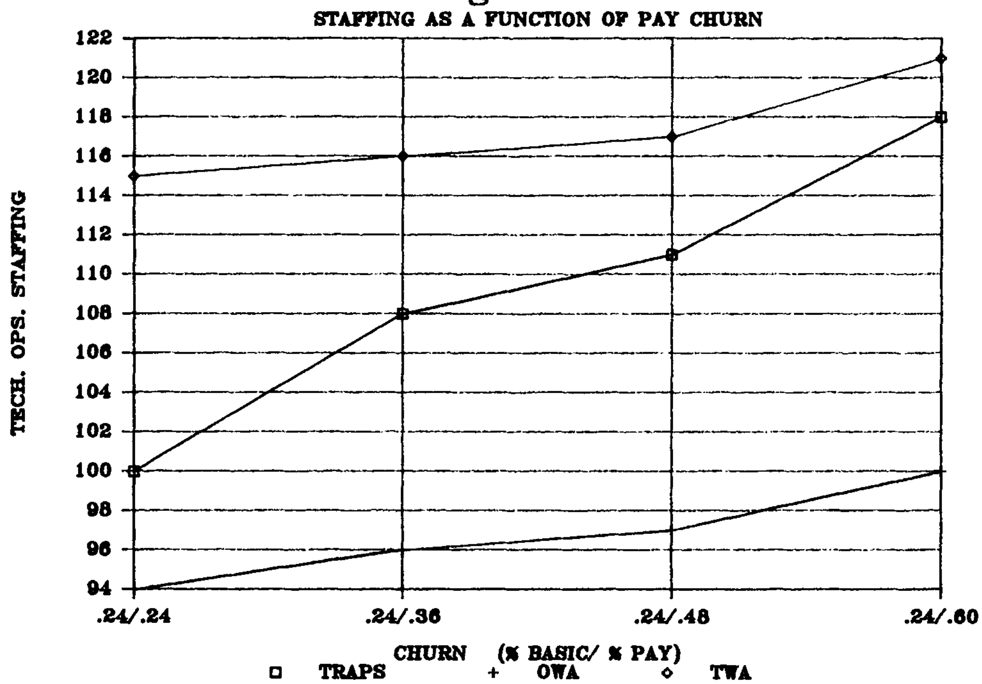


Figure 5.0

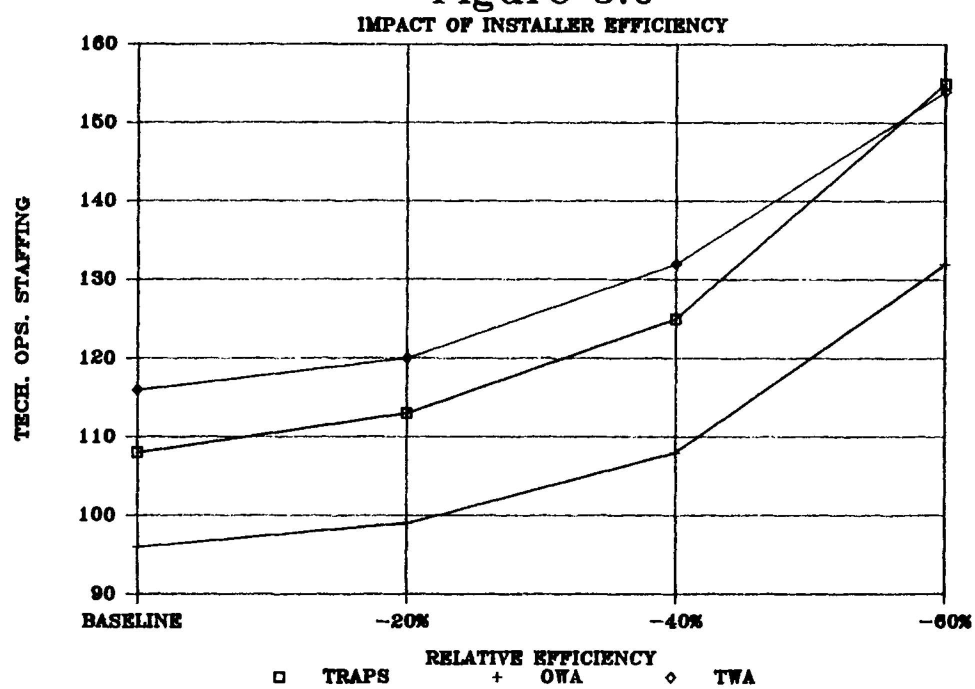


Figure 6.0

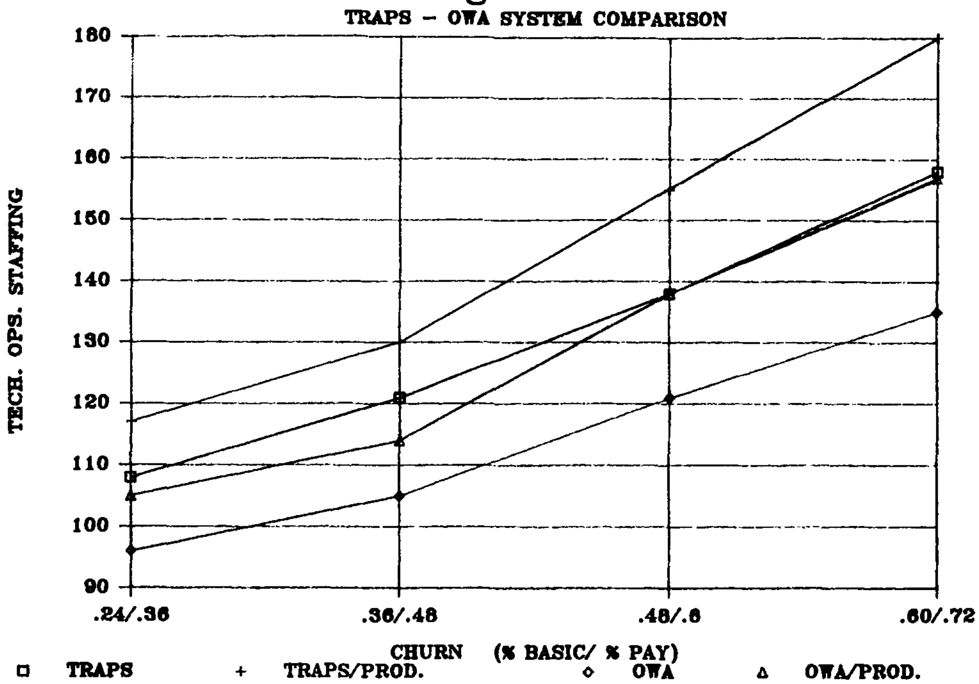
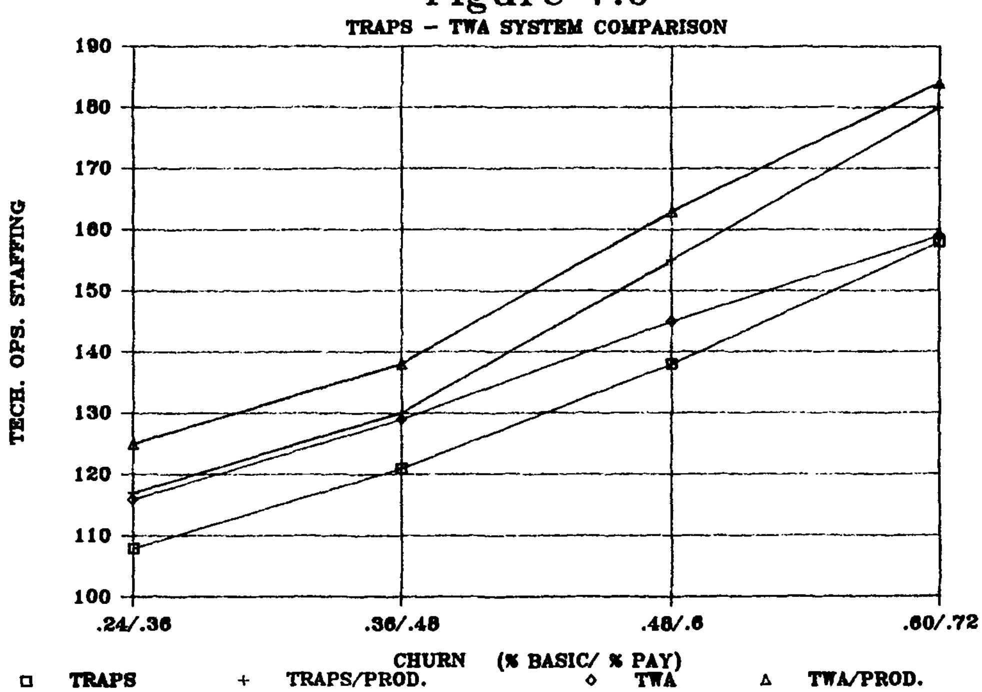


Figure 7.0



TECHNICAL AUDITS FOR LARGE METROPOLITAN CABLE TELEVISION SYSTEMS

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ABSTRACT

As CATV operators secured franchises in large metropolitan cities, it became apparent that the services promised would provide an enormous technical and organizational challenge. In the initial stages of the system build, the overriding focus is the construction of facilities and outside plant while equilibrium in operations is struggling to emerge. During this period, technical quality is sometimes compromised by underqualified and transient personnel, lack of interdepartmental communications, absence of standardized practices and procedures, as well as a non-uniform understanding of the overall goals of the system. The system operator will eventually move out of this construction mode and into the real day-to-day operations of a large system, but by this time there will be many technical problems and non-standard procedures that have become part of the daily operations. A technical audit at this time can stabilize operations, reduce technical problems and solidify the communications between system personnel and Corporate Engineering.

INTRODUCTION

Warner Amex currently has franchises in several large metropolitan areas such as Houston, Dallas, Cincinnati, Pittsburgh, St. Louis, Columbus Ohio, Milwaukee and New York City. The construction is basically complete in all of these cities except Milwaukee and New York City, which meant that six sites consisting of approximately 13,000 miles of plant, large master control facilities, studios, video vans, high speed two-way data communications, complex AML and satellite networking, would now be faced with maintaining the technical integrity of the system.

Corporate Engineering was tasked to develop a method of providing senior management with a clear understanding of the present technical operations of these large systems and outline a long term plan for improved technical integrity with standardization of practices and procedures. A technical audit was then outlined to accomplish this goal.

The key technical areas were chosen and classified as CATV Engineering, Data Communications Engineering and Video Engineering.

CATV Engineering was defined to encompass the main headend, all hub sites, the outside plant and the records and procedural documents associated with each area. The testing at each of these locations was intended to give insight into the performance of modulators, processors, microwave equipment, satellite receivers and peripheral equipment used to supply programming for transmission on the CATV plant. Forward signal quality is observed at selected extremities of the system, and the physical condition of the outside plant is checked for proper construction practices. Subsequently, a set of tests were prepared with specific parameters that would allow an efficient and expedient analysis of CATV Engineering in the system.

CATV ENGINEERING

A. The headend/hub tests are performed at all sites and consists of the following:

Hum	-	60 dB down
C/N (Headend)	-	55 dB or greater on all channels
C/N (Hub Sites)	-	hubsite C/N dependent on interconnect to main headend

All of the above tests are to be performed on three selected channels, preferrably off-air, satellite and pay-per-view (or subscription pay) channels that represent low frequency, mid-band and high frequency portions of the spectrum.

The picture quality, audio levels and video levels are checked on all channels and the operation of standby power at all sites was evaluated. General observations are made at all sites with respect to neatness, cable identification, space utilization, and equipment grounding.

B. Outside plant testing is divided into field tests and field observations.

Field tests are performed at the last trunk location of a long cascade in every 200 miles of plant and the field observations are performed on 10% of the total plant. Field testing consisted of the following:

Peak to Valley	=	[N/10 + 1/N] N = number of trunk amps
C/N	=	Base # - N.F. + input - 10 log N, where N = # of trunk amps
Hum	=	less than 2%

These three tests are performed on the three channels defined in the previous section. In addition, picture quality, audio levels, video levels, and visual observation of the spectrum are to be checked on all channels. Signal leakage should also be checked.

Field observations are performed on a 10% random sample of the system with attention given to grounding, bonding, expansion loops, lashing wire, equipment placement, splicing, clearance, sagging, riser attachments, pedestal installation, subscriber installation, apartment lock boxes, apartment conduit and molding placement, apartment cable routing, apartment security and general condition of the plant.

C. Technical records are checked for FCC public files, PM (Preventative Maintenance) procedures, PM reports, as-built maps and availability of spares.

This list was prepared for CATV Engineering along with a list of test equipment required and a proposed schedule (time-frame) for the testing to be completed.

DATA COMMUNICATIONS ENGINEERING

Data Communications Engineering on a large scale in a CATV systems is relatively new and fairly specialized to individual systems or MSO's. This section will attempt to remain as generic as possible, but will undoubtedly refer to some specifics in an attempt to fill up the pages of this report. (Ha! Ha!) The systems that were to be audited were all high speed (256 kbs), two-way interactive with several pay-per-view channels delivered to the subscriber. In order to understand the reasoning for our selection of testing, I will give you a brief overview of the data communications network.

A Data General computer (Model C-350) formats the data necessary to talk to the BGC's (bridger gate controllers) and the subscriber terminal and delivers it through a two-way communications interface board (BCU), which in turn provides the path to and from the RF modem. This modem is located in the computer room and is interfaced to the headend for transmission onto the cable system and to the terminal in the subscriber's home. The terminal responds on the reverse spectrum, is routed through the headend and is received by the modem in the computer room and provides the necessary data back to the computer. All of the systems have been subdivided into sections of approximately 200 miles of plant for each modem and interface board. This was done in conjunction with the BGC's to help control the ingress for proper data communications. The BGC's also provide system status monitoring for outage analysis.

Data Communications Engineering tests and parameters were selected as follows:

A. Error analysis - Error testing was performed on each BCU (approximately 200 miles of plant) to determine the overall error rate and identify the types of errors in a given area. Special software diagnostics allowed us to perform error rate analysis without using bit error rate testers or specialized equipment. The areas tested were:

BCU Timeout -	This is an error associated with communication between the main CPU and the BCU interface board.
PSK Errors -	Errors associated with excessive noise in the reverse portion of the CATV plant. PSK (Phase Shift Keying) is used on the upstream data carrier.
Parity Errors -	Errors associated with block code checking of the received data.

B. Distribution Analysis - Three distribution amplifiers are randomly selected per BCU area to observe the overall RF level variance of terminal responses to analyze reverse distribution balancing. The RF levels are provided via the modem to the computer (A to D conversion) and can be printed.

C. Modem analysis - FSK (Frequency Shift Keying) is used on the downstream data carrier. Frequency accuracy, output level and sideband equality will be checked. On the PSK receiver portion, receiver level tracking and input sensitivity will be checked.

D. Data path checking - The downstream and upstream paths to and from the headend will be checked for attenuation accuracy and overall design to ensure the design parameters of the modem are met.

E. Reverse Plant C/N and C/I -

C/N - A 6 MHz and 29 MHz CW carrier will be injected at proper levels into one of the longest trunk cascades within a BCU area. One location per BCU will be selected and the C/N will be measured at the main headend.

C/I - Carrier to interference will be measured in a spectrum ± 3 MHz from the center frequency of the data carrier.

F. Non-RF analysis - Non-RF (data related) is the name we have given to the overall data base management and data related workflow associated with a two-way system. This encompasses installation, DM, PM, billing, data entry and computer operations. A review of the overall procedures and interdepartmental communications was the key focus of this analysis.

G. Headend diagnostics - In a two-way interactive system, the headend becomes the hub for communicating and analyzing data, plant, service, computer and video related problems. Special software and test procedures were developed to assist the headend technician in his role as departmental coordination. All of the procedures are reviewed and software functionality checked.

H. Encoder analysis - This was included under data communications because it was directly related to the two-way terminals and the expertise for alignment and testing was within the Data Communications group. The test performed was residual ripple (analog scrambling was used) and the alignment procedure was reviewed in addition to checking the setup log.

A list of test equipment required and a proposed schedule for the testing was included for this section.

VIDEO ENGINEERING

Video Engineering was defined to encompass master control and equipment center, commercial insertion edit suites, local access studios, post production edit suites and remote vans.

The tests conducted on the master control facility were designed to give an indication of the general condition of all of the equipment in the signal path. This was accomplished by making baseband measurements at various points in the path. The points that were measured were; as the signal exited the headend for processing in the master control, as the signal exited the master control and finally, as the signal appeared after being modulated onto the cable system. This provided an overall view of the path travelled by the video signals. In addition, approximately 10% of the video tape playback machines and character generator equipment is evaluated.

The tests performed on the production facility consists of measuring the baseband response of the signal at the location closest to the point of origination and then making a similar set of measurements at a point closest to its final destination.

Parameters for this testing are as follows:

1. Video amplitude
2. Burst amplitude
3. Sync amplitude
4. Pedestal amplitude
5. Horizontal blanking interval
6. Front porch width
7. Vertical blanking interval
8. Burst frequency
9. Video signal to noise
10. Chrominance to luminance gain
11. Chrominance to luminance delay
12. Differential gain
13. Differential phase
14. Video crosstalk
15. Video frequency response
16. Audio level
17. Audio gain
18. Audio hum

The number of channels subjected to the above tests are to be 33% of the total and the test results should conform to EIA specification standards. In addition to the quantitative tests made, qualitative tests and observations will be made on general operations of the system, neatness, efficiency, etc.

GENERAL

The final area is classified as report analysis and deals with DM service and outage log reports. DM service should be averaging six (6) calls per one hundred subscribers per month or less. If this number is significantly higher than six, a recommendation should be made to have a complete analysis of this situation performed by on-site personnel so that it can be rectified.

The outage log reports should be analyzed for repetitive technical discrepancies, and if found, a report prepared that outlines the specific steps to be taken to rectify the situation. In addition to this, the average resolution time for outage related problems should be noted. Analysis of the above areas provide insight into the relative balance of preventative maintenance and demand maintenance in the system.

The areas of the techncial audit have now been defined and a plan must be devised to perform the test in a concise manner, coordinated with on-site personnel.

To achieve this goal, an on-site audit coordinator should be selected who will organize the personnel, test equipment, vehicles and appropriate time for testing. An outline of the technical audit should then be sent to the audit coordinator so that the on-site assistance will match the overall needs of the audit team. An agreed upon time for starting the audit is now selected and a preliminary meeting is scheduled with on-site personnel. This meeting usually takes one full day and allows system personnel that have been selected for the audit testing to review the test procedures with the corporate audit team and get acquainted with the key people from corporate engineering. The second day, testing can begin in each area with a target for completion of approximately two weeks. Two important things should happen in conjunction with the testing that enhance the performance of the audit and they are:

1. Repair of technical problems encountered if schedules permit.

2. Schedule meetings with various departments to improve technical knowledge and interdepartmental communications (i.e., technical operations, billing, and non-RF departments).

As the testing portion of the technical audit comes to a close, a review meeting should be held with the general manager and the key members of the techncial auditing team. The meeting should be structured to communicate the results of the technical testing, comment on the overall technical performance of the system, provide recommendations and discuss the time frame for the delivery of an executive summary and a final audit report to the system. The executive summary should be completed in approximately two weeks and the final report in approximately five weeks.

CONCLUSIONS

This now concludes the technical and organizational makeup of the audit and I would like to end this paper with a few general comments about the results of technical auditing.

The primary benefits that we have realized from the technical audits have been:

A. movement from demand maintenance to preventive maintenance

B. improved interdepartmental communications

C. correction of repetitive problems

D. increase in on-site knowledge of technical areas

E. improved communications between on-site personnel and corporate engineering

F. coordinated effort to lower service calls, churn and disconnects

THANKS TO THE MEMORIES: TELEDELIVERY, DOWNLOADING AND THEIR ROLES IN CABLE TV

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ABSTRACT

Teledistribution of video and data software will become an increasingly important part of the cable TV and communications industry. Video-on-demand systems, including hybrid facilities, are being introduced and tested. This paper describes downloading services as well as ones which use constant cycling of data or video, to be retrieved via a home terminal/receiver. Newly installed addressable cable equipment and headend computer/control devices will accelerate the growth of teledistribution, as cable operators seek ways to use facilities for revenue-generating services. This paper also reviews broadcasting and telephone industry activities to develop teledistribution services, notably for games and information.

The success of teledelivery depends on a trade-off between the cost of communications versus the cost of memory. As memory and storage devices drop in price, teledistribution becomes more feasible.

INTRODUCTION

Today's cable industry, eager for revenue-producing lift, may be quick to latch onto the looming concept of "teledelivery." Video-on-demand, telesoftware and a range of other enhanced services are ideally mated to new cable technology. In particular, the new breed of addressable decoders and headend management computers can be put to good use in sending and billing for electronic software.

At the same time, teledelivery of data, video and voice are high on the agendas of telephone, computer and broadcast firms. Downloading of software figures extensively into the videotex plans of companies such as IBM and CBS.

Warner Amex Cable experimented with a hybrid form of video-on-demand to augment or replace the beleaguered Qube system (although a parallel project at Warner Communications was abandonned in January 1984). An impressive Atlanta consortium which includes telephone, power and cable companies and retailing firms is putting together a service called TranstexT to offer interactive residential services, including video-on-demand through cable channels.

The success of teledelivery depends on a number of factors -- mostly technical and economic. Although the concept of electronic transmission and downloading may be attractive, its marketplace impact will depend on how cheaply video or computer data can be stored at the user's site. Currently transmission is cheap, but memory is fairly costly; that is -- it is relatively inexpensive to transmit data when needed, but the storage device to keep and recall material at each customer's home or office is comparatively high priced.

DEFINITIONS AND DIRECTIONS

Teledelivery systems distribute programming via electronic means such as broadcast or cable TV transmission, bypassing traditional sales or rental of a physical product at retail stores. Teledelivery could involve downloading of data or video programming into a home receiver or it could offer constant transmission, with viewers "tuning in" at any point in the cycle to pick up material using a special decoder-converter-receiver. Such programs could be stored in conventional electronics equipment, including VCRs or computer discs.

Teledelivery will take several shapes as the business develops. The concept of teledelivery will become vital to many segments of the consumer electronics industry. For manufacturers, it will create a new way to control production and operations. Programs -- be they they computer software or video shows -- can be distributed on demand where they are needed, thus avoiding costly manufacturing and shipping steps.

By the end of this decade, tele-delivery will grow into a $10 billion industry. That total will be split among software producers, communications firms and hardware makers, with software companies taking the largest share, probably about 50%.

Communications is the key factor in the development of teledelivery systems. The telephone industry break-up will wreak havoc with rates and services. Tele-delivery via phone lines is only feasible if rates stay reasonable. That is why alternative distribution systems, such as new broadcast channels and cable TV, will be so important.

WHO'S WHO

At least a dozen companies involved with the cable TV business are developing teledelivery schemes. NABU Network has introduced a system in Canada, and will soon begin service in Alexandria, Virginia. Cable Applications Inc. plans to develop a cable-based service called Cabletex. Group W Cable will include such services in its "Request Teletext" venture in California. CBS is expected to experiment with similar services on its Texas cable systems. Jones Futurex is working on data delivery systems.

CHEAPER MEMORY

Developments in storage and memory technology suggest that the balance may shift, however, and when the cost of data and video storage drops, then the era of teledelivery will begin in earnest. This financial balance will also shift because of the expected rise of transmission costs, especially those involving local telephone lines. Indeed, cable's role in teledelivery of data/computer services as well as video programming will escalate thanks to the coming rise in telephone rates.

Cable is not alone in eyeing tele-delivery technology. ABC's broadcast group is already commercially testing its Telelst service in Chicago, a system which offers overnight downloading of pay TV movies to home VCRs. Direct broadcast satellite companies, low power TV stations and others with spectrum to spare may look to teledistribution as a way to generate new revenue from channels which are otherwise under-utilized. In the process, conventional media (notably FM radio) are being eyed for their capability to transmit telesoftware. Atari and Activision, leading computer videogame firms, are testing a service which will use broadcast sidebands to distribute games -- mainly for previewing and updating data. AT&T has developed a deal with gamemaker Coleco to distribute videogames via phone lines, even permit interactive playing so that users willing to tie up phone lines can play against each other from their home game units. Control Video Corp., a Virginia company has a marketing agreement with BellSouth, the most aggressive of the divested Bell Operating Companies, which will offer CVC videogames and information.

In short, there is great activity as program distributors, communications companies and equipment makers look for a niche in the promising new world of teledelivery. Computer and data processing executives are also eyeing developments which will help them solve their distribution problems, including updates and additions to software. Moreover software programmers are looking for ways ways to download and cycle material directly to homes, bypasssing conventional -- and costly -- retail distribution. It appears that devel-opments, especially technological breakthroughs, in computer software teledelivery will be translated into video and cable distribution.

HYBRIDS

Hybrid systems using combinations of telephone and cable facilities appear very attractive. Cable's broadband capacity and time-insensitive pricing encourages telesoftware purveyors to transmit large quantities of data at relatively high-speed.

Requests for specific programs or interactive transactions can be handled by using a conventional telephone connection for upstream communications.

Hybrid versions of teledelivery are already available in the retail videogame environment. At least four electronic distribution systems are available. Retailers are still wary about how such systems fit into their profit scheme. In the ideal world, electronic delivery could be an answer to the expensive mistakes of inventory control (i.e. overstocking a turkey title but not getting enough copies of a sleeper hit program). In the retail environment, copies of programs would be made on demand through high-speed duplication of a program while the customer waits about three or four minutes in the store. The electronic distribution systems involve expensive hardware at the store; each has a slightly different arrangement for sending master copies of the programs to the duplication device, as well as deals to give a commission to the retailer.

For now, these retail-oriented electronic schemes are aimed primarily at delivery of videogames and computer programs. But the technology could be expanded to involve video shows, although economics of all sorts then become a more massive problem. Not the least of these problems are concerns about piracy and unauthorized access.

OPTIMISTIC FEATURES

Teledelivery has the ability to transmit updated, and refreshed information, making it valuable as a way to generate a continuing revenue stream.

It can be used as a sales tool to preview and promote new software. Subscribers would have the opportunity to sample new material, which they then could buy in a store or order via electronic transmission.

Coding for anti-piracy protection and "timely" sales raise other issues. The potential of unauthorized duplication may deter the quick development of teledelivery. Equally important, some software companies express interest in ways to license software on a usage basis, vaguely akin to pay-per-view concept of video programming.

The solution to this may be in time coding processes already available in computer software. Indeed, ABC's Telelst uses a similar approach in its downloaded video programming. Certain new movies are encoded so that they can only be played back during a limited time period. Through a complicated time-coding system, ABC (and the studios and producers) can control how often or during what time span the Telelst shows can be played back. Some of the newest movies, are coded so that they must be viewed within a two or three week span, otherwise the tape won't play back. For other shows, with less timely box office appeal, the encoding may permit endless reruns over a period of months or years.

The growth of pay-per-view technology in the cable TV industry should help the cause of teledistribution. By familiarizing viewers with a per-show viewing arrangement, cable is building the foundation for a market which involves selling individual programs directly into homes. The addressable facilities being developed for such services will create an important technical resource for other teledelivery projects, setting up procedures for encoding, authorizing and billing electronic delivery.

ADDITIONAL CONSIDERATIONS

Development of teledelivery services will raise many financial and technical problems, starting with compensation and affiliate relationships. The issue of unauthorized duplication is the most vital concern, especially for program producers who already are victimized by video piracy. By giving their blessing to a system which sends programs through the airwaves, they may be contributing to the problem which cuts to their wallets. That's why addressable technology and encoding systems are so high on the agendas of teledistribution pioneers -- along with formats that can assure instant billing and tracking of who has copies of each program.

WHAT'S AHEAD

Video-on-demand systems are the next important stage of teledelivery. Creating such services may be more complex -- but infinitely more rewarding. The objective is to use as much bandwidth as necesary to send programs to viewers when they want to see them. In a cable system of unlimited capacity, any subscriber could log into any program at any time he had the impulse to see it. Realistically such a situation would lead to drastic problems -- starting with the barrier of shows not being available at the cable headend. A more frequent problem would arise over the issue of "contention" if every home decided at the same hour to call up a different show. Even in a state-of-the-art 100-channel system, channel capacity would quickly be exceeded.

That is why efforts are underway to develop hybrid teledistribution systems. Problems could arise if too many users queue up for certain programs. That is, they will be offered a large menu of programs they could see -- but they might have to wait in line for the material to be transmitted to their receiver. In the case of feature length movies that might mean overnight delivery, downloaded into a home receiver set-up akin to Telelst. In other cases, when technology permits high-speed video transmission, it's conceivable that shows could be sent into the home receiver for later playback the same evening.

Integrated Communications Systems, which is planning the Atlanta TranstexT service, conceives of teledelivery as part of a larger package offering energy management, teleshopping and the vast range of services now planned for two-way cable systems. Using a hybrid format of cable linked to telephone lines, ICS foresees downloading of a variety of video and data material, which can be processed through a "gray box" at customers homes.

Warner Amex had been working on interactive projects, including teledelivery, with GTE and Bank of America. The project, which was abandoned in early 1984, used sub-hubs, based around cable's headend hub principle. In theory the package would have involved a series of neighborhood cable centers, each equipped with a bank of videodisc players or other video devices. When cable subscribers within a neighborhood wanted to call up a specific program, they would be directed to the video center with available capacity, thus drawing the load off a single megacenter -- and presumably allowing users in different parts of town to use the same channel simultaneously (e.g. customers in different neighborhoods could all be seeing different shows on their own channel 65 at the same time).

Teledelivery is an idea whose time has not quite yet come. But the eager activity and the potential benefits it can offer throughout the electronics business suggest a promising future -- and offer further reasons why so many organizations are working so hard to make teledelivery a part of the new electronic environment.

THE BRIGHTER SIDE OF TELEVISION: DELIVERY OF INFORMATION IN THE VBI

Eric Rayman
and
William C. Schneck*

ABSTRACT

This article will attempt to describe the VBI to (and by) non-engineers, discuss some of the issues raised by the FCC's rulemaking and consider, in light of WGN v. United Video[1], the effect of the copyright laws on VBI teletext.

Television watching is undergoing some fundamental changes. Cable, satellite distribution and home video recorders have all had an effect on the use of the old TV set. Now a new technology, teletext, has arrived which, while not yet fully developed, could change the meaning of "watching television".

Teletext is a system for displaying information - text and graphics - on a television set in response to user commands. It delivers instantly access to news and sports information, entertainment guides, financial listings, emergency advice, educational material and recipes as well as entertainment such as horoscopes and video games. Some teletext services will probably be offered on a subscription basis while others will be advertiser supported, or both, depending upon the size of the audience and the medium's appeal to advertisers.

While teletext can be transmitted in a variety of ways, including over cable television lines or by radio or microwave signals, for the purposes of this article we are going to concentrate on the legal issues raised by broadcasting teletext information over-the-air in the vertical blanking interval ("VBI") of the television signal.

The Federal Communications Commission has authorized TV broadcast stations to transmit teletext in connection with their regular television transmissions. On May 20, 1983, following over a year of public debate and comment, the FCC released a Report and Order which established technical standards and regulatory policies to govern broadcast teletext.[2]

More recently, the FCC has proposed that television stations be permitted to employ their VBI's for various other data transmission services, such as paging services, in addition to teletext.[3] The Commission is currently considering public comments on this proposal.

TELETEXT IS INTERACTIVE, BUT NOT TWO-WAY

First, a statement of what teletext is not: it is not videotex. Videotex requires a two-way communications path between the user and the system operator's computer. In a videotex system, such as the Mead Data Central's Nexis service or the terminal at an airline reservations counter, the user and the computer send information back and forth. Teletext, on the other hand, disseminates information in one direction only, making distribution via television signals feasible.

In the case of a VBI teletext service, the information is broadcast by a TV transmitter in a repeating cycle and received by all of the homes within reach of that TV signal. Each teletext page is digitally encoded and transmitted as a stream of binary electronic impulses. The user selects a particular page for viewing by pressing a button on a keypad, which sends a signal to the user's teletext decoder. The decoder scans all of the data as it passes by, "grabs" the data selected by the user and displays it on the user's TV screen.

A teletext user who wishes to see news headlines, for example, pushes a

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button on this keypad to display an index of the available news stories. By pushing another button indicated on the index, he can retrieve the desired story. The communication is between the television set, the decoder and the user. No signal is sent back to an off-premises computer, so the costly upstream path from the user back to the sender is eliminated.[4]

WHAT IS THE VBI?

The picture on a television set is created by a beam of electrons emitted from an electron gun which scans from left to right across the back of the picture tube screen. When the gun reaches the end of a line, it drops down to the beginning of the next line. When the gun reaches the bottom right-hand corner of the screen, it has displayed one television field. The gun then shuts off and returns to the top left-hand corner of the screen to repeat the process. The VBI is the time period during which no television picture information is transmitted in order to allow the electron gun to travel from the end of one field to the beginning of the next. It shows up as the horizontal black bar you see when the picture rolls and you must adjust the vertical hold.

The FCC established a standard for U.S. television manufacture and transmission: 525 scan lines per frame. Each frame contains two interlaced fields of 262 1/2 lines and is transmitted 30 times per second. The first 21 lines in each field constitute the VBI. Not all of these 21 lines are needed to separate the fields composing a television picture. Some lines in the VBI are available to carry information in digital form. For example, line 21 is currently used with some television programs to send closed-captioning for the deaf.[5] Other lines are used to send a code which enables certain color sets to make automatic color adjustments or to identify the broadcaster and the place and date of the broadcast. All of this information is invisible - unless you have some way of decoding the digital data.

FCC VBI RULEMAKING

The FCC has taken a laissez faire attitude toward teletext. The Commission has left entirely up to the broadcaster such decisions as whether or not to offer a teletext service, whether to provide such a service on an advertiser-supported or subscription basis and whether to embrace a particular technical mode of transmission or display. The FCC has limited its role to designating the VBI scan lines on which teletext may be transmitted and setting such minimum technical standards as are necessary to prevent interference to other broadcast services.

The FCC has authorized broadcasters to offer teletext service on six designated scan lines in the VBI which the Commission thinks will not cause interference on existing television sets and which are not reserved for other uses. Over nine years, as newer television sets replace existing sets, four more lines will be made available, increasing the quantity of information which can be transmitted in a given amount of time.

One controversial aspect of this designation involved the possible use for teletext on line 21, which as noted had been reserved for closed-captioning. A number of hearing-impaired television viewers have purchased "Telecaption" decoders which display the closed-captioning transmitted with certain broadcasts. These viewers were concerned that the success of teletext would make their equipment obsolete. On the other hand, teletext has the potential to offer the deaf a superior means of receiving information, including and in addition to closed-captioning, than was previously possible.

