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A TECHNIQUE USING SEVERAL DELAY LINES TO CORRECT FOR
MULTIPLE GHOSTING AND POOR FREQUENCY RESPONSE DUE TO MULTIPATH

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A Subsidiary of Viacom International Inc.

Ghosting on received television pictures can be minimized by directive antenna arrays if the reflected signal arrives at a significantly different angle than the desired signal. When the angle between the desired and undesired signal is small, this method is not feasible and other methods are used.

This paper describes a method of minimizing the effects of ghosting by branching the received signal into a multiplicity of parallel paths of different delay times and recombing the result into a single feed for the active processing equipment. Methods of estimating the required delay times from the detected waveform are discussed. The equipment and technique for evaluating the results are discussed with the aid of photographs and plots of an actual case.

Broadcast signals which would optimize the adjustment of this equipment at the receiving site are discussed.

This technique provides an answer to a common problem that usually goes uncorrected, or has rather expensive alternates.

Television and television ghosting came into being at the same time. With the vast increases in technology, it would appear that little knowledge could be added as to the effect, causes and remedies of ghosting on television pictures.

Ghosting that occurs during the transmission of television signals is due to more than one propagation path, and the time delay differences due to differences in the length of paths the transmitted signals travel.

Short differences in delay times affect frequency response causing problems with color and definition of picture.

Elimination of reflected signals occurring in the small cone in the direction of the wanted signal, a 5° arc in any direction from the direct line with antenna phasing or arrays are not practical.

The effect of reflected signals from within the small cone may be minimized by branching the received signal into multiple paths through parallel and series coaxial cable delay lines, and then combining so that the resulting signal through the delay lines will then minimize the effect from the received multipath signals.

The technique will first be described and later its application to a specific case.

The method for estimation of delay time of the individual component delay lines consists of a careful examination of the demodulated waveform.

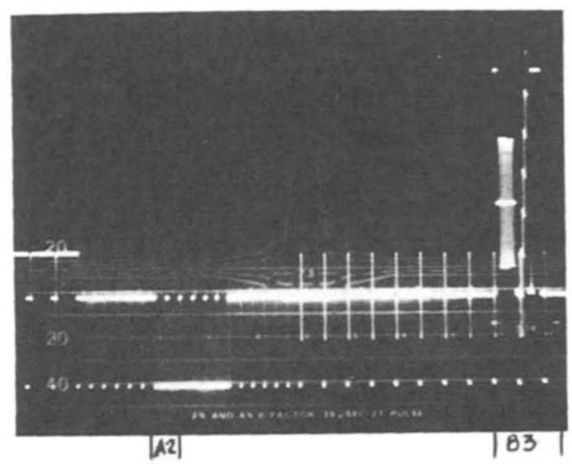


FIGURE 1. Laboratory generated television video signal vertical interval. A2 portion expanded in Figure 2. B3 portion expanded in Figure 3.

The first blanking level-to-peak sync step of the vertical sync pulse provides a single step in which to identify polarity as well as amplitude and time delay of multipath signals. The presence of echos on the following peak sync level allows timing measurements out to approximately 30 microseconds.

A horizontal sync pulse and blank line in the vertical interval provides echo time measurement to near 60 microseconds. The vertical interval test signals (V.I.T.S.) extends the time and frequency domain measurement to less than 10 nanoseconds. Figure 3 shows that the multiburst provides a measurement of frequency response to short multipath delays. The 2T and bar are areas to analyze for time and polarity of multipath delayed signals.

The modulated FM audio carrier of the television signal with its associated frequency domain, FM AM information can be observed on an X-Y scope to identify phase, amplitudes and time delays as shown in Figure 5.

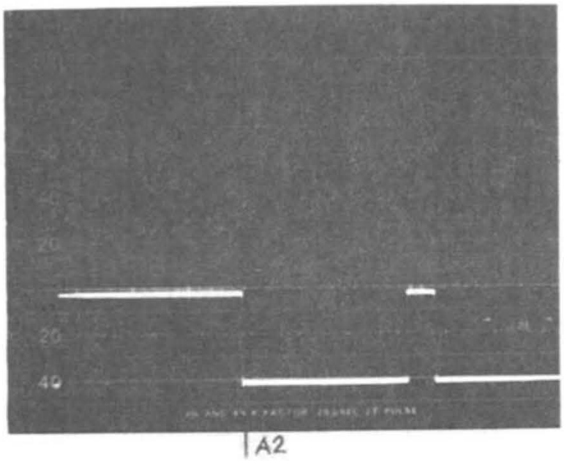


FIGURE 2. First vertical sync pulse.

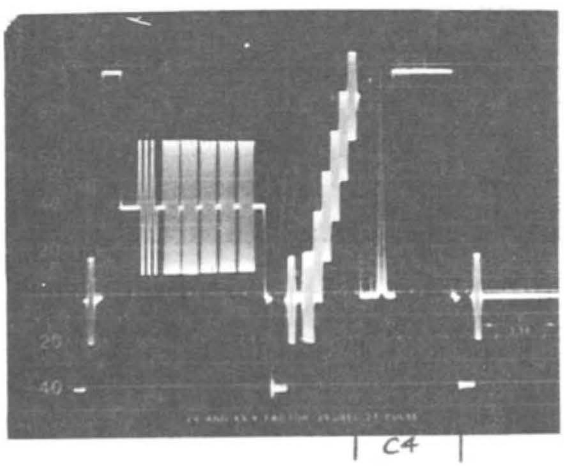


FIGURE 3. One frame of vertical interval test signals, white flag, multiburst, stair step with color, 2T, 12.5T with color and bar.

The direction of the multipath signals can be determined to within a fraction of a degree by phasing antenna arrays.

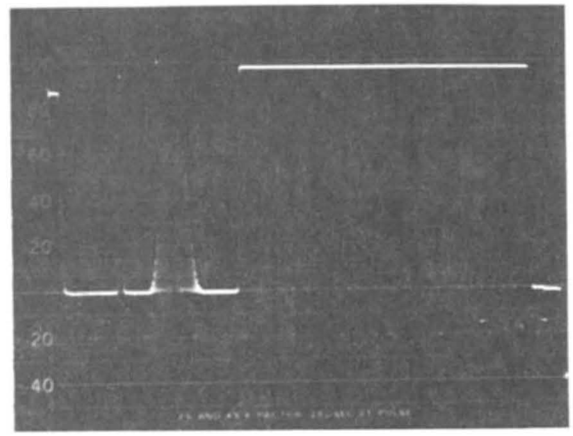


FIGURE 4. Expanded portion of C4, Figure 3. 2T, 12.5T with color and bar.

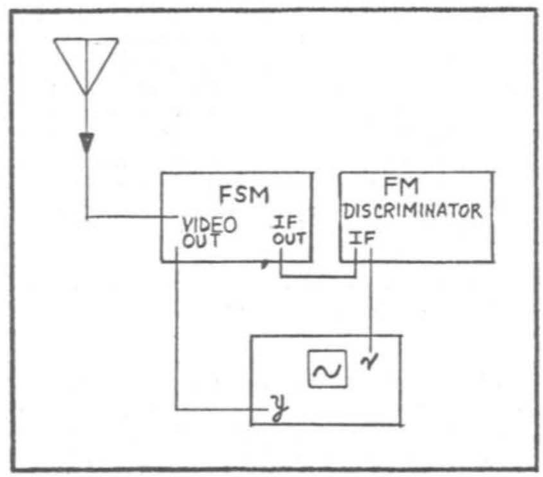
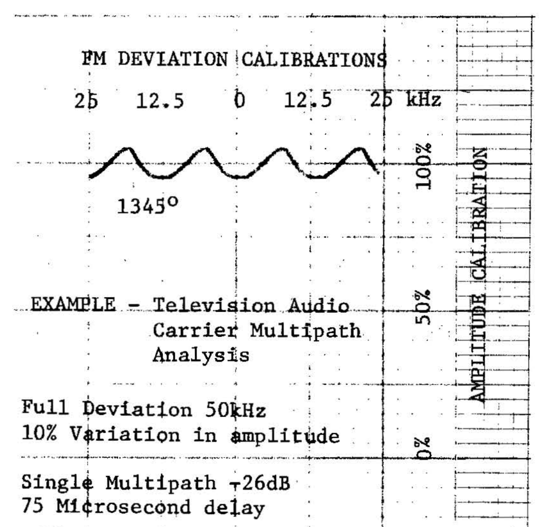


FIGURE 5



A case history showing use of technique.

July 4, 1973, heralded the first telecast in San Francisco from the new Sutro Tower with its candelabra arrangement of television transmitting antenna.

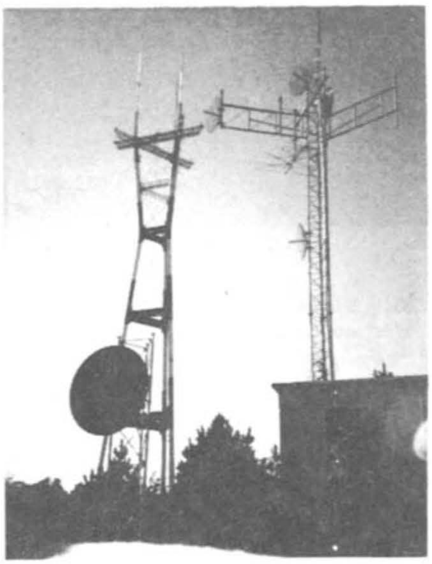


FIGURE 6. Head end site with Sutro Tower in background.

Surprisingly, multipath free signals were not received at the cable system's head end 1,500 feet east of Sutro Tower. Attempts to eliminate multipath by directional antennas and phased arrays indicated nearly all the multipath was originating from the direction of Sutro Tower.

This then confirmed the longer than 2 microsecond multipath delay with an associated very short delay as originating from the transmitting antenna. Other multipaths that affected frequency response were due to the antenna supporting structure. Longer multipath delays to over 60 microseconds originated from large buildings toward the east caused streaking of the picture appearing similar to low frequency response.

Test coaxial delay lines were constructed using RG6 cable and A.B. type switching with incremental control of delays to 2 microseconds in 5 nanosecond steps. (Figure 11.)

Two adjustable delay lines in series were used to cancel the longer than 2 microseconds and its shorter second reflection, as shown in Figure 12.

Delay times were duplicated with fixed coaxial delays and adjustable path loss.

Three adjustable delay lines in parallel were placed in series with the previous fixed longer delay, 2.435 microseconds and .160 nanosecond delay correction. (Figure 13.)

Observing 2T and multiburst frequency presentation, adjustment on all the delays and their attenuation were made for best overall response and pulse shape correcting to near normal.

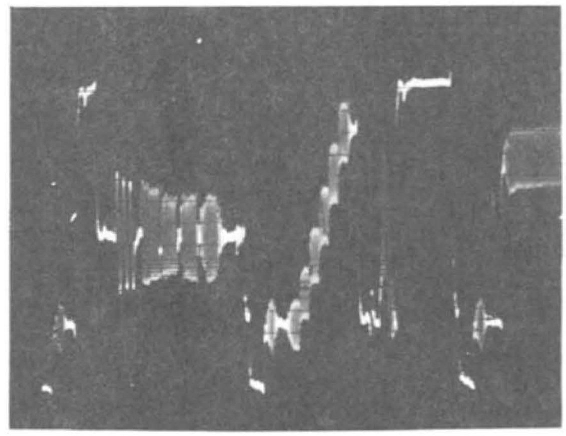


FIGURE 7. V.I.T.S. observed 13,600 feet east of Sutro Tower. The bar portion is expanded in Figure 9(a), the time is taken from the calibration of the waveform monitor. 25 x .25H per CM, 4CM delay

$$\frac{4 \times 63.56 \times .25}{25}$$

equal 2,540 nanosecond, plus a second reflection.

$$\frac{.25\text{CM} - \times .25 \times 63.56}{25}$$

equal 158 nanoseconds.
Several shorter delays affect the leading edge of the bar, the vector sum of the multiburst also showing short delays.

The delays of each adjustable line were measured and duplicated for permanent use.

The best test of the multiple delayed lines as a means of cancelling multipath was performed with the cooperation of the television station KPIX, Channel 5, engineers.

The television station uses a video sweep of the video transmitter during non-broadcast hours. This allowed testing of the delay lines, as well as giving definite proof of the effects of multipath and its correction. (Figures 16 and 17.)

Incorporation of a video sweep during vertical interval would be a method of thorough investigation or propagation effects on television signals.

Cable television uses "No ghost interference free signal" as a selling point.

Note: The long delay signal of a 2.4 microsecond and 160 nanosecond, has been since corrected in the transmission system, leaving only three parallel delay lines in present use.

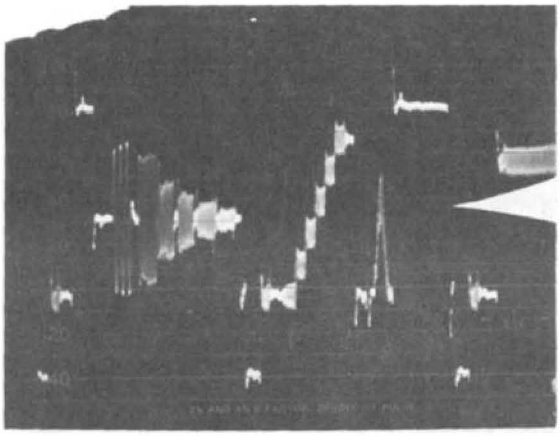


FIGURE 8. V.I.T.S. observed 1,500 feet east of Sutro Tower at head end with approximately some delay, but with opposite vector sum.

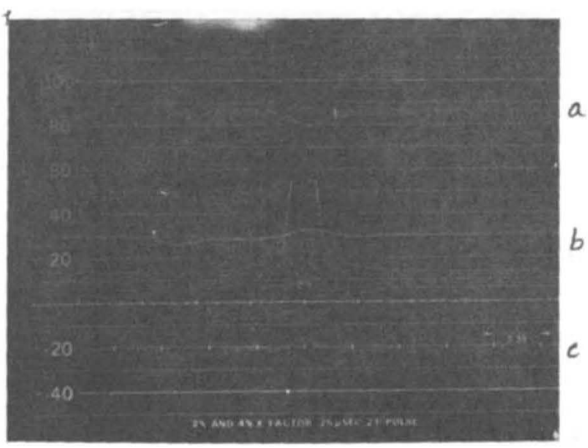


FIGURE 9. V.I.T.S. bar expanded 25 times. "c" portion is expanded bar of Figure 8.

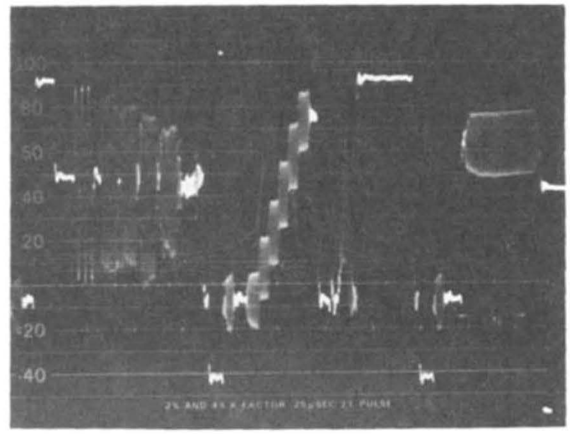


FIGURE 10. Signal, as shown on Figure 8, with corrective delay lines.

This section of delay line constructed in triplicate

Only one section with these delays

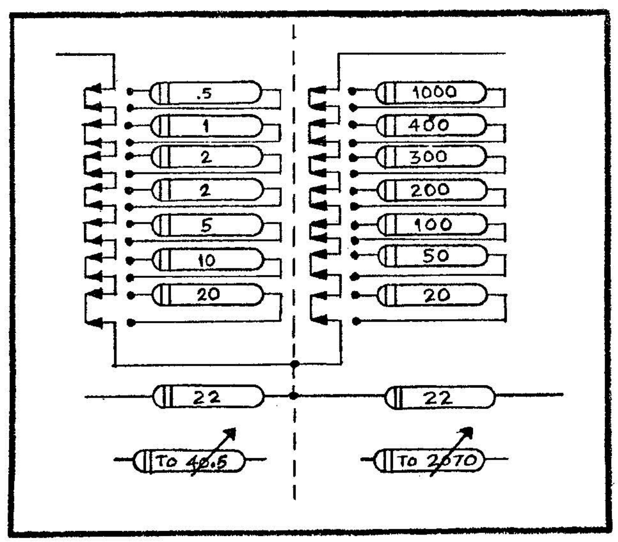


FIGURE 11

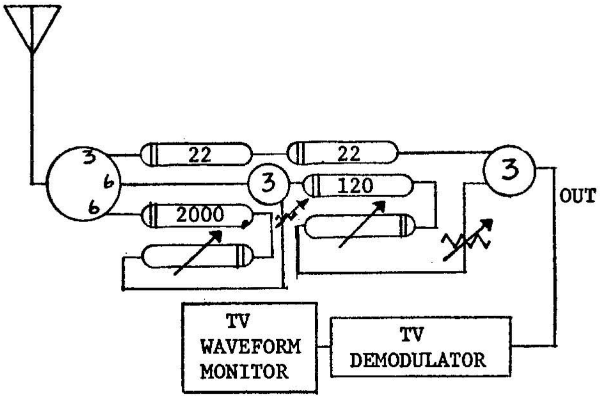
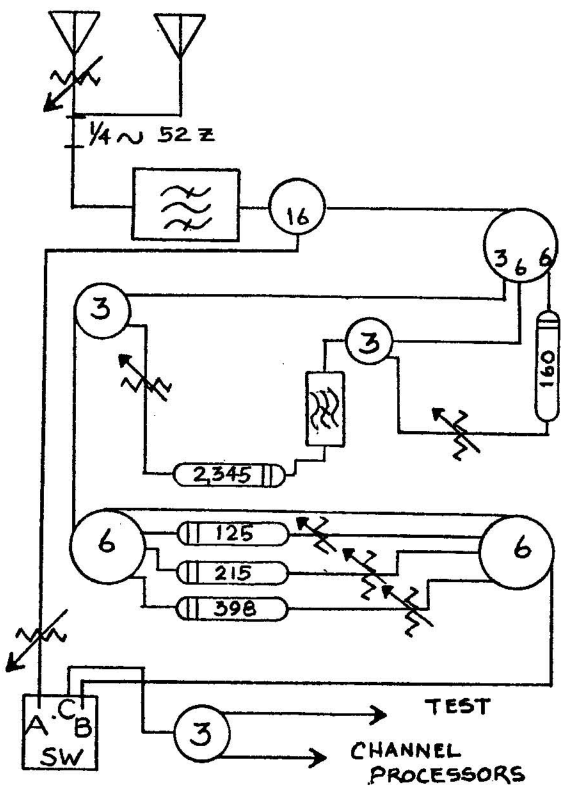


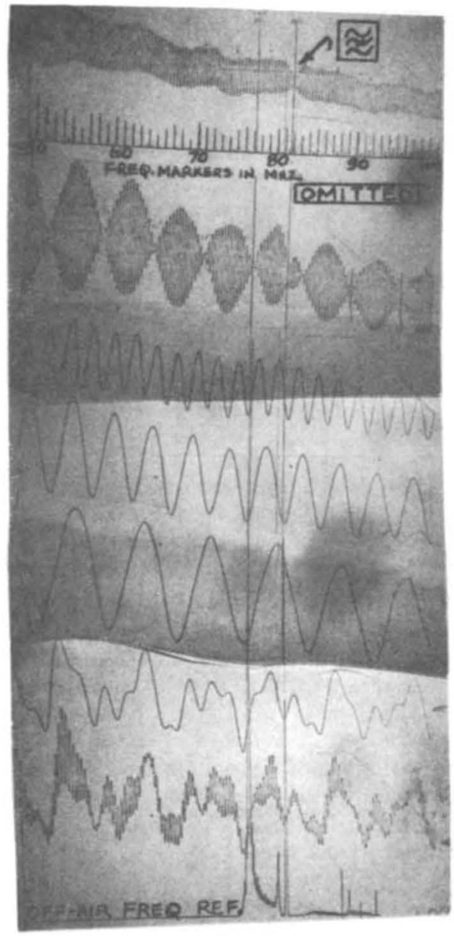
FIGURE 12



MULTIPATH DELAY PROCESSING

Delay time nanoseconds
All attenuators 0-20dB

FIGURE 13



Delay time in nanosec.

(a) 2,435

(b) 160

(ab) V3

(c) 398

(d) 215

(e) 125

(cde) V3

(ab)(cd)V3

FIGURE 14. X-Y Plots of individual coaxial delay line in reference of RF signal, the combination of each section and ultimate combination. Individual amplitude response to sweep is not calibrated.

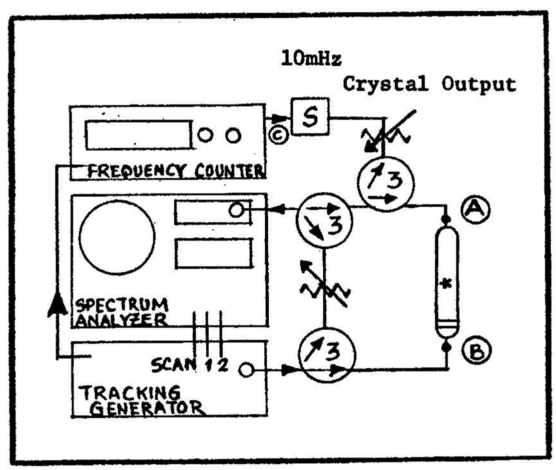


FIGURE 15. Delay Line Calibration with S-Scaler on 10mHz crystal source divided by 10, divided by 100, provides 1mHz and .1mHz calibration of any delay inserted between A and B .

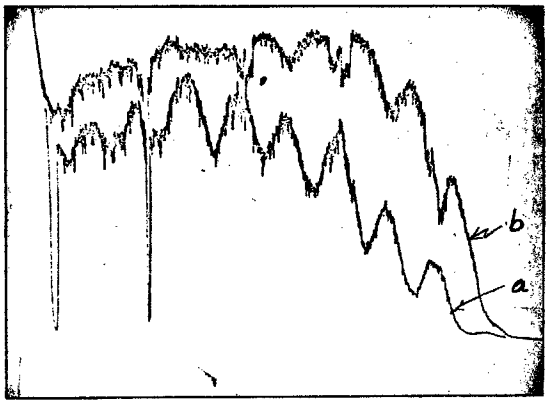


FIGURE 16. Spectrum response to video sweep of station transmitter.
Plot "a" - trace uncorrected.
Plot "b" - corrected response.

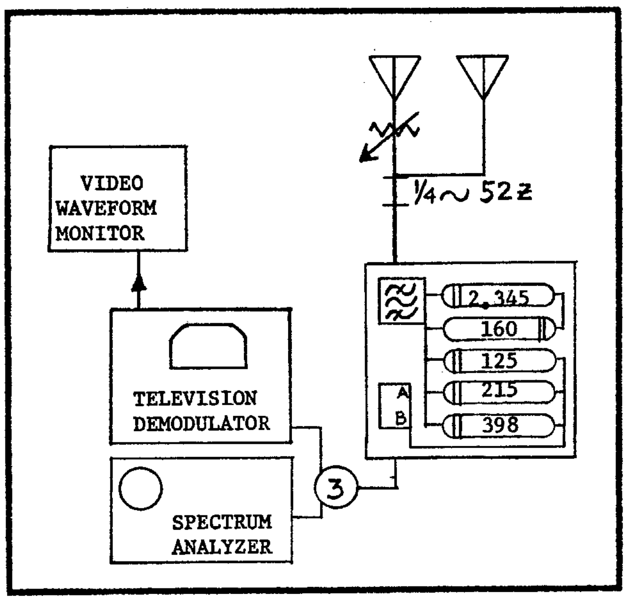


FIGURE 17. Final test of television V.I.T.S. and video sweep.

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1. Jerrold Electronics Corporation, Reference Data.

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3. Radio Shack Electronics Data Book.

4. A.B.C. Report #26
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Thanks to Jim Vaughn, Chief Technician, Viacom Cablevision of San Francisco; and KPIX Channel 5, Engineering personnel: Ray Holtz, Chief Engineer; Don Lincoln, Assistant Engineer; Walt Nichols, Technician Supervisor; Fred Neidert, Transmitter Crew Chief.

A VIDEO-OVER-VIDEO MULTIPLEXER FOR MULTI-HOP MICROWAVE RADIO SYSTEMS

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Introduction

Microwave radio relay equipment capable of carrying up to 1800 FDM telephone channels on one RF carrier over 4000-mile routes are presently being manufactured in North America. Plans call for capacities of 2100 or 2400 channels in the near future. Radio systems with capacities of 2700 channels are now being operated in Europe.

The baseband of a typical 1800 channel microwave radio link extends from 300 kHz to 8.2 MHz. To transmit this traffic load with minimum distortion, the useable bandwidth of such a radio will extend to over 12 MHz.

The standard 525 line video signal has frequency components that extend up to approximately 4.2 MHz. Thus a radio designed for 1800-channel operation has excess baseband capacity when carrying one video signal. It would seem reasonable that this excessive capacity could be used to carry additional telephone channels or an additional video signal, if a suitable multiplexer was available. This paper describes such a multiplexer, the GTE Lenkurt 46V.

46V Video Multiplexer

The 46V Video Multiplexer is designed and manufactured by Siemens AG for use on long distance coaxial cable carrier systems and is marketed in the USA by GTE Lenkurt.

This equipment translates a video signal, using a vestigial sideband amplitude modulation process, to a frequency band on the cable between 6.3 and 12.3 MHz. The cable system on which this multiplexer has been used has a nominal capacity of 2700 voice channels, or 1200 voice channels plus one video signal.

Coaxial cable systems using this video multiplexing technique are in use in a number of locations around the world.

Ref. 2 describes a 600-mile system in Australia that can carry 1200 telephone circuits and one television channel. This system, between Perth and Carnarvon, uses 0.375 inch coaxial cable and repeater spacing of 5000 yards. Ref. 3 describes the video test results that were obtained for a 308-mile section. These tests indicate that the system was capable of delivering a high quality video signal. The attenuation distortion was less than 0.2 dB, the delay distortion was less than ±25 ns, and the differential gain and phase were less than 1% and 0.7 degree, respectively. A weighted S/N of 61.2 dB and a S/hum of 45 dB were obtained.

The baseband frequency allocations for this system is shown in Figure 1C.

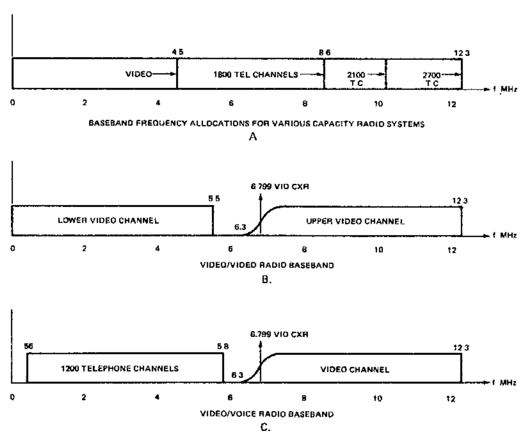

Figure 1. Radio Baseband Frequency Allocation

Figure 1A shows the baseband frequency allocation for various capacity radio systems. Figure 1B shows the frequency allocations for the video-over-video multiplexing configuration. Here, the 1200 voice channels of Figure 1C were replaced with 1 video signal.

VSB-AM was used to permit the transmission of the low-frequency components of the video signal with minimum distortion using minimum bandwidth. This technique (discussed in Reference 1) has been used on coaxial cable systems in this county by AT&T.

A carrier frequency of 6.799 MHz is employed to minimize the effects of any intermodulation products on the 4 kHz-spaced telephone channels.

A modulation index exceeding 100% is used to maximize the amount of information in the sidebands, in order to minimize the loading on the cable repeaters. The modulated signal envelope is shown in Figure 2. When 100% modulation is exceeded, it is more convenient to use the term "excess carrier ratio" (ECR) to describe the modulation index. ECR is the ratio of the peak carrier amplitude to the peak-to-peak modulation available. An ECR of 1.0 corresponds to 100% modulation, as shown in Figure 2.

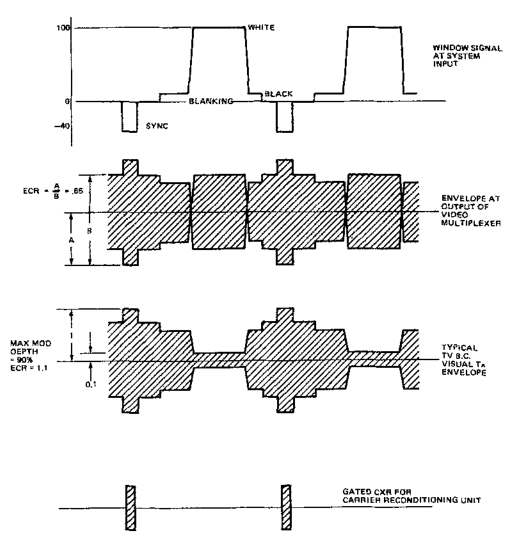

Figure 2. Modulation Envelopes

The modulation envelope of a typical broadcast transmitter is shown in Figure 2 for reference. Here, the maximum modulation depth is 90%, with an ECR of 1.1.

The use of this modulation technique complicates the demodulation process at the receiving end of the system. When the modulation depth of an AM signal exceeds 100%, the phase of the carrier is reversed and is therefore unsuitable as a reference for the local carrier at the demodulator. If the local carrier in a product detector is not inserted in the proper phase relationship with the incoming signal, the detector output will contain quadrature distortion terms.

The 46V demodulator overcomes this problem by sampling the receive signal when sync information is present, as shown in Figure 2. During this time, the modulation index is low, and the carrier has a constant phase. The carrier sample is filtered and used to phase-lock the receiver local oscillator, thus minimizing the effects of quadrature distortion.

These design features, which make the 46V useful in a coaxial cable system, also make it attractive for applications with microwave radio as the transmission medium. In summary, their advantages are:

1. The VSB modulation requires a minimum of bandwidth for low-distortion transmission.

2. The high-modulation index minimizes the carrier content, and thus the system loading.

3. Two video signals can be modulated on one carrier, which doubles the capacity of the radio.

4. The system is capable of high-quality transmission.

The video multiplexer is shown in Figure 3. Two 6 MHz HP/LP filters are used to both combine and separate the HF multiplexer line signal from the lower video signal. A phase correction network is used to equalize the phase characteristics of the HP side of these two filters. Not shown on the diagram is a phase equalizer that was used to correct the characteristics of the low-pass section of the two filters.

These factors were taken into account during feasability tests with the 46V modulator connected to a microwave system. Because the two video signals to be multiplexed are complex, it was thought easier to set up the equipment and make empirical measurements rather than depend on a theoretical analysis. We felt that one of the major problems to be encountered would be intermodulation products generated between

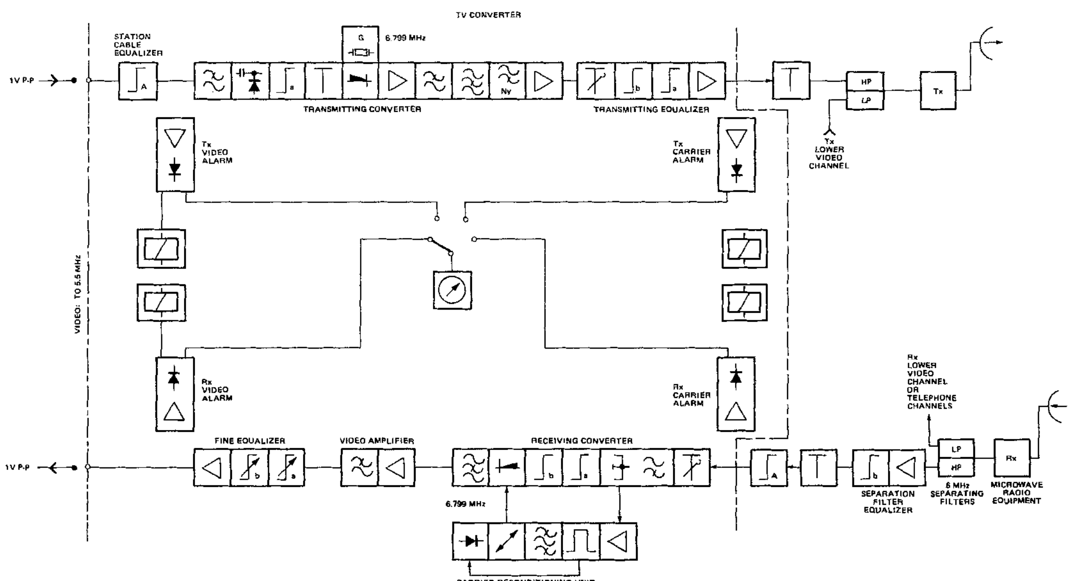

Figure 3. 46V Video Multiplexer

Video Multiplexer on Radio Considerations

Microwave radio and coaxial cable are two vastly different transmission mediums. The former is subject to propagation fading and its bandwith is limited (usually by regulatory agencies, rather than by design). It has a few pluses, however. Fading can be counteracted by space or frequency diversity switching technique; there are fewer parts to malfunction, and it is less expensive to install and maintain.

the two video signals, and that subjective testing was the best method of determining their effects.

Consequently, the 46V video modulator was connectea to two hops of radio in the laboratory, with the path loss being simulated by suitable RF attenuators.

Two independent, nonsynchronous video signals were used to drive the system. A number of tests were made to determine the quality of transmission of each signal path, and the amount of interaction between the two signals. Tests were also conducted with the LP channel carrying white noise, simulating various telephone channel loadings. The results of the video-over-video tests are discussed below.

Video-Over-Video Test Results

1. Test Conditions

	HP (Upper Video Chan)	LP (Lower Video Chan)
Modulation	525 Line Video	525 Line Video
Deviation	4 MHz (peak)	4 MHz (peak)
Emphasis	Internal	525 Line CCIR

2. Measured Test Results

	HP Chan	LP Chan
S/N Weighted	66 dB	>70 dB
S/Hum	>73 dB	>73 dB
Receive Signal Level for 37 dB Video S/N	-58 dBm	-70 dBm
Diff. Gain 10-90% APL	1%	1%
Diff. Phase 10-90% APL	0.5°	0.6°
Multiburst Response Variation	5 IRE Units	2 IRE Units
Sin^2 2T Pulse Overshoot	1%	1%
60 Hz Square Wave Tilt	1%	1%(unclamped)

3. Subjective Test Results

Subjective tests were carried out to determine the effects of crosstalk between the HP and LP video channels. No discernable crosstalk was seen on the color picture monitor connected to either of the two channels with a multiburst on the interfering channel, using the above deviation. We noticed that if the LP signal level (deviation) was increased by 5 dB, some discernable interference was visible on the HP channel in the form of horizontal bars. The use of 525 line preemphasis in the LP video channel reduced the effect of interference on the HP video signal.

The 4 MHz peak deviation represents a considerably heavy loading for the radio system. In practice, less deviation would be used in order to stay within the FCC criteria for occupied bandwidth.

The effects of varying receive signal level of the video S/N in the HP and LP video channels for one hop of radio is shown in Figure 4. As expected, the HP channel had a S/N that was 16 dB worse than the LP channel for the same deviation. This was caused by the "triangular" thermal noise spectrum of an FM system, and by the vestigial sideband process used to translate the video. It follows also that the threshold level (or mute point) will be correspondingly reduced for the HP signal.

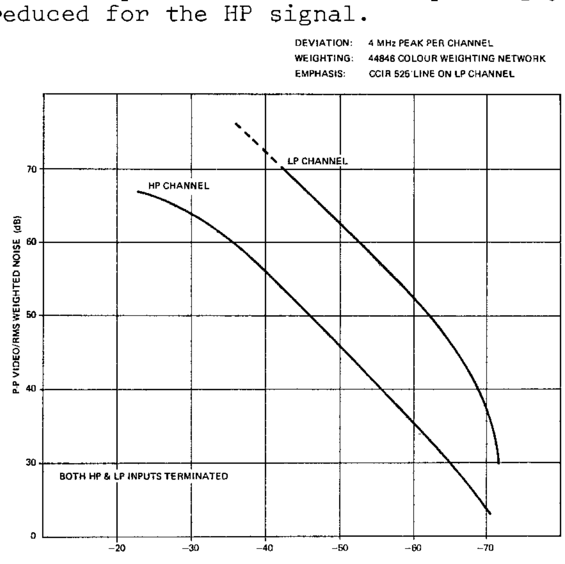

Figure 4. Video S/N vs Receive Signal Level

Radio Deviation Considerations

The tests indicated that both video signals could be sent over the system at full 4 MHz per channel peak deviation, with no noticable intermodulation problems. Maximum deviation will be determined in the USA by FCC criteria for "necessary bandwidth," which is the familiar "Carson's Rule" for FDM-FM radio systems. The expression for FCC necessary bandwidth is:

$Bn = 2M+2DK$

where Bn = Necessary bandwidth
= 30 MHz in 6 GHz common carrier band
= 40 MHz in 11 GHz common carrier band
M = Maximum modulation frequency
D = Peak deviation
K = A constant, taken as 1 for this case

The peak deviation for both video signals (assuming worst-case coherent addition) will be 8 MHz and the top modulating frequency is 11.1 MHz.

The necessary bandwidth is then 38.2 MHz, which exceeds the FCC limit by 8.2 MHz. To reduce the necessary bandwidth, the deviation of the lower channel was reduced by 16 dB to equalize the S/N in both channels. If the composite deviation is reduced by 0.4 dB, the occupied bandwidth of 30 MHz will be met. Of course the relative deviation of the two signals could be changed, depending on the application. A deviation of 40 MHz is permitted in the 11 GHz common carrier band, which would allow both signals to be applied at 4 MHz peak deviation.

Conclusions

The 46V video multiplexer provides a useful way to multiplex two video signals on a single radio bearer. Tests (not described here) have shown that it is also feasible to combine up to 1200 FDM telephone channels and one video channel on a microwave system. This multiplexer is designed for radio systems having capacities of 1800 telephone channels, or greater. The limitations are associated with the restrictions that licensing agencies place on the occupied bandwidth, which limits the deviation, and thus the thermal S/N. Application of this multiplexer will therefore be limited to those microwave systems having adequate receive signal levels and fade margins. The multiplexer effectively doubles the capacity of a video microwave system, which should be of interest to those concerned with frequency conservation.

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ANOMALOUS PROPAGATION FADING IN CARS BAND LOCAL DISTRIBUTION SERVICE

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Fading phenomena, due both to rainfall and to atmospheric conditions constitute a basic limitation on the reliability of CARS band Local Distribution Service. Long paths are of particular interest since both fading mechanisms are critically dependent on path length.

This paper describes the results of several months of continuous observation of fading over a 24 mile path in eastern Connecticut. Fades have been correlated with rainfall and those due to this source have been separated as non-contributory to the body of information already available. All other fades are summarized by number of fades, total duration, and by daily time slots corresponding generally to different television viewing habits.

Empirical expressions are derived describing the occurance of anomalous propagation fading and the effect on path reliability.

I. INTRODUCTION

The increasing use of microwave local distribution service (LDS) to reduce the required length of trunk runs to population centers generates the need for data from which transmission reliability can be predicted. Paths have generally been limited to 10 to 15 miles because of fears that outages will be of a frequency and duration sufficient to affect subscriber retention. If the path can be increased to 20 to 25 miles, with good reliability, it would be possible to provide service to many communities not economically viable if another head end were required.

This very situation was encountered in eastern Connecticut. It prompted the establishment of a 24 mile long path over which signal fluctuations were continuously recorded for a period of several months.

II. FRANCHISE GEOGRAPHY

This franchise as awarded by the Public Utilities Commission of the State of Connecticut is outlined in Figure 1. It is 50 air miles between extremities and bisected by a franchise of another company. The northern towns are sparsely populated and would not be generally considered a viable cable television area if not subsidized by the more densely populated southern towns. Furthermore, the northern towns lie in a river valley with an elevation of 150-200 feet AMSL and surrounded by hills of 500-800 feet elevation. This geography dictates use of either a very tall tower situated in the valley or a tower in the hills. Hilltop sites would be sufficiently remote from the towns to require either microwave distribution or two head ends. The combination of sparse population and high head end costs to provide service to those northern towns required a search for an alternative which would reduce costs while still providing satisfactory service.

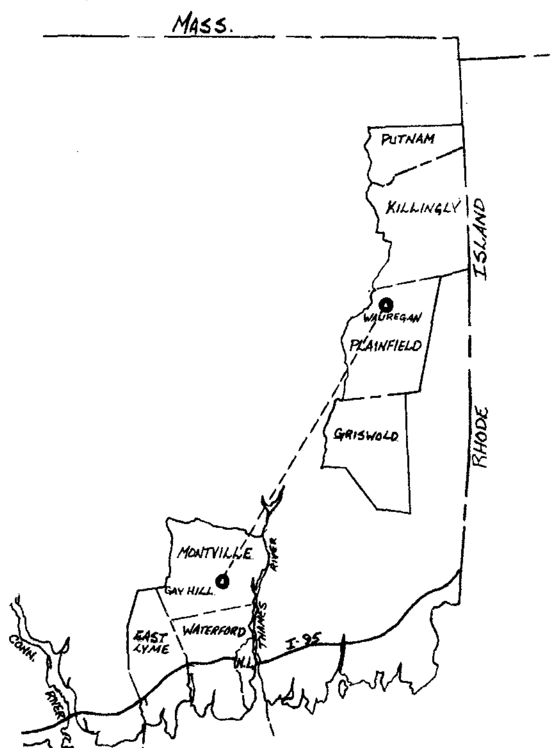
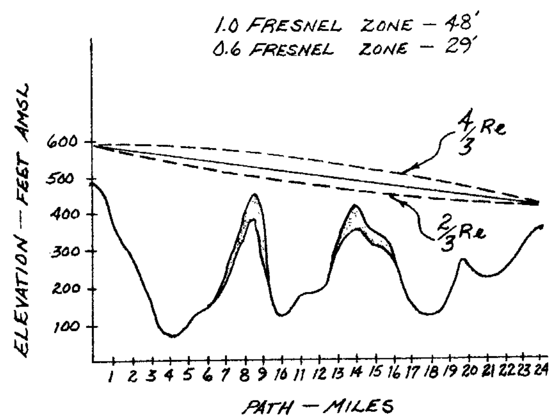


FIGURE 1

The head end located in the town of Montville in the southern town area already contained an LDS microwave system which distributes the signal to those parts of the towns of New London, Waterford, and East Lyme lying south of Interstate 95.

The path profile from the existing head end to a centrally located site in the northern towns is shown in Figure 2. The terrain is hilly but not mountainous, the shaded area on the two highest hills represents trees. Drawn on the profile are dashed lines which represent the clearances for refractive conditions equivalent to 4/3 and 2/3 earth's radius bending. It is seen that the minimum clearance for 2/3 earth radius bending is about 45 feet. Since a 0.6 fresnel zone height is 29 feet, adequate clearance is achieved for any of the above refractive conditions.



PATH PROFILE

FIGURE 2

III. FADING CAUSES

Microwave path reliability is dependent on two fading sources, rain attenuation and fading due to abnormal atmospheric conditions.

Rain fading has been exhaustively studied by many investigators dating back to the 1940's and is well understood. It can be readily predicted over a period of time if the rainfall statistics for the area are known. This 24 mile path should experience about 9 hours a year when the signal is faded 20 dB by rainfall.

Fading due to atmospheric conditions can result from substandard refraction conditions or from multipath effects. The former occurs when the transmitted beam is bent upward sufficiently far to be no longer intercepted by the receiving antenna. It is called inverse bending and appears to be a relatively rare phenomenon. When it does occur, however, it may last for several hours. Multipath fading occurs when signals from the transmitter traverse two or more paths to the receiver and interfere destructively upon combination. It will occur regardless of the height of the path above the terrain since the interfering signal generally traverses a path above that of the direct signal.

The most significant study of multipath propagation near CARS band frequencies was done by Bell Telephone Laboratories. The work centered upon worst-case fading for time of day and time of year so that extrapolation to yearly television viewing reliability is not possible.

Because multipath fading is proportional to the cube of the path length, this 24 mile path is generally considered long for CARS band LDS distribution and an appropriate one to study the effect.

IV. MEASUREMENT ARRANGEMENT

The equipment employed in making measurements were the Theta-Com Model AML-TC-121 transmitter and Model RC-230 receiver. Both transmitting and receiving antennas were 10 feet in diameter.

The unfaded signal to noise ratio at the pilot tone with the AGC disengaged was 55 dB, the AGC was set for 6 dB to a S/N of 49 dB out of the receiver.

The AGC voltage was calibrated with respect to signal level then continuously recorded. The data was reduced to number of fades and duration of fading when fade depths were greater than 6 dB. Since fade outage time is proportional to the power ratio of the fade except for a 15% correction factor at low fade level, the 6 dB fade data can be readily extrapolated to outage times for greater fade depths. A 20 dB fade depth was taken to define true microwave outage time since it results in a 35 dB S/N which is noisy but still watchable.

Rain fading was separated from atmospheric fading by keeping a record of weather conditions over the general area. Rain fading is readily distinguishable from multipath fading as the latter is always accompanied by large fluctuations of signal level while rain fading causes the signal to smoothly enter the fade condition.

V. DATA SUMMARY

Unlike telephone service which requires essentially constant reliability throughout the day, the nature of television viewing is such that certain times are much less important than others. Thus, if a large portion of signal fading occurs in the 1 a.m. to 7 a.m. time period, overall performance may be acceptable. For this reason, the data has been accumulated by daily time periods corresponding roughly to different viewing habits.

Table 1 is a summary of the collected data by time period. The last column is an extrapolation to yearly outage time.

TABLE 1

Time Period	Data Base	# of Fades	Total Fade Time	Hours/Year @ 20 dB
7 am-1 pm	37,800 min.	22	366 min.	0.977 hrs.
1 pm-7 pm	39,000	4	25	0.060
7 pm-10 pm	19,620	32	170	0.438
10 pm-1 am	19,620	27	420	1.078
1 am-7 am	37,440	106	1887	5.077
TOTALS	153,480 min.	191	2868 min.	7.63 hrs.

Based on the above, it is expected that 7.6 hours per year will experience fades greater than 20 dB with 5.1 of those hours occurring in the 1 a.m. to 7 a.m. period.

There was multipath fading on 24 of the 119 data days.

There were 3 days during which either inverse bending or stable multipath fading occurred. These long term fades constituted 22.5 hours of the total 47.8 hours of anomalous fading observed. These fades existed from 4 a.m. to 7:30 a.m., 10 p.m. to 10:30 a.m., and 12 p.m. to 7 a.m. respectively. The depth of these fades is not known; but no reports of outages were received from a number of observers on the cable.

Based on the observations, the fractional outage time for all periods of the day can be expressed by

(1) $$P = 6.30 \times 10^{-6} D^3 L \quad \text{for } L \leqq .01$$

where

P = fractional outage time

D = path length in miles

L = power ratio of fade depth

If 1 a.m. - 7 a.m. fade time is removed as unimportant to viewing reliability, the following equation describes the outage time:

$$P = 2.11 \times 10^{-6} D^3 L$$

CONCLUSIONS

Data collected over a 24 mile path for nearly 1/3 of a year indicate a total yearly outage time for anomalous fading of about 7½ hours. This added to a predicted 9 hours of rainfall fading indicates less than 17 hours per year during which viewing is interrupted. Since 2/3 of the anomalous fading and a part of rain fading will occur during non-viewing hours, this projected outage time does not seem excessive. Although anomalous propagation fading is a function of the character of the terrain and of the temperature and humidity conditions of an area, it is to be expected that the bulk of this kind of fading will occur during the early morning hours when propagation reliability is of less importance.

Although each system designer will have to judge whether the expected outage time on a long path is acceptable, it does appear that a more aggressive approach may often be of economic advantage to the operator.

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APPLICATIONS OF OPTICAL FIBER TO CATV SYSTEMS

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The advent of low loss optical fibers has stimulated interest in the possible application of this new technology to CATV. In addition to low loss, fiber optics offer the potential advantages of broad bandwidth, small cable size, and immunity to RFI. This study summarizes the characteristics of the fiber optic components and systems. Extrapolations of presently available cost and performance data are applied to three types of CATV applications:

(1) Relatively low data rate upstream data transmission,
(2) Super trunk type applications, and
(3) Downstream trunk and distribution of a large number of television signals.

The sensitivity of the assumed systems to parameter variations is investigated. This investigation indicates that fiber optics may have a very limited application in CATV systems within three-five years. However, both economic and technological factors must be overcome before widespread use of fiber optics can become a reality.

I. INTRODUCTION AND SUMMARY

Since the announcement of optical waveguide attenuations below 20 dB/km, optical fibers have been mentioned as a possible transmission medium for broadband networks. This paper specifically addresses such possibilities in the CATV industry. Various CATV configurations using optical waveguides are evaluated to determine their technical feasibility and estimated cost characteristics.

The Appendix to this paper summarizes the pertinent characteristics of various optical components. Optical fiber parameters which are presently available are contrasted with what is expected to be available by 1976. These assumed parameters are then applied in Section II to three types of CATV applications.

The first application considered is that of upstream data transmittal. Star and tee coupler configurations are compared. It is concluded that the use of star couplers will lead to a more cost effective system and in fact, that the costs are at least in the same ball park, given the validity of the basic assumptions, as with the use of standard sub-low equipment.

Application of fiber optics to supertrunk also appears to be technically feasible provided each TV channel is carried on a separate fiber. Both analog and digital operation is possible, although the former requires a greater number of repeaters. Costs could be comparable to present VHF techniques for up to about ten channels. For the digital system, repeaters may not be required even up to six miles. The trade-off versus microwave is similar to that between microwave and supertrunk, i.e. for short distances, the fiber would be more cost effective. However, because of the diminished distortion, an optical fiber supertrunk could reach further than standard VHF supertrunk lines.

The most difficult application for the optical fiber is in the downstream trunk and distribution of a large number of TV channels. A system employing either digital or analog modulation on the trunk, and analog modulation on the distribution with interface to the customer at video baseband, is technically feasible but appears to be prohibitively costly within the near future.

It is concluded that fiber optics may play a limited role in some CATV applications within the next three to five years, particularly with supertrunks, but that more extensive applications will have to await further cost/performance developments in a number of areas. This is particularly true of high data rate digital systems requiring D/A and A/D converters. Other unknowns include the optical interconnect hardware and the long term reliability of semiconductor laser transmitters.

II. APPLICATION SCENARIOS

A. Low Data Rate Upstream Transmission

When consideration was first given to the application of optical fiber to CATV systems, a relatively low data rate upstream transmission system, such as SRS [1], appeared to be an ideal candidate system to consider. This initial evaluation stemmed from the realization that the low data rate poses no problems whatsoever to any of the fiber optic system components. Dispersion limits on the fiber itself need hardly be considered for 1 megabit data rates. Even the simplest LED's and optical detectors are capable of responding to these low modulation rates. Thus the optical system components would be relatively inexpensive. They exist today and would be available at low prices without the need for extensive development.

Another factor in this evaluation was that the low data rates would not require as high a received signal level for acceptable system performance. Thus high coupling losses would be less of a system constraint than might otherwise be expected.

Finally, there were problems associated with the sub-low VHF upstream data transmission which the optical system promised to avoid. These included the maintenance of adequate grounds, interference due to RF leakage into the cable system - aggravated by loose connections anywhere on the system, and interference caused by TV tuners belonging to the CATV customers who did not choose to participate on a two-way basis. Not only did the optical system avoid these problems, but also, existing upstream data transmission systems would require relatively simple design modification to substitute the optical LED and driver circuit for the sub-low transmitter and modulator.

In considering the upstream communication line, it is assumed that the optical cable is strung along the same path as the downstream coaxial cable. Although this constraint is not absolutely necessary, to violate it would be to sharply increase construction costs. Therefore, the system can be divided, as on the downstream, into the distribution and trunk portions.

The distribution system is characterized by relatively short distances but a large number of customer "taps". Several cases may be considered. As one extreme, individual optical fibers are run all the way from the customer's home to the trunk bridger. The opposite extreme is to emulate the VHF distribution and mount an optical tap near each subscriber's home. Figure 1 illustrates some of the distribution system designs which were considered.

Evaluation of the alternate systems requires first a calculation of system losses and a comparison of these losses to a permissible loss budget.