The Commission chose to withhold authorization to use line 21 for teletext for five years. How much information can be transmitted in a given amount of time is a function of how many VBI lines are made available for teletext (see the example of Teletext Arithmetic in the Appendix). While appeasing those who have purchased Telecaptioning devices, the FCC reduced the number of teletext pages which can be broadcast on the VBI and, consequently, the attractiveness of the service and its ability to gain a foothold in the marketplace. There seems to be no reason for the FCC to depart from its "hands off" approach in this area, as the competitive forces of the marketplace, in conjuction with the copyright laws (discussed infra), would assure that closed-captioning had a place in the VBI.

TELETEXT TECHNICAL STANDARDS

The Commission decided not to adopt a particular technical standard for teletext, but to let the marketplace determine which systems would be used. While the advantages of the open market philosophy are numerous, one area where its shortcomings are evident is the selection of technical standards. Television and radio broadcasts follow technical standards which are designed to create uniformity of equipment throughout the country. A TV set purchased in New York will work just as well in Philadelphia and San Francisco. On the other hand, a lack of standardization in other areas, for example video cassettes and video discs, results in incompatible technologies, delays in their implementation, increased expense to consumers, and significant losses to all the companies which invested in the technology.

This question of standards was one of the most controversial of the rulemaking proceedings. While the Commission's "hands off" approach was preferred by some of the companies involved, for many U.S. companies a Commission abdication of decision-making in this area raises serious threats from foreign competition.

The existence of an open marketplace in the U.S. is questionable when all of the leading technological work in this area has been done in Europe and Canada, where it was supported by government subsidies. The U.K. supports an open marketplace in the U.S. because it needs the U.S. marketplace to expand. The U.K. system has six years of proven experience and claims a tremendous cost advantage over other systems.

In the view of many U.S. companies, however, the U.K. system is the horse-and-buggy of teletext. Many U.S. firms favor a standard known as the North American Broadcast Teletext Standard, which can deliver superior graphics and is significantly more flexible. These firms are concerned that without FCC intervention, the transient advantages in cost of the U.K. system would saddle the U.S. with a de facto standard which fails to fulfill teletext's potential.

The standards debate is not limited just to the VBI. While the FCC did not rule on teletext standards for cable, radio or other transmissions, the lack of a decision on a VBI standard will undoubtedly influence development in these other media.

The key to the development of teletext in the U.S. is reducing the cost of the home decoder unit. As in the early days of television and radio, a successful advertiser-supported teletext industry requires a significant number of homes with terminals which can receive the service, i.e., an audience. Proper standardization of teletext display devices, whether de facto or de jure, would have hastened the introduction of these services, by assuring decoder manufacturers the volume they need to cut costs.

WHO OWNS THE VBI?

The last significant VBI issue is often, if inaccurately, referred to as "Who owns the VBI?" The FCC's rules will permit broadcasters to transmit teletext with their television signals, but the question arises: are others who retransmit those TV signals required to include the VBI in their retransmissions?

WGN v. United Video

The courts have only considered the obligation to retransmit a broadcaster's VBI in one case, WGN v. United Video, supra, which arose in a copyright context.

WGN, a Chicago television station, was experimenting with teletext in the VBI of its regular programming. WGN is a "superstation," meaning that its signal is transmitted via satellite to cable television systems nationwide which elect to distribute WGN's programming. A WGN subsidiary operates a cable system in Albuquerque, New Mexico, which was to distribute WGN's signal to homes equipped with teletext decoders.

United Video, Inc. ("UVI") is the satellite common carrier which picks up WGN's signal and distributes it to cable operators, who pay UVI for the transmission. UVI does not obtain WGN's authorization for this retransmission because retransmissions by companies like UVI are not copyright infringements due to the so-called passive carrier exemption in the Copyright Revision Act of 1976.[6] This provision provides that retransmission of a copyrighted television broadcast is not an infringement if the retransmitter "has no direct or indirect control over the content or selection of the primary transmission."

The controversy arose when UVI began stripping the VBI from WGN's signal and inserting its own when it distributed the signal to cable operators. The new VBI contained the Dow Jones business news service. WGN sought an injunction against this practice, claiming that it infringed WGN's copyrights in two of its evening news shows. The WGN teletext which was broadcast (and stripped) was a test signal during the first show, and a program guide and news story during the second show. WGN registered and claimed one copyright, including the teletext, for each of the two evening news shows.

The District Court found that by "primary transmission," Congress meant the copyrighted work being broadcast, whether or not it included teletext. The court found, however, that WGN's newscast and accompanying teletext could not be covered by a single copyright as "they were not intended to be viewed together as a single work by the same viewer at the same time," 523 F.Supp at 412, and that the teletext was not part of the "series of related images" which made up news show. As a result, UVI remained within the passive carrier exemption when it stripped WGN's VBI.

The court also found that UVI's retransmission to cable operators was not a performance to the "public" even though those operators sent the signals to a general (albeit subscribing) audience, thus making it impossible for UVI's retransmission to be a copyright infringement.

The Seventh Circuit reversed, holding that the primary transmission is the complete broadcast signal, and the fact that the viewer has to switch from one picture to another to watch the teletext does not preclude the underlying program and the teletext together from being a single copyrighted work.[7] The court set up a three-pronged test, requiring that a passive carrier must retransmit the original teletext with the underlying program if "the teletext is intended to be seen by the <u>same viewers</u> as are watching [the underlying program], during the <u>same interval of time</u> in which [that program] is broadcast, and as an <u>integral part of the ... program</u>." 693 F.2d at 626 (emphasis added). The court also expressly stated that its holding was not that WGN "owns" the VBI in the programs that it copyrighted, <u>Id</u>. at 628.

UVI petitioned for rehearing. In denying that petition the court took the opportunity to clear up some imprecise technical language in the original opinion, and to state that the "integral part" test is not a "loose and spongy 'relatedness' test . . . . More than 'relatedness' is required, and is present here." <u>Id</u>. at 629.

Although its test was phrased in precise language, the Court was nevertheless sloppy in applying it to the facts of the case. The teletext broadcast with the first of the two news shows contained test signals, and the second contained "a news story and program schedule." 523 F.Supp. at 408. Only the news story could pass the "integral part" test, as the other material was not even "related" to the news shows. Any other application of the test would indeed be "loose and spongy."

Under the Seventh Circuit's test the VBI may be stripped when it is not an "integral part" of the underlying broadcast, since refusal to retransmit one of two separate and distinct copyrighted works is not an infringement. This is sure to be the case in many situations, as the market for separate teletext services, such as the Dow Jones news service which UVI transmitted or a brokerage firm's use of teletext to transmit information to its customers, is at least as broad as that for program-supplementing teletext, such as a sports statistics service during sports programming or closed-captioning for the hearing-impaired.

Nevertheless, the end result of the <u>WGN</u> case is to place retransmitters at the mercy of broadcasters. If the teletext is not retransmitted and subsequent judicial examination determines that the "integral part" test was met, then the cable company or resale common carrier will be liable for copyright infringement.

<u>THE FCC "MUST CARRY" RULES</u>

As part of its rulemaking, the FCC had to decide whether a cable operator who carries an off-air broadcast station should be <u>required</u> to carry the VBI of that station (in the absence of a relevant copyright) or should be permitted to delete data in the the VBI and even replace it with other data of different origin.

In the relatively early days of cable TV, broadcasters became concerned that if their signals were not retransmitted by the cable systems in their market, they would lose their audiences to these systems. Broadcasters are obligated to provide community programming, cover issues of local interest and present balanced discussions of issues of national impact. In order to assure the continued availability of local broadcast signals to local communities, the FCC adopted rules (the "Must Carry" rules) requiring the carriage by a cable system of the UHF and VHF television signals broadcast in its vicinity.[8]

In the case of teletext, the Commission specifically chose not to impose any content requirements upon broadcasters. Nevertheless, broadcasters argued that communications policy, wholly apart from copyright, should compel a cable system to include the VBI teletext of the broadcast stations it carries.

The broadcasters argued that 1) the viability of teletext requires the FCC to assure it access to its full potential audience, 2) the VBI should remain under the control of the TV station licensee, and 3) cable systems will willfully delete broadcast teletext in order to promote their own services.

Those opposed to mandatory carriage urged legal, technical and policy rationales. First, since teletext is a service ancillary to television broadcasting and without any obligation to provide local community programming, it should be classified with other ancillary services, such as pay television and low power TV, for which cable carriage is not required. Second, a cable operator may experience technical problems in the delivery of teletext. If so, it would be preferable to allow the cable operator and broadcaster to negotiate the steps necessary for the cable operator to deliver a usable teletext signal and to allocate the costs so involved. Lastly, the open marketplace approach favored by the FCC in other contexts suggests that the solution here is to allow the broadcaster and cable operator to negotiate between themselves the terms of cable carriage in the absence of a compelling need for government regulation.

The Commission, noting that copyright concerns are quite distinct from communications policy, rejected the mandatory carriage of teletext by cable systems. Accordingly, a cable system evaluating whether to retransmit a particular broadcaster's teletext needs to consider whether it meets the "integral part" test of <u>WGN</u>, and if not, it can then exercise its discretion with respect to such carriage. Of course, the cost of deleting the teletext signal and the attractiveness of the teletext offering to the cable operator's subscribers will likely deter cable operators in many cases from taking affirmative steps to delete a broadcaster's teletext.

1. 523 F. Supp. 403 (E.D. Ill. 1981), rev'd 693 F.2d 622, reh. denied 693 F.2d 628 (7th Cir. 1982).
2. Some companies, such as Time Inc., have experimented with the delivery of teletext in the full video signal of a cable channel, instead of in the VBI of a broadcast signal. The FCC has not sought to exercise jurisdiction over cable-delivered teletext.
3. Federal Communications Commission, Notice of Proposed Rulemaking, Docket No. 84-168, Released March 8, 1984.
4. The teletext system operator has no record of the page accessed by the user and, consequently, no new privacy problem is created.
5. "Closed" because a viewer requires a special decoder to display the information; "open" captioning refers to subtitles displayed over the video picture without the use of a special decoder.
6. 17 U.S.C. §111(a)(3).
7. The court also held that public performance includes "indirect transmission to the ulimate public," in this case the public being the Albuquerque cable subscribers, 693 F.2d at 625.
8. 47 C.F.R. §§76.51-67.

TELETEXT ARITHMETIC

How many teletext "pages" can you transmit in the VBI?

<u>Constants</u>

- o U.S. television picture resolution is 525 scan lines/frame ("NTSC").
- o The VBI is 21 lines/field. The first 9 are not usable for data.
- o There are 2 fields in a frame.
- o U.S. TV "flickers" at the rate of 30 frames/second.
- o One line contains 27 data bytes (in the North American Broadcast Standard).
- o The FCC designated 6 lines for broadcasters to use for teletext.

<u>Assume</u>

- o An average teletext page is 1000 bytes.
- o Ten seconds is probably the longest a person will wait for a page ("access time").

<u>Therefore</u>

27	bytes
x 6	lines
162	bytes/field
162	
x 2	fields in a frame
324	bytes/frame
324	
x 30	frames/second
9,720	bytes/second
9,720	
x 10	seconds max. access time
97,200	bytes/10 seconds

$$1{,}000 \overline{)97{,}200} = 97.2$$

Approximately 97 pages of teletext can be carried in the VBI with a maximum access time of ten seconds.

For full-field teletext delivered by cable, do the same arithmetic with 506 lines (i.e., 525-(2x9)-1) instead of 6.

THE EFFECTS OF SINGLE ENDED, PUSH-PULL, AND FEEDFORWARD DISTRIBUTION SYSTEMS ON HIGH SPEED DATA AND VIDEO SIGNALS

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ABSTRACT

Field testing was conducted to investigate the effects of cable television system electronics on downstream video and high speed data transmission. Three system configurations were used for the testing: a 15 year old single ended 12 channel plant; a 3 year old 35 channel push-pull plant; and a 1 year old 54 channel feedforward plant. Various RF, video, and digital tests and measurements were performed to determine if a relationship exists between typical cable television system operating characteristics and the performance of video and high speed data signals on these systems.

INTRODUCTION

Cable television systems have provided operators with an excellent means of delivering entertainment services to subscribers for over 30 years. The nature of the coaxial cable distribution network lends itself to being much more than an entertainment delivery system. This "electronic pipeline" can just as easily move information.

As the industry evolved, technology kept pace to accomodate the increased number of services carried on cable systems. Additional video signals, and now even data communications, are rapidly filling the cable spectrum. But are these signals being affected by the systems carrying them?

The effects of noise, cross-mod, composite triple beat, and other distortions are well documented. Modern cable system electronics incorporate phase inversion circuitry, delay lines, error amplification, and other complicated circuits. Video signals are themselves inherently complicated, using amplitude and phase modulation techniques to transmit a large amount of information that includes fast risetime waveforms, pulses, high frequency energy, and phase sensitive signals. High speed data also includes fast risetime waveforms and high frequency energy, and digital transmission schemes such as PSK (phase shift keying), QASK (quadrature amplitude shift keying), and QPSK (quadrature phase shift keying) are very sensitive to phase distortions.

Do different types of cable television distribution electronics -- single ended, push-pull, and feedforward -- have any effect on video or high speed data signals in the downstream path? Are video signals and high speed data signals affected similarly by cable system characteristics such as frequency response, noise, channel loading, and signal levels?

To address these questions, several tests and measurements were performed in cable systems operating with single ended, push-pull, and feedforward distribution electronics. Measurements were made to determine the extent of video delay and phase distortions, data errors, and data waveform envelope distortions in the three types of distribution systems. Analog RF tests and measurements determined the effects of frequency response, carrier to noise, channel loading, signal amplitude and signal amplitude variations on video and data transmission performance.

THE CABLE SYSTEMS AND TEST LOCATIONS

Cable System #1

Cable system #1 is a classic rural system serving approximately 1200 subscribers in a small Colorado mountain community. The system is 15 years old, and is a 12 channel single ended configuration with some push-pull equipment located in newer areas. The plant is one-way capable only, and operates with 11 downstream television channels and one midband pilot carrier. Built originally with non-integral sleeve type connectors, the plant is 88% aerial and 12% underground.

Cable System #2

Cable system #2 is located in the metropolitan Denver area, and serves approximately 5700 subscribers in Denver's southwestern suburbs. It is a 3 year old 35 channel push-pull two-way capable system, operating with 30 downstream television channels and 1 upstream television channel. The plant is 85% underground and 15% aerial, and was built using integral sleeve type connectors. Diplex filters have been installed in all amplifiers.

Cable System #3

Cable system #3 is located in the metropolitan Los Angeles area, providing service to approximately 7500 subscribers. The system is between 1 and 2 years old, and is a 54 channel feedforward two-way capable system operating with 42 downstream television channels. Built with integral sleeve type connectors, the plant is 55% underground and 45% aerial. Diplex filters have been installed in all amplifiers, but the upstream path has not been activated.

System Test Locations

In each of the cable systems, the headend and two field locations were used for the various tests and measurements performed.

TABLE 1

SYSTEM	LOCATION	TRUNK CASCADE	BRIDGER	L.E.
	Headend	N/A	N/A	N/A
#1	Field #1	6 S.E.	1 S.E	1 P.P.
	Field #2	6 S.E., 2 P.P	1 P.P.	1 P.P.
	Headend	N/A	N/A	N/A
#2	Field #1	14 P.P.	1 P.P.	0
	Field #2	10 P.P.	1 P.P.	0
	Headend	N/A	N/A	N/A
#3	Field #1	8 F.F.	1 F.F.	0
	Field #2	9 F.F.	1 F.F.	1 F.F

S.E.-single ended; P.P.-Push-pull; F.F.-feedforward

Measurements were made at the output of the headend combining network. The results were used to establish a baseline reference to allow determination of actual system contribution to signal degradation. The two field locations in each of the systems were subscriber drops located at amplifier cascade extremities varying from 6 to 14 trunk amplifiers. The cascades also included a bridger, and, depending on the location, a line extender.

TESTS AND MEASUREMENTS

RF

- Visual and aural carrier amplitudes were measured on all channels
- Separation between visual and aural carrier amplitudes was measured and recorded
- Visual carrier to noise ratios were measured and corrected for 4 MHZ bandwidth on selected channels at all field locations
- Visual carrier amplitude variations were monitored over a 24 hour period to verify headend processor and system AGC performance
- Full spectrum swept frequency response and in-channel frequency response (on one selected reference channel) were measured at each location

Video

- Chrominance-luminance delay, differential phase distortion, chrominance non-linear phase distortion, and ICPM (incidental carrier phase modulation) were measured on one selected reference channel

Digital

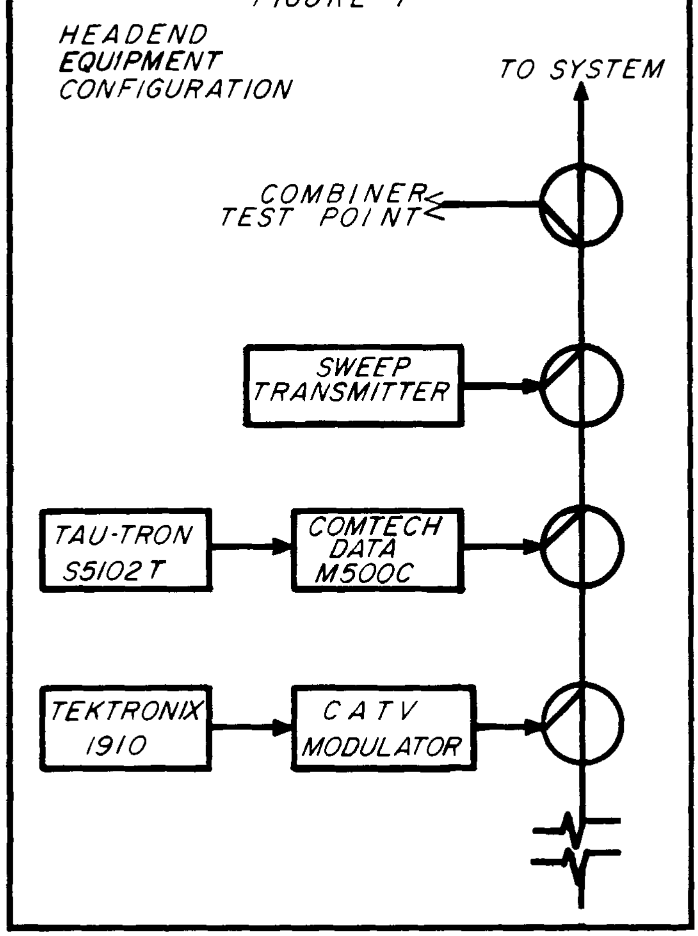
- A data carrier transmitting a 1.544 Mb/s QPSK pseudo-random data stream was monitored at each location for bit errors over periods ranging from 1 to 17 hours
- A 5.72 Mb/s eye test data pattern was observed for distortion of the overlaid clock and data pattern

TEST EQUIPMENT CONFIGURATION

Headend (Refer to Fig. 1)

The sweep transmitter was connected to the headend combiner sweep input and was adjusted for normal operation per the manufacturer's instructions.

FIGURE 1



To accomodate bit error rate measurements, a Tau-Tron S-5102-T Error Rate Test Set Transmitter was configured for a 1.544 Mb/s pseudo-random data output and connected to the data input port on the Comtech Data M500C RF modem. The modem RF output was connected to a spare headend combiner input port, and the modem RF level was adjusted to approximately 15 dB below system visual carrier levels.

One of the headend modulators was chosen to be the reference channel for all the video testing. The aural carrier on that modulator was turned off, and the Tektronix 1910 Digital Video Signal Generator full field output was connected to the modulator video input. Video depth of modulation was adjusted to 87.5%, as required. Proper modulator RF output level was verified.

An individual remained in the headend during field tests to select video signals on the Tektronix 1910, and to turn the sweep and data signals on and off as necessary.

Field Locations (Refer to Fig.2)

Signal from the subscriber drop fed the Comtech Data RF modem through the tap leg of a directional coupler. The data output from the modem was connected to the Tau-Tron S-5102-R Error Rate Test Set Receiver. After configuring the receiver for the 1.544 Mb/s pseudo-random data stream, the internal timer on the receiver was set for the desired test duration. Bit error counts were displayed directly on the Tau-Tron.

One port of the two way splitter was connected to a 75 to 50 ohm matching adapter at the input of the Tektronix 1450-1 Television Demodulator. The demodulator was tuned to the reference channel, and the video output connected to the vectorscope and waveform monitor. After setting the demodulator to its measurement mode, video delay and phase measurements were made on the vectorscope and waveform monitor.

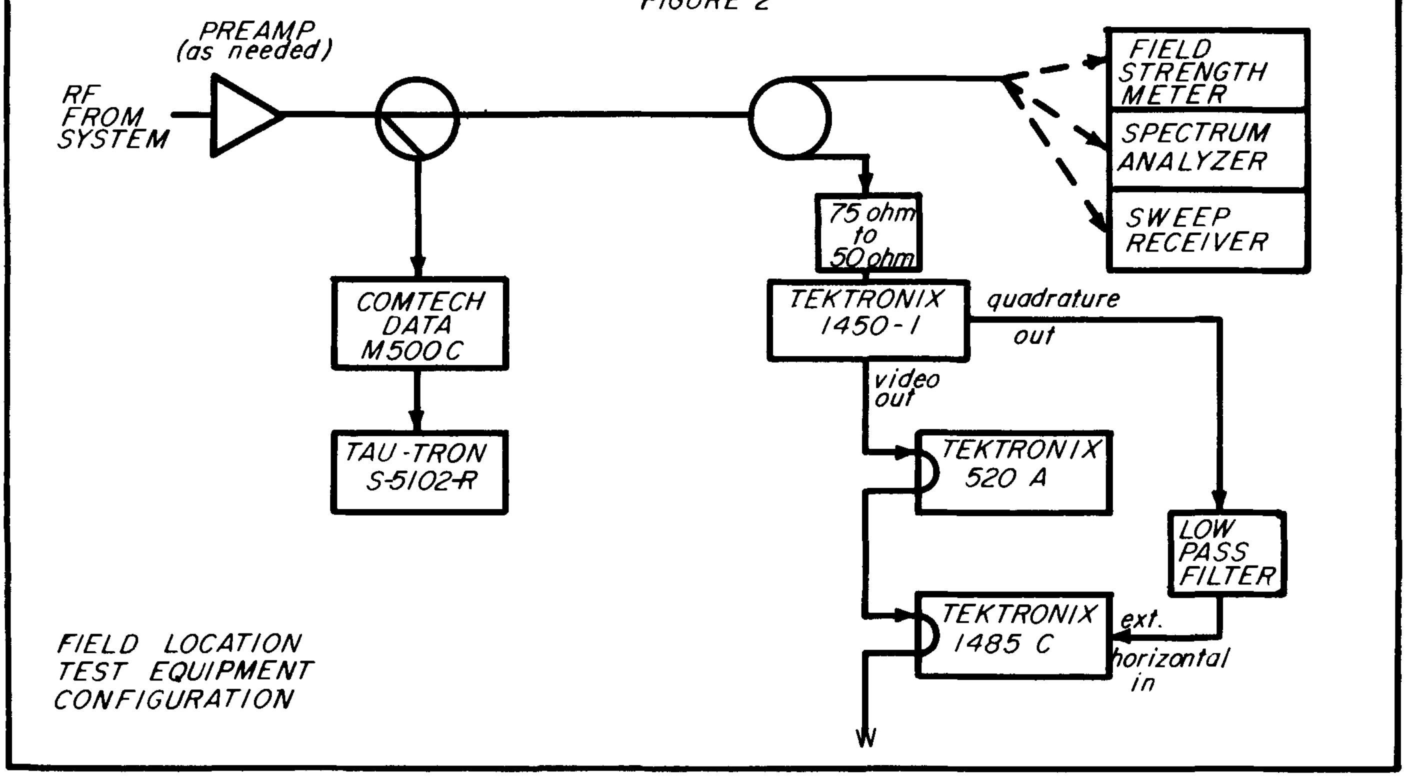
To perform the ICPM test, the demodulator quadrature output was connected to the waveform monitor external horizontal input through a 250 KHZ low pass filter. This test required the use of a special graticule (Tektronix P/N 331-0393-12) on the waveform monitor, which allowed direct indication of ICPM on the waveform monitor CRT.

For the RF measurements, the second port of the two way splitter was connected to the remaining test equipment. Signal levels were read directly on the field strength meter. Carrier to noise measurements were made through a tunable bandpass filter connected to the field strength meter.

Full spectrum swept frequency response was read directly on the sweep recovery receiver display; in-channel frequency response on the reference channel was measured on the spectrum analyzer by observing the frequency domain display of the SIN X/X test signal.

A preamplifier was used in some cases to provide suitable signal level for carrier to noise measurements and any other tests requiring additional signal.

FIGURE 2



FIELD LOCATION
TEST EQUIPMENT
CONFIGURATION

TEST AND MEASUREMENT PROCEDURES

RF Measurements

Visual and aural carrier amplitude, carrier to noise ratio, 24 hour signal amplitude variation, full spectrum swept frequency response, and in-channel frequency response measurements conformed to cable and broadcast industry accepted practices. (1,4)

Video Distortions

Table 2 outlines the video test signals used and their application. All of these test signals were generated by the Tektronix 1910 Digital Video Signal Generator. (2,3)

TABLE 2

VIDEO TEST SIGNAL	APPLICATION
SIN X/X	In-channel frequency response
FCC Composite (12.5 T Pulse)	Chrominance-luminance delay
5-Step Staircase	ICPM (Incidental carrier phase modulation)
80 IRE Modulated Ramp	Differential Phase Distortion
Modulated Pedestal	Chrominance Non-Linear Phase Distortion
Eye Test Data Pattern	Expanded waveform observed for distortion of overlaid clock and data pattern

Digital Testing

The 5.72 Mb/s eye test data pattern was expanded horizontally on the waveform monitor and the clock and data patterns overlaid. Any distortions occurring to the data pattern envelope were displayed on the waveform monitor CRT.

Bit errors occurring in the 1.544 Mb/s QPSK data stream were counted by the Tau-Tron receiver and displayed directly on the receiver LED readout. (5) This unit also provided a count of total error seconds during the measurement periods.

RESULTS

The cable systems in which the tests were conducted were not "tuned up" beforehand. RF levels varied considerably from test point to test point: the lowest visual carrier level measured was -9.5 dBmV, and the highest was +19.5 dBmV. Aural carrier amplitudes ranged from 9 to 21.5 dB below visual carrier amplitudes.

Corrected visual carrier to noise ratios ranged from 40.5 to 50.5 dB, with the majority from 47 to 50 dB.

System full spectrum swept frequency response was anywhere from 2 to 8.78 dB P-V (peak to valley), with the average being about 5 dB P-V at system cascade extremities. In-channel frequency response was in the 1 to 2.5 dB P-V range, with the average being about 1.5 dB. In some cases, in-channel response did not change from measurements at the headend.

Video phase distortions -- differential phase distortion, chrominance non-linear phase distortion, and ICPM -- did not change in any of the systems from what was measured in the headends. Chrominance-luminance delay did change in some instances, but only when the in-channel frequency response changed from that measured in the headend. The eye test data pattern also changed in some cases, paralleling changes in the in-channel frequency response and chrominance-luminance delay. When in-channel frequency response did not vary from the headend reference, chrominance-luminance delay did not change, nor did the eye test data pattern.

The 1.544 Mb/s QPSK data signal carrier to noise ratio varied from 30.5 to 40 dB during field tests, with actual data modem RF input levels ranging from -10 dBmV to +17 dBmV. It was observed that the data modem would not provide data output when the RF input level dropped below about -12 dBmV. This was found to be a function of the modem circuit design.

During the measurement periods, bit errors did not occur at any of the test locations in System #2 and #3. Bit errors were recorded at both field locations in System #1; however, none occurred in the headend. The bit errors occurred randomly in bursts of 10 to 20 errors at a time. The measured bit errors were 2.52×10^{-8} and 2.63×10^{-8} respectively.

During equipment setup at one of the field locations in System #2, a single static discharge to the grounded metal case of the error test set receiver (caused by walking across the carpet and touching the unit's case) resulted in a single burst of 93 bit errors.

DISCUSSION

The results of these tests and measurements indicate cable television distribution electronics are transparent to video and high speed data. Limited research has been conducted in this area, much of it under laboratory conditions. This testing has used "real world" operating cable systems to take the research one step further.

Concerns voiced in the Introduction of this paper regarding video and high speed data transmission do not seem to be a problem. Testing indicates that video and high speed data are not affected by the types of amplification techniques used in cable television signal delivery.

Several video distortion measurements were performed as part of the overall testing, and it was found that video phase distortions did not increase in the CATV distribution system. The phase distortions observed were generated in the headend modulators, and remained unaffected by the performance of the cable systems. Two video signals that did change in the distribution systems were the 12.5 T pulse and the eye test data pattern. The 12.5 T pulse was used to measure chrominance-luminance delay, which was observed to change with variations in the in-channel frequency response of the reference channel under test. The envelope of the eye test data pattern also changed with variations in the in-channel frequency response. But when in-channel frequency response did not change in the distribution system, the 12.5 T pulse and eye test data pattern did not change either.

This suggests that in-channel frequency response variations have a parallel effect on video distortions and data signals: as frequency response worsens, the video chrominance-luminance delay degrades, and the data envelope distorts.

Envelope delay and in-channel frequency response variations can be reduced by locating data channels away from the extreme ends of a system's transmitted spectrum. This would avoid problems associated with diplex filter cutoff response, equalizer response, and amplifier rolloff. Maintaining system swept frequency response to closer tolerances would also reduce in-channel response problems.

As far as system sweeping is concerned, high level sweep equipment should be used with caution in systems transmitting data. The high level sweep in system #2 had to be shut off during bit error rate testing and video distortion measurements. It was observed that the high level sweep caused between 13 and 33 bit errors every time the signal swept through the spectrum. Later measurements resulted in a bit error rate of 4.9×10^{-6} with the high level sweep in operation. The high level sweep also affected the AGC circuitry in the demodulator, causing poor clamping action in the test equipment. The low level sweep used in System #1 and #3 did not cause bit errors, nor did it affect the test equipment.

A partial solution to this is to trap out the high level sweep at critical frequencies; however, this precludes frequency response measurements at those frequencies.

As mentioned earlier, a static discharge to the case of the error rate test set receiver caused a single burst of 93 bit errors. This points to the need for designing consumer oriented data equipment in static-proof enclosures.

Video distortions varied with each modulator used in the system testing. As with broadcast transmitters, many cable television headend modulators incorporate delay predistortion circuitry for color transmission (F.C.C. §73.687 a.5) which "artificially" introduces a chrominance-luminance delay of -170 nanoseconds (advanced chroma) into the video signal. The modulators in System #1 and #2 both exhibited the effects of delay predistortion circuitry (as per manufacturer's specs), but neither met the -170 nanosecond specification. The reference channel modulator in System #3 apparently did not incorporate delay predistortion, since the demodulated 12.5 pulse had no measurable chrominance-luminance delay. These variations may preclude "blanket" compensation for delay predistortion in data equipment, if cable television modulators are to be used for high speed data transmission. Modulators used in this capacity may have to be ordered without delay predistortion circuitry installed or have the circuitry bypassed to avoid potential problems with envelope distortion of the data.

Signal levels and channel loading did not appear to affect the video and data test signals. Measured carrier to noise ratios were suitable for data transmission, even with a reduced amplitude data carrier. Depending on the circuit design of the RF data modems used, low signals can affect modem operation. However, operating levels encountered in the testing presented no problems and did not affect the outcome of the testing.

The results of the bit error rate tests at the field locations in System #1 support previous research: data transmission is degraded in "loose" cable systems. Intermittent connections, impulse noise, ingress, and other problems common to "loose" systems definitely increase data errors. Measurements in System #1 indicated that the physical condition of the 15 year old plant, particularly the lack of integral sleeve type connectors, contributed to data errors. While the bit error rates were on the margin of being acceptable, they would very likely have been much worse in a metropolitan area subject to higher levels of ingress and impulse noise, than in the rural mountain community where this system is located.

CONCLUSIONS

The three types of distribution electronics used in cable television -- single ended, push-pull, and feedforward -- do not affect video and high speed data transmission. Video and data signals are affected similarly by cable system characteristics such as frequency response.

Cable television -- the electronic pipeline -- can be used as an efficient transmission medium for high speed data and other information. While many systems will have little trouble carrying relatively error-free data signals, others will have to be "tightened up" and "fine tuned." Improving system reliability through better maintenance procedures, equipment alignment, and physical integrity will ensure the coaxial cable network is recognized for its capability to deliver entertainment and information.

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THE EVOLUTION OF AUDIO/VIDEO SYSTEM FACILITIES AT WARNER AMEX METROPOLITAN CABLE TELEVISION SYSTEMS

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ABSTRACT

This paper traces and illustrates the evolution in the design of Audio/Video systems at Warner Amex Cable Communications. It discusses early approaches based on broadcast techniques followed by the introduction of automation to Master Control Transmission Centers. It concludes by describing latest designs based on operating efficiency and economy in edit suites and TV studio control rooms as well as modern master control transmission centers.

INTRODUCTION

During the past decade, cable television systems have been constructed in numerous major population centers of the United States, the large cities and "bedroom" communities that make up their suburban metropolitan areas. In many of these there is a requirement or desire to produce and cablecast television programs locally, by individual cable companies for presentation in the communities that they serve. Most of these metropolitan cable television systems include therefore, technical facilities for production, post-production, and cablecast origination of locally produced television programs.

Audio/Video facilities necessary to produce and cablecast local programs fall into just exactly those two categories; program production facilities, and cablecast origination facilities. These are individual units that operate independently of each other except in the case of LIVE program cablecasting when the activities of each must be co-ordinated.

Program production facilities consist of: television studios and control rooms; outside or remote cablecast units such as field production and news gathering vehicles and porta-packs; and post-production facilities, typically edit suites where video taped material can be assembled into complete programs. Today, production facilities are used to create two distinct categories of programming: "local origination", general community interest programs produced by the cable company and its staff; and "public access", usually special interest programs produced by individuals or groups within the community but not associated with the cable company or its business. Often, facilities separate from those utilized for local origination program production are provided for public access program production.

Cablecast origination facilities, commonly known as "master control rooms" or "transmission centers", are equipped and operate to cablecast the locally produced programs, both local origination and public access, onto specific channels of the cable TV system in accordance with the daily program schedule. Since the majority of local programs are video taped rather than cablecast live, the principal activities in the master control rooms are playback of video tapes, switching audio/video signals, and monitoring picture quality. Recently, the advent of advertising sales and commercial insertion in some metropolitan cable systems has added commercial video tape playback and insertion as a major master control room activity.

Since 1976, Warner Amex has constructed major cable television systems in seven United States cities and all have been provided with television program production, and master control room cablecast origination facilities. Program production facilities have evolved in essentially a single major step from sophisticated to conservative technical systems and will be described separately following review of cablecast origination systems. Each master control room possesses one or more unique characteristics, however, and tracing these chronologically reveals an informative process of evolution leading to the efficient and cost effective master control room of the most recently completed facilities. Before tracing their history, and the variety of physical and operational characteristics unique to each, a description of the audio/video equipment and operations generally common to all of them is helpful.

The most significant item of equipment in all Warner Amex master control rooms is the video tape player. Each metro cable system is equipped with as many players as are necessary to cablecast local origination and public access programs, and commercial insertion onto some of the advertiser supported satellite networks. Additionally, the QUBE two way interactive technology installed in every Warner Amex Metropolitan cable system provides an opportunity to offer PAY PER VIEW features and movies, and approximately 50% of the video tape players are utilized for such service. An average of about 35 players are installed for all these playback activities at each metro cable system. 3/4 inch U-Matic format players are universally used for these services at all Warner Amex metro cable systems while in their pursuit of the lucrative broadcast market for expensive machines, the video tape recorder manufacturers continue to ignore cable's need for simple, reliable recorders of excellent picture quality at a reasonable price. Second most important item in the master control room is the audio/video switching equipment necessary to effect changes of program source on certain cable channels. Additionally these "routing switchers" connect any of the average 35 video tape players to the cable system modulators as necessary. The final significant item in the master control room is the informational character generator which provides information in the form of text on several cable channels.

The remaining equipment found in master control rooms functions to support these three major items. Time base correctors and audio and video processors maintain consistent, high quality signals from the video tape playback channels. Picture and waveform monitors, and vectorcopes are included so that picture and signal quality can be monitored and trouble analysis accomplished when necessary.

Principal operations necessary in each master control room are three:

(1) Operation of the video tape players; loading, cueing, rewind and unloading.

(2) Switching; switching programs to certain cable channels according to the daily program schedule, and starting and stopping the video tape players at the appropriate times.

(3) Monitoring; assuring that picture quality is good on every cable channel, assuring that the right program is on the correct channel at the scheduled time.

COLUMBUS

In 1976, Warner Amex constructed its first metropolitan cable system in Columbus, Ohio and equipped it with QUBE two way interactive technology. QUBE allows viewers to participate in the television shows they are watching by providing them means to respond instantaneously to questions and prompts included in the shows via special cable converter boxes installed in their homes. A natural application of QUBE technology is PAY PER VIEW service which allows the viewer to decide and purchase a program instantaneously through his cable converter at home. QUBE and the PAY PER VIEW possibilities it offered was responsible for the design and construction of Warner Amex's first master control room in Columbus.

This first master control room was designed and outfitted originally with just the necessary equipment to fulfill video tape play back, and informational cablecasting requirements. Built into a small area of about 1360 sq. ft., it contains 30 video tape players utilized mostly for playback of PAY PER VIEW features and movies. Three video tape players are dedicated to each playback channel since as many as three one hour long tape reels might be required to contain a single motion picture. Each playback channel is supported by a single time base corrector, audio processor, and a device to automatically start the first and subsequent players in sequence at the conclusion of previous reels. The sequencing devices in each playback channel must be individually programmed at each playback rack.

Although immense by very recent standards, Columbus was equipped with an audio/video routing switcher which would have been considered small compared to those in some Warner Amex master control rooms that immediately followed it. Its rectangular matrix dimension of 40 x 30 provided 1200 available crosspoints. A multi-channel informational character generator was custom constructed and is still in use today in Columbus. This was a forerunner of standard products available for this application today from several manufacturers. Finally, a full complement of picture monitors at the operators console allows continuous observation of all pictures on the cable system.

Arrangement of master control equipment in the room was determined by where it would best fit and staff is deployed where and when necessary to accomplish the required tasks of operation. Except for the video tape player starter/sequencers, all tasks must be accomplished manually. No computers automate or aid in operation of the room.

CINCINNATI

From the arrangement of best fit in Columbus, the next master control room, Cincinnati, contributed an equipment arrangement that was to prevail through the construction of several future master control rooms. In a dedicated room considerably more generous with space: the video tape playback equipment is lined along one wall; routing switcher, informational character generator, and various support equipment along the opposite wall; and a console oriented so the operators face the video tape players is placed on the floor about 2/3 the distance across the room from the video tape players.

Substantive routing switching was introduced in Cincinnati and a switcher with rectangular matrix dimension of 80 x 60, and 4800 total available crosspoints was installed in the master control room. An automation system was acquired and installed to manage and accomplish the switching of programs onto the cable system. In future master control rooms, this system was to grow and control each video tape player and additional switching but initially in Cincinnati it controlled only the routing switcher and sent simple start signals to each video tape playback channel.

As in Columbus, video tape playback utilized three dedicated players per channel and a device to start and sequence it through reel changes. Similarly, time base correction and audio signal processing were part of each playback channel.

PITTSBURGH AND DALLAS

A broadcast influence bouyed by the cable industry optimism of recent years lead the Cincinnati master control room design to its grandest application in Pittsburgh and Dallas. From areas of 1360 and 1600 sq. ft. respectively in Columbus and Cincinnati, a master control room area of 2275 sq. ft. in Pittsubrgh lead to the 3600 sq. ft. area in Dallas. Other dimensions were to swell to enormous proportions as well. Three routing switchers were installed in Pittsburgh; the main one having a rectangular dimension of 140 x 140, another a dimension of 60 x 40, and yet another with a dimension of 40 x 40. Grand total crosspoints in Pittsburgh reach 23600 available in all of these switchers. All were installed in virtually the same room within feet of each other. Not to be outdone, in Texas where the biggest and best of everything can be found, 24800 total crosspoints were installed in two routing switchers; a main one of 160 x 140 and a "random access" switcher of 60 x 40. These too were installed in the same room.

Finally in Pittsburgh and Dallas, the master control automation system grew to its greatest capability gaining control of an additional "random access" routing switcher and about 40 video tape players as well as the main routing switcher. In this configuration, specific groups of video tape players no longer needed to be dedicated to distinct playback channels and started with a sequencing device. Instead the automation system controls each player individually and assigns it to any playback channel through a "random access" routing switcher located upstream of the main routing switcher. Time base correctors and other signal processing items were placed at the outputs of the "random access" router so video tape player support equipment was no longer dedicated to any single or group of players. In theory this was intended to reduce the number of audio/video signal processor sets needed but in practice usage went from 1 set per 3 players to 1 set per 2 players. In addition to starting the video tape players, the Pittsburgh and Dallas version of automation also controlled their shuttle functions and was designed to cue and park 3/4 inch cassettes at any location on the tape without the use of SMPTE or other time code techniques. Today, these automation systems are being expanded further to accomodate the unique requirements of commercial insertion.

Summarizing, the size, arrangement and technical sophistication of Warner Amex master control facilities culminated in Pittsburgh and Dallas.

HOUSTON

The Houston master control was the first of a series of designs in which sound justification determined technical complexity, and operational considerations began to influence the arrangement of master control rooms. First to be corralled was floor area. The 1475 sq. ft. master control room in Houston consumes 3/5 the space of Pittsburgh's, and 2/5 the space of the Dallas arena. This was accomplished in part by constructing the master control room into only that area necessary to comfortably house the required equipment, and by more space effective arrangement and actual elimination of some equipment used in previous rooms.

A process of stern justification forced a decline from the 24800 switching crosspoints of Dallas to only 5600 total within an 80 x 60 main, and 40 x 20 "random access" routing switcher. Although not yet to the starting number of 1200 in Columbus, Houston returned almost to the Cincinnati level of 4800. Most important, a technical justification process was established which was to reap great rewards in the near future.

The master control room automation system of Pittsburgh and Dallas was installed in its entirety but implementation of an independent commercial insertion system in Houston has precluded expansion of it. The Houston master control room was the last to utilize the arrangement first applied in Cincinnati.

SAINT LOUIS

The traditional equipment arrangement that prevailed from Cincinnati through Houston was abandoned in Saint Louis. Introduction of new front loading, "narrow body" video tape players provided an opportunity to combine what was formerly a wall of players into a single, reasonably compact panel that included monitoring and controls necessary to accomplish all master control tasks. Not only did this trim the area required for master control to a slim 890 sq. ft., it also put all manual operations within the reach of a single operator thereby offering opportunity to trim staff and cost as well.

A new, crosspoint conservative switching scheme was devised but implementation of it was postponed for the Chicago master control due to the availability of an unused traditional routing switcher. Nevertheless, total crosspoints in Saint Louis were reduced almost to the original Columbus level, summing up to 1600. Only a single main switching system is utilized since no master control automation system was installed, therefore eliminating need for a "random access" routing switcher.

Observation of operations in the previous master control rooms seemed to reveal that A SINGLE PERSON might comfortably operate the room manually and without aid from man or computer if the racks and equipment were placed around him in a good ergonomic design. Instead, several people could usually be found in these hovering around a variety of dislocated attention centers despite the presence of a functioning automation system. The Saint Louis master control room combined all the attention centers together in a single location so only one person would be needed to hover about them, and the automation system was eliminated so that the same single person could function as central processing unit and machine controller. A small home-made switch panel was provided to start any several video tape players simultaneously when necessary.

Previous philosophies of time base correcting ALL video tape playback, and continuously monitoring ALL pictures on the cable system were altered in Saint Louis. Only pay service and video tape playback pictures are continuously monitored, and only premium and pay video tape playback is time base corrected. Video processing amplifiers are substituted for time base correctors in the local origination and public access playback channels so that picture characteristics from marginal tapes can be adjusted before they're cablecast. One standby time base corrector can be patch connected into any playback channel where time base instability is observed. Substitution of processors for time base correctors and elimination of picture monitors saved space, air conditioning, power, and especially capital purchase cost.

CHICAGO

All the lessons learned in Houston and Saint Louis culminated in the Chicago master control room where a compact yet complete, efficient, and ergonomic arrangement was implemented. Although 680 sq. ft. was actually consumed, 575 sq. ft. would have comfortably housed the complete master control equipment complement. Forces not in touch with the pending electronic system design provided 1120 sq. ft. of space for the Chicago master control. Extra effort was applied to designing an equipment arrangement that is especially convenient for a SINGLE person to operate. The one rack of Saint Louis which encompassed ALL video tape players, monitors, and controls was bent to wrap around the operator in a horseshoe like fashion so that everything would be within his reach in just a few short steps. A panel of support equipment not requiring regular attention is installed behind the operator and makes up the rear wall of the master control unit.

Major change in master control switching was made in Chicago and total crosspoints installed there are a mere one hundred sixty (160), a far cry from the 24800 of Dallas. This was achieved by a disciplined justification process which judged each and every switch on its absolute necessity, and the frequency that it would be made. Switches judged unnecessary were eliminated entirely. Only frequent, regular switches are assigned electronic, vertical interval crosspoints. To accomodate infrequent channel changes and realignments, every cable system channel is passed through a simple in-out panel of BNC connectors in the head end. End result of the process is an implementation of just 16 individual 10 x 1 vertical interval switchers for a total of 160 crosspoints.

Elimination of the traditional any input to any output routing swither no longer allowed assignment of any video tape player to any cable channel, and dictated a return to dedicating groups of players to specific cable channels as in Columbus and Cincinnati. Such configuration, however, has no operational disadvantages, is BEST for a human to operate and keep track of, and is inexpensive and technically simple. In fact, some of the automated master control rooms previously described configured their "random access" systems in a dedicated player group manner.

To facilitate simultaneous control of the switchers and video tape players from a central location, an economical, digital, twisted wire pair machine control device was adapted by its manufacturer for use in the Chicago master control room. Now programmed by the operator just before each switching event is to occur, the device is provided with an RS-232 port for connection to a small personal computer should the operator require aid in the future.

FUTURE WARNER AMEX MASTER CONTROL ROOMS

The Chicago master control is the benchmark for future Warner Amex systems. Saint Louis and Chicago revealed that a single person can manually operate a master control system just as well as several people had operated automated master control rooms in previous systems. Should master control requirements remain the same in the future as they are in current operating rooms, new Warner Amex systems will be of a SINGLE operator arrangement similar to Chicago. Nominal floor area will be about 800 sq. ft. and switching should not exceed 250 crosspoints. Switching will as well be accomplished by individual 10 x 1 units rather than traditional rectangular matrix routing switchers.

Introduction of new concepts and equipment might make possible a partially attended master control. Video tapes might be loaded and cued by simple and reliable auto loaders, and starting and switching them might be controlled by an economical, reliable and repairable PERSONAL COMPUTER. Good electronic devices are available today that can continuously monitor the presence and quality of every picture originating in, or passing through the cable system and alert the staff should a discrepancy arise. Such a master control room need only be attended once or twice a day, perhaps even less, to change video tapes in the auto loaders.

COMMERCIAL INSERTION

All Warner Amex metropolitan systems but Chicago currently insert commercial advertising on some satellite networks that make time available for local advertising. Most use the simple "sequential access" method of video tape commercial spot playback in mini electronic systems that are independent of the master control room systems. They are, however, located in the master control room and operated by its staff. Pittsburgh and Dallas utilize their master control automation systems to insert commercials and consequently have some flexibility in establishing a method of operation due to the real and potential random access capabilities of the automation system.

Today, the normal master control room staff performs the tasks of commercial insertion almost as a function secondary to their program origination chores. In some cable systems, however, advertising sales has matured and grown such that commercial insertion is becoming the principal activity of master control. Should the business continue to develop and grow, it is conceivable that master control rooms will become commercial insertion centers, necessarily manned to cope with cablecasting a high volume of short commericals on many cable channels with short notice changes and special requirements near and dear to every advertising sales manager's heart. As it becomes more automatable, program origination is liable to become the secondary master control activity.

PRODUCTION FACILITIES

The implementation of QUBE two way interactive technology in Columbus made possible unique programming in which the home viewer could participate directly in locally produced shows. In order to exploit the possibilities that QUBE seemed to offer, three television studios were constructed at Columbus to produce and cablecast interactive programs. These were equipped with a full complement of audio, video and lighting equipment, all of modest quality but traditional to the broadcast industry nevertheless. Two ENG vans and an EFP vehicle were added for news and location production outside the studio. When fully operational, Columbus production facilities rivaled those of any broadcaster in a medium size American city.

The broadcast influence prevailed through construction of the Dallas cable system providing Cincinnati and Dallas with fully outfitted TV studios of 40 by 60 foot dimension, and Pittsburgh a whopper of 60 by 80 feet. All were equipped with remote production and news vans many of which sported some of the most popular and costly broadcast ENG and EFP equipment of their days. Each system was fully staffed to make the most of these resources.

A new studio was never built in Houston but the system was equipped with a field production van made up of some of the finest broadcast equipment available. A very small staff produces programs in Houston with the van and a small acquired studio utilizing the van as a control room.

New production facilities were constructed in Saint Louis and Chicago but their design and equipment complement departed radically from those of their predecessors. The broadcast influence was scrapped and instead, modest 30 by 40 foot studios were provided with equipment just correct in quantity and type to produce QUBE programs of very good technical quality. ALL production support equipment is located within the studio control room and arranged so that a single person can comfortably perform all studio control room tasks for the majority of simple programming that is typical of these local origination studios. Integrating video tape recorders and a controller into the system allows the studio control room to double as a quality edit suite during the majority of time that production is not taking place in the studio. Saint Louis and Chicago each have a single remote production vehicle, regular vans that are equipped with high performance but economical audio/video equipment. Whatever is the future of local orignation and QUBE programming, Saint Louis and especially the Chicago production facilities will serve as the benchmark for future production systems in Warner Amex cable systems.

SUMMARY

Both cable origination and program production audio/video facilities within Warner Amex metropolitan cable systems grew from modest beginnings to apparent excess over the construction of the first few systems. Application of a disciplined justification process, careful selection of equipment and integration of it into systems, and design of compact, yet efficient and ergonomic areas achieved a humble but thoroughly functional, effective, and high quality conlcusion in the most recently completed Warner Amex audio/video system facilities. Reward was SUBSTANTIAL saving of capital and construction costs, and most important, significant reduction of annual expenses for cablecast operations.

THE EVOLUTION OF THE COMMERCIAL INSERTION BUSINESS

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Considered by many the most important non-subscriber revenue producer of the 1980's, the business of commercial insertion is discussed along its evolutionary milestones of the past two years.

Since the insertion of spot commercials depends upon the smooth interaction of technical, operation, marketing and production personnel, it is important that both hardware and software of the commercial insertion equipment satisfies a complex number of desirable features.

This paper presents a look at commercial insertion hardware and software from the viewpoint of features.

Features are grouped by production, insertion, random access, programming, logging, fail safe, remote operation, expansion, automated billing and management information.

Tele-Engineering's family of commercial insert equipment, the AD MACHINE™, the AD CUE 84™ and the AD CUE 100™ systems are then compared to these features to make the user aware of the differences.

1. EVOLUTIONARY DEVELOPMENTS

Tele-Engineering Corporation has been a designer and manufacturer of commercial insert equipment from the beginning, or since 1979.

At the time, we had a line of programmable time switching equipment on the market, which featured a seven day per week programmer for 8, 16, and 32 channels and to one second resolution.

The first commercial insert product was the AD MACHINE™ system. It is still being sold. It features semi-automatic operation and we like to refer to it as the "Starter Kit".

The AD CUE 100™ system is at the other end of the scale of our hardware development. We call the AD CUE 100™ the "Total System".

The AD CUE 100™ system is a sophisticated microprocessing time/tone switching system expandable to 18 channels of commercial insert.

The AD CUE 100™ system supports commercial insertion with time assignment cueing, up to 96x96 channel routing switches at baseband video, composite video and IF, as well as Local Program source switching and an array of special baseband and IF switching modules.

Last year, Tele-Engineering Corporation added the AD CUE 84™ system that we call the "Econoline" which is a compact 2 channel, four tape player version of the AD CUE 100™ system.

Early this year, Tele-Engineering Corporation introduced the COBIAS I™ automated billing system and the COBIAS II™ management information system. Both software programs can be used by replacing the Z-29 or WY-50 terminal with a Columbia MPC 1600-4 or IBM XT personal computer.

The business of commercial insertion has matured both in hardware and software to provide you, the user, with the proper tools required to conduct your business efficiently and economically.

FEATURES OF COMMERCIAL INSERT EQUIPMENT

- PRODUCTION FEATURES
- INSERTION FEATURES
- RANDOM ACCESS FEATURES
- PROGRAMMING FEATURES
- LOGGING FEATURES
- FAIL SAFE FEATURES
- REMOTE OPERATIONAL FEATURES
- EXPANSION FEATURES
- AUTOMATED BILLING FEATURES
- MANAGEMENT INFORMATION SYSTEM FEATURES

2. FEATURES OF COMMERCIAL INSERT EQUIPMENT

Without going into the vast differences between these product lines, it is appropriate to take a look at the features of commercial insert equipment.

Since the insertion of a spot commercial depends on the interaction of technical, operations, marketing and production personnel, it is appropriate to group the desirable features into the following categories:

Now, we can analyze each of these main categories individually.

2.1 Production Features

The production of spot commercials follows standard practices of the broadcast industry. The time slot reserved for commercial insertion varies from 30 seconds to two minutes, with most services, making available a two-minute period.

The length of the spot commercial has been standardized to 30 seconds. This means that, depending on the time slot, either one, two, three or four 30-second commercials are shown in sequence.

Ideally, then our commercial production department would produce 4 video cassettes with 30-second commercials and we use 4 tape players per channel.

At a price of about $1,500. for a Sony VP 5000 tape player, this method, however, does not appear cost-effective.

The compromise is 2 tape players per channel to retain flexibility.

Production would edit one, two or three 30-second commercials back-to-back on the first cassette and then use the second cassette for special, last minute, infrequent or fill-out commercials. An example may be the local hardware store that only bought one spot at 6:59 p.m. every day or an "HBO Tonight" message that is inserted whenever the last 30-second spot has not been sold.

PRODUCTION FEATURES OF
COMMERCIAL INSERTION EQUIPMENT

- CHANNEL UNIT MUST SUPPORT 2 TAPE PLAYERS PER CHANNEL
- EXPANDABILITY TO 4 TAPE PLAYERS DESIRABLE
- FIXED ASSIGNMENT OF CHANNEL UNIT AND TAPE PLAYERS TO A NETWORK
- SIMPLE PRODUCTION METHOD TO DETERMINE START POINT OF SPOT COMMERCIALS
- SIMPLE PRODUCTION METHOD TO IDENTIFY SPONSOR AND COMMERCIAL NUMBERS
- UP TO 1 HOUR LONG CASSETTES DESIRABLE

To avoid coincidences between spots of different networks, it is good practice to associate a channel unit with each network and to assign the playback equipment in the same manner.

Production can now proceed with the grouping of the commercials in a flexible manner and in accordance with the schedule of spots sold by the sales force.

Upon completion of the master tape, production has to determine the start location of each commercial group. This can be done by frame number count. There are 30 frames per second on a video tape that need to be counted in an accurate manner. A special unit is required to count the frame numbers of all commercial start locations for random access programming.

The second audio track can be used to carry sponsor identification and commercial numbers. A special unit is required to insert these identification numbers as cue tones. In this manner, there is correlation with the network cue tones and logging can become cue tone based.

At 30 frames per second, there are about 108,000 frames on a one hour cassette. It is, therefore, required that the frame number counting system of the commercial insert equipment can handle 6-digit numbers.

2.2 Insertion Features

The category of insertion features includes all functions of the commercial insert unit that are required to provide a clean and timely transfer to the commercial and back to the network.

INSERTION FEATURES

- VERTICAL BLANKING INTERVAL SWITCHING
- SYNCHRONIZATION TO THE SATELLITE SOURCE
- PROGRAMMABLE SELECTION OF PRE-ROLL TIME
- TIME ASSIGNMENT CUEING BY FRAME NUMBERS

Vertical blanking interval switching by itself is not sufficient to assure a clean picture transfer. Synchronization to the satellite source is mandatory. Each of Tele-Engineering's commercial insert systems incorporates this feature.

Digitally programmable selection of pre-roll time is an important consideration. Otherwise, a chip change is required to alter the pre-roll timing.

Most satellite services provide 5 and 8 second pre-roll allowance. The Sony VP 5000 tape player requires over 6 seconds to come up to speed and requires modification to comply with the 5 second allowance. It is hoped that the satellite services will soon standardize their pre-roll allowance to at least 6.5 or 7 seconds to account for sloppy VP 5000 players.

Time Assignment Cueing permits the association of a particular spot commercial with the desired time of insertion. Let us suppose for a moment that you have your spot commercials sold for a particular time slot. If for some reason the cue tone does not come or there is a short power failure, then the commercial insertion did not take place and your commercial will be played one hour later. Any following commercials would be played later as well and the entire spot programming is out of step.

Time Assignment Cueing is programmed on the CRT. The selected time assignment will move the tape player within 3 frames of the commercial start.frame.

Should the cue tone not come or the power fail, the tape player will advance to the next selected time assignment and only the execution of one commercial is affected.

2.3 Random Access Features

Random access programming is provided by using keyboard and CRT to enter the beginning frame numbers of all commercial spots in the desired sequence of playback.

RANDOM ACCESS FEATURES

7-DAY PROGRAMMING OF ANY AND ALL CHANNELS

100 SEQUENTIAL STEPS PROGRAMMABLE PER CHANNEL
(DAY PART AND ROTATOR SELECTION)

SECOND TAPE PLAYER PROGRAMMING INTERACTIVE
WITH FIRST

TIME ASSIGNMENT CUEING FOR EACH SEQUENTIAL STEP
OR GROUP OF STEPS

All of Tele-Engineering's family of commercial insert equipment permits programming for 7 days a week for every channel or network.

Each channel can be programmed for up to 100 sequential steps using 6-digit frame numbers to identify the begin location of each commercial spot. The equipment can be programmed optionally by position numbers, which is a data reduced frame number and defines the exact position on the tape. When two playback machines are used, then the second unit will interactively cue and pre-roll upon command of the first machine. This is accomplished by start-up cue tones on the second audio track of the first machine.

Time Assignment Cueing permits the rotation of a group of commercials during day part periods as well as the selection of promo material for any unused 30 second to two minute time slot. Time assignment cueing will protect the execution of a rotation sequence, a group of commercials or each individual sequential step.

2.4 Programming Features

User friendly programming must combine set-up, random access programming, logging recall and utility programming.

PROGRAMMING FEATURES

SET-UP PROGRAM
- IDENTIFICATION OF CHANNEL NUMBERS AND SATELLITE SERVICES
- SELECTION OF MENU

RANDOM ACCESS PROGRAM
- CHANNEL SELECTION
- TIME ASSIGNMENT SELECTION
- STEP AND FRAME NUMBER SELECTION

LOGGING RECALL PROGRAM
- LOGGING SELECTION BY DAY
- CONTINUOUS MEMORY DUMP

UTILITY PROGRAM
- MATRIX SWITCHING
- LOCAL ORIGINATION PROGRAMMER
- SUBSTITUTION SWITCHING

The set-up program permits the initialization of the system. It defines, for example, that CNN will be run on channel unit number 2. It defines the pre-roll time selection for the network. It identifies the cue tone sequences of the individual services and is used to set-up sub-carrier services like MTV.

Upon completion of initialization, any operator can now select the menu to proceed with:

CI - Commercial Insertion and random access programming
LOG - Logging recall
UT - Utility functions

The CI commercial insert random access programming proceeds by channel or network and associates the frame number listing from production with the desired sequence of playback.

In this manner, every channel can be programmed in sequence. The addition of time assignment programming now provides an association of the commercial position with day, hour, minute and seconds of the expected insertion. In this manner, seven days of programming can be completed in less than one hour per channel.

The LOG program simply recalls all recorded commercial information and displays it on the CRT. The user can verify on a continuous basis that the commercials are being aired.

The Utility program is used only for ancillary equipment programming, such as:

routing switching
protection switching
matrix switching
local origination switching

These time programmable switching functions are a part of the expansion capabilities of Tele-Engineering's insertion equipment.

2.5 Logging Features

Record keeping in the commercial insert business is important. In order to verify that a commercial has played, it is desirable that the following LOG features are incorporated.

LOGGING FEATURES

- RECORDING OF START CUE TONES
- RECORDING OF SPONSOR AND COMMERCIAL IDENTIFICATION
- RECORDING OF DAY, HOUR, MINUTE OF COMMERCIAL START
- RECORDING OF DURATION OF COMMERCIAL
- CONTINUOUS MEMORY TO STORE DATA UP TO 7 DAYS (ALL NETWORKS)
- ABILITY TO DUMP AND PRINT ON COMMAND SORTED BY CALENDAR DAY

All logging is cue tone based. Each commercial is logged by channel number along with sponsor or commercial number that was imprinted on the second audio track of the commercial.

The seven-day continuous memory logs the commercial identification by day, hour and minute of the start sequence and counts the running period by using a length code of 1 for every 15 seconds of the commercial time played.

In this manner, a sequential log of all commercials played is maintained in the continuous memory, which can be recalled at any time by the operator. The log schedule can be reviewed on the CRT and/or printed for affidavit and billing purposes on a day-by-day and line-by-line basis.

The capacity of the continuous memory is of importance to avoid frequent recall that may interfere with the operational billing intervals.

The commercial log print-out is purposely condensed and does not include any English notations because it has to be sent via telephone line to the distant business office. At 1200 bps, it is important to keep the connect time as short as possible.

2.6 Fail-Safe Features

Power failures are an important consideration in the commercial insert business. It would be disastrous to lose programming, clock reference and logging in a momentary power outage. Without proper fail-safe features, any commercial insert schedule would be altered by a power failure and go out of step.

FAIL-SAFE FEATURES

- MAINTAIN PROGRAMMING OF STEPS AND FRAME NUMBERS
- MAINTAIN TIME ASSIGNMENT CUEING
- MAINTAIN EXACT DAY, HOUR, MINUTE
- MAINTAIN LOGGING
- STAND-BY OPERATION DESIRABLE UP TO 1 WEEK
- MAINTAIN SATELLITE PROGRAM DURING POWER FAILURE
- COMPLETE AND AUTOMATIC RECOVERY AFTER POWER FAILURE

It is then of utmost importance that all programming of step and frame numbers, all Time Assignment Cueing, all logging and exact clock references for day, hour, minute and second are protected.

What is meant by complete and automatic recovery is that clock memories, logging and programming have been properly maintained and that the commercial that is scheduled to play on the next day at 11:57 a.m. will play as scheduled.

The one week stand-by operation may sound like overkill, but we have received programmers for repair and returned them to the customer clear across the country, without loss of any memory, clock, programming or logging information.

2.7 Remote Operational Features

Most of Tele-Engineering's commercial insert equipment can be remotely programmed over standard telephone lines and can be remotely called to transmit the logging data back to the central location.

All interfaces of CRT's, printers and modems are RS 232C. Remote operation requires 1200 bps modems at both ends which is about the highest possible speed that produces error free transmission on the standard dial-up telephone network.

REMOTE OPERATIONAL FEATURES

- PROGRAMMING OF TIME ASSIGNMENT CUEING OVER STANDARD DIAL-UP TELEPHONE NETWORK
- PROGRAMMING OF STEP NUMBERS AND FRAME NUMBERS OVER THE TELEPHONE NETWORK
- DEMAND ACCESS TO RECALL LOGGING INFORMATION BY DAY CODE
- THREE DIGIT SECURITY CODE FOR REMOTE ACCESS
- FOUR DIGIT LOCATION CODE FOR LOGGING IDENTIFICATION

To facilitate remote programming, it is important that the operator is given a schedule of time assignments, step numbers and frame numbers for each location to be programmed.

He then dials up the telephone number of the location to be programmed, waits for the programmer to respond to the call and dials the security code for access to the programming unit. He is now ready to transfer the programming information into the station's memory using the keyboard and CRT as if he were sitting next to the machine.

Verification of the completed programming should become standard operating procedure as errors on telephone lines can occur.

Demand access to recall the logging of executed commercials is established in an identical manner. After gaining access to the programmer, the logging program is selected by the operator and the command to send the information held in continuous memory is given. The operator can view all data sorted by day on the CRT and record the log on a standard line printer connected to the CRT.

The operator can execute the retrieval of data line by line and repeat each line in case of errors of the transmission medium.

A four digit location code is sent from the participating programmer so that it is easy for the operator at the central location to identify the market location after print-out.

2.8 Expansion Features

The business of commercial insertion will expand over the next decade. It is, therefore, important to consider related time and tone programming functions. Good commercial insert hardware should provide expansion in the following areas.

EXPANSION FEATURES

AUTOMATION OF LOCAL ORIGINATION CHANNEL

AUTOMATION OF ACCESS CHANNELS

MATRIX ROUTING SWITCHING

PROTECTION AND SPECIAL FUNCTION SWITCHING

FLEXIBLE EXPANSION OF COMMERCIAL INSERT CHANNELS

To automate the Local Origination channel, it is required to arrange a number of playback units in a manner that would allow sequential playback of program cassettes, infomercials, alphanumeric announcements as well as live programming.

Tele-Engineering's local programming switch shelf can be provided for up to 13 separate time programmmable video inputs. Two, four or eight inputs can be provided with tape player control and random access spot selection.

A cue tone option can be added which can be used to enter program and infomercial identification numbers and thus provide logging for operational record purposes.

The same method can also be used for commercial insert on the Local Origination channel as well as for automation of any desired access channel.

The programmer of Tele-Engineering's commercial insert system can support matrix switching configurations up to 96x96 switch points.

The switching equipment can be configured for baseband video with audio follow-on, for composite video and for IF frequencies.

The programming of protection switching and any special function switching, such as 4 on 1, dual 4 on 1, 8 on 1, 11 on 1 and alternate program (AB) switching, can be accomplished with the same programmer.

The expansion of the commercial insert business is only a matter of time. The commercial insert shelf configuration should permit easy expansion. Tele-Engineering's total system, the AD CUE 100™ system permits the installation of 9 channel units in the first shelf and can go to 18 channels by adding a second shelf.

2.9 Automated Billing Features

Stand alone automated billing is as important for the business of commercial insertion as it is for subscriber billing.

An automated billing system must be able to maintain the data on customer transactions, recall the logging of commercial spots that have been shown and print the invoices with affidavit or verification statement

The MENU selection establishes the execution of the automated billing program.

The selection of FILES enables the user to record data on customer, transactions, past dues, and commercial rates.

AUTOMATED BILLING FEATURES

- MENU
- FILES
- COMMCALL
- PRINTLOG
- BILLING
- BILLING SUMMARY

The COMMCALL program enables the user to call an unlimited number of markets or commercial insert locations by dial-up and retrieves the logging information from the continuous memory of the commercial insert equipment. It also converts the numeric information to English for print-out and billing.

The PRINTLOG program sorts the logs of each commercial in chronological order, by day and by sponsor or customer. The PRINTLOG report is used as a verification report that the customer's commmercial ran as scheduled. It can serve as an affidavit of performance.

BILLING is selected to print invoices for verified and executed commercials. The program tracks past dues as well as all transactions, rate schedules, payments, credits and debits for each advertiser.

A SUMMARY program prints the summary of all invoices that were printed for each advertiser and consolidates the totals of all advertisers.

The COBIAS I™ automated billing software will operate on any IBM PC compatible computer. It requires two 5 1/4 inch disk drives and is programmed for three color presentations. The computer requires a standard RS-232C printer interface and a 1200 bps modem when remote operation through the dial-up telephone system is required.

2.10 Management Information System Features

It is appropriate to computerize the business of commercial insertion beyond the fairly simple billing program. Larger commercial insert networks require information relative to availability of spots, scheduling of available time periods, sales activity to monitor the effectiveness of the sales force, correlation between tape production and commercial numbers as well as information on spots sold, in which time frame and at which location.

To assure a total Management Information System, the COBIAS II™ software has been developed.

MANAGEMENT INFORMATION SYSTEM FEATURES

- MENU
- ALL AUTOMATED BILLING FEATURES PLUS
- CONTRACT FILE
- SCHEDULING
- SALES ACTIVITY
- COMMERCIAL LISTING
- SPOT SALE
- SCHEDULE REPORT
- MARKET SHARE

The CONTRACT file has been added to the FILES program and permits the storage of rates and commercial information in the form of a contract with all advertisers, sorted by market location.

The SCHEDULING program indicates which spots are available and which spots have been sold. Again the sorting is by network and market or location.

The SALES ACTIVITY report indicates all sales during the current month and for the past 5 months, sorted by salesman, network, market or location.

There is a COMMERCIAL LISTING program which cross references the production on file by tape master number with the commercial number of the various advertisers. This program enables the production personnel to quickly select repeat spot sales from the tape library and save time in the preparation of new tapes.

The SPOT SALE report will inform, at a glance, about what has been sold in each market, by network and time schedule.

A SCHEDULE REPORT informs the traffic manager every day which spots are open, so that he can schedule his own local insertions as filler material. This could be HBO program announcements, discount offers for subscribers, important local announcements or simple reminders for the subscribers.

The MARKET SHARE report lists the payables from advertisers sorted by name, contract, market location, rate structure and billing, inclusive of payments made and ageing for 30, 60 and 90 days.

The COBIAS II™ software requires the IBM XT version hard disk computer. In case you wanted to upgrade from the Automated Billing System to the Management Information System, only the computer units and the software needs changing. All other equipment remains identical.