This budget can be established by estimating on the one hand the optical power which can be coupled into a single optical fiber from an LED and on the other hand by estimating the optical power required at the receiver (or repeater) for a 10^{-9} bit error rate. As much as +2 dBm of optical power has been coupled into a high numerical aperture fiber from an experimental high brightness, small size LED[2]. However, more typically one can obtain only -20 dBm to -10 dBm from currently available LED's and optical fibers.

As an optical receiver, a photodetector with avalanche gain which helps overcome thermal noise in the load resistance will yield greater sensitivity than a simple pin diode photodetector. However, the former requires more critical thermal compensation networks and will therefore be more expensive. For a 1 megabit data rate one requires -60 dBm input to a receiver employing no avalanche gain, and -70 dBm input if avalanche gain is available[3].

Combining the above two criteria one establishes a permissible loss budget of 40 to 60 dB depending on the choice of components. Ultimately, with the most advanced components a loss spacing in excess of 70 dB may be achieved.

Table I defines the parameters and indicates the nominal values assumed for this portion of the study.

Table II summarizes the loss calculations for the various cases. It is clear that of the first three cases, the lowest loss is obtained with equation (3). This is compared in Figure 2 to the loss calculated using the optical tee configuration. It is clear that the star coupler configuration is not only greatly superior to the tee configuration, but also that the technical feasibility seems well established even for fibers having as much as 24 dB/mile insertion loss. These points are further underscored when one recognizes that the assumption, $t = 1$ dB, and the assumed optimum use of variable fraction tee couplers are both highly optimistic in terms of minimizing loss. On the other hand, s 8dB has been measured with prototype star couplers.[4] In any case, equation (3) has only limited sensitivity to variation in the value of s.

The per mile costs of the distribution portion of the optical system is given in Table III. The value of m should be chosen to minimize the total cost in equation (5). In equation (6) the value of k is determined from Figure 2 assuming 24 dB/mile fiber and maximum 40 dB spacing between repeaters. The results are plotted in Figure 3 for the two assumed costs. Note that

TABLE I - OPTICAL SYSTEM PARAMETERS

			Assumed Values
n	=	number of optical sources/distribution mile	variable
m	=	number of star couplers/distribution line	optimized
D	=	distance from bridger to end of distribution line	0.6 mile
f	=	fiber loss/mile	8 dB, 24 dB, 48 dB
s	=	star coupler insertion loss	8 dB
t	=	tee coupler insertion loss	1 dB
F	=	cost of fiber/mile	\$160, \$320
S	=	cost of star coupler	\$100, \$200
T	=	cost of tee coupler	\$10
R	=	cost of repeater	\$250
d	=	spacing between bridgers	1/3 mile
k	=	number of repeaters/distribution line	as required

TABLE II - LOSS CALCULATIONS

Fig 1a;

Distribution Loss = Df

Trunk Loss = s + 10 log (4nD + 1) + fd

Maximum Total Loss to Nearest Repeater:

$$L = Df + s + 10 \log (4nD + 1) + fd \qquad (1)$$

Fig 1b

Maximum Loss to Nearest Repeater (Bridger):

$$L = Df + s + 10 \log \left(\frac{2}{3} nD + 1\right) \qquad (2)$$

Fig 1c;

Maximum Loss to Nearest Repeater (Bridger):

$$L = Df + s + 10 \log \left(\frac{2}{5} nD + 1\right) \qquad (3)$$

Fig 1d;

Maximum Loss to Bridger with no Repeater in Distribution:

$$L = Df + nDt + 10 \log \left[2 + \sum_{i=1}^{nD-2} \left(\frac{1}{\text{antilog } t/10}\right)^i\right] \qquad (4)$$

Above assumes that the various optical fiber inputs are combined either in a star coupler or directly on the surface of a photo diode which acts as the input stage of an optical repeater. In order to minimize the total quantity of optical fiber, the coupler in 1b is located 2/3 of the distance from the bridger to the end of the line and 2/3 of the fibers are coupled into it.

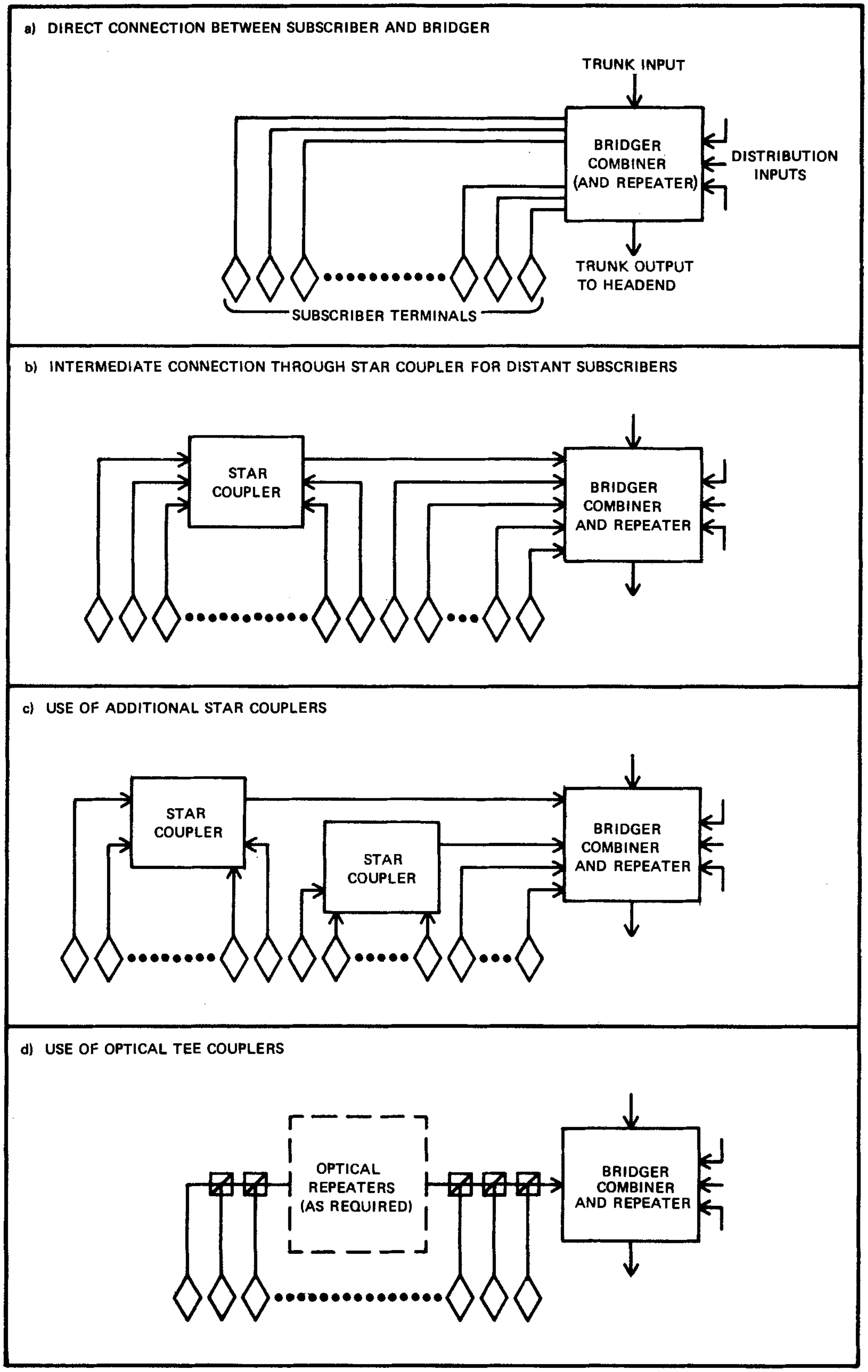


FIGURE 1 ALTERNATE FORMS OF OPTICAL UPSTREAM DISTRIBUTION

FIGURE 2 COMPARISON OF OPTICAL UPSTREAM DISTRIBUTION LOSSES USING STAR AND TEE COUPLERS

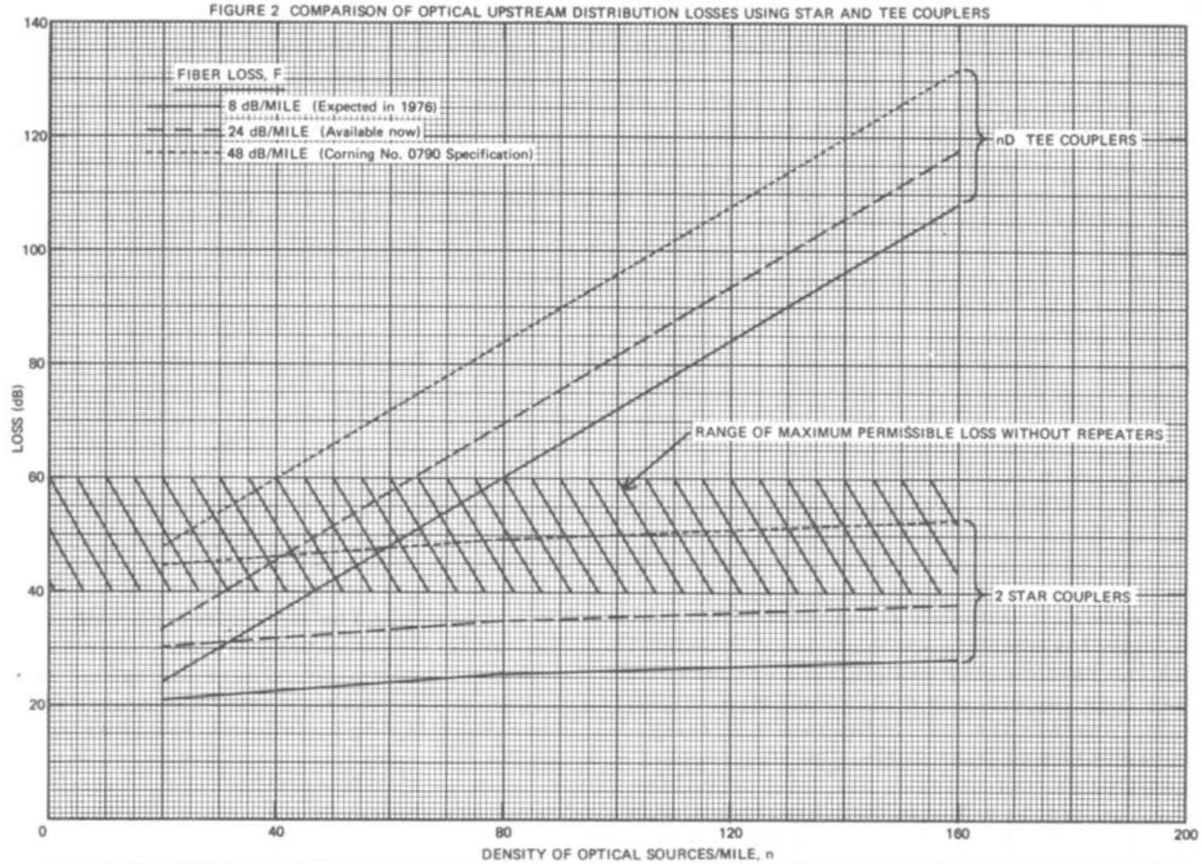


FIGURE 3 COMPARISON OF OPTICAL UPSTREAM DISTRIBUTION COST USING STAR AND TEE COUPLER STAR COUPLER

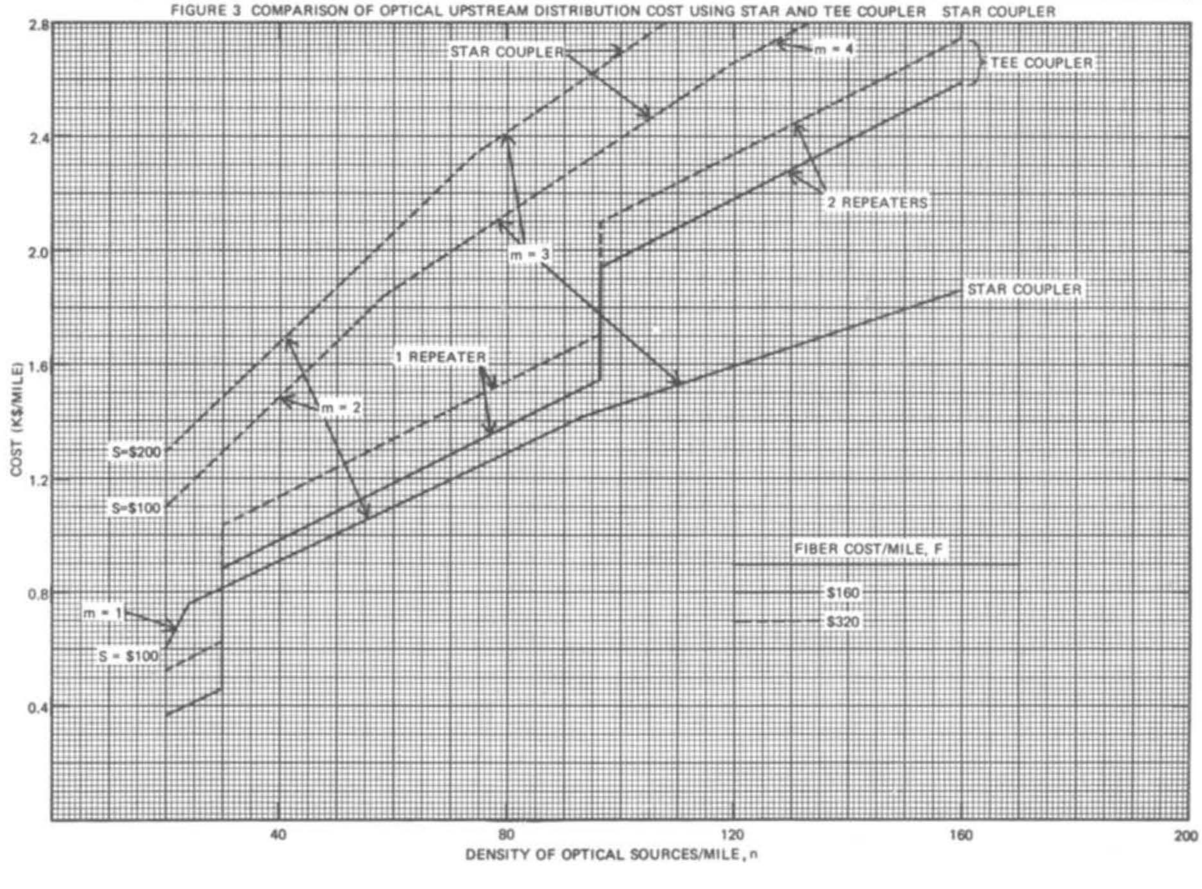


TABLE III - PER MILE COST OF OPTICAL UPSTREAM SYSTEMS

With m star couplers per distribution line:

$$C = \frac{1}{2m+1}\left[\frac{nD}{2} + \sum_{i=1}^{m} 2i\right]F + \frac{mS}{D} \qquad (5)$$

With tee couplers and with k repeaters per distribution line:

$$C = F + nT + kR/L \qquad (6)$$

Upstream trunk cost:

$$C = F + \frac{R}{d} \qquad (7)$$

as n increases, in actuality D will tend to decrease rather than stay constant as assumed. Thus the cost for the star coupler system would in fact increase less rapidly with n than indicated. Note also that, whereas the tee configuration is relatively insensitive to fiber costs, the star coupler configuration is economically practical only if the fiber cost is kept to a minimum. Therefore, it is probably essential to consider only single fiber, rather than multiple fiber bundles, in this application. Moreover, to minimize n, it would appear that pole mounted optical sources should be shared among several upstream subscribers. On the other hand, the star coupler configuration is relatively insensitive to the cost, S, of the coupler as indicated in the Figure. However, the slope of the tee coupler lines would double if the assumed value of T were doubled. The costs of the tee configuration are also indirectly tied to the value of t by the necessity of employing additional repeaters when the coupler insertion loss is increased.

Note that neither the subscriber terminal (source) cost, nor the construction cost is included in Figure 3. It may, however, be assumed that the terminal cost would be roughly comparable to the cost of a terminal using the sub-low frequency band for upstream distribution. Construction costs might well be relatively low for the optical fiber because of its lighter weight but the actual tradeoff would depend on whether or not the upstream is being added to an existing cable system and whether or not that system requires any new VHF cables and/or new line extenders.

The cost of the upstream trunk is given by equation (7) in Table III. With the parameter values listed in Table I this cost is, at worst, \$1,070/mile. The cost is determined to a large extent by the repeater cost, R. Therefore, it would be reasonable to have the optical trunk cable include multiple fibers to allow for some breakage during installation and later operation.

B. Fiber Optic Supertrunk

As we have seen, optical couplers tend to have a relatively high insertion loss. Therefore, the low loss characteristic of optical fiber realizes its full potential only when applied to a long uninterrupted supertrunk line. In such an application the optical transmitter and receiver could, if necessary, be quite complex since the total system cost will be largely dependent on the optical fiber and installation costs. Thus, a wide range of possible modulation concepts may be considered.

We consider three cases in particular. The system configurations are outlined in Figure 4. The first variation of baseband analog, pictured in Figure 4a, utilizes a high power laser to permit the greatest possible non-repeatered distance while maintaining reasonably good picture quality. The output from this laser is split into the N channels to economize on transmitter costs. The only high power source which can be considered is a 2 Watt cw YAG laser. A major drawback to this laser is that the tungsten iodide lamps which are required to "pump" the laser rod must be replaced at 100 hour intervals.

The alternate analog modulation system shown in Figure 4b would not suffer this severe maintenance limitation. It will, however, require repeatering at more frequent intervals, since it

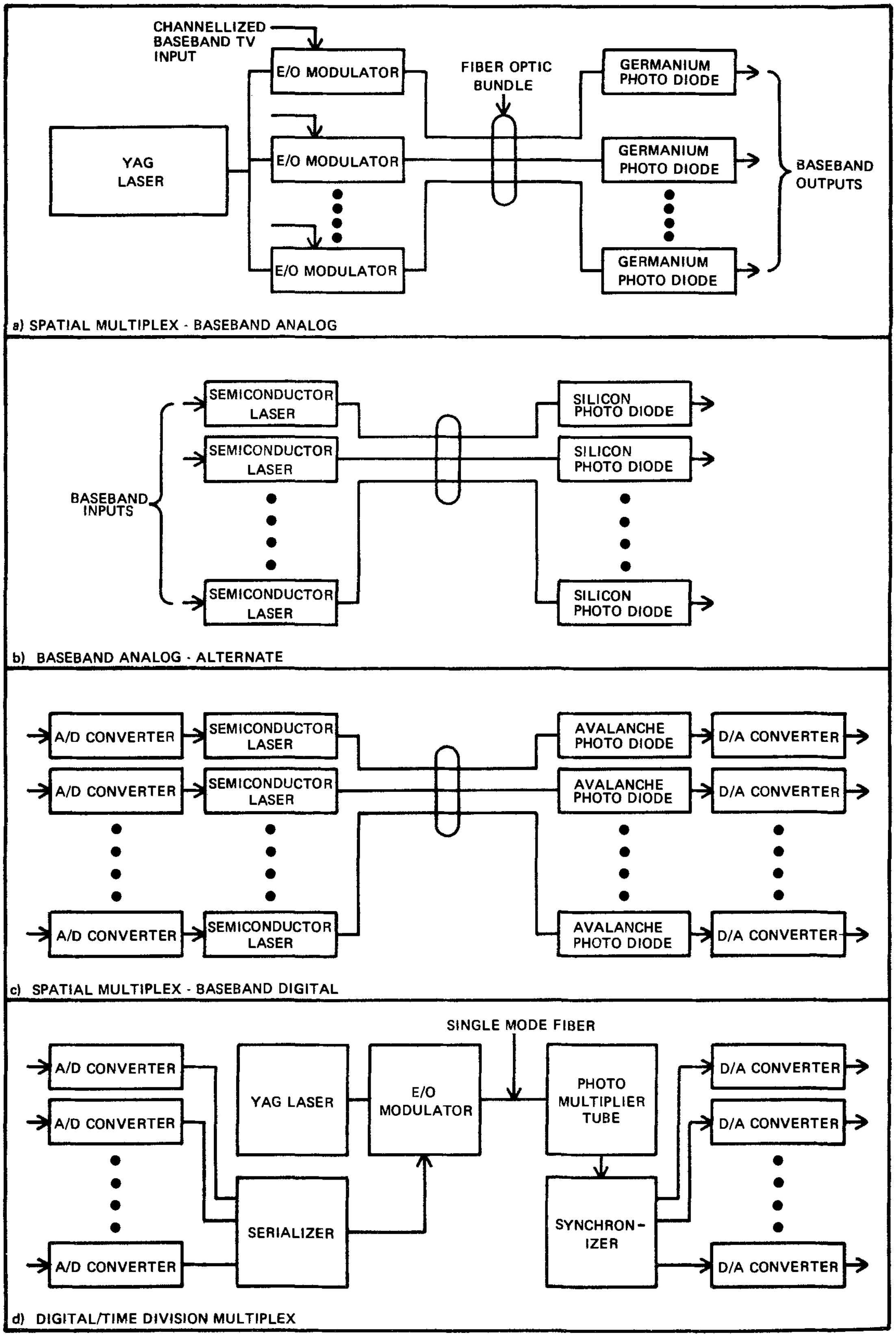


FIGURE 4 CANDIDATE SUPERTRUNK SYSTEMS

is assumed that only +8 dBm of optical power is injected into the fiber.

For the third case, baseband PCM, 80M bits/sec is a requirement for high quality color TV. The maximum super trunk distance is then 6 miles without any repeater.

The fourth case, PCM/TDM, involves equipment which today is very much state-of-the-art or beyond. If we assume up to 20 TV channels, the data rate is 1.6 Gigabits. In order to avoid the severe dispersion limit, one then requires that single mode fiber be used. One possible photodetector capable of responding to the high speed pulses is a special crossed field photomultiplier tube. Even then, because of the large noise bandwidth, a high power laser should be used to extend the range of the unrepeatered super trunk. High speed electro optic modulation has been demonstrated in the laboratory, but digital serializers and synchronizers for gigabit data rates are today simply not available.

Returning then to the cases which seem to offer the greatest practicability, Figure 5 plots the system cost versus distance for various values of N. The analog system with 10 dB/mile fiber requires 2-mile repeater spacing to obtain 60 dB S/N.

A comparison of the analog and digital system costs shows that the costs are equal between 4 and 6 miles. Since the same transmitter and receiver costs, the same fiber costs, and the same construction costs are assumed for either system, this cross-over distance is determined solely by the ratio of the converter cost to the repeater cost.

If we further assume that the digital repeater cost is comparable to the analog repeater cost, the analog system will cost more than the digital system for distances in excess of 8 miles. Moreover, one must recognize that the S/N ratio in the analog system will degrade 3 dB each time the number of repeaters are doubled. The digital system degrades much less, particularly since the repeater spacing is three times as great.

C. Downstream Trunk and Distribution

The analyses of the previous sections can serve as a guideline in determining what can and cannot be done if fiber optics are to be used for the downstream trunk and distribution of a multiplicity of TV channels. The situation is, however, more complex due to the constraints imposed by having ultimately to interface with the CATV customer's TV sets. This interface is today at VHF, but may conceivably also be with an analog baseband signal. It may, in the distant future, even require a digital input.

Figure 6 shows a possible repeater terminal configuration in which digital modulation is assumed on the trunk, and interface with the subscriber is assumed to be with analog baseband signals. The bridger terminal, which in this case is located at the trunk station repeater, converts the digital signal back to analog. It also serves as a switching center connected directly to the subscriber by means of a two-way optical fiber. The subscriber selects the TV channel by means of an upstream command which connects the subscriber-dedicated LED transmitter in the bridger to the desired baseband signal. Since the distance to the furthest subscriber is assumed to be no more than 0.6 miles, a relatively inexpensive LED and photodiode would suffice to provide the customer with a 50 dB S/N when using a 10 dB/mile insertion loss optical fiber. The total cost for fiber for each mile of distribution is nDF, assuming a fiber pair for each customer. One drawback to this scheme is that a fiber pair is needed for each additional program that is simultaneously tuned to in a given residence.

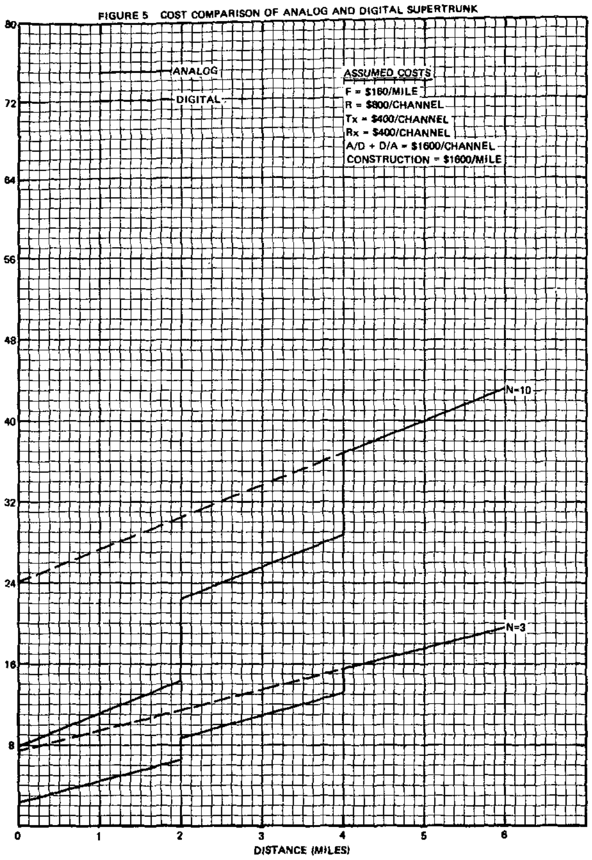
An alternative solution is to use star couplers, as with the upstream system. The costs are given by equation (5) but now multiplied by N, the number of TV channels carried by the system. In addition, the optical source at the bridger terminal must be a semiconductor laser to obtain the received power required for a minimum 50 dB S/N. Only N such lasers are required in place of the nD LED's required in Figure 6 for each arm of distribution. However, neither solution appears to be economically viable in the near future.

III. CONCLUSIONS

Fiber optics provide a potential means for providing high quality communication in CATV systems. The technical feasibility for building a fiber optic system is well established for a number of system concepts including low data rate upstream requirements and spatially multiplexed multichannel television systems. On the other hand, components required to build a truly wideband (gigahertz band width) system for CATV applications, are as yet unavailable.

Even for the relatively narrow band system solutions to important engineering problems will have to be found before implementation can take place. Foremost among these is the

FIGURE 5 COST COMPARISON OF ANALOG AND DIGITAL SUPERTRUNK



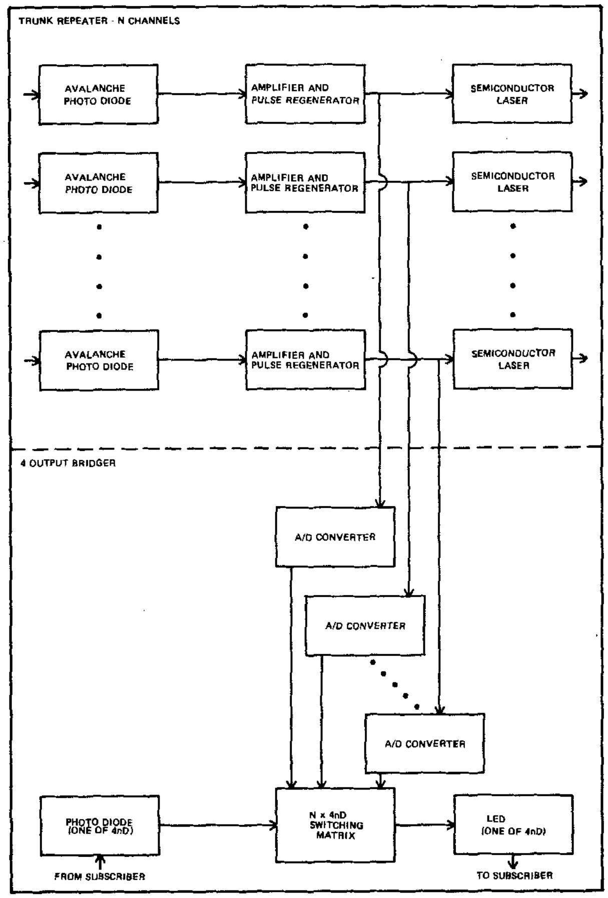


FIGURE 6 OPTICAL TRUNK REPEATER (DIGITAL) AND BRIDGER (ANALOG)

question of fiber optics cable packaging and its associated temperature effects. Other questions relate to field maintenance of a fiber optic system including fault location and the practicability of field splicing.

Economic feasibility of some fiber optic applications, particularly supertrunk for studio to headend links, has also been established provided the purposefully optimistic cost estimates made in this study can be realized. Developments within the next year or two will shed further light on the prospect for some limited applications by 1980. At this point great uncertainty still exists in both cost and performance parameters of the various system elements. On the other hand, widespread application of fiber optics in CATV systems appears to be highly unlikely until further breakthroughs are made in both technical and economic areas.

IV. APPENDIX

Background material describing the characteristics of optical waveguides is available in a number of articles (5, 6). This section assumes the reader has the general knowledge and therefore provides only information peculiar to the needs of this study.

Table IV describes the fiber parameters which are available today and what is expected to become available in the near future. This prognosis is to a large extent based on what already exists today in the engineering laboratory.

TABLE IV - FIBER PARAMETERS*

OPTICAL	Today	Near Future
Attenuation	< 15dB/km	5-7 dB/km
Dispersion (monochromatic source)		1 ns/km
(LED)		3 ns/km
Crosstalk	-60 dB	-60 dB
N. A. (peak, with graded index profile)		0.4

*See Reference 7 for packaging details, including preliminary mechanical data.

Another area under active investigation deals with cable connectors and splicing. Experimental results with cable connectors using index matching fluid shows less than 0. 5 dB loss. Permanent hot splices are obtained with only 0. 2 dB loss, although this is only achieved when the fiber is cut with a special apparatus and then rejoined at the same point. By careful control of production fiber parameters, it is expected that by 1976, less than 1 dB loss will be obtained in the general case. The techniques will of course have to lend themselves to field repair of the optical cable.

The power which can be coupled into a fiber from a given optical source is a function of the fiber's numerical aperture. Present step index production fibers [8] have N. A. = 0. 14. The more optimistic power budgets referred to in Section IIA of this study will require a higher numerical aperture.

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CABLE TV IN ORBIT

by courtesy of
Canadian Cable Television Association

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TransCommunications Corporation
Greenwich, Connecticut

An Advanced Management Concept is proposed for the entire cable TV industry, in which related industries with a delivery requirement to home, office, school or public authority find a participative role. The objective of such a concept is to stimulate the growth of the communications industry in all branches while reducing the time and effort now devoted to rationalizing present and future institutional arrangements.

The ample capacity of cable, from head-end to end user, is capable of expansion to national dimensions through new technologies such as satellite transmission. This concept may be arrived at in phases, the first being regional in scope utilizing microwave extension from a strategically placed satellite receive station. Eventual national satellite-cable distribution systems may replace microwave subsystems with earth stations as added channel usage brings into play the economics of extended terrestrial versus space methods.

Inherent in such a concept is the question whether competition in delivery systems will proliferate customer services or have the opposite effect. The broadest economic advantage arises from contact with the eventual consumer, the general public. As telephone delivery system technology has prospered by orderly access to the consumer, so might other electronic services, but order in the development of cable TV toward its true potential is not currently apparent, either in the USA or in Canada.

A possible solution lies in the creation of national cable-TV operational entities outside of the trade associations. Patterns for such a development are found in the Intelsat structure, Aeronautical Radio Inc, and in certain other techno-economic organizations. Evolutionary efficiency is achieved through the use of existing talent and expertise together with the regenerative discipline of avoiding obsolescence rather than being overcome by it.

A management and capital concept for maximizing service to the public, profit to entrepreneurs and incentive to innovation is proposed, emphasizing the private sector. The profit centers would be found in participation in transmission methods and provision of viable services to customers, with emphasis on the latter, where the effects of open competition would have a beneficial effect on economic, social and political communities.

The introduction of new technology into an established pattern of economic and political relationships is seldom an orderly process. Arthur C. Clarke, speaking of the synchronous satellite, observes "thus science, with its usual cheerful irresponsibility, has laid another squalling infant on the doorstep of civilisation". It took from 1945, when the theory of extraterrestrial relay was set forth in Clarke's modest essay, to 1962 before a suitable method of introducing this technology into practical use was devised, and more confusion attended the creation of institutional arrangements than the construction of a working satellite system itself.

The engineering debate over the merits of stationary or orbiting model communications satellites was resolved by a practical demonstration in 1965 which proved the technical feasibility of Clarke's concept. The right to use it for communications services, however, and to operate it as a business, created a legal, political and industrial battle for years, involving regiments of lawyers, legislators and lobbyists. And if an acceptable pattern of usage seems to have emerged in the international arena, the same drama begins again wherever the use of satellites is contemplated for domestic communications, including broadcasting and the newest arrival in communications, cable television.

Clarke's 'squalling infant', therefore, in a domestic context might better have been announced as twins. In at least one nation, the United States, domestic communications satellites and cable television were officially blessed by the regulatory authorities at about the same time by the announcement of policy concerning both industries.

The Telesat Canada Act of 1968-69 makes no mention of cable television or of broadband networking at all, probably because nobody quite knows who would preside over the introduction and nurture of such a concept. But nowhere in that Act is the idea foreclosed, nor is the cable industry excluded by any provision of the Act from a place on the Telesat Board, along with the 'approved' common carriers, should it wish to participate as an industry. The difficulty arises in prescribing just what the boundaries of the cable television industry might be, particularly in such company.

In other countries the timing of policy directives has not been quite as clearly indicative of the basic proposition that cable and satellite have arrived together "on the doorstep of civilisation" and must henceforth be reared as members of the same family. Nor, perhaps, did the United States Federal Communications Commission mean to establish this relationship quite so precisely in its 1972 outburst of policy-making. But the relationship exists in the thinking of engineers and entrepreneurs, as well as in certain official though discreetly objective circles in many countries, -- England, Japan, Mexico, Canada, France, -- to name a few, and the principles to be followed in developing it are already the subject of debate, encouragement, and, quite naturally, strong opposition.

It is the fundamental theme of this paper that the communications industry as a whole is greater than the sum of its individual parts. This is true largely because of what happens to the community when its communications systems function efficiently, and what happens when they do not. Like the spin-offs of a space program, communications by-products find their way into every aspect of community life, and if the community as such does not exist to start with, an appropriate communications structure will sooner or later bring it into being. This will be observed in the gradual emergence of a world community around the global satellite system, now in its adolescence.

Eighty-six nations now communicate directly amongst themselves through the Intelsat organization and its space system. While there may be that many different national reactions to the scoring of a goal in a soccer match, eight hundred million viewers of this single event surely constitute a community in some sense. As domestic satellites move into service in such amorphous and dispersed communities as India and Indonesia, a sense of cohesion must inevitably result among formerly heterogeneous populations. And as naturally curious people come to realize that the synchronous satellite is an incorrigible border-jumper, domestic and international satellite systems will sooner or later find a way to interact officially instead of simply experimentally. The population of Sacramento, California in 1973, for example, became incensed when an experimental satellite transmission of a Canadian rugby game had to be terminated; the experiment was in fact too successful and embarrassed everybody but the engineering staff. Geographical borders had become anachronisms.

Cable television, the natural partner of the satellite in bringing high-capacity service to the individual user, seems capable both of creating new communities and of energizing those that already exist. The logical development of the cable industry would lead one to expect new types of programming, informational uses enhanced by the computer and greatly increased delivery capability for social services, to mention but a few of the possibilities. The total effects of this process are not yet clear, but without doubt will be pervasive, touching the community and the individual in many and varied ways. Cable television is a multi-medium. Its constituencies include the financial, the educational and the political, in addition to the technical. It ranges far beyond video programming in its potential effects and perturbations. It is hardly surprising that its status in the communications family answers rather well the same definition which Clarke applied to his satellite.

Hence it is well to try, at least, to apply the 'unified field' approach to the unruly state of known facts and unknown potentials of the communications industry of the present day. Emphasis on cable and satellite in this paper does not mean that organizational principles herein are restricted to those two disciplines and could not therefore be superseded by a new technique, whatever it might be. Technology moves too rapidly to permit such a view. It is the purpose, rather, to give technology free rein and let the public be not damned, but served, by a sensible combination of experience and innovation. Fear of obsolescence and preoccupation with the status quo are not material objections. However real they may be, good marketing is a more powerful influence, when coupled with a logical technical development, and that is where the communications industry now stands. The future belongs to those who will take the initiative with the materials available today.

Cable-Satellite Policy

Most of the discussion about cable television up to now has centered on the local scene into which cable has intruded with such disturbing effects. With few exceptions, cable is an intra-urban medium. Exploitation of its abundant capacity is limited to mostly minor attempts at local program origination and hesitant experiments in home terminal technology for which the public may be ready but the hardware is not. The cable 'industry', if it can be called that, is growing to national dimensions in the size of its subscribership but still consists of a collection of locally autonomous entities whose power as an industry is dissipated and ineffective compared to the older established practitioners of communications.

It is not in the least surprising that those concerned with cable have concentrated mainly on extending their clientele in order to improve their financial health. This is the obvious growth area of the new industry. But as the total subscribership begins to attain the figures representing a major market, whether for advertiser, subscription TV or other 'ancillary' services of which cable is capable, it would appear that the cable industry was ready for the centralized business structure which would be needed to manage large scale marketing of a full range of broadband services. And as the market begins to assume such dimensions, by coincidence the technology needed to concentrate it also has appeared, has been tested and has been proven effective. This is the technology of the communications satellite.

It has been noted that this technology is so far ahead of the market for useful application that every satellite launched now or in the near future will be obsolescent, in terms of its basic design and capacity, before it leaves the pad. The same thought might apply to the cable television industry whose capacity, even with coaxial cable techniques, can well exceed current marketable uses. Should future cable systems turn to fibre optics for local distribution, the imbalance would be even more severe.

However, the basic pattern for this decade is fairly clear. The long-haul transmission of broadband communications at economical cost is rendered feasible by the satellite and therefore a broadband national service makes economic as well as technical sense. There are those ready to provide this long-haul service but the potential user, cable television, is not yet a national entity. It may indeed suddenly become one, but an equally possible pattern of growth toward that status would be by the step-by-step formation of regional groupings using terrestrial interconnection and regional interest programming. This can be observed currently in the United States, notably in the midwest, where a single-channel microwave link brings a cable-only program service to over a million subscribers. The extension of this service to other areas and with multiple channels is a function of the relative costs of distance-based terrestrial charges versus the cost of an earth station plus a proportionate share of the cost of the distance - insensitive satellite circuit. The probable result, however, would be a mix of terrestrial and space distribution methods, with the latter supplying the main momentum toward a truly national interconnection.

Fortunately, in both Canada and the United States the satellite was recognized as an innovation too broad in its implications to fit into the existing communications industry pattern as simply an add-on to what was already there. The long and involved legislative history which led to the United States Communications Act of 1962 reveals attempts by many different segments of industry, as well as government, to gain an exclusive jurisdiction over satellite technology. The final result was an ingenious compromise amongst government, carriers and public, the latter meaning principally Wall Street, which was worked out between the late President Kennedy and certain powerful elements in the United States Congress. Of particular interest was the fact that broadcasting and cable television interests as such were more or less neglected in that Act, the assumption being that as a carrier's carrier the international satellite system would function as a wholesaler, selling service only through the carriers. This is an important reference point for subsequent history. Domestic regulatory policy in the United States thereupon did an about-face and opened satellite ownership and access to anyone.

During 1972, the same year that United States domestic satellite policy was promulgated, the FCC addressed itself to the release of the cable television industry from the freeze under which it had lain for several years. The Report and Order of February 12, 1972, while hardly a license to complete and open expansion, at least recognized cable as a legitimate partner in communications enterprise. There was no resolution of the question of whether or not it would grow up as a common carrier. There was, however, recognition of cable's responsibility to develop and market new communications services. The Order also made passing reference to the eventual interconnection of cable systems by satellite. This may have been the most significant sentence in the entire document. For much of the rest concerned rules under which distant broadcast signals might be carried, and the satellite, if put into the service of cable-originated material, simply renders these rules obsolete.

The passing mention of satellites in the FCC Cable Order of 1972 suggests them as a technique for networking, but no rules or principles are set forth as guidance toward this goal. The FCC simply erected a signpost, pointing the way to whomever wished to pioneer. The timing of the Order, however, was a clear enough implication that if only somebody would bring about a convergence of cable and satellite, the regulators would be greatly relieved and the public might even benefit. The technological implications might help resolve some otherwise insoluble politico-economic problems such as the distant-signal rules. But the private sector clearly would have to rise to this challenge in some manner other than with jurisdictional dispute and positional warfare. This has not yet occurred.

The Telesat-Canada Act of 1968-69 was also a compromise among established interests. Broadcasters are not included in the corporate structure, nor is cable television. Broadcasting would seem to be clearly identified, by omission, at least, as a customer for satellite carrier distribution. Cable television, with both a local and long-haul carrier potential as distributor of broadband services, might be less capable of definition. Dependent to an extent on broadcasters for its main fare, it must look elsewhere for the development of its true broadband potential. Would its natural ally in the process be Telesat, as a compatible technological extension of its services, or the terrestrial common carriers, as themselves interested in developing those same services? Since Telesat is partly owned by the carriers, it might itself bridge the gap, but until this question is resolved, the rapid expansion of the communications industry's potential service to the public would seem to be impeded.

It is central to the theme of this paper that this policy question could be resolved more readily in the private sector than on the official level, both in Canada and the United States. Public administration tends to follow the principle that the more complex a problem, the more official agencies must be created to manage it. A corollary is that more attention is then given to jurisdictional than to substantive aspects, affording ample opportunity for the perpetuation of whatever advantages were built into the status quo. It is this cycle which, given the present promise of technological advance, must be broken.

Meanwhile, public policy regulating cable and satellite development treats each as a separate industry, as it does, indeed, the broadcasting and terrestrial carrier industries. This overlooks the scientific fact as noted in recent proceedings, that "Communications technology is now imposing unity upon all communications techniques. There is no longer any distinction among the various forms of communications. "All of them can pass through the same relays in the form of identical electronic pulses". The distinction would appear to lie mainly in the marketing area, and in access not to <u>facilities</u>, but in access to the customer.

<u>Space Segment</u>

A satellite communications system consists of space segment, including control stations, and earth segment, meaning earth stations for transmitting and reception of communications traffic.

Domestic satellites are now on station providing service both to the United States and Canada. While the Canadian entity, Telesat-Canada, clearly has a common carrier franchise, United States policy in theory at least, allows anyone possessed of sufficient financial and other responsibility to engage in satellite transmission. In practice, as far as the space segment is concerned, the United States carriers have preempted the field for the immediate future. In view of the fact that there will be an abundance of satellite channel availability, this prospect seems not to worry users, who assume that the rate structure will reflect the supply conditions. Aggressive marketing of this supply will be a new and welcome turn of events to users such as the cable industry. Broadcasters, who must plan cautiously before changing from one method of distribution to another, nevertheless have moved to take advantage of satellite economy when it appears feasible to do so.

The use of satellite transmission to extend the local reach of cable systems to network dimensions is a natural technical development. The satellite, with its insensitivity to distance, makes broadband networking economically practicable for all conceivable services. The problem arises when the service comes back to earth after its relay through space. It is the ultimate delivery first to earth receiver and then to end user, that causes both problem and opportunity. The time to structure a solution is now, before policy or practice has hardened into a pattern.

Earth Segment

The terrestrial facilities of a satellite system consist of stations performing both transmission and reception, and receive-only stations.

Transmit/receive stations in the United States are at present only provided by the common carriers who have initiated domestic satellite service. Although point-to-point service generally is not considered the peak efficiency use of the satellite mode, the satellite carriers are still able to provide considerable cost reductions for this type of service compared to terrestrial carrier rates.

Broadcast and cable industries contemplate the use of satellite distribution for point-to-many-points service. In the future these users might turn from carrier-provided transmission service to their own, but economic and other considerations indicate that the origination of traffic of this kind will pass through carrier-owned-and-operated transmission facilities for the foreseeable future. United States carriers plan such facilities in the basic pattern represented by the major markets of New York, Los Angeles, Dallas, Chicago, Seattle, Atlanta and Washington. Beyond these transmit/receive locations, the broadcast and cable industries have the opportunity in the immediate future to establish their own receive/only stations wherever it makes sense to do so. The cross-over point where they undertake the same task in the major markets is arrived at, if ever, merely as a question of economics and relations with those who now provide the services needed.

While it appears to an observer that Telesat-Canada has a satellite-carrier monopoly by law, it by no means appears certain that Telesat would not readily supply satellite transmission directly to earth stations at CATV system head-ends. In fact, David Golden, President of Telesat, proposed exactly that, in an address to the CCTA in June 1974. He was referring to the transmission of broadcast entertainment, however, and did not touch on the matter of the capacity of cable to deliver other services the long-haul of which might be rendered more convenient by satellite. But his silence on this point is deafening. Telesat's facilities could be heavily used by non-broadcast customers as soon as it becomes clear how the ultimate delivery to the customer is to be accomplished.

Telesat seems to have both ends of the monopoly of satellite traffic at present, but it is not clear what might happen if other broadband services developed first on a local basis and then, through the proliferation of receive/only earth stations, on a network basis. In Canada, as in the United States, future activity of this type seems to turn largely on this point; who will own and operate the earth stations, both in their simple receive/only configuration and in the inevitable increasing complexity required as the broadband network moves toward the ultimate pattern of the wired nation?

The first United States applications for earth stations (and satellites) for domestic use were filed by the ABC network. In rapid succession applications came from independent network affiliates and from cable TV concerns. The broadcast networks aimed at thus lowering line charges, and their applications for satellite systems seem to have had a certain competitive effect even before any domestic satellite left the ground. A network-affiliates' application for earth stations looked toward achieving some degree of local program autonomy, but also aimed at the future when the local earth station would be the interface with the entire world of broadband services including television entertainment. The cable system applications for earth stations contemplated a new industry entirely, in which cable as the high-capacity delivery means to the customer opened up new horizons of industrial, entertainment, educational and public service activity. Cable people in all countries share these visions. And just as with Intelsat their realization at a profit is closely tied in with ownership and operation of the earth station.

A survey of these applications and interests reveals the conflicts that inhibit the marketing of new communications services today. The United States cable operator looks forward to the day when he can offer, in addition to good reception, a variety of alternative programming and some new computer-assisted and two-way delights. But, as does his Canadian counterpart, he quickly runs afoul of some real or imaginary existing franchise. His troubles over pole-attachments are rarely simply economic bargaining. His potential for subdividing the mass audience frightens the networks. His pay-TV possibilities throw the conventional broadcaster into a panic.

If to these perturbances is added the satellite link to which cable TV gains access through an earth station at the system head-end, the possibilities for doing mischief to one or another Establishment would seem to multiply. For example, if United States cable penetration climbed above 50% on a national basis, the satellite-to-earth-station-to-cable link could well become the primary distribution link for the broadcaster himself. At that point he probably would depart the crowded air waves and rely mainly on cable to reach his audience. What once was the Establishment would have become an Appendage. This is not to denigrate the former, but only to support the principle of offering alternatives to the public, some of which, as in the motor car industry, might well originate from the Establishment itself.

It will be seen that it is not the network as a program source which would risk loss of position in this event. It would be the individual broadcast station, which clearly reveals why certain United States broadcast stations applied for a local satellite receiver on their own and actually against the wishes of their network headquarters.

In the absence of a conceptual approach to the configuration of the ground environment, there is a fair prospect for some strife over earth station proprietorship. Policy in the United States says that anybody can enter the game. Policy in Canada may not yet be clearly defined in this area, which is why the private sector should perhaps take certain initiatives. Meanwhile, the satellite, like a moon, pulls the economic tides this way and that, inundating some, and possibly leaving others on the beach.

A Modest Proposal

The principal business interests which are touched by the foregoing are the terrestrial and space carriers, cable TV and the broadcasters. Regulators have, but are not, interests. It is assumed that manufacturers can produce appropriate hardware for everyone within today's state of the art. The objectives of all can be grouped under the principle of providing greater service to the public, and since all parties are dealing with the same commodity, identical electronic impulses, the differentiation of interest only arises in the origination,creation and delivery of the end product, the form in which those impulses are received by the customer.

As in the case of the telephone monopolies, the most sensitive area of dispute and future economic advantage is that of contact with the customer who pays the bill without knowing by what route a communications service has reached him. If the route itself becomes a battleground, the service may never reach him at all.

Influences, therefore, should be created which stimulate the variety and form of communications services offered to the customer, which maximize the usage of facilities in being and which provide at least one area of cooperative activity among currently hostile interests.

Of those facilities in being, the space segment, the cable systems, the terrestrial lines and the broadcast stations are proprietary interests which nobody has the slightest intention of relinquishing to any degree whatsoever.

The least-defined area, and smallest in capital requirement, is that of the earth station, which is the key link in a broadband, satellite-interconnected delivery system for maximum communications service to the public.

It is also the factor which could trigger the amalgamation of autonomous cable systems into a continent-wide interconnection, an event which today is awaiting the resolution of the chicken-and-egg syndrome or the appearance of risk capital which will underwrite the first orders. The regulators, however, do not stand in the way.

In view of the fact that carriers, cable TV, broadcasters and satellite companies have all made what are in effect adverse claims to ownership and operation of various parts of satellite systems, they must all envision substantial benefit from being seized with such rights. So it was with the international satellite. The result there was a pooling of interests at least in the space segment.

The prospect domestically could well be a pooling of interests in the earth segment. If so, how could this be constructed, and what benefits might flow?

Initially, it must be noted that if such a proposal is acceptable in principle, its particular application to Canada, the United States or other environment must be left to further study, in light of current conditions.

In organizational terms what is proposed is either a corporate or cooperative entity the business of which is the leasing of satellite channels from carriers and the provision of earth stations to CATV systems for delivery of traffic through cable systems to end users. The entity would be so constructed, by statute if necessary, to permit inclusion of the primary interests involved, for which there is precedent in other industries.

Domestically the space facility is already in place. The cable earth station is not, and is not likely to be until the prospect of business is more clearly seen. It is proposed that those who would originate such business organize to establish the earth station network, on the basis of their own self-interest, if nothing else.

Intelsat provides some patterns on the cooperative side. There the percentage cost of building the space facilities is borne by each nation on the basis of the traffic expected to be generated by that nation. Revenues are divided by the same rule, resulting in a wash operation. Profits of participants derive from the use of the earth stations providing access to the satellite.

Domestically the cost of building and emplacing earth stations could be borne by cable systems, if there were in existence some body dedicated to developing services to be put over them. A cooperative aimed at filling this gap could be formed by those who would supply such services and market them, the earth station being a mere adjunct to this end. But, excluding known services such as broadcasting, cablecasting, pay-casting and some local community services, the license to develop fully the broadband potential is not firmly in any hands. Whatever participant in a cooperative developed a profitable communications service which used the earth station would at least be sure of this means of access to the market. Were the station in other hands this might not be the case. Recovery of initial costs would be followed by revenue sharing among users of the earth station, according to volume of usage.

A corporate form of joint venture would place both satellite leasing and earth station ownership and access on a profit basis. Should the participants be the major interests above, what they really agree to share is the development of the widest possible communications services to the public, available through leased satellite channels and earth stations, both being the profit centers of such an entity.

It is easy to see what might happen if this present vacuum were to be filled by an entity not representative of the interests most directly concerned. The CATV operators would have lost any control over their own growth as a communications medium of national scope. The carrier would have lost any hold they might have had on broadband access to the customer. The broadcaster would be left to wither away on his own single channel as did Life and Look in the print media.

If on the other hand there is profit both in retailing satellite capacity and in the leasing, ownership and operation of earth stations, that profit is directly tied to volume, and the members of such a venture would naturally look to every means possible of increasing use of the facilities. It would be less than wisdom on the part of carrier participants to delay initiation of services the right to delivery of which, for example, was currently a matter of controversy. It would be equally unwise for cable operators to seek to preserve their present customer access on the basis of today's technology over which others might have a technological advantage. The joint venture which brought an earth station network into existence might provide the basis for cooperation in this and other areas.