3. THE AD INSERT FAMILY OF PRODUCT LINES

As mentioned in the beginning, Tele-Engineering's family of Ad Insert product lines consists of:

The AD MACHINE™ System (Starter Kit)
The Ad CUE 84™ System (The Econo System)
The AD CUE 100™ System (The Total System)

It is appropriate to spend a few minutes to review the features of these products.

3.1 The AD MACHINE™ System

The AD MACHINE™ system consists of a two- or four-channel commercial insert shelf, the AD CUE II™ command console and the AD LOG™ cue tone recorder.

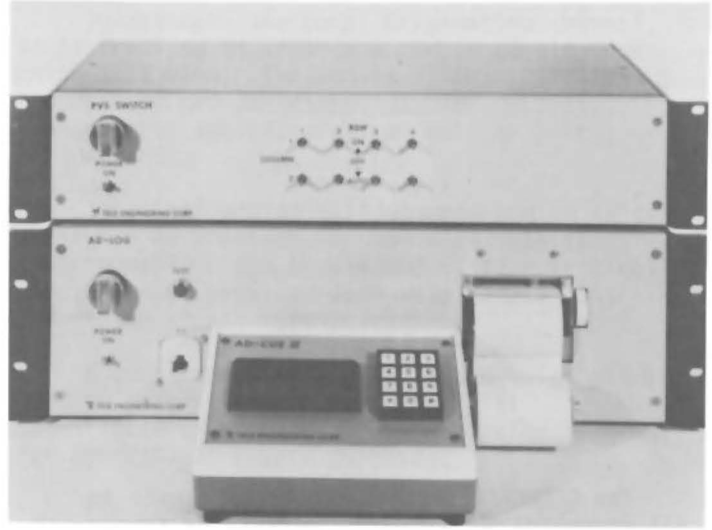
The AD MACHINE™ commercial insert shelf accommodates up to 2 dual channel modules that provide switching to the video tape player (VP-5000) in response to satellite cue tone sequences. A digital cue tone receiver can be programmed to the desired cue tone sequence and permits accurate responses without drift. The pre-roll delay is pre-programmable and pre-set to the satellite pre-roll time allocations. Switching is accomplished in the vertical interval of the satellite video signal.

The AD CUE II™ command console is a random access programmer that permits the sequence selection of the commercial spots on the video tape player by step numbers. There can be up to 99 steps selected per channel. The step numbers are programmed by frame numbers on the video tape. There are 30 frames per second. The AD CUE II™ console accommodates five-digit frame numbers. The AD CUE II C™ console accommodates six-digit frame numbers.

Upon execution of a commercial insertion sequence, the AD CUE II™ command console will advance the video tape player to the next selected frame number and park the player until the next cue tone insertion command is received. Off cue tones are used to switch the transmission back to satellite. Should the off cue tone not be received, the unit will return to satellite after a period of 2 minutes.

Additional cue tone sequences for spot commercial and sponsor identification can be added to the second audio track using the AD PRO™ automatic hand-held tone sequence generator. Cue tones are individually dialed and then executed in the proper 40 milliseconds per tone sequence.

Both satellite and AD PRO™ tone sequences are recorded by the AD LOG™ dual-channel, paper strip recorder expandable to 6 channels. The AD LOG™ recorder has a buffer to permit sequential printing of simultaneous cue tones by month, day, hour, minute and second of occurrence.



The AD MACHINE™ complement of equipment incorporates all features required for semi-automatic operation. It does not support Time Assignment Cueing, computerized logging or automatic billing.

The AD MACHINE™ system features are indicated below:

AD MACHINE™ SYSTEM - FEATURES

- 2 CHANNEL OPERATION
- 1 INPUT FOR VCR PER CHANNEL
- PRE-PROGRAMMED PRE-ROLL TIME SELECTION
- RANDOM ACCESS PROGRAMMING WITH AD CUE II™ PROGRAMMER OF UP TO 100 SPOTS PER CHANNEL AND 5 DIGIT FRAME NUMBERS
- VERTICAL BLANKING INTERVAL SWITCHING
- 7-DAY PROGRAMMING (AD CUE II™) PROGRAMMER FOR 2 CHANNELS WITH 1 VIDEO CASSETTE PLAYER
- FAIL-SAFE OPERATION OF SATELLITE PROGRAM DURING POWER FAILURE
- STAND-BY POWER TO MAINTAIN PROGRAM OF AD CUE II™ PROGRAMMER AND CLOCK OF AD LOG™ THROUGH EXTENDED POWER FAILURES

3.2 The AD CUE 84™ System

The AD CUE 84™ system is a compact 2-channel random access commercial insert processor.

The AD CUE 84™ system supports 2 VCR's for cue tone derived commercial insertion and 1 character generator or video source for local program insertion. The AD CUE 84™ system permits 30, 60, 90 and 120 second commercial spots or local program insertions under time assignment control and satellite cue tone execution.

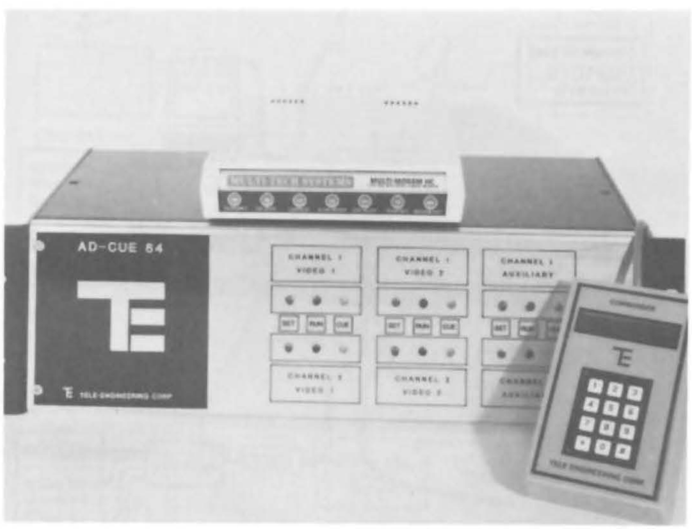
There can be up to 100 spots per channel and up to 200 time-program entries per channel and per week. The AD CUE 84™ system consists of the the AD CUE 84™ programmer, the hand-held Command Terminal, two 4-ft. cable assemblies for VCR's and two 4-ft. cable assemblies for video source equipment.

The AD CUE 84™ programmer features colored LED's to report the status of each VCR or video source equipment, i.e., ready, run and cueing conditions.

The AD CUE 84™ system can be programmed from the hand-held Command Terminal (COMMANDER™ microterminal), or from local or remote CRT terminals such as the Scanset or a Zenith Z29 or a Wyse WY-50 terminal.

The AD CUE 84™ system includes a continuous memory for cue tone and commercial verification of all spot commercials for at least one week. The commercial verification log can be printed locally through the CRT printer port or remotely accessed via dial-up telephone line.

By using an optional Columbia or IBM PC microcomputer, the AD CUE 84™ system can be expanded to provide automatic billing, commercial affidavits and management information system software.



The AD CUE 84™ system combines all the features that we have been talking about except for expandability.

The AD CUE 84™ system is a cost-effective re-packaging for markets that operate 12 channel systems and that do not expect to run commercials on more than 2 channels.

THE AD CUE 84™ SYSTEM - FEATURES

- 2 CHANNEL OPERATION
- 2 INPUTS FOR TAPE PLAYERS PER CHANNEL
- 3rd INPUT FOR VIDEO SOURCE OR CHARACTER GENERATOR
- UP TO ONE HOUR CASSETTE PROGRAMMING
- UP TO 100 STEP NUMBERS PER CHANNEL
- VERTICAL BLANKING INTERVAL SWITCHING
- SYNCHRONIZATION TO SATELLITE SOURCE
- PROGRAMMABLE PRE-ROLL TIME SELECTION
- TIME ASSIGNMENT CUEING
- 7 DAY PROGRAMMING FOR ALL CHANNELS
- SET-UP PROGRAM, RANDOM ACCESS PROGRAM AND LOGGING RECALL PROGRAM
- CONTINUOUS MEMORY FOR 7 DAYS
- RECORDING OF TIME, DURATION, COMMERCIAL I.D.
- FAIL SAFE FOR PROGRAMS, TIME ASSIGNMENT CUEING, CLOCK, LOGGING FOR 1 WEEK
- REMOTE PROGRAMMING WITH ACCESS CODE
- REMOTE RECALL OF LOGGING INFORMATION
- EXPANDABLE FOR LOCAL OR REMOTE
  - COBIAS I™ AUTOMATED BILLING SYSTEM
  - COBIAS II™ MANAGEMENT INFORMATION SYSTEM

3.3 The AD CUE 100™ System

The AD CUE 100™ system is a sophisticated microprocessing time/tone switching system expandable to 9 channels of commercial insert in one shelf. Expansion to 18 channels can be achieved by adding an additional shelf.

The AD CUE 100™ system supports commercial insertion with time assignment control, up to 96x96 channel routing switches and Local Program source switching, as well as an array of special baseband and IF switching modules.

The AD CUE 100™ system consists of the PVS-100™ Q Programmer, SW-20 or SW-48 shelf that can be equipped with cue tone, matrix and special purpose switching modules.

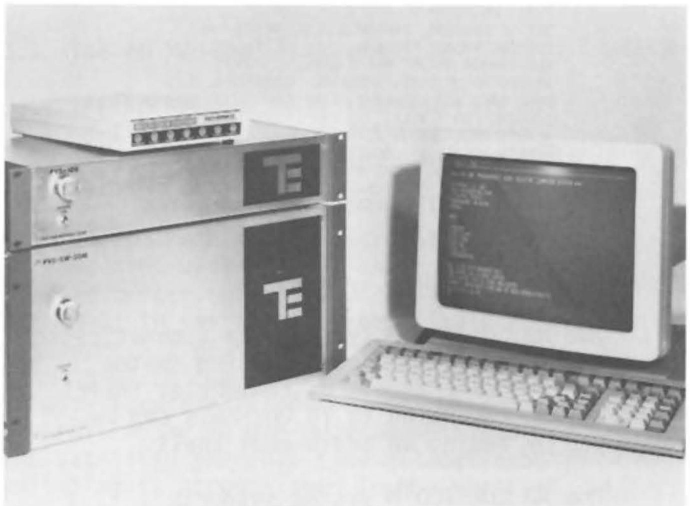
The command post of the AD CUE 100™ system can be a Z-29, a Wyse WY-50 or a Scanset terminal that can be located remotely and interconnected with the programmer via dial-up telephone lines.

The AD CUE 100™ system permits 30, 60, 90 and 120 second commercial spots on every channel. The LP local programming module can be expanded from 4 to 15 source inputs per channel. These sources can be time-programmed or cue tone sequenced and can be used for local origination channel programming as well as spot commercials.

The AD CUE 100™ system features RS-232C interfaces between programmer, switching shelf and command terminal and works for remote programming and commercial verification with standard 1200 bps modems on the dial up telephone network.

The continuous memory of the AD CUE 100™ system records commercial start times and duration per day and per channel. The memory can be recalled by the Command Terminal, locally or over telephone lines, by simple dump command. All commercial spots for up to 18 channels and up to seven days can be verified in this manner and a hard copy obtained by the simple connection of a printer to the CRT printer port.

By using the optional Columbia or IBM PC, the AD CUE 100™ system can be expanded through COBIAS I or II™ software to include total management information for the commercial insert business.



The AD CUE 100™ commercial insert system is indeed the Total System. It combines all features that we discussed with an unlimited expansion capability. It supports networking of an unlimited number of markets as well as the addition of any desirable switching function. It supports fully automatic programming locally and remotely as well as a total management information package that permits efficient conduct of a growing commercial insertion business.

Some of the features are highlighted below:

THE AD CUE 100™ SYSTEM FEATURES

- UP TO 9 or 18 CHANNELS
- UP TO 96x96 IF OF BASEBAND MATRICES
- UP TO 15 L.O. PROGRAMMING INPUTS PER CHANNEL
- ACCEPTS 4 AB, 4 ON 1, 8 ON 1, 11 ON 1 IF OR BASEBAND SPECIAL SWITCHING REQUIREMENTS
- UP TO ONE HOUR CASSETTE PROGRAMMING
- UP TO 100 STEP NUMBERS PER CHANNEL
- VERTICAL BLANKING INTERVAL SWITCHING
- SYNCHRONIZATION TO SATELLITE SOURCE
- PROGRAMMABLE PRE-ROLL TIME SELECTION
- TIME ASSIGNMENT CUEING
- 7 DAY PROGRAMMING FOR ALL CHANNELS
- SET-UP PROGRAM, RANDOM ACCESS PROGRAM, LOGGING RE-CALL PROGRAM AND EXPANSION PROGRAM
- CONTINUOUS MEMORY FOR 7 DAYS
- RECORDING OF TIME, DURATION, COMMERCIAL I.D.
- FAIL SAFE FOR PROGRAMS, TIME ASSIGNMENT CUEING, CLOCK, AND LOGGING FOR 1 WEEK
- REMOTE PROGRAMMING WITH ACCESS CODE
- REMOTE RECALL OF LOGGING INFORMATION
- EXPANDABLE FOR LOCAL OR REMOTE OPERATION OF
  - COBIAS I™ AUTOMATED BILLING SYSTEM
  - COABIA II™ MANAGEMENT INFORMATION SYSTEM

4. COMMERCIAL INSERTION NETWORKS

Using the AD CUE 84™ and the AD CUE 100™ systems, regional and national programming is feasible.

If we assume that the Billing Center and Operations Control is at one location, then all we need at this location is the IBM PC or XT or Columbia MCP 1600-4 computer plus a good commercial printer.

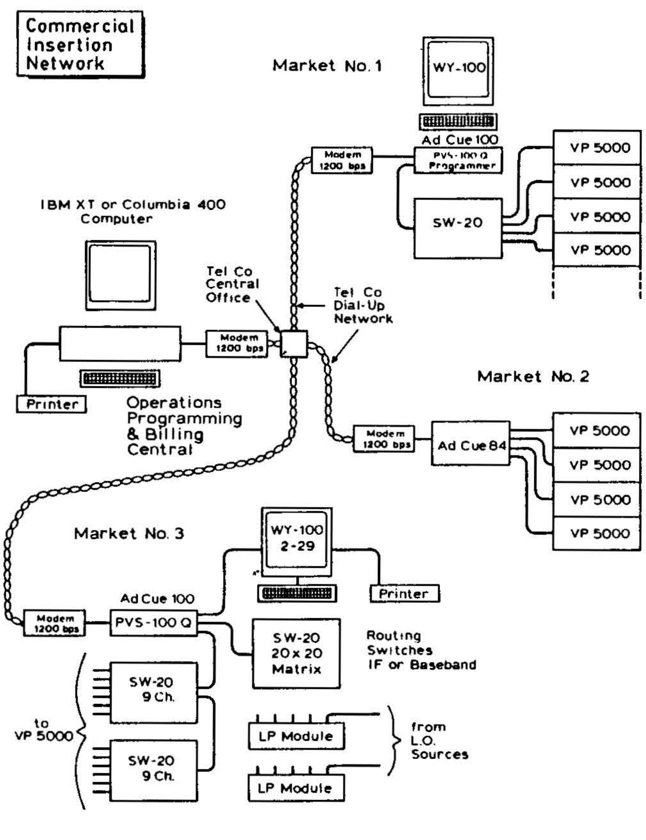


FIG. 19

TE TELE-ENGINEERING CORP.

At the outlying locations or markets, we find the AD CUE 84™ or AD CUE 100™ systems installed and interlinked via standard dial-up telephone network.

All programming and logging retrieval is done over the telephone network. Distance is not a factor for the operation of the commercial insert network. It is, however, a detriment if the production of commercial cassettes is not conducted at the insert locations.

Should centralization of tape production be a desirable feature, as it may be for national commercials, then tape shipping, deployment and placement may become a problem.

For national commercial insert networks, down loading of the tape production via satellite, at night and during off-hours, appears to offer a good alternate solution.

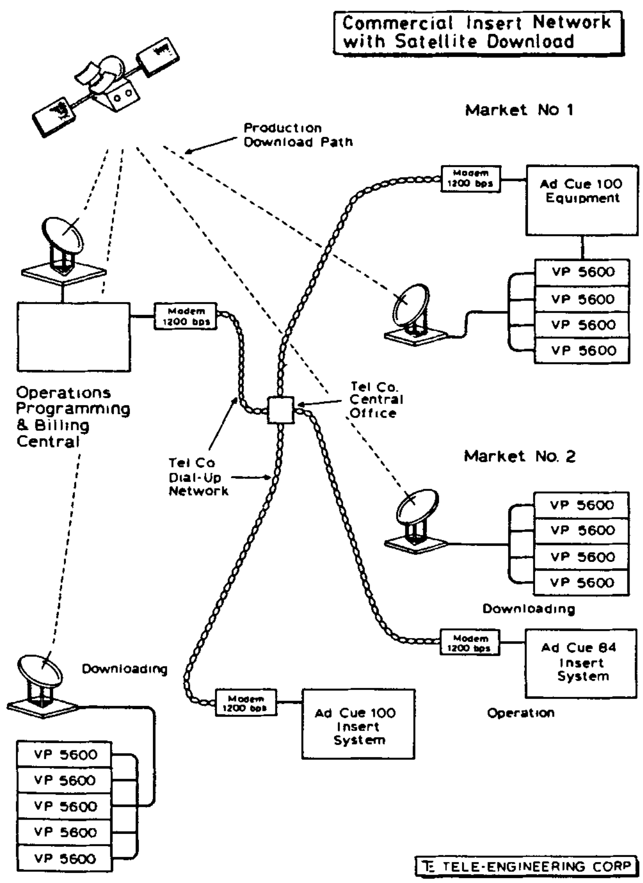


FIG. 20

All that has to change are the playback machines. The Sony VP 5000 has no recording capability and would have to be replaced with the VO 5600 model. No changes have to be made to the commercial insert equipment or the network.

Programming and log retrieval would still be conducted over the dial-up telephone network.

5. SUMMARY

The business of commercial insertion consists of a number of complex problems that all have found reliable solutions through evolutionary development.

Tele-Engineering has been at the forefront in this evolution and can proudly point to the fact that all hardware and software is available and field proven to establish nationwide commercial insertion networks.

The potential user does not have to ask the question anymore whether commercial insertion is a viable business.

Commercial insertion is not just here to stay, but when planned properly in the beginning, i.e., when operations, marketing, and production are clearly defined - will lead to revenue growth that will out-perform any business forecast. Statistics show that the capital equipment can be paid for within the first six months of operation.

Tele-Engineering Corporation is proud to be in the position to assist you in developing this new and exciting business area. The most flexible and expandable hardware and software package of the industry is available to enable you to build your commercial insert business on pay-as-you-grow basis into the revenue leader on your company's balance sheet.

THE KEYS TO EFFICIENT, EFFECTIVE INTRODUCTION OF ONE-WAY ADDRESSABILITY

J. Curt Hockemeier

NATIONAL CABLE TELEVISION ASSOCIATION

ABSTRACT

From the outset one-way addressable equipment manufacturers misunderstood the principal importance of their product to cable operators. The assumption they made -- that one-way pay-per-view would be wildly successful among cable viewers -- and that revenues from pay-per-view would easily offset the product's higher cost -- turned out to be a not insignificant leap of faith from early STV experience. This of course, has not yet been shown to be true.

The future of this new source of revenue is still unclear; however, there do appear to be economically attractive reasons to implement addressability if approached properly, whether or not the pay-per-view promise ever materializes.

The results of Cox Cable's studies of the technology, as applied to its own cable systems, suggest a formula for both making the addressable decision, and guidelines for getting the greatest economic benefit from addressability.

INTRODUCTION

The importance of addressable technology in the reduction of cable system operating expenses was universally misunderstood by equipment manufacturers. Instead, they overestimated the potential of pay-per-view in the equation.

This realization, that pay-per-view would not be as successful for the cable operator as it had been earlier for the STV operator, left MSO's which had already implemented addressability looking around for additional revenues or expense reductions with little experience to indicate either was available.

Cox Cable Communications was one of those MSO's. As a result, the Company undertook a study of the benefits of addressability. What Cox found was a way to implement one-way addressability which promised an attractive return on the operator's investment. But the Company also found that knowing where to look for the operating efficiencies addressability can deliver in advance of implementation was the key to achievement of that return.

WHERE ARE THE COST SAVINGS?

In its earliest research Cox had the disadvantage of having but one completely addressable system to study; that is, only one of its systems provided all customers with addressable converters. All other systems were partially programmable, partially addressable. This made separating addressability's cost efficiencies from other operations difficult. It made sense then to model the ideal addressable cable system on paper to determine whether in theory there really were any benefits, and above all, was the incremental investment warranted?

A FORMULA

The Company studied its own addressable operations, some wire linked, others stand-alone operating with double data entry (authorization through the addressable computer and input of the same transaction in the billing computer to start or change the billing). The Cox study team also interviewed other operators and the manufacturers themselves. And finally, the actual operating costs of the Company's own major urban programmable systems were compared with its major market addressable systems. The result was an assumptions model which could calculate the internal rate of return on the incremental addressable investment.

Although the model contemplates a large urban market with 85,000 subscribers, the size of the cable system is relatively unimportant in the calculation because the fixed costs of implementing addressability are also relatively unimportant compared to the converter investment.

The model compares the cost and revenue differences associated with the operation of this system in two different modes...programmable, and addressable. For example, in its programmable form the cost of making a service change in the home is assumed to be $18.31. For making this change... let's say a swap of services (HBO for Showtime)... the operator charges the subscriber $15. The operator's loss on paper, although currently a hidden cost for most cable systems, is $3.31. But the same change of service in an addressable system costs only 44¢ -- the cost of having a customer service representative take the call and make the change on line. For this change the operator charges $7.50.

Not only did the operator not lose the $3.31 on the change, but he also improved his revenue by $7.06. This service change revenue is critical to the achievement of an appropriate return on the operator's addressable investment.

ASSUMPTIONS MODEL

1. 85,000 subscriber system remains stable (no growth) over a 5-year period.

2. All subscribers are equipped with addressable converters.

3. Total converters in the system are assumed to be 85,000 Basic sets and 21,250, or 25% second set penetration for a total of 106,250.

4. 8,500 spare converters are also assumed.

5. Pay churn will cause a number of changes in service level equivalent to half the Basic subscriber base each year over the 5 year period.

6. The incremental cost of addressability is assumed to be $20 per converter plus $86,000 for addressable computer, data signal generator, software, protocol converter, printer, etc.

7. The percentage of truck rolls to over-the-counter service changes in a programmable operation will be:

Year	Field	Counter
1	65%	35%
2	59%	41%
3	56%	44%
4	53%	47%
5	50%	50%

8. The net ending result of service changes will be:

Year	Upgrades	Swaps	Downgrades
1	38%	13%	49%
2	33%	4%	63%
3	35%	4%	61%
4	45%	4%	51%
5	55%	4%	41%

9. Field swaps will be charged $15; field upgrades will be $7.50; $7.50 for counter swaps; $5.00 for counter upgrades; nothing for downgrades in either the field or over the counter as the ordinance prohibits such a change.

In addressable operation, all upgrades and swaps would be charged $7.50

10. Over a 5-year period a premium service will fail. It will have 4% pay-to-basic penetration. All subscribers will require a truck roll in the programmable operation to change out the converter. Ten percent of these subscribers will require a revisit because of "not home"

11. Over a 5-year period a premium service will be introduced. It will achieve 10% pay-to-basic penetration. 70% will be upgrades; the balance, swaps. 64% of upgrades will require field changes; balance will be over the counter.

12. In addressable operation pay-per-view events would be offered once a quarter. Average penetration will be 6%; revenue will be split 50/50 on a $15 retail ticket. Average net to the operator is $3.

13. Addressable converters will have a slightly higher failure rate and will be somewhat more expensive to repair. (1% higher rate at $3 incremental is assumed.)

14. Unit costs of making service changes average $18.31 for field changes and $7.55 for counter changes. Includes labor, vehicle maintenance and fuel, converter repair and maintenance, customer service support, CRT rental/lease, installation support (verification), issue and return, and other costs associated with field changes. Counter costs include facility lease, labor, communications lines, CRT rental/lease, and others.

In addressable operation it is assumed that the average service level change can be made for 44¢.

15. Incremental addressable operation costs include wire link communications costs, computer maintenance agreement, modem lease, and modem sharing device lease.

INCREMENTAL ADDRESSABILITY COST/BENEFIT ANALYSIS

($000's)

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Incremental Investment	$2,381					
Net of ITC	$2,143					
Incremental Income/Cost						
--Pay-Per-View		61.2	61.2	61.2	61.2	61.2
--Cost Reduction in						
Launch		127.4				
Demise				50.6		
--Service Changes		586.6	578.8	567.5	560.3	553.7
Increase in Converter Repair/Maintenance		(3.4)	(3.4)	(3.4)	(3.4)	(3.4)
Addressable Operating Costs (incremental)		(11.4)	(11.4)	(11.4)	(11.4)	(11.4)
Net Cash Flow		$760.4	$625.2	$664.5	$606.7	$600.1
Discounted Cash Flow @ 15%		$661.2	$473.6	$437.2	$346.7	$298.6
Sum of Discounted Cash Flows		$2,217.3				

COMMENTS ON THE MODEL'S APPLICABILITY

Using conservative assumptions, the model produces a somewhat greater than 15% internal rate of return on the addressable investment before taxes. The operator who wishes to make a similar computation may have the freedom to charge for downgrades; the model will obviously produce a much higher return when the losses associated with truck rolls for downgrades in the programmable operation are combined with the revenue associated with making these same changes in an addressable operation. In other words, the operator who had been programmable could forecast a real operating cost for making downgrade changes in the field. If addressable, the operator could eliminate the costs of making these field changes and and would produce certain operating income making the same changes through the customer service organization.

There is a case that can be made that addressability reduces theft and office errors which lead to giving service away. Although this model does not include incremental income associated with such a reduction, the result of including this calculation, even conservatively projected, is dramatic. Assuming for example that the current theft rate in the programmable system is 9% of gross revenue, and addressability can eliminate half of that the first year, and that the loss of revenue grows each year over the next 4 years by a full percentage point each year (because of pirate converters), the internal rate of return could be doubled.

It is clear that another operator's assumptions may differ from those presented in the model. It simply sets a framework and may be changed to reflect the unique characteristics of any given system operation.

THE MODEL'S IMPLICATIONS

The most obvious difference, in economic terms, between the programmable operation and the addressable operation, is obviously in the virtual elimination of costs associated with making service changes. To make the most efficient conversion to addressability then, the operator needs to focus on all the component costs of making service changes in his present operation, and eliminate them quickly as addressability is implemented.

WHERE TO LOOK FOR ADDRESSABILITY'S IMPACT

So you've computed your internal rate of return and find that addressability makes sense. You're ready for a conversion. But what processes and systems need changing? Which expenses can be eliminated? Here's a sample check list which may help realize those efficiencies faster.

Rates and Charges

--Be sure your second outlet will produce the margin you've been experiencing. Don't forget, you're adding to your investment.

--Can you restructure your service change charges to produce an average of $10 per net ending transaction? The convenience of not having to stay home for a change of service is worth something. Make certain your change of service rate is understood by your subscribers and consider calling it an "administrative transaction charge" instead of an upgrade or downgrade charge.

Installation

--Since service changes will not be made by installers, what impact will this have on your staffing? And how about the number of vehicles you require with their associated maintenance and fuel costs?

--Don't forget the more subtle savings including uniforms and tools for those employees.

--Since you'll experience an installation staff reduction, what costs can you eliminate in supervision and the routing of these employees?

Look at automating your installation process using voice response technology so that the installer can automatically authorize the addressable converter in the home using touch-tone telephones. This can further reduce support resources which will be required if the installer must call customer service for converter authorization.

Service Centers

--If you've established converter exchange locations to reduce your programmable operation costs, you may wish to close them altogether. Your converter changes to upgrade or downgrade services will be eliminated.

Converter Reprogramming/Repair

--Whatever staff you have employed today to reprogram converters for changing service levels can be eliminated altogether. This will be one of your most significant savings.

Paperwork/Check-In/Work Verification

--Most programmable systems have a function they call "work verification" but may be called "check-in" by others. It's the clearing house for all completed work orders and generally is responsible for starting or changing the subscriber's billing. Stop and think that when you're addressable, all service change paperwork will disappear. It will be handled on-line. If you have a clerk that files this paperwork, look for ways to reduce this expense. There will be a savings. Won't you also have a reduction in your forms printing expense also?

Repair

--Whereas your technicians now carry a full complement of converters programmed to all possible required service levels, once you're addressable they may need to carry 85% fewer converters. This has implications to you in the control of your most mobile asset.

Disconnection

--There are of course conflicting views as to whether to leave the drop active to the home. You'll have to balance the cost of disconnection of drops against the possibility that you may be encouraging pirate converter operation in your system if you leave them active.

Collections

--Rather than lose a customer who is obviously not able to pay for the level of service he's currently subscribing to, your collections effort may need to incorporate a voluntary downgrade program. It will of course be far less expensive to downgrade the subscriber by computer than by truck roll.

Sales

--Providing you leave drops active and you assign fully authorized converters to your direct sales staff, they could be demonstrating your product in the home. Consider also that free previews will be far less complicated to conduct using addressability. No scheduling of service changes and no delay in responding to your subscriber's interest in upgrading. Wouldn't you also want a telemarketing staff to be selling additional premium services by phone?

CONCLUSIONS

The conversion plan Cox Cable employs is somewhat more complicated and detailed than this check list. It diagrams present and future converter flow through warehouse operations. It also is specific in identification of staff functions and support resources which will be changed by addressability or eliminated altogether.

For the operator who's convinced a conversion is right, my recommendation is to spend at least two days in an audit of system functions to determine how each will change with the conversion. After identifying the expense reductions, chart retraining requirements, and be sure you understand your communication requirements. If subscribers currently call installation for a change of service, for example, won't you want them calling customer service for instant authorization in the future? And what number do you have listed in your phone directory, newsletter, or subscriber information booklet?

If you have the right regulatory environment consistent with fair rate setting for addressable services and are careful in the detailed planning for conversion there is every reason to believe you can make one-way addressability pay in your system.

THE MAGIC TEE AMPLIFIER AND DISTRIBUTION SYSTEM PERFORMANCE

HARRY J. REICHERT, JR.

GENERAL INSTRUMENT JERROLD DIVISION

ABSTRACT

Various Hybrid Amplifier Circuit Configurations are being used in CATV Distribution equipment to improve output capability and provide better reliability.

The MAGIC TEE AMPLIFIER Configuration, which is the utilization of two Hybrid Integrated Circuits in parallel, will be treated in depth in this paper. An analysis of the circuitry and the performance characteristics that can be expected in the normal operating mode and various failure modes will be discussed.

Gain variation, Distortion and Noise Figure performance characteristics are compared to those of the conventional single hybrid circuit. Specific System Performance Degradation Analysis and Measurement data will be presented for MAGIC TEE AMPLIFIERS operating in "soft" failure modes. Also, the performance of MAGIC TEE and conventional single hybrid trunk amplifier cascades is compared.

INTRODUCTION

In response to the demand for cable television signal distribution equipment which has the capability of providing acceptable distortion performance with an ever increasing television signal load, equipment manufacturers are constantly looking for new technology and novel ways to use existing technology. Hybrid integrated circuit technology is continually being advanced as equipment manufacturers constantly convey the need for better distortion performance to the vendors of these circuits. However, the responsibility for improving equipment performance does not rest on the shoulders of the hybrid amplifier manufacturers alone. The equipment manufacturers must also be creative in approaching this problem and do whatever they can to improve the distortion performance of the equipment they supply.

While it is true that the basic distortion performance of cable television signal distribution equipment is controlled by the individual hybrid amplifier performance, the overall performance of this equipment can be improved by using these hybrid amplifiers in various circuit configurations. The MAGIC TEE amplifier is one of the circuit options available to equipment manufacturers which, when used as the output stage amplifier in distribution equipment, provides several advantages over the traditional single hybrid amplifier output stage.

THE MAGIC TEE AMPLIFIER

The basic form of this amplifier has been known to engineers for many years. However, as so often happens, the advantages of this circuit were not necessitated in cable television system distribution equipment until recently. Significantly better distortion performance, relative to the traditional single hybrid amplifier circuit, is the main reason for implementation at this time. However, there are other advantages provided by this circuit which will be detailed as the operation is explained. Figure 1 contains a block diagram which shows the major components of the Magic Tee amplifier.

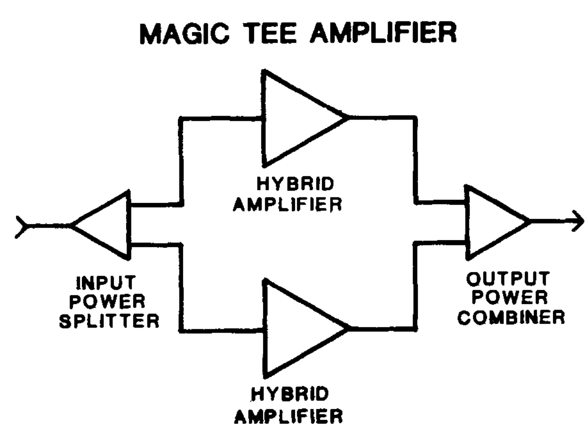


FIGURE 1

The components at issue in this circuit are the input power splitter and the output power combiner. Both of these circuits are constructed exactly the same and are of the circuit configuration known as the Magic Tee. The generally accepted schematic diagram for this circuit is contained in Figure 2.

MAGIC TEE CIRCUIT

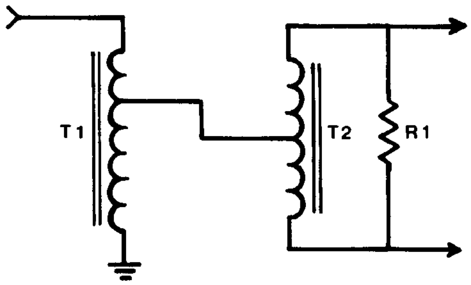


FIGURE 2

The importance of this circuit lies in the fact that it can be used to split a signal or combine two signals with a theoretical loss of 3 decibels. It also provides good isolation between the two output ports when used as a signal splitter and good isolation between the two input ports when used as a signal combiner. The significance of this port to port isolation will be explained later in this paper. The other two major components of the Magic Tee amplifier are the hybrid integrated circuit amplifiers. Let us assume that these are standard units available from several manufacturers.

In order to explain the operation of the Magic Tee amplifier, a signal flow diagram with signal level magnitudes at various key circuit locations will be used. For comparison purposes, a single hybrid integrated circuit amplifier is also provided. Both diagrams are contained in Figure 3.

Part "A" of this figure illustrates the performance that can be expected from a single hybrid. The amplifier output level and noise figure formulas are as follows:

OL = IL + HG

where: OL = Amplifier output level

IL = Input level

HG = Hybrid amplifier gain

NF = ONL - INL - HG

where: NF = Noise figure

ONL = Output noise level

INL = Input noise level

HG = Hybrid amplifier gain

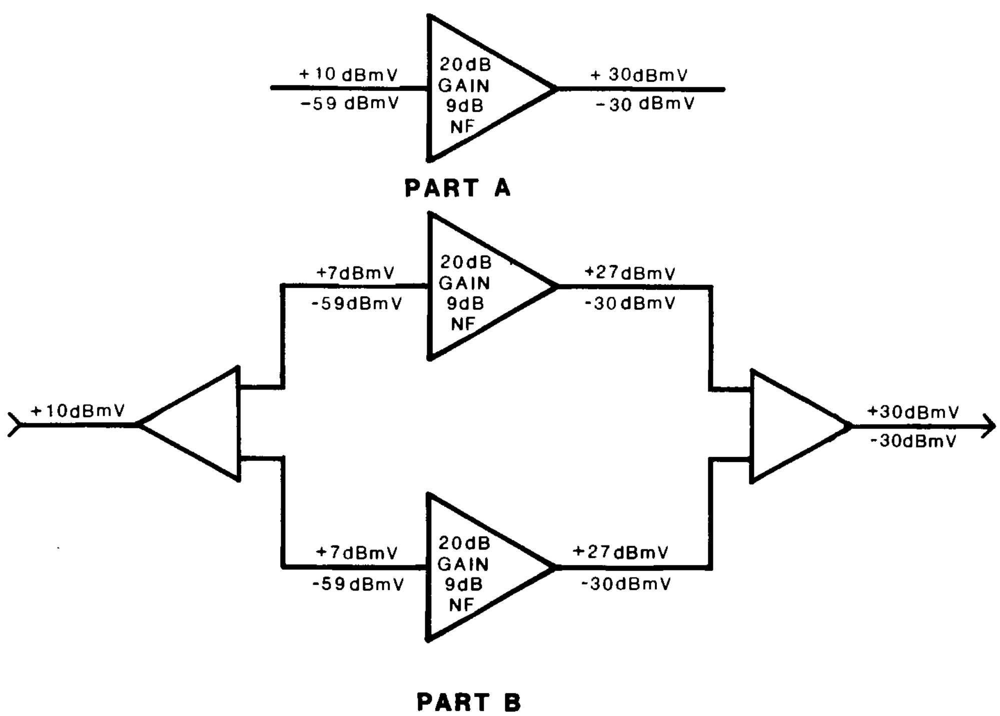


FIGURE 3

Part "B" of Figure 3 illustrates the theoretical performance that can be expected from a Magic Tee amplifier. The amplifier output level and noise figure formulas are as follows:

OL = IL + SHG

where: OL = Amplifier output level

IL′ = Amplifier input level

SHG = Single hybrid amplifier gain

NF = ONL - INL - SHG

where: NF = Noise figure

ONL = Output noise level

INL = Input noise level

SHG = Single hybrid gain

The operation of the single hybrid amplifier is straightforward. However, the operation of the Magic Tee amplifier is not as obvious. Therefore, a detailed explanation will be offered.

The key to correctly analyzing the operation of this amplifier is to view it as two hybrid amplifiers operating in parallel because this is exactly the case. The input splitter provides a signal to the input of each hybrid which is 3 dB lower than the signal level at the splitter common terminal. The output of each of the hybrids is attenuated 3 dB by the output signal combiner. Therefore, at the combiner common port there are two in phase signals which are 3 dB lower in level relative to each of the hybrid amplifier output levels. If both of these signals are of equal level then they will combine on a voltage basis producing one signal which is 3 dB higher in level relative to each of the hybrid amplifier output levels. If the output levels of the individual hybrid amplifiers are not equal then the two signals will combine on a voltage basis to produce one signal which will be less than 3 dB higher in level relative to the higher of the two hybrid amplifier output levels.

When analyzing the noise performance of the Magic Tee amplifier, the standard -59 dBmV must be used directly at the input to the individual hybrid amplifiers, not at the common terminal of the input splitter. The noise level at the output of each of the hybrids is attenuated 3 dB by the output combiner and these two signals arrive at the combiner common terminal. If the noise levels are equal then the resulting noise level will be 3 dB higher and will be equal to the noise output level of each of the hybrid amplifiers. It is important to note that at the output combiner of the Magic Tee amplifier the two signal voltages are coherent and therefore will add on a voltage basis. The two noise voltages will add on a power basis because they are incoherent as a result of being generated independently in each of the hybrid integrated circuit amplifiers.

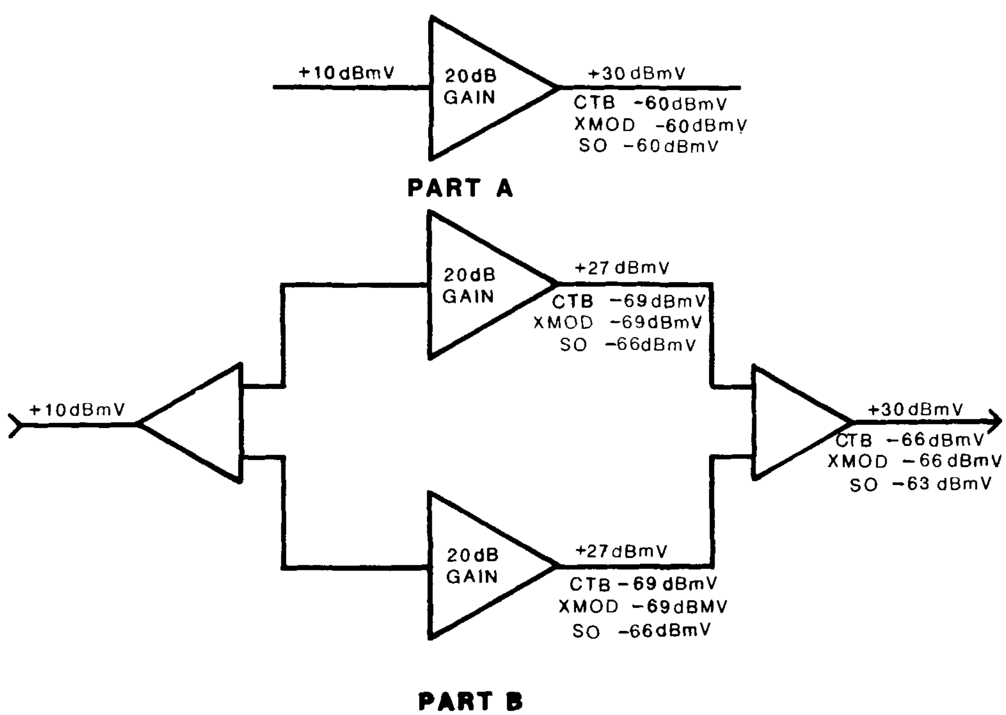


FIGURE 4

The distortion performance of the single hybrid amplifier and the Magic Tee amplifier are illustrated in Figure 4. The gain and signal levels are the same as those used for the previous exolanation. The arbitrary output capability chosen is maintained for both types of amplifiers.

The distortion performance improvement of the Magic Tee amplifier over the single hybrid amplifier can be directly attributed to the lower output level of the Magic Tee amplifier hybrids while still achieving the same total amplifier output signal level. As can be seen in Figure 4B, the theoretical output level of the hybrids will be 3 dB lower than the output level of the single hybrid amplifier which equates to an output capability improvement of 3.0 dB. Therefore, the relative distortion improvement for second order distortion products will be 3 dB and the relative distortion improvement for third order distortion products will be 6 dB. This distortion performance improvement holds true as long as the distortion contribution from each of the hybrids is the same. If the distortion contribution from the hybrids is not the same in terms of magnitude, then the Magic Tee amplifier averages the two distortion levels. The relationship between the distortion level difference between the hybrids used in a Magic Tee amplifier and the total distortion from the Magic Tee amplifier can be seen in Figure 5.

Refering to Figure 5, if the third order distortion contribution from each of the hybrids is the same, then the Magic

MAGIC TEE DISTORTION ADVANTAGE

THIRD ORDER

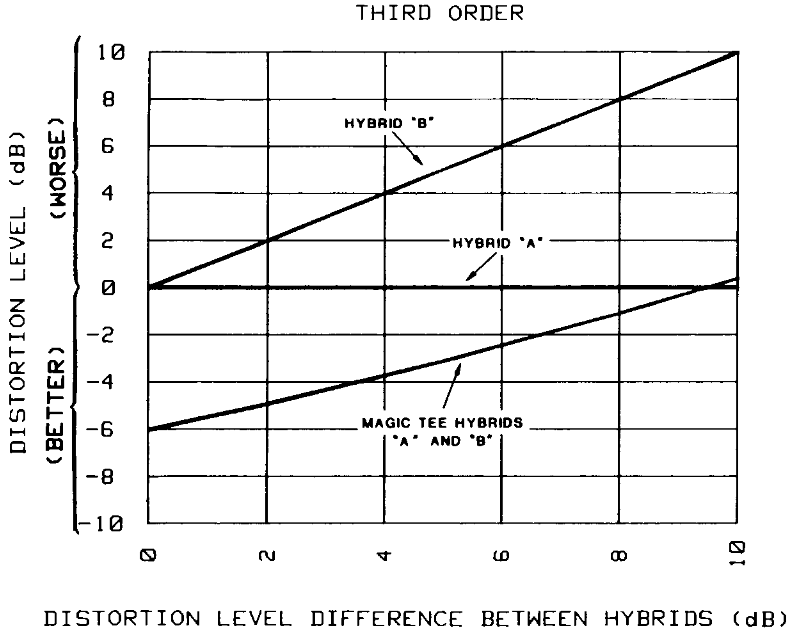


FIGURE 5

Tee amplifier will provide a 6 dB distortion advantage relative to one of the hybrids providing the same output level. However, if the distortion contribution from each of the hybrids is not the same, then the Magic Tee amplifier tends to average the contributions from each of the hybrids. For example, if there is a 4 dB difference between the distortion contribution from each of the hybrids, then the total distortion level from the Magic Tee amplifier will be 3.75 dB better than the best hybrid in the circuit and 7.75 dB better than the worst hybrid in the circuit. It is significant to note that this inherent distortion performance averaging provides more consistent overall distortion performance and tends to minimize the normal performance distribution of the hybrid integrated circuits.

Practical Applications

In practice, not all of the theoretical advantages are achieved. This is due primarily to the fact that the loss of the splitter and combiner exceeds the theoretical 3 dB loss by approximately 0.5 dB. This condition causes the signal arriving at the input to the hybrids to be 0.5 dB lower than the single hybrid case. This of course causes an apparent noise figure increase of 0.5 dB. Correspondingly, the signal level out of the hybrids must be approximately 0.5 dB higher than the theoretical signal level in order to produce a total amplifier output level equal to the single hybrid amplifier output level. Therefore, a real world Magic Tee amplifier provides 1 dB less gain, 2.5 dB second order distortion advantage and 5 dB third order distortion advantage relative to the single hybrid amplifier.

Laboratory Test Results

In order to verify the anticipated performance of the Magic Tee amplifier, relative to the single hybrid amplifier, many laboratory experiments have been conducted. The test data obtained from some of these experiments provides valuable insight into the real world performance of the Magic Tee amplifier.

Of primary importance is the gain provided by the Magic Tee amplifier relative to a single hybrid amplifier. The Magic Tee amplifier will provide approximately 1 dB less gain than one of the hybrids that is used in it. This condition results due to the greater than theoretical loss of the input splitter and output combiner. While this is an apparent disadvantage, there are advantages which are offsetting.

One of the advantages relative to the single hybrid amplifier becomes obvious when catastrophic hybrid failures are considered. If a single hybrid amplifier fails catastrophically, then there will be a signal level reduction of approximately 40 dB at the place of occurrence in the system. However, if one of the hybrids in the Magic Tee amplifier fails catastrophically, there will be a signal level reduction at the place of occurrence in the system of approximately 6 dB. This limited gain reduction is made possible by the isolation capabilities of the Magic Tee circuit. If a circuit is used which does not provide isolation from one hybrid to the other, such as a transformer, then signal level reductions of approximately 20 dB can be expected if one of the hybrids fails catastrophically. Supporting test data is provided in Figures 6 and 7.

MAGIC TEE CIRCUIT WITH ISOLATION

GAIN REDUCTION UNDER VARIOUS CONDITIONS

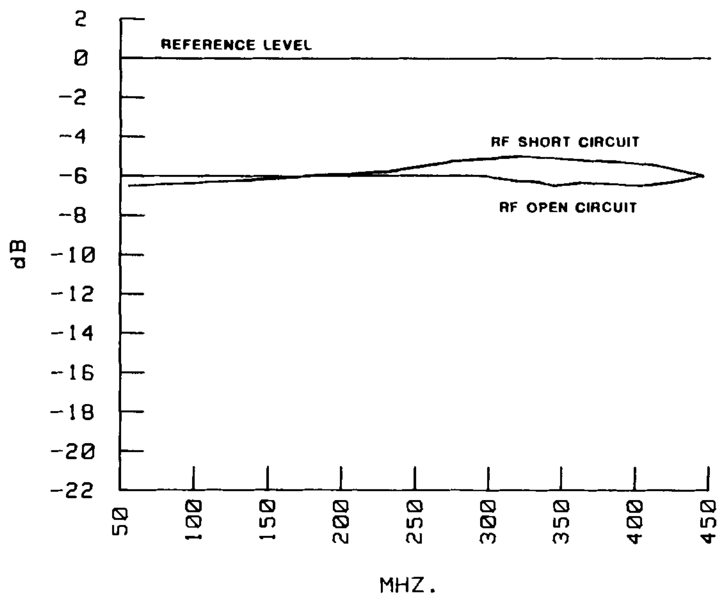


FIGURE 6

Figure 6 shows the gain reduction which resulted when catastrophic failure of one of the hybrids was simulated in a Magic Tee amplifier. Notice that for both the RF open circuit condition and the RF short circuit condition the gain reduction was close to 6 dB. When various "soft" failures of one of the hybrids was simulated, the resultant gain reductions fell between the reference and the open circuit plots. However, when this experiment was repeated using input and output circuits which provided very little isolation between the hybrids, the results were significantly different. This is illustrated in Figure 7. A low frequency gain reduction of approximately 20 dB was observed when a RF open circuit was simulated in one of the hybrid amplifiers.

TRANSFORMER CIRCUIT WITHOUT ISOLATION

GAIN REDUCTION UNDER VARIOUS CONDITIONS

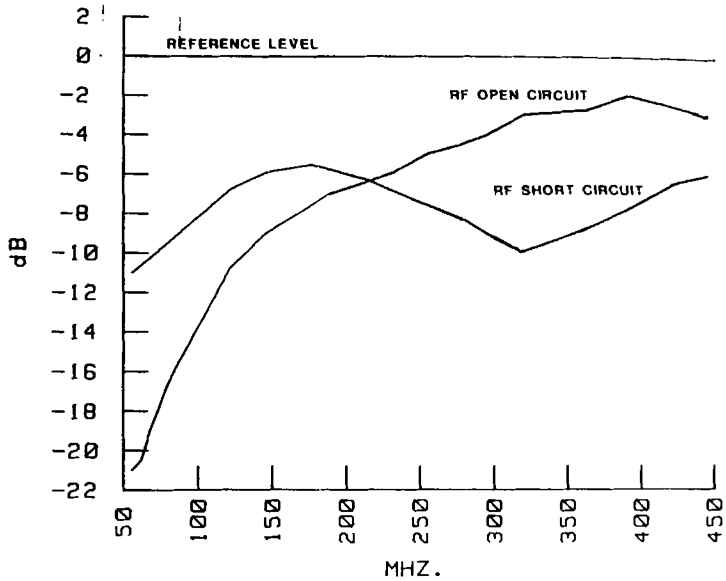


FIGURE 7

Therefore, in order to have as much control as possible over the resultant amplifier gain when a hybrid fails catastrophically, the input power splitter and the output power combiner must provide good isolation between the hybrids.

Distortion Performance

In order to establish a reference against which the performance of the Magic Tee amplifier could be compared, two hybrid integrated circuit amplifiers were characterized for distortion and noise figure performance. The two hybrids were then used in a Magic Tee amplifier and the same characterizations were performed.

60 CHANNEL COMPOSITE TRIPLE BEAT PERFORMANCE

OUTPUT @ +32dBMV W/6dB TILT.

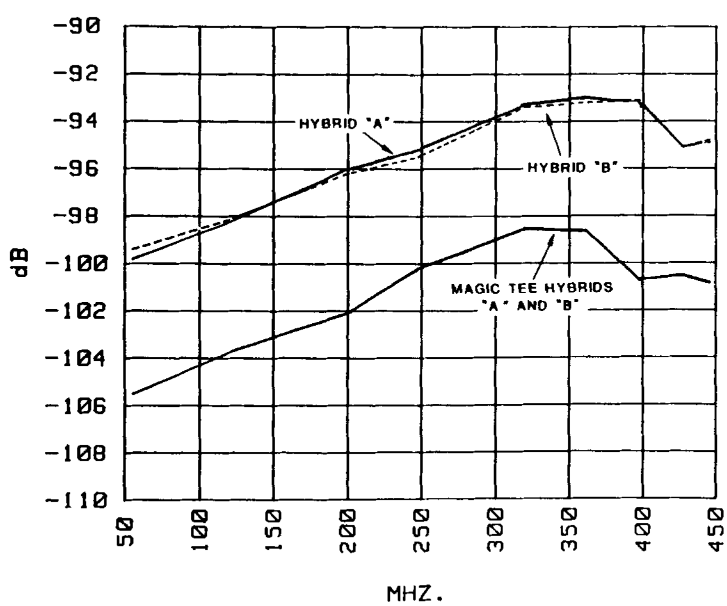


FIGURE 8

The composite triple beat performance obtained from each of the hybrids and the Magic Tee amplifier are contained in Figure 8. This comparison process was repeated for cross modulation and noise figure. The cross modulation data is presented in Figure 9 and the noise figure data is presented in Figure 10. In all cases the modified theoretical performance as detailed earlier was obtained. Note: In all cases, the distortion performance, at the typical trunk operating

60 CHANNEL CROSS MODULATION PERFORMANCE

OUTPUT @ +32dBMV W/6dB TILT.

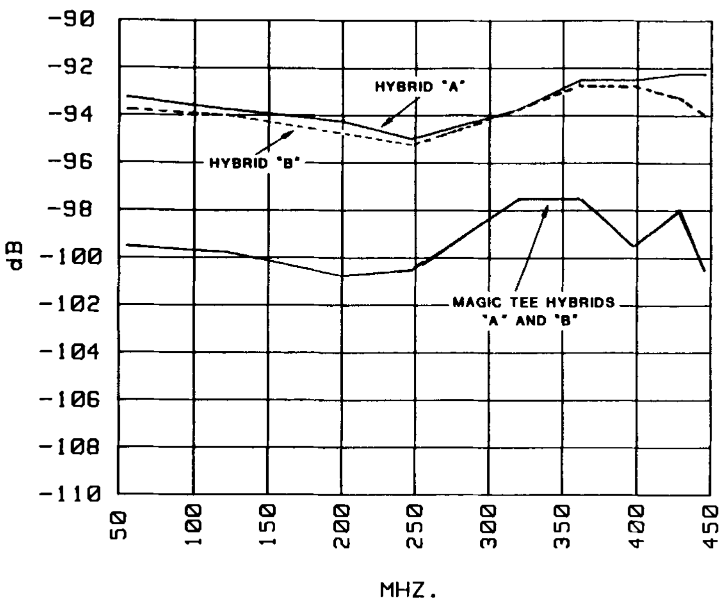


FIGURE 9

level of + 32 dBmV, has been projected from data obtained at higher output levels.

NOISE FIGURE PERFORMANCE

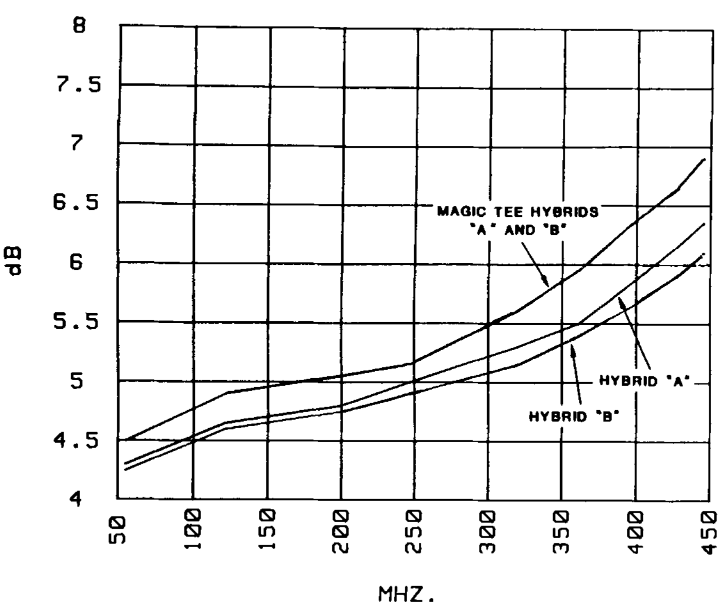


FIGURE 10

60 CHANNEL COMPOSITE TRIPLE BEAT PERFORMANCE

OUTPUT @ +32dBMV W/6dB TILT.

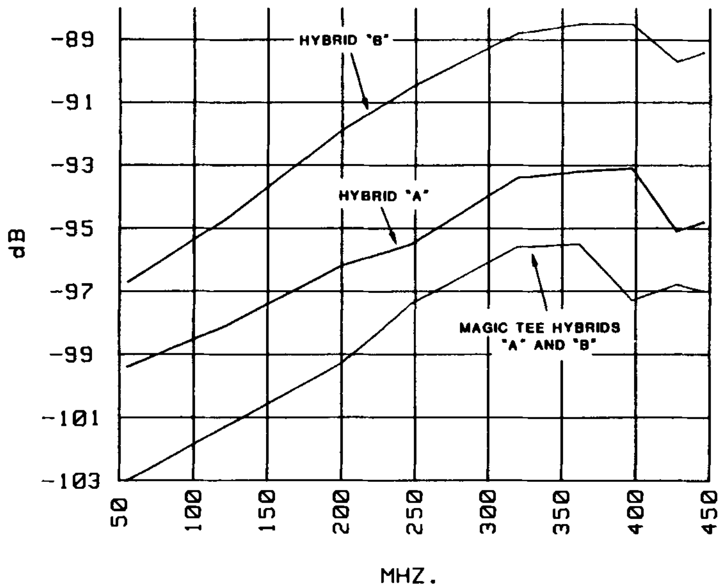


FIGURE 11

Due to the obvious significance of the theoretical distortion averaging capability of the Magic Tee amplifier circuit, an experiment was designed to prove or disprove this advantage. Two hybrids with significantly different composite triple beat performance capabilities were used in a Magic Tee amplifier circuit. The distortion performance obtained from each of the hybrids and the complete amplifier circuit are shown in Figure 11. The data clearly shows that the theoretical analysis presented earlier in this paper is correct when modified to reflect the real world performance in terms of distortion, of the Magic Tee amplifier.

System Performance Data

Eight trunk amplifiers were cascaded in order to verify that the distortion performance improvement observed for a single Magic Tee amplifier would also manifest itself when several amplifiers were cascaded. For comparison purposes, a cascade of traditional single hybrid output stage amplifiers of the same length was also constructed. While all operating conditions for the two cascades were maintained identical, substantially different distortion performance results were obtained from each. The composite triple beat performance of each cascade is contained in Figure 12. The cross modulation performance of each cascade is contained in Figure 13.

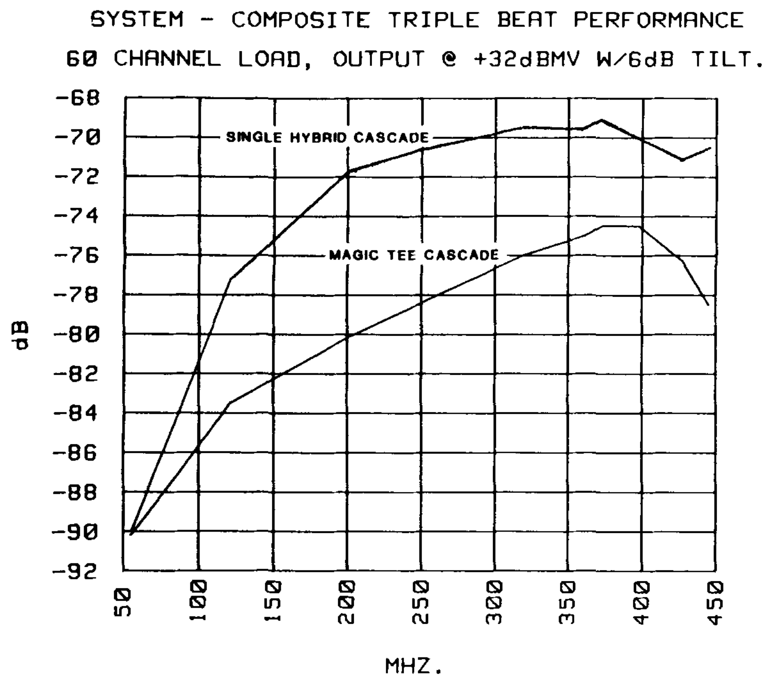


FIGURE 12

Figures 12 and 13 clearly indicate that the composite triple beat and cross modulation distortion performance of a Magic Tee amplifier cascade will provide the anticipated distortion improvement based on individual amplifier performance. It is for this reason that the Magic Tee amplifier is gaining widespread acceptance.

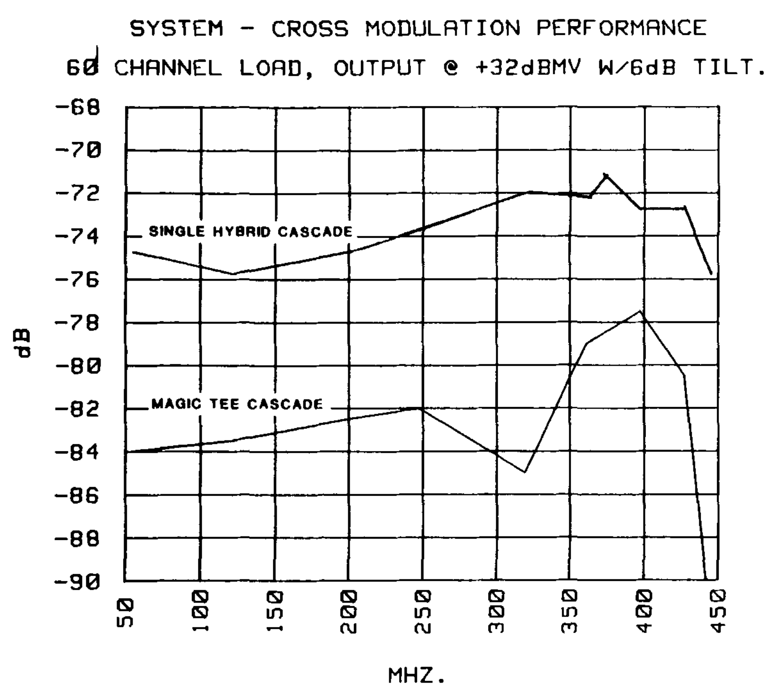


FIGURE 13

The second order performance of trunk amplifier cascades containing Magic Tee amplifiers will be the subject of a future paper. Phase matching and inverting techniques that can be used with this basic circuit configuration provide substantial latitude by which this distortion form can be minimized.

SUMMARY

In response to the demand for cable television system distribution equipment which can provide improved distortion performance, the Magic Tee amplifier has been implemented. This amplifier circuit is composed of a Magic Tee input power splitter, a Magic Tee output power combiner and two hybrid integrated circuit amplifiers. In theory, this amplifier will provide the same gain and noise figure, a 3 dB second order advantage and a 6 dB third order advantage relative to a single hybrid amplifier. In practice, due to the higher than theoretical loss of the input power splitter and the output power combiner, the Magic Tee amplifier provides approximately 1 dB less gain, 0.5 dB worse noise figure, a 2.5 dB second order advantage and a 5 dB third order advantage relative to a single hybrid amplifier. Inherent hybrid amplifier distortion averaging and limited gain reduction when one of the hybrid amplifiers fails catastrophically are other features of the Magic Tee amplifier.

TV CABLE TRANSMISSION UP TO 900MHz

GEORG LUETTGENAU

RF DEVICES DIVISION
TRW ELECTRONIC COMPONENT GROUP

ABSTRACT

Increased system bandwidth has been a technological trend for a number of years. Present-day amplifiers can handle full channel loading up to 550MHz.

There exist a number of requirements and possibilities which make an even wider frequency range desirable. Direct UHF distribution, as practiced and contemplated in Europe (and the U.S.) is one case. The thought of placing reverse transmissions into the higher frequency range has also been entertained. Obviously there are applications in MATV and similiar systems.

Hybrids suitable for the range from 40 through 900MHz have become available. This paper relates these devices to specific applications. Conventional performance characteristics are given and compared to "Noise-in-the-Slot" behaviour, which is a most revealing criterion for ultra wideband systems.

The feasibility of feedforward realizations based on these hybrids is discussed.

INTRODUCTION

The CATV industry seems to have an insatiable appetite for additional channel space. While in the past the justification for this has been the need to transmit more TV programs, other considerations have been voiced lately. The main theme is that the bulk of the UHF frequency range, which has been exclusively assigned to television signal transmission, is not available for CATV. Instead, cable transmissions have to share frequencies which are used by other services, resulting in the well-known problems of ingress and radition.

The reasons for the present situation are, of course, technical. Nothing ever seems to become easier as the frequency of operation is increased; losses are up, distortion rises, components become more critical. But it is also true that the same problems have existed in electronic communications since the beginning. Take transistors, for instance: The F_t of early devices was barely good enough for AM radios, now we operate at X-band.

Encouraged by progressive members of the CATV community, we felt the need to present our findings. To remain realistic, the maximum frequency of interest was limited to 900MHz. Hybrids with various output capabilities reading up or close to this frequency are available off-the-shelf. They are: VHF-UHF amplifiers used mainly for MATV, general purpose hybrids in TO-8 cans, and at least one specific CATV-type hybrid, appropriately called CA900.

The latter two types may be combined to form a high-gain circuit, which in turn becomes a candidate for a feedforward block.

In the following, the performance of these devices in 900MHz applications is discussed in detail.

900MHz CIRCUITS

The CA900

This hybrid consists of two cascaded common-emitter push-pull stages in a regular CATV package. It has a nominal gain of 17dB. The device has a CTB performance of -58.5dB measured with 85 channels, flat, 40dBmV.

It is a characteristic of the common emitter configuration that CTB remains rather flat vs. frequency. Therefore, one may predict with some confidence a CTB performance of -53.6dB for full channel loading over the enitre 900MHz band-width. This condition was simulated by broad-band noise loading, described later. Operation or testing with 150 channels ($\approx$900/6) at 46dBmV is an unrealistic proposition. As seen from the following test results, 85 channels at 46dBmV constitute substantial overloading.

Part Name	Lot Name	Unit	Level dBmV	Slope dB	V Volts	I Amps	No Chan	Chan Name	CTB dB
CA4800	SAMPLE	4532	46.0	0.0	24.0	0.229	85	H47	-41.8

Part Name	Lot Name	Unit	Level dBmV	Slope dB	V Volts	I Amps	No Chan	Chan Name	CTB dB
CA4800	SAMPLE	4532	40.0	0.0	24.0	0.230	85	H47	-58.5

FIGURE 1, CTB Readings of 900MHz Hybrid

Feedforward

For extra performance or when running against technological stops, the feedforward circuit has become an effective remedy.

The feasibility of a 900MHz feedforward gain block was studied. No prototypes exist at this time. However, all the necessary ingredients are there, so that, if called upon, a device could be realized.

As a matter of fact, it appears that all circuitry can be housed in the same package that is presently used for 500MHz feedforwards. For comparison this package is shown next to a 900MHz hybrid. (CA4800 is a 50 ohm version).

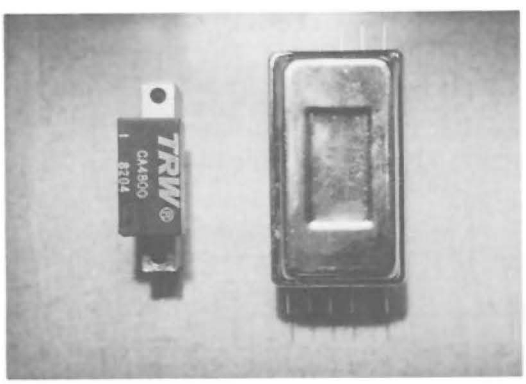


FIGURE 2, Feedforward Gain Block

The most important component is the gain block. A combination of the basic 900MHz circuit and a 15dB low-noise single ended pre-amp was breadboarded yielding a suitable 32dB block. One of the attractive properties of this arrangement is its excellent phase-linearity, brought about by the absence of transformers in the pre-amp and the use of transmission-line types in the final stages. This characteristic mates well with printed delay lines, which have an essentially linear phase. Delay-lines and directional couplers used in 550MHz feedforwards hold up remarkably up to 1000MHz; the main observed deteriorations being a few tenths of a dB increase in through-loss for the coupler and transmission loss for the delay line.

Based on measurements of the individual components, one may project a 21dB feedforward circuit with 20dB distortion improvement over that of the plain 17dB gain block.

900MHz TRUNK ANALYSIS

A program was written to determine the performance of the 900MHz circuits discussed in a trunk application. The extreme case of 150 channels and that of partial loading with 60 channels are analized. The following input data decks are self-explanatory with the exception of the value of interstage flat loss: The program automatically increases the number entered by 12% of station spacing to consider the necessary increase in range for tilt and gain controls. Further, the value of CTB is based on 46dBmV flat. Since the amplifier treated here are already in compression at this level, the number entered is measured data at 40dBmV plus 12dB.

TRUNK CTB	-57.
TRUNK CNR	43.
GAIN,BLOCK #1	17.5
GAIN-SLOPE,BLOCK #1	0.
NOISE FIG. BLOCK #1	9.
NF CHANGE, BLOCK #1	1.5
CTB BLOCK #1	-41.47
CTB CHANGE,BLOCK #1	0.
GAIN, BLOCK #2	17.5
GAIN-SLOPE BLOCK #2	0.
NOISE FIG. BLOCK #2	9.
NF CHANGE, BLOCK #2	1.5
CTB BLOCK #2	-41.47
CTB CHANGE BLOCK #2	0.
INPUT CKT FLAT LOSS	-1.5
INTERSTAGE FLAT LOSS	-10.
OUTPUT FLAT LOSS	-1.5

FIGURE 3, Input Data 2 X CA900

Because both CTB and Noise Figure vary very little vs. frequency, the performance cannot be improved by operating with a tilted spectrum. The summary of performance

STATION	2 X CA900
SPACING	19.6dB
NO. OF STATIONS	10
STATION OUTPUT	25.4dBmV
LOADING	150 Channels

Next the input data for a station consisting of two feedforward amplifiers:

TRUNK CTB	-57.
TRUNK CNR	43.
GAIN,BLOCK #1	21.
GAIN-SLOPE,BLOCK #1	0.
NOISE FIG. BLOCK #1	8.2
NF CHANGE, BLOCK #1	1.5
CTB BLOCK #1	-61.07
CTB CHANGE,BLOCK #1	0.
GAIN, BLOCK #2	21.
GAIN-SLOPE BLOCK #2	0.
NOISE FIG. BLOCK #2	8.2
NF CHANGE, BLOCK #2	1.5
CTB BLOCK #2	-61.07
CTB CHANGE BLOCK #2	0.
INPUT CKT FLAT LOSS	-1.5
INTERSTAGE FLAT LOSS	-10.
OUTPUT FLAT LOSS	-1.5

FIGURE 4, Input Data 2 X FF900

The results are:

STATION	2 X FF900
SPACING	25.9dB
NO. OF STATIONS	19
STATION OUTPUT	33.1dB
LOADING	150 Channels

This performance is similar to that obtainable with conventional hybrids at frequencies up to 400-500MHz.