The broadcaster who feels threatened by the many-channel capability of cable is also staking too much on his present mode of operations. Participation in an earth station venture, whether as network or independent, gives him a lead on tomorrow's inevitable multiple-network broadcasting-cablecasting developments. As today's network begins to subdivide itself, a process which the satellite will accelerate, earth stations emerge as the pivotal point for the change and the most convenient entry point for the broadcast industry's ownership stake in the future. It was earlier noted that the private sector could probably energize the communications expansion herein discussed more readily than if regulators were awaited as the prime movers. In the United States there is a visible disposition in Washington toward the encouragement of a broadband network by any means.

Perhaps it is realized that rather than any restraint of trade this prospect carries with it quite the opposite. In Canada it would seem that the process of forming a cable network is under way unimpeded by anti-trust law but retarded by a complex mixture of regulatory and industrial restraints. It is this impasse which the concept of a new communications enterprise built around the earth station is aimed at dissolving. While regulation struggles with a maze of adverse relationships,private enterprise could assist in providing solutions by joint-venturing in the only unstaked territory left.

Conclusion

In today's communications, spheres of influence have been assigned, or appropriated by major segments of the industry. These relate to the telephone monopolies, the cable franchises, the broadcasting frequencies, the satellite and other common carriers. Competition among these entities is sometimes real, sometimes artificial and protectively structured. Given the influence of regulatory bodies,none of these entities is likely to disappear or to relinquish the ground upon which it stands.

A new technological partnership, that of the satellite and cable TV,offers potential and real grounds for competition with existing interests. These interests if given a role within the framework of the new technology could enhance their own prospects while at the same time stimulating the growth of total communications service to the public.

The one area of the total industry which has not been pre-empted is that of the earth station required to provide cable system interconnection through satellite. This part of the complex provides the interface between a long-haul and a local delivery to the customer. Its viability increases in direct proportion to volume of traffic. Its usefulness to all forms and volume of traffic should not be artificially limited, as all traffic is, ultimately, the same thing in transmission.

To initiate the manufacture, installation and use of earth stations at cable head-ends, it is proposed that the various interests concerned with selling a service to a customer form a joint venture, either as a cooperative or in corporate form. Coupled with the earth station activity the joint venture would lease satellite channels either for retail at a profit or as a 'wash' operation as in Intelsat, fostering the widest use of these channels to minimize the cost.

Such a joint venture would have every incentive to make the greatest possible use of the earth station. It would form a basis of cooperation to develop new services to the public. It would serve as the origination point of the next generation of technological development presumably because of greater efficiency and profit potential.

Finally, unless such a joint venture breaks the current impasse, the various reverberations associated with a new industrial initiative will be slow in coming. Communications as an industry would suffer from this delay, and the community, region and nation would be deprived of the great benefits to orderly social development which can be provided by a mature and stable communications environment.

CATV SYSTEM PERFORMANCE -- THE NEW YORK EXPERIENCE

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The Commission on Cable Television is comprised of several divisions. However, the Telecommunications Division is most visable to operators.

Details of a mobile monitor van, as well as conclusions and recommendations on operational testing, will be discussed.

Activities of the van and results of testing systems of all sizes throughout the state will be analyzed. Performance, as it relates to over one hundred system tests, will be detailed.

Possible technical solutions to line extensions in low density areas will be considered in the light of actual system performance measurements.

The paper will conclude with a discussion of current system design based on measured performance.

I believe it is necessary to provide a brief history of the New York State Commission and its involvement in cable as a backdrop to the discussion which follows.

The Commission was established by the State legislature through enactment of Article 28 of the Executive Law. The Commission is empowered by the legislature to exercise a broad range of supervisory authority over cable systems operating within the state. Among those are regulations pertaining to contents of franchises, review of rates charged to subscribers, assistance and guidance to municipalities considering franchising, resolution of complaints, transfers of control and rules related to construction and operation of cable systems to ensure safe and adequate service.

The experience gained in enforcement of rules regarding safe and adequate service is the topic of this paper. The rules, or technical standards, are officially known as Part 596 of the Rules and Regulations of the New York State Commission on Cable Television. Unofficially they are called many things -- some of which can not be printed.

My Division operates a mobile test van which is used to evaluate performance in systems throughout the state. Currently, there are 156 systems serving approximately 635,000 subscribers in nearly 500 communities. As you might suspect, utilizing a single test unit to test systems state-wide is a major undertaking. The old saying "You can't get there from here." is appropriate. Although Albany is located in the Up-state area, travel time to a system may well take more than 8 hours.

A prime function of the Division is assistance to cable operators in complying with both State and Federal annual testing requirements. The majority of our requests for assistance come in the 3 months preceding the Federal test deadline on March 31. In 1974, despite the severe gasoline shortage in the Northeast, we kept the van on the road for all but 6 days in February. In so doing we tested 35 systems. I must add that there was no charge for the service.

The van is well equipped for testing all facets of system performance. Table I lists the major, on board, test equipment.

Table I

Spectrum Analyzer	Frequency Counter
Tracking Generator	VHF-SLM
Sweep Oscillator	Sweep Receiver
Precision Demodulator	Pre-Amplifiers
Signal Processor	Color Receiver
Oscilloscope	Test Generators
Vector Scope	Calibrator

The van is a heavy duty, long wheel base unit which contains, in addition to the equipment listed in Table I, a variety of cables, fitting and miscellaneous pieces. Power for operation of the test equipment, lights, heaters and air conditioner is provided by a gasoline engine driven 7.5 Kw alternator.

The Telecommunications Division has tested and evaluated one hundred systems to date. Approximately 50% of the requests for testing come from cable operators. The majority of the remaining requests come from municipal officials who wish to verify proper system operation as they consider rates, or renewal of franchises. Municipal officials also request the testing of systems where there are large numbers of complaints. While I have the authority to order special testing, specific maintenance procedures and general service improvements, I do not feel the need to do so, except in cases of deviations from accepted system operating practices. Our experience to date has indicated that fewer than 5% of the cable system operators require an official notification that they are in violation of a specific rule or technical operating requirement.

The testing done for cable operators is an obvious benefit. The testing done for municipal officials also benefits the cable operator, since our testing usually indicates that the system is performing adequately. When data are collected by certified test equipment and objectively evaluated, the facts usually support the cable operator.

The technical performance standards we have imposed on some cable systems in our state have been the cause of a great deal of "red-necked" debate. We do require that systems in the six Urbanized Areas of our state and systems serving more than 10,000 subscribers from a single headend maintain a higher performance standard in regard to carrier-to-noise, cross-modulation, intermodulation and FM radio carriers than is required by Part 76 of the FCC rules. We hold firmly to the opinion that these standards are not excessive or burdensome, nor do they in any way interfere with a national cable television development policy. As I write this paper, I am not aware that a national policy on cable has been clearly defined by the Congress.

The vast majority of our state systems are outside Urbanized Areas, thus are subject to only the technical requirements of the FCC. We do require some additional tests of all systems: old, new, urban and non-urban. The requirements most discussed are those of establishment of monitor test points and a subscriber complaint procedure. Later, I will address these points.

The requirements which are different from the FCC Part 76 technical standards are listed in Table II. I would ask the reader to keep these values in mind. He should question whether he would design a system that did not meet these goals, as an absolute minimum. In the discussion which follows the table, the reader will see the results of numerous carrier-to-noise tests conducted by our Commission.

Table II

Carrier-to-Noise Ratio	40dB*
Cross Modulation Ratio	-46dB*
Intermodulation Ratios	Variable**
FM Radio Carriers	10dB below Ch. 6 Visual Carrier*

*Urban Area and 10,000 + Systems
**Modified Jeffers Curve

We do require that all systems in the state make a telephone number available to which subscribers may direct their comments, questions and complaints. You may call this petty, but there also may be cable operators in your state with an unlisted telephone.

In the many comments that have been filed with our Commission regarding technical standards, the one which drew the most fire (and continues to do so) was that of a 40dB carrier-to-noise ratio requirement. It follows quite naturally that in system testing we would direct our attention to that parameter. The results obtained in our tests were, at first, very confusing.

We have concluded that carrier-to-noise measurements made at subscriber drop levels do not truly represent system performance. At the inception of our testing program we thought that our spectrum analyzer was defective. We were measuring noise figures which did not compute. The analyzer was returned to the manufacturer for repair and recalibration. We were surprised to find that the analyzer did not need repair <u>or</u> calibration. Further work in the field indicated that the noise measurements varied significantly as signal levels were varied.

Our spectrum analyzer has a noise floor of -110dBm. However, when used as directed by the manufacturer, the <u>best</u> carrier-to-noise ratio that can be measured is 38dB at a tap level of 0dBmV. It becomes obvious that, if we are to measure carrier-to-noise ratios accurately, we must always look to signal levels which will allow us a measurement range in excess of the expected noise level. Therefore we have made standard the practice of measuring carrier-to-noise ratios at signal levels not less than +20dBmV.

Our field strength meter presents a similar problem when looking at 0dBmV tap levels. The noise floor begins to influence measurements at +3dBuV. We are fortunate in owning a meter which always reads positive numbers. The zero on our field strength meter is 0dBuV, or -60dBmV. The narrow IF of the meter requires an 18dB noise power bandwidth correction factor. Therefore, when used at a tap level of 0dBmV, the best carrier-to-noise measurement which can reliably be read is 39dB. When utilizing the signal level meters commonly in service, with -40dBmV as a minimum measurement capability and as IF power bandwidth correction of 3 to 4 dB, there is no way a system can be certified to meet a 36dB carrier-to-noise with a 0dBmV subscriber drop level input! I submit that every cable system operator who used the signal level meter to measure his system carrier-to-noise at zero level drops has recorded readings which may have a significant error.

Our carrier-to-noise investigation has resulted in a significant discovery regarding system performance as it relates to system cascadability. The importance of this discovery can not be underestimated. In these days of economic woes which assail the cable industry, the ability to extend trunk systems, rather than construct new headends, or establish microwave links, may well make service available to areas which otherwise could not be built.

We do not have a laboratory, nor do we have the equipment or manpower to establish such a laboratory. Our data is empirical and is based on our work in many systems utilizing many types of equipment in widely varying conditions of cascade length, temperature and system age. Our data are not weighed to a greater degree than is the industry in utilization of specific equipment types. Our conclusions are not colored by manufacturers names, since the performance of trunk line equipment did not differ significantly regardless of make or model.

I submit that current methods of designing systems utilizing the well established formulae for cascadability, carrier-to-noise and cross-modulation, mandates systems and service areas that are much smaller than are necessary. The current practice in system design precludes long cascades. It is common to hear that cascades in excess of 30 amplifiers can not be built. Our state has at least two areas where cable operators, apparently on the advice of manufacturers, will not build beyond 30 amplifiers despite the need and the more than adequate density beyond that point. I am certain that manufacturers who test systems for performance as a part of their turnkey obligation are no longer surprised when the test data shows that the system design is most conservative.

I have avoided use of specific manufacturers names in this paper and, with the one exception which follows, I will continue to do so. We do not make recommendations regarding test equipment or CATV system components. However, everyone seems to be familiar with Starline I equipment. If I said that, at best, Starline I could not be cascaded beyond 50 amplifiers in a loaded 12 channel system, I'm sure that no one would argue, except perhaps to say that 50 amplifiers is too many. Using accepted calculations for cascadability the Starline I will meet 36dB C/N and -57dB cross-mod 50 amplifiers out. We have measured 37dB C/N and -51 cross-mod at a bridger output 71 trunk amplifiers deep in a New York system. Those performance figures have been measured in January, May and October. Currently accepted engineering calculations will tell us that we have somehow defied or repealed the laws of physics. That, as we know, is beyond the realm of possibility - even for the New York State Commission!

I believe that the above must lead us to conclude one of two things: the data were improperly derived, or the formulae were somewhat misleading. I reject the first, since long experience, certified equipment and many hundreds of individual measurements must lead us to conclude that when systems consistantly outperform the calculated criteria, the calculations rather than the measurements are to be questioned.

We could show that an improvement of about 1.5dB in noise figure in all 71 of the amplifiers above would result in the carrier-to-noise performance we measured. It is very unlikely that that is the case.

We could show that operation of the amplifiers at an output level resulting in a combined trunk-feeder cross-modulation performance of -46dB (the State and Federal requirement) would result in the performance measured. This would entail a minor readjustment in amplifiers in the trunk to increase the output by 2.5dB. The resultant cross-modulation in a well behaved amplifier would be -52dB and cascadability would be increased to more than 70 amplifiers. To our knowledge this was not done. The cable operator indicated that the equipment was adjusted to manufacturers recommendations. Our limited tests within the trunk system bore this out. Short spacing at about

18.5dB would accomplish a similar effect. However, that was not done.

A factor we do not often hear discussed in CATV may be the one we should address. It is assumed that all amplifiers are operated flat and that all amplifiers have a perfect frequency-amplitude response in the band of interest. It is further assumed that these ideal amplifiers are both amplifiers of incoming white noise and generators of white noise.

While we always consider white noise in our calculations, the actual amplifier does not exhibit the specific characteristics which allow white noise to pass through unchanged. It may well be that the amplifiers in cascade are actually generators of pink noise due to the bandpass shape and the overall response of the amplifier at the various frequencies within its bandpass.

We do not, as stated earlier, have a laborabory in which to investigate the performance of cascaded amplifiers. We do have many test reports which indicate that systems do not perform as expected. Table III indicates a range of cascade lengths and carrier-to-noise performance.

Table III

System	Mi.	Age	Test Location	C/N
a	220	9 yrs.	HE	49-51
	Tr 1		29A	40-42
	Tr 1		71A+B	37
b	156	9 yrs.	HE	46-47
	Tr 1		24A+3LE	42-43
	Tr 2		30A+3LE	42
	Tr 3		19A	44-45
c	285	9 yrs.	HE	44-48
	Tr 1		7A+1LE	39-46
	Tr 2		7A	39-41
	Tr 3	5 yrs.	35A+B	43-45
d	85	2 yrs.	HE	48-53
	Tr 1		8A	48-53
	Tr 2		16A	43-51
e	220	3 yrs.	HE	49-53
	Tr 1		21A	47-51
	Tr 2		24A+B	48-50
	Tr 3		22A	48-50
f	45	16 yrs.	HE	42-48
	Tr 1		8A+1LE	37-42
	Tr 2		14A+1LE	35-37

HE - Headend
A - Trunk Amplifier
B - Bridger
LE - Line Extender

Analysis of the measured performance of system in regard to carrier-to-noise reveals a very startling fact. System noise performance is not degraded in a logarithmic progression. Given a specific carrier-to-noise ratio at the headend we have not found, for example, a 10dB degradation at the tenth amplifier. Systems that are engineered, however, rather than strung from pole to pole, do not follow the usually accepted cascade factor. It does not appear to be very important whether the amplifiers are push-pull or single ended so long as the system has had the benefit of engineering talent in its design. Table III includes new Urbanized Area systems as well as older single ended systems. It is not exhaustive in that I have selected system test data representing large and small plants in widely varying localities within the state.

There are no standard levels in a cable system, thereby making most difficult the task of comparing performance between systems. It would be desirable to establish specific operating parameters which could be applied to each amplifier in a system. An amplifier being operated at a +32dBmV output with a +12dBmV input will have significantly better noise performance than that of an amplifier with the same output, but with +7 or 8dBmV input. While those two conditions might well represent "normal operation" for those amplifiers in a system, they do not allow the ready comparison of data between systems, or amplifiers. I would urge the NCTA, SCTE and IEEE to address this problem of standard levels, so that we all are referencing identical conditions when making performance measurements.

We have concluded that cross-modulation is not as severe a problem as has been previously thought. We do not make synchronous cross-modulation tests of systems. Our goal is to perform system tests in a way which does not interfere with subscribers viewing pleasure. We do not intend, except in rare instances, to perform tests which are service disruptive. Since the goal of all system testing is to ascertain system performance in actual normal operation, we have made every attempt to allow reasonable test procedures which do not disrupt service.

Every system test requires both objective measurements and subjective observations. We observe our monitor for cross-modulation and measure the pilot carriers. In every instance where we have seen and measured cross-modulation, we also have seen and measured objectionable intermodulation products. However, we have measured cross-modulation on pilot carriers and have seen none in pictures. We have been led to conclude that where a system condition exists which creates severe intermodulation products, we will observe cross-modulation. Corss-modulation measured in the low 50 and high 40dB ranges does not appear to present a noticeable picture impairment to even trained observers.

I have a reservation in regard to the definition of cross-modulation as a ratio of peak carrier power to modulation sideband. As you know, this definition is that of the NCTA in Engineering Standard NCTA 002-0267. Since it is sideband power (particularly the first) which causes the undesired modulation, a more appropriate method of definition would appear to be the ratio of desired modulation to undesired modulation. Since the first sideband, as observed on a spectrum analyzer, is 16 to 18dB below carrier peak power the numbers produced would be shocking to those of us accustomed to the threshold of visibility of cross-modulation as -51dB. Utilizing the ratios of sideband powers, we would have cross-modulation visibility thresholds at -33 to -35dB. I would strongly urge that the ratios of sideband powers, rather than peak carrier VS sideband power, be used to determine the cross-modulation ratios.

Earlier, in the text I referred to the modified Jeffers curve* for intermodulation products. The modification smooths the curve and adjusts the values as suggested by Jeffers. As published in our rules, it is a very close approximation of the intermodulation curve published in BP-23.** In our intermodulation curve, the values range from a -30 to a -57dB in relation to the visual carrier. It is my opinion that the values shown by the curve are valid and are attainable with reasonable system design.

The majority of problems encountered are those of spurious signals generated at the headend. Most of these come from strip amplifier headends. Our long experience with strip amplifier headends indicates that many cable system operators utilize the amplifiers at full gain, thus allowing placement of the first trunk amplifier between 3000 and 4000 feet from the headend. This, of course, saves one trunk amplifier at the expense of the viewer. The cable system operator is generally not aware that manufacturers do not recommend full output from strip amplifiers when used in adjacent channel systems.

* Jeffers, Michael, NCTA Convention Record, 1970

** Canada, Department of Communications, Broadcast Procedures 23

The maximum output from strip amplifiers, when used in an adjacent channel headend, should not exceed +66dBmV when the individual amplifiers are rated for a +72dBmV output. The AGC action is still adequate at a gain which results in a +66dBmV output and spurious signals are reduced by 12dB. The addition of channel pass filters is strongly recommended to further reduce spurious signals.

Heterodyne signal processors offer greater control of signal levels, but can create additional problems from several sources. One very noticeable defect is 45MHz IF leakage to the trunk. Another is the color subcarrier image at 3.58MHz, placing a color beat in the lower adjacent channel. Common in older processors was the local oscillator leakage at the input terminals. Without a preamplifier to act as a buffer, these local oscillator signals could radiate from the antennae, mix at pre-amplifier inputs thus creating significant intermodulation products in other channels on the system. We have measured leakage signals as high as +25dBmV from processor inputs.

Our rules require that cable operators establish monitor test points in systems and that the monitor points be measured once a month to determine carrier levels. Additionally, a subjective evaluation of picture quality is required. Many hold the view that the information is neither valid nor useful. I believe that monthly tests are important to the system operator to determine the operating characteristics of the system. When compared to the results of the annual tests it is relatively simple to determine system performance. Experience will show the operator when to begin a distribution and trunk maintenance program rather than continue to dispatch technicians on subscriber complaints.

An example of how this may work for the operator is in measurement of the visual-aural carrier ratios. When properly set at the headend, the ratio is 15dB. The system should not change this ratio. However, we measure many systems where the ratio does change. The cause of the change in ratio is a change in system flatness due to reflections from bad cable, connectors or taps, or poor amplifier response. When an operator sees, during the monthly monitor tests, that the visual-aural ratios are not uniform from headend to subscriber tap, he should begin a system sweep to determine the cause.

A particularly vexing problem which cable operators must attempt to solve is that of line extensions into less dense population areas. Many municipal officials insist on extensions when, in fact, the economics of the situation do not warrant the plant construction. We have begun to assist in the resolution of the different views which may result from an operator's insistance that he cannot afford to build, while local officials insist that he can.

We are operating a programmable calculator programmed to consider construction and operating costs, potential subscribers, acceptable installation and monthly charges and a reasonable profit (as determined by the operator). Many variables and combinations of variables can be considered in the program. Given monthly and installation charges and desired profit, for example, we can help the operator determine the maximum he may spend in construction to achieve his goals. While we have not had the program in operation a sufficient length of time to ascertain its degree of success, we are guardedly optomistic in predicting that it will be successful.

The requirement for lower cost construction, sometimes indicated by our line extension program, has dictated that we evaluate construction practices which heretofore have been considered only for very short extensions. Specifically, we must now consider utilization of one-way-only trunk amplifiers, twelve channel capacity (where the rules do not preclude these) and line extenders cascaded beyond two or three.

Line extenders have been developed to a degree approaching trunk amplifier performance. Extensive use of IC chips and the addition of AGC make these units viable in long extensions. Where there are limited numbers of subscribers along the trunk route, it is practical to tap the trunk. However, it is not recommended that trunk taps be other than directional coupler types. We have seen pressure taps in trunks, but do not recommend their use.

I know of fourteen systems in the state, dating from 1967, which are tapped trunk twelve channel systems. Of these, thirteen use single-ended trunk amplifiers and are short (up to 9 miles) systems. The remaining system has a subscriber density below 25 per mile, has all line extenders, is a 40 mile plant and meets all pertinent parts of Part 76 and Part 596. We are not aware of subscriber complaints, which seems a good indicator of acceptable performance.

In conclusion I would stress some key paragraphs. Carrier-to-noise ratios, exceeding 36dB in systems are not a deterrent to long cascades even with single ended equipment. It is not more costly to design a system for high performance than to string it from pole-to-pole. When strand mapping is done in a way which allows good system continuity, it is likely that a system can be built less expensively to perform better than Part 76 envisions. With the advent of high performance IC chip amplifiers, a system can be built with a feeder-to-trunk ratio as high as 6 to 1, dramatically reducing per mile cost while maintaining excellent signal quality.

Amplifier design has changed radically in the last year. The net effect is that trunk and feeder systems have vastly improved performance. Notwithstanding, the changes in design, actual systems utilizing older single ended amplifier design perform significantly better than can be calculated from existing formulae.

Line extender design has improved with the advent of IC chips, improved AGC, slope and thermal control. Line extenders from some manufacturers have performance nearly equaling (sometimes equaling) trunk station specifications. I have no hesitancy in recommending that cable system operators should very seriously consider cascades of twenty or more line extenders in low density areas to bring cable to potential subscribers at reasonable costs.

Measurement of carrier-to-noise, cross-modulation and intermodulation should not be done at subscriber drop levels. This procedure will result in significant errors in measurements. Measurement techniques must be reevaluated and the objective measurement correlated with subjective observation of picture quality. Discrete amplifiers respond differently from IC units and measurements do not track with visual observations.

Without the aid and cooperation of the New York Network technical staff, several munufacturers, and most importantly the cable system operators in the state, this paper would not have been possible. To all of them and to my staff-thank you.

COMPOSITE TRIPLE BEAT MEASUREMENTS

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Abstract

This paper presents a set of curves which show the relative readings between a power meter signal level meter and spectrum analyzer, when measuring the composite (summation) triple beat on a particular channel. The curves allow the CATV operator to obtain a correct measurement (RMS) of composite triple beat for system performance when using common instruments such as the spectrum analyzer or signal level meter.

A plot of a computer run made at RCA is also given showing the total equivalent triple beats on the worst case channel versus the number of channels.

Introduction

The question of how to measure triple beat (third order intermodulation) has been a problem in the CATV industry. One method is to measure a single triple beat and extrapolate to a 35-channel case. The problem with this method is that the single triple beat level will vary depending on the test frequencies used, resulting in poor correlation with the composite triple beat level produced when all channels are operated. A measurement of the composite triple beat per channel would be more practical since the composite triple beat produces the undesirable effects on a Television screen. The problem with measuring the composite level is that it is below the system noise level in the trunk line. In the high level distribution, the composite level is above the system noise level, but the problem becomes one of instrumentation. Most signal level instrumentation available to the CATV operator is not capable of true power (RMS) measurement of complex signal waveforms such as noise or multiple sine waves. Correction factors need to be established for typical signal level instrumentation used in the cable industry such as spectrum analyzers and signal level meters. The purpose of this paper is to present a set of curves which show the relative readings between a power meter (RMS), signal level meter (peak) and a spectrum analyzer (peak or average).

Figure 1

This figure shows the relative instrument measurement in dB versus the total equivalent triple beat per channel for the worst case channel. The data was taken by measuring a single frequency signal with each of the instruments to obtain a reference point on the meter or CRT. Additional signals were added, then additional attenuation to return the readings to its reference point. The attenuator reading was used as the measured value. Individual signal generators were combined to form the composite beats when the number of measured beats was below 7. Amplifier distortion was used to generate beat combinations which were greater than 7. The Test Setup is shown in Appendix A.

Curve 1 has a 20 log N slope and is shown for reference only.

Curve 2 was plotted using the readings of the noise peaks measured on a spectrum analyzer in the log mode without the video filter. The analyzer used was a HP8554L/8552A.

Curve 3 is the reading on a Jerrold 727 Signal Level Meter.

Curve 4 is the true RMS reading mode with an HP 435A power meter.

Curve 5 was made with the spectrum analyzer in the linear mode and with the 100 Hz video averaging filter switched in.

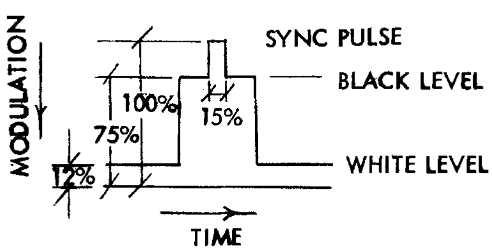
Curve 6 was made with the spectrum analyzer in the log mode and with the 100 Hz video averaging filter switched in.

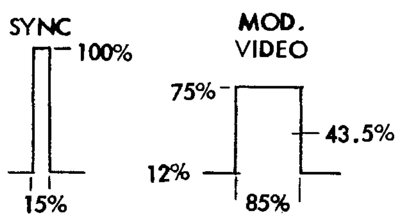
One can see from the curves that the commonly used instruments can be calibrated to the power meter or to each other. The averaged readings on the spectrum analyzer parallel the power meter readings which would require a constant correction factor, whereas the signal level meter would require a variable correction factor depending on the number of channels.

Effects of Modulation

The threshold of perceptibility of the composite triple beat on a TV receiver, based on subjective tests performed at RCA, was the same RMS level for modulated carriers as it was for unmodulated carriers. The difference was that the output level of the amplifier could be increased approximately 5 dB when the carriers were modulated to obtain the same RMS level for the composite triple beat.

The 5 dB change in level would mean that the modulation caused the average level to change 5 dB. This can be verified by calculating the average level of a modulated carrier, assuming that the distribution of grey level information is approximately uniform.





Total Average Level = Average level in sync pulse + average level in modulated video

$$= 100 \times .15 + \frac{(75 + 12)}{2} \times .85$$

$$= 100 \times .15 + 43.5 \times .85$$

$$= 51.98\% = 52\%$$

The average level in a modulated carrier versus an unmodulated carrier would be 52% or 5.6 dB from the peak carrier.

When measuring the composite triple beat with a power meter (true RMS), the reference should be measured without modulation on the observed channel because the power meter will not measure the peak (which is the desired reference) with modulation.

Threshold of Perceptibility

Figure 2 is a plot of two curves, Curve 1 being the required system level of an individual triple beat as a function of the total number of beats per channel. The measured points on Curve 1 were found by observing the threshold of perceptibility on a TV receiver of the total third order intermodulation (composite triple beat) on one channel and then measuring the level of an individual triple beat.

Curve 2 is a plot of the threshold level of perceptibility of the total third order intermodulation (composite triple beat) per channel. Curve 2 was derived from Curve 1 mathematically by summing levels of the third order intermodulation products that fall on one channel and the curve was verified by measuring the composite triple beat with the power meter as indicated in this paper.

A detailed analysis of Figure 2 is given in a previous paper. (1)

Figure 3

This figure is a plot of a computer run made at RCA showing the total equivalent triple beat on the worst case channel versus the number of channels. The worst case channel as shown in the computer run is the center channel in any group of channels. For this figure, channel 8 was used as the worst case channel and other channels were added evenly on each side of Channel 8.

The lower curve was derived by adding channels, 6 MHz apart on each side of channel 8. The discontinuity shown by the dotted lines is the point where the low band channels (2-6) were added, beginning with channel 6.

The upper curve began with the standard 12 channels adding the midband channels and then the superband channels.

Summary

1. The correction factor can be found from Figure 1 for two common instruments used in CATV for measuring the composite triple beat.

2. The effect of modulation is to reduce the average level approximately 5 dB.

(1)
Arnold, Bert "Required System Triple Beat Performance" RCA, North Hollywood, California 91605, 1973.

3. Figure 2 gives the threshold of perceptibility for third order intermodulation (triple beat) for a single triple beat and a composite triple beat.

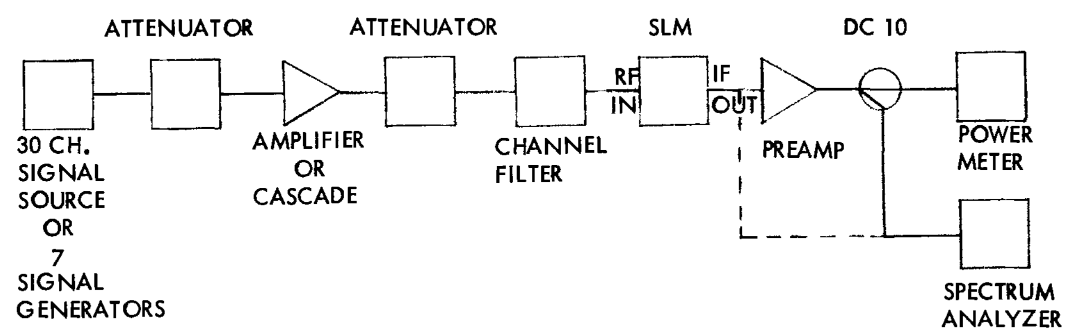
4. Figure 3 gives total triple beat per channel versus the number of channels.

5. The curves in this paper gives the system designer the tools to design and proof a system to insure the system is within the output capabilities of the system equipment.

APPENDIX A

Test Set Up for Triple Beat Measurement

Equipment	Manufacturer	Model
30 Ch. Signal Source	Theta Com	KTSS
Signal Generators	Hewlett-Packard	3200
Attenuators	Texscan	SA-70
Amplifier	TRW	206
Cascade	RCA	150
Filter	RCA	-
Signal Level Meters	Jerrold	727
Directional Coupler	Dolphin	DC-10
Power Meter	Hewlett-Packard	435A
Spectrum Analyzer	Hewlett-Packard	8554L/8552A



The IF output (TP2, J203) was used on the Jerrold 727 in order to provide selectivity for the power meter.

FIGURE 1

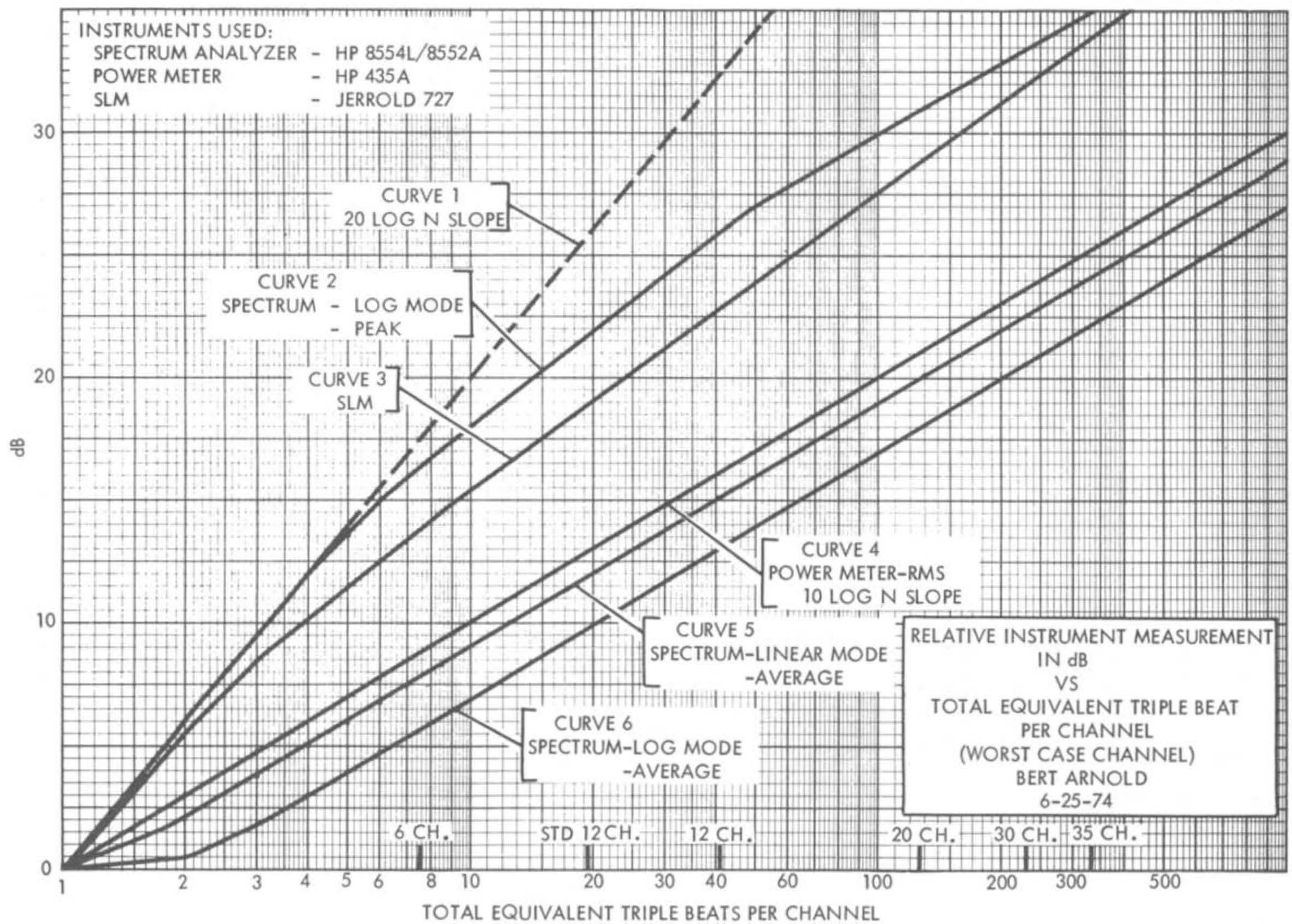

INSTRUMENTS USED:
SPECTRUM ANALYZER - HP 8554L/8552A
POWER METER - HP 435A
SLM - JERROLD 727
CURVE 1
20 LOG N SLOPE
CURVE 2
SPECTRUM - LOG MODE
- PEAK
CURVE 3
SLM
CURVE 4
POWER METER-RMS
10 LOG N SLOPE
CURVE 5
SPECTRUM-LINEAR MODE
-AVERAGE
CURVE 6
SPECTRUM-LOG MODE
-AVERAGE
RELATIVE INSTRUMENT MEASUREMENT
IN dB
VS
TOTAL EQUIVALENT TRIPLE BEAT
PER CHANNEL
(WORST CASE CHANNEL)
BERT ARNOLD
6-25-74
6 CH.
STD 12 CH.
12 CH.
20 CH.
30 CH.
35 CH.
dB
0
10
20
30
1
2
3
4
5
6
8
10
20
30
40
60
100
200
300
500
TOTAL EQUIVALENT TRIPLE BEATS PER CHANNEL

FIGURE 2

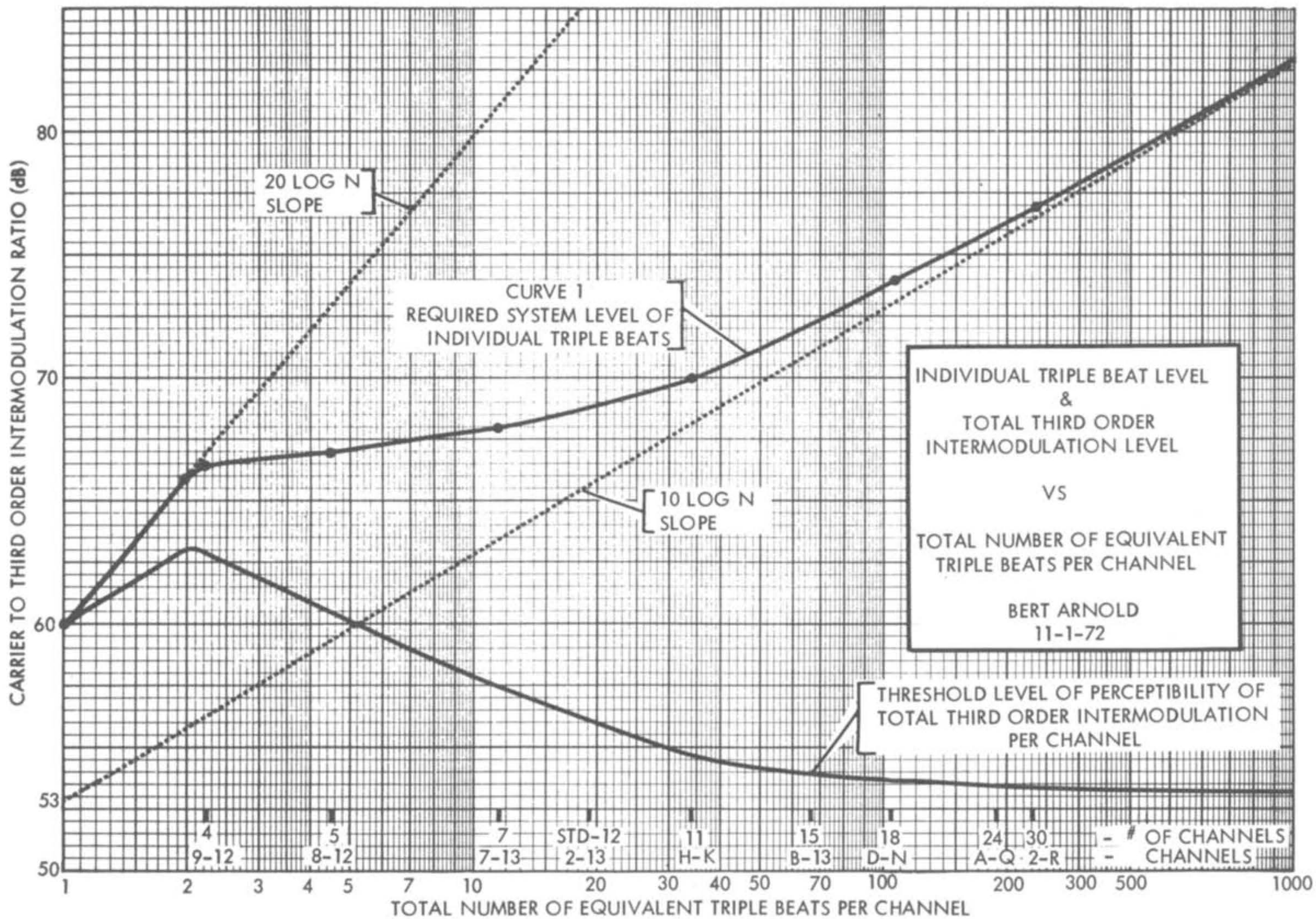
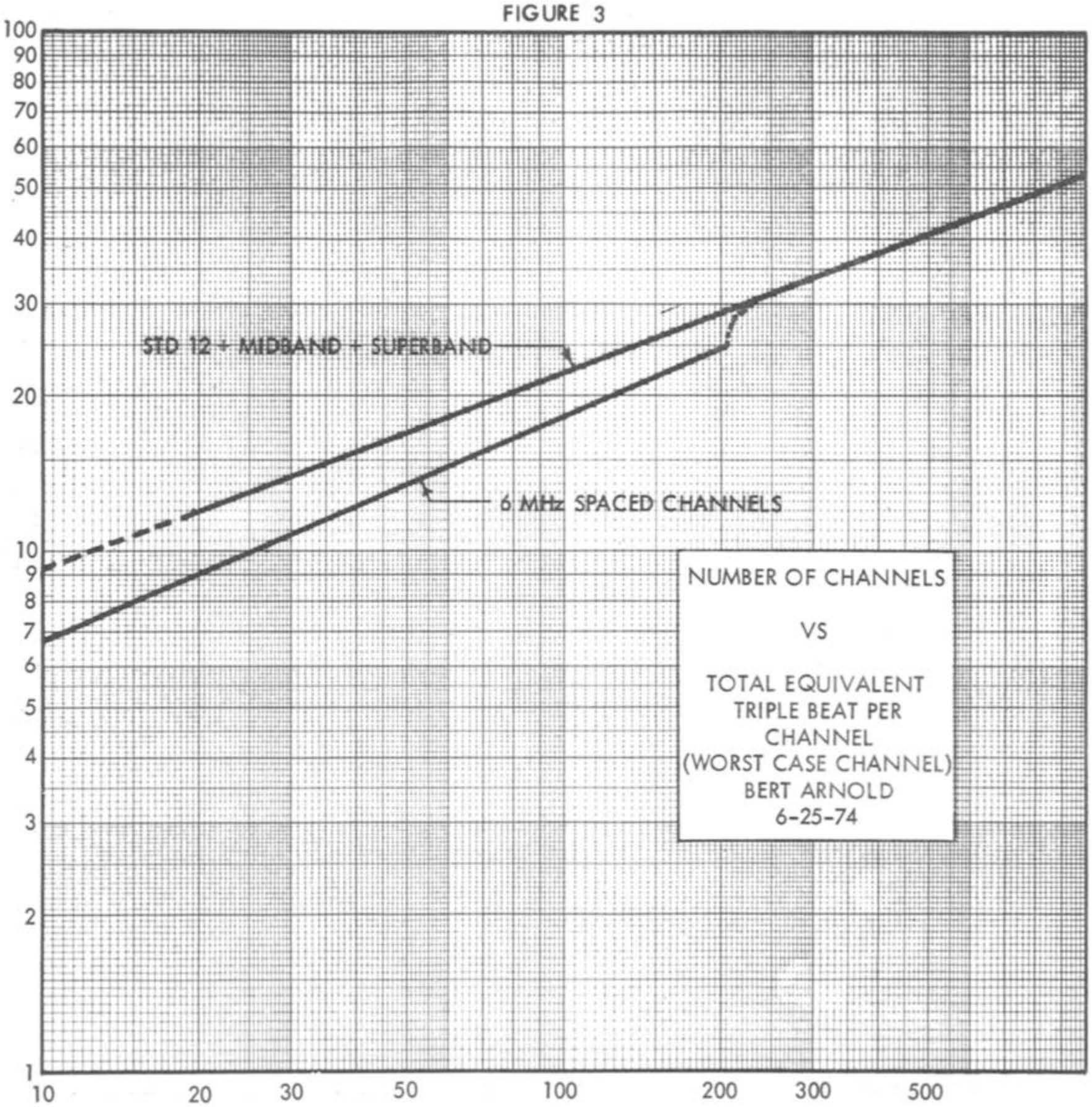

80
70
60
53
50
CARRIER TO THIRD ORDER INTERMODULATION RATIO (dB)
20 LOG N
SLOPE
CURVE 1
REQUIRED SYSTEM LEVEL OF
INDIVIDUAL TRIPLE BEATS
INDIVIDUAL TRIPLE BEAT LEVEL
&
TOTAL THIRD ORDER
INTERMODULATION LEVEL
VS
TOTAL NUMBER OF EQUIVALENT
TRIPLE BEATS PER CHANNEL
BERT ARNOLD
11-1-72
10 LOG N
SLOPE
THRESHOLD LEVEL OF PERCEPTIBILITY OF
TOTAL THIRD ORDER INTERMODULATION
PER CHANNEL
4
9-12
5
8-12
7
7-13
STD-12
2-13
11
H-K
15
B-13
18
D-N
24
A-Q
30
2-R
- # OF CHANNELS
- CHANNELS
1
2
3
4
5
7
10
20
30
40
50
70
100
200
300
500
1000
TOTAL NUMBER OF EQUIVALENT TRIPLE BEATS PER CHANNEL

FIGURE 3


STD 12 + MIDBAND + SUPERBAND
6 MHz SPACED CHANNELS
NUMBER OF CHANNELS
VS
TOTAL EQUIVALENT
TRIPLE BEAT PER
CHANNEL
(WORST CASE CHANNEL)
BERT ARNOLD
6-25-74
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
10
20
30
50
100
200
300
500

DIGITAL FRAME GRABBING

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ABSTRACT

A system for delivering news and information to cable television subscribers using "digital frame grabbing" is being developed. The use of digital frame grabbing instead of video frame grabbing is rationalized in the light of present technology. Alpha-numeric information in digital form is transmitted repetitively at a very high data bit rate making use of the wide band capability of cable television channels. Information recycle rate is set according to the expected public demand for each particular class of information being handled. A subscriber controlled digital "frame grabber" compares the requested "page number" with the "page numbers" in the data stream in the cable. When the required digital page number is recognized the frame grabber reads the entire "page" into local memory where it is displayed on the subscriber's TV receiver through a local character generator. The cable transmission system acts like a long delay line memory being constantly refreshed by a computer at the "head-end" and being scanned for desired information items by the subscriber's frame grabber. Access times contemplated range from an average one second up to times in the 10-20 second range.

INTRODUCTION

Information delivery on cable systems began more than ten years ago by placing a camera in front of newswire teletype machine. Cable subscribers could tune to one of the cable TV channels and see the teletype machine printing out news and weather information in just the same way that news editors in radio and TV newsrooms were watching the news being printed out in their newsrooms. At the same time similar cameras were mechanically scanning time clocks and weather display dials to provide this information on a cable television channel. The development of electronic character generators allowed the newswire lines to be transferred directly to electronic television format and these systems were gradually refined and improved. As these services grew more popular the news services took the trouble to re-write and re-edit their services specifically for this delivery medium. The service in its present form is an alpha-numeric character generator system operated at TTY speeds, or slightly faster and displayed on TV screens at a speed judged slow enough to suit the lowest common denominator of reading speed in the subscribing public. Most systems make no special charge for this service, the cable system usually absorbing the charges made by the wire services for supplying the copy. The material displayed, order of presentation and duration of display is controlled by the wire service and the subscriber can only tune in and take "pot luck". Some newer cable systems with surplus channel capacity have installed multi-channel character generator systems with computer controlled formatting and editing which allows the editing of newswire feeds into various categories for display on specialized channels, e.g. a "sports channel", "news channel", "weather channel". These augmented systems usually provide facilities for generation and display of information on a local basis to supplement the wire service feeds.

All of these improvements still leave the service as a rather rudimentary display of information. Channels are used rather wastefully and users still participate on a "pot luck" basis - only the number of "pots" has been increased.

THE IDEAL SYSTEM

At the other end of the information system technology spectrum we have seen demonstrations of interactive information retrieval systems in which the cable system acts as a communications medium between a computerized information bank and a computer terminal in the subscriber's home. Ideally the whole system would be capable of handling "pictures" as well as alpha-numeric information. These idealized systems require a bi-directional transmission capability in the cable system. Such capability is not generally available on Canadian cable television systems except on a strictly experimental basis nor have we seen any systems elsewhere in the world with a fully developed, practical two-way transmission capability.

A PRACTICAL SYSTEM

We have developed concepts and practical designs for a system that permits a usefull information system to operate on conventional cable television systems, i.e. on "one-way" systems of the type currently in widespread operation. System and detailed circuit designs *have been developed and now await successfull market research studies before large scale pilot operation is attempted.*

Our first decision was that a cable information system would have to depend on "frame grabbing" and that such frame grabbing would have to be digital, limiting the system capability to alpha-numeric information and simple graphics. Video frame grabbing, particularly in full colour, was considered too expensive and too complicated to be used in practical home terminals at low cost for perhaps a decade. Digital frame grabbing could be executed with digital integrated circuit technology. Digital IC technology is low cost and is becoming increasingly cost-effective year by year. The phenominal technical and commercial success of pocket calculators and the long delay and expected high cost of video cassette and disc devices convinced us that digital technology was the route to follow at the present time.

We decided to simulate interactive operation by repetitively feeding information into the cable at very high speed. We also decided that digital transmission at rates of 2 MBit minimum would be required to build a usefull system. Our previous experience with conventional character generators for cable television indicated that a 256 character page of 8 lines of 32 characters each would be suitable as an initial format. This is a rather small number of characters compared with computer type CRT displays but this service is intended for display on home type television receivers in a home type environment. Tube masking is rather uncertain and unpredictable and the sharpness and resolution on many home receivers is marginal. The information displays would be viewed at regular "home distances" as a short term alternative to entertainment viewing.

We decided also to contain the basic service within the bandwidth of a standard television channel - 6MHz. Modems would be developed with this constraint, i.e. the transmission must fit within a 6MHz RF channel and be compatable with conventional television signal transmission on adjacent channels if necessary. We then decided that the first level of information would be provided with a 2 second repeating cycle time so that the average access time for a subscriber would be one second. A subscriber requesting a particular page number might get it immediately if that page happened to be "passing by" or he might wait as long as two seconds if the subscriber "just missed it". The average time would be about one second. Provision has been made for handling full upper and lower case alphabetic characters and the usual complement of numerics and special characters. An 8 bit ASCII code has been selected for initial work. A full 256 character page requires about 2,000 bits and a 2 MBit data rate is capable of transmitting about 1,000 such pages per second. Compare this with the 30 or 60 frames of video transmitted in a television channel each second. A 2 second cycle time means that the full information magazine will be about 2,000 pages.

The "magazine" size can be increased by developing hierarchies of information on longer cycle times interleaved with the shorter cycle time information. Types and items of information judged less popular would be interleaved with cycle times of 4, 8, 16 or more seconds. Subscribers requesting these less popular categories or items would have to wait longer average times for the requested frame to appear. We estimate that the usefull "magazine" size can be increased to about 10,000 frames in this way.

Magazine size is also limited by the data transmission rate. Our initial design is based on simple AM NRZ modulation. We are studying more complex modem technologies that would push our data rate up toward 6 MBit/second. This transmission rate is limited by the economics of the data demodulator that has to be provided in each home terminal and the economics of the refresh memory and data buffer for each home terminal.

The home terminal which we have designed has a simple numeric keyboard on which the subscriber keys the page number desired. It is proposed that the information system be designed around a system of index pages which guide the subscriber to the desired level through three levels of indexing. The terminal grabs the desired digital frame from the system as it becomes available and stores it internally. A complete character generator system within the home terminal provides a colour alpha-numeric display for the home receiver. Initial design integrates the terminal with a conventional set-top converter for tuning function.

Present design uses shift register memory within the home terminal. Present technologies seem to limit us to the 2,000 bit storage requirement of one page as economical for consumer terminals. This means that the subscriber grabs and reads one page at a time. When the subscriber finishes a page he keys a "next page" key which automatically increments the page counter to await the next page. We are watching the development of CCD type shift registers which will give us up to 1,000 characters in local storage at very attractive prices. This is equivalent to four pages and will allow a whole "story" or at least four pages of it to be grabbed at one time for local storage and display. Display of "next page" up to the full four page local memory would be instantaneous. Use of these larger local memories would allow us to increase the size of the magazine since cycle times could be lengthened. A subscriber getting four pages at a time would be more tolerant of a longer waiting time between "stories".

The present design is in the form of conventional TTL digital IC's, and LSI's for character generator ROM and TV sync generator. Pilot tests will use terminals built from these or slightly updated designs. Economical expansion of a successfull pilot project to a full scale *operating system will require use of several specialized LSI's.*

PROJECTED IMPROVEMENTS FROM PRESENT DESIGNS

We are working on improving our modem techniques to allow economical demodulators for very high speed data transmission (up to 6 MBit). We are experimenting with techniques that would use available, low cost colour television receiver IC's. Colour television chroma demodulation involves "clock recovery" and a complex demodulation of phase and amplitude demodulation. We believe that it should be possible to design a data transmission system that would be compatable with colour television principles. This would allow use of colour television receiver devices and possibly allow future integration of the data terminal into home television receivers as an optional feature. We are also studying the problem of making the terminal compatable with other sources of digital data, e.g. cassette systems which might be plugged in locally. This would allow the terminal and television set to be used with local inputs other than the high speed cable feed.

System capacity can be multiplied by using additional RF channels in the cable system, if these are available.

SOFTWARE

The system has been designed as a generalized alpha-numeric information system. Some market studies have been undertaken and additional studies are under way to determine the best and most economic uses to which this system might be put. Our corporate interest is in the consumer market, i.e. home subscribers as contrasted to commercial subscribers. Initial studies indicate that "hard news" is the likeliest application for this system although the principles can of course be used for other purposes. For hard news delivery we expect that the system would be operated either by or in co-operation with a local newspaper or other undertaking which already has an active news gathering and editing facility. News for cable delivery would be re-edited and reformatted for this particular medium with the help of a "head-end" computer that would also handle the repetitive data transmission.

ACKNOWLEDGEMENTS

This particular system development began about four years ago. Similar systems have been developed in the United Kingdom using broadcast transmission in vertical interval with a much smaller "magazine". Such systems are now being operated experimentally by both the BBC and IBA. A similar system appears to have been developed in about the same time by Reuters and is being operated experimentally in New York City. The U.K. systems have been widely described under the names "CEEFAX" (BBC) and "ORACLE" (IBA). The Reuters system has, to my knowledge, not yet been described in public.

The contribution of ETC Systems Limited, Rexdale, Ontario, to the detailed circuit designs is acknowledged, and the contribution of Dr. Wes Vivian, of Ann Arbor, Michigan, to some of the system concepts is acknowledged.

FEEDFORWARD APPLIED TO CATV AMPLIFIERS

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ABSTRACT

The small size, stability, and efficient use of power of hybrid integrated circuits makes feedforward an attractive design technique for CATV amplifiers. This paper discusses the general design technique of feedforward and the resultant advantages and disadvantages. The most significant advantage is the reduction of all distortion products appearing at the output of an amplifier.

Introduction

In the late 1920's H. S. Black rigorously characterized and patented the technique he described as feedback. In the succeeding years feedback has been used in virtually every area of active circuit design. A few years prior to his work on feedback, Black invented and patented the technique of feedforward. By comparison with feedback, feedforward has found very limited usage. In recent years it has been shown[1,2] that feedforward, when applied to a wide band amplifier can produce some very attractive properties. The most significant advantage is the reduction of all distortion products at the output of the amplifier. Perhaps the most significant disadvantage of feedforward is the extra circuit complexity involved. However the small, stable and efficient integrated circuit amplifiers currently available tend to offset this disadvantage and make feedforward an attractive design technique for CATV Amplifiers. This paper will discuss the theory of feedforward and its application to CATV amplifiers.

To best understand the principle of feedforward consider the properties of a wide band RF amplifier as used in CATV. Such an RF amplifier performs three operations upon the input signals applied to it: (1) amplifying the signals, (2) delaying the signals, (3) and adding errors in the form of noise and distortion products to the signals. The first operation, amplification, is the reason for the amplifier's existence and nothing more need be said about it. The second operation, delay, is an unavoidable consequence of the first operation. The delay is generally uniform across the bandpass of the amplifier and small, perhaps no more than the delay provided by two feet of coaxial cable. The delay is insignificant when added to the delay of a cable system made up of many thousand feet of cable. The last operation, the added error signals, is another unavoidable consequence of amplification and, since these errors ultimately limit the performance of the system, it is desired to minimize them. If the error signals could be isolated from the fundamental signals then one could reinsert the errors back into the main signal path in such a way as to eliminate them. In order to isolate the errors, the output can be smapled and subtracted from a sampled portion of the input. However the output is no longer synchronous with the input, having been delayed by the amplifier. We cannot undelay the output, but we can delay the sampled input by an amount equal to the amplifier delay. Having thus synchronized the sampled input and output, the two can be subtracted leaving only the errors. Thenisolated error signals, having been scaled down by the sampling networks, must be amplified before being reinserted into the main signal path. The delay resulting from this amplification must be offset by an equal delay in the main signal path before complete cancellation can occur. It is important to recognize the significance of the delay caused by the amplifiers. Although the delay is small in terms of the system delay, it is large when compared to the period of the signals involved. Thus comparing the output to the input directly and modifying the input (feedback) is not possible. Feedforward recognizes the passage of time and compensates for it always in the forward direction.

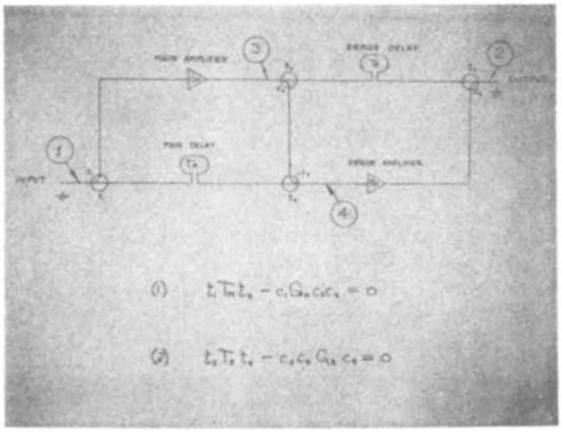

Figure 1

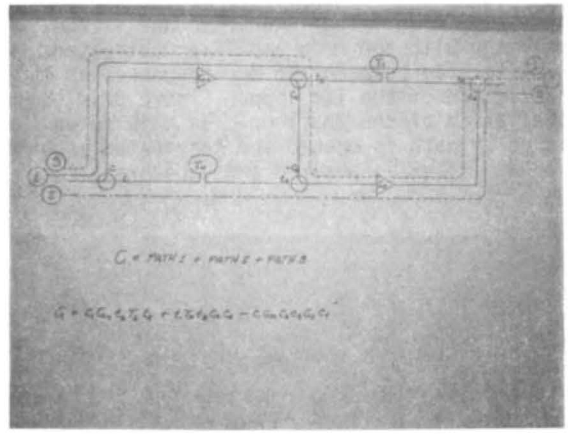

Figure 2

Fig. 1 is a block diagram of a typical feedforward amplifier. The points in the diagram indicated by 1 and 2 represent the input and output of the amplifier respectively while points 3 and 4 are internal to the network. Between points 1 and 4 there are two possible paths for the input signal to take. The following constraint is placed upon these two paths.

$$-C_1C_2C_3G_M + t_1T_M t_3 = 0 \qquad (1)$$

And similarly between points 3 and 4

$$t_2T_E t_4 - C_2C_3G_E C_4 = 0 \qquad (2)$$

Equation 1 is said to describe the 1st or main loop while equation 2 describes the 2nd or error loop. The 1st loop cancellation (equation 1) means that any signal applied to port 1 does not appear at port 4. Hence any input signal is not influenced by the cancellation of the 2nd loop by virtue of the 1st loop cancellation and is coupled directly to the output through the error delay path. However at the output of the main amplifier there are "error" signals as well as amplified input signals. The error signals are the noise and distortion products generated by the main amplifier. They are, by definition, not present at the input and hence are not cancelled at point 4. Hence equation 2 applies to these error signals and they appear at the output reduced by the cancellation of the 2nd loop. These two amplifiers then, connected as indicated in figure 1, cancel all the noise and distortion generated by the main amplifier. The noise and distortion generated by the error amplifier of course appear at the output uncancelled. However, since the error amplifier nominally carries only error signals, which hopefully are several orders of magnitude below the fundamentals, it can have a low power front end to optimize its noise figure, and a medium power output to keep the distortion down.

Of course the success of such a feedforward amplifier depends on the degree of cancellation that can be reliably accomplished. Fig. 2 is a photograph of the cancellation of the 1st loop. In order to measure this cancellation the error delay path was opened and terminated thereby disabling the 2nd loop. The upper response represents the setup with the main amplifier unpowered--namely the transmission through the main delay with the error amplifier acting as simply a post amplifier. The lower response is the same setup with the main amplifier activated. The difference between the two responses is the cancellation of the 1st loop. Figure 3 is the cancellation of the 2nd loop. In this setup the main delay path is opened and terminated and the error amplifier is powered and unpowered.

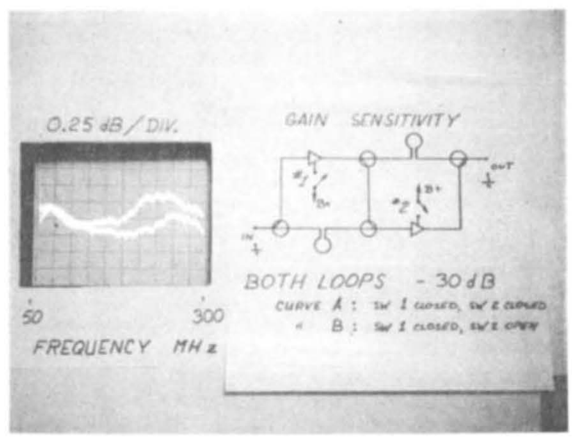

Figure 3

Both loops were aligned for the best possible cancellation, approximately 30 dB worst case. To produce 30 dB cancellation across the band the two paths involved must match to within 0.27 dB in amplitude or 1.82 degrees in phase. Such a matching of the paths appears to be as good as one can do using the integrated circuit amplifiers currently available. The phase matching of about 2 degrees out of a total path length of some 500 degrees is perhaps a more severe requirement than the amplitude match of .27 dB when compared to the amplifier gain of about 30 dB. Moreover to maintain these kinds of tolerances over the temperature variations encountered in CATV systems would be at the least very difficult and perhaps impossible. Our measurements indicate that, given a 30 dB cancellation at room temperature, the cancellation degrades to some 24-20 dB at the extremes of temperature. This change does not represent much drift between the two paths involved and is very encouraging. However rather than either accepting this performance or attempting thermal compensation to improve this performance, a different alignment strategy was sought. Before describing this alternate alignment strategy, some of the unusual properties of a feedforward amplifier will be discussed.

One of the properties of feedforward is parameter desensitization. Specifically the overall gain of a feedforward amplifier is remarkably independent of the gain of either of the internal amplifiers. Figure 4 demonstrates this behavior.

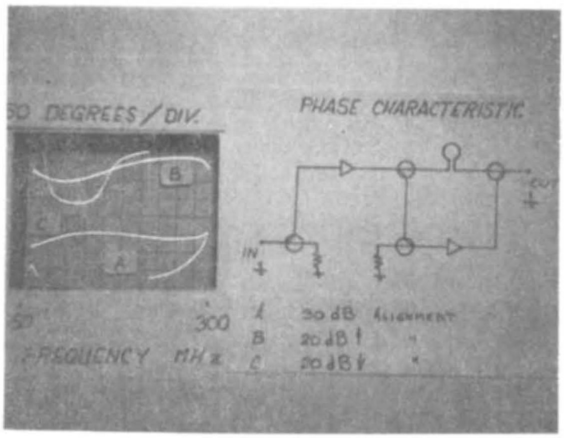

Figure 4

From figure 4 it can be seen that the overall gain expression is equal to the sum of three expressions. Because of the constraints placed upon the two loops, each of these three expressions can be shown to be equal to one another except that path 3 has a negative sign associated with it. Depending on how the substraction is carried out, the gain can be represented by either the expression for path 1 or path 2. It is easy to see intuitively and arithmetically that when either amplifier gain is made to go to zero the overall gain is unchanged. Figure 5 is a double exposure photograph of the frequency response of a feedforward amplifier. One exposure is with both loops operating normally. The 2nd exposure is with the error amplifier unpowered. The total change worst case is approximately .3 dB. Since both loops are not aligned perfectly--approximately 30 dB cancellation worst case--some gain change is to be expected, in this instance about .3 dB. The expressions predicting this behavior are derived in Appendix A.

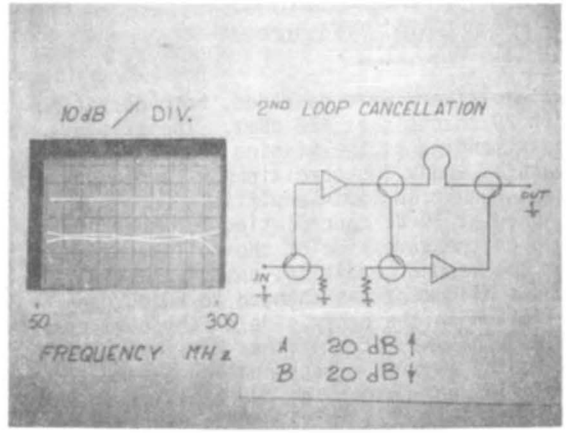

Figure 5

Another parameter that is desensitized upon the application of feedforward are input and output impedances. Specifically the output impedance of the main amplifier can be completely mismatched to optimize its output capability and the input impedance of the error amplifier can be completely mismatched to optimize its noise figure. Neither mismatching has a significant effect on the input or output match of the overall amplifier. With the first loop cancelling, virtually zero input signal arrives at the input of the error amplifier. Hence the input impedance of the error amplifier is "improved" by the cancellation of the first loop. On the output side the situation is slightly different. Any signal impressed upon the output does arrive at the output of the main amplifier via the error delay path. However, any reflected component of this signal is regarded as an "error" signal by the 2nd loop and is subject to the cancellation of the 2nd loop before reappearing at the output. The 2nd loop "improves" the output match of the main amplifier.

Another very interesting property of feedforward is the resultant phase of the distortion products after cancellation by the second loop. As we have seen earlier changing the gain of the error amplifier has a minimal effect of the overall gain. It can be easily shown that the phase characteristic is also unaffected. Hence small gain changes in the error amplifier produce nominally zero changes in the amplitude and the phase of the fundamental signals appearing at the output. However error amplifier gain changes do have a direct bearing on the resultant distortion products appearing at the output. Assume that the error amplifier gain is adjusted for the best possible cancellation of the error loop--say 30 dB cancellation. If the error amplifier gain is increased 1 dB, the cancellation goes to approximately 20 dB and the phase characteristic of the error loop is dominated by the error amplifier path of the loop. If the gain of the error amplifier is decreased by 1 dB, the cancellation again is 20 dB but the phase is dominated by error delay path of the error loop. The error delay and the error amplifier paths have identical phase characteristic except for a 180 degree offset. On either side of the best null position the phase characteristic of the error loop undergoes a complete inversion.

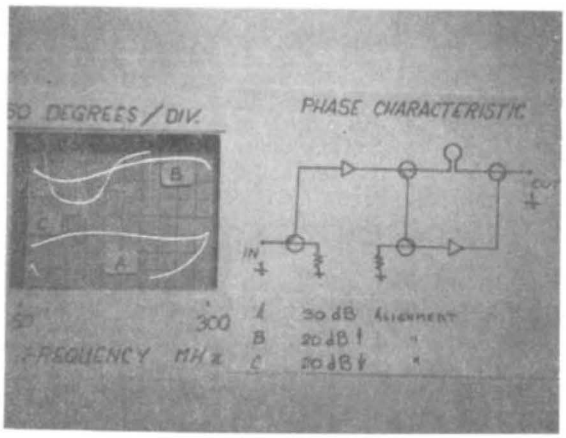

Figure 6

Figure 6 shows the cancellation of the 2nd loop with the error amplifier gain first increased and then decreased 1 dB from the best alignment position. The cancellation in both instances goes to approximately 20 dB. Figure 7 shows the phase characteristic of the error loop for three positions of error amplifier gain--best null, ± 1 dB from best null. A linear phase characteristic is subtracted from the setup so that the curves may be more easily compared. The best null phase curve undergoes a number of transitions where the amplitude characteristic of the two paths involved cross one another. The 1 dB phase curves are about 180 degrees offset from one another. This means that the phase of the distortion products produced by a feedforward amplifier can be made to undergo an inversion without affecting the fundamental signals.

This unusual property of feedforward provides the basis for what was described earlier as an alternate alignemnt strategy. Each amplifier's error loop is slightly misaligned on one side or the other of the best null. Actually each amplifier would be aligned on both sides of the null and provided with a switch to select the desired mode.

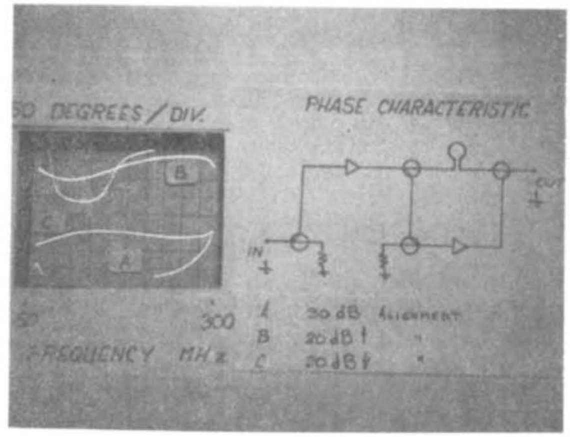

Figure 7

In a cascade of such amplifiers alternate amplifiers would be operated in alternate modes. The distortion generated by the 1st amplifier would tend to be cancelled by the distortion of the 2nd amplifier; the distortion of the 3rd cancelled by the 4th, etc. The penalty paid by individual amplifier misalignment would be offset by cancellation between cascaded amplifiers. Another advantage of this alignment strategy is temperature stabilization. Small changes in the gain of the error amplifier have a large effect on the 2nd loop cancellation at the null position. As the alignment is moved away from the null, small gain changes have a smaller and smaller effect on the 2nd loop cancellation. It seems clear that an "optimum misalignment" must exist to minimize the distortion at the end of a cascade at the worst condition of temperature. At this writing work is proceeding to find this optimum.

A number of measurements were made on a feedforward amplifier with a 30 channel set of CW signals and a spectrum analyzer. Figure 8a is the output of the amplifier with the error amplifier unpowered. The amplifier was operating with 29 channels (2-13, A-F, H-R) at +52 dBmV flat. Figure 8b is the same situation with the error amplifier powered. Since this amplifier is operating with 30 dB cancellation it is not surprising to see all the distortion products go below the noise floor. The remaining spurious signals in figure 8b in the FM band and at channel 7 sound were traced to off air interference and were not generated by the amplifier. Figure 9 is a double exposure under the identical conditions of Figure 8 except that the spectrum analyzer dispersion was reduced to 50 kHz per division centered on the missing channel G. The distortion is the spectrum of the some 200 odd triple beats falling on or around channel G carrier. It is evident that the full benefit of the 30 dB cancellation is achieved. Figure 10 demonstrates the effect of cancellation between cascaded amplifiers.

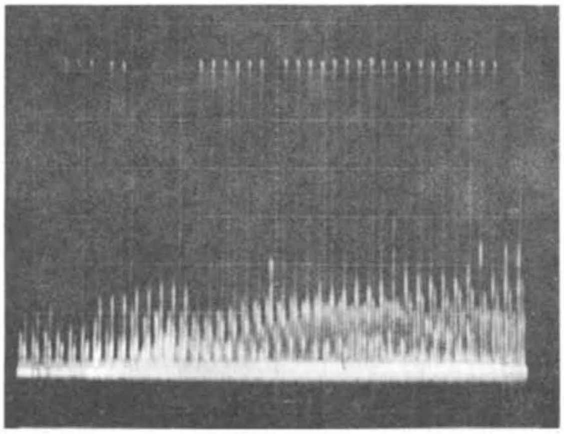

Figure 8a

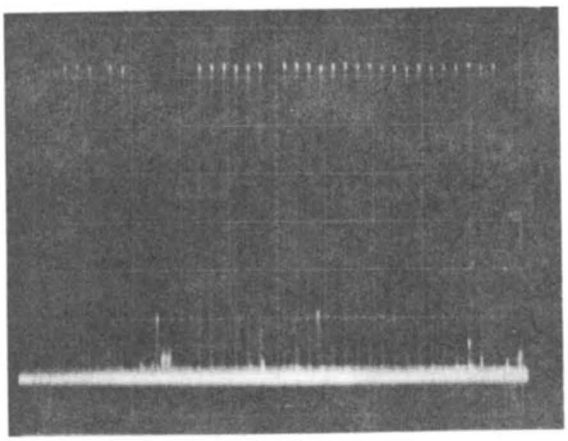

Figure 8b

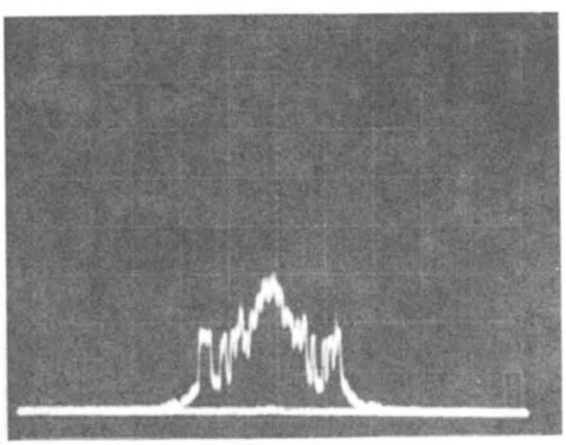

Figure 9

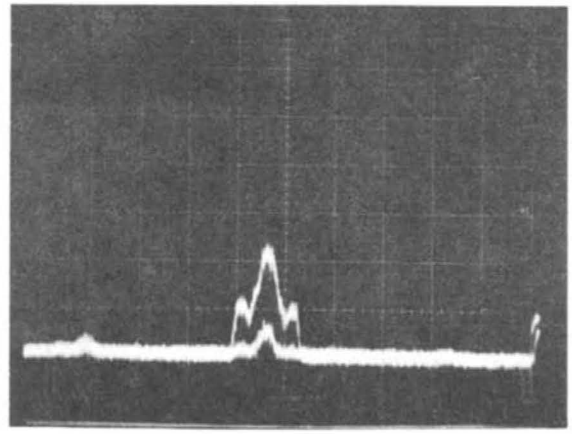

Figure 10

Two amplifiers were cascaded, both operating with 29 channels at +52 dBmV. The triple beats landing at the missing channel G were measured under two conditions. For the first condition, both amplifiers were aligned at 20 dB cancellation for the 2nd loop on the same side of the null position. For the second condition, one of the amplifier's alignment was changed to 20 dB cancellation on the other side of the null position. This was accomplished by simply switching in 2 dB of attenuation in the error amplifier path of one of the amplifiers. The 2 dB pad switch allows a double exposure to conveniently record the difference between the two conditions. Figure 10 shows the distortion falling about 16 dB when the amplifiers are operated in opposite modes.

All the distortion measurements taken are in very nice agreement with the performance predicted by the linear measurements taken on the individual loops. The results of these measurements indicate that feedforward applied to CATV amplifiers can yield a significant reduction in the total distortion generated by a cascade of amplifiers.

Appendix A

From Figure 4,

$$G = C_1 t_2 t_4 T_E G_M + t_1 t_3 C_4 T_M G_E - C_1 C_2 C_3 C_4 G_M G_E. \qquad (3)$$

Differentiating with respect to G_M

$$\frac{\partial G}{\partial G_M} = C_1 t_2 t_4 T_E - C_1 C_2 C_3 C_4 G_E \qquad (4)$$

Multiplying both sides by $\frac{G_M}{G}$

$$\frac{\frac{\partial G}{G}}{\frac{\partial G_M}{G_M}} = \frac{G_M C_1}{G}\left(t_2 t_4 T_E - C_2 C_3 C_4 G_E\right) \qquad (5)$$

Substituting in equations (1) and (2) and rearranging yields

$$\frac{\partial G/G}{\partial G_M/G_M} = \frac{t_2 t_4 T_E - C_2 C_3 C_4 G_E}{t_2 t_4 T_E} \qquad (6)$$

The right hand side of equation (6) is simply the cancellation of the 2nd loop. The equation says that percentage gain change of the feedforward amplifier is equal to the percentage gain change of the main amplifier multiplied by the cancellation of the 2nd loop.

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(1) H. Seidel, "A Feedforward Experiment Applied to an L4 Carrier System Amplifier," IEEE Trans. Comm. Tech., Vol. Com-19, June 1971, pp.320-325.

(2) R.G.Meyer, R.Eschenbach, and W.N.Edgerly,Jr., "A Wide-Band Feedforward Amplifier," IEEE Solid State Cir., Vol. SC-9, Dec. 1974, pp.422-428.

FUNDAMENTAL RELATIONS IN CATV COSTS ENGINEERING

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Some of the fundamental relations between costs and technical parameters are derived in exact form. Others are shown in a general manner, graphically. Such analysis is useful in applying historically proven cost minimization techniques.

If a man buys 200 apples and 50 oranges at a total cost of 20 dollars, and then buys 200 oranges and 50 apples at a total cost of 42 dollars and 50 cents, what was the cost of each apple? Do you remember problems like this when you were in school? And were you tempted to answer "Who cares?".

That, of course, might be a reasonable attitude for a kid who wants to get out of the classroom and into a hockey game. But the problem can have some interesting aspects to a business man. Suppose the man in the problem is a storekeeper, and suppose further, that he has simplified his accounting system so that he enters the first purchase as:

250	Fruit	\$20.00

On this basis he finds his unit cost to be 8 cents per fruit and decides that a markup to 15 cents will take care of his overhead costs and provide him with a nice little profit. Now, suppose that the oranges sell very well but the apples sell more slowly, so he now orders 200 oranges and 50 apples, and gets a bill for \$42.50. He now enters:

250	Fruit	\$42.50

and finds that each fruit now costs him 17 cents. Galluping Inflation! He has to raise his prices. His fruit sales drop. He still sells some oranges, but nobody buys apples.

Sometime after the bankruptcy proceedings were over he found that his real costs never actually changed. Apples were costing him 5 cents and oranges 20 cents.

Of course, no one would set up an accounting system where you averaged the costs of apples and orange in this manner. Or would they? Do you really know, for example, what it costs you to use 3/4" cable in your trunk rather than ½" cable? Or to provide 3 dB more signal to you customers? Or is the extra cost the same with a potential of 100 customers per mile as with 400 customers per mile?

As long as you are making a profit you may be able to take the schoolboy's attitude of "Who cares?". But unless you know how to find the answer to these and similar questions, you certainly cannot know whether you are minimizing costs, or for that matter, even taking steps which may lead to future losses.

The solution to the problem of our hypothetical fruit dealeris really very simple. He merely had to be sure that his accountant and bookkeeperknew, and kept track of the differences between apples and oranges. He would then have had the necessary information to make much better decisions about purchasing, pricing, etc.

In a field as technical as CATV, costs are affected by many technical parameters in many diverse ways and it is obvious that the decision making process must involve a considerable amount of technology. Some of the relations between technical parameters and costs are very simple. Others exhibit varying degrees of complication.

KELVIN'S LAW

In 1881, Lord Kelvin demonstrated that, in the case of electric power transmission, the most economical wire size is that where the annual interest on the investment in the wire is equal to the annual cost of the energy lost in the wire resistance.

This result, commonly known as Kelvin's Law, may be one of the first applications of costs engineering procedures.

Of course, stated in this way, Kelvin's Law is only exactly true if the cost of the wire is exactly proportional to the amount of metal in the wire. However, it can be shown that the principle involved can be stated in a slighly different form so as to be exactly true in those cases where partial costs vary in opposite ways with respect to a technically definable parameter.

First, separate those costs which vary with the parameter from those which do not.

(1) $C_t = C_f + C_v$ i.e. total costs equal the sum of fixed costs and variable costs. (relative to the parameter in question)

Taking the derivative, we obtain:

(2) $\frac{dC_t}{dP} = \frac{dC_v}{dP}$ Where P is the parameter involved. If there is a minimum cost, it will be possible to solve

(2a) $\frac{dC_v}{dP} = 0$. If not, the sign of the expression will indicate the direction in which P should be varied in order to reduce costs.

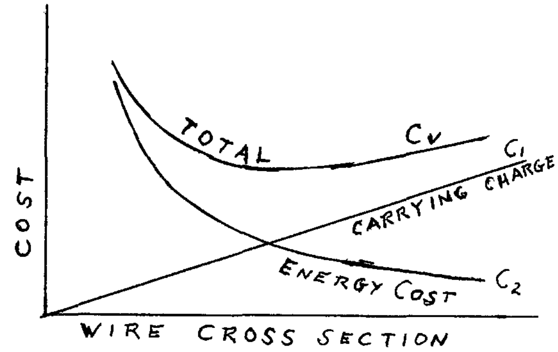
A very common situation is one in which the variable costs vary with the parameter through two (or more) mechanisms affecting cost in different ways. Let:

(3) $C_v = C_1 + C_2$ Then (2a) requires

(4) $\frac{dC_1}{dP} = -\frac{dC_2}{dP}$ which will determine the conditions of minimum cost. Note that the existence of a minimum requresthat C_1 and C_2 vary in opposite ways with P.

Fig. 1 shows the relations assumed by Kelvin in his derivation. Notice that the occurrence of the minimum at the point of equality of the two costs is dependant on the fact that one varies directly with the parameter (area of wire), and the other varies inversely to it. The rather broad minimum is also typical of many situations of this type. In this case, the broad minimum suggests that the additional investment which could provide either better voltage regulation or capacity for future growth would be rather small and ought to be investigated.

Although Kelvin's Law was originally applied to the problem of minimizing annual costs, the principles are applic-



$$C_1 = K_1 A \qquad C_2 = K_2' I^2 R \simeq K_2/A$$

$$\frac{dC_1}{dA} = K_1 \qquad \frac{dC_2}{dA} = -\frac{K_2}{A^2}$$

$$A = \sqrt{K_2/K_1}$$

$$C_1 = C_2 = \sqrt{K_1 K_2}$$

Fig 1

able to the case where total costs vary in opposite ways with respect to any parameter. A rather simple and instructive case is that of a dead run trunk. In this case we have two costs which will vary with the attenuation of the cable which might be used. One, the total cost of amplifiers will increase in dirct proportion to the cable attenuation, and, two, the cost of the cable will decrease with the cable, although not in a simple inverse proportion. The situation is shown in Fig.2.

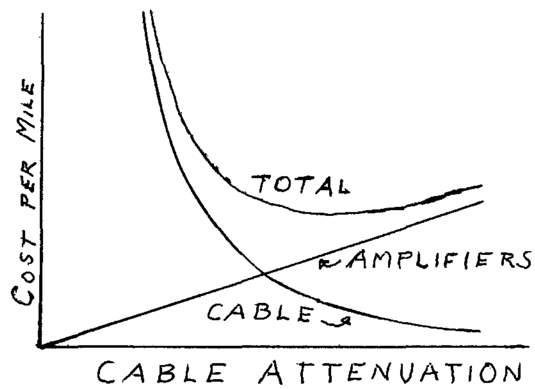


Fig 2.

The total variable cost in this case is:

(5) $C_v = C_c x l + C_a x n$

Where C_v = total variable cost, C_c = cable cost per unit length, C_a= cost per amplifier, l= length of trunk, and n= number of amplifiers. Equation (4) becomes:

$$(6) \qquad \frac{d(C_c l)}{d\alpha} = - \frac{d(C_a n)}{d\alpha} \qquad \text{and with}$$

The obvious relation n = 1/G we get:

$$(7) \qquad \frac{d(C_a n)}{d\alpha} = C_a l/G \qquad \text{and}$$

$$(6a) \qquad dC_c/d\alpha = - C_a/G$$

There are several ways to handle this result. The most obvious is to follow the method used in Fig.1 to derive Kelvin' Law. That is, find a simple relation between the attenuation, the cable dimensions and the cost. First, let us assume that the cost of the cable is directly proportional to the amount of material in them and that the different sizes are exact scale models of each other. In this case we find

$$(8) \qquad C_c=K_1 r^2 \qquad \alpha=K_2/r$$

since the "skin depth" will not vary appreciably with cable size. This leads to the relations $C_c= K_0/\alpha^2$ $K_0=K_1K_2$ and

(8a) $dC_c/d\alpha = -2K_0/\alpha^3$. Equation (6a) can now be solved for

(9) $\alpha^3=2K_0G/C_a$, leading to:

(10) $nC_a= 2lC_c$ or , the total amplifier cost should be just twice the total cable cost.

It is of course, unlikely that the cable cost will be exactly proportional to costs of the material in the cable. One very likely thing is that there will be some fixed costs involved in the cable. in this case we will have, instead of (8)

(11) $C_c=C_{fc}+C_{vc}$ with C_{vc} as in (8)

Now, instead of (10) we will have

(12) $nC_a= 2l(C_c-C_{fc})$, and the lowest cost for the trunk now requires that the total amplifier cost be lower than twice the cable cost. As a matter of fact it is possible and even likely, that the variable portion of the cable cost will not vary exactly as the square of its diameter but in some manner slightly different due possibly to manufacturing differences.

The preceeding approach is probably more suitable for a cable manufacturer to use in developing a cable most suitable for a market, rather than for a system operator or designer attempting to set up a set of parameters leading to the best system at the lowest cost. However, the above relations do indicate some limits which are useful in approximations.

The cable operator, or designer, is more apt to be presented with the cost of cable in the form of a price list such as:

SIZE	ATTEN db/M	COST $/M
1.000	8.3	479.10
.750	10.5	238.50
.500	15.1	113.30
.412	18.4	78.15

Amplifier costs are available in a similar form, for example:

MODEL	REC. SPACING	COST
PDE	24 db	753.99
VDC	31 db	75.50

Suppose a designer has, for some reason selected the more expensive amplifier. He may still wish to select the cable size which will minimize investment cost. How should he go about it? One way is to design the system for each cable and then select the lowest cost design. Another way is to either analytically or graphically find a continuous expression for the variation of cable cost with attenuation so as to use equation (6a).

Fig. 3 shows a smooth curve joining points plotted from the price list, and Fig. 4 shows the negative of the slope of the curve in Fig. 4. Since the amplifiers cost 753.99/24 = 31.42 dollars per db, the designer will look for a cable for which the differential cost will be just $31.42 per db. He finds from Fig. 4 that this requires a cable with an attenuation of about 13.5 db/M. Since this cable is not for sale (except probably on special order) he still has the problem of selecting between 1/2" and 3/4" cable. He may decide that because 13.5 is nearer to 15.1 than it is to 10.5 and because 1/2" cable costs less per foot, he should select the half inch cable. And he will be wrong! His trunk costs would have been less using the 3/4" cable.

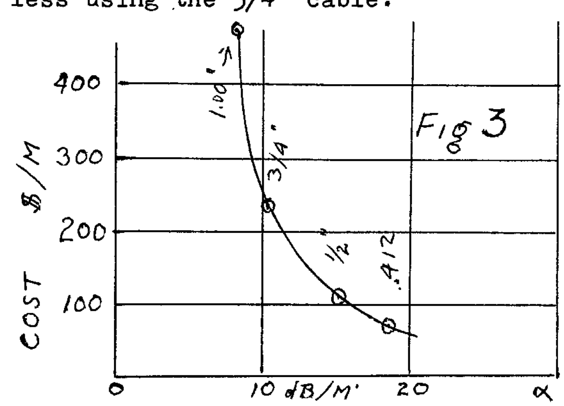


Fig 3

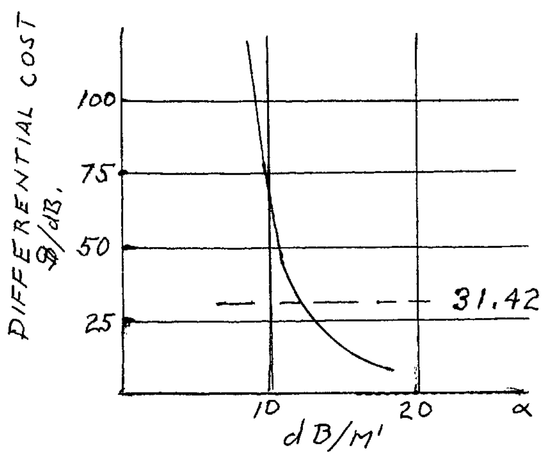


Fig 4

Of course, if cable of the optimum attenuation could have been obtained at the price predicted by the smooth curve, he could have done better than with either 3/4 or 1/2" cable. On the other hand it is important to see how to use the equations in a real world situation. The problem is easily solved if we look at Figs. 5 & 6. In Fig. 5, which is really only Fig.3 re-drawn , we take into account the fact thatthere is no choice of cables between the values in our price list, and that we must go directly from one point to the next. Thus when we plot or differential cost ratios in Fig. 6 we obtain a step function as shown. The amplifier differential cost of $31.42 per db. is now seen to intersect the step function at the value for 3/4" cable.

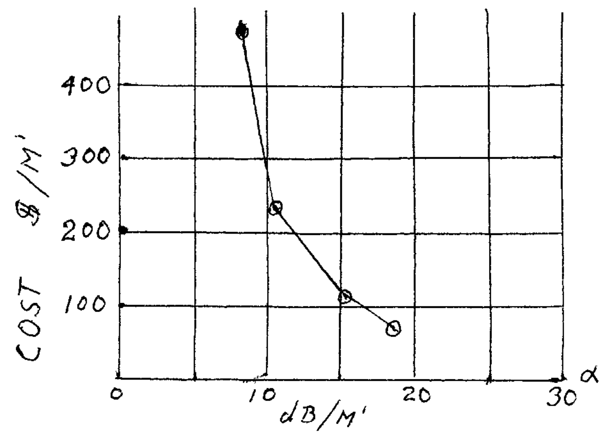


Fig 5

Fig. 6 makes it readily apparent that, given the cable attenuations and cost in our list, the minimum investment in cable and amplifiers will occur under the following conditions:

CABLE SIZE	AMPLIFIER COST $/db.
1.000	over 109.36
.750	27.22 to 109.36
.500	10.65 to 27.22
.412	under 10.65

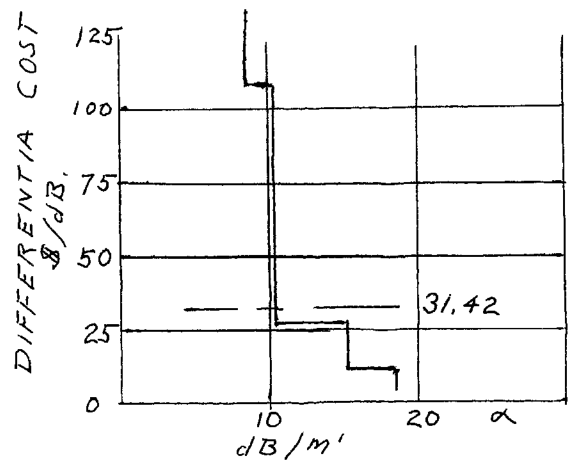


Fig 6

Thus, if one is considering a system small enough to allow the use of the very inexpensive amplifier with 31 db. gain at $75.50 shown in our price list, ($2.44/db) the least investment will occur with 0.412 or perhaps even cheaper cable. On the other hand if performance requirements indicate the probable necessity of the use of 1" cable, it would certainly be desirable to look into the possibility of obtainig amplifiers with high enough quality to justify a price of over $109.36 per db.

More exact results can, of course be obtained if installed and balanced costs are used instead of catalog prices, including any differental costs involved in connectors etc. On the other hand, corrections such as these will not change the results unless the situation is close to a transition value. Under these circumstances, it will however, usually be more productive to consider the effects of the decision on operating costs.

SIGNAL DISTRIBUTION

In the case of the dead run trunk, the problem required only the obvious relation between the number of amplifiers and the cable attenuation per unit length. In the distribution portions of the system there is the problem of cost per subscriber in addition to that of cost per mile of plant. These two cost measures can be related without too much difficulty by taking into account the subscrber density (actual or potential).Since some of the relations are a little intricate, it is probably worth while to examine a few idealized situationsbefore investigating the general problem.

The number of subscribers which could be fed from a single amplifier if we could somehow feed them with 100% efficiency is:

(13) $N=P_o/P_s$ where P_o is the amplifier power output and P_s is the required power input to the set.This can obviously be written inthe form:

(14) $10 \log N = L_o - L_s$

where $L_x = 10 \log P_x$. This relation is shown in Fig. 7. With an amplifier output level of 40 dbmv. and a required set level of 5 dbmv., one amplifier could serve 3,160 subscribers.

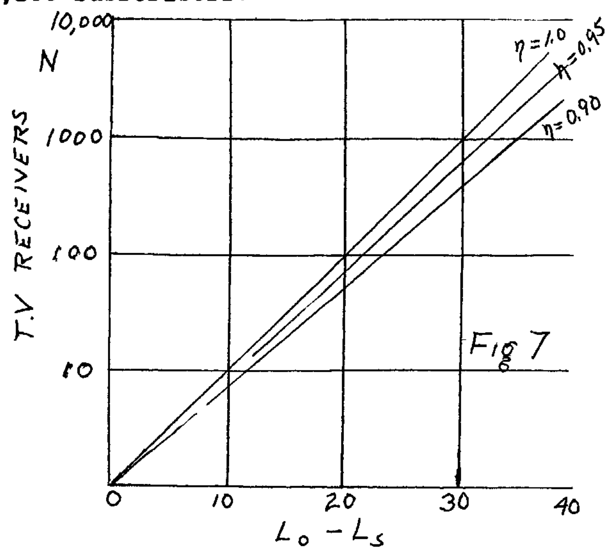


Fig 7

To approximate a real situation, the effect of splitting losses can be included in the equations. This is most readily done by assuming the use use of cascaded two-way splitters, each operating at an efficiency η . The number of sets which can be served is then:

(15) $$N=(P_o/P_s)^{\left(\frac{1}{1-\log_2\eta}\right)}$$

Splitting losses are usually of the order of a few tenths of a db per split, corresponding toan efficiency of between 90 and 95%.The number of sets corresponding to splitting efficiencies of .90 and .95 are also plotted in Fig. 7. It is interesting that efficiencies of even 90% will only drop the number of sets in the previous example from 3160 to 1090. Splitting losses by themselves are obviously not the major limitation on the number of subscribers which can be fed from an individual amplifier.

1000 TV sets could be easily packed into a cube about 25 feet on a side, and the longest run of cable required to feed them from an amplifier in the center of the cube is less than 30 feet. It becomes obvious that the fundamental problems in distribution are not a great deal different from those in trunk. It is still largely a matter of getting the signal from one point to another through cable.

In the distribution portions of the system, however, there is the problem that the losses due to tapping do not follow the same mathematical law as the losses due to cable attenuation.

The attenuation of signal in the cable is exactly analogous to the increase (or decrease) of principal under the conditions of continuously compounded interest. (In the case of the cable there is a negative interest factor - the attenuation.) The tapping of fixed signal levels to the subscribers is likewise the exact analogy of fixed annuity payments at intervals corresponding to the subscriber density. In what follows, the analogy be with an annuity paid out continuously at a fixed rate, rather than in lump sums for simplicity, The extension to the case of discrete real tapping can be easily made if the particular situation should justify it.

First, define:-

$P(x)$= The power being propagated through the cable at point x.

P_t = The tap level required per subscriber

$a = -\frac{dP(x)}{dx} \cdot \frac{1}{P(x)}$ = attenuation per unit length of the cable.

D= The subscriber density in subscribers per unit length.

$A=DP_t$ = Thesignal power tapped off per unit length for subscribers.

The equation representing distribution conditions is:

(16) $dP/dx = - aP - A$ This is readily solved to obtain:

(17) $$P=P_o e^{-ax}\left(1-\frac{A}{P_o a}\left(e^{ax}-1\right)\right)$$ where

P_o is the amplifier output. If A varies along the span, equation (17) must be written:

(17a) $$P=P_o e^{-ax}\left(1-\frac{1}{P_o}\int_0^x A(x)\, e^{ax}dx\right)$$

With subscribers tapped off at fixed locations rather than continuously as is assumed in (17), this equation will still hold if the integral is taken in the

Lebesgue- Stieltjes sense. Note that P_o needs merely to be the signal into the section of cable under consideration, as for example, a section of cable after a split.

Equation (17) can be rewritten as:

$$(18) \qquad \ln \frac{P}{P_o} = -ax + \ln \left(1 - \frac{A}{aP_o}(e^{ax}-1)\right)$$

If we set $P=P_i$, the power level into the next extender (or into the line termination) the left hand side of the equation becomes the amplifier gain, (or actually, the total span loss), and it is possible to solve for the max. spacing.

$$(19) \qquad l_1 = \frac{G}{A}\left(1 + \frac{1}{G}\ln\left(\frac{a+A/P_o}{a+A/P_i}\right)\right).$$

This result could be plugged into equation (5), using the relation $n=l/l_1$ for the number of amlifiers in a given distance l, to obtain the lowest investment cost for cascaded line extender situations. On the other hand, this equation is applicable to a wide range of situations, including feeders which split, etc. It is therefore probably more worthwhile to examine (19) in some detail to see more of the information it contains. A few points are immediately apparent;

1. The expression would be the same as for an untapped line, $l_1=G/a$, except for the expression in parentheses which represents a spacing factor due to subscriber tapping.

2. Since $A=DP_t$, it is obvious that doubling the subscriber density will shorten spans by the same amount as increasing tap levels by 3 db. etc. and vice versa.

3. As subscriber density is reduced, the spacing factor approaches unity, which is the same condition as in a clean trunk.

4. As subscriber density increases, the spacing factor approaches zero and we approach the situation of very dense packing considered in equation (13) where the cable loss becomes less important.

Equation (19) points out that the spacing (or feeder lengths) in distribution areas depends on subscriber density in a very non-linear way. A somewhat clearer understanding of this dependance can be achieved by writing the spacing factor in a slightly different form.

First, it is desirable to introduce a reference density, the saturation density. This is the density at which the loss of signal per unit length in the cable due to tapping is equal to the loss dur to cable attenuation. This density, in the case of 100% efficient tapping is:

$$(20) \qquad D_s = \frac{aP}{P_t}$$

Fig, 8 shows how the saturation density varies with signal level in the cable from a low level equal to the tap level up to a level 35 db higher than tap level, such as might occur right at an amplifier output.

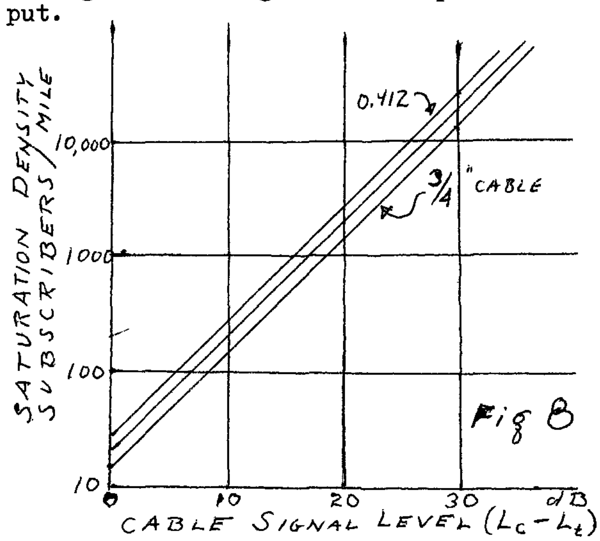


Fig 8

At the highest cable level shown, the saturation density of approximately 50,000 subscribers per mile corresponds to about 1000 in 100 feet, which is very close to the densely packed case. On the other hand, near amplifier input levels, or line terminations, the saturation density can be in the order of tens of subscribers per mile. In a real system, we can expect to encounter actual densities ranging from close to saturation density to as low as one one-thousandth of saturation density.

It is possible to write the portion of equation (19) representing the spacing factor as:

$$(21) \qquad s = \left(1 + \frac{1}{G}\ln\left(\frac{1+D/D_{so}}{1+gD/D_{so}}\right)\right) \quad \text{where}$$

$g = P_o/P_i = e^G$ and D_{so} is the saturation density at the amplifier output. Figs. 9 and 10 show how the spacing facto varies with G and D/D_{so}.

It can be seen that except for very low densities, an increase in gain (spacing in db) begins to decrease the spacing factor noticeably at even moderate values of gain. Design phiosophies which attempt to reduce costs by the use of high gain amplifiers could under the right circumstances easily run into the law of diminishing returns.

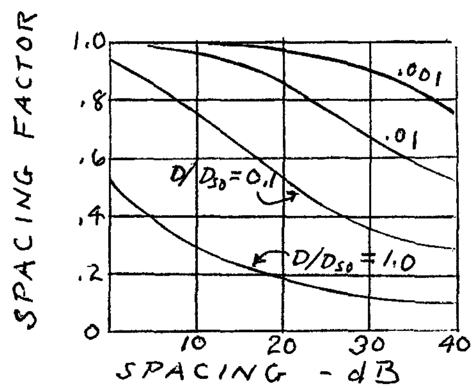


Fig 9

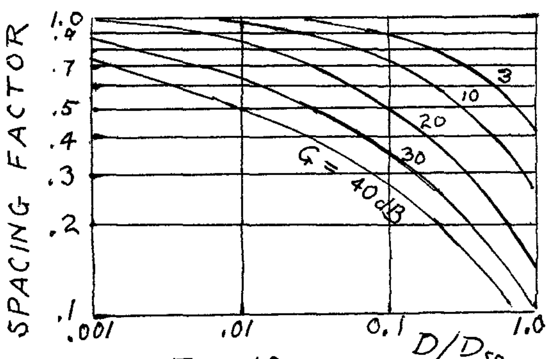


Fig 10.

The fact that taps are not 100% efficient devices, but involve some losses of their own can be included in the calculations in the following manner.

In order to take into account the fact that the taps may handle the through signal with a different efficiency than they handle the tapped off signal, let:-

η_1 = the efficiency with which the through signal is handled.

η_2 = the efficiency with which the tapped signal is handled.

The effect of η_2 requires that an amount of signal equal to DP_t/η_2 be tapped off rather than just DP_t. This is just the same as if their were an effective density of $D_e = D/\eta_2$. With average tap efficincies this would represent an increase in density of approximately 10% and is in many cases less than the effect of unused tap ports, and the effect of steps in tap values available.

The effect of η_1 will be to reduce the cable signal level by an amount $(1-\eta_1)P$ for each tap installed. Since the number of taps per unit length will be equal to (or greater than) D/N_t, where N_t is the number of output ports per tap, the signal will be reduced by an amount equal to $D(1-\eta_1)P/N_t$ per unit length. This is the same as if the cable attenuation were increased by an amount, $D(1-\eta_1)/N_t$. At low densities, this will generally have little effect on costs. However, at higher densities the effect can be noticeable.

ANNUAL COSTS

The same principles can obviously be used in the minimization of annual costs as have been shown to apply for investment.

Fig. 11 shows a first degree approximation of a method by which the selection of cable size might be modified so as to mimize annual costs. The basic relations shown are those of initial cost from Fig. 2, but with the scale of the vertical axis changed in a proportion to reflect total annual cost on the investment. To this another curve is added to reflect the items of annual operating cost affected by the choice of cable.

The first and most obvious of these costs to take into account are those which are directly proportional to the number of amplifiers in the system, amplifier maintainance and energy costs. With this relation added to the chart, it is immediately apparent a higher initial investment in cable can reduce total annual costs.

The next step requires a more thorough investigation of the effects of amplifier gain, operating levels, system size, and general design philosophy on operating costs. The analysis so far indicates that the use of higher gain amplifiers, running at higher levels will frequently allow the the use of lower cost cable in a way which might reduce the investment in both amplifiers and cable. It might be expected that the reduction in number of amplifiers occasioned by this approach would also reduce the maintainance and energy costs, ending up with an extremely low investment and an almost maintainance free system. That there is clearly a limit to this process, can be shown by the calculation of the requirements for a single amplifier to operate a large or even moderately sized system. The energy costs alone become astromical. On the other hand there are limits which begin to show up in the real world.

It has been proven by several methods, that if <u>any</u> limits are set on the allowable degradation of signal quality due to amplifier distortion and/or noise buildup in the system, there will be an optimum amplifier gain which will the construction of either the largest system which can provide the signal quality or a smaller system with the maximum operating safety margin without exceeding the limits. This optimum gain will be between 4.3 and 13.0 db depending on the nature of the limits . Als associated with the gain will be an optimum signal level for operation. Increasing the deviations from these optimal conditions will reduce the operating safety margin first and eventually cause the originally established limits to be exceeded. All present systems are operated at gains and levels higher than the optimal values in order to keep down the first costs.

It is very seldom proposed that a system be designed so as to just meet quality requirements with no operating margin because of the effects of operating safety margin on operating costs. It is somewhat difficult to set up exact mathematical relations in this area. Individual variations in maintainance methods, procedures and efficiency often make exact base data difficult to obtain. However, it is possible to show some of the important general relations by graphical means, and point up possible danger areas.

Limit specifications can be approachin in several ways, thereby reducing operating margins. Amplifier levels can be increased or decreased or gain can be increased, thereby both raising output and lowering input levels; lower cost cable (with higher attenuation, or other reduction in performance) can be used with more amplifiers, or higher gain amplifiers, or any combination of these situations.