The effect of partial loading of the amplifiers may be simulated by an improvement in amplifier CTB by approx. 20 * log (channels/150). Because of the insensitivity to frequency of operation mentioned before, the loading may be at any segment of the total available 900MHz. Following are the computer analysis results for 60 channels:

STATION	2 X CA900
SPACING	19.6dB
NO. OF STATIONS	16
STATION OUTPUT	27.5dBmV
LOADING	60 Channels

STATION	2 X FF900
SPACING	25.9dB
NO. OF STATIONS	30
STATION OUTPUT	35.1dBmV
LOADING	60 Channels

NOISE-IN-THE-SLOT

As the number of channels is increased, test equipment and test procedures become more cumbersome and expensive. As a possible alternative, or perhaps a complement to conventional distortion testing, a test method was investigated which has been applied successfully in the areas of microwave and telephone transmissions. Its popular identification is that of the "Noise-in-the-Slot method".

The principle is to drive an amplifier (or system) with a spectrum of white noise, such that the total output noise power corresponds to the summation of all the signal powers delivered by the amplifier under normal test conditions. A sharp notch filter is inserted before the amplifier, thus creating an empty slot in the drive spectrum. At the output of the amplifier inter-modulation noise will cause a partial filling of the slot. The exact distortion level can be measured with a selective meter such as a spectrum analyzer. Although equipment to perform such tests is commercially available, a noise source and notch filter were built in order to gain more "hands-on" experience.

Noise Source

A suitable source was obtained by cascading four general purpose 1GHz amplifiers type 1006 with a combined gain of 76 dB. This chain was driven by an HP Noise Source with a Noise Figure of 15dB. The expensive Noise Source could be replaced by another GPA which would be equivalent to a Noise Source with an approximate Noise Figure of 23.5dB. Figure 5 shows the four-amplifier cascade.

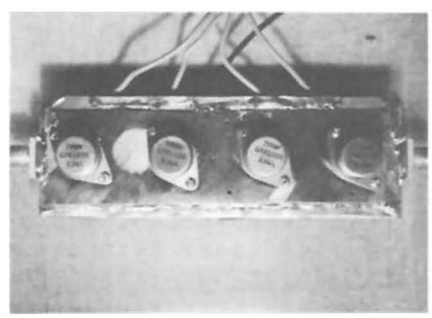


FIGURE 5, Noise Amplifier

Notch Filter

Somewhat arbitrarily the slot was placed at 750MHz. The filter used consisted of two quarter-wave sections of semi-rigid coax and three identical series traps, as shown

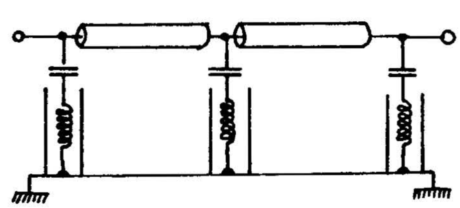


FIGURE 6, 750MHZ Band-stop Filter

The responses of the filter, S_{21} and S_{11}, are shown on the following photograph. Horizontal sweep is 5MHz/division, vertical resolution is 10dB/division.

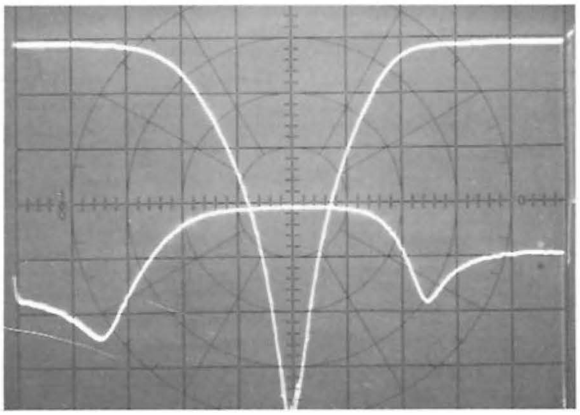


FIGURE 7,Response of Notch Filter

Noise Test

Following is a block diagram of the entire test set-up.

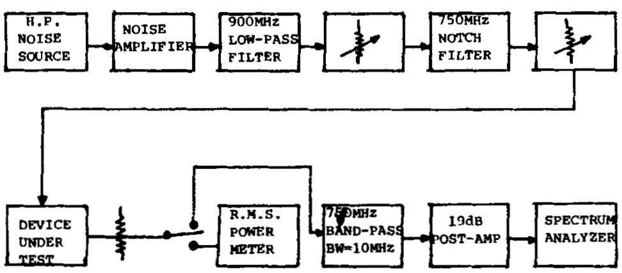


FIGURE 8, Test Set-up Block Diagram

The input noise spectrum was limited from 900MHz on by a three-pole low-pass filter. The amplifier under test was buffered by loss-pads at both input and output to avoid changes in performance due to the VSWR of adjacent filters.

The test procedure was as follows: Over a range of 20dB the input noise power was varied in steps of 1dB. The total 900 MHz Noise power was measured with a true RMS power meter and recorded for each attenuator setting. The range of output powers was from about one to one-hundred milliwatts. The next photo shows the output displayed on a spectrum analyzer.

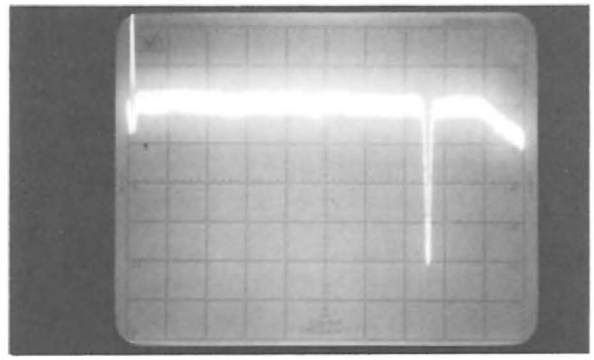


FIGURE 9, Output Noise Spectrum

The notch depth is not as deep as on Figure 6, because intermodulation is generated in the amplifier and spectrum analyzer.

Subsequently the distortion products were measured for each attenuator setting by tuning the spectrum analyzer carefully to the deepest point of the slot. Settings were: Zero-span, 1MHz BW, Video Filter 100Hz. The spectrum analyzer was calibrated in dBm (HP Model 8565A). By making the proper bandwidth and impedance conversions and taking into consideration the gain of the post-amp circuitry, dBm readings were converted to dBmV, RMS in a 6MHz segment, in a 75 ohm system.

Following are two plots, one in dBmV, the other one in millivolts, of the signal-to-intermodulation relationship.

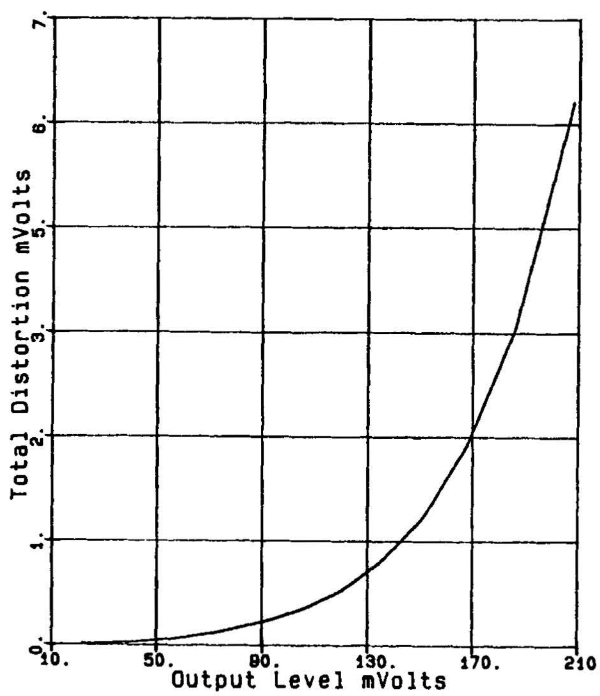


FIGURE 10, Intermodulation Noise - mV

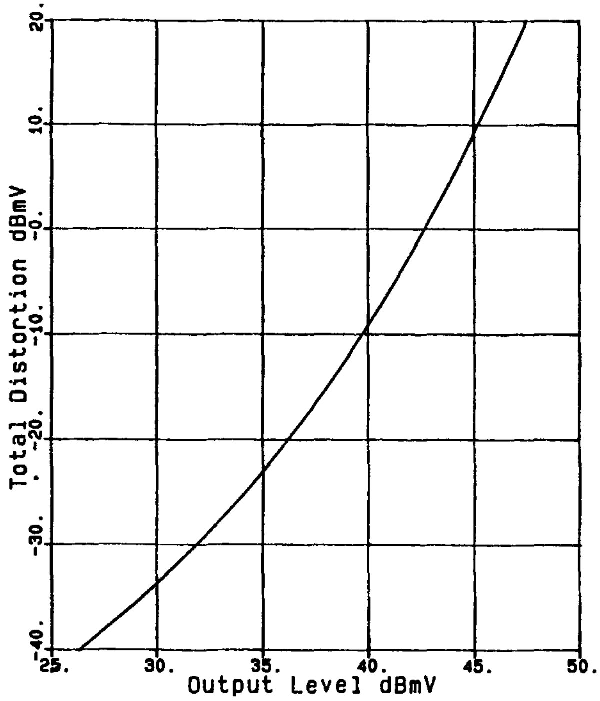


FIGURE 11, Intermodulation Noise-dBmV

Figure 11 reveals the increase in slope from 2:1 at low levels to more than twice that at high levels. This indicates primarily second-order distortion at low levels, with increasing amounts of higher-order components, possibly up to fifth order, as the output rises. For HRC Systems, which are likely candidates for high capacity installations, total composite distortion is a good quality indicator, since all distortion products, regardless of order, show up as "apparent cross-modulation". On the other hand, for conventional systems, and to predict distortion build-up in trunks, it is of interest to know the individual components of the total intermodulation noise. The data which went into Figure 10, may be used as a base for a mathematical analysis,which yields just that type of information.

Following is a computer print-out which lists the values of composite N-th order distortion, in dB, relative to carrier-equivalent noise. At 26dBmV the dominant distortion is of second order, while @ 46dBmV 4-th and 5-th order magnitudes indicate heavy overload.

Output Level dBmV	Distortions 2nd Order	3rd Order	4th Order	5th Order
26.80	-67.43	-79.17	-96.24	-116.00
27.80	-66.43	-77.17	-93.24	-112.00
28.80	-65.43	-75.17	-90.24	-108.00
29.80	-64.43	-73.17	-87.24	-104.00
30.80	-63.43	-71.17	-84.24	-100.00
31.70	-62.53	-69.37	-81.54	-96.40
32.70	-61.53	-67.37	-78.54	-92.40
33.70	-60.53	-65.37	-75.54	-88.40
34.60	-59.63	-63.57	-72.84	-84.80
35.60	-58.63	-61.57	-69.84	-80.80
36.60	-57.63	-59.57	-66.84	-76.80
37.60	-56.63	-57.57	-63.84	-72.80
38.60	-55.63	-55.57	-60.84	-68.80
39.60	-54.63	-53.57	-57.84	-64.80
40.60	-53.63	-51.57	-54.84	-60.80
41.60	-52.63	-49.57	-51.84	-56.80
42.60	-51.63	-47.57	-48.84	-52.80
43.60	-50.63	-45.57	-45.84	-48.80
44.50	-49.73	-43.77	-43.14	-45.20
45.40	-48.83	-41.97	-40.44	-41.60
46.40	-47.83	-39.97	-37.44	-37.60

FIGURE 12, Intermodulation by Order

The third order distortion at 40dBmV can be interpolated to be be 52.8dB. It must be pointed out at this time that all levels quoted and used in calculations are true RMS values. When calibrating the spectrum analyzer, it was (once again) observed that the spectrum analyzer noise reading was about 2.5dB below the power meter reading. Since the industry has become accustomed to quoting CTB in terms of spectrum analyzer indication, without applying a correction factor, -52.8dB corresponds to -55.3 db in customary terms. Applying further a a correction of -4.9dB to relate 150 channel performance to 85 channels, finally yields -60.2dB, which is within about 1.5 dB of the value of the convential 85-CH CTB for this device. This remarkable correlation is encouraging, but may have to be substantiated by further testing and method refinement.

CONCLUSION

The data shown and the projections made, indicate that technology has reached a level, where operation up to 900MHz is feasible.

A practical noise-loading test for very high capacity systems has been demonstrated, which yields new and interesting insight into the distortion behavior of CATV circuits.

TWO-WAY CABLE PLANT CHARACTERISTICS

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ABSTRACT

Two-way cable plant characteristics, specifically of the return plant, are needed to aid cable operators and cable engineers in understanding the problems encountered in a return plant. This is extremely important with the advent of two-way interactive services being included in franchise contracts.

Data from twelve operating two-way plants was gathered and correlated, resulting in a "composite" or typical return plant. From this "composite", five major characteristics were constructed and analyzed. These five characteristics are: white noise floor, the tunneling effect; ingress, unwanted external signals; common mode distortion, the difference products resulting from forward plant rectification; impulse noise, specifically 60 Hz power line contributions; and amplifier nonlinearities.

INTRODUCTION

The five characteristics of a return plant (white noise, ingress, common mode distortion, impulse noise and amplifier nonlinearities), will be discusssed individually with data taken from one or more of the twelve analyzed cable plants illustrating a particular characteristic. Following the discussions of each characteristic, a sampling of the twelve return plant measurements will be presented. In conclusion, a return plant "composite" will be constructed depicting the characteristics of a "typical" return plant.

RETURN PLANT CHARACTERISTICS

White Noise

The white noise of a return plant, like the forward plant, is based on the thermal noise of a 75 ohm terminating resistor, the bandwidth under consideration, the amplifiers noise figure and the number of amplifiers. The noise floor of a return plant differs from the forward plant in one fundamental concept: noise funnelling.

A 75 ohm terminator in the plant generates thermal noise. This noise is carried through each return distribution amplifier, which adds its own noise, and bridged to the trunk. Noise figure is a method of measuring amplifier noise contribution. The return trunk amplifiers carry this distribution noise to the headend, also adding their own noise. Since all distribution has a 75 ohm terminator, each distribution leg adds its own noise to the trunk system. This "addition" of noise from each distribution leg is called "noise funnelling". Since each amplifier, both trunk and distribution, contributes its own noise to the return system, the total number of amplifiers in a cable plant is used to calculate the return plant noise floor. This is different from the forward plant noise floor calculations, where only the longest cascade is required.

A common plant design uses a 0 db or unity gain design scheme. If this scheme is assumed, then the white noise floor of a return plant can be calculated using equation (1).

$$\text{WN floor (dbmv)} = -59 + 10\log(\text{BW}/4\text{Mhz}) + \text{nf} + 10\log(\text{N}) \quad (1)$$

where

- -59 = noise generated by a 75 ohm resistor in a 4Mhz bandwidth in dbmv.
- BW = bandwidth other than 4Mhz.
- nf = amplifier noise figure (assuming the same for all amplifiers).
- N = total number of amplifiers in the cable system.

The following example illustrates the use of equation (1):

Example:

A cable plant with 14,000 subscribers consists of 642 amplifiers with a noise figure of 7 db. Assuming a unity gain design and a noise bandwidth of 100Khz, calculate the return plant white noise floor.

$$\text{WN floor} = -59 + 10\log(100\text{Khz}/4\text{Mhz}) + 7 + 10\log(642)$$
$$\text{WN floor} = -59 - 16.02 + 7 + 28.08$$
$$\text{WN floor} = -39.94 \text{ dbmv}$$

Fig. 1 shows the return plant spectrum of an actual cable plant with the specifications described in the above example. The results of equation (2) correlate well with the measured data. The nominal or reference level shown is a typical return plant operating level of 20 dbmv. If a return signal is at 20 dbmv then the carrier to noise ratio, C/N, is 59.94 db.

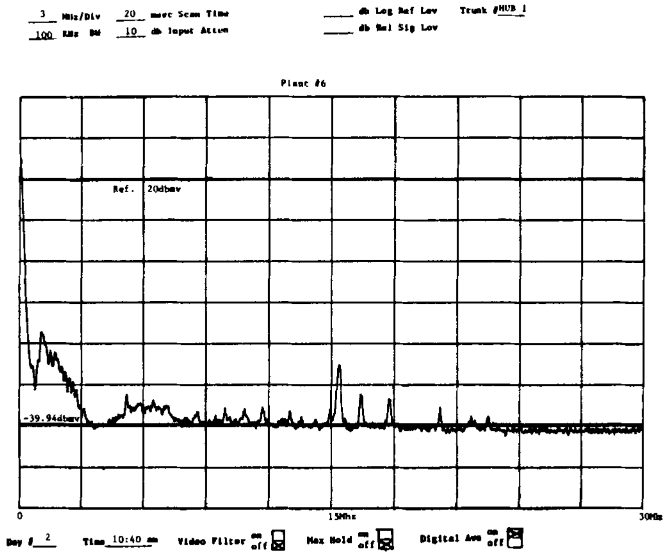


Fig. 1

The cable plant of fig. 1 is a very "clean" plant. Fig. 2 shows a return plant that is quite different. In Fig. 2 the lower graph is an 8-hour average of spectrum analyzer sweeps taken every six seconds with 100Khz bandwidth. The upper graph is an average of 8 one-hour interval quasi-peaks. The quasi-peak is the peak value of each frequency, during the one-hour interval, of a ten-sweep average. This method retains the peak value of time varying signals but eliminates impluse noise. The specifications of this plant are 31,000 subscribers, 2312 amplifiers with a noise figure of 9 db, and a unity gain design. Using 100Khz as a bandwidth and these specifications, equation (1) yields a white noise floor of -32.38 dbmv with a C/N of 52.28 db.

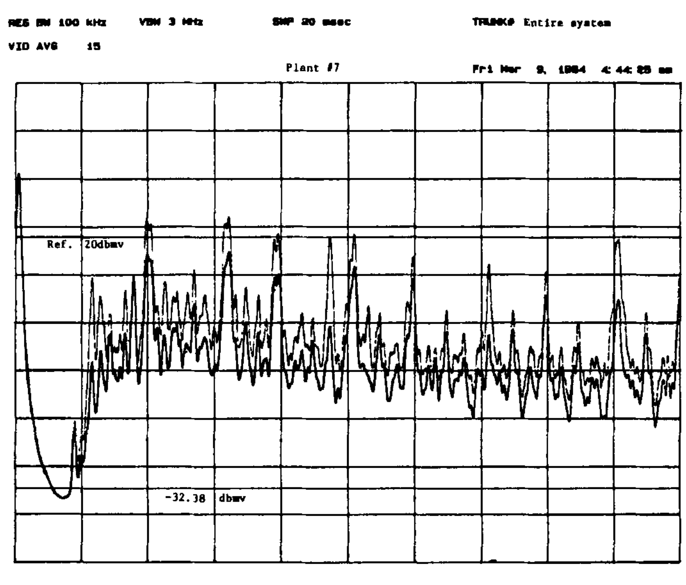


Fig. 2

The calculated white noise floor is significantly lower than the measured noise floor. The graph shows numerous extraneous signals. These signals and their associated sidebands raise the noise floor of the return plant above the calculated noise floor. The C/N appears to vary from 25 db at 6Mhz to 32 db at 24Mhz. These extraneous signals are the result of ingress and common mode distortion.

Ingress

Ingress is defined as unwanted external signals entering the cable plant. These signals enter the plant at weak points in the cable system. The most common weak points are drops and/or faulty connectors where shield discontinuities or breaks reduce the ground shield effectiveness. The common ingress sources found in a return plant are amateur radio operators, citizen's band operators, local AM broadcast, local shortwave and international shortwave. Fig. 3 shows the locations of these possible ingress sources on a return plant spectrum. It is clear that any return plant communications system may be adversely affected by these unwanted signals.

In fig. 3 the solid bars indicate shortwave bands, the crosshatched bar citizen's band, the diagonal bars amateur radio bands and the dotted bar AM broadcast.

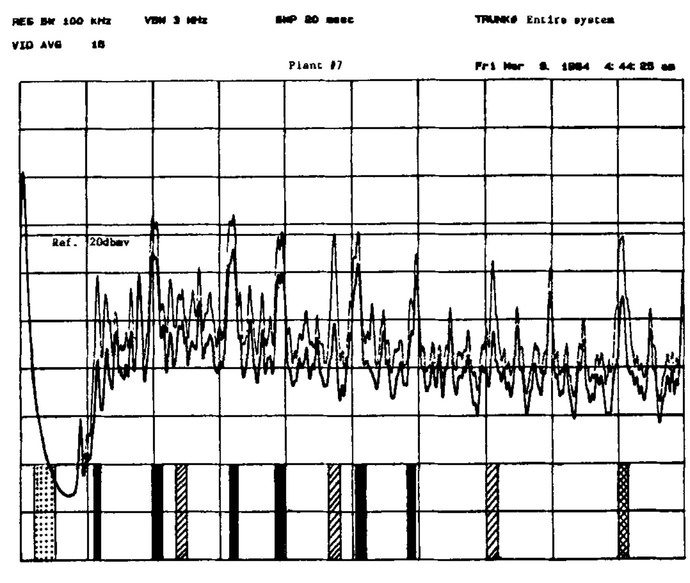


Fig. 3

Amateur radio and citizen's band ingress are a result of local operators transmitting near a cable plant in close proximity to bad connectors and/or poor shielding. Entry points for these ingress types are not difficult to locate if code operated switches are available.

AM broadcast and shortwave, especially international shortwave, are another matter. Field intensities for these signals are constant in almost the entire plant distribution. Consequently, determining the entry points of these signals becomes much more difficult.

Five major international shortwave bands appear in the return plant: 5.95-6.2Mhz, 9.5-9.775Mhz, 11.7-11.975Mhz, 15.1-15.45Mhz, and 17.7-17.9Mhz. Fig. 4 and fig. 5 show the spectra of two of these shortwave bands.

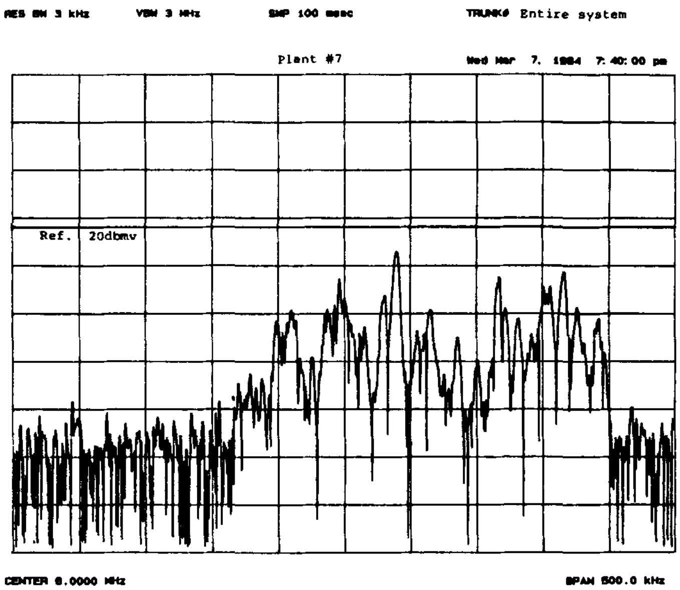


Fig. 4

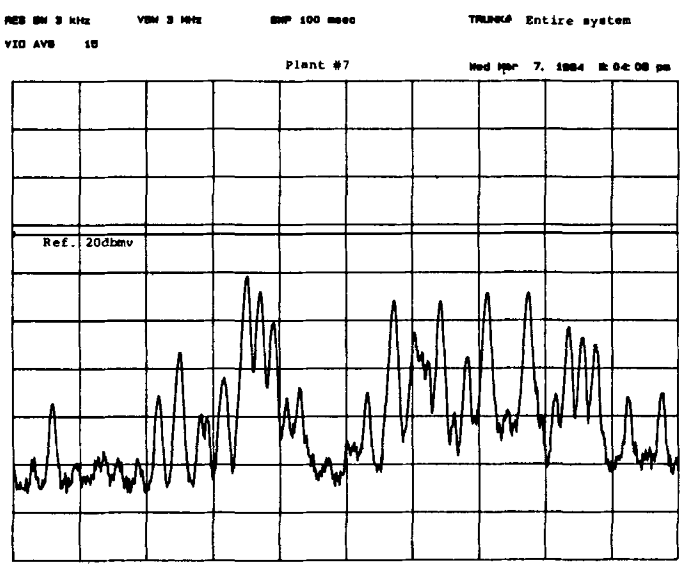


Fig. 5

An interesting characteristic of international shortwave signals worth noting is its time variation. These shortwave signals, commonly originating in Europe and the Far East, reach the United States via the "skip" phenomenon. This "skip" is accomplished by signals reflecting off atmospheric layers. The "skip" area is usually located midway between the source and receiving points.

Temperature has a positive gradient effect on the reflective atmospheric layers. As these layers are warmed by the sun, they rise, increasing the reflecting height, causing the receiving point to increase in distance from the source. The opposite is also true. In general, the shortwave bands vary in the following manner: 5.95-6.2Mhz, active at night, decreasing in the daytime; 9.5-9.775Mhz, activity varies several times during the day and night; 11.7-11.975Mhz, 15.1-15.45Mhz and 17.7-17.9Mhz, active during the day, decreasing at night. Fig. 6 was taken from the same cable plant as fig. 4 but at a different time during the day. Fig. 4 shows active international shortwave while fig. 6 shows no activity.

Fig. 6 shows another characteristic in a return plant: common mode distortion.

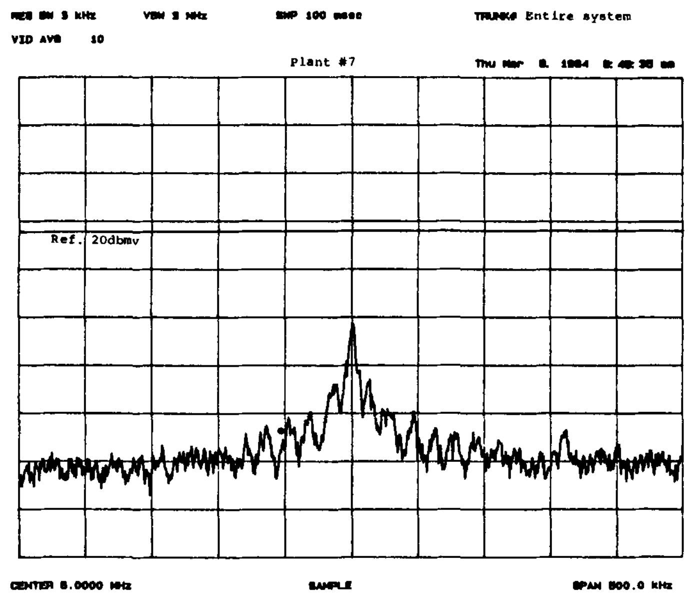


Fig. 6

Common Mode Distortion

Common mode distortion, also known as common path distortion, is the result of nonlinearities in the cable system that are not a result of active devices. This nonlinear function is generated by corrosion in the cable plant connectors, commonly in distribution, when oxide forms between two metal surfaces, creating a point contact diode. This diode may appear in the ground portion of the connector, thereby producing common mode distortion and allowing ingress to penetrate the plant, or it may appear in the center conductor, producing only common mode distortion.

The effect of this diode creates problems in both the forward and return plants. When the forward plant signals drive this diode, sum products of the driving signals may appear in upper channels of the forward plant, producing unwanted frequency beats. In the return plant the difference products are present and their effect is more dominating.

In all systems a majority of the forward or driving signals are 6Mhz apart. When these signals drive a nonlinearity, the difference products will always appear at 6Mhz and its harmonic multiples. A return plant with common mode distortion produced by these difference products has a spectrum consisting of frequencies at 6Mhz, 12Mhz, 18Mhz, 24Mhz, 30Mhz, etc. This phenomenon was discussed and published by Reichert in 1982.[1] Fig. 7 indicates where these signals reside.

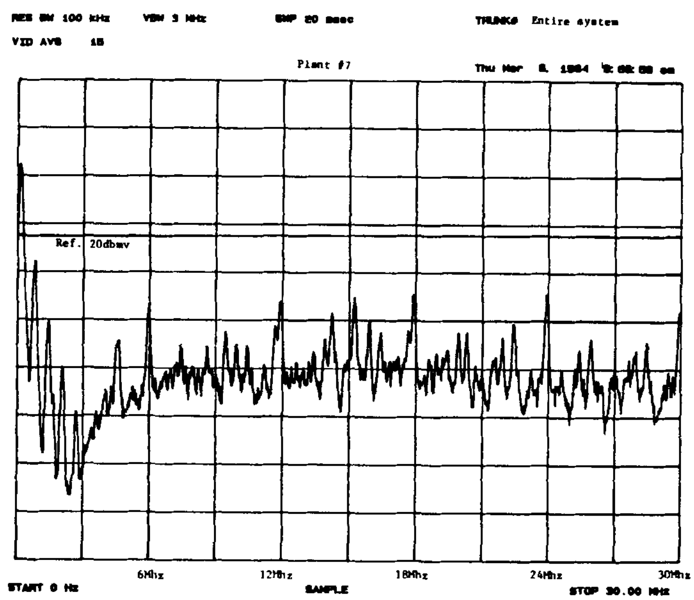


Fig. 7

Fig. 3 also has common mode distortion present but the 6Mhz and the 12Mhz are dominated by international shortwave signals. Fig. 8 shows the common mode distortion at 6Mhz with symmetrical sidebands. These sidebands are at 15,734Hz intervals, which are the harmonics of the video horizontal sweep.

Fig. 9 and fig. 10 show the spectra of the 12Mhz and the 18Mhz common mode distortion products.The frequency area just below 12Mhz and 18Mhz are sections of the international shortwave bands.

These nonlinear effects seen in the return plant can be the result of one faulty connector or many faulty connectors. The actual number is indeterminant. These nonlinear transfer functions vary from diode to diode. Consequently, the resultant effect on the return plant can be generated by one, several or many connectors, depending on the extent of corrosion. This makes maintenance very difficult and time consuming without code operated switches.

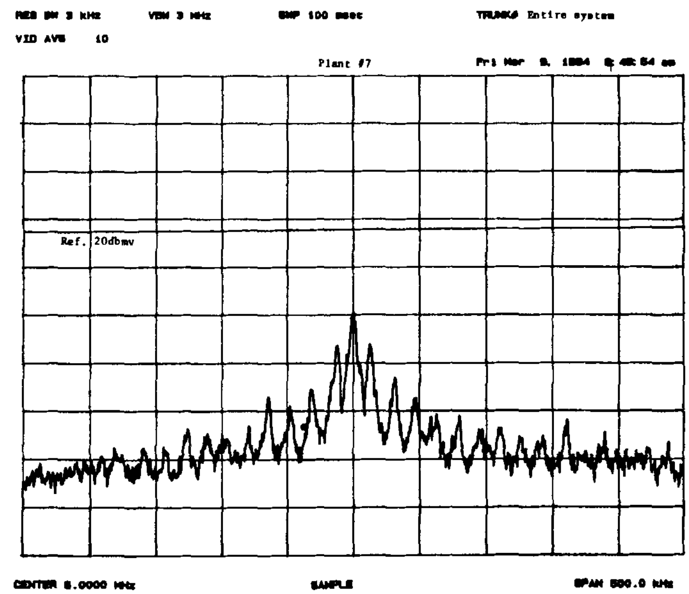


Fig. 8

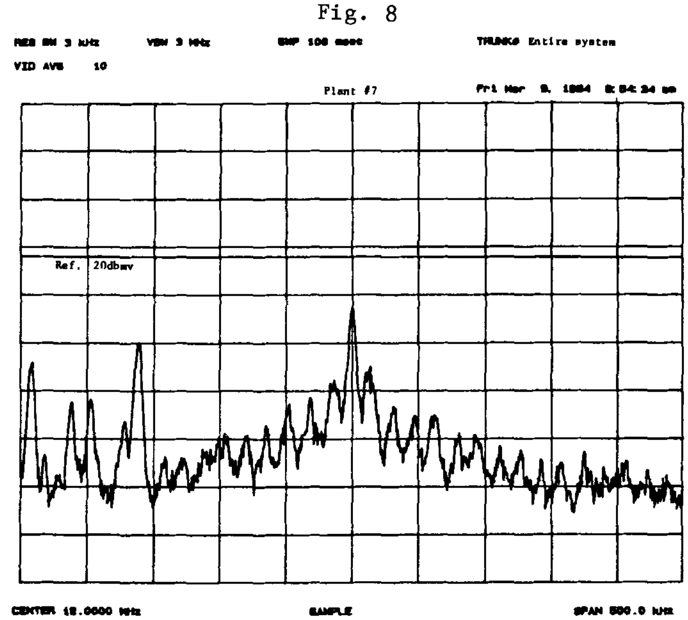


Fig. 9

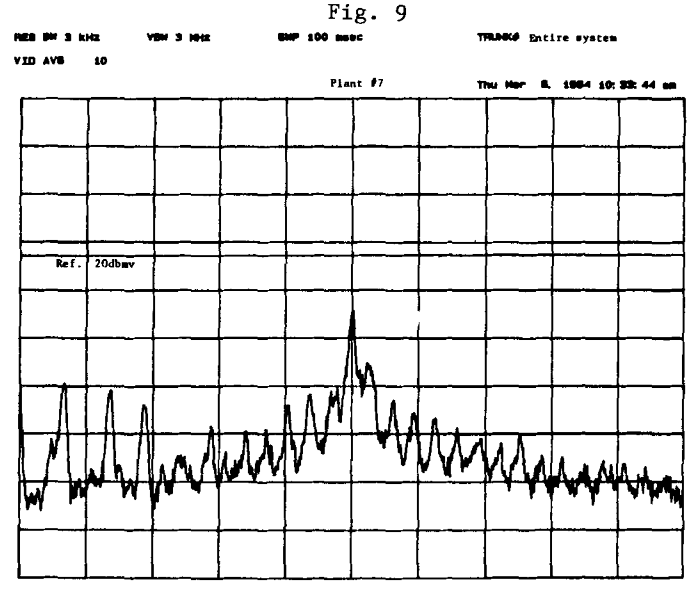


Fig. 10

The amount of common mode distortion can vary from day to day and even hour to hour in the same cable plant. In some systems, the common mode distortion level remains relatively constant, while in others it may vary a great deal. Since common mode distortion is a nonlinear exponential effect, slight variations in forward levels will cause significant changes in common mode levels. Fig. 11 and fig. 12 show how 6Mhz common mode distortion can vary in the same plant. Speculation has it that weather conditions, such as temperature, humidity and wind velocity, play a major role in physically altering the point contact diode structure of the connector thereby affecting the nonlinear tansfer function.