Fig. 12 shows two possible limit situations. One way in which the operating margin might be reduced so as to come out exactly at the specification limits is to use a higher loss cable. The point marked A in the figure represents such a possible situation. If cable of any higher attenuation were to be used, it would be impossible under any conditions of maintainance to meet the requirements. Even at the exact limiting value, it would be necessary to maintain all system levels, responses etc. at <u>exactly</u> the design conditions if limits on picture quality are not to be exceeded. In the real world, this is impossible at any realistic cost.

If now, lower loss cable is used, the maintainance costs will come down as as the increased safety margin makes it easier to keep the system within limits. The exact rate at which the costs will decrease will depend on a great many factors but will certainly be quite rapid at first and eventually approach the straight line curve of Fig. 11.

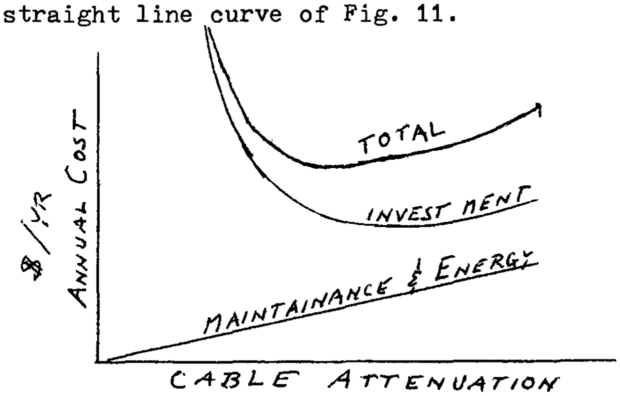


Fig 11.

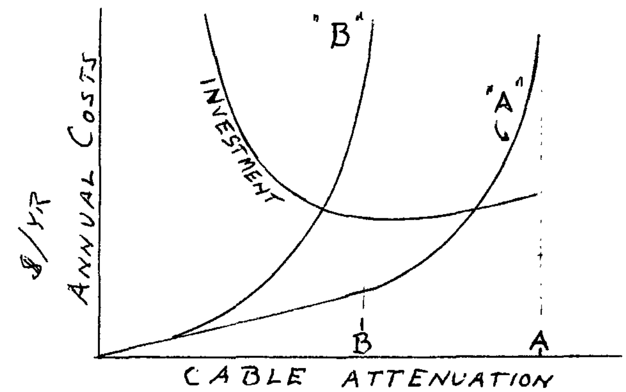


Fig 12

In the case represented by the curve "A" of Fig 12, the operating margin will normally be large, even if the design were based on first cost alone, and for all practical purposes, the situation reduces to the approximation used in Fig. 11. However, if a larger system is under consideration, or if a different design philosphy is adopted, the limit conditions, and therefore the maintainance cost curve can move towards the left of the figure as shown by curve "B". This situation obviously requires either an increase in investment costs or a different design philosophy if total annual costs are to be minimized.

CONCLUSION

The relations developed here are not complete by any means.The intent has been to show how much more remains to be done. However, it has been shown that in a great many areas, exact expressions can be written relating costs and importamt technical parameters.

For reasons of simplicity, most of the relations have been developed as continuous functions. Obviously, much of the hardware represented by the parameters is not available in continuous form.

However, just as was done in the case of cable values, which were available only in steps, it is usually possible to interpret the results in terms of step or impulse functions.

In the area of maintainance costs much more work is obviouly needed. The relations between equipment costs, system costs, and maintainance costs contain many complex factors. In addition, much basic maintainance cost data has not been assembled in as simple and exact a form as is the case with hardware and design costs.

If there is any moral to this story, it would appear to be best expressed as an answer to the frequently made comment that "You can't compare apples and oranges".

The most reasonable answer appears to be "Then we had better not get into any enterprise as highly technical as the retail fruit business."

IMPROVING L.D.S. MICROWAVE RELIABILITY USING REMOTE MONITORING AND AUTOMATIC CONTROL OF REDUNDANT RECEIVERS

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With the increasing use of L.D.S. microwave systems, the use of redundant and automatic control of microwave headends becomes a necessity. As a result of technological advances in L.D.S. microwave systems, CATV companies can reduce long amplifier cascades, increase technical performance, and add CATV coverage to nearby cities. With these uses in mind, the microwave system may potentially serve thousands of cable subscribers, and the reliability of the microwave system is paramount. This article will include design parameters and practical circuits to afford remote monitoring and control of the microwave headends.

INTRODUCTION

Madison, Wisconsin, is a city of 170,000 population. Since the city is located between two large lakes, which cause the city's growth to move out in parameters around these large bodies of water, the total cable system is distributed over a large geographical area. Using standard CATV design parameters, cascades of up to 60 amplifiers would be required to provide cable reception throughout the city. In order to eliminate these large amplifier cascades and improve technical performance and reliability, L.D.S. microwave transmission is utilized.

The city is divided into four headends of roughly equal subscriber penetration. Three of the headend sites are connected to the master headend via Theta Com AML microwave. The remaining headend is connected directly to the master headend. Utilizing this city division, a maximum cascade of 22 amplifiers is realized. The headend division is illustrated in Figure #1.

The traditional reception of broadcast channels over-the-air for headend purposes was deemed less desirable since a more reliable and controlled signal can be received from each local broadcast facility via direct cable interconnection. All local Madison television channels are landline interconnected to the master headend. Using this method, direct video connections were made to each station's master control room or transmitter. As a result of these connections, not only is the signal quality improved, but cable television signals can be received when the station has transmitter difficulties and is off-the-air. This results in a continued service to cable television subscribers even at those times when transmitter failures occur at local broadcast facilities. In addition, picture degradation created when transmitting a television signal, such as ghosting caused by icing, aircraft, or local interference, is entirely eliminated providing the subscriber with the best possible reception.

As a result of the benefits of direct video connection to the local television stations, all television channels are transmitted from the master headend via L.D.S. microwave. Therefore, a high reliability microwave system had to be utilized since a malfunction of one receiver in the microwave system could potentially effect the entire reception of up to 15,000 subscribers. In order to insure minimum interruption of cable service to subscribers, a second redundant microwave receiver is utilized at each headend site. In addition, at times when a L.D.S. microwave transmitter failure might occur, a back-up off-air headend is incorporated at each headend site to allow subscribers continued reception of all local television channels This headend interconnection is diagrammed in Figure #2.

With these three levels of redundant protection available, it became desirable to incorporate an automatic switching and monitoring device to effect a rapid change of deffective equipment in order to provide minimum interruption of service. This paper will illustrate a simple method of automatic protection which has been in use at Complete Channel TV, Inc., for the past year, while allowing the method to be modified for use with other microwave systems.

AUTOMATIC CONTROL OF MICROWAVE HEADENDS

The first step in designing an automatic control system is the determination of parameters to be measured and utilized for control. The following parameters were chosen to verify correct operation of the Theta Com Wideband AML microwave receivers. The design parameters are:

1) All microwave receiver voltages are to be isolated from the control circuit.

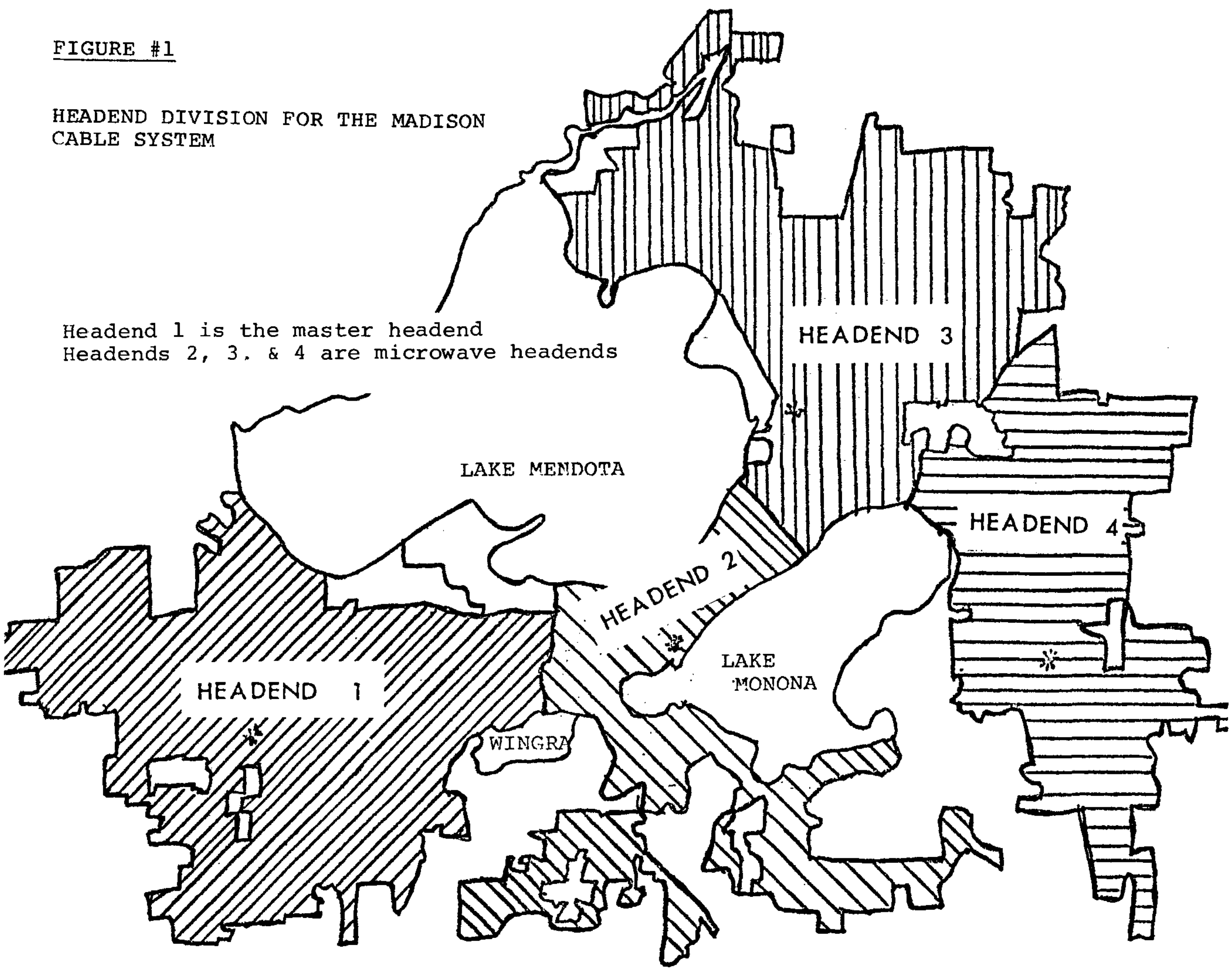
2) Control circuit must monitor:
   a) All power supply voltages.
   b) Solid state source lock.
   c) Phase lock condition.

3) Control unit is to be self-contained.

FIGURE #1

HEADEND DIVISION FOR THE MADISON CABLE SYSTEM

Headend 1 is the master headend
Headends 2, 3, & 4 are microwave headends



4) Control circuit should require little or no modification of microwave receiver circuitry.

5) Control circuit should allow monitoring of all receiver conditions not used for control.

6) Visual indication of microwave malfunction would be desirable.

In order to achieve the desired electrical isolation between the microwave receiver and the control circuit, optical isolators were used as interface units. In addition, the use of the optical couplers, (Motorola MOC 1000) enables different polaraties of control voltages and different control signal levels. As example of this, (See Figure #3), the +24 volt power supply is monitored by IC1, whereas the -20 volt power supply is monitored by IC2. Another feature of the optical couplers allows the device to give either a positive 1 output or zero output for any given input signal. This use is illustrated in the use of IC1 and IC2 as an inverting device in a common emitter configuration, and IC3 and IC4 as a non-inverting device in an emitter follower configuration.

Operation of the circuit is as follows: IC1 monitors the +24 volt supply and delivers an output of zero for normal operation and output of 1 for malfunction. IC2 monitors the -20 volt supply and delivers an output of zero for normal operation and output of 1 for malfunction. IC3 monitors the solid state source voltage. When a voltage is present, the solid state source is malfunctioning. Since this IC is in the emitter follower configuration, the output is not inverted. Therefore, an output of zero indicates normal operation while an output of 1 indicates a malfunction. IC4 operates in the exact same manner as IC3. The input of IC4 is connected directly to both the high and low receiver alarm. Since the phase alarm fluctuates between high and low, an additional capacitor C1 is utilized to provide a delay in device switching.

IC5, a 7402, is a quad two input NOR gate with the following logical Truth Table.

TRUTH TABLES

7402			7403		
INPUT		OUTPUT	INPUT		OUTPUT
A	B	Y	A	B	Y
0	0	1	0	0	1
1	0	0	1	0	1
0	1	0	0	1	1
1	1	0	1	1	0

During normal operation outputs of all optical couplers are zero. Therefore, for normal operation the outputs of IC5 are 1. During a malfunction of any of the four input parameters, the output of IC5 would change to zero. The additional gates in the 7402 are used to light two light emitting diodes when failure occurs One light is associated with phase lock problems, and the second indicates power supply failure. The two outputs of IC5 feed a 7403 quad two input nand gate with open collector output. Again the Truth Table illustrates that under normal operation both inputs are 1. Therefore, the normal output voltage would be a zero, and the relay would be energized. Any malfunction would cause RY1 to open.

The actual RF switching device is left to the discretion of the individual system. At Complete Channel TV, Inc., two identical control circuits were assembled, one monitoring each receiver as illustrated in Figure #4. The actual switching device is a Jerrold Model IFS Switcher. As shown in the diagram, a failure in microwave receiver 1 will automatically transfer microwave receiver 2 on line. If a failure occurs in both receivers or a transmitter failure occurs, then the back-up headend is transfered to the line out.

FIGURE 2.

Redundant headend configuration

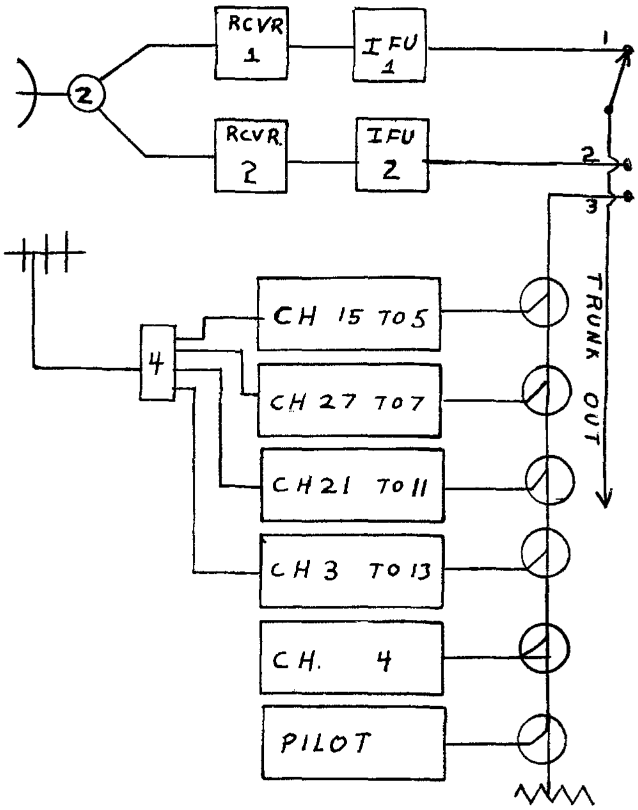
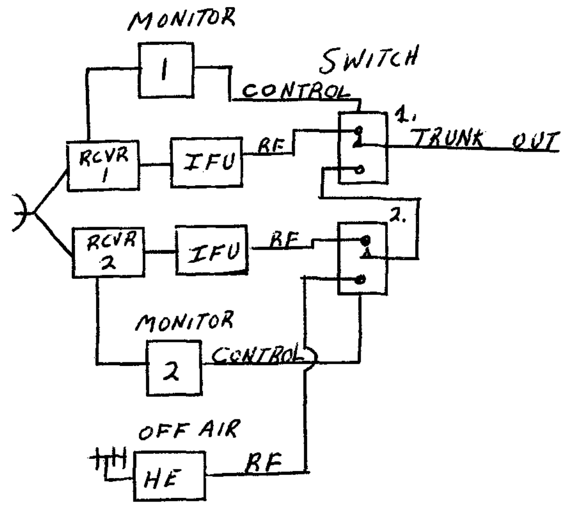


FIGURE 4.

Block diagram of system interconnection



EQUIPMENT UTILIZED

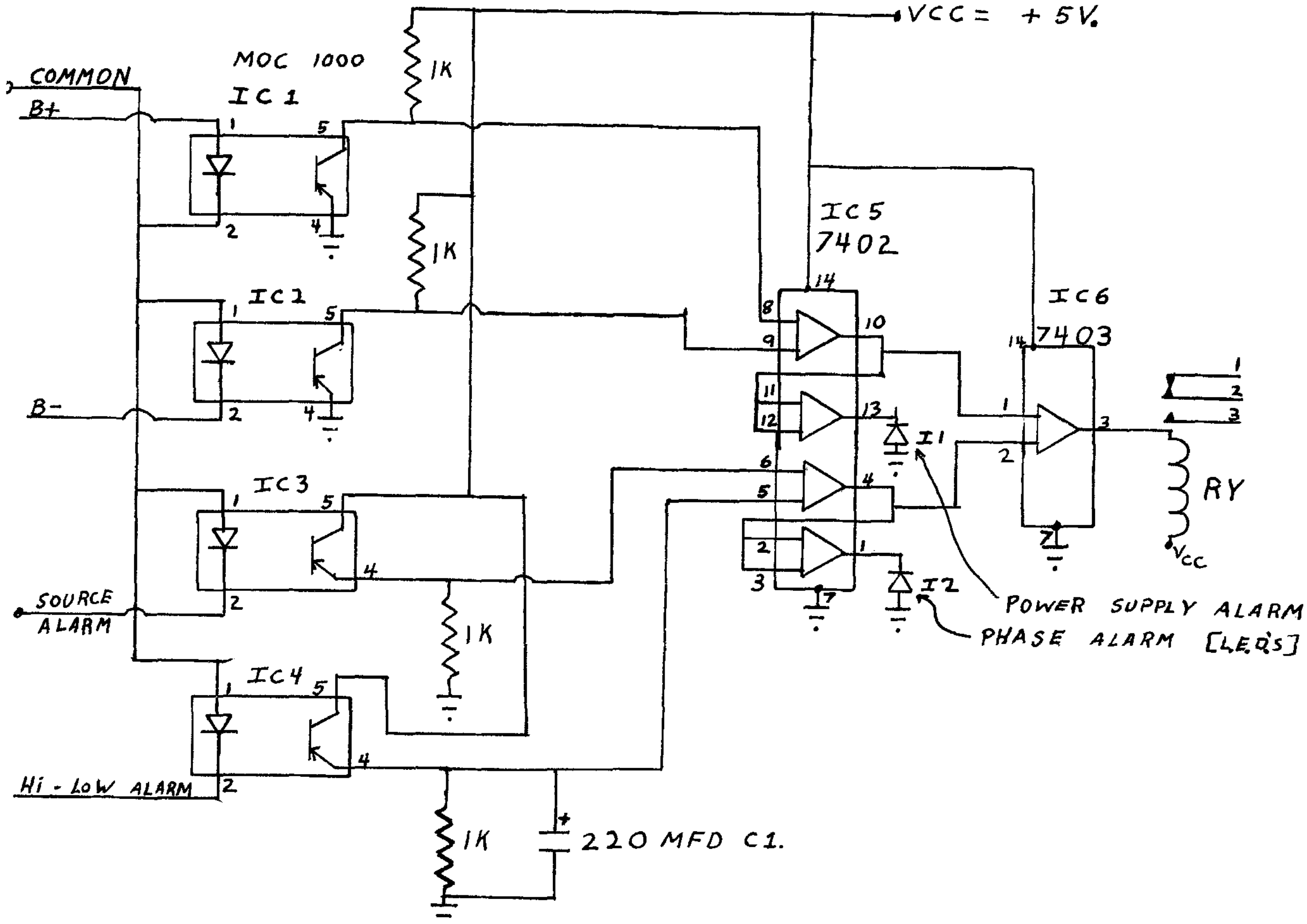
1 Andrew 6' Dish
3 3' Andrew Flex Waveguide
1 Theta Com Magic Tee
2 Theta Com AML Wideband Receivers
2 Theta Com Interface Units with Pilot Carrier
4 Jerrold Channel Commanders
1 Jerrold Modulator Channel 4
1 UHF-VHF Yagi Antenna
1 Jerrold Pilot Carrier Unit
Various Taps and Double Shielded Cable

MONITORING

The microwave receivers in use at Complete Channel TV are equipped with the Theta Com external metering. Therefore, all connections to the receiver are made through the entrance connection for the meter box. The only change in the receiver was the change in power values of the isolating resistors in the receiver. Each resistor in the monitoring circuit was changed to a 1/2 watt carbon resistor. In addition, a duplicate type mode switch was installed with two poles. One pole of the switch was utilized for the first microwave receiver and the second pole is utilized for the second receiver This connection is illustrated in Figure #5 The use of this monitoring arrangement allows direct comparison of each receiver.

FIGURE #3

Schematic Diagram of Control Circuit



PARTS LIST

Part	Qty	Description
R1 Thru R4	4	1 kΩ 1/2 watt carbon resistor
C1	1	220 MFD at 50V
IC1 Thru IC4	4	MOC-1000 IC
IC4	1	7402 IC
IC6	1	7403 IC
I1, I2	2	LED Diodes
RY1	1	Coil (6VDC, 500Ω, 12Ma) SPDT

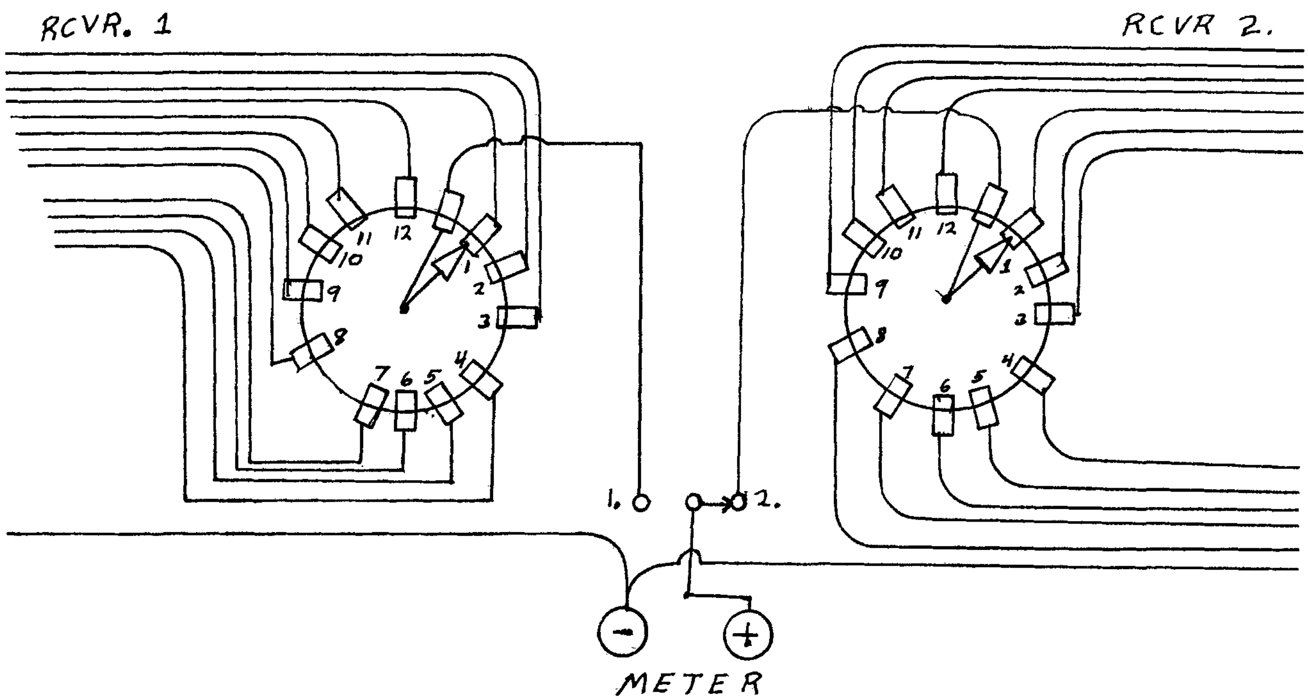
CONCLUSION

The control circuit as described has been in use at Complete Channel TV for the past year It has proven to be a very reliable device as it continues to provide the least interruption of reception to subscribers. The power supply required for the control circuits is best provided by a rechargable battery such as a nickle cadmium battery. The battery should be constantly trickle charged by the standard 110 VAC line.

Future additions to this system are contemplated by using telephone lines to control the microwave receivers. This would allow the change of receivers at any remote point for signal comparisons. Also, using standard voltage variable oscillators, it would be possible to use the standard telephone line to provide actual microwave receiver parameter measurements. Using the basic approach, it is possible to modify the circuit for other microwave systems and different signal parameters.

FIGURE #5

Monitoring of Microwave Receivers Equipped With External Monitoring



METER POSITIONS

1) Temperature calibrate
2) Temperature
3) Solid State Source Lock
4) Solid State Source Alarm
5) Phase Lock Voltage
6) High Alarm
7) Low Alarm
8) A.G.C. Voltage
9) +24 Volt Supply
10) -20 Volt Supply
11) 60 Volt A.C.
12) Meter Short

INCREASING THE CHANNEL CAPACITY OF SINGLE ENDED CATV AMPLIFIERS

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Don Mills, Ontario

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J. Cappon & Associates Limited
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PATENT PENDING

Investigations were conducted on an operating cable television system to explore methods of increasing the channel capacity of broadband single-ended amplifiers.

The resulting data indicated that this could be achieved by judicious selection of the carrier frequencies.

An original method of deriving the desired carrier frequencies is presented to enable channels to be added in the midband spectrum 120-174MHz. The equipment requirements are discussed, and test results obtained under dynamic conditions allows a comparison with standard carrier operation.

Introduction

It is well known that when the standard low and high band television carriers are applied to broad band CATV amplifiers intermodulation products are generated which appear in the mid band, and conversely when the standard mid band carriers are introduced, intermodulation products appear in the low and high bands.

One result of this is that many CATV systems, particularly those which are operating with single ended amplifiers are denied the use of all but a small portion of the mid band spectrum. This paper proposes a method of controlling the restrictive second order intermodulation products which will allow the use of the mid band channels in addition to the low and high band channels.

Discussion

The investigation commenced with a measurement of the spurious frequencies generated by intermodulation through a chain of CATV amplifiers. It was decided to use this emperical approach because the results of previous attempts to correlate between the predicted and measured amounts of intermodulation products has in general been poor.

The location chosen for the measurement was a point on the system preceeded by fifty seven amplifiers, all single-ended and comprising fifty one trunk stations, a bridger, and five line extenders. A full complement of standard low and high band carriers was applied, and the tests conducted using a spectrum analyser whose output was recorded on an x, y plotter.

Fig. 1 x, y Plot of Midband Spectrum

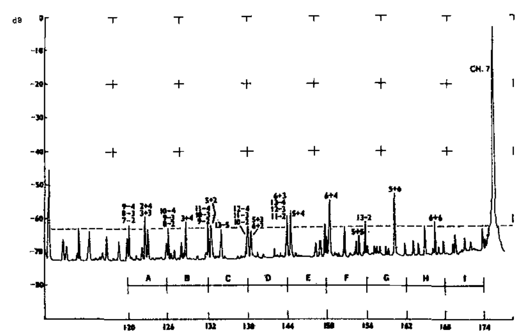


Fig. 1 illustrates how the intermodulation products due to the high and low band channels restricts the mid band use, and it is important to note that the intermodulation products with the highest amplitude and the most critical locations can be identified as the second order sum and difference products.

Fig. 1 suggests that if the positions of the interfering intermodulation products could be relocated such that they would be coincident in frequency with the mid band carriers then perhaps they could be phaselocked and the resulting beats would be eliminated.

To examine this possibility a table of the standard carriers was developed in a form that would permit analysis of the intermodulation products. Introducing the constants x and y and assigning values of 6 and 0.25 to them respectively, the standard carriers can be expressed in analytic form as shown in table 1.

Table 1

Standard TV Carriers

x = 6MHz, y = 0.25MHz

Channel	Frequency (MHz)	Equation
2	55.25	9x + 5y
3	61.25	10x + 5y
4	67.25	11x + 5y
5	77.25	13x - 3y
6	83.25	14x - 3y
A	121.25	20x + 5y
B	127.25	21x + 5y
C	133.25	22x + 5y
D	139.25	23x + 5y
E	145.25	24x + 5y
F	151.25	25x + 5y
G	157.25	26x + 5y
H	163.25	27x + 5y
I	169.25	28x + 5y
7	175.25	29x + 5y
8	181.25	30x + 5y
9	187.25	31x + 5y
10	193.25	32x + 5y
11	199.25	33x + 5y
12	205.25	34x + 5y
13	211.25	35x + 5y

Table 2

Standard and Modified Television Carrier Equations

Channel	Freq MHz	Standard	New Assignment
2	55.25	9x + 5y	9x + 5y
3	61.25	10x + 5y	10x + 5y
4	67.25	11x + 5y	11x + 5y
5	77.25	13x - 3y	13x - 3y
6	83.25	14x - 3y	14x - 3y
A	121.25	20x + 5y	20x + 2y
B	127.25	21x + 5y	21x + 2y
C	133.25	22x + 5y	22x + 2y
D	139.25	23x + 5y	23x + 2y
E	145.25	24x + 5y	24x + 2y
F	151.25	25x + 5y	25x + 2y
G	157.25	26x + 5y	26x + 2y
H	163.25	27x + 5y	27x + 2y
I	169.25	28x + 5y	28x + 2y
7	175.25	29x + 5y	29x + 7y
8	181.25	30x + 5y	30x + 7y
9	187.25	31x + 5y	31x + 7y
10	193.25	32x + 5y	32x + 7y
11	199.25	33x + 5y	33x + 7y
12	205.25	34x + 5y	34x + 7y
13	211.25	35x + 5y	35x + 7y

By examining the values of x and y resulting from the various sum and difference combinations, the positions of the second order products can now be seen at a glance. This can be illustrated with two examples, as follows.

1) Channels 4 + 6 = 25x + 2y

2) Channels 10 - D = 9x

A glance at table 1 shows the sum product of the first example to be troublesome to channel F because its equation is 25x + 5y, hence a 3y or 0.75MHz beat will occur.

The difference product of the second example appears at a distance 5y removed from channel 2 hence a 1.25MHz beat is predictable.

From this it is apparent that the controlling factor in the formulation of beats is the resulting value of the y constant and that by reassigning the values of y, the desired frequency congruence can be accomplished.

Table 2 lists the modified carrier equations, and if the examples are re-examined it is now evident that the sum product of example 1 falls at 25x + 2y and is identical to channel F, and the difference product of example 2 occurs at 9x + 5y which is identical with channel 2.

It follows that if the values of x and y are resolved and used as the base oscillators in an appropriate synthesizer, the desired output frequencies can be realized.

The values of x and y are derived by solving two of the carrier equations simultaneously. This method allows considerable flexibility as the equations can be selected to produce the least amount of shift off the standard carriers, and may be chosen to allow phaselocking to off-air carriers where on-channel operation is necessary.

As an example of the solution of x and y and to illustrate the flexibility afforded by this method, a situation is assumed where it is necessary to phaselock channels 11 and 6, both offset by 10kHz.

From table 1

Channel 11 = 33x + 7y = 199.26MHz
Channel 6 = 14x - 3y = 83.26MHz

By simultaneous solution the values realized for x and y are 5.9929MHz, and 0.2135MHz respectively.

Substituting these values for x and y in the carrier equations results in the reassigned carriers shown in table 3. The amount of shift from standard carriers is included.

Table 3

Comparison of Standard and Reassigned Television Carrier Frequencies With Two Carriers Phaselocked

Channel	Standard Frequency (MHz)	Reassigned Frequency (MHz)	Frequency Shift Off Standard (KHz)
2	55.25	55.0036	246
3	61.25	60.9965	253
4	67.25	66.9893	260
5	77.25	77.2671	17
6	83.26	83.26	zero (locked)
A	121.25	120.2850	965
B	127.25	126.2779	972
C	133.25	132.2708	979
D	139.25	138.2635	986
E	145.25	144.2564	993
F	151.25	150.2495	1000
G	157.25	156.2422	1007
H	163.25	162.2351	1015
I	169.25	168.2280	1021
7	175.25	175.2884	38.5
8	181.25	181.2813	31.3
9	187.25	187.2742	24.2
10	193.25	193.2671	17.1
11	199.26	199.26	zero (locked)
12	205.25	205.2529	2.9
13	211.25	211.2457	4.2

Table 4

Reassigned Television Carrier Frequencies With No Phaselocking Requirements

Channel	Equation	Reassigned Frequency (MHz)	Frequency Deviation (KHz)
2	9x + v	55.125	-125
3	10x + v	16.125	-125
4	11x + v	67.125	-125
5	13x + u - v	77.125	-125
6	14x + u - v	83.125	-125
A	20x + u	120.25	-1000
B	21x + u	126.25	-1000
C	22x + u	132.250	-1000
D	23x + u	138.250	-1000
E	24x + u	144.250	-1000
F	25x + u	150.250	-1000
G	26x + u	156.250	-1000
H	27x + u	162.250	-1000
I	28x + u	168.250	-1000
7	29x + u + v	175.375	+125
8	30x + u + v	181.375	+125
9	31x + u + v	187.375	+125
10	32x + u + v	193.375	+125
11	33x + u + v	199.375	+125
12	34x + u + v	205.375	+125
13	35x + u + v	211.375	+125

Where there are no phaselocking requirements, the amount of shift from the standard carriers can be minimized by expanding the carrier equations. The y components, 5y, -3y, 2y, and 7y are replaced by v, u-v, u, and u + v and by assigning the values of 6MHz to x, 0.25 MHz to u, and 1.125MHz to v, the second order cancellation objective is achieved with minimal carrier shift, as shown in table 4.

The expansion to three variables permits phaselocking to a maximum of three off-air carriers. The amount of frequency shift is determined by the channels to be phaselocked, as shown in table 5.

Table 5

	Phaselock to	Max freq shift in kHz*						
Channel Groups	one or two out of CH 2 - 4	0	0'	0	-167	-250	-167	-125
	one or two out of CH 5 - 6	-250	0	-500	0	0	-167	-125
	one or two out of CH 7 - 13	+250	+500	0	+167	0	0	+125
	none out of CH C - I	-1000	-750	-1250	-917	-1000	-1083	-1000

Use of table 5

a) Decide the channel(s) to be locked to "off-air" signals (max. 3).

b) Determine the channel group(s) to which they belong 2-4, 5-6 and/or 7-13.

c) Select the column(s) which indicate a 0 freq. shift for those channel group(s).

d) The shift in other channel groups is indicated in that same column.

Note: It is not possible to lock three carriers when each one is in a different channel group.

To illustrate the use of table 5.

Assume a lock is required to channels 5, 7 and 9. Channel groups to which they belong are 5-6 and 7-13. The fifth column shows 0 shift for channel group 5-6 and 7-13, it also shows a shift of -250kHz for channel group 2-4 and -1000 kHz shift for channel group C-I.

* Slightly greater values may occur depending on the 10kHz off-sets of the channels to be locked.

Effect of Carrier Reassignment on Second Order Products

Assuming the use of the modified carrier frequencies contained in Table 3, a calculation was made of all second order sum and difference products arising from the inclusion of five lowband, nine mid-band and seven high band channels. The complete results of the channel by channel analysis is appended to this paper, however, it can be summarized as follows.

1. Total possible unwanted products = 108

2. Number locked to wanted carriers = 72

Of the 36 which remain, 18 are located at a position of wanted carrier plus 1.72MHz and 18 are located at wanted carrier plus 4.28MHz.

Comparison of the locations of the un-locked products to the susceptability curve contained in Graph 1 reveals that a product at wanted carrier plus 1.72MHz requires a margin of 46dB. A product located at carrier plus 4.28MHz, or carrier minus 1.72MHz requires a margin of 34dB.

Considering that the product of greatest amplitude was measured at 49dB below nearest carrier as shown in Fig. 1, it can be reasonably expected that no beat interference due to second order inter-modulation will be visible.

Equipment Requirements

To obtain the required modulated RF carriers at the precisely inter related frequencies (based on x, u and v), a master generator was built employing 3 crystal oscillators as shown in Fig. 2.

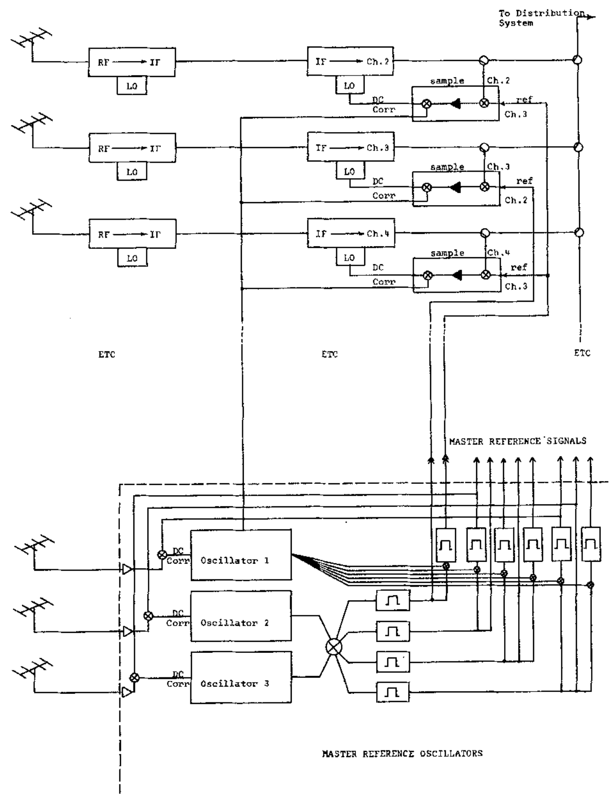
By mixing a sample of the outgoing RF signal of each processor with its adjacent channel signal from the master generator, a "difference frequency" at the approximate value of x is generated. A further comparison between this "difference frequency" and x, produces the DC correction voltage which controls the local oscillator frequency of the processors output converter thereby obtaining a precise lock.

Since either adjacent channel can be used to develop the "difference frequency" only a limited number of reference carriers need to be generated. Fig. 2 illustrates a situation where 15 carriers can be locked to the master oscillator by use of 11 reference signals. Locking to "off-air" signals requires the master generator to be slaved to the "off-air" signals, which is also shown in Fig. 2.

Fig. 2

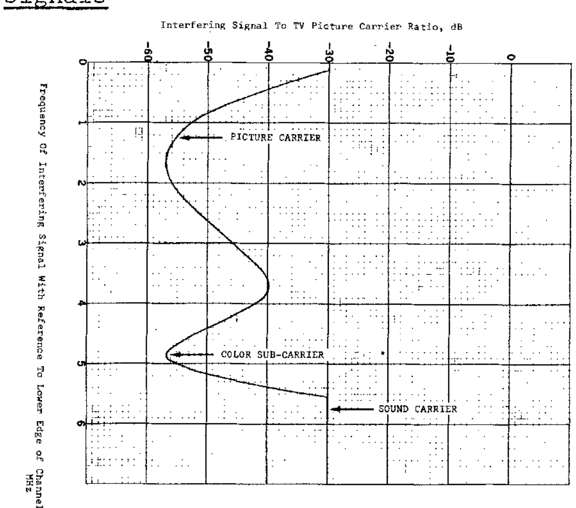
Simplified Block Diagram of Master Carrier Generator

Head-End Processors



Graph 1

Permissible Limits For Intermodulation And Other Undesired Single Frequency Signals



System Tests With The Reassigned Carriers

Measurement of Triple Beat

Recognizing that the coherent aspect of the proposed carrier arrangement would produce the stacking effect associated with third order products, it was decided to measure the amplitude of the triple beat described as $f1 \pm f2 \pm f3$. This could then be directly compared with the non coherent or random carrier use generally encountered in CATV operations.

To conduct this test a carrier generator was built to provide seven carriers tuned to the high band channels (7-13), and spaced at precise 6MHz intervals as shown in Fig. 3. The triple beats appearing in the region of the channel I carrier (168MHz) were recorded using a spectrum analyzer at the same test location described earlier.

The x, y plots given in Figures 4 and 5 indicate that the triple beats resulting from the seven coherent carriers added to produce a single spurious frequency whose magnitude was 10dB greater than the individual triple beat resulting from a random carrier source.

Fig. 3

Coherent Carrier Generator

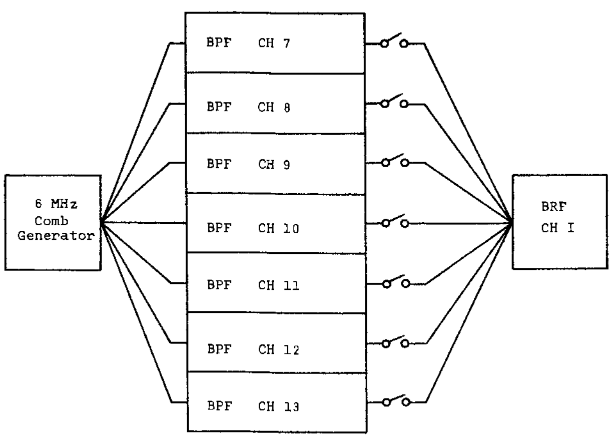


Fig. 4

Triple Beat With Coherent Carriers

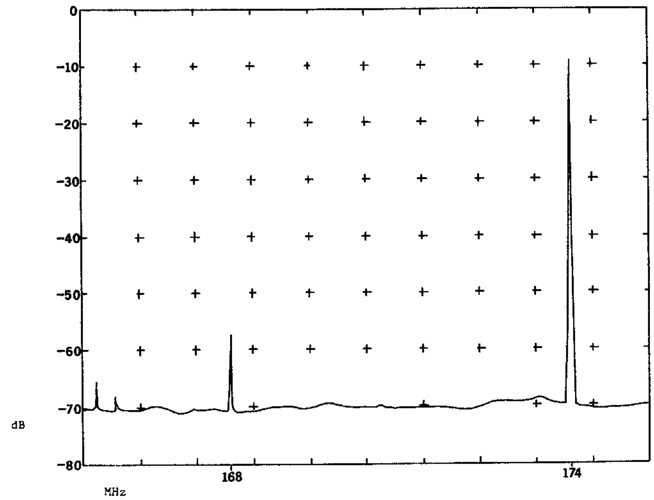
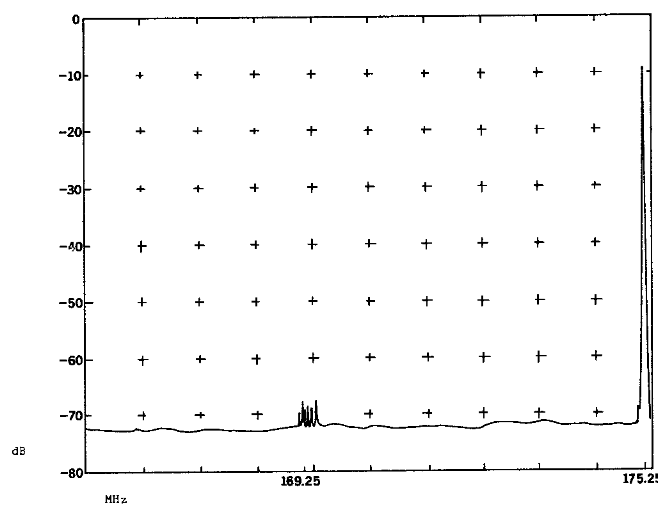


Fig. 5

Triple Beat With Random Carriers



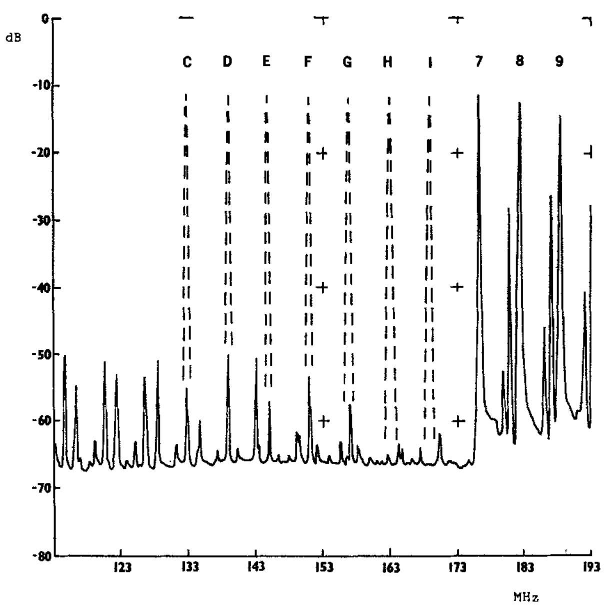
Measurement of Second Order Products

With the output frequencies corresponding to those listed in table 3, a 17 channel head-end was installed and connected to the system. The number of channels used was restricted in deference to the regulation of the Canadian Department of Communications against the use of mid-band channels A and B.

At the same location used to obtain the results shown in Fig. 1, the midband spectrum was plotted and is shown in Fig. 6. This allows direct comparison with the results shown in Fig. 1 and to this comparison, the positions of the reassigned carriers have been superimposed on to Fig. 6. The frequency coincidence of the wanted carriers and unwanted products is self-evident.

Fig. 6

x, y Plot of the Midband Spectrum



The placement of carriers in the midband as an addition to the carriers of the low and high band channels produces second order combinations whose products appear in the low and high band. This aspect was included in the analysis of second order products described earlier in this paper, and to confirm this analysis two of the spurious frequencies which are not congruent with wanted carriers were measured.

Again the same test location was used together with a spectrum analyzer and x, y plotter. The products measured were channel I minus channel 6, which was expected to appear at channel 6 picture plus 1.72MHz, and channel 6 + channel 6 predicted to appear at channel H picture plus 4.28MHz.

Examination of the results which are given in Figures 7 and 8 reveals the channel I - channel 6 beat was not measured and can therefore be considered to be at least 14dB below the permissible level established by Fig. 1. The channel 6 plus channel 6 product was measured at 27dB below the permissible level.

Fig. 7

Spectrum of CH. 6

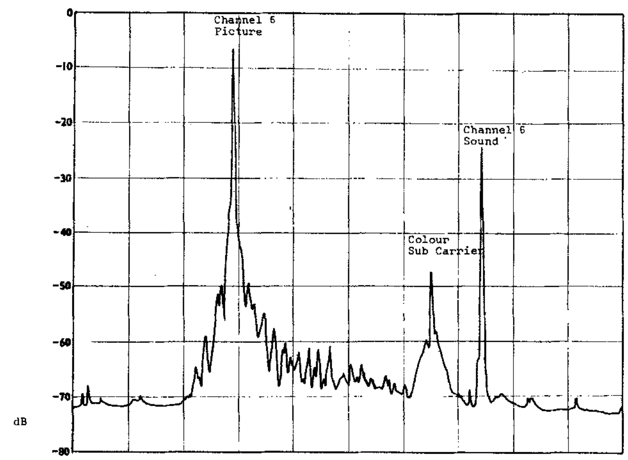
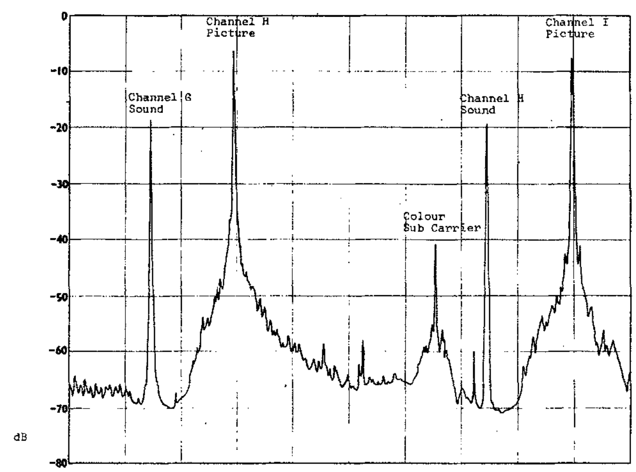


Fig. 8

Spectrum of CH. H



Subjective Tests

The objective tests described previously were supplemented by a critical viewing test of each system channel. The tests were conducted at three system locations, the head-end, a mid point preceeded by twenty two trunk amplifiers plus a bridger amplifier, and finally the deepest point of the system comprising 51 trunks, 1 bridger and 5 line extenders.

Typical broadcast receivers of different manufacture were used to evaluate the picture quality, including two receivers supplied by member representatives of the Electronic Industry Association of Canada. It can be noted that the two receivers referred to are purported to have the tightest A.F.C. ranges of any receivers available to the public.

In relation to the system considerations the tests can be described as follows.

1. When viewed at the systems deepest point, no beat frequency interference was observed.

2. Accompanied by member representatives of the E.I.A.C. tests of the compatibility with receiver fine tuning was conducted by switching back and forth between the standard and reassigned carriers. All receivers required slight adjustment of the fine tuning control. Predictably, the receivers local oscillators could accomodate a 250kHz shift, however, the small amount of adjustment required exceeded expectations, receivers equipped with A.F.C. required no adjustment.

3. No visible evidence of crossmodulation was observed. This was confirmed by conducting a "blank screen" test on the systems community channel, channel 10 by removing the modulation and operating with normal sync and pedastal levels.

Conclusions

The test results indicate that the use of judiciously selected carrier frequencies as a means of circumventing second order intermodulation distortion in order to permit use of the midband is practical.

The amount of carrier shift resulting from the use of this system was demonstrated to be fully compatible with standard television receivers.

The frequency shifts occurring in the midband region, 1000kHz, is not anticipated to be problematic since the number of receivers in use that are equipped with midband tuners is negligible. Hence to accomodate the use of midband channels the standard receivers will be dependent upon an external converter. The tuning range of these converters is more than adequate to meet the prescribed frequency shift.

Because the results were obtained through an operating CATV system with 51 trunk amplifiers, 1 bridger amplifier and five line extender amplifiers in cascade, all single-ended, it can be reasonably assumed that better results will be obtained in systems with a shorter amplifier cascade.

As noted earlier the tests did not include midband channels A and B, however, since these channels are included in the analysis of second order products and in the light of the test results obtained, they can predictably be used.

Circumvention of second order distortion leads logically to a discussion of third order problems. The results of tests described herein suggest that triple beats will not impose a severe constraint on midband use on a typical system. However, as more channels are added the third order distortion products must be considered as the limiting factor to system reach. In particular the effects of coherent carrier operation will require close attention since the amplitude of triple beat was shown to increase dramatically in this mode of operation.

Another third order problem that will be encountered by additional channel operation is crossmodulation. Increasing the number of system carriers will reduce the amount of crossmodulation margin on a CATV system however, this form of distortion is not related to the choice of carrier frequencies.

APPENDIX 1

SECOND ORDER PRODUCTS RESULTING
FROM THE REASSIGNED LOW, MID AND
HIGH BAND TV CARRIERS

LOCATION OF SECOND ORDER PRODUCTS BY CHANNEL

2	3	4	5	6	A	B	C	D	E	F	G	H	7	8	9	10	11	12	13
A-3	A-2																		
B-4	B-3	B-2																	
C-5	C-4	C-3																	
D-6	D-5	D-4	C-2																
7-A	E-6	E-5	D-3	D-2	2+4														
8-B	8-A	F-6	E-4	E-3	3+3	3+4	2+5												
9-C	9-B	9-A	G-5	F-4	7-2	8-2	4+4	2+6	3+6								2+E	2+F	2+G
10-D	10-C	10-B	H-6	H-5	8-3	9-3	9-2	3+5	4+5	4+6						2+D	3+D	3+E	3+F
11-E	11-D	11-C	11-A	I-6	9-4	10-4	10-3	10-2	11-2	5+5					2+C	3+C	4+C	4+D	4+E
12-F	12-E	12-D	12-B	12-A	11-5	12-5	11-4	11-3	12-3	12-2	5+6			2+B	3+B	4+B	5+B	5+C	5+D
13-G	13-F	13-E	13-C	13-B	12-6	13-6	13-5	12-4	13-4	13-3	13-2	6+6	2+A	3+A	4+A	5+A	6+A	6+B	6+C
11	11	10	8	7	7	6	6	5	5	4	2	1	1	2	3	4	5	5	5

TOTALS

(LOCKED PRODUCTS ARE UNDERLINED)

LOCAL DATA TRANSMISSION VIA CABLE: SYSTEM CONSIDERATIONS

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IBM Corporation

INTRODUCTION

Over the past several years, many new uses of CATV have been examined by the industry. These have tended to be oriented to private homes due to the nature of the present services being rendered. We argue here that data transmission services for the business community represent a viable opportunity.

As contrasted with new home services, the data transmission needs of businesses are well established. The uses of data transmission are known, the amount can be measured, and the demand is strong and growing.

Several new data transmission services have been introduced recently and others are on the horizon. We refer to the various special data carriers and the advent and extension of satellites and microwave. All of these are long-distance services, both high-speed and low-speed in nature.

CATV systems have at least three distinct advantages for local data distribution. First, the channels are inherently high speed. They will permit computer systems to develop along lines where communication speed is matched to computing speed, which in turn will make new uses of computers possible.

Second, the relatively fixed connection pattern of boxes in a data system is known, thus permitting the shared use of cables and limiting the need for extensive switching hardware at some central site.

Third, the CATV facilities can be shared for TV programming and data transmission channels. Thus, the incremental cost for data is low. Also, the two way retrofit of the cable plant provides the capability of handling future home services.

In this paper we discuss the technical environment of CATV and data systems, and review the relative merits of design approaches for the necessary facilities.

ENVIRONMENT

Before a data transmission business can be designed and instituted on CATV, an understanding of the technical environment is needed. This environment relates to CATV systems and data processing systems.

For CATV systems, a basic consideration is RAS: reliability, availability, and serviceability.

Reliability refers to the fidelity with which the system performs its function. For data on CATV, it may be measured in bit error rate and signal-to-noise ratio. We have run tests that indicate the bit error rate on CATV is an order of magnitude better than can be expected from other local carriers. Signal-to-noise ratio is another matter. The effect of cascaded amplifiers puts a distance limit on signals before they must be reprocessed. Electromagnetic ingress on two-way systems is a particular problem which can be alleviated by partitioning the network and digital repeating. See the discussion below under Performance Factors.

Availability refers to the proportion of time the system is actually available for use out of the total time scheduled. In a typical tree structure the effect of a failure increases in severity as it approaches the head end. Failure at the head end shuts down the entire system. For an acceptable data transmission business, such a failure needs to be prevented. Approaches to this problem are partitioning of the network (sub-hubs), alternate routing (at least for trunks), and duplexing of critical head end control equipment.

Serviceability refers to the amount of time required to repair a failed unit. Generally, a cable is quickly repaired due to its single conductor nature. For the data business, the cable operator must provide a maintenance force and spare units for customer attachments.

It is the nature of the cable that all signals exist everywhere. Hence, privacy and security are an issue. Data processing systems can provide a high degree of security for themselves with passwords and encryptions. The cable operator could provide a further degree of security by denying users access to the common cable, putting the customer attachment device on the pole and running a single line to deliver only the contracted service to the end user. Also, there is the question of the protection of the CATV network from signals of too high a level and out-of-band signals imposed on the cable by the user. The attachment device must provide safeguards.

Regarding data systems, a number of trends are important. The total number of terminals installed is growing rapidly. The distribution of terminals is somewhat bimodal. There are many single-terminal installations and many installations with a large number of terminals. The result is that most terminals appear in clusters, but the cable operator must be prepared to serve one or many.

There is a tendency to distribute intelligence in data systems. This brings compute power closer to the user and results in higher availability to the user. This trend results in interactive transactions taking place in-plant or over short distances, and batch type transactions over longer distances.

A new trend is toward networking. This means allowing any user at his terminal to have access to any application in any computer in the network within procedural limitations. Therefore, the ability to reconfigure and change the patterns of connectivity will be important.

A characteristic of data systems is their variability. Terminals are attached in stars, loops, and multipoint. Different code structures and transmission protocols are used. Data systems have built-in procedures to handle errors, to recover from failures, to time out devices in checking their operation, and to check message sequences to insure none are lost. It is most important that the CATV system not affect any of these or impose a new burden or protocol of its own.

Lastly, although a CATV system is local in nature, it must be remembered that a data system may not be. Interconnection to other carriers will have to be provided.

IMPLEMENTATION

Any discussion of transmission over a shared facility soon gets to a comparison of Frequency Division Multiplexing (FDM) vs. Time Division Multiplexing (TDM). In FDM a separate channel is given to each user. In TDM a high-speed channel is shared among many users and specific time slots are assigned to individual users. Of course, even with a TDM approach on CATV, the TDM channel is obtained by frequency division of the total cable bandwidth.

Within the categories of FDM and TDM, a further distinction is made: Fixed Assignment (FA), and Dynamic Assignment (DA). In FA a rigid designation of frequency in FDM or time slots in TDM is made to users independent of traffic. In DA a control mechanism is used to determine service needs and assignments are made on a demand basis dependent on traffic.

In the discussions that follow, we contrast FDM FA with TDM DA. These two systems provide for crisp distinction and represent the most probable approaches for implementation. One further word on TDM. Multiplexing can occur on the bit, byte, or message level. Due to considerations of synchronization and delays for turning carriers on and off, we assume TDM will occur at the message level.

Generally, for CATV, we conclude that where there is an abundance of bandwidth relative to demand and where distances are relatively short, FDM FA is better. This implies CATV in cities of relatively small size. The advantage of FDM FA is low initial cost, with cost rising in direct proportion to sales and installation. The disadvantage of FDM FA is poorer utilization of bandwidth due to interchannel guardbands and the dedication of bandwidth independent of traffic.

Conversely, TDM DA is better where bandwidth is scarce such as in large cities. The advantages of TDM DA are high utilization of bandwidth by dynamic assignment in relation to actual instantaneous traffic and the use of digital repeating to extend distance and circumvent noise. The disadvantages are the hardware and software overhead required in control of bandwidth assignment and the need for an initial expenditure for a control system when the first installation is made.

In our example of FDM FA systems, one TV channel is divided into many smaller channels. These channels are assigned to data systems on a permanent basis. Once the assignment is made between 2 (or more) units, information can be passed over the channel without further head-end involvement.

The equipment involved in FDM systems is minimal. At the user attachment point, there is an interface unit which connects through a standard digital interface. The incoming and outgoing data streams are signal converted in the RF spectrum and passed between the cable and the interface unit. The data rate on the channel matches the user device data rate.

In a TDM system, a TV channel is operated with a high data rate and is shared by all users. Time slots are assigned to users in proportion to the data rate required by the using device, and dynamically on the basis of traffic. Certain time slots are system privileged and are used for an order wire function to communicate service needs and to assign time slots. Once the assignment is made between 2 (or more) units, information can be passed without further head-end involvement. Switched line and private line service operate in substantially the same way. A variation of this scheme is to pass data through the head-end in a message store-and-forward operation.

The equipment needed for TDM systems is more involved than for FDM. At the user end signal conversion of digital data into the RF spectrum is needed. Also, digital logic is needed for system control. Since the attachment device operates at the CATV channel speed, which is much higher than the attached device speed, buffering of data is required. Lastly, head-end signal conversion equipment is needed.

The relative merits of FDM FA vs. TDM DA are discussed below grouped under system factors, performance factors, service factors and cost factors.

System Factors

Bandwidth utilization is measured in terms of how much data is being handled by a channel relative to its raw capacity. A number of factors favor TDM DA.

The same modulation techniques can be used in either TDM or FDM. Hence, the same number of bits per Hertz is possible over the bandwidth used. In FDM, however, many more guard bands are necessary between the relatively finely divided frequency slices than for the wider band TDM channels. Balanced against this is the need for system control time slots in TDM. We find for practical situations, TDM offers some advantage over FDM.

In addition, in FDM FA the channels are dedicated regardless of the presence of traffic. Line utilization of data systems is usually low. Therefore, a TDM system which dynamically assigns time slots on the basis of traffic, has an additional significant advantage over FDM FA.

Lastly, TDM lends itself to a wider range of user data rates. Time slots can be assigned in exact proportion to the net rate desired. In FDM, channels of relatively few different bandwidths are practical.

The signals in both TDM and FDM are affected by system noise and degradation through the cable amplifiers. Noise is a particular problem in 2-way CATV systems, since all attachments that enter information signals also introduce noise.

Digital repeating is a means for rejecting in-band noise and reconstituting the digital signal. In TDM systems, digital repeaters are practical, since only one is needed for the entire TDM channel at any system point. In FDM a separate repeater is needed for each FDM channel.

Digital repeaters would be placed at whatever points noise and signal degradation have reached unacceptable levels. Almost certainly a repeater would be used at the head-end. A message store-and-forward TDM system would, by its nature, provide the repeater function at the head-end.

FDM FA systems have the feature of being able to carry both analog and digital signals. This means FDM channels can carry audio and touch tone signals, as well as data. (Video, we believe, will continue to be carried at the major FDM channelizing level.) TDM DA can handle these signals, but only after converting them to digital form.

Performance Factors

Data system performance is measured by 3 major parameters: capacity, response, and throughput. Using message transmission as an example, capacity is the instantaneous data rate. Response is the amount of time from the end of a request for a message until reception begins, and throughput is the total number of messages handled over a given time interval.

Data systems use three general attachment configurations between computer sites and terminal sites to achieve desired performance: star, multipoint, and loop. In a star there is a separate computer connection and communication channel for each terminal. Terminal performance is highest with a star at the expense of multiple connections and channels.

Where lower performance is acceptable, multipoint or loop is used. In both, a single connection at the computer and a single channel exists. In multipoint, individual invitations to send data are transmitted from the computer to specific terminals. Unless a hub-polling scheme is employed, each terminal must respond, if only negatively, to assure the channel is clear for the next invitation. The capacity of individual terminals is not affected by multipoint, but response and throughput may be affected by the activity at other terminals.

In most data systems, most responses from terminals are negative. Therefore, the computer may be called upon to handle a large amount of null data. Loops are used to avoid this. In loops a general invitation to respond, sent from the computer, is examined and passed on sequentially by each terminal in turn. Any terminal with a positive response seizes an available frame. This frame is then denied to all following terminals. In this manner, only positive responses reach the computer. However, should any terminal fail, the loop is broken and all service ends. Therefore, in loops an additional level of control is needed to bridge around failed terminals.

In our TDM example, multiplexing is done at the message level. An entire message is put into the attachment device before being transmitted. This introduces a delay, which affects the response and possibly the throughput performance of the using data systems. This is certainly true for star-connected terminals and for loop-connected terminals. In the latter case the delay is compounded by the need for each terminal to handle every message. For multi-point connections, the response is affected but the throughput at the computer end can be improved over that using present carrier facilities. This is possible by providing a higher data rate service at the computer attachment than the limited rate of the terminals.

In any demand assignment system, some delay exists. Some time is needed for scanning to determine service needs and the assigning of time slots. Proper design of the system can limit the delay to acceptable levels so that user response requirements can be met.

The bit error rate attributable to the CATV medium is comparable for FDM and TDM. However, the apparent error rate as viewed by the using data system can be improved by a TDM DA service. This is possible since messages are buffered by the interface units (due to the difference in data rates between the cable and the data device). Transmission can be checked for errors and retries made by the communication system. The existence of a transmission error, in this case, affects response and throughput momentarily. But the data system is saved from invoking its own error recovery procedure, which would involve a retry plus control program execution time.

A second side of the performance issue involves the network itself. In any shared system such as TDM DA, there is a finite probability that the facilities will not be able to respond to a service demand. Proper system design and loading can keep the occurrence of "system busy" incidents low. System control can be structured to provide levels of service ranging from dedicated to a dial-up equivalent to assure performance at the user level commensurate with need (and cost). A property of a TDM DA system is that its control mechanism is constantly scanning and examining all its system elements. The primary purpose of the scan is to locate those users needing service. Given this property, however, it becomes easy to add new features. The system can locate failing attachment devices. It can identify faulty lines and institute alternate routes. In short, the system can monitor its own performance and take actions necessary to remedy failures.

Service Factors

The communication services available in an FDM FA system are essentially those presently available from existing carriers. Dedicated frequency bands substitute for hard wire channels. Proper selection and use of these new frequency channels will accommodate star, multi-point, and loop terminal operations. Also, the frequency bands can be provided in a variety of bandwidths to match popular data rates.

TDM DA can match these same services. However, new communication services become possible. A private line service with billing based on actual usage can be offered. A wider range of data rates is possible. Various levels of service priority can be offered and charged for accordingly. The TDM DA system can be instructed to alter the using data system connectivity paths so that the using data system can be reconfigured. This alteration can take place on a scheduled or on a demand basis.

Finally, the using data system cost/ performance can be enhanced by the transmission error checking and retry of the TDM DA system, and having a higher data rate service at the computer attachment as described above.

The usefulness of CATV for data transmission would be greatly enhanced through interconnection to other media and carriers. These include telephone companies using switched, private line, T1, and DDS services, satellites, microwave, etc.

Interconnection can be viewed from the standpoint of the user or of the cable operator. The user can achieve his own interconnection by using separate attachment ports on his equipment. Where the cable operator provides interconnection, it is most likely to be on a bulk basis shared over multiple users. With an FDM FA system, some signal processing is probably unavoidable to make the frequency bands contiguous. The problem of S/N degradation limits the amount of interconnection and the distances involved. Digital repeating can be done, but has the problem of multiple and separate channels. It may be possible to treat a group of channels as a single signal and perform an analog-to-digital conversion. These approaches, however, add cost to the interconnection equipment.

Cost Factors

The equipment cost in a CATV data transmission system is divided into three main categories: the attachment device, the communication channel, and system control.

Attachment device cost is directly related to function. TDM DA and FDM FA have similar functions in signal conversion and RF (radio frequency) modulation and demodulation. TDM DA has additional function in buffering and logic for system control.

Channel costs relate to the bandwidth used, equipment added to the cable plant to permit transmission, and in the case of TDM DA, the amount of time the channel is occupied by a user. Since typical data systems have relatively low channel utilization, we find that substantially more users can share a TDM DA channel than can share the same bandwidth in FDM FA and the cost per user is less.

System control cost relates to that part of the system that handles the dynamic assignment of bandwidth. This cost is imposed when the TDM DA system is installed. It can be a major item relative to other equipment cost for the first customer. However, it quickly reduces on a pro-rata basis as customers are added so that it is only a few percent for a fully loaded system.

The attachment device will cost more for TDM DA. Recently there have been a number of developments in digitally controlled frequency synthesizers capable of RF. These devices are attractive for FDM attachments. A single type number box can be used for all frequency assignments. This eases maintenance and system management. Any box can be used at any point and its assigned frequency programmed into it. Frequency assignments can be altered to reoptimize the cable system and permit system testing.

Conclusions

Based on our studies we conclude data transmission can be accomplished on CATV. Further, as pointed out above, CATV has some unique advantages over present facilities.

From an implementation viewpoint, FDM FA seems a low cost way to enter the business and probably satisfies the small city case. TDM DA offers significant system advantages and better satisfies the large city case.

Finally, we note the great diversity in data systems -- codes, line protocols, logical attachment modes, procedures, system programming, and data equipment. Behind these lies a great industry investment. To be successful, cable systems, providing communication links, must not impose unique modifications or requirements.

MANHATTAN'S DATA-BY-CABLE - A BUSINESS REALITY

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ABSTRACT

During the last two years Manhattan Cable TV has taken positive steps to technically develop a data transmission system and to market the service in the New York City business community. The approach has been largely along the lines established at the outset of the project, but there have been several important technical and business departures from original plans. The data interface equipments have been developed and are now in production. New cable system maintenance instruments and procedures have been developed. System tests have shown excellent performance. A number of contracts for service have been negotiated and circuits are now in continuous operation. The outlook for a large user market is good.

Manhattan Cable Television is a wholly owned subsidiary of Time Inc. and operates the cable franchise in the southern half of Manhattan Island. Formerly known as Sterling Manhattan Cable TV, the company has for some time, with the assistance of Time Inc., sought to develop extra revenue producing services on the cable. As a result of various study programs concrete efforts toward development of a commercial data transmission system were instituted early in 1973. Original system concepts were established, breadboard equipment constructed and tested, prototypes developed, and finally production interface equipments procured. Concurrent with the technical development market surveys were carried out and a number of contracts for data services have been written.

A paper outlining the original system concepts was given at the 1973 NCTA meetings at Anaheim and an unpublished paper dealing with a variety of possible applications was distributed at the NCTA Chicago meetings in 1974. The purpose of the current paper is to summarize the progress of the project highlighting various technical and business matters important to the implementation and success of the enterprise.

BASIC ASSUMPTIONS

At the outset of the project certain basic assumptions were made which became the basis for system development. It is well to reflect upon these and to briefly comment upon the current status and validity.

1. Point-to point operation: After much consideration a generally switchable network was rejected in favor of point-to-point organization. This means that circuits would be installed so that point-to-point or poled operation was normal and there would be no ability to switch circuit terminations at will. This conclusion has been tested by many contacts with potential users who have had virtually no requirements for a switched service beyond that which is realized in the poled mode of operation. A poled system is under the control of a central terminal which commands a group of terminals on the same channel causing each terminal to transmit data in a noninterferring sequence. To date there has been no firm requirement for a system with flexible destination switching such as provided by the telephone dial network.

2. Frequency division multiplexing: At the outset there was a great deal of thought given to the method to be used to multiplex the various data signals onto the cable. There were many who recommended time division multiplexing. TDM boasted the advantages of better bandwidth efficiency at peak loading plus a system which could arbitrarily switch circuit destinations. After much deliberation FDM was chosen. The choice centered largely upon the lower initial cost per channel, the simplicity of the equipment and the similarity of FDM equipment (use of separate, preassigned r.f. channels) to cable TV r.f. hardware. The total dependency of the data system upon a foreign machine

like a sophisticated computer sounded like the "hard way" for a cable company to get into the data transmission. What is more it cost too much.

The decision in favor of FDM has been proven correct over the past two years. There have been no requirements for switched service. The up-front costs with the present hardware are quite reasonable. Concern over the efficient use of bandwidth has not hampered the sales effort. The data communications community presently uses leased, point-to-point facilities therefore equivalent service is offered on the FDM system at competitive costs. This is good for the user and profitable for the cable operator.

One side benefit of FDM's lower up-front cost is that a small cable system can afford to install one or two circuits since an expensive computer system is not required.

3. Full duplex capability: To date we have found some users requiring half duplex service (only one direction at any one time) and a few needing only simplex transmission (one direction only). In the case of the half duplex user we are supplying a full duplex channel but in the case of the simplex requirement we may remove parts of the interface hardware to decrease costs and to provide appropriately priced simplex service.

4. Transparent service: The reference to transparent means that the data signal provided at the circuit input will be recovered and presented back to the user at the receiving end without knowledge or manipulation of the customer's data or data format. Simpler equipment is required and the user need not divulge information about his data. This continues to be the preferred mode of operation.

5. Synchronous transmission only: The decision to provide only for synchronous transmissions was based upon the knowledge that most new equipments operate in this mode. (This means that there is a steady, clocked data stream with no start and stop pulses). The current service offering is for 1200 bits per second to 230.4 kilobits per second. Several requirements to handle asynchronous transmissions have been encountered. Because of these requirements a special asynchronous interface is being provided to allow conversion to synchronous at the input and reversion to asynchronous at the output. Although the trend is away from asynchronous transmission, there is a good deal of equipment in the field which still employs it. The accommodation of asynchronous signals is not an expensive modification.

6. Low speed circuits: In establishing a minimum data rate of 1200 bits per second a substantial section of the existing market is eliminated in terms of the various teletype and low speed terminals now in use. It was originally felt that it would be uneconomical to offer transmission of these services. This is still the case at least on a single circuit basis. The one situation where these low speed circuits can be accommodated is where a customer has a great number of parallel low speed lines running between the same two locations. This condition is encountered with the brokerage firms, etc. Here a simple, low cost, single purpose multiplexer is proposed which allows stacking of these low speed circuits in groups of 20 or 40 for transmission over a single higher speed channel. No contracts have been received for this service, hence the multiplexer design has not been carried to completion but is ready to move rapidly when needed.

The above summarizes the major decisions made and the opinion to date is that these early decisions were generally correct. (So far there are no major regrets.) From our experience it appears that the system which has been developed will serve this market well for quite a number of years. As the data business increases and its profile changes, as it is bound to, it is possible that more sophisticated circuits using TDM or TDMA may be required to serve the market. When (and if) these requirements become a reality, the additional business requiring this sophistication will be sufficient to support the required development.

BUSINESS OPPORTUNITIES

Before addressing the technical aspects of the hardware and cable system operation, a look at the MCTV business opportunities is in order. A large amount of effort has been expended in surveying the market and selling the service to potential customers. Mr. Joseph Kelly, who is Director of Cable

Services at MCTV, has spearheaded this effort over the last year. He has been in contact with virtually every major data user and potential user in the franchise area. Many prospective customers have telephone-based systems in operation. Some are interested in replacement or backup. Most are very conservative, wanting "to be shown," while a few have felt that cable represents a technological giant step and are eager to at least experiment or to order first line circuits. Initial experiments and first contracts were with Bankers Trust Company. The test circuits were two 50-kilobit links paralleling Telco wideband facilities from Midtown (58th Street) to the Financial District. These two 50-kilobit circuits were run for thousands of hours in a period of more than one year and one circuit was finally placed in service under contract. Performance on an error basis was excellent and the short downtime experienced in one case of catastrophic failure was very impressive to all concerned. In the Financial District, crosstown links were provided for Bankers Trust at 230.4 kilobits on dedicated cables between two buildings within a few thousand feet. Both circuits have been very successful and have been invaluable for reference purposes.

The major market to date has been with the banks. All of the major banks have been approached and MCTV is providing, or expects to provide services for several of them. One of the interesting new services is transmission of high speed digital facsimile signals utilizing 19.2-kilobit circuits. Another similar application is to transmit the Xerox LDX very high speed fax at 230 kilobits. The LDX signal is not truly synchronous and therefore requires a simple adapter for compatibility.

A number of the banks are involved in credit card verification and point-of-sale terminal activities. To date this market has not developed for MCTV in terms of carrying signals for the individual terminals. This is due to the low speeds used and the inability to provide competitive rates at these speeds. There are, however, a number of applications to provide the lines to interconnect concentrators to the main computer. These lines are generally in the 2400-bit category and seem to be the weakest link in the present telephone network.

An analog service is also offered. This is provided for a voice grade (3 kHz) equivalent or a 15 kHz analog circuit. The major use for this offering to date is for the lower speed facsimile machines which are quite prevalent.

Applications for high speed circuits are slowly coming. We find that there are relatively few 19.2, 50, and 230 kilobit circuits in the area. Communications managers are moving in this direction and are pleased to find that there is another means of transmission available to them. As a matter of fact, the circuit charges for 9600 Bps on the cable are considerably lower than telephone lines with Telco or customer-owned modems and the higher speeds are even more favorable.

The MCTV data service is sold on a "no mileage factor" basis and has no additional charges for multidrops. This is very appealing to the potential customer because these charges often constitute a large part of the bill. In general, the cable rates are more or less comparable at the lowest data rates, i.e., 1200 and 2400 Bps and to come in comfortably below the competition at higher speeds. Savings on distant and multidrop circuits are quite attractive.

The biggest selling problem is the up-front cost of getting out of the street into the building and through the building where no wiring has been done before. It often costs several thousand dollars to get into a building and a substantial amount, depending upon the building size, to wire it. This effect is often cancelled by the fact that once we are in the building we can install an additional new service at a very low installation figure and in a very short time. Where a customer is contemplating a number of circuits the unit installation cost becomes proportionately lower and hence less discouraging.

Various other services somewhat removed from direct data continue to arise. There have recently been a number of requests for video trunking in connection with various television and network distribution applications. The new longhaul common carriers have shown interest in local loop circuits from their headends. There is now talk of higher speed service of 1.544 megabits (T1) and even T2 (600 mBs) service. It is fortunate that MCTV is in a phase of system expansion allowing simple addition of cable and spectrum to satisfy new requirements.

HARDWARE

In the paper of June 1973, there was a detailed description of the data system and the interface equipment. The final development of this equipment was contracted to Intech Laboratories of Ronkonkoma, New York. Development has been completed and production units are being purchased from Intech. The basic system approach outlined in June 1973 has been followed. However, certain significant innovations have been added by Intech and a very imaginative and efficient design has evolved.

The original system used a single r.f. pilot in the data channel for a frequency reference. In considering the possible adjacent channel interference to television signals, it was decided that the pilot or pilots should be located at the standard video and audio carrier frequencies. This was instituted and the decision was made to run both pilots at audio carrier level (-15 dB referenced to normal video carrier level) thereby reducing what would have been the largest signal in the channel and hence the interference potential, system loading and intermodulation products. Instead of phase locking the receiver to a pilot at a high VHF frequency (TV channel "O" at Manhattan Cable) the entire 6 mHz channel is converted to a lower i.f. frequency and detected. The data channel is then extracted based upon the difference frequency between it and the pilot. In order to confine the difference frequencies to a reasonable range, the video pilot is used to recover all channels lying 3.25 mHz to 6 mHz from the lower channel edge while the other pilot is used to recover all frequencies between the lower channel edge and 3.25 mHz. The output of this detector is processed by a fixed tuned receiver capable of being set to any frequency from 2 to 5.75 mHz. The desired data channel is finally selected by phase lock techniques and demodulated.

In order to eliminate the need for a frequency determining crystal for each channel, a synthesizer technique has been employed. The two pilots are inserted at the headend (before translation) and very accurately controlled in frequency. Their difference frequency (4.5 mHz) is counted down to 600 Hz. This 600 Hz is used for a reference to synthesize the transmit frequency. Since all frequencies are now referenced to the same system parameters, if there are small frequency changes everything tracks so that there is no degradation in system performance. These modifications in the system frequency reference concept and receiver design have resulted in a lower cost unit with less critical parameters.

A second major change from the original concept involves the modulation technique. At first a phase-shift keying approach was selected. This was later rejected due to possible phase stability problems involved with low cost hardware and unknowns of cable system operation. The current modulation uses bandwidth compression as originally proposed but substitutes a 4 level AM, double side band, suppressed carrier modulation. Theoretically and practically, 4 level AM is slightly more noise sensitive than 4 level PSK. However, it is much easier to handle from the point of view of phase stability and demodulation techniques.

Intech has developed and applied for a patent on a system of modulation using highly effective coding and a unique filtering technique which have yielded a very powerful, all digital, modulation, filtering and demodulation system. As a result the difference in performance between DSSC and PSK is quite small and with the favorable signal-to-noise ratios present on the cable the error rate is vanishingly small. The initial prototype of the Intech equipment running at 50 kBs over an approximate 8-mile circuit length operated for 28 hours completely without error. In general, our tests have shown average error rates of a few parts and 10^9.

The Intech interface unit is packaged for desk or rack mounting. It has no front panel controls but displays five pilot lights on the front panel. These lamps are "POWER," "PILOT LOCK," "CHANNEL LOCK," "DATA," and "TRANSMITTER." The PILOT LOCK, CHANNEL LOCK and DATA lamps indicate the various receiver functions including acceptable received data patterns and when all are lit, give a nearly infallible indication of proper receiver operation. The TRANSMITTER light indicates correct transmitter operation and power output.

The whole unit is 16-3/8" wide x 14" deep x 5" high and weighs approximately 15 pounds and consumes approximately 100 watts of AC power. The transmitter output is the vicinity of +50 dBmV and the receiver accepts an input equivalent to a TV channel system level of 0 dBmV. This assures that the unit will function on any properly operating customer tap. The Intech digital interface units cost between $1000 and $2000 each, depending upon the data rate and optional features.

An analog interface unit is also available currently in 3 kHz and 15 kHz bandwidths. The cost of this unit is considerably less than $1000. This unit uses single sideband, suppressed carrier transmission.

SYSTEM CONSIDERATIONS

In introducing the data service to the Manhattan system it became obvious that tight system control would be necessary to achieve the reliability required by the sophisticated New York City data market. Many construction and operational techniques and procedures have been tightened up in the company so that better control of the system is possible. With nearly 300 trunk amplifiers, mostly in hard to reach places, special steps must be taken to assure system quality.

The conventional summation sweeping technique was expected to cause data errors as it swept through the data channel. These expectations were borne out. Steps were taken to block the sweeper at the data channel frequencies. However, the ultimate solution has the implementation the Avantek low level sweeper system. This system has been well accepted by our service personnel and can be used in the presence of the data transmissions.

The major method of trunk maintenance has traditionally been constant alignment using sweep techniques. Obviously only so much of this can be done since it takes a great deal of time to get through all the amplifiers in the system. Many amplifiers which are in good alignment still must be accessed and measured consuming much unnecessary time and effort. With this in mind, a system for remote spectrum analysis was conceived and given to Intech to develop and produce. This system employs remote spectrum analyzer units packaged in trunk amplifier housings. These units are located throughout the system at critical points such as ends of trunks, branch points, and the like. They are connected back to the laboratory on dedicated telephone lines (reverse cable carriage could also have been used but it was decided to defer that sophistication for the time being). At the lab there is a central controller which on command, or periodically, interrogates each remote analyzer unit sequentially. Upon interrogation the remote analyzer sweeps the spectrum and feeds this information back down the telephone line as a frequency modulated tone signal. The controller receives the signal, demodulates it, and drives a strip chart recorder which plots a spectrum of the signals received at the remote point.

The resolution of the analyzer is approximately 200 kHz, its dynamic range is 70 dB and slightly over one minute is required to make the printout. The printout can be in the form of a chart about 6 inches long or where more detail is required, the chart speed can be increased and the printout becomes nearly 30 inches long for the 50 to 300 mHz range. (Other analyzer models are used for sweeping other frequency ranges such as 5-120 mHz for upstream trunks.)

There is a status monitor feature in each remote unit and a status monitor readout in the controller. If the composite system level changes by ± 3 dB at any remote analyzer, the controller is immediately alarmed and switched to the alarming location nearest the headend. The spectrum at that location is immediately plotted. In this way real time warning of catastrophic failures is achieved at all analyzer points. By use of the charts, which come at periodic intervals, the maintenance crew can see those sections of the system where performance is degrading and concentrate upon them in their maintenance scheduling.

One final problem which is of obvious concern on any two-way system, is that of locating interfering signals arriving on the upstream trunk and quickly locating them and eliminating their effects upon system performance. The MCTV solution to this problem is a remotely controlled switch which may be installed in the reverse system at the points necessary to isolate individual branches or whole sections. This switch has the unique feature of controllable attenuation. One command will insert approximately 6 dB of loss in the local circuit. The 6 dB change will not affect the operation of the data circuits in that path but when viewing the interference problems on the spectrum analyzer at the headend a level change of 6 dB in the interference signifies that the trouble is coming from that branch. When the individual area is located, a second command will turn that switch completely "off" and remove the interference from the system. Only those circuits in the branch where the interference is introduced will be interrupted. These units are also being supplied by Intech.

As far as basic system problems are concerned, to date few have been encountered. Much of our upstream carriage has been on a dedicated trunk used for origination. This wiring is some of the oldest in the system and not equipped with RFI type connectors. Still there has been a minimum of intrusion. This trunk is in the process of being replaced so it is expected what few problems exist will be further diminished. In other sections of the system, the Anaconda 2200B series trunk amplifier stations are capable of accepting diplexing filters and reverse amplifiers. These are being installed as new data customers are added and new areas activated.

MCTV is in the process of changing its backbone distribution to a supertrunk down Broadway from the headend to the financial district. Concurrently trunk is being extended down 8th Avenue and will act as a backup for the Broadway supertrunk. Automatic trunk switchover equipment will be installed so that loss of signal on the supertrunk will initiate immediate changeover to the backup trunk with only momentary loss of continuity.

In summary, it appears that the development of MCTV's commercial data communications system over the past two years has been well spent. The initial predictions seem to have been relatively accurate and the effort involved in equipment and market development has established a sound base for a profitable business. The ultimate "proof of the pudding" involves securing a sufficient business volume and providing highly reliable and customer satisfying service. The present outlook is optimistic. We trust that we have done our homework carefully and that these questions will be answered affirmatively within the next 12 to 24 months.

MULTIPLEXED AUDIO/DIGITAL SERVICES FOR THE BLIND, DEAF AND DISABLED

Glenn Ralston
Donald Kendrick
Alar Kruus
Thomas Freebairn
David Othmer

In our 600,000 hour lifetime, future adults will have typically spent 50,000 hours watching TV. Some of these 50,000 hours will of course be of considerable quality--most will be "more of the same."

In order to accomplish this feat, we have presently supplied ourselves with 100 million TV sets (and have already junked an equal number). Today, somewhat more than half of these are color; approximately 65% of all US households will have color TV this year (Japan will reach 75%). Thus, the ubiquitous color CRT (cathode ray tube) has become one of America's most common household instruments.

These simple industrial facts may portend an elaborate arrangement of individualized home information services tied into the conventional TV receiver as the home CRT display screen, and presently a number of prototype community information utilities are in various stages of development. Some use regular telephone circuit to dial up a computer sharing resource. Others are shaped similarly around the greater communications capacity of a local CATV system. 13% of US households are now on CATV (with an average penetration of about 54% of homes passed) and by 1984 perhaps as many as 40% of all households will be wired.

Whatever the particular variations in format, it appears that:

--the technology of cable communications is inevitable,

--the impact is already beginning to be apparent,

--we must shape it for humanistic concerns.

The following then is a brief description of the proposed audio multiplexed system which provides 96 access tracks to cultural, educational and general interest information that could be made available to eligible users at their residences or at services centers such as libraries and hospitals over a regular CATV system that accomodates this proposed sort of quasi-institutional use channel. The New York Public Library has assisted in presenting a limited demonstration of these services at their Inwood Branch. They are exploring the feasibility of another temporary installation that would provide a larger area for the ad hoc committee to work with potential users. We anticipate that various organizations will help in assessing the needs of handicapped persons so that the system itself can be responsive and easily manageable by persons with differing disabilities.

The objectives of these proposed demonstrations are presumably to determine whether telecommunications may offer some promise of economically delivering compensatory services to the handicapped, and further, whether telecommunications are an effective means of outreach to the socially isolated.

It may be important to consider whether the proportion of eligible clients that would be served within a particular community is modest or large in relation to the total population (usually somewhat more than 5%). We note for comparison that the utilization of any one of the lesser watched Cable TV channels out of 20 would usually capture an audience ratio of less than 1%, being those people actually watching a typical limited interest program. More importantly, because of its dual qualities of outreach and significant capacity, this communications capability enables compensatory services to be offered to those of us who are unfortunately deprived of access to cultural and community resources by virtue of lacking normal mobility or lacking normal sensory powers. Our Federal and State guidelines have established the principle that parity of access to public resources is a basic right of all.

Descriptively called "AUDIO 96," this broadband communication system has the capability of transmitting and receiving up to 96 tracks of audio and digital information on a single 6 MGHz TV channel, utilizing standard microwave and CATV distribution equipment.

This system offers a cost effective way of delivering full-scale audio information with a high degree of selectivity, from a custom designed audio library. The audio library can be divided into various categories, with selected subcategories, such as the following examples:

I EDUCATIONAL

- A Career Development
- B Special Education
- C Academics
- D Foreign Language

II CONTEMPORARY WORLD

- A World Affairs
- B Perspective on America
- C Changing Culture
- D International Shortwave
- E Consumer Information

III SPECIAL INTEREST AREAS

- A Novelty
- B Sports
- C Cinema & Theatre
- D The Arts

IV MUSIC

By reformatting the audio tapes to master reels, the system all but eliminates the need for the individual user--who desires special interest programs--to have on hand countless and expensive audio cassettes or reel tapes, which are inevitably lost or erased mistakenly. There is also the elimination of tape playback units which are costly.

Selective access is provided by special "channel time-frame techniques" (time division multiplex). Since the system has a channel selector to handle programming for the 96 tracks, it can actually eliminate the need for tape players. The channel selector offers the flexibility of 96 programs within one time-frame, making it possible for any eligible person to choose his desired material in his home or residential facility.

This system is made up of four basic units: 1) an audio player, 2) a transmitter, 3) a broadband distribution net, 4) a track selector and receiver unit.

1) PLAYBACK UNIT: Because of the multiple input requirements, a special audio input will be used which has a unique format. The usual method of providing the audio source would be to input a standard multi-track audio taped output into the transmitting unit; these tapes would provide the audio signal as an analog source; the standard reel-to-reel format would have been used. In place of this standard analog input, this system will provide the audio to the transmitter in a digital format. The information will be placed on a standard one-inch video cassette tape, to be played back using the AUDIO 96 Playback Unit. This format provides all 96 tracks of audio data as one tape source, thus elminating the number of playback units required for source information. Locally selected programming, scheduling and sequencing will be easily provided by the selection of audio source tapes that can have different programming sequences provided.

2) TRANSMITTER: The AUDIO 96 Transmitter will be installed at the Cable TV studio or distribution studio from which the audio materials will originate. It is designed to handle from 6 to 96 tracks of programmed materials for transmission. The transmission will utilize one video bandwidth channel on the microwave link or cable.

3) NETWORK: A conventional CATV system, omnidirectional or point-to-point microwave serves as the distribution network.

4) RECEIVER & CHANNEL SELECTOR: In the AUDIO 96 Receiver, the transmitted signal is detected, demultiplexed and made available through the individual track selectors. The individual user equipment consists of a small box with a selector switch, volume control, headphone jack, audio output or speaker. The track selector is integral with the receiver and operates independently of any of the other user selector units.

In consultation with potential users, the terminal equipment would be designed to achieve the greatest ease of use for those with different disabilities.

Thus far the development of program requirements included the participation of the following organizations: Eduplex, Inc. (Technical Design); New York Public Library and the Deafness Research Center (Software Programming); and The Mayor's Office of the Handicapped (User Orientation).

DIGITAL COMMUNICATIONS FOR THE DEAF AND FOR THE BLIND:

It is expected that several of the audio tracks could instead be utilized for digital character generation for subtitling the regular television programming to be read by the deaf. A standard video field grabber would intercept and momentarily hold the character display. Additional tracks could also be utilized for programmed remedial literacy courses for the deaf in response to a characteristic need of this disability.

As you may know, the Deafness Research and Training Center in New York has been exploring the ability of television to more effectively meet the needs of the hearing impaired population. Some 15 or 20 major urban areas do originate programs which have some signing for the deaf, including 8 or 9 that routinely sign the news. Another 30 or so areas carry signed programming when made available to them. Signing is easier, cheaper, and quicker than captioning, but a relatively minor proportion of the hearing impaired community are able to understand the sign language. Of the 13.4 (6%) million hearing impaired, only 1.8 (.9%) million are totally deaf, and signing is used by about 95% of the smaller number. Captioning then reaches everyone, including those with normal hearing. But captioning that is received by everyone can be irritating to some.

"Closed" captioning is being developed in cooperation with PBS and can be broadcast under temporary and experimental FCC authorization and only received by the user's decoder ($100). A similar effect can be achieved over CATV. In a limited survey of deaf people (who were TTY users) in the New York metropolitan area, 75% of the respondents "enjoyed" a partially captioned WNET Christmas program. Of these, 53% preferred both captioned and signed, 44% preferred captioned only, and 3% preferred signed only (Freebairn, 1974). Captioning as we noted, is much more time-consuming and therefore more costly.

As we understand it then, captioning does have widespread utility in the mass communications mode of broadcast TV. But captioning is also the graphic mode used by the TV Phone for individualized and point-to-point interactive conversation by the deaf. The TV Phone has a keyboard for output and provides a modem interface to adapt the home TV receiver into a CRT character display. Connections with other users are made over conventional telephone dial-up. The TV Phone is compatible with the teletypewriter (TTY) and is also compatible with the conventional 8 baud computer access terminal. It is not unlike the conventional office keyboard CRT teleprocessing display terminal, but differs in that it adapts the home TV receiver instead of providing its own CRT. For these reasons, there are understandable tradeoffs between cost and reliability.

It would appear that the only relatively large demonstration of the TV Phone was administered by the University of Massachusetts with 40 sets in the New York area and 30 sets in the Boston area. This demonstration has recently ended. The results seem to have been mixed, and most observers felt that the six month duration was a severe time constraint and that the number of users did not establish a sufficiently large "environmedia" for significant extrapolation of user experience. A number of additional observations, characterized by respondents as intuition, were offered: The use of TV Phones does awkwardly tie up a home TV receiver during phone calls. If the set is not a large model solid-state device, clarity of image suffers, and the warm-up time on older sets is inconvenient for incoming calls. The unexpected expense of telephone bills had a discouraging effect on some deaf users. The level of quality control on these 100 prototype units forced some deaf users to be displeased with their experience of interrupted service. Some of the apparent advantages of the TV Phone over the TTY were its faster operation (more useful for computer access), quiet operation (doesn't bother one's family), and is relatively moveable.

It was also reported that some deaf users expressed that the lack of a written record offered them less assurance that they had understood the communication. Perhaps this reluctance is not unlike the early resistance and critical observations on the invention of the telephone, which was initially considered a useless novelty for businesses because it too didn't provide a written record. There is perhaps considerable unanimity by users on two overall constraints: the devices are still somewhat costly, and their friends and business contacts don't have one with which they can converse (ie, lack of ubiquity).

Of the estimated 6.4 million persons (3%) in this country with visual impairments, 400,000 (0.2%) have no useful vision (Goldfish & Marx, 1973). Only 43 US cities offer comprehensive low vision care even though there are over 800 service organizations for the blind (Scott, 1966).

Rather quick processing of printed resources into either audio or braille format is obviously of great utility for those of the blind who are students or who have professional responsibilities. One propietary device, the ARTS system, uses dial-up telephone connections to a computer program that takes the output from a standard keyboard typewriter and quickly translates this output into embossed grade II braille. Alternatively, in the voice mode the same system can produce computer generated human speech. Thus, the typist is able to hear what he is typing and mitigate errors. Any "written" material can be composed and edited in privacy with full confidentiality and without sighted assistance. In the same manner, a sighted person without knowledge of braille is able to produce a braille record for his communication. Again alternatively, devices are independently under development that optically scan (OCR) and convert conventional printed material (as well as computer printouts) via photo cells into a computer-generated audio format of "spoken English" (Stereotoner).

EFFECTIVE INTEGRATION:

If one were to then schematically overlay these several different teleprocessing systems that are amenable to use by either the blind or by the deaf, the resulting pattern would show a converging at several complementary intersections, even while respecting the important and considerable differences between individualized and mass modes.

It seems that both the vision impaired and the hearing impaired can benefit from the utility of existing telesensory devices, teleprocessing programs, and telecommunications linkages if there is sufficient ubiquity of these instruments to provide a suitable "environmedia."

LIBRARY OF CONGRESS REGULATIONS: Eligibility of Blind and Other Physically Handicapped Persons for Loan of Library Materials.

A) "Legally Blind"--those whose visual acuity is 20/200 or less in the better eye with correcting glasses, or whose widest diameter of visual field subtends an angular distance no greater than 20 degrees. The degree of such blindness shall be certified by a duly licensed physician, ophthalmologist, or optometrist.

B) "Visually Handicapped"--those whose visual disability, with correction and regardless of optical measure with respect to "legal blindness," are certified as unable to read normal printed material.

C) "Physically Handicapped"--those who are certified by competent authority as unable to read or use ordinary printed materials as a result of physical limitations.

D) "Competent Authority" is defined as including doctors of medicine, ophthalmologists, optometrists, registered nurses, therapists, professional staff of hospitals, institutions, and public or welfare agencies (e.g., social workers, case workers, counselors, home teachers, and superintendents). Certification of physical disability sufficiently severe to prevent reading or using conventional printed materials may be made by professional librarians or by any person whose competence under specific circumstances is acceptable to the Librarian of Congress.

The reading (software) materials for the blind and physically handicapped, including sound reproducers, may be loaned not only to individuals who qualify but also to hospitals, institutions, and schools and centers for the use of such readers (users).

PROPIETARY CLEARANCES:

Many of the 50-60,000 titles of software presently available in audio format are produced with propietary restrictions by about 7-9 national sources. It is contemplated that most, if not all, of these software resources can be cleared of propietary restrictions if used in full accord of LOC eligibility requirements.

The user terminal can be so designed that only its particular features provide access to these proposed services. The New York Public Library for the Blind and Handicapped would authorize or loan the terminals only to eligible users or certified institutions.

NEW YORK PUBLIC LIBRARY FOR THE BLIND AND PHYSICALLY HANDICAPPED:

This facility serves as a Regional Library for special services of the Library of Congress. Adults and children residing anywhere in New York City or Long Island, who are unable to use regular print materials, may apply for talking book service at home and at school. Additionally, institutions having eligible residents, students, patients or clients may also be served.

The library also provides four additional services:

a) Information and Referral: General information on, and referral to other agencies serving the blind and physically handicapped.

b) Telephone Reference Service: Simple reference information is given over the phone.

c) Consultation: Advice on making maximum use of Library services and materials is available by appointment to teachers, agency directors and librarians.

d) Promotion: Demonstrations of equipment, information brochures, and applications for service are offered to agencies serving eligible clients.

THE PRINCIPLE OF COMPENSATORY SERVICES:

It is important to consider whether the proportion of eligible clients that would be served is modest in relation to the total population (5%). We note for comparison that the utilization of one Cable TV channel out of 27 (about 4%) would probably capture an audience ratio of less than 1%, being those people actually watching a typical public service program. More importantly, because of its dual qualities of outreach and significant capacity, this communications capability enables compensatory services to be offered to those of us who are unfortunately deprived of access to cultural resources by virtue of lacking normal mobility. Our Federal, State and City guidelines have established the principle that parity of access to public resources is a basic right of all.

CATV'S FRACTIONAL AUDIENCES

If we performed a hypothetical abstraction based upon CATV's economy of abundant channels, rather than scarcity, an array of captured audience percentages might look something like this:

audience percentage	stations	# channels (totals 20)	audience aggregate percentage	cumulative audiences
22%	network			
20	"			
18	"	----- 3	60%	
10	strongest independents			
8	"			
6	"	----- 3	24%	
5	educational station			
4	marginal independents			
2	"	----- 3	11%	
		(9)		(95%)
plus 11 channels, each more or less than 0.5%--		11	5%	
		20	Totals	100%

It appears to some observers--admittedly on the basis of unsubstantiated abstractions--that these latter fractional audiences (11 channels attracting less than 1% each) could not support standard programming production costs. Nor are all of these fractional audiences likely to be attracted by standard production values--the distancing effect of overproduced programs, particularly if re-run interminably.

On the other hand, since video is likely to be an involving experience in these fractional situations--where viewers or users are probably highly motivated in their selected interests--let's retire the shibboleth that all television experience must be costly to be effective.

Have I done the world good or have I added a menace?

Guglielmo Marconi

For all who in a world of untold beauties are consigned to unremitting darkness,
Here is light.

Guild for the Blind

OPERATIONAL EXPERIENCE OF FEED-FORWARD HIGH LEVEL AMPLIFIERS

James B. Grabenstein

POTOMAC VALLEY TELEVISION CO., INC.

The use of Feedforward amplifiers in bringing existing systems into compliance with F.C.C. Standards. The conversion of a low band system to a high band system by changing amplifiers only with feedforward amplifiers. Our experience with feedforward amplifiers has led us to the conclusion that this amplifier has some promising advantages in the CATV industry.

I would like to start this paper by going back a few years and reviewing some of the operational problems that lead to our use of feed-forward amplifiers.

All of our systems have either been rebuilt or built since 1966. Potomac Valley Television Co., Inc., operates four systems in the Maryland and West Virginia area. The largest of the systems is Cumberland, Maryland, with 21,000 subscribers; and the smallest is Paw Paw, West Virginia with 235. The other two systems are Romney, West Virginia, with 1,000 subscribers; and Moorefield, West Virginia with 800.

A few years ago when the F.C.C. 1977 standards came into being, we started to take a hard look at these systems. The Cumberland system was started in 1951 and now serves a number of smaller communities in the area. When it was rebuilt, it was changed into a 12 channel hub system with 8 major legs with an average of 40 amplifiers each. The longest leg is 50 amplifiers long.

When we rebuilt the system, it was designed with SKL Amplifiers spaced at 22dB. We used high level distribution amplifiers in some areas rather than bridgers. The distribution lines were designed for a signal at the back of the sets of 10dBMV.

We found the distribution amplifiers, when 12 channels were applied to them, did not perform well. In fact, we had our first introduction to 2nd and 3rd order products. Although the distribution amplifiers met the cross mode standards set up by the N.C.T.A.

Like everyone else in the industry, we had our doubts about the new F.C.C. standards, so we embarked on an indepth testing program as did most everyone in the industry. Some of our findings were very disheartening and some results were better than we expected. So, where ever we could, we tried to increase our standards as compared to the F.C.C. minimums.

	FCC MINIMUM	DESIRED ENGINEERING STANDARDS OF PVTV
System flatness per channel	±2dB	(-7.5MHZ + 3.6 MHZ from visual carrier) ±1dB for head end ±1dB for system
amplitude response for entire system	--	±3dB
Hum or low frequency variations	5% peak to peak	3% peak to peak
Visual carrier to noise radio(4MHZBW)	36dB	46dB
Min. visual sync-tip level	0dB	+3dBMV
Max. visual sync-tip level	--	+10dBMV

The decision was made to either make the systems conform to our standards within the next three years, or start plans for another complete rebuild. One of the first steps was to obtain some meaningful testing equipment.

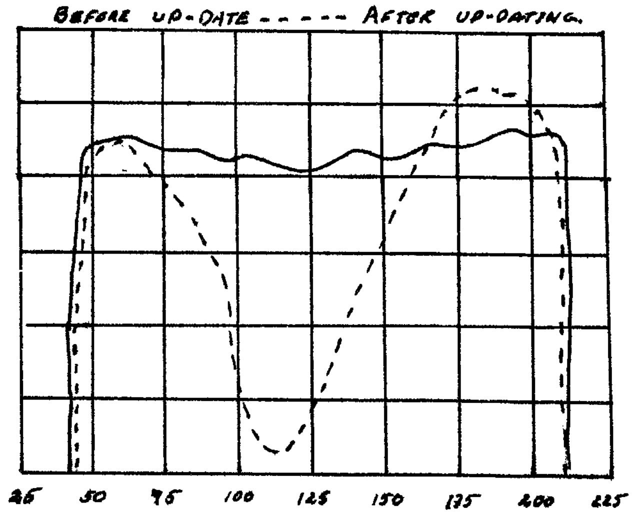
We purchased what we felt was a good choice of test equipment at that time. A Tektronix T.D.R. and a 7L12 spectrum analyzer with a 7K11 preamp. At the same time, we changed our sweep system to an Avontek CR1000. In addition, we installed the sweep receiver in a new Telsta step-van. By changing the amplifier maintainence crew from a two man to a one man operation, it helped to defray some of the cost of the new test equipment.

An internal trouble reporting system was started in addition to the normal customer trouble calls. If any condition was found that did not meet our standards, a report to the engineering office is filled out by our personnel. These reports are followed through until that problem is resolved. The following is a summary of the results of these reports:

In checking out the response and noise of the head ends and the microwave systems, we found them to be in reasonably good condition. Although the response was very difficult to maintain to within +-2dB over a single channel. The trunk line amplifiers had some problems. The response at the ends of the system had as much as 16dB peak to valley in the mid band through 40 amplifiers. Our reports showed the total system needed routine maintainence. We started a program of returning each line amplifier to the shop for repair and updating. The photo mod A.G.C control units were removed and replaced with PIN diodes. The transistors were replaced with Amperex A230 devices.

None of our systems are in the top one hundred markets, but we felt that every effort should be made to well surpass the F.C.C. standards. Our early testing proved to us that our trunk line amps were capable of operating with midband channels, if we could control the response. The bridgers were marginal, so every effort was needed to maintain signals to a minimum of level change. This was accomplished by very close alignment and by increasing the number of duel pilot slope control amplifiers. The over all signature of the system was controlled by mop-up equalizers. These units were placed at every 20th location, or ahead of major branching points. The results of this work can be seen in the graph.

AMP 46-5 RESPONCE AFTER 40 AMPS.