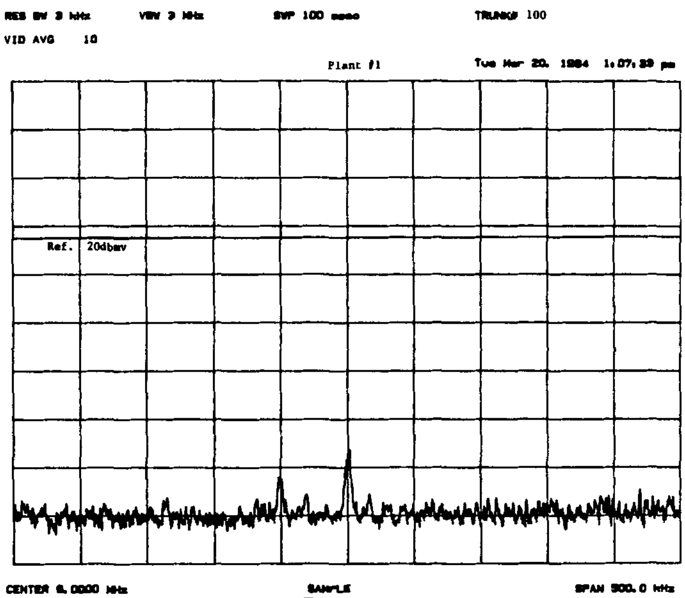


Fig. 11

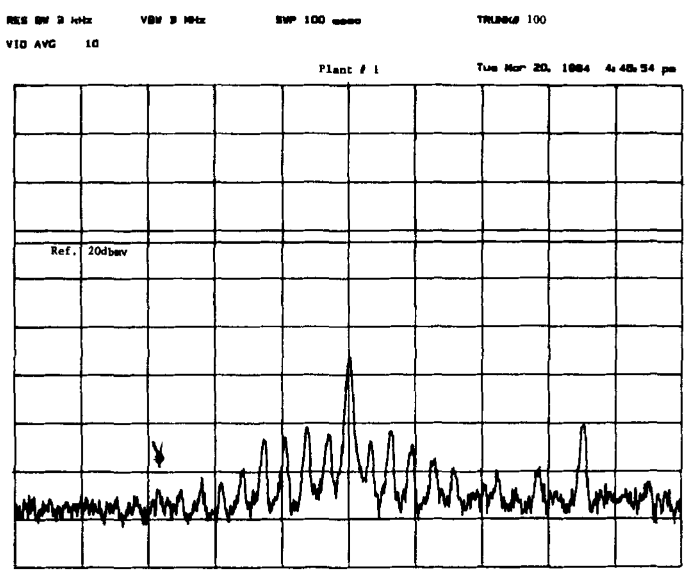


Fig. 12

When common mode distortion is present, it is either time invariant or slowly time varying. A characteristic of a return plant that is randomly time variant is impulse noise.

Impulse Noise

By far the dominant source of impulse noise in a return plant is 60Hz high voltage lines. There are two types of discharge noise that are associated with high voltage lines: corona and gap noise. Corona is a result of high voltage energy actually discharging into the air. This is primarily on 300Kv or higher lines and it is random in nature. Temperature and humidity play a vital role in this phenomenon. The other type of discharge, gap noise, is a direct result of a system fault. This fault is usually a bad or cracked insulator. When the voltage on the line rises to near the peak level, either positive or negative, a discharge through the insulator's discontinuity takes place. This can occur on 100Kv lines as well as 300Kv lines. Since discharge takes place on both peaks, the spectrum of this discharge has impulses at 120Hz intervals. This discharge or arc has a duration in the microsecond region with very sharp rise and fall times. Consequently the spectrum can extend into the tens of megahertz range at 120Hz intervals. If the discharge time is fairly constant, then the frequency spectrum takes on a sin x/x distribution.

There are two ways this interference can enter a return plant. One way is through bad connectors, entering the plant by the same mechanism as shortwave ingress. The other way is due to insufficient ground of the cable shield.

Fig. 13 compares the average peak power of a return plant with its average power. The upper graph is the average peak power which is dominated by gap noise power.

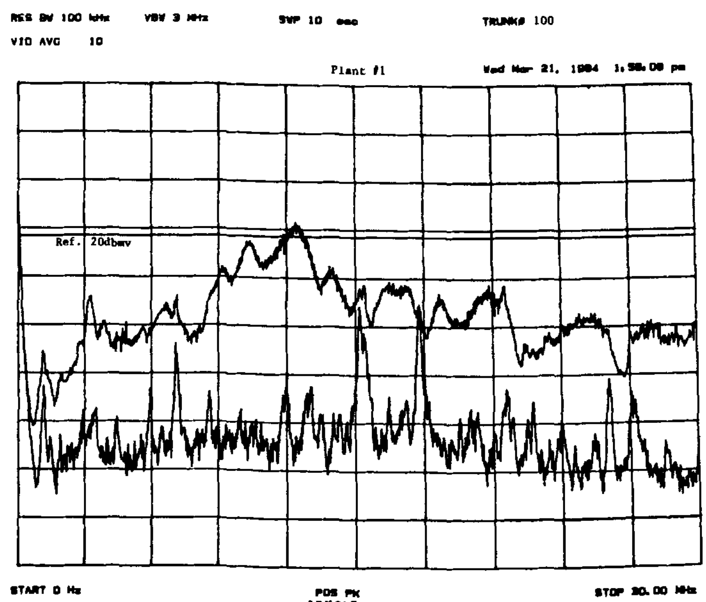


Fig. 13

The spectrum analyzer used in these measurements uses a positive peak detector for measuring the average peak power. A digital average algorithm is used on the data taken from ten sweeps. This measurement technique captures impulses in the return plant which appear at a relatively constant rate. Because this technique weighs each signal by a certain fraction, it eliminates impulses that occur only once or twice during the ten sweeps. The lower graph uses the same digital average algorithm except a sampling detector is used. It is evident from fig. 13 that at a specific frequency the average peak power caused by gap noise can be as much as 40 db higher than the average power. This difference must be understood if the return plant is to be used as a communications link.

The discharge through a faulty insulator is not exactly of a certain duration nor does it occur exactly at 8.33ms intervals. This is because of the unknown conditions at the faulty insulator. If it is "dirty" with debris or moisture, the discharge will not occur at exactly the peak voltage but it may occur within a certain "window" around the peak. This causes multiburst and/or high density discharges. Fig. 14 is a time domain graph at a center frequency of 9.54Mhz. Notice the voltage spikes appearing in pairs and the high density pulses appearing at lower levels slightly prior to these pairs. This is an example of multiburst gap noise. It is interesting to note that the central moment of these pulses appears at 8.33ms intervals.

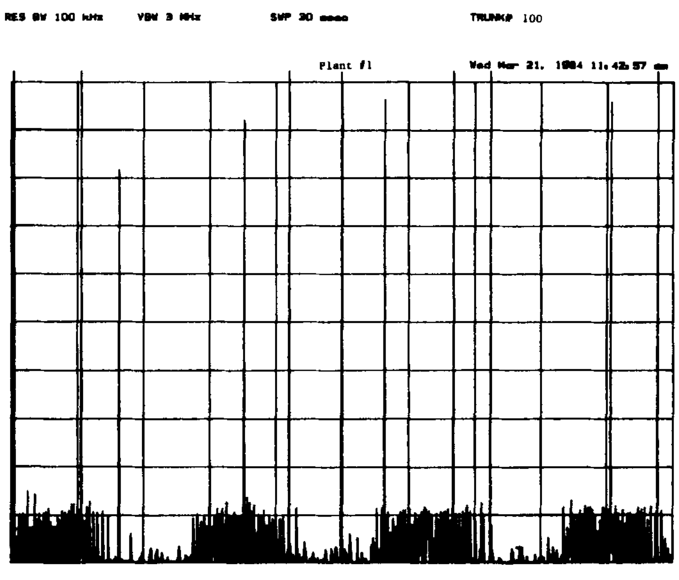


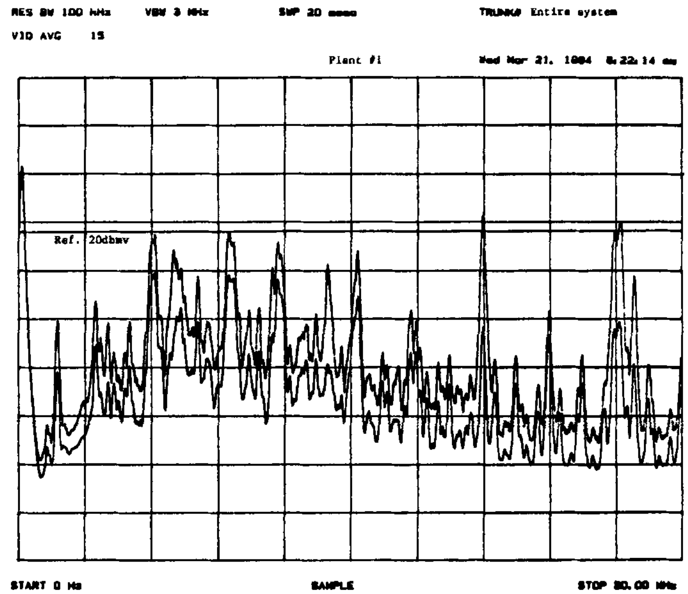
Fig. 14

Amplifier Nonlinearities

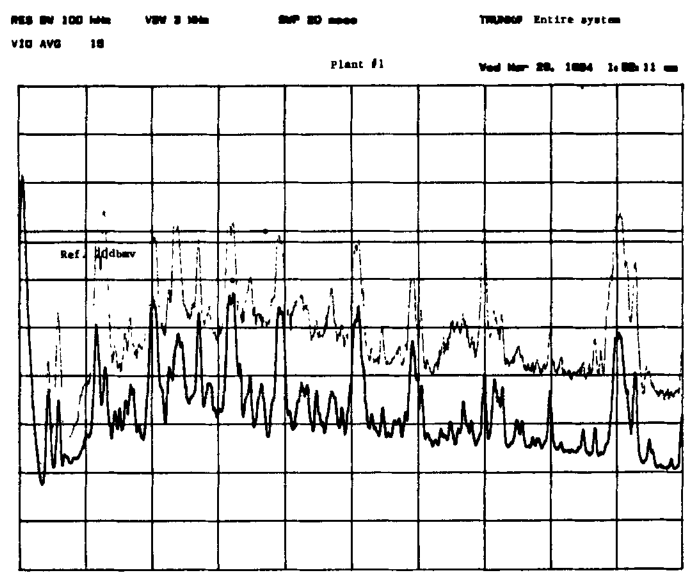
A problem that is not very common in a return plant but nonetheless can exist is amplifier nonlinearities or oscillations. Pulse regenerative oscillations are the most common types found, and they are the result of a marginally stable amplifier either driving a reactive load or terminating a reactive line. In either event mistermination of the transmission line is the cause of the instability. A spectrum of this problem is a comb of frequencies within the return plant frequency band. The frequency spacing is related to the distance of the mistermination from the amplifier in question.

RETURN PLANT DATA

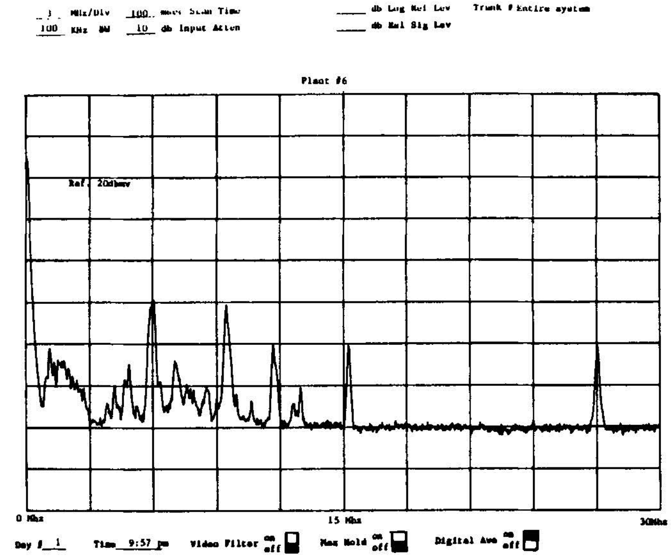
Figures 15 through 20 are return plant spectra of five of the twelve cable plants that were analyzed. Single plots are spectra taken at the time indicated. Double plots, except for fig. 16, are twelve-hour averages. On these plots the upper graph is the average of the quasi-peaks and the lower graph is the total average. Fig. 16 is a six-day average of plant #1. Plant size in both number of subcribers and total number of amplifiers is provided.



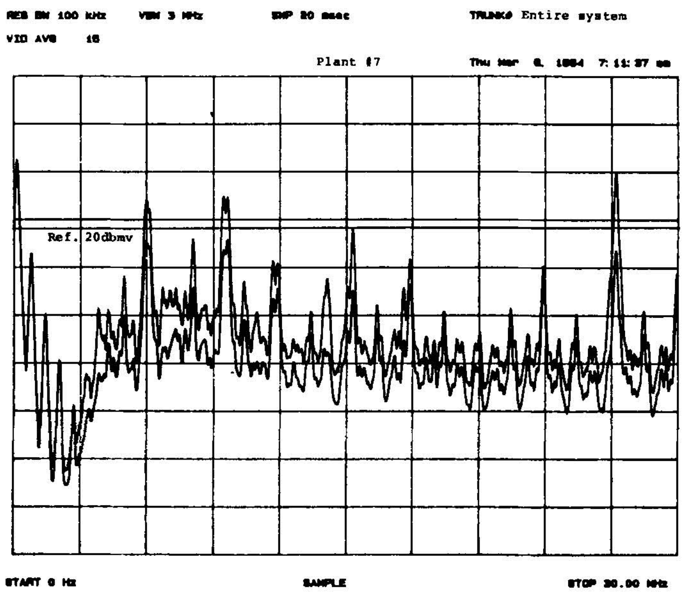
13,000 subs Fig. 15 444 amps



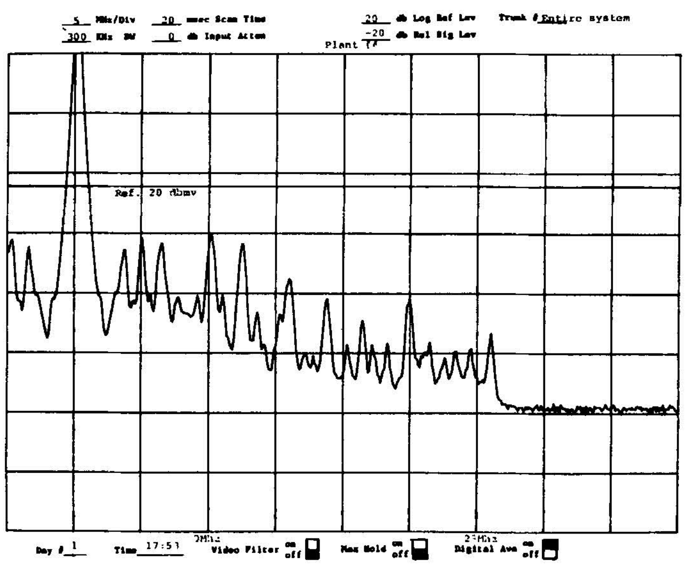
13,000 subs Fig. 16 444 amps



14,000 subs Fig. 17 642 amps



31,000 subs Fig. 18 2312 amps



30,000 subs Fig. 19

Plant #2

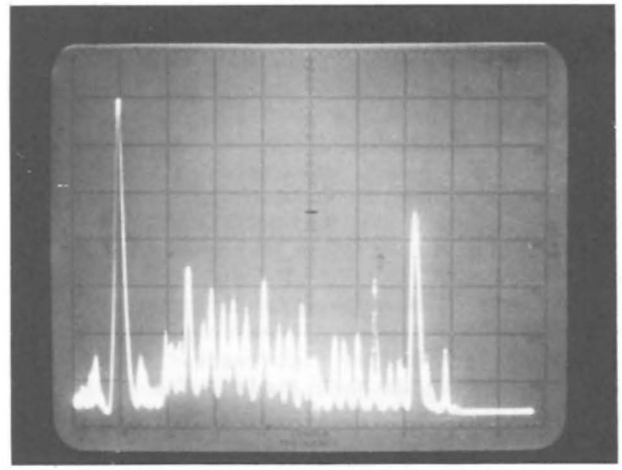


Fig. 20

Conditions: 5Mhz/div
300Khz res BW
20Mhz center frequency
57 dbmv reference
32Mhz pilot at 22 dbmv ref.
7,000 subs

The data presented in this section is a representative sample of the data accumulated from the twelve cable plants.

CONCLUSIONS

Spectrum Summary

There are five characteristics of a return plant: white noise, ingress, common mode distortion, impulse noise and amplifier nonlinearities. If amplifier problems are eliminated, then ingress and common mode distortion can be thought of as long term problems and impulse noise as a short term problem. The long term problems also affect the noise floor of a return plant. The sidebands of common mode distortion raise the noise floor of the return plant, and if international shortwave is present, it produces an apparent tilt in the noise floor. Impulse noise, unless extremely high, does not appreciably affect the noise floor. These problems can be attributed to faulty or corroding connectors in the cable system.

Fig. 21 is a "composite" of the twelve cable plants that were measured and analyzed. This "typical" plant is the average of the common mode distortion products, ingress sources and white noise sources of the twelve cable plants. The horizontal tick marks indicate the maximum values reached by ingress or common mode distortion products.

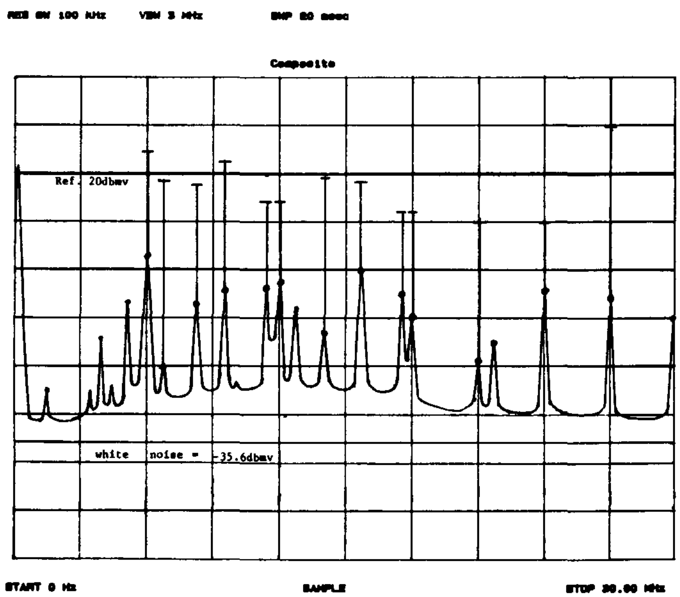


Fig. 21

Maintenance

The amount and type of maintenance vary from plant to plant. By far, the most efficient means of locating trouble spots in a cable system is the code operated switch system. Using COS's, the cable operator can quickly search the system to find the faulty connectors. If code operated switches are not used, then the labor intensive "sniffer" technique must be used.

In general, it is much more labor intensive to incorporate return plant maintenance procedures than it is to use forward plant maintenance procedures. Much more ingress, common mode distortion and impulse noise can be tolerated in the forward plant than in the return plant.

Fig. 17 is cable system that uses return plant maintenance procedures, and figs. 15, 16, 18, 19 and 20 are cable systems that incorporate a forward plant maintenance schedule.

Communication Viability

If two-way communication links are to be used in return plants, then the type of communication system used must be balanced with the amount of maintenance required to guarantee reliable service. If a wide band system is used, i.e. return video, then a substantial amount of maintenance will be required. If wide band data transmission is used then the return maintenance will be somewhat less.

It is possible to use the return plant for data communication with only forward plant maintenance and with little or no return plant maintenance. If narrow band data transmission is employed, i.e. bandwidth less than 100Khz, then the return carriers can be "slotted" into the "holes" of the return plant spectrum. By avoiding the common mode distortion and ingress frequencies, long term reliability is possible. If the bandwidth is narrow, then impulse noise susceptibility is reduced and short term reliability is possible.

If these criteria are met, then reliable, practical, two-way cable communications can be achieved with no substantial increase in maintenance costs.

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USE OF HYBRID CARS MICROWAVE/CABLE FOR MULTISITE LOCAL-AREA NETWORKING

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ABSTRACT

In this paper, we first review the new role of CATV coaxial cable systems in supporting point-to-point voice/data networks and their inherent capacity to work as broadband local-area networks for distributed data communications. Then, the use of CATV-compatible AML microwave links to interconnect dispersed LAN systems is discussed.

GENERAL

Coaxial cables have in the past played a major role in providing high-capacity point-to-point communication systems for the transmission of voice, using the frequency-division multiplexing (FDM) technique, all over the country. Subsequently, the use of coaxial-cable systems for the distribution of entertainment video in urban areas saw explosive growth which is still going on. While the application for FDM voice traffic was limited to the base-band method of transmission using only a small portion of the cable spectrum, the CATV industry makes full use of the cable potential of up to 500 MHz of the RF spectrum.

The more cost-effective microwave radio systems practically ended the non-CATV use of cable for the past several years. However, with the explosion of distributed data processing, and advent of affordable workstations, the business world is forcing the communications industry to look into the coaxial-cable-based transmission techniques once again.

Although novel ideas are being introduced in the domain of radio communications technology, the limited available RF spectrum is putting a crunch on many radio users. On the other hand, the unsuitability of existing Telco subscriber loops for higher data transmission rates and the high cost of dedicated "T1" lines have prompted potential users to by-pass the local telephone companies.

The advent of local-area network (LAN) technology to satisfy the growing need for more efficient data transmission networks is another factor that is opening the door to a more novel and challenging use of cable systems to support a large data user population in metropolitan areas.

These facts, plus the widespread proliferation of CATV cable systems in urban/metropolitan areas are actually the driving forces behind the emerging interest in cable systems as alternate communications media for non-video applications.

While the use of coaxial cables for dedicated point-to-point transmission systems is well defined and known to system designers, it is their unique application in a distributed LAN environment, in conjunction with microwave interconnect systems, that is the topic of this paper.

REVIEW OF LAN TECHNOLOGY

There are two broad categories of local-area network systems presently developed to meet the ever increasing need for the transmission of data in a limited geographical area. These are the so called baseband and broadband LAN concepts. While many of the underlying principles of operation are very similar in nature, the two concepts are distinctively different when it comes to their transmission techniques.

The baseband LAN routes the data signals around the network in a modified version of their basic digital form without using a "carrier" signal, thus the name baseband. The broadband LAN, on the other hand, will take the processed digital signals and modulate a "carrier" signal for transmission around the network in the form of an "RF" signal. While a detailed comparison of the two LAN categories is beyond the scope of this paper, it is the broadband version which is fully compatible with the CATV cable technology.

BROADBAND LANs

Figure 1 shows a simplified overview of a broadband (BDB) local-area network. The topology is physically of the inverted-tree configuration which provides a logical bus structure. The system could be a single-cable or dual-cable based network. The single-cable version, being the closest to the majority of existing two-way CATV cable systems, uses a so called head-end frequency translator at the root of the "tree" which is the cable hub.

Figure 2 shows a general allocation concept of the frequency spectrum on a CATV cable system supporting LAN/p-t-p traffic. The BDB-LAN industry has basically opted for the existing CATV channeling plans and their various cable configurations such as sub-split, mid-split, etc. While each vendor allocates the cable spectrum for many services such as video, voice and alarm/security, their main concern is the provision of data communication channels. Depending on their system architecture, several 6 MHz channels in each direction are needed to support an entire Data Terminal Equipment (DTE) population of several thousand.

Based on the required data transmission rate, each 6 MHz channel is subdivided into many narrow-band

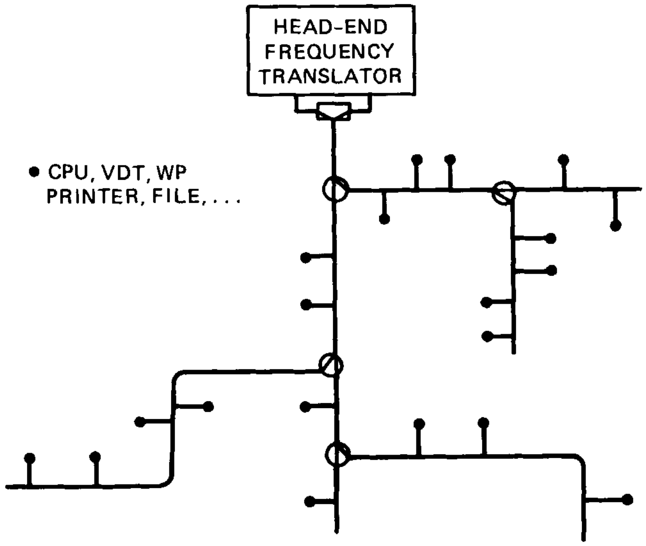

Fig. 1: Broadband LAN Topology

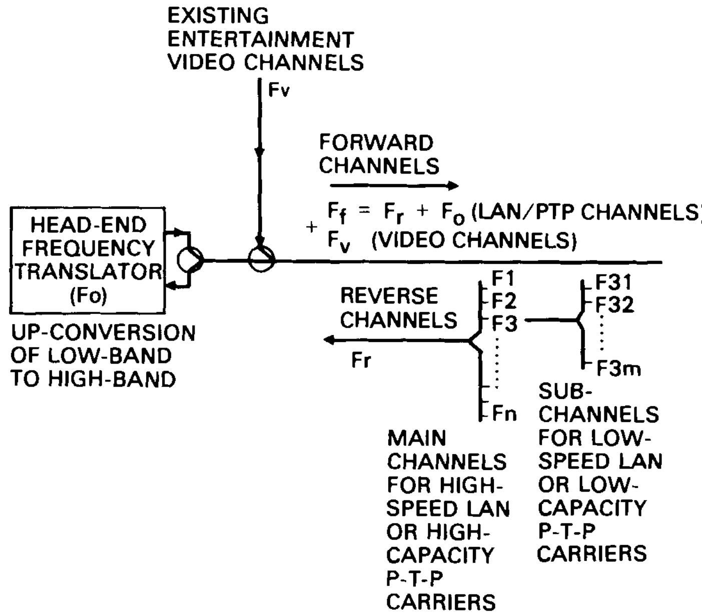

Fig. 2: CATV Plus LAN/p-t-p Channeling Concept

channels (10-300 kHz for example). Several systems in the market use the 300 kHz basic channeling scheme; thus providing 20 RF data carriers in a 6 MHz (TV) channel. Each 300 kHz carrier is capable of carrying a minimum of 128 kbps of digital information using the simple FSK modulation technique. This basic capacity of each carrier could be shared among many lower speed (e.g. 9.6 kbps) DTEs on a virtual-connection basis. The maximum number of DTEs sharing a given RF carrier is basically determined by their traffic rates and patterns and the medium-access mechanism of the LAN system. The most popular CSMA/CD (Carrier Sense Multiple Access with Collision Detection) method can provide system throughputs as high as 96 percent of the total available capacity. A thorough data communication traffic study must be done to determine the optimum number of shared users on any given RF carrier in order to meet the required system response time and/or grade of service.

INTEGRATION OF DISPERSED LANs

Many of the available broadband LAN systems on the market are specified to support as many as 65000 DTEs on 60 300 kHz wide RF carriers, occupying a total of 18 MHz of cable spectrum in each direction of transmission. Such an inherent huge capacity of BDB LANs is far beyond the normal need of any single organization, particularly if confined within a very limited geographical area that a "local" area network is designed to support. For this reason, BDB LAN's are generally highly underutilized in private business applications.

One way to increase the utilization factor of a given LAN system is to integrate several dispersed "mini" LANs into a larger network. In real life, these could, for example, be the various buildings or plants of a large corporation scattered in a 20 mile radius as shown in Figure 3. The problem is to expand the basic LAN tree to reach every facility in the network. In urban areas this becomes almost an impossible task if one had to run dedicated coaxial cables across town.

This is where the existing CATV cable systems prove their value. Being designed to serve a large community, the cable systems can easily function as a real LAN tree if many of the existing or new subscribers require data communications services. It also pays to interconnect large isolated users to the main cable tree through dedicated "branches".

CARS-MICROWAVE INTERCONNECT SYSTEMS

The problem of integration of widely dispersed cable systems, or large customers not passed by cable, into a comprehensive LAN system can easily be achieved through dedicated CARS microwave radio links. Just as video channels have been distributed from a program origination point to several cable hub locations, the cable compatible Hughes AML^R microwave concept can be used to extend or interconnect several "mini" LANs into one large network.

The AML concept that is so well known to the CATV industry is based on the heterodyning principle where any given VHF carrier, with whatever type of modulation, can be up or down-converted to another frequency when properly mixed with a locally-generated signal. This process is basically independent of the modulation content of the desired carrier; analog AM, FM or digital FSK, QPSK, etc.

While the use of AML in VSB-AM transmission of video signals is well defined, its new application in interconnecting cable systems supporting LAN networks, or point-to-point voice/data traffic, needs redefining. The standard 6 MHz VSB-AM channel carried by each AML transmitter is characterized by the video, color and audio carriers in a well defined relationship. The new LAN or p-t-p carriers are as yet not standardized in terms of bandwidth, modulation type, their sensitivity to system non-linearities, frequency shifts, and a host of other parameters. For example, the low-speed 300 kHz wide RF carriers of a CSMA/CD LAN network using FSK modulation can only tolerate a frequency shift of 10 kHz when going through any interconnect link. Their threshold response of 10^{-6} BER requires certain minimum values of

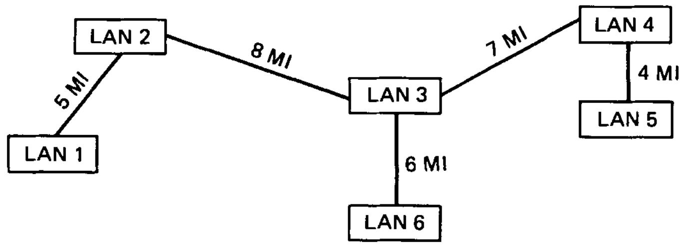

Fig. 3: Integration of Dispersed Mini LANs Into One Network

carrier-to-noise or carrier-to-intermod noise ratios. Their sensitivity against carrier level variations is another point that must be considered. The number of RF carriers and their relative levels in any given bandwidth also directly affects the system I.M. performance.

With LAN systems, even when we have perfect transmission channels, the actual transmission delay experienced by the carriers in going from the farthest user terminal to the head-end translator and back will affect the overall LAN system throughput. So, the location of the head-end translator and the maximum length of the LAN tree branches becomes critical in the context of the LAN performance constraints. It is interesting to note that the transmission delays introduced by the AML link is about one tenth that of a coaxial cable of comparable length.

With all the above in mind, every AML-LAN interconnect system must be carefully tailored to meet the performance requirements of a given LAN or p-t-p system if true transparency on the part of the AML equipment is to be achieved.

TYPICAL APPLICATION

Figure 4 shows the simplified block diagram of a typical AML microwave LAN interconnect where two independent LANs are to be integrated into one system. In this example all the users on LAN 2 are to become part of the population of LAN 1.

To implement such an integration, the coax cable of LAN 1 is tapped through a standard directional tap at a convenient point closest to the location where the AML microwave equipment is to be housed. The choice of this location is dictated by the need to have line-of-sight transmission between the two sites of LAN 1 and LAN 2. At the other end, the AML radio equipment is directly interfaced with the LAN 2 coax cable at its head point.

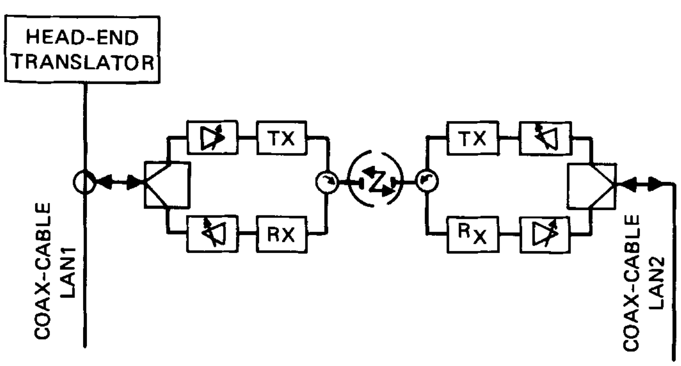

Fig. 4: AML-LAN Interconnect

With the connections so made, the coax cable of LAN 2 becomes a major "branch" of the system "tree" under LAN 1 and the two-way communications among the users of LAN 2 themselves and the other users on LAN 1 take place as if all the users were connected by a single network. The flow of signals to/from LAN 2 take place in the following manner.

The channel carriers within a given window, up to 20 MHz, transmitted by the cable modems of the users on LAN 2 will arrive at the AML equipment. They first pass through a diplexer filter which separates the "forward" and "reverse" frequency bands in order to be compatible with the single-cable mid-split system. The carriers then go to an amplifier where their level is adjusted to the optimum value required by the transmitter (TX) unit. The TX unit upconverts the carriers to the designated microwave band for onward transmission. At the other end, the microwave signals are picked up by the antenna and passed to the microwave receiver unit (RX) where they are downconverted to their original VHF frequencies. They will then pass through an amplifier that sets their levels to the optimum value for injection onto the LAN 1 coax cable.

The carriers, now being on LAN 1 cable, will be treated like the other in-house carriers. That is, they will be received by the LAN 1 headend translator, converted to the forward frequencies, and injected back onto the cable to go to all users on LAN 1 cable. To go to LAN 2 users, the carriers will enter the AML radio equipment through the directional tap and undergo a similar process as they did in the return direction. In this manner, the LAN 2 system will be fully integrated into LAN 1.

The coverage range of the AML microwave radio system basically depends on the operating microwave frequency, the terrain and climatic conditions of the areas and, of course, the availability of line-of-sight propagation between the two LAN sites to be interconnected. However, for many applications such distances could range up to 20 miles.

Figure 5 shows the detailed block diagram of a fully protected AML-LAN interconnect system as implemented in a single-hop application in a university environment. Here, the two buildings are separated by about 2 miles in a very crowded part of Chicago, where laying of coaxial cable was impractical. The AML link interconnects 18 MHz of the cable spectrum that is supporting about 800 DTEs plus the entire central data processing equipment of the university.