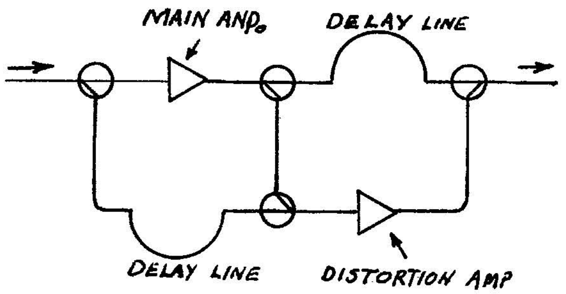
When we were in the midst of this up-dating, Bill O'Neil, of Amplifier Design and Service, Waltham, Massachusetts, asked if we could do some field testing of an amplifier that he was in the process of designing.

We agreed, and Bill brought his black box amplifier to Cumberland and it was tested at our hub head-end in Cumberland. The amplifier had a gain of over 50dB and a noise figure of less than 10dB. When we checked it's out-put ability, we found it to be capable of over 60dBMV with 12 channels flat. With all distortions cross mod, 2nd and 3rd order well below 57dB. The amplifier was installed in the head end and drove the feeder lines in the down town area. It also was monitored on the 12 monitors in the head-end daily. The amplifier was returned to Boston for further testing. At the time, patent clearances were being processed so the details of the unit were not revealed to us.

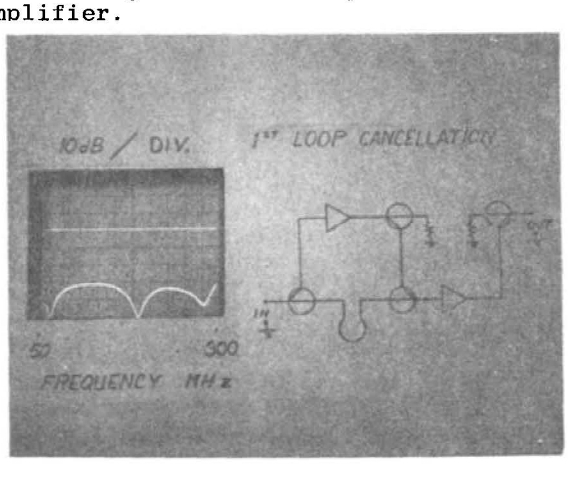
However, we did still have a problem with our high level distribution amplifiers that had a gain and out-puts that were similar to the amplifier that was now called an H60M. This new feed forward amplifier could be mounted in our existing locations. So we started plans to change out the two hundred high level distribution amplifiers with H60M's. This took 18 months to complete.

The feed forward amplifier works on the concept that the input signal is compared to the output of the main amplifier section 180° out of phase. This compared signal will contain the distortion of the main amplifier. The distortion is then amplified and used to cancel these distortion products at the output combiner. The results are an amplifier that has about a 20dB advantage over the single devices in the amplifier.

FEED-FORWARD AMPLIFIER

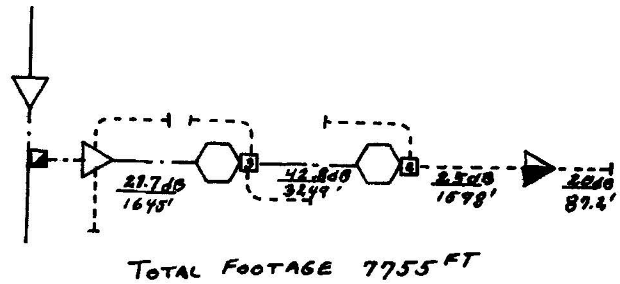


We have now installed over 200 of the feed forward units in high level locations so far. They are being ran out 50dB on channels 2 through 6 and 57dB on channels 7 through 13. Like any new design, we have had some problems; but in every case the trouble has been traced down to a mechanical fault. To date, the oldest units have been in operation about 2 years. We have had about 10 units in for service and in each case the trouble was traced down. Six of the failures were due to broken wires in the delay lines in the early production units. This breakage was due to too much strain on the wire in assembly. Two of the troubles were traced to poor solder joints. Two intermittent problems were traced to bad connection inside of the amplifier chips. We have no evidence that the delay loops have shifted in phase, or the cancellation has changed with temperature of aging. If, for any reason, the cancelling amp or loop should fail, the signal level will remain about the same. So when the amplifiers are checked, picture quality must be monitored. At the present time, the cancellation loops can best be checked on a tracking sweep or checking the overload point of the amplifier.



The photo shows an H60M after a cascade of 49 rebuilt amplifiers and the 50th is an H60M with 12 TV channels and over 40 FM channels.

We were so pleased with the performance of the high level feed forward units, we set up a new test. This time we installed 2 - H60M's in cascade with a three way split on the output of the first one and a two way split on the second H60M's output. The object was to serve a rural area with a minimum number of amplifiers.



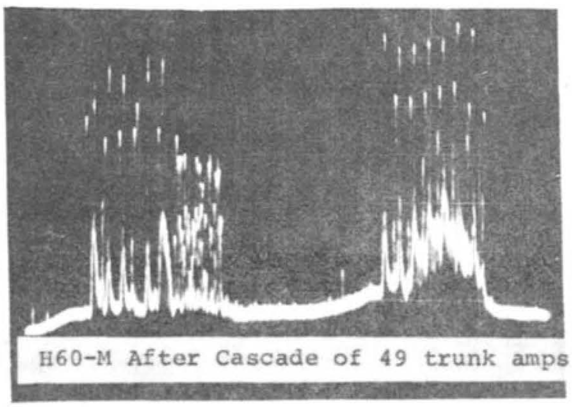
The results of this cascade showed the H60M amplifier could be cascaded at high levels and supply good service to the customer at the same time.

The philosophy of the company is to go out and look for trouble. Do not wait for service calls. For this reason, the Cumberland system is maintained daily by in-service sweeping. Any trouble found is cleared that day, if possible. There are servicemen on duty or on call from 8:00 AM until 12:00 Midnight, seven days a week. Any customer that has had a call back on service is used as an F.C.C. check point. This gives a random selection to the checks. We receive less than 12 trouble calls a day from all the systems. Of the 12 calls, about half of these are matching transformers.

Now we had a problem in Paw Paw, West Virginia. That system was built with equipment that was removed from the old Cumberland low band system. We needed more channel handling capability because of a new educational station that was now available in the area.

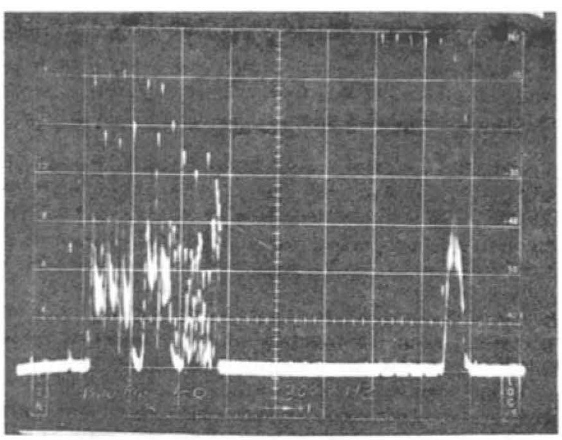
If we would use conventional amplifiers, we would have to change the amplifiers spacing, the feeder lines and reset most of the taps. The old amplifiers were running out at 32dB on channel 2 and 38dB on channel 6 into the feeder lines. We projected it would take 47dB on channel 13 and 40dB on channel 2 into each feeder line to meet the requirements of the high channels. The feed forward amplifier was designed with an automatic slope and gain control circuit. The power supply was changed to line powered and the unit was mounted in a strand mounted housing.

In order to serve our needs and test for a worse case condition, each amplifier was ran out at 56dB on the high band and 50dB on the low band. The signals were fed to the feeder lines by splits and the trunk was fed by a 10dB directional coupler. To maintain 40dB, spacing pads were used on the inputs when needed. The layout of the Paw Paw, West Virginia system as shown:



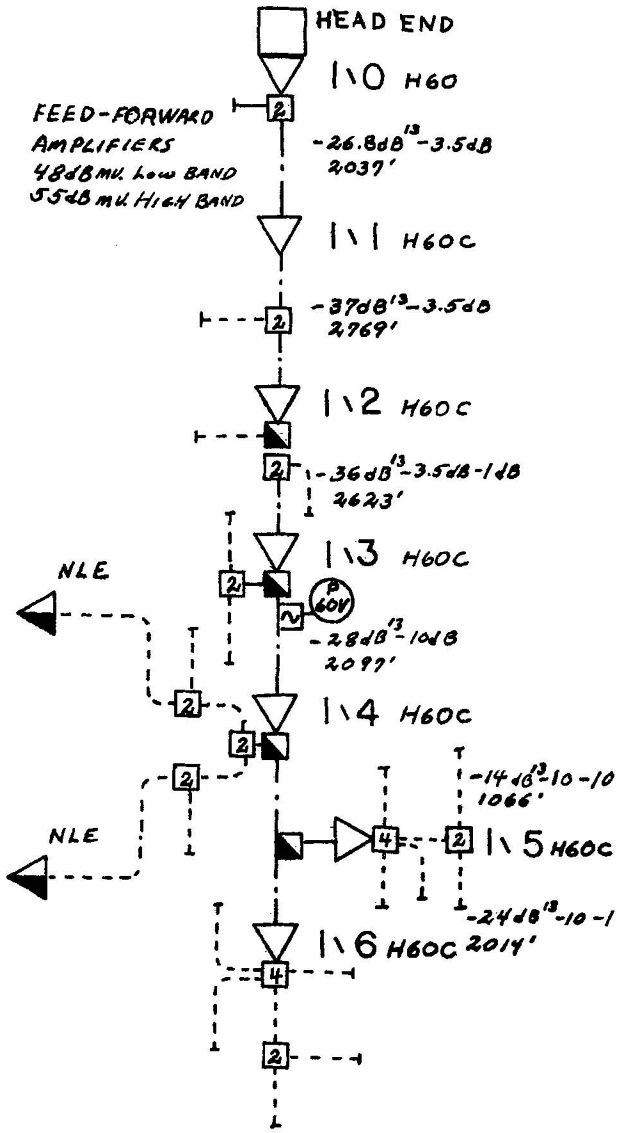
H60-M After Cascade of 49 trunk amps

1ST AMP AT HEAD END



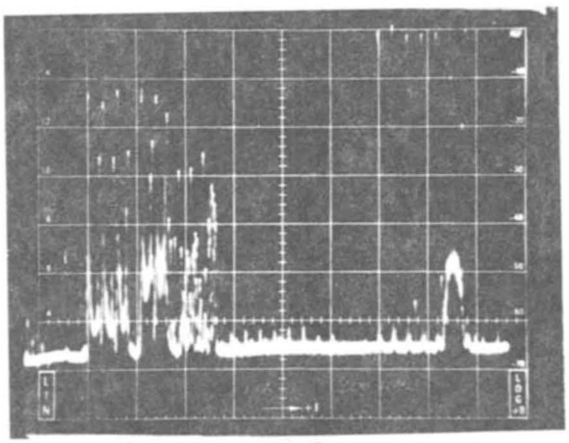
1ST AMP AT HEAD END
4TH AMP

PAW PAW, W, VA.



You will note each unit has automatic slope and automatic gain controls. There is no bridgers; so in order to meet the level requirements, the feeder makers are designed with the trunk line having the most loss.

The system was changed from a low band system to a high band system in one day. Not one tap had to be changed and no cable had to be rerun. When the end of each tap line was tested for a minimum of 20dBMV, two tap-line equalizers were installed to maintian a 6dB window.



6TH AMP PAW PAW

The Paw Paw system will be able to handle over 20 channels without any amplifier changes. The problem is due to the terrain. There are only 7 channels available and three of them are NBC.

The results of the Paw Paw experiment showed these results of the cascade of 6 amplifiers. The tests were made with 12 channels with the low band operating at 50dBMV and the high band was 57dBMV.

Signal to noise ratio low band	-45dB
Signal to noise ratio high band	-54dB
Cross mode 12 channels	54dB
2nd order products from low band	50dB

One of the findings in the Paw Paw cascade was the cross mode. Second and third order distortions did not add up as would be expected in standard amplifier cascades.

Our conclusions of feed forward amplifiers are these. We first used the amplifier to solve a problem in high level distribution. We found it to be capable of signal levels at least 10dB better than the amplifier it replaced with less distortion.

The most important finding, after experimenting and testing for over two and one half years, is their excellent cascade ability. In Paw Paw, West Virginia, we were able to maintain an input of 17dB of better. The gain was set at 40dB each. The amplifiers were equalized for flat system response with a 7dB block slope. The high channels were held at 57dB. The system has had one failure. That was traced to a water leak in a strand mounted cabinet.

We are starting to evaluate the feed forward amplifier as a trunk line replacement unit. Not only for it's ability to handle more channels, but to meet the demand for a much higher signal to noise ratio on our existing systems. Modern color television receivers are being designed with signal to noise observable to -50dB and better. We are starting to consider this in our designs. Tests conducted with newer television receivers have shown us we should be designing for a minimum of -53dB signal to noise in our systems now.

The heart of the new amplifier will be a feed forward output stage which will be run at about 45 to 50dB flat. The bridger will have unity gain on the high end with about 5 to 7dB slope. The input stage will have an average noise figure of about 8dB. To design an amplifier with extremely lower noise figure would be impractical. With this amplifier, we intend to keep the inputs about 20dBMV. With this design, the unit will drop into our standard locations spaced at 22dB plus at channel 13. The amplifier will be capable of being equalized for 12, 20, or 30 channels as we decide.

We should be able to cascade over 100 of these amplifiers and retain a signal to noise of better than 50dB. Distortions should be below 50dB for 30 channel operation.

REFERENCES: A Wide-Band Feedforward Amplifier, Robert B. Meyer, member IEEE, Ralph Eschenbach, and Walter M. Edgerly Jr. IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. SC9, No. 6, December, 1974.
NO LOOSE ENDS, Tektronix By, Clifford B. Schrock

REMOTE BASEBAND SWITCHING FOR VIDEO MICROWAVE SYSTEMS

Mike McKeown

UNITED CABLE TELEVISION CORPORATION

The capability to remotely insert both full field and inservice VITS video test signals at a microwave headend is a highly valuable maintenance tool to the microwave system and CATV operator. A video routing system also allows video program material to be switched to alternate microwave channels on the occasion of a microwave failure downstream from the switcher or during routine maintenance.

Design concepts of such a remotely controlled switching system, including "touchtone" remote control via wire or radio, are described here. Status monitoring and other refinements are included for the operator who desires a more versatile, more sophisticated switching system.

If you have ever operated a microwave system and wished that you could test it on an inservice basis, locate a fault without visiting every site, or route your signals around an outage, then perhaps what you should consider is a remotely controlled switching system. These types of problems prompted United Cable Television Corporation to install such a system on a combination Business Band-CARS Band microwave system which it operates in Wyoming. The microwave system brings Denver television signals to CATV systems in Wheatland, Torrington, Rawlins, Glenrock and Casper, Wyoming on a cost-sharing basis.

THE CONTROL SYSTEM

The very basics of such a system are outlined in Figure 1, titled "Remote Video Switching System - Simplified Block Diagram". At the heart of the system is the video switcher. The switcher without remote control capability is of little use to the microwave operator. The encoder, signaling path and decoder permit control of the switcher, often located at a remote unattended microwave headend, from other points in the system. Normally the end terminal of the system is a logical control point since this site is usually manned and results of the switcher operation can readily be observed. It is desirable, however, to implement a control system which allows control from any microwave site for maintenance purposes.

Reliability, simplicity, versatility and the capability to expand, in that order, were considered the most important requirements for the switching system. Several types of control methods were considered, including dual-tone pulsing, single tone on-off keying, frequency shift keying, carrier keying and dual tone multifrequency (DTMF) which is the technical term for AT&T's registered trademark Touchtone. DTMF signaling was selected because of its reliability, high immunity to voice and noise signals, and proven track record in the telephone industry. Touchtone consists of eight (8) discrete (individual) tone frequencies, ranging from 697 Hz. to 1633 Hz., arranged in two groups of four tones each (a high group and a low group). Sixteen (16) digits can then be represented by the combination of one tone from the high group and one from the low. The normal home phone uses seven of these tones and, therefore, has only twelve digits. The signaling path need only be a "voice grade" circuit for successful transmission of DTMF signals. In a two way or duplex microwave system the most obvious signaling path is the microwave radio itself using subcarriers to carry the audio control signals. Since most microwave systems in video use are not duplex, some alternatives must be considered. In the Wyoming case, all microwave sites were linked by an existing 150 MHz. two-way radio system and DTMF signals from the control point encoder are transmitted over this radio system to the decoders at the microwave headends. If phone lines are available, they could be used instead of or in addition to radio. Control by both wire and radio would add to the system's versatility.

The normal DTMF decoder has sixteen (16) parallel output lines. These sixteen functions are all that are required in switching systems containing up to fourteen (14) inputs and fourteen (14) outputs. Expansion beyond this size is easily done by adding logic which recognized two, three or more digit combinations. The handling of multiple switchers in the system, each located at a different site, only slightly complicates the control methods. If a microwave radio using a different frequency subcarrier for each switcher location or a phone line control system is used, there is no need to encode signals which allow differentiation between stations since this is accomplished by the selection of a subcarrier frequency or a phone number. In a system using the same subcarrier or two way radio frequency or the same wire pair for all stations, then an "on line" condition exists. It is then necessary to assign an address to each station and place an additional address decoder at each site. Typically a two or three digit number is assigned to each station and this number encoded in DTMF format must first be received by the address decoder before the DTMF selector with its sixteen outputs is enabled to receive switcher control signals. A timer in the address decoder keeps the selector enabled for five seconds after which a reset occurs and access to the selector can only be regained by encoding the station address. The decoder can also be reset manually by sending the DTMF pound digit (#). A four digit command is normally used to control the switcher and consists of a CLEAR command (DTMF asterik digit - *) and input selection (DTMF digits 1-14), an output selection (DTMF digits 1-14) and a TAKE command (DTMF pound digit - #). Five seconds is adequate time for the operator to encode these digits and the pound digit (#) not only serves as a TAKE command for the switcher, but also resets the address decoder. An almost unlimited number of switching sites may be controlled by this method which uses a seven digit number similar to your telephone number.

Even in systems having only one switcher, it is desirable to include an address decoder because of the additional security provided against unauthorized control of the switcher and false triggering of the DTMF selector by noise and voice signals. Two way radio systems equipped with continuous tone coded squelch systems (CTCSS), known by such brand names as Motorola's "Private Line" and General Electrics's "Channel Guard", are relatively immune to false triggering since audio from the radio receiver is not available at the DTMF selector input unless the two way radio signal contains a sub-audiable tone capable of operating the CTCSS decoder in the radio receiver.

A sixteen digit DTMF encoder can be permanently installed at the microwave end terminal and a portable decoder allows control of the switching system from any microwave site or other locations linked to the microwave headends by radio or wire, depending upon the signaling path chosen for control. DTMF encoders, decoders, selectors, and accessories are available from Speedcall, Solid State Communications, Secode, Bramco and others. Encoder costs range from $100 to $300 and each station of decoding equipment, which includes a decoder, selector, power supply and card cage or other mounting hardware, can be expected to cost between $600 and $900.

THE VIDEO SWITCHER

A multiple input, multiple output video switcher takes the form of an X-Y matrix when represented by a drawing. The columns being the inputs and the rows the outputs. Each point at which an input line or bus meets an output line or bus is designated a crosspoint (X) and is a potential input to output connection within the switcher. Figure 2, "Video Switcher - Simplified Diagram", shows a matrix type switcher with an n x k configuration where n is the number of inputs and k is the number of outputs. Usually integral to the control systems of this type of switcher are provisions to preclude more than one input at a time on a single output line. On the other hand, it is possible to feed all outputs from a single input line. These large matrix type switchers are often called routing switchers and in addition to the video only type used for this application combination video-audio units are available for studios where "audio follow video" applications are frequent. Vertical Interval switchers are also made which switch only during the vertical interval to prevent any noticable interruption of the picture. The video inputs to such a switcher must share a common sync source for no interruption of the picture using vertical interval switching. In a CATV microwave headend, it is highly unlikely that the video sources will have a common sync source. This expensive feature is, therefore, not needed, besides, the millisecond switching time of these switchers is so fast that even without vertical interval switching the switch itself will not be noticeable. Tally outputs which indicate which crosspoints are energized within the switcher can provide both local and remote monitoring of the switching status of the switcher. This is a highly desireable feature of any large switcher when you consider the myriad of possible input to output combinations. The status monitoring feature of this system is discussed later in the paper.

When selecting a switcher, do not forget to use the same care and criteria which you used in selecting the microwave or any other device in the baseband video path. These switchers are active devices and are not without distortion although a good switcher is practically "transparent". Differential gain, differential phase, envelope delay, transient response, frequency response, signal to noise, input and output return loss, gain, hum and crosstalk are all important considerations.

Most of these switchers use a mainframe or motherboard which may contain control electronics, power supplies and interconnecting wiring including input and output wiring. The actual switches or crosspoints and video amplifiers are usually on separate circuit boards which are either hard wired or plugged into the mainframe. The mainframe will have a maximum capacity of n x k (inputs x outputs) and the actual crosspoints come in smaller units such as 4 x 1, 12 x 1, 1 x 4 or 1 x 8. In the 12 x 8 switcher featured in Figure 5, the mainframe capacity is 20 x 8. Crosspoints are available in 1 x 4 increments for plug in installation, so it takes twenty-four (24) of these 1 x 4 boards to implement a 12 x 8 switcher.

The mainframe costs are major and may range from $1,500 to $3,500 with each crosspoint costing up to an additional $50.00 each. Each manufacturer will approach the mainframe-crosspoint board problem in a different manner. The engineer designing the remote video switching system may realize significant savings by matching his current and future size requirements to the particular switcher which meets his needs without providing excessive mainframe or crosspoint board capacity. As an example, suppose the switcher in Figure 5 need only be a 6 x 5 unit with no provisions for future expansion. First, the use of a 20 x 8 mainframe is an overpowering of the situation. Secondly, since crosspoint boards come in 1 x 4 units, the fifth output requirement would require purchasing six (6) additional boards which would expand the switcher to a 6 x 8 size. A 6 x 3 portion of the switcher containing eighteen (18) crosspoints would go unused. If a smaller mainframe with 6 x 10 capacity would cost $1,000 less than the 20 x 8 unit and 6 x 1 crosspoint boards were available which would exactly fit our 6 x 5 requirement a savings of $1,900 would result if crosspoints cost $50.00 each.

All of the criteria used in switcher selection above are overshadowed by the control electronics which interface the DTMF selector and the switcher. Local control methods offered by switcher manufacturers include thumbwheel and pushbutton schemes and remote control options include BCD Keyboard, X-Y coordinate, computer BCD control and others. Use of the DTMF selector sixteen parallel lines in a serial decimal format to control the switcher is a special application.

The switcher in Figure 5 was manufactured by American Data Corporation and they modified their X-Y coordinate control system to be compatible with the DTMF control system. Most manufacturers will provide switcher control electronics to interface with your control system if you furnish them with adequate information. Manufacturers that build video switchers are American Data, Central Dynamics, Grass Valley, Telemation, Telemet, Matrix Systems and others.

Electronic video switchers normally employ digital logic circuits which provide the memory to latch chosen crosspoints until a new command calls for a change in the switcher status. If the power is interrupted for even the shortest time, this memory is lost and when power is restored the previous video paths thru the switcher will no longer exist and it will be necessary to reprogram the switcher locally or remotely using the DTMF control system. It is, therefore, imperative that the system design include a reliable, non interruptible power supply for the switcher. The standby battery supply commonly used in microwave systems is an extremely reliable -24V DC, positive ground, power source. It is likely that the switcher will also require a positive polarity, negative ground, supply. Input voltages may also be much lower than 24 volts. Electronic regulation of 24 volts down to a lower voltage is a relatively simple and straightforward problem, but a polarity change can be much more difficult.

In the Wyoming system, the switcher required -11 VDC and + 11 VDC. Initially DC to DC converters were used to provide +11 VDC and -11 VDC outputs with a -24 VDC input. Not only was a reliability problem encountered with these units, but the noise on their outputs often interfered with the operation of the digital control electronics. After varying degrees of success with other power supplies, the -11 volts is now supplied by regulating the existing -24 volt microwave battery down to -11 volts and the addition of a high quality 12 volt charger and a battery serves as a positive voltage source.

APPLICATIONS

Now that we have progressed through engineering the DTMF control system and selecting a video switcher, how can it all be put to use ? Figure 3 shows some typical routing paths thru a video switcher. In normal operation a video signal is routed to its corresponding microwave channel as shown in the middle diagram. If your microwave system includes channels which are considered to be more important than others, the switcher may be of help during a failure of one of these primary microwave channels. Until the outage can be corrected, a "primary" video source can be routed to a "secondary" microwave channel. This means, of course, the loss of the lower priority secondary video signal until normal operation can be reinstated.

If you ever wondered whether the distortion you were viewing at a microwave receive terminal was a microwave problem or was coming from a video source such as a demodulator, the switcher offers many alternatives to locating the problem. One solution might be to put the video in question on two or more microwave channels and make a side by side comparison. If the problem is now apparent on all microwave channels carrying the signal, then more than likely the video source is at fault. If the problem is evident only on the original microwave channel, then that particular channel is at fault. A more definitive solution would be to use the full field test signal capacity of a signal generator such as the Tektronix 147A. This is shown in Figure 3 by the diagram on the right. By routing a known to be good test signal down the microwave channel, it is very easy to locate any distortions associated with the microwave. The microwave technician who can control the switcher from each site using the portable DTMF encoder can isolate a problem very quickly. The switcher is almost like having another man available on a twenty four hour basis to change the baseband inputs to the microwave during outages or for testing.

So far the use of the switcher for testing has involved "out of service" conditions. This interruption of service is often untenable and the next step is inservice testing. Figure 3 in the left hand diagram shows how a video signal is routed to allow vertical interval test signals (VITS) to be inserted using a VITS inserter such as the Tektronix 147A. Now you can monitor your system's performance while it is in service. Localizing faults before they become outages becomes a day time job rather than a task done only after hours when the television stations sign off. Those twenty four hour stations are really a problem without inservice testing capability! In a multihop system with switchers and VITS inserters located at intermediate points, even greater possibilities are available. The build up of distortions in the video signal can be monitored at the end terminal of the system by progressively inserting VITS starting at the microwave headend and moving toward the end terminal. Even noise buildup can be measured by using the noise deletion feature of the Tektronix 147A. This strips all noise off a line in the vertical interal of video routed through the 147A. Signal to noise can then be measured in the microwave system downstream from the VITS inserter using instruments such as the Vista Systems Noise Meter or the Tektronix 1430 Noise Measuring Set.

Television sound is usually carried on a 4.5 MHz. subcarrier on a video microwave system. Other subcarriers above 4.5 MHz. carry FM broadcast program material and service channels for microwave maintenance. The VITS inserters currently available are designed for use on video only lines as found in television broadcast studios. Deletion of incoming VITS at a field rate (60 Hz.) is done by the VITS inserter before inserting its own VITS. This deletion feature also "chops holes" in the subcarriers with 60 Hz. frequency. In the Wyoming system, which is in use, this problem is solved on the most important subcarrier, the 4.5 MHz. sound, by bypassing it around the VITS inserter. A Jerrold CST-4.5 is used to separate the subcarrier from the video on the input line to the VITS inserter. A 10 dB amplifier is then used for the 4.5 MHz. signal to compensate for the insertion loss of the "video and sound" to "sound only" path of the CST-4.5. A Jerrold SCC-4.5 is used on the output line of the VITS inserter to recombine the 4.5 MHz. sound with the video. The variable gain feature of the Tektronix 147A is used to provide unity gain in the video path between the CST-4.5 "video and sound input" to the SCC-4.5 "video and sound output". Bypassing the other subcarriers above 4.5 MHz. could probably be done in a similar manner although it has not been tried in the Wyoming system yet. Care must be exercised in inserting numerous high-Q traps in the video line since frequency response and group delay problems are the likely result.

STATUS MONITORING AND OTHER REFINEMENTS

With the many possible routing combinations in a large matrix type switcher and the use of multiple switchers, it becomes almost a necessity to have a status monitoring system. Such a system should provide the control operator not only a real time indication of all energized crosspoints in each switcher, but will confirm that his encoded commands have been properly received by the decoder and executed by the switcher. Both local and remote status indicators are useful. Only a duplex control system can offer "real time" status monitoring, so whether the control signaling path is wire or radio, the microwave system itself is useful in returning status data to the control point. The DTMF decoder system in one manufacturer's configuration can also be used to encode the tally outputs of the switcher into a DTMF format for transmission via subcarriers to the control point for decoding into a visual display. Figure 4 shows a block diagram of a typical video switching system with full status monitoring. At this time, the monitoring system is still in the conceptual stages. A simpler system has actually been implemented. By using the tally outputs of all crosspoints normally energized, as inputs to an AND gate, a normal condition causes the output of the gate to remain "high". Any "not normal" routing causes the gate output to go "low" which is used to drive a number five (#5) alarm on an existing eleven (11) point alarm system on the microwave. At the control point reception of a number five (#5) alarm from a particular station reminds the operator that the switcher at that site is no longer in a normal routing condition. This system works well, but it is more limited than the more extensive system shown in Figure 4.

Another accessory to the switcher now under development is the use of a read only memory (ROM) to provide automatic programming of a switcher's many normally energized crosspoints when the power returns to the switcher control electronics after a power supply failure. A single command signal from the control point could also be used to reset the entire switcher to a normal condition or any other preprogrammed routing scheme.

A digital counter is used with a single input from the DTMF control system to sequence the Tektronix 147A signal generator through its available full field outputs, including Flat Field, Noise, Field Square Wave, Window, Sin^2 Pulse and Bar, Composite, Linearity and Multiburst.

The DTMF control system could also be used to control standby generator exercising, charger output failure simulations, battery equalization charges and a host of other functions.

CONCLUSIONS AND RECOMMENDATIONS

A remote baseband switching system as described in this paper has been implemented in a microwave system serving CATV systems and in daily use it has proven its value and capability in allowing bypassing of microwave outages and in both routine and emergency maintenance. As an instrument in testing a microwave system, it has saved engineers and technicians alike valuable time by allowing problems to be localized by switching from the control point rather than sending technicians to remote sites to try and track down a problem. The inservice testing capability it offers is an extremly valuable tool in performing routine maintenance on a microwave system.

The major limitation to the use of such a system is its cost. A 12 x 8 matrix switcher and the DTMF control system may cost up to $7,000. The microwave system operator must balance this cost against the projected cost savings in labor and reduced downtime which the switcher may reasonably be expected to produce.

Another disadvantage from an engineering viewpoint is the addition of another active device in the video signal path. A total failure of the switcher is one of the only events which can cause an outage on all channels. This is a catastropic failure. Although the reliability of the switcher itself in the Wyoming system has been quite good with only two single channel failures in over two years of operation, outages caused by power supply failures during the first year of operation occurred four times. The power supply problem has since been rectified by using separate battery systems for both negative and positive supplies. A needed feature of video routing switchers is provision for automatic bypassing during a failure.

The entire remote switcher concept could be further developed by work in the area of higher reliability power sources, computer control for automatic channel switching and status monitoring, and the use of a switcher in a multichannel microwave system to implement automatic inservice monitoring of video quality.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation and thanks to Ms. Carolyn Ningen for typing the manuscript and to Mr. R. C. Schneider, Vice-President of Engineering, United Cable Television Corp. for his patience and help throughout this project.

REMOTE VIDEO SWITCHING SYSTEM - SIMPLIFIED DIAGRAM

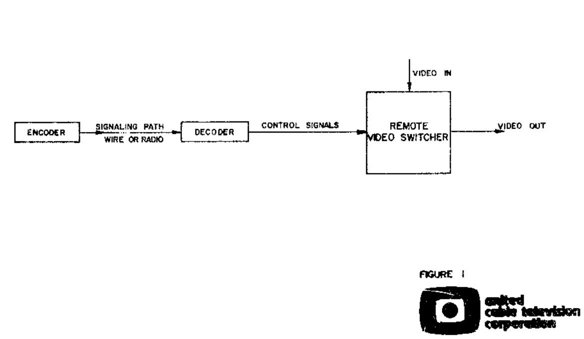


FIGURE 1

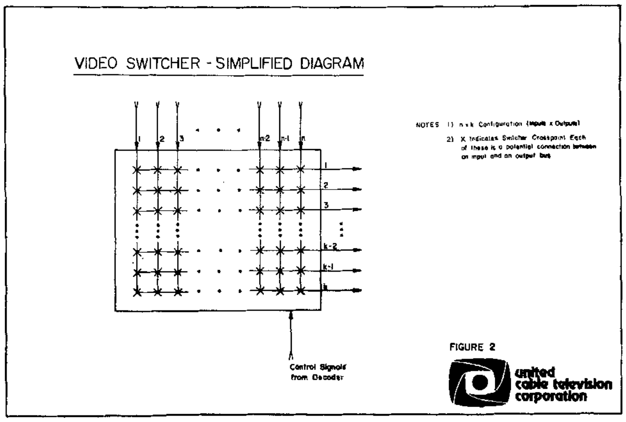


FIGURE 2

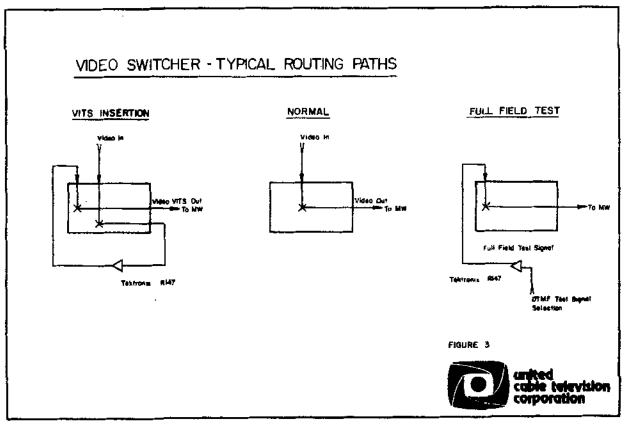


FIGURE 3

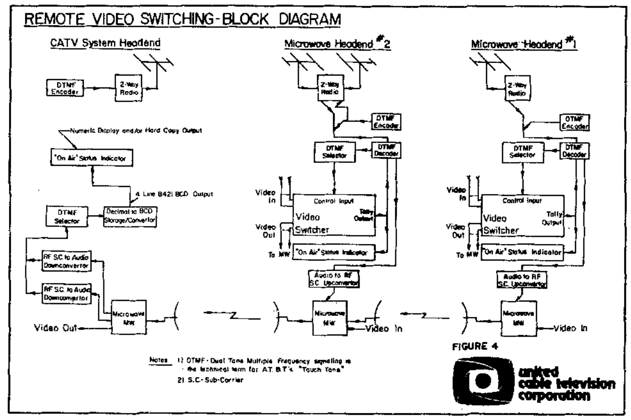


FIGURE 4

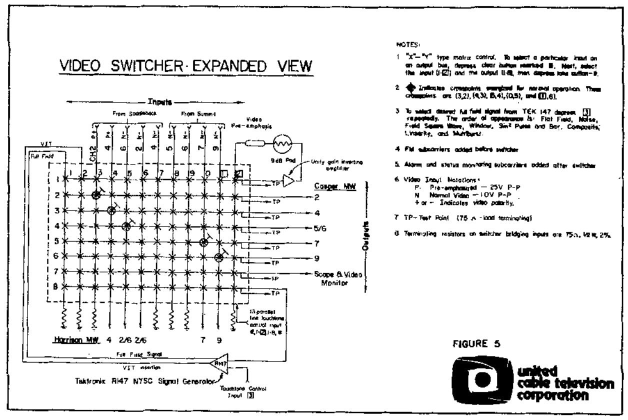


FIGURE 5

SECOND ORDER BEATS ON CATV SYSTEMS

Bert L. Henscheid

Theta-Com

With the advent of hybrid technology and the increased prevalence of 35 channel testing, an updated view of second order intermodulation behavior is needed. This paper is a report of studies made on a "latest generation" of hybrid amplifiers showing levels of distortion in the hybrid module, single station, and a cascade. Conclusions are drawn on a method of testing, and it will be shown that the commonly accepted cascade derate factors are invalid.

It has been observed for some time in testing cascades for second-order performance in the lab and on proof of performances that the second order beat levels are not predictable at any given location. At some points in the system, a beat level is considerably less than it was in the previous station. In fact, as every station is probed, nulls are seen to occur in a number of locations as shown in Figures 1 and 2. Notice that complete nulling does not necessarily occur and that there is very little pattern or order to the curve.

The data in Figure 1 was taken on a twenty station cascade of discrete push-pull amplifiers. Notice the wide excursion of the beat in Channel 3. The peaks and valleys seem to have no relation to the peaks and valleys of the beats in Channels J and T. There are four stations at which the beat level exceeds the 10 log N curve, but at no station does it approach the visible level above -60 dB.

The data in Figure 2 was taken on a twenty amplifier cascade of hybrid amplifiers. The excursions are similar but again no pattern is evident. In order to try to explain this situation, an investigation of theory and hardware was undertaken. A number of papers have been presented in past years showing how intermodulation distortion is generated in an amplifier. Briefly, an amplifier was described as having a transfer function similar to a Taylor power series expansion, that is,

$$V_o = A_o + A_1 V_i + A_2 V_i^2 + A_3 V_i^3 + \_\_\_\_$$

This is sufficient for our discussion here, although other papers (1) (2) have shown that a Voltera series is more accurate. If the input signal, V_i, to an amplifier consists of two carriers

$$V_i = V_1 \sin \omega_1 t + V_2 \sin \omega_2 t$$

the second order term at the output, $A_2 V_i^2$, yields

$$\begin{aligned} A_2 V_i^2 &= A_2 (V_1 \sin \omega_1 t + V_2 \sin \omega_2 t)^2 \\ &= A_2 V_1^2 \sin^2 \omega_1 t + A_2 V_2^2 \sin^2 \omega_2 t \\ &\quad + 2 A_2 V_1 V_2 \sin \omega_1 t \sin \omega_2 t \end{aligned}$$

The first two terms are the second harmonic, respectively, of ω_1 and ω_2. It is the last term which accounts for the second order beats. For simplicity, assume unity amplitude, and in the absence of phase-locked headends, assume a phase difference. Then,

$$\begin{aligned} &2 \sin \omega_1 t \sin (\omega_2 t + \beta) \\ &= \cos (\omega_1 t - \omega_2 t - \beta) \\ &\quad - \cos (\omega_1 t + \omega_2 t + \beta) \end{aligned}$$

The first cosine term represents the difference beat, f1 - f2, and the second cosine term represents the sum beat, f1 + f2.

If all of these carriers are inserted in a second identical amplifier, two more beats, f1 ± f2, will be generated and the original beats will be amplified. In two CATV stations where unity

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(1) A. Prochazka, "Cascading of Distortion in CATV Trunk Line", IEEE Transactions on Broadcasting, Vol. BC20, No. 2, pp 25-31, June 1974

(2) S. Narayanan, "Application of Voltera Series to Intermodulation Distortion Analysis of Transistor Feedback Amplifiers", IEEE Transactions on Circuit Theory, Vol. CT17, No. 4, pp 518-527, November 1970.

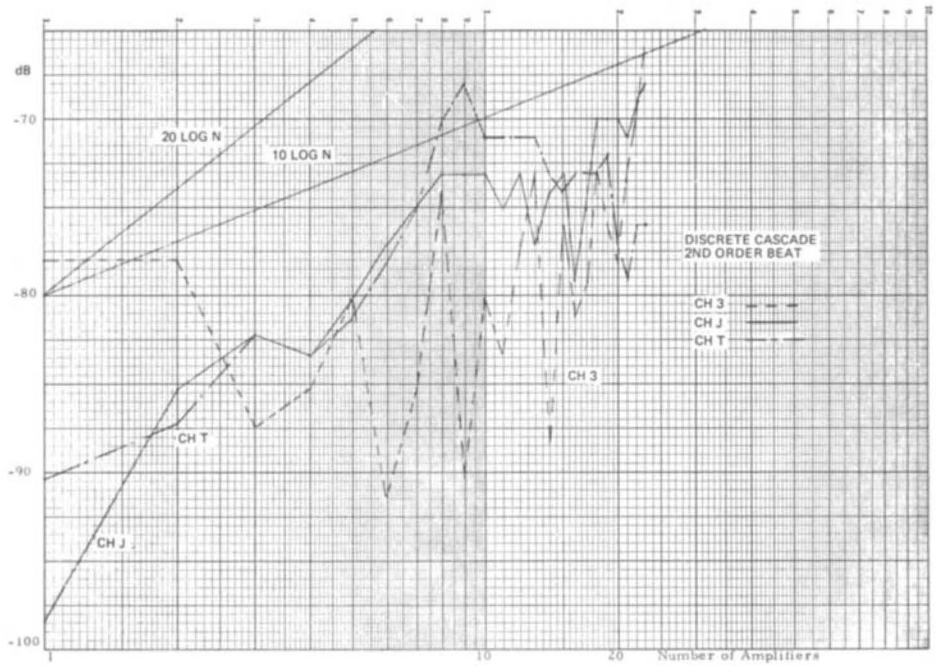


FIGURE 1

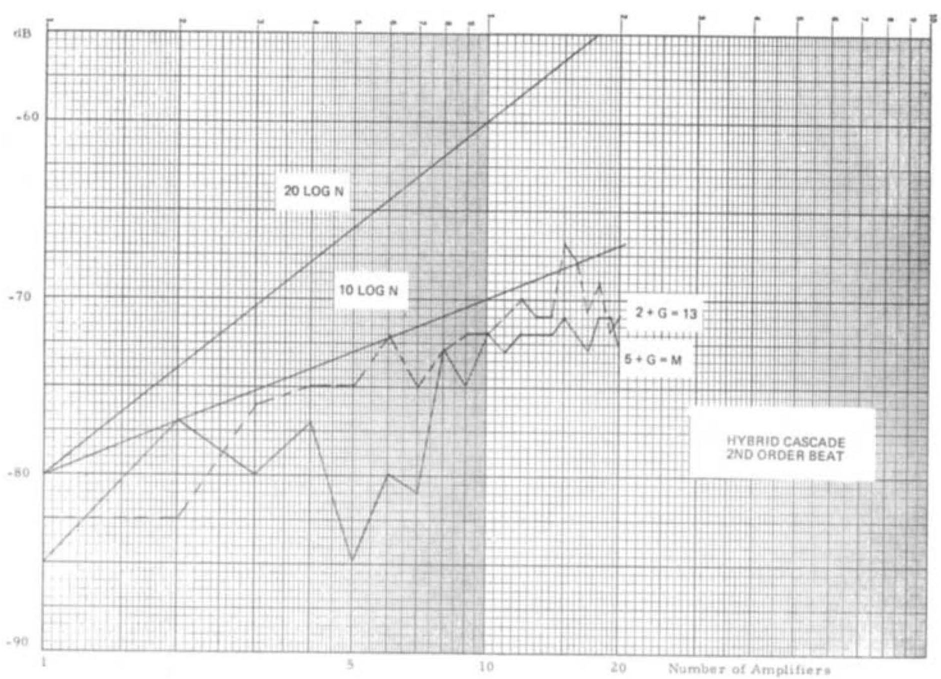


FIGURE 2

gain occurs due to cable losses, the output of the second amplifier will have two beats at exactly f1 - f2 and two beats at exactly f1 + f2. For example, if Channel 2 and Channel G are inserted, one of the beat frequencies will be at

$$157.25 + 55.25 = 212.50 \text{ MHz}$$

The output of the second station will contain two carriers at 212.50 MHz at the same level. These two carriers will add together and the resultant amplitude will be a function of the phase difference between them. That relation is:

$$\cos \omega_r + \cos(\omega_r + \beta_r)$$
$$= \cos\left(\omega_r - \frac{\beta_r}{2}\right) + \cos\left(\omega_r + \frac{\beta_r}{2}\right)$$
$$= \left(2\cos\frac{\beta_r}{2}\right)\cos\omega_r$$

The first term, $2\cos\frac{\beta r}{2}$ is the magnitude of the resultant frequency, ω_r, as shown in Figure 3.

For phase angles less than 120°, the magnitude will increase, and for phase angles greater than 120°, the magnitude will decrease. At 180°, complete cancellation occurs.

For unequal amplitudes,

$$V_1 \cos\omega_r + V_2\cos(\omega_r + \beta)$$
$$= \sqrt{V_1^2 + V_2^2 + 2V_1V_2\cos\beta}\ \cos\omega_r$$
$$= 2\cos\frac{\beta}{2}\cos\omega_r \quad \text{when } V_1 = V_2 = 1$$

This equation is plotted in Figure 4 and shows the resultant magnitude with unequal carriers. Complete cancellation cannot occur under this condition.

To understand how phase differences occur in a system, some of the components starting with the cable were characterized. The phase constant of coaxial cable is given by:

$$\beta_c = \omega\sqrt{LC}$$
$$= \omega\ CZ \text{ where } Z = \sqrt{\frac{L}{C}}$$

for foamed polyethylene with $Z = 75\Omega$, $C = 17$pf/ft

$$\beta_c = 0.459f \text{ degrees/ft where f is in MHz}$$

A modern hybrid linear amplifier has a phase constant of

$$B_a \approx 2f \text{ where f is in MHz}$$

and an AGC variation of $\Delta B_a = \pm 10°$.

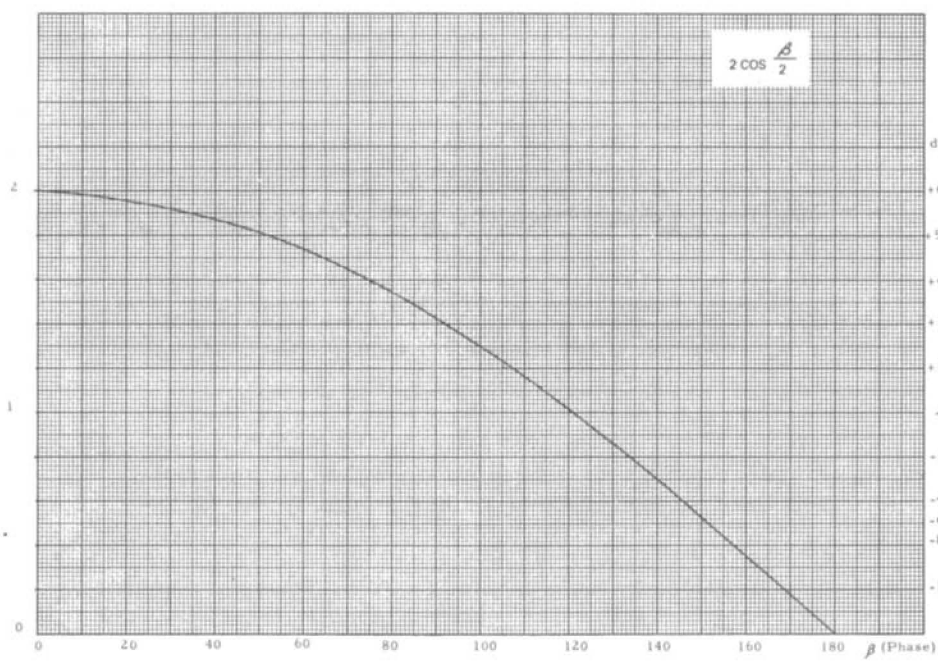


FIGURE 3

BEAT COMBINING CURVE

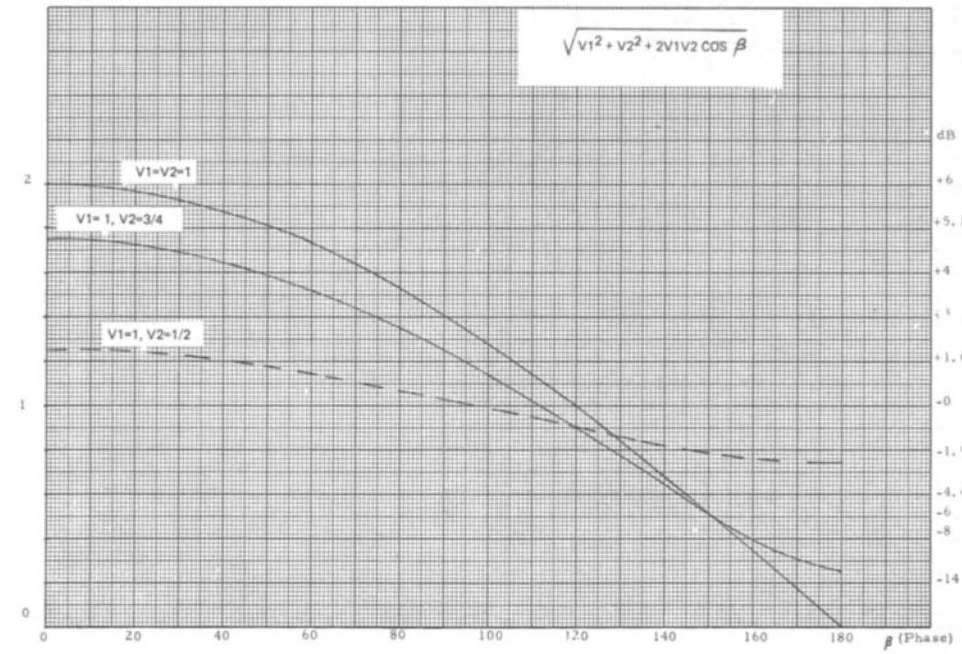


FIGURE 4

BEAT COMBINING CURVE

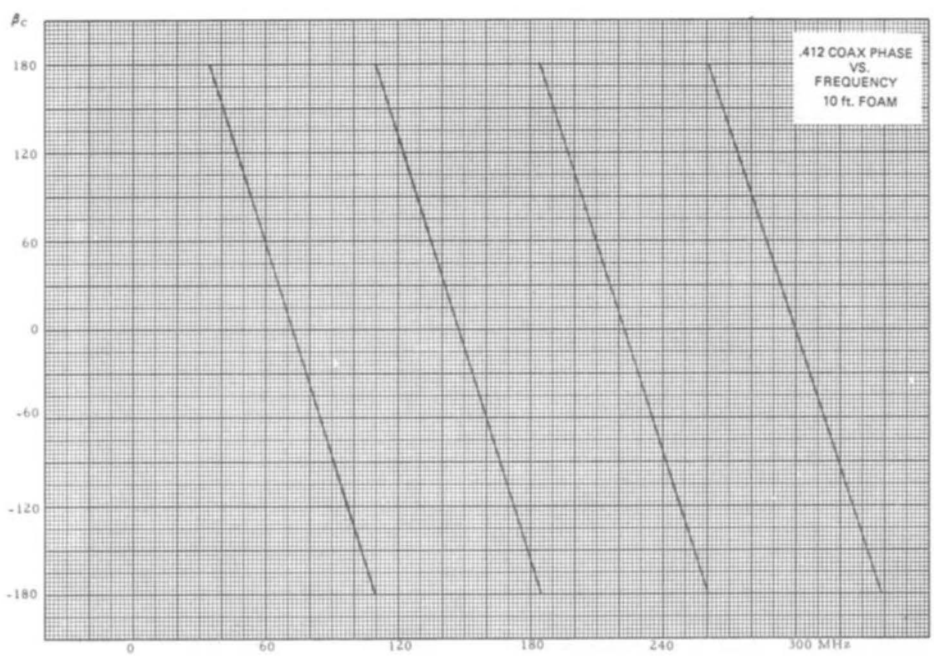


FIGURE 5

COAX PHASE VS FREQUENCY

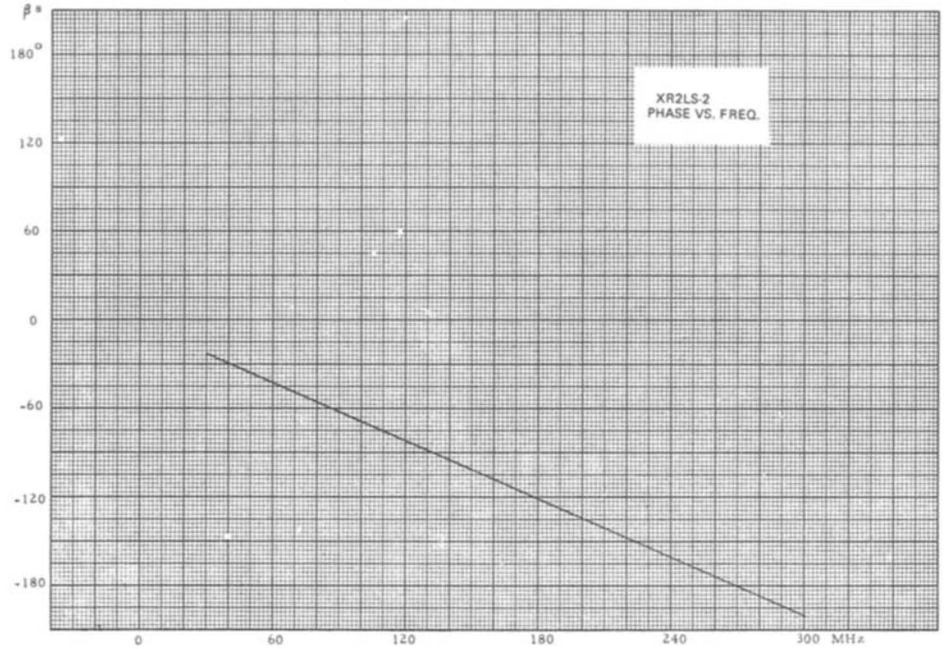


FIGURE 6

LINE SPLITTER PHASE VS FREQUENCY

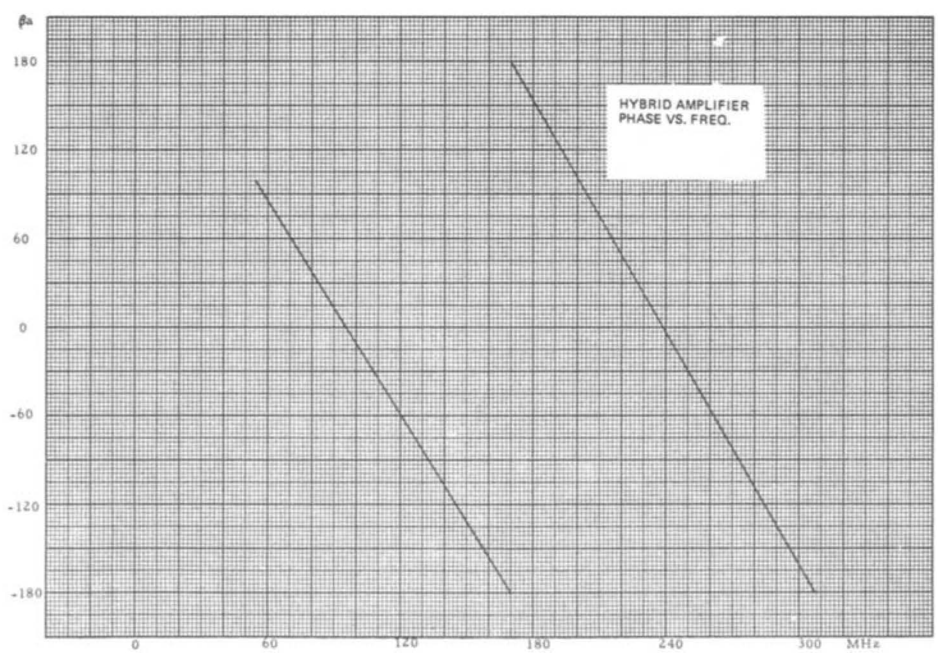
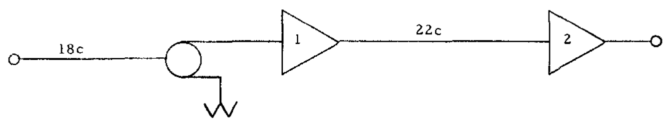


FIGURE 7

HYBRID AMPLIFIER PHASE VS FREQUENCY



CHANNEL	INPUT	STATION 1	STATION 2	COMPOSITE
5	0°	$+178^{\circ}$	-5°	
6	0°	+82	-67°	
5 + 6 5 + 6		-80 dB /$+130^{\circ}$	-80 dB /$+95^{\circ}$ -80 dB /-106°	-80 dB /0°
5	0°	$+178^{\circ}$	-5°	
M	0°	$+50^{\circ}$	-80°	
M - 5 M - 5		-80 dB /$+178^{\circ}$	-80 dB /$+173^{\circ}$ -80 dB /$+38^{\circ}$	-83 dB /$+105^{\circ}$

FIGURE 8

SYSTEM BEHAVIOR EXAMPLE

A two-way line splitter has

$$\beta_s \approx 0.67f \text{ where f is in MHz}$$

The phase measurements were made with a General Radio Model 1710 Network Analyzer and apply only to frequencies between 50 and 300 MHz.