CONCLUSION

Existing or new CATV cable systems are inherently capable of supporting other types of traffic besides traditional entertainment video. Through proper design and allocation of the freqeuncy spectrum they can be used to provide point-to-point transmission channels to the business community as "by-pass" links for their inter-office use. In a more universal role the cable system can be employed as a broadband local-area network supporting thousands of data terminal users.

In all cases, any cable system may have to be extended to cover distant clusters of users in order to be more viable as a LAN or a by-pass. In such cases, proven microwave transmission techniques are available to extend the branches of any cable system for this purpose.

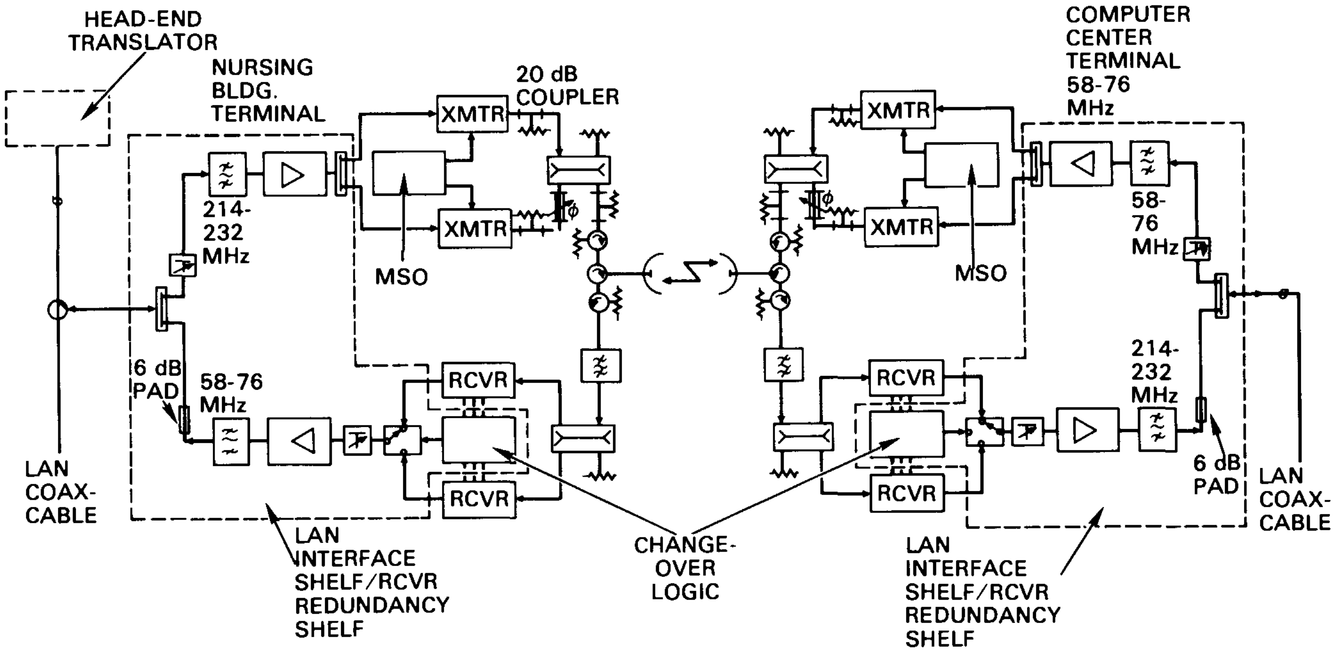

Fig. 5: Fully Protected AML-LAN Interconnect System Block Diagram

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VIDEO SCRAMBLING - AN OVERVIEW

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ABSTRACT

As cable systems evolve, they will handle diverse information sources such as revenue-generating programs (pay-per-view events), video-text, computer games and two-way services. To ensure the revenue generating potential of such services and to prevent unauthorized reception of signals, the sender and/or receiver may scramble or encrypt the signals.

In this paper, an overview of video scrambling techniqees is provided. Each technique is asessed in terms of its scrambling depth (degree to which recognizability of an image is destroyed), security (degree to which the technique resists pirating), residual effects in descrambled video and coexistence with other scrambling schemes - in selected cases, computer simulation results are included to demonstrate the efficacy of the scrambling technique. Cost-performance tradeoffs for each scrambling technique and future trends in scrambling are also discussed.

I. INTRODUCTION

Presently, CATV systems offer from 35 to 64 or so channels of programming. Depending on the type of programming, typically there is a mix of scrambled and unscrambled channels, the primary intent of scrambling being to deny access to the unauthorized viewer (in this paper "scrambling" implies manipulation of an analog signal so as to render it unintelligible, whereas, "encryption" implies manipulation of a digital signal to achieve the same result). As addressability becomes increasingly prevalent and two-way services become a reality, two trends in CATV video transmission may emerge -

- Video signals might be transmitted unscrambled and the HTU (home terminal unit) will be controlled to deny access to unauthorized channels. Such an approach would be best suited for an off-premise decoder and could be cost-effective in a MDU (multiple-dwelling-unit) environment. However, it may be susceptible to spoofing (fooling the upstream channel) and other easy means of piracy.
- Video signals would be scrambled and access to a channel is provided by means of a descrambler in the HTU. Such a scheme would be cost-effective in a SDU (single-dwelling-unit).

In a CATV system, there will be mix of MDU's and SDU's. Furthermore, in the future, there will be wide variety of information sources offered such as teletext, home-banking etc. Hence, it may be cost-effective to incorporate a descrambler in each HTU and ensure that unauthorized reception of revenue generating video programming is prevented using an effective video scrambling technique.

There are several ways in which a video signal can be scrambled. Although the scrambling techniques vary significantly, the following attributes can be considered to be fundamental in any scrambling technique:-

- Depth of Scrambling - The technique must not enable observable detail to the extent that programming material offers no entertainment value to the unauthorized viewer. In some instances, the nature of programming material may be such that the scrambled picture should provide no observable details to offend the unauthorized viewer.
- Security - The technique must a) be time-varying such that real-time descrambling is not (inexpensively) possible, or, b) require very expensive or absoutely unavailable descrambling hardware.
- Non Degrading - The results of descrambling must not exhibit component or circuit-sensitive residuals, nor be discernable in the descrambled picture.
- System Complexity - The HTU may encompass several functions besides the descrambler and since the overall cost of the HTU should be low, descrambler hardware must be fairly simple.
- Multiple Scrambling - As the type of programming offered changes in the CATV system, there may be a need to overlay the previous simple scrambling technique (which gives good depth of scrambling) with a hard to defeat technique (which gives good security).
- Bandwidth Expansion - Scrambled signal bandwidth should be such that video, audio and synchronization signals can be transmitted in a 6MHz bandwidth.

Scrambling techniques that meet one or all of the attributes can be implemented at RF or BASEBAND.

First generation of video scrmablers were implemented at RF since such schemes resulted in a simple descrambler which did not require any demod-remod configurations. Most RF schemes implemented to date posess weak security and marginal scrambling depth.

Baseband techniques evolved later and are widely prevalent now. Such schemes offer flexibility in that they can be applied to a satellite, STV or CATV environment easily. Baseband schemes can be implemented using digital or analog means. When digital video signal processing becomes cost effective, digital implementation of baseband scramblers may become prevalent.

At OAK, several RF and BASEBAND scrambling techniques have been simulated on a computer. The simulation methodology is described in Section II. A brief description of various RF scrambling techniques is provided in Section III and baseband methods are described in Section IV. In Section V, cost/performance tradeoffs are given for various scrambling techniques. Future trends in scrambling and integration with non-video services in the HTU are discussed in Section VI.

II. COMPUTER SIMULATION PROCEDURE

Simulation procedure consists of the following steps:-

(1) A frame of monochrome video is digitized by a DeAnza image-array processor - display area of digitized frame is 512 scanlines and 512 picture elements per scanline with each picture element represented as a eight bit quantity. Digitized image can be displayed on a DeAnza monitor. This image is input to the VAX 11/780.

(2) Algorithm describing the scrambling technique is implemented on the VAX. All filtering operations and various transmitter, transmission link and descrambler functions are also modelled here.

(3) Scrambled image and descrambled image can be viewed on the DeAnza display monitor.

Simulations were performed for a still-frame of monochrome video - a test frame used in all the simulations is shown in Fig. 1. For NTSC color signals, perceived scrambling depth would be more than that depicted in the simulation results reported in this paper since even a slight modification in the video signal alters the color properties in the perceived image and tends to be annoying to the viewer.

III. RF SCRAMBLING

Conventional RF scramblers accomplish video and/or audio scrambling by jamming video signal using a tone or inverting video signal or suppressing sync in the video signal.

A. Tone Jammer Interfering carrier is placed near the video carrier, thus, causing a beat pattern in the receiver which masks the actual video signal. Scrambling depth depends on the level of the interference carrier and the frequency at which it is located. One possible tone jamming frequency is 2.25MHz above the picture carrier. Due to the manner in which the audio signal is recovered in the receiver, jamming tone at 2.25MHz yields a beat at 4.5MHz which in turn jams the audio signal also. For effective descrambling, a trap is needed to attenuate the interfering carrier - trap attenuation must be around 40 to 60dB to avoid any residual effects in descrambled video. The trap will also attenuate useful luminance energy. Scrambling depth on video is marginal. Video signal security is very weak since the scheme is not time-varying and traps can be built inexpensively. In a cable system, introduction of a tone-jamming carrier for each scrambled channel will increase the number of beats in the system and depending on the receiver front-end, may cause degradations in the non-scrambled channels also.

B. Video Inversion Scrambling is achieved by subtracting from the signal a constant RF carrier at same frequency and phase as actual RF carrier. This will result in the active video signal being treated as a sync signal in the receiver, thus yielding a jagged sync bar in the middle of the displayed picture. Video scrambling depth is marginal. Audio is not scrambled in this method. Descrambling operation is complex since RF carrier must be recovered with correct amplitude, phase and frequency. Errors in recovered carrier phase will appear as color distortions and errors in recovered carrier amplitude will cause luminance distortions. In a multipath environment it will be nearly impossible to reconstruct the carrier accurately - thus luminance and color distortions are inevitable in a multipath environment. A PLL system may be needed to regenerate the RF carrier and depending on the number of scrambled channels, the PLL system may turn out to be fairly complex.

The scheme posesses weak security since the subtraction of RF carrier is not done in a time-varying manner. Time varying scrambling can be realized by subtracting from actual carrier an RF carrier with the same frequency, amplitude and a phase which is varying on a line-by-line or scene change basis - information pertaining to phase can be sent as low level modulation on the aural carrier. If phase is varied on a line-by-line basis, the inaccuracies in reconstructed RF carrier at receiver will cause annoying flicker in displayed image.

C. Sync Suppression Sync suppression scramblers can be realized in one of two ways -

(1) Sine-Wave Scrambler: Video signal is exponentially modulated by a low-frequency sinewave; for descrambling purposes, information regarding this sinewave is transmitted as AM on the aural carrier. The phase and amplitude of the low-frequency sinewave are chosen so as to cause sync suppression. The receiver false locks on active video, thus yielding a jagged sync bar in the middle of the picture. By varying the frequency of the sinewave, time-varying scrambling is achieved.

(2) Square-wave or Gated Sync Scrambler: In this method, during the blanking interval, moulated signal is attenuated by atleast 6dB causing sync and color-burst to be below active video, thus yielding a scrambled signal similar to that

obtained with the sinewave sync suppression scheme. In descrambler, a gain of 6dB is switched in during the horizontal blanking interval - the time instants at which the gain is switched in is transmitted by modulating the aural carrier.

Depth of scrambling is identical for sinewave and squarewave sync suppression schemes. Audio is not scrambled in either method. Sinewave scheme posesses better signal security due to the time-varying manner in which the scrambling frequency can be chosen. With the advent of digital TV chip sets in TV receivers, it is possible to defeat squarewave sync suppressors since such chip sets work on standard and non-standard sync signals (provided color-burst and standard vertical blanking interval synchronization signals are available). A sinewave scheme cannot be defeated by merely reinserting sync; modulation on video must be removed as otherwise luminance and chrominance distortions will result in the descrambled signal.

Descrambler complexity is more for sinewave scheme since in the receiver, circuitry is needed to accurately recover amplitude, phase and frequency of modulating signal. In squarewave scheme since the descrambling signal is a squarewave, such signals can be generated accurately and easily by digital methods.

Descrambler residual effects may degrade video in sinewave scheme. Since the AM signal on the aural carrier is used for descrambling, interference from in-channel chroma subcarrier, strong upper adjacent channel video carrier can cause constant luminance residuals in descrambled video if the descrambling loop bandwidth is not tight. Furthermore, in the sinewave scheme any noise in the descrambling signal is transferred onto the video during the demodulation process. In the squarewave scheme, since active video is never manipulated during the scrambling process there is no noise transfer in descrambling process - any inaccuracies in sync regeneration causes side-by-side motion of displayed picture signal.

At OAK, two other RF schemes have been investigated.

D. Frequency Inversion Inversion of video frequency spectrum leads to a scrambled signal. Frequency inversion schemes can accomplish video and audio scrambling jointly. Furthermore such a scheme can co-exist with the conventional RF schemes described previously.

E. Non-Linear Filtering Video signals can be scrambled by performing a non-linear filtering operation on the IF signal. Example of the computer simulated scrambled signal obtained with a specific non-linear filter is shown in Fig. 2a. Comparing this result with the scrambler input (Fig. 1), the scrambling depth appears to be inadequate - however in a NTSC color signal, perceived scrambling depth would be much more. Descrambling is achieved by using the inverse non-linear filter. This filter can be implemented as a passive device and such a descrambler can be very inexpensive.

If fixed nonlinear filtering is used, the scheme can be defeated fairly easily. Computer simulated result for a time-varying scrambler employing two non-linear filters randomly chosen, is shown in Fig. 2b; good scrambling depth is obtained with this method. A PN sequence can be sed for random filter selection and this sequence in encrypted form can be transmitted to the receiver thus ensuring excellent video signal security.

Residual effects on descrambled signal can be minimized if a nearly exact inverse of the transmitter non-linear filter can be realized - based on the extent of non-linearity required, this is feasible with today's technology.

In this scheme audio is not scrambled. A sync suppression scheme can be added to further enhance scrambling depth.

IV. BASEBAND SCRAMBLING

Baseband schemes posess analog and/or digital (or CCD based) implementations. Presently, most baseband techniques are implemented using analog systems; while, good scrambling depth and security can be obtained, a greater variety of scrambling techniques can be implemented using digital systems. Several baseband scramblers have been studied via computer simulations; a brief description and simulation results are included here.

A. Video Inversion/Sync-Suppression Such a scheme is used in OAK's SIGMA and ORION products and also in various other commercially available scramblers. In SIGMA, sync is suppressed, digital audio is inserted in sync interval and video is inverted randomly on a scene change basis. Even though a non-standard signal is transmitted in SIGMA, it is not easily defeated in a ITT digital TV chip set based receiver since both vertical as well as horizontal sync signals are eliminated (not suppressed) and nonstandard signals are used in VBI. In SIGMA, extremely high security obtained by digitizing and encrypting digital audio, coupled with the video scrambling scheme would thwart unauthorized viewers from deriving any entertainment value from the received signal. Due to the high performance of the HTU, such an approach will be very attractive for a CATV system.

Instead of suppressing sync, sync could be randomly inserted within each video line. This will yield a jagged bar in the middle of the picture. Since sync insertion introduces discontinuities in the video line, bandlimiting the signal will cause distortions in descrambled video.

B. Video Jitter Start time of active video of each scanline is randomly jittered. This has the effect of breaking vertical correlation in a picture. Larger values of jitter yield increased scrambling depth. Large values of jitter can be obtained by modifying blanking interval signals. Computer simulated results obtained for the video jitter scrambler with a random jitter is shown in Fig. 3. This scheme offers good scrambling depth; additional scrambling depth can be obtained using non-standard sync. The start time of jittered video is obtained from a PN sequence and this sequence is sent to HTU in encrypted form for high video security. Simulations have indicated that inaccuraccies in line start-time regeneration at the descrambler can be controlled such that negligible perceptual degradations result in the descrambled signal. For unauthorized descrambling, the receiver must estimate the amount of time-jitter. This can be done by estimating inter-line correlations and then advancing or delaying received signal until the correlation is maximized; however such computations cannot be performed inexpensively in real-time.

Instead of jittering the video, random video fields can be delayed. Descrambling is achieved by delaying the fields which were not delayed in the scrambler. Even though extremely simple hardware can be used for descrambling, this scheme is unacceptable due to inadequate scrambling depth.

C. Time-Reversal Active video of each line is transmitted as is or in time-reversed manner; sync and color-burst are sent as is since unauthorized descrambling would be simple if these signals were also time-reversed. A PN sequence can be used to randomize the time-reversal process; for descrambling, the PN sequence in encrypted form is transmitted thus ensuring a high level of security. Computer simulated result for this scrambler is shown in Fig. 4a.

Good scrambling depth on the video can be obtained with such a scheme. Video security is acceptable for CATV transmissions. The scrambling technique can be defeated using correlation techniques; this requires several lines of storage and high speed logic (an expensive solution).

The scrambler and descrambler are implemented using A/D and two lines of storage. This scheme in combination with a secure audio scheme as in SIGMA is capable of offering a high performance HTU. The residual effects introduced by the descrambler are negligible (line time distortion effects only) except when the PN sequence is received with errors - the digital PN sequence can be error protected to overcome this problem.

Sync suppression can be included to enhance scrambling depth. Furthermore, since the signals are digitized, linear transformations on the digital signal can be performed to further increase the scrambling depth. In Fig. 4b, we show video scrambler output wherein video lines are randomly linear transformed and randomly time-reversed. This two-level scrambling process offers excellent signal security even though the linear transformation method by itself is insecure (an analysis of signal security of the linear transformation scrambler is described in [1]; this analysis indicates that simple operations can be performed to accurately descramble the video without knowledge of the PN sequence). In Fig. 4b, linear transformation is applied to randomly selected lines; if the inverse transformation process in the receiver is not exact, annoying flicker will be perceived in the descrambled image and to avoid this flicker, it is preferable to apply the linear transformation randomly on the basis of scene change.

D. Permutation Of Video Lines A set of video lines is randomly permuted and the re-ordered lines are transmitted. At the receiver, lines are first stored and then re-ordered. Permutation of the lines is accomplished by a PN sequence which must also be available at the receiver for correct descrambling. In Fig. 5a, we show video scrambler output when a set of 16 lines is permuted and in Fig. 5b, scrambler output with 128 line permutation is shown.

Excellent scrambling depth can be achieved with a 128 line store in transmitter and receiver. Due to storage requirements, the HTU would be fairly expensive. Storage requirements can be halved with no decrease in perceived scrambling depth by randomly time reversing some of the permuted video lines - simulation result for a 64 line permutation scheme with random line reversals is shown in Fig. 5c. Excellent signal security is also achieved since (1) unauthorized descrambling would be expensive, and (2) the PN sequence used in head-end for line permutations is encrypted and transmitted to HTU.

Since sync and color burst are not modified, secure audio transmission as per SIGMA scheme can be easily incorporated.

E. Line Dicing In this scheme, active video portion of each line is split into two fragments and these fragments are interchanged prior to transmission; length of each fragment is randomly changed on a line-by-line basis and this information is sent to the HTU. Computer simulated result for such a scrambler is shown in Fig. 6a. This scheme offers excellent scrambling depth and security. The descrambler can be implemented using digital systems or CCD's.

Since video line is fragmented and interchanged, abrupt discontinuities may be introduced in each scrambled video line causing an increase in bandwidth of scrambled signal. Bandlimiting the scrambled signal introduces distortions at the discontinuities causing segment distortions in the descrambled video. In the presence of multipath similar distortions will arise. In Fig. 6b, descrambler output is shown; in this simulation, the line diced signal was filtered by an idealized VSB filter and then transmitted over a link which posessed a multipath of 10dB, 500Nsecs (10dB is the attenuation of the reflected signal relative to the direct signal and 500Nsecs is the delay in the reflected signal relative to the direct signal). Multipath and VSB filtering causes significant segment distortions. The VSB filtering effect can be minimized by stretching a few samples between segment boundaries; however multipath impairments can still be significant.

In unscrambled video signal transmission in CATV systems, a 5% line tilt causes no visible effects, whereas with a line diced signal even a 1% tilt will cause visible low frequency noise (less than 0.5% line tilt is required for no visible noise effects).

Due to degradations caused by VSB filtering, multipath and line-tilt, line-dice scrambling may not be viable in a CATV system.

F. MAC A,B or C Several MAC formats have been proposed for video and audio transmissions over a satellite link. MAC formats by the manner in which it is created, yields a scrambled signal; the scrambling depth can be enhanced by using any one of the baseband techniques we have described in this paper. In its present form, the MAC signal is not directly applicable to CATV transmissions since baseband bandwidths are in the neighborhood of 6MHz. Furthermore, with VSB-AM modulation, there is greater potential for crosstalk within the luminance and chrominance channels (assuming imperfect detection in the receiver).

V. VIDEO SCRAMBLING METHODS - SUMMARY

Various attributes of the video scramblers discussed in this paper are summarized in Table 1. For a CATV system, the scrambling method will be selected based on the performance and whether the type of programming warrants extremely high scrambling depth or moderate scrambling depth which could be realized at a lower cost.

VI. FUTURE TRENDS IN VIDEO SCRAMBLING

It would be attractive to use a video scrambling method which would work well in a satellite, STV and CATV environment so that widespread dissemination of the signals is possible without any intermediate decode/re-encode processing; clearly, a baseband scrambling method would be preferred. With the development of low-cost, high-speed digital signal processors, baseband scramblers would be implemented in the digital domain.

Looking further into the future, fully digital video transmissions will be accomplished in CATV systems. Here, digitized video would be encrypted prior to transmission. When a DES-like encryption algorithm is applied to the digitized video signals of Fig. 1, computer simulated encrypted signal is as shown in Fig. 7. Encryption offers unsurpassed scrambling depth and security. In a CATV environment, most of the proposed new services (e.g. teletext, home-banking, digital audio etc) are essentially digital information. These sources can be time-division multipexed with digital video - the HTU architecture will now resemble a small but powerful computer which is capable of performing a myriad of functions such as decryption, error-correction, noise-reduction etc.

REFERENCES

[1] D. Rayhaudhuri and L. Schiff, "Unauthorized Descrambling of a Random Line Inversion Scrambled TV Signal," IEEE Trans. Commun., vol. COM-31, pp. 816-821, June 1983.

TABLE 1

SUMMARY OF SELECTED VIDEO SCRAMBLING METHODS

Scrambling Technique	Scrambling Depth	Video Security	Residual Effects in Descrambled Video	Descrambler Hardware Complexity	Cost
RF METHODS					
1. Tone Jammer	Marginal. Scrambles Audio also	Inadequate	Useful luminance energy lost	Low. 1 Trap per scrambled channel	Low
2. Video Inversion	Marginal	Inadequate	Luminance and chrominance distortions due to imperfect carrier recovery	Complex	High
3. Sinewave sync suppression	Adequate	Adequate	Noise transfer from descrambling signal to video	Low	Low
4. Squarewave sync suppression	Adequate	Inadequate (sync easily restored)	Video jitter due to inaccurate timing	Low	Low
5. Frequency Inversion	Good. Scrambles Audio also	Good	Scrambled picture due to inaccurate timing	Moderate	Moderate
6. Nonlinear Filter	Good	Good	Distortions due to filter mismatch	Low	Low
BASEBAND METHODS					
1. Video Inversion/ Sync Suppression	Adequate	Adequate	Distortions due to inaccurate DC restoration	Moderate	Moderate
2. Video Jitter	Good	Excellent	Jittered video due to inaccurate timing	Moderate	High
3. Line Reversals	Good	Adequate	Negligible	Low	Moderate
4. Line Permutations	Excellent	Excellent	Negligible	High	High
5. Line Dicing	Excellent	Excellent	Significant segment distortions in CATV links due to VSB filtering and multipath	High	High
6. MAC A,B or C	Good - in conjunction with other scrambling methods	Good	Not presently applicable to 6MHz CATV links	Not Known	Not Known

Fig. 1 Scrambler Input

Fig. 2a Fixed Nonlinear Filter

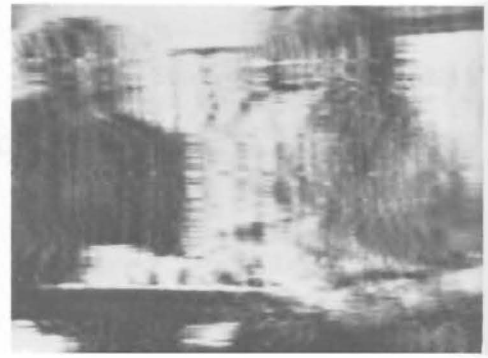

Fig. 2b Time-varying Nonlinear Filter

Fig. 3 Video Jitter

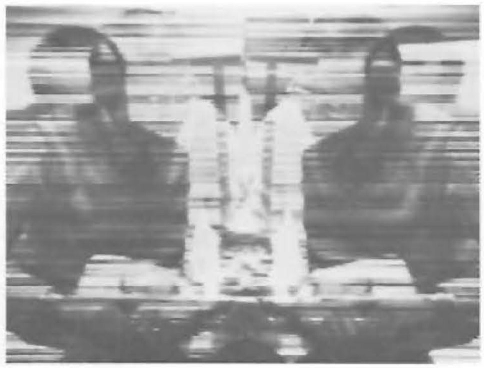

Fig. 4a Random Line Reversals

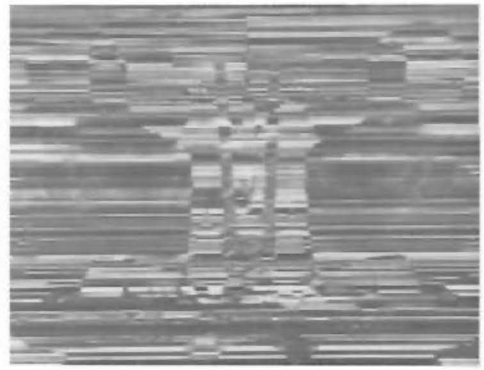

Fig. 4b Random Line Reversals, Random Line Transformation

Fig. 5a 16 Line Permutations

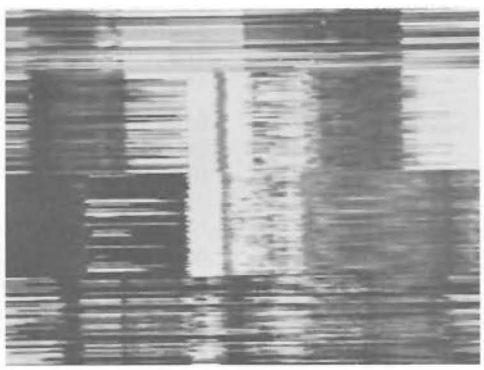

Fig. 5b 128 Line Permutations

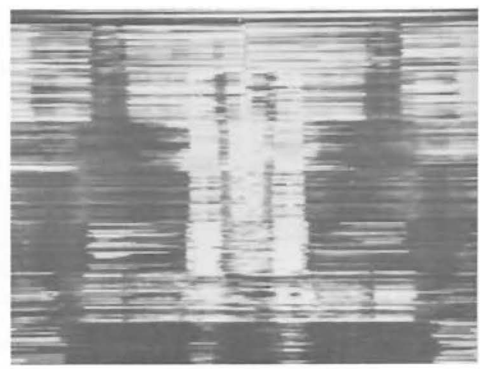

Fig. 5c 64 Line Permutations, Random Line Reversals

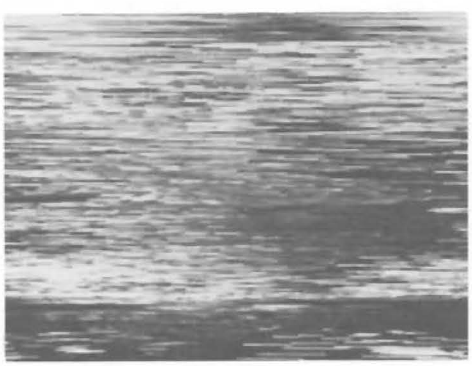

Fig. 6a Line Dicing

Fig. 6b Line Dicing Descrambler Output VSB Filter Effects, Multipath (10dB, 500nsecs)

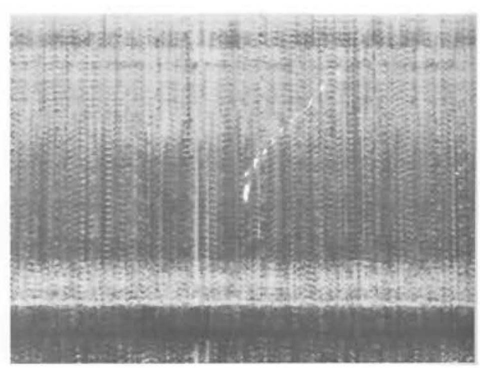

Fig. 7 Encrypted Video

WILL CABLE EVER BE READY TO DELIVER DATA?

Lee R. Greenhouse

E.F. Hutton & Company, Inc.

ABSTRACT

Cable has long held promise as a medium for two-way data services. E.F. Hutton & Company considered the use of cable for delivering Huttonline, its two-way electronic information service for clients. However, cable was not selected for a variety of reasons. First, there are few two-way cable systems available nationwide. Second, cable does not generally offer the ability to connect the user to a variety of information services beyond the headend host computer. And finally, cable has not taken steps to exploit the popularity of the personal computer as a home terminal.

THE CABLE PROMISE

There is little question that cable is technically an excellent medium for transmitting data. In either one-way or two-way transmission, cable systems can provide massive capacity, high speed, and high reliability. Somehow, however, the marketplace has let the promise of cable systems go unfulfilled. More than a decade after the FCC ordered two-way capibility on all cable systems, few have ever put data services, one-way or two-way, into operation. The problem with cable as a medium for transmitting data is not technical; rather the problems are political and economic.

HUTTONLINE: E.F. HUTTON'S TWO-WAY INFORMATION SERVICE

In December 1983, E.F. Hutton & Company became the first major Wall Street firm to offer its retail clients an electronic information service -- Huttonline. It provides clients with access to a daily account status, research information, and electronic mail to and from their account executives. The planning and implementation of Huttonline provides a case study of how a leading service provider approached the problem of data transmission -- and decided against the use of cable.

Although Huttonline was launched in 1983, formal planning began in 1981. It was at that time that E.F. Hutton made its decisions about transmission methods, primarily a choice between telephone lines or cable. In 1981, the two choices had their drawbacks:

- Cable was already showing that it could not afford the massive financial obligation of wiring new communities or upgrading existing systems.
- Telephone deregulation was coming, but the AT&T divestiture issue was far from clear, much less its impact on local phone service and rates.

PHONE VS. CABLE

Of the two choices, E.F. Hutton judged telephone to be the better bet, since phone lines were already ubiquitous and were already providing an essential service, voice telephone. While cable had some clear technical advantages, the cable industry's inability to put together more than a handful of commercial two-way data transmission ventures, was judged to be a sign of the industry's unreliability.

In retrospect, E.F. Hutton's decision to make Huttonline accessible by phone lines was a correct one. It is important to note that cable's few ventures in two-way data transmission have been primarily for business applications, not delivery to the home. Moreover, cable seems to be most feasible in point-to-point uses involving data transmission between two pre-determined sites, such as two computers. As a medium for connecting multiple individual terminals to host computers on a switched basis, cable has not been implemented in more than a handful of pilot systems.

REACHING CLIENTS NATIONWIDE

E.F. Hutton has 500,000 retail clients across the U.S. These clients are the target market for Huttonline. Given the nationwide market for Huttonline, it is difficult to see a role for cable. Even in the few communities where two-way cable exists today (or might exist in the next five years) it would be difficult to justify developing a new business, such as

Huttonline, around such a fledgling medium.

Huttonline was specifically designed to be accessible by a variety of terminals from any location -- home, office, or "on the road." The ubiquitous nature of phone service matches well with this requirement.

Another requirement of Huttonline is the ability for a user to gain access to other information services without resorting to other terminal equipment. Cable has failed to crack the "credibility barrier" with the many information service providers necessary to make such connections possible.

THE NEED FOR GATEWAYS

Huttonline is a two-way service that allows clients not only to retrieve information, but also to send information, such as electronic mail to their account executives. To accomplish these tasks, Huttonline requires a two-way connection between the user's terminal and the Huttonline host computer in New York City. As a switched network, telephone meets this requirement. Cable systems however, generally are not ready today for such traffic. Even where two-way cable exists, its transmission is usually only within the local system itself; a user can communicate with a host computer at the cable headend. Generally, however, the host is not set up to have a "gateway" to external host computers. While this is not technically impossible, the notion of establishing gateways from every cable system in the U.S. is certainly economically questionable.

The issue of headend gateways directly affects the marketing of home data services. In the past, two-way cable, where it could be found, was pitched to consumers as "interactive cable," something to be purchased for its futuristic value. Increasingly, however, consumers are showing their interest in specific, identifiable services with known benefits, such as home banking and home brokerage services. Cable will be marketable as a data service only when it can also give consumers such services.

THE FAILURE OF THE TV SET AS A TERMINAL

Another related issue is that of cable as an entertainment technology. Consumers have come to associate cable with TV -- movies, sports, and, to a lesser degree, culture. With data services, the cable industry will have to re-shape consumer thinking and build confidence in a new image of cable as a medium for "serious" tasks, such as home banking and home brokerage.

The terminal itself plays a key role in consumer perception. Consumers have experienced the TV set only as an entertainment device. Even in cases where TV sets have been adapted, it has been for attaching entertainment devices, such as videocassette recorders, videogame consoles, and low-end personal computers which are used primarily for playing games.

THE RISE OF THE PERSONAL COMPUTER AS A TERMINAL

By contrast, consumers have become aware of the personal computer as a device for "serious" tasks, such as work or education. Most personal computers are physically separate from a TV set that is used for TV viewing. Furthermore, many personal computers reside in the "work" part of the home (e.g. study, den, or even kitchen), whereas TV sets tend to be found in "play" areas (e.g. living room, rumpus room). Therefore, two-way cable terminals that seek to take advantage of existing TV sets will have to overcome the consumer's predisposition to regard the TV set as an entertainment box. At the same time, the cable industry would be missing an important opportunity if it does not try to exploit the ever-popular personal computer. Consumers are showing that it is their terminal of choice.

If the cable industry does try to hook up to personal computers, it will have to grapple with the different physical locations of most home cable outlets and personal computers. This local link may prove the most difficult to establish.

AN EMERGING OPPORTUNITY FOR CABLE?

Many factors militate against the use of cable as a two-way delivery vehicle. At the same time, it is important to note that the electronic service business is still young. As demand for such electronic services grows, the local phone systems will face much higher demand.

Under the AT&T divestiture, it is unclear whether local phone companies will be able to meet the need for more capacity fast enough. Without the traditional cross-subsidies from long distance revenues, local phone companies will be hard pressed to find new ways to finance improvements in their physical plants. Raising rates is one possible solution. In New York State, for example, phone rates went up more than 10% in just the first two months following the AT&T divestiture. Under conditions like these, cable may find some renewed opportunities.

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