A typical system span with 18 dB of cable and a two-way splitter would have:

$$\beta_t = \beta_c + \beta_s + \beta_a$$

$$= [(0.459)(1600') + 0.67 + 2]f$$

$$\approx 734f \text{ degrees}$$

With this information, several beats on a system can be followed. Assume two spans of cable, the first with 18 dB and a two-way splitter, and the second with 22 dB of cable as shown in Figure 8. Apply Channels 5 and 6. At the first station, a beat will be produced at

$$77.25 + 83.25 = 160.50 \text{ MHz}$$

Assume also that all beats are generated at -80 dB. At station two, Channels 5 and 6 will cause another beat at 160.5 MHz. This beat is -80 dB but shifted $+95^{\circ}$ from the beat at the first station due to the phase shifts of Channels 5 and 6. The first beat will be amplified by station two and its phase shifted to 106°. If these are added by Figure 4, the resultant is -80 dB / 0° . It would appear to a spectrum analyzer or field strength meter that the second station did not generate a beat. As a second example, apply Channels 5 and M to the input, and a beat will appear at M-5=158 MHz. At station one, the magnitude and phase is -80 dB / + 178°. At station two, this beat is shifted to $+38^{\circ}$. The beat generated at station two is -80 dB / $+105^{\circ}$ or 3 dB lower than at station one. Similar analysis with other beat combinations shows various levels of addition and cancellation up to the full 6 dB addition.

If two pairs of carriers are selected such that their respective beats fall on the same frequency, the previous analysis can be used except that the two resultant beat frequencies may differ by up to 40 KHz. For example:

$$\text{Ch 2 + Ch G} = 55.25 + 157.25 = 212.50$$

$$\text{Ch 4 + Ch E} = 67.25 + 145.25 = 212.50$$

The original Channel 2, 4, E and G frequencies will vary slightly depending on crystal tolerances or on deliberate offsets such as local 10 KHz as required by the FCC. The 40 KHz difference amounts to 0.08% at Channel 2 and will have insignificant effect on the beat amplitudes. A small sideband may exist on the resultant beat, but will probably not be seen if the level of the beat is very low.

A test method that is instructive but very time consuming consists of viewing the composite beats with all cw carriers on the system simultaneously as is done with triple beats. This is done with a spectrum analyzer with storage mode capability. A narrow band filter in front of the spectrum analyzer is useful in order to prevent distortion in the analyzer. With a scan width of 0.5 MHz, the triple beat can be seen right at the carrier frequency and the composite second-order beats can be seen at 0.75 MHz and at 1.25 MHz above the picture carrier. On some channels, a second order pile-up will be seen at 0.75 MHz below the picture carrier. Figure 9 shows a typical plot of composite beat versus frequency, and Figure 10 shows composite beats in a cascade. Due to ever present noise, a narrow bandwidth and slow scan rate is necessary.

Table 1 shows the number of mathematical combinations of beats on a 35 channel system in each channel. Below Channel 10, the beats are primarily 0.75 MHz above the video carrier, and above Channel 10, the beats are + 1.25 MHz above the channel carrier. Due to their 2 MHz offset, Channels 5 and 6 contain a large number of in-band beats. Except for Channels 5 and 6, the maximum number of beats at the same frequency is eight in super band. The standard twelve channels have only two or three beats. If the spectrum analyzer scan width is made narrow enough, these beats can be separated on the display since they are at slightly different frequencies. The beat with the highest amplitude will be more premoninant in a visual test. The effect of viewing two such beats on a TV set is the grid or "screen-door" effect. Since this is a time consuming test, it is not necessarily recommended for proof of performance and maintenance tests.

The visual aspects of the beat frequency relative to the video carrier frequency have been known for some time. One of the more recent and well-illustrated curves for this is published by the Department of Communications in Ottowa, Canada.(3) The results show that the permissible level for a beat at 0.75 MHz above the carrier is -56 dB and a beat at 1.25 MHz above the carrier is -52 dB. The limit for a beat at 0.75 MHz below is -42 dB.

These levels agree very closely with work done at Bell Laboratories(4) in 1960 and separate tests performed by this author in 1968. Note

(3) Technical Standards and Procedures for Cable Television (CATV) systems, Broadcast Procedure 23, Telecommunication Regulation Branch, Department of Communications, Ottowa, Canada, March 29, 1971.

(4) C. A. Collins, A. D. Williams, "Noise and Intermodulation Problems in Multi-Channel Closed Circuit Television Systems", AIEE Winter General Meeting, New York, N. Y., Jan. 29-Feb. 3, 1961.

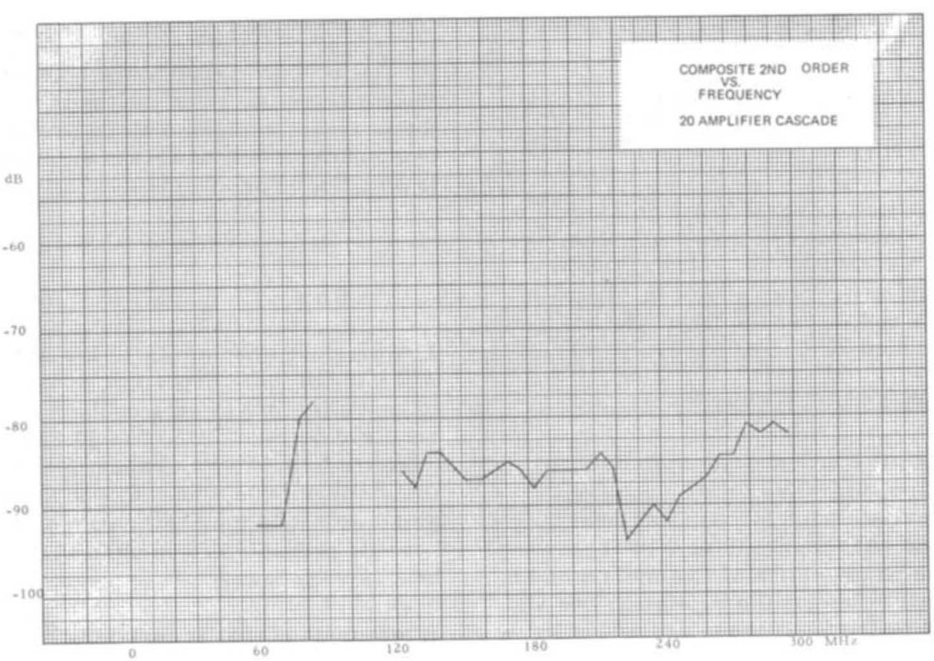


FIGURE 9

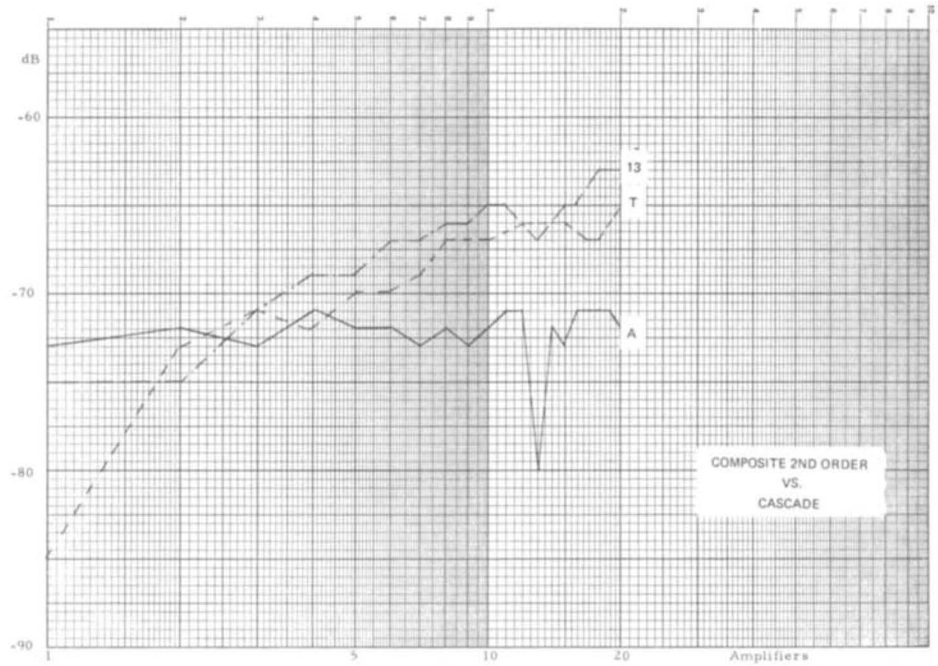


FIGURE 10

that the beat at 0. 75 MHz below the carrier is near the band edge. If a combination of test signals is chosen such that one of the beats is on a band edge, such as Channel 13 minus Channel 2 equal 156. 0 MHz, the resulting beat is a good indicator of the performance of the system, but by itself should not be used to reject a system since a real acceptable band edge level is -30 dB.

CONCLUSION:

One can see from Figures 1 and 2 that the cascade derating is not a simple logarithmic curve, and that predicting beat levels is virtually impossible. It appears that the only way to insure that system performance will meet a given specification is to specify a minimum acceptable level that applies to any point in the system. At Theta-Com, we prefer to specify a minimum second order beat in any channel of -60 dB at any point in the system. The contributing channel carriers for test purposes may or may not be specified.

TABLE 1

BEAT LOCATIONS PER CHANNEL

Ch.	-0.75	+0.75	+1.25	+2.75	+3.25 MHz
2		2			
3		2			
4		2			
5		22		2	
6		21		2	
A		2	2		
B		2	1		
C	1	2	1		
D	2	2			
E	2	2			
F	1	2			1
G		2			1
H		2	1		1
I		2	1		
7		2	2		
8		2	2		
9	1	2	2		
10	1	1	3		
11	1		3		
12	2		3		
13	2		3		
J	2	1	4		
K	2	1	3		
L	2		4		
M	2		4		
N	2		5		
O	2		5		
P	2		5		
Q	2		6		
R	2		6		
S	2		7		
T	2		8		
U	2		8		
V	2		8		
W	2		8		
Visual Limit	-42	-56	-52	-43	-53 dB

PREVIEW

SUNRISE SESSION

CTAC REPORT

CABLE TELEVISION TECHNICAL ADVISORY COMMITTEE

MODERATOR

Hubert J. Schlafly
TransCommunications Corp.
Greenwich, Conn.

PANELISTS

H. M. Diambra
Westinghouse Research
Silver Spring, Md.

David Sillman
Hazeltine Research
Chicago, Ill.

Keneth A. Simons
Simons Wydro & Associates
Hilltown, Pa.

Archer S. Taylor
Malarky Taylor & Associates
Washington, D.C.

- - - -

Two and a half years of work went into the CTAC Report. It has been completed and was delivered to the Federal Communications Commission during the month of March 1975. This NCTA Sunrise Session presents the CTAC definition of the purpose of Standards and discusses the results of some of the major areas of investigation - Cable Channel Planning, Cable Compatible Receiver specifications, Subjective Evaluation of Picture Quality and a new and simplified proposal for Performance Testing.

The Cable Television Technical Advisory Committee was an industry committee, authorized by the FCC Report and Order on Cable Television of Feb.2, 1972. It was created for the purpose of providing a base of information relating to technical and economic factors of cable television system operation. These data are to serve as a guide for regulatory bodies in the preparation or revision of technical standards for cable television. It may also serve as an industry textbook for understanding, coordination and growth.

The group was organized in the summer of 1972. It was composed of volunteer members who responded to an FCC public invitation to participate in preparing this comprehensive report. A broad base of the communications industry responded. The members brought a variety of technical backgrounds including electronic manufacturing, cable operation, broadcast, program production, interconnection, communications consulting and engineering associated with citizen, state and local government bodies. A Steering Committee of 27 members guided nine working panels and one ad hoc group, making a total of approximately 170 representatives from all parts of the country.

The Committee believes that the preparation of this report was an unusual opportunity to present information in advance of regulation rather than complaints after the fact. It may be a major step forward in coordinating industry and regulatory thinking in the direction of practical system operation. It proposes a realistic growth pattern, attempts to avoid undue economic burden, and encourages innovative equipment development and user applications. Every NCTA member should plan to become acquainted with the Steering Committee Report in Volume I. Engineering personnel will want to study the complete working panel reports in Volume II of the CTAC Report to the Federal Communications Commission.

PREVIEW

TECHNICAL EYE OPENER WORKSHOP

A DISCUSSION OF POWER RELATED PROBLEMS IN CATV SYSTEMS

Sponsor

Society of Cable Television Engineers

National Organizer

Robert Bilodeau
Suburban Cablevision
East Orange, N.J.

Moderator/Organizer

Travis Nabors
Columbus TV Cable
Columbus, Miss.

Panelists

Dr. Jacob Shekel
Jerrold Electronics
Horsham, Pa.

Norman Everhart
Jerrold Electronics
Horsham, Pa.

James Herman
Jerrold Electronics
Horsham, Pa.

Harry Perlow
Suffolk Cablevision
Central Islip, N.Y.

Dr. Jacob Shekel and James Herman

A well-designed coaxial transmission system is presumably enclosed and protected from any outside influence; however, every cable operator has experienced system and equipment failures due to external sources such as power line surges and lightning storms.

This paper proposes the explanation that any external cause must first generate longitudinal sheath currents (LSC) along the cable, which in turn induce voltages between the inner and outer conductors of the cable. Simple network models are developed to show how the LSC are generated, and to compute the magnitude of the induced voltages.

The model shows that system components may be subjected to excessive voltages not only during extraordinary circumstances (storms or power surges), but even during normal, day to day, steady state operation.

The theory is supported by controlled laboratory simulation, and by measurements of LSC and resultant voltages on live CATV systems. Various failures reported from the field are explained by the model. The paper also discusses the effects of system grounds on the magnitude of the LSC's, and whether the regular grounding practices can be expected to provide adequate protection against the generation of LSC's and their effects.

Norman Everhart

The paper explores the advantages and disadvantages of various protection devices which are used in CATV systems. It then discusses the inter-related effects of other components related to system reliability, such as time-delay relays, stand-by power supplies, and system grounds.

A new revolutionary circuit for protection of CATV amplifiers is described. The operation and advantages of this circuit are analyzed by system modeling, and supported by laboratory simulation and experimental use in the field.

PREVIEW

TECHNICAL EYE OPENER WORKSHOP

THE RECEIVER AND THE CABLE

Sponsor

Society of Cable Television Engineers

National Organizer

Robert Bilodeau
Suburban Cablevision
East Orange, N. J.

Moderator/Organizer

Frank Bias
Televue Systems
Pleasanton, California

Panelists

Robert L. Grant
Magnavox Company
Fort Wayne, Indiana

C. Bailey Neal
GTE-Sylvania
Batavia, New York

Gil Hermerling
RCA Corporation
Indianapolis, Indiana

Robert Cowart
Gill Cable
San Jose, California

James Neese
United Cable Television
Tulsa, Oklahoma

Television receivers on cable have special considerations dictated by their environment. Present day receivers accommodate some of these needs and as the cable television industry grows, the receiver manufacturing interests will take note of the more obvious requirements and incorporate them into their designs.

The time has come, however, to look long range and begin to sort out the problem areas between the cable entrepeneur, the broadcaster, receiver manufacturer and the user. Only then can we serve the public interest in its requirement to utilize receivers in both off-air and cable environments. The cable operators on the panel will point up some of the existing problem areas of the standard receiver with regards to adjacent channel handling, front-end overload, shielding, etc. The receiver manufacturers will address the statistical and engineering problems related to accommodating the peculiar needs of a cable receiver. The regulatory and control groups will be those oriented towards the public interest aspect of the consumer market.

In addition to technical performance, the parameters of the cable television receiver in terms of channel capacity, operational features, and safety will be discussed.

In 1971, Broadcasting Magazine ran an article on cable television receivers entitled, "Cable Receivers Are On The Way." Since that time, the set top converter has improved in quality and in channel capacity and to some extent impacted on the need to have a 12 channel +VHF tuning capability in a cable receiver.

Notwithstanding this, the development of a pure cable television receiver seems to be somewhat obscure at this time, but if cable television is to meet its promise in the major markets it would seem that the stand alone compatible receiver ultimately must emerge.

PREVIEW

TECHNICAL EYE OPENER WORKSHOP

TRAINING/JOB CLASSIFICATION/LICENSING FOR CATV?

Sponsor

Society of Cable Television Engineers

National Organizer

Robert Bilodeau
Suburban Cablevision
East Orange, N. J.

Moderator/Organizer

Steven Dourdoufis
Vision Cable Communications
Fort Lee, N. J.

Panelists

O. D. Page, P.E.
Cable Dynamics
Bethesda, Maryland

Tom Straw
Texas A&M University System
College Station, Texas

James Wright
Rockford Cablevision
Rockford, Illinois

Robert Bilodeau
Suburban Cablevision
East Orange, N. J.

A. M. Rutkowski
FCC Cable Bureau
Washington, D.C.

The CATV industry may be at the crossroads of a decision - a significant decision which could affect all of us in a positive or negative way.

The general subject matter is - Technical/Job Classification/Licensing - how much is needed and who will speak authoritatively for the various areas. Will the training come from commercial suppliers or from within - assuming we recognize that additional training will almost always be required. Is classification of job functions really necessary - useful - or self-defeating? Who will make such determinations and what weight will those determinations have? Is licensing, as we know it, a desirable direction to go .. for the employee .. for the employer .. for the industry .. for the viewer - and who should judge, regulate and/or direct a program of licensing? The federal government, states, municipalities, the industry, an outside source or, in fact, should the question of licensing even be raised in the absence of an absolutely defined need? These questions and the answers to them are complex and thought-provoking. Diverse viewpoints will be offered by various sectors of the industry and roundly debated. The work of C-TAC and SCTE has demonstrated this quite vividly. This Eye Opener panel may open some eyes and close some others, but in so doing we hope to illuminate various facets of the perpetually sensitive subject.

"The Influence of Transistor and Circuit Design Philosophy on the Performance of CATV Amplifiers"

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Abstract

This paper discusses the characteristics of CATV transistors and circuits with respect to intermodulation. Individual distortion mechanisms are located and described by means of a precision computer program. Practical measurement techniques are evaluated.

Introduction

The major performance - limiting factors in CATV systems are noise and distortion, resulting mainly from the nature and imperfections of the bipolar transistor.

In the early days of CATV extensive testing and screening of transistor candidates by the manufacturer and user was the only way to determine the suitability of a device for this demanding application. Little was known about the mechanisms contributing to undesirable traits, let alone about their control and possible elimination.

This situation has changed. The sales volume for CATV-transistors has reached a level high enough to allow and justify the expenditure of sizeable R&D funds in the areas of device study and improvement. The development of new mathematical tools and the availability of powerful computers have resulted in a much better understanding of noise and distortion mechanisms. New manufacturing techniques like ion implantation, diffused ballast resistors, gold-metallization, etc., are available to implement the new-found knowledge. Therefore, the much improved characteristics of todays CATV transistors are the result of specific, targeted design and tightly controlled manufacturing.

Analytical Methods

When trying to improve a transistor, one will soon realize that there are certain objectionable properties which cannot be eliminated because they are founded in the very mechanisms which make a transistor what it is, and that there are others which can be manipulated. For instance, the exponential V-I characteristic of the base-emitter diode and the random nature of the processes of diffusion and re-combination are unalterable. On the other hand, one can do something about base-widening and squeezing (Kirk and Early Effects), one can control avalanche phenomena, parasitic resistances and non-linear capacitances.

The first step in an effort to understand the complicated situation calls for a mathematical analysis. In recent years several methods have been proposed and used with varying degrees of success. Most often, non-linear mechanisms involving reactive elements (having memory) are represented by means of a Volterra series.[1)] The method is applicable to the most sophisticated transistor models. It yields accurate results as long as the device is operated at low signal levels. Another method, thought to be more efficient by some,[2)] consists of perturbing a model of any degree of complexity to find an equivalent circuit. The linear portions of the device may be represented by the familiar PI-circuit. Non-linear effects are described by the addition of controlled current sources shunting input and output terminals of the PI-circuit.

Yet another way is to refrain from the use of series-representations or small signal approximations completely and to perform an analysis similar to that used to investigate the transient response of transistors. The efficiency of modern computers permits the use of extremely small integration times at a reasonable cost, resulting in a high degree of accuracy. The advantages of this approach are:

1. There is no "small-signal" limitation.
2. Several input signals, e.g., a two-or three-tone test signal, may be applied to the transistor model simultaneously. An automatic Fourier analysis performed on the output will yield detailed information in the frequency domain.

A program of this kind, which may be said to operate in "real-time" was written. The input Questionnaire is shown in the appendix. One may specify all pertinent transistor characteristics, bias points, signal level, as well as circuit parameters, including negative feed-back. All frequencies must be multiples of 10 MHz. Up to five inputs may be used. The program will automatically calculate all harmonic frequencies, 2nd order beats, intermodulation - and triple-beats. Desired and spurious signals listed in dB-magnitude and phase are shown in the output table in the Appendix.

The resolution of the output wave-form is good enough to show spurious responses in the microvolt range. This means that the "computer-noise-level" is at about -60 dBmV.

The program may also be used to calculate the performance of amplifier chains. This works as follows: The output wave-shape of the first stage is Fourier-analyzed and stored along with the amplifier gain at each frequency of interest. Each frequency component is then divided by the respective amplifier gain. After that the individual components are combined to form the time-varying input signal for the next amplifier stage. The cascading feature allows the study of distortion build-up.

Study Results

The greatest benefit derived so far has been insight into the behavior of individual distortion mechanisms. Table 1 shows 2nd and 3rd order distortion for a transistor having no distortion mechanisms other than the non-linearity of the base-emitter diode. Notice the 3rd order null and phase-reversal at

$$Rg = 1/2\ R_{in} = \frac{26mV}{I_e}(1+\beta) = 13\ \Omega$$

Table 2 shows the influence of the avalanche voltage, which determines the output characteristics of the transistor. Observing the phase of the distortion products, one sees at once the possibility of canceling one mechanism by another through the proper choice of circuit impedances and device characteristics.

Table 1. Distortion vs. Source Resistance

Rg	2nd Order		Triple-Beat	
Ω	dB	∅	dB	∅
6.5	-19.85	180°	-45.56	180°
13.0	-21.43	180°	- ∞	-
26.0	-23.89	180°	-48.1	0°
75.0	-29.53	180°	-45.7	0°
1kΩ	-49.44	180°	-61.3	0°

V_{out} = 3 x 120 dBμV

R_c = 75Ω

I_e = 75mA

Common - Emitter

$1 + \beta = 75$

Table 2. Distortion vs. Avalanche Voltage

V_A	2nd Order		Triple-Beat	
Volts	dB	∅	dB	∅
50V	-42.32	0°	-57.37	180°
75V	-52.56	0°	-68.67	180°
100V	-62.00	0°	-76.44	180°

V_{out} = 3 x 120 dBμV

R_c = 75Ω

I_e = 75 mA

V_{cc} = 24 Volts

V_c = 18.375 Volts

Common - Emitter

Usually, it is not possible to minimize both 2nd and 3rd order distortion simultaneously when only two mechanisms are at play. There is a third major source of distortion, which is the result of the change of transistor current gain as a function of I_C. This dependency can be described by:

$$\beta = \frac{\beta\ peak}{1 + A \cdot \ln^2 \frac{Ic}{I_{c\ peak}}}$$

where A is a shape factor, typical for a specific transistor type. At a given value of operating collector current, one may readily determine the percent-change of β per decade I_C. Shown in Tables 3 and 4 are distortions as a function of negative and positive β slopes. The reader is invited to attempt to balance the various undesired outputs and thus take a first step towards becoming a CATV-transistor designer.

Table 3. Distortion vs. Negative β - Slope

Slope	2nd Order		Triple Beat	
	dB	∅	dB	∅
-6.7%	-41	0°	-60.2	180°
-3.3%	-46.3	0°	-66.3	180°
-1.33%	-53.8	0°	-74.4	180°

V_{out} = 120 dBμV

I_c = 75 mA

β = 75

Table 4. Distortion vs. Positive β - Slope

Slope	2nd Order		Triple Beat	
	dB	∅	dB	∅
+6.7%	-46.34	180°	-59.5	0°
+3.3%	-53.95	180°	-65.8	0°
+1.33%	-6115	180°	-74.0	0°

V_{out} = 120 dBμV

I_c = 75 mA

β = 75

Good Nulls - Bad Nulls

Not long ago, a major transistor manufacturer claimed for his product, that all non-linearities, except the one of the E-B diode, had been suppressed to insignificant levels. If this was a true statement (which it was not) the transistor would not be optimum. In order to achieve the degree of linearity compatible with CATV System design goals, compensation must be used. Once this philosophy is adopted, of course, there is always the possibility of obtaining perfect cancellations or nulls at specific operating conditions. For a long time devices having nulls were eyed with great suspicion and often rejected as potentially ill-behaved.

Obviously, since the magnitude of the spurious outputs due to the various distortion mechanism are bias voltage or current dependent, circuits with insufficient stabilization of the operating point, may show a shift of null-locations. Fortunately, understanding the cause points to the remedy. Much more dangerous however, are situations in which the location of the null is signal level dependent. Such nulls are typically very sharp, which indicates precarious balancing between strong distortions. In these cases higher order products are no longer negligible, resulting in a deviation from the "2 for 1"-law. Mathematical analysis entailing series-representations in which terms above the third are dropped, are not suitable to investigate the amplitude dependence of nulls. No such limitations exist for the large-signal computer program described in this paper.

Distortion at high frequencies

In addition to the mechanisms described so far, there are two more sources of distortion: Emitter and Collector Junction-capacitance. As the frequency of operation is raised into the VHF range, these mechanisms dominate, especially with respect to second order performance. In order to display its detrimental effect, the emitter capacitance need not be non-linear at all. It acts by shunting input current past the base-emitter junction, thereby modifying the instantaneous current gain. The collector capacitance, although a negative-feedback element, is non-linear and therefore at once suspect.

In order to determine the magnitudes of distortion, a model which had no deficiencies except some emitter capacitance, was operated under the following conditions:

I_e = 100 mA

R_ℓ = 75Ω

V_{out} = 120 dBμV

f = 10 MHz

C_e = 39 pf

The amplitudes of the 2nd and 3rd harmonics were:

2nd = -45.18 dB

3rd = -67.20 dB

Subsequently, C_e was removed and some collector capacitance installed instead. Increasing the value of C_c, a point was found at which

C_c = 0.283 pf

C_e = 0 pf

2nd Harm. = -45.67 dB

3rd Harm. = -71.10 dB

Adding the emitter capacitance, the situation was:

C_c = 0.283 pf

C_e = 39 pf

2nd Harm. = -85.18 dB

3rd. Harm. = -63.54 dB

The second harmonic distortion was nearly cancelled out, while the 3rd harmonic components added up on a voltage basis. The following additional observations were made:

*Emitter Distortion

Change	Result
$C_e \rightarrow C_e/2$	6 dB better
$I_e \rightarrow 2 \cdot I_e$	12 dB better
$R_\ell \rightarrow 2 \cdot R_\ell$	6 dB better

*Collector Distortion

Change	Result
$I_e \rightarrow 2 \cdot I_e$	no change
$C_c \rightarrow C_c/2$	6 dB better
$R_\ell \rightarrow 2 \cdot R_\ell$	6 dB worse

Feed-back

All examples mentioned so far, pertained to basic amplifiers without negative feed-back. Practical circuits employ heavy shunt and series feed-back. Through most of the operating frequency range the transistor gain decreases 6dB/Octave. Feed-back results in gain-linearization Spurious signals are reduced by about the same amount as the gain is reduced by means of negative feed-back. The net effect is an increase in distortion by about 6 dB for every octave-increase in signal frequencies. A new generation of CATV-transistors with F_t values of 5 GHz is now available. These devices allow the application of stronger and more uniform feed-back throughout the VHF range resulting in much improved performance at the high frequency end. Negative feed-back is not always without problems. In one experiment, a transistor operating at a point of perfect 3rd order cancellation, was subjected to negative feed-back. While the effect on second order outputs was beneficial, as expected, there was now an output on frequencies normally occupied by 3rd order products. The explanation lies in the fact that feed-back allows 2nd order products to get back to the amplifier input and mix with the original drive signal. A similar effect exists in cascades. Amplifiers which by themselves may have only 2nd order distortion, result in cascades with apparent 3rd order by-products. In this respect push-pull amplifiers show a decided advantage over single-ended circuits.

Distortion Testing

Traditionally, cross-modulation has received most attention in the U.S. Later other 3rd order tests, such as triple beat, gained importance. Often the lack of correlation between cross-modulation and triple beat was puzzling, if not frustrating. The only consolation (?) was that cross-modulation values were always better than theoretically possible. The explanation of this phenomenon is easily seen, if one examines the equation for the gain of a feed-back amplifier.

$$\text{Voltage Gain} = \frac{1}{\frac{1}{\alpha} - \beta}$$

were α is the transistor gain and β the attenuation of the feed-back network. At high frequencies, α lags about 90 degrees while β is largely resistive. Cross-modulation results from the modulation of α by the envelope of an interfering signal.

If $\left|\frac{1}{\alpha}\right| << |\beta|$ and, as stated before:

$$\text{Gain} = \frac{1}{j\frac{1}{\alpha} - \beta}$$, then a change of

α will have little effect on the magnitude of the gain, but will change the gain phase. The result is that an unmodulated carrier passed through the amplifier is not amplitude - but rather phase (cross) modulated by the interfering signal.

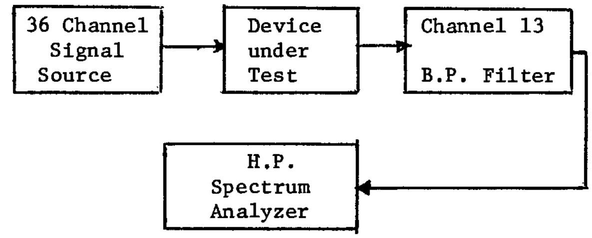
Perfect conversion exists if

$$\underline{/\ 1-\alpha\beta} = -90^{\circ}$$

Many CATV amplifiers operate under conditions where, with or without intent and knowledge, considerably AM to PM conversion takes place. The authors built one amplifier in which the β-phase could be manipulated by a small trimmer capacitor. Adjusting the phase caused all cross-modulation to disappear from a previously poor off-the-air channel 13 picture.

Therefore, since X-mod is heavily circuit dependent, it is not a good quality indicator for transistors. Triple-beat or similar tests in which only amplitude and not phase is of significance, are preferred. Presently en vogue is a test in which the combined spurious power caused by triple-beating 35 carriers is measured in an empty channel 13. Since some 360 components are involved, the spurious power has noise character and may be treated as such. Following are two test setups.

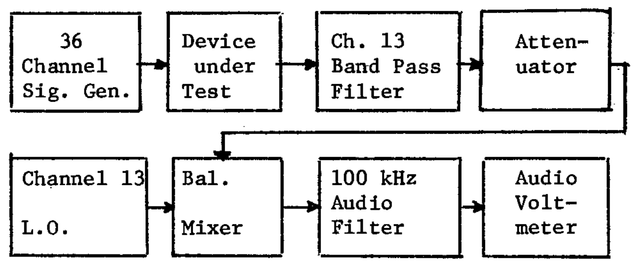
T-B Noise Test using Spectrum Analyzer



Sweep Width	= 0
IF Bandwidth	= 50 kHz
Video Bandwidth	= 10 Hz
Tune-in channel 13	= 0 dB Reference
Switch off channel 13	= dB Beat Noise

Add 2.5 dB to reading to account for noise-like signal and log-amplifier characteristics.

T-B Noise Test using Balanced Mixer



Tune-channel 13, using L.O.
Use Attenuator to establish reference on Audio Voltmeter. Be careful not to overload balanced mixer.
Turn-off channel 13 signal source.
Read Beat-Noise on Voltmeter add 1.05 dB to reading, if voltmeter is average-reading.

References:

1. S. NARAYANAN "Applications of Volterra Series to Intermodulation Distortion Analysis of Transistor Feed-back Amplifiers," IEEE Transactions on Circuit Theory, CT-17, November '70, pp 518-527.

2. R.M. - M. CHEN, C.F. HEMPSTEAD, Y.L. KUO, M.L. LIOU, R.P. SNICER, and E.D. WALSH "Role of Computing and Precision Measurements," The Bell System Technical Journal, December 1974, pp 2249-2267.

APPENDIX

```
OWN OUT. FREQS. OR CALC. (O,C) ? C
0  NOS. OF IN. FREQS.  ? 3
0  INPUT FREQS.  ? 70E6,110E6,120E6
0  AMP. REF. TO VOUT (DB)  ? 0,-6,-6
1  SUPPLY VOLT.  ? 24
2  AVALAN. VOLT.  ? 1E20
3  REF. OUT VOLT.(DBUV)  ? 110
4  LOAD RESISTANCE  ? 75
5  SOURCE RESISTANCE  ? 75
6  BETA OR ALP. OF TRAN.  ? 80
7  MAXIMUM BETA OR ALPHA  ? 80.1
8  IE FOR MAX. BETA/ALP.  ? 150E-3
9  EMITTER CURRENT  ? 90E-3
10 TRANSIT FREQUENCY  ? 5E9
11 EMITTER JUNC. CAP.  ? 20E-12
12 COLLECTOR CAP. AT VCC  ? .2E-12
13 FB. CUTOFF FREQ. # 1  ? 1E20
14 FB. CUTOFF FREQ. # 2  ? 1E20
15 FEEDBACK FACTOR  ? 0
16 NOS. OF CYCLES  ? 3
17 NOS. OF STAGES  ? 2
NEED VOUT BETWEEN STAGES  ? Y
P. PULL OR S. ENDED STAGES (P/S)  ? S
```

First Stage Output

DC. CURRENT = 8.8980E-02 AMPS.

FREQ.(MHZ)	123MIT	LEVEL(DB)	PHASE(DEG)	GAIN(DB)
10	100	-42.82	167.2	35.51
20	10	-68.58	321.3	34.98
30	10	-70.43	312.7	34.21
40	100	-42.19	133.7	33.33
50	100	-42.65	126.6	32.41
60	1	-70.09	299.1	31.50
70	100000	-.01	125.7	30.62
80	1	-71.33	294.9	29.79
100	10	-83.62	293.4	28.27
110	100000	-6.01	116.2	27.58
120	100000	-6.01	114.8	26.93
130	10	-83.74	291.7	26.32
140	10000	-63.52	101.4	25.75
150	10	-82.22	285.7	25.20
160	1	-75.75	283.9	24.69

First Stage Output continued

170	10	-82.02	283.8	24.20
180	100	-60.16	125.2	23.74
190	100	-59.42	127.3	23.30
210	1000	-87.98	264.7	22.48
220	10000	-68.20	130.6	22.09
230	100	-61.53	130.8	21.72
240	10000	-66.90	130.7	21.36
250	10	-82.92	266.9	21.02
260	10	-82.64	267.1	20.69
290	10	-87.37	267.8	19.77
300	1	-80.94	268.0	19.48
310	10	-86.63	268.5	19.21
330	1000	-104.49	273.6	18.67
340	10	-91.27	269.1	18.42
350	10	-90.83	269.4	18.17
360	1000	-102.58	276.2	17.93

Second Stage Output

DC. CURRENT = 8.8980E-02 AMPS.

FREQ.(MHZ)	123MIT	LEVEL(DB)	PHASE(DEG)	GAIN(DB)
10	100	-57.67	251.5	35.51
20	10	-61.70	113.7	34.98
30	10	-63.03	100.0	34.21
40	100	-47.93	199.3	33.33
50	100	-47.17	188.3	32.41
60	1	-62.76	71.1	31.50
70	100000	-.01	251.4	30.62
80	1	-64.41	59.2	29.79
100	10	-75.45	51.2	28.27
110	100000	-6.01	232.4	27.58
120	100000	-6.01	229.5	26.93
130	10	-76.60	40.4	26.32

Second Stage Output continued

140	10000	-66.62	284.1	25.75
150	10	-75.39	31.9	25.20
160	1	-69.40	31.8	24.69
170	10	-75.35	29.8	24.20
180	100	-61.95	301.3	23.74
190	100	-61.03	302.4	23.30
210	1000	-84.45	327.8	22.48
220	10000	-68.70	301.1	22.09
230	100	-61.86	300.4	21.72
240	10000	-67.06	299.6	21.36
250	10	-80.40	325.7	21.02
260	10	-80.14	325.2	20.69
290	10	-85.58	323.4	19.77
300	1	-79.43	323.7	19.48
310	10	-85.19	324.0	19.21
330	1000	-101.22	287.9	18.67
340	10	-90.63	323.5	18.42
350	10	-90.48	324.7	18.17
360	1000	-102.31	292.9	17.93

WANT ANOTHER RUN ? N
END.

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The Potential Benefits of Precise Frequency Control of Television Transmitters

John A. Pranke

Theta-Com

When the present television channel assignments were made by the FCC in 1952, the visual carrier frequency tolerance was specified as ± 1 KHz, with provision for a ± 10 KHz offset where necessary to minimize co-channel interference. These assignments have, with exceptions, proved satisfactory for twelve channel reception and cable transmission, since all second order products fall out of band and the magnitude of triple beats had not been a limiting factor. Recent industry efforts to standardize on a channeling plan for expanded channel systems and an off air, cable compatible receiver have pointed out a number of problems with the present transmission assignments. This paper reviews the various plans proposed within CTAC and other organizations, their advantages and limitations, and concludes that operation of broadcast transmitters on precise frequencies or phase locked to a national standard could effect a major improvement in off air and cable television performance. Methods to achieve such frequency control are also reviewed.

Before going into the main subject matter of this paper, it is desirable to briefly review the history of television channel frequency assignments in the United States. The FCC first assigned frequencies for commercial television broadcast in 1937. At that time the channel width was made 6 MHz, and the form of transmission was double sideband AM, with the picture carrier 2.5 MHz above the lower band edge and an AM modulated sound carrier located 3.25 MHz above the picture carrier. In 1940, the original assighments were slightly modified, and, with the exception of Channel 1, retained the original format of 6 MHz channels with the channel edges on multiples of 6 MHz. The form of transmission was changed to vestigial sideband with FM sound as we know it today. The upper spectrum of Figure 1 shows the 1940 assignments, which provided 18 channels. It is interesting to note that in 1940 this band of frequencies was called UHF.

After the Second World War, the FCC made extensive changes in the 40-300 MHz band, which resulted in the television assignments we have today, shown in the lower spectrum of Figure 1. Again, with the exception of Channels 5 and 6, the format of 6 MHz channels with band edges on 6 MHz multiples was retained. In retrospect, it almost appears that the 1940 assignments were preferable to those of today, since we would not have the problem of Channels 5 and 6. It is also regrettable that the carrier frequencies, instead of the band edges, were not put on 6 MHz multiples, but then hindsight is 20-20.

From 1940 to 1948 (with the exception of the war) the standard picture carrier assignment was 1.25 MHz above the lower channel edge, with a tolerance of ± 1 KHz. In the period from 1947 to 1948, following the war, an ever increasing number of stations went on the air. With more and more stations, reports began to come in about unexpected interference due to long distance propagation. (Marconi had predicted this as early as 1932.) (1) Consequently, in September, 1948, a "freeze" was put on further station construction until the problem could be studied.

After four years, in 1952, it was concluded that the interference could be considerably reduced by the use of ± 10 KHz "offset carriers" for some channels to minimize co-channel interference, and assignment locations based on increased knowledge of VHF propagation. However, as we know, the solution was far from perfect. In 1952, the "freeze" was lifted, and there was a rapid increase in VHF station construction, principally in the late 50's and early 60's.

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(1) Alexander A. McKenzie, "The Three Jewels of Marconi", IEEE Spectrum, PP 46-49, December 1974

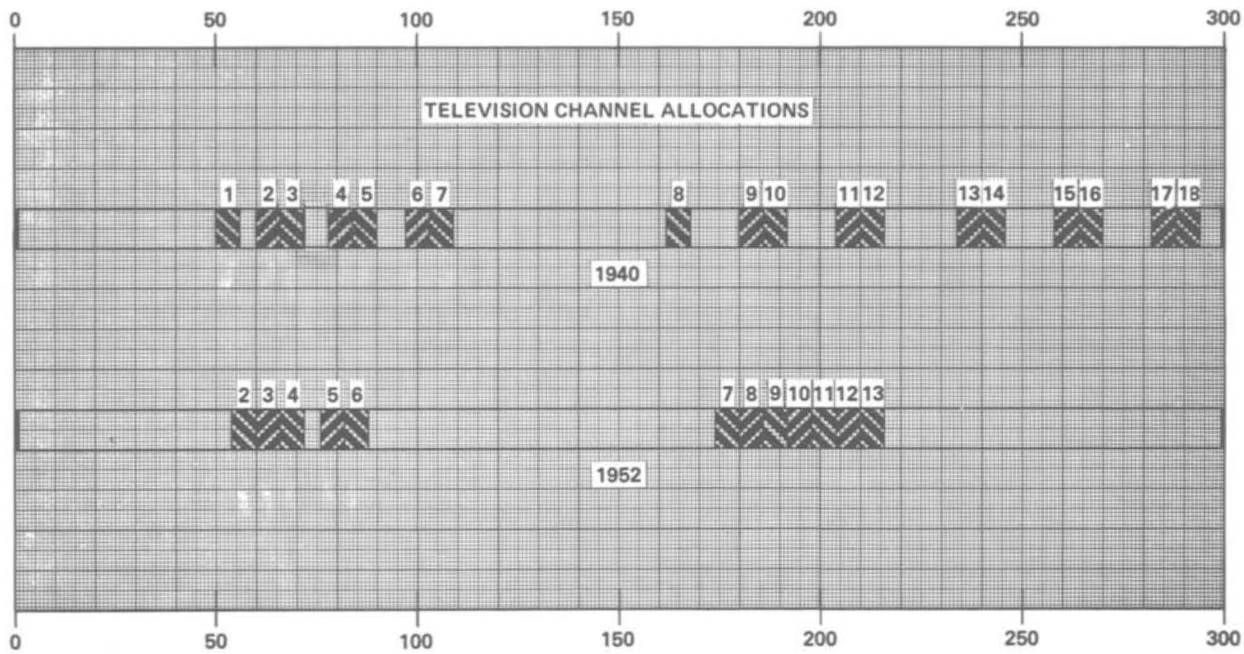

FIGURE 1.

These assignments have, with exceptions, proved satisfactory for twelve channel reception and cable transmission, since all second order products fall out of band and triple beats have not been a limiting factor. However, in the late 1960's, CATV started moving into the larger metropolitan areas and a demand arose for greater channel capacity both where the VHF plus UHF complement of stations exceeded twelve, and to provide extra services to attract revenue. With the advent of push-pull amplifiers, use of the midband for these extra channels became feasible, since the push-pull configuration reduced second order distortions below the interference level. There was some brief interest in single octave systems (120-240 MHz) but they never gained popularity since a standard TV receiver would be restricted to only seven channels on the dial. The most generally accepted channelling plan was simply an extension of the existing FCC allocations both up and down from the high VHF band.

Recognizing the need for additional channels, the FCC, in its Cable Television Report and Order of February 2, 1972, required that cable systems built after that date have a minimum of 20 channel capacity, and that by 1977 all systems over a certain size have 20 channel capacity. In the same Report and Order, the FCC also created a Cable Television Technical Advisory Committee (CTAC) to deal with engineering and operational facts and make recommendations to the Commission regarding technical standards for cable services, limitations on signal degradation, measurement techniques, and in the formulation of future policies in these areas. One of the more important charters of CTAC was to recommend a channeling plan and receiver requirements which would result in a compatible off-air and cable television receiver having minimum economic impact on the consuming public.

Nine working panels were set up within the CTAC organization to investigate different aspects of the problem, and to coordinate with other organizations such as EIA, IEEE, and various governmental departments. CTAC Panel 5 was specifically charged with the task of recommending a channeling plan for cable television use. This paper is based on the work of Panel 5, as viewed by the author, and should not be construed as representing all points covered or the final panel report to the CTAC Steering Committee.

As a starting point, the panel first reviewed all of the previous ideas and proposals for channeling plans from other groups of which it had knowledge.

The majority of these were discussed in the paper "Channel Allocation Options" by Robert S. Powers of the Office of Telecommunications, presented at the 1972 NCTA convention.

After the first few meetings of Panel 5, it became obvious that what at first appeared to be a relatively simple task was indeed going to be a formidable one. This was because of the many areas that would be impacted by the choice of any channeling plan, some of them subtle, and some of them not so subtle. One of the not so subtle facts was the large population of existing TV receivers, coupled with the mobility of the American citizen. A more subtle item was the limitations of the receiver manufacturers in producing a compatible set without undue economic impact. While a beautiful engineering solution could be achieved with relative ease, the panel had to spend a great deal of time considering the other factors involved.

Following the review of the various channeling plans brought forward, it was the consensus of the panel that only three merited further, in-depth study. Briefly, these plans may be described as follows:

Plan 1 - Augmented FCC assignments with standard tolerances and offsets. This is essentially the "de-facto" situation currently in use by most CATV systems using the mid and super bands.

Plan 2 - Constant interval assignments based on a 6N + 1.25 MHz comb of frequencies. This would put all picture carriers on the system in a phase stable condition, but requires rather complicated equipment at the headend.

Plan 3 - Harmonically Related Coherent (HRC) assignments based on a 6N MHz comb of frequencies. (Other frequencies close to 6 MHz could also be considered.)

The picture carrier frequencies resulting from these plans are shown in Table 1. Here the mid band channels, A through I, and the super band channels, J through W, are shown with their common alphabetic designation. For practical considerations affecting tuner channel identifications, a national standard for a 20 channel receiver might employ a numeric system such as 92-99 for the eight augmented channels.

Channeling plans, with respect to CATV system performance, primarily affect three areas:

A) Direct off-air pick-up
B) Second order distortions
C) Third order distortions

In the case of direct off-air pickup, Plan 1, assuming the cable is locked to the local, presents only the problem of leading ghosts, since the broadcast and cable frequencies are the same. Plans 2 and 3 could create co-channel type interference since there is a frequency off-set.

Second order distortions ($F1 \pm F2$ and $2F1$ products) are a problem with Plans 1 and 2, and especially with regard to Channels 5 and 6. HRC is the only plan with potential for reducing these interferences, but it in turn creates problems in receiver compatibility and off-air pickup. Second order distortion is generally not a limitation with modern push-pull equipment in expanded channel systems, but is quite serious in older single ended equipment.

Third order distortions ($F1 \pm F2 \pm F3$ and $2F1 \pm F2$ products) are a problem with Plan 1 since the carriers are not on precise frequencies and the resultant beats appear as sidebands or "busy background". The number of these beats and their visible effect increase very rapidly as the number of channels is increased. (2) Plan 2 substantially reduces this interference since the majority of carrier beats are zero beats and only have a minor effect on luminance. Plan 3 (HRC) makes all visual carrier beats zero beats. (Note: Cross modulation is a special case of third order distortion and will occur with any channeling plan.)

During discussions of the full panel, it was evident that certain members of the panel, especially those concerned with receivers, preferred Plan 1 because of compatibility problems with an off-air and cable receiver. Plan 2, the constant interval assignment, with the exceptions of Channels 5 and 6, results in channel frequencies which are the same as Plan 1, but with the added requirement that all of the carriers be phase stable. This immediately suggests an eminently practical compromise to the off-air cable compatibility problem. Namely, in order to utilize the interference reduction potentials of Plan 2 in the most economical and nationally standardized manner, that the FCC adopt a 6N + 1.25 MHz constant interval channeling plan, but with <u>all broadcast transmitters on precise frequencies or phase locked to a national standard.</u>

(2) "A New Approach to Evaluating CATV System Triple Beat Performance" - John A. Pranke, April 1974

(Proposals for handling Channels 5 and 6 will be discussed below.) In 1952, precise control of carrier frequencies would have been very difficult to achieve. Today it can be quite easily accomplished, particularly with the availability of atomic frequency standards at moderate cost. In fact, some broadcast transmitters now are using Rubidium standards as their carrier source, complete with ± 10 KHz off-set if required by their channel assignment.

Precise control of broadcast transmitter frequencies would have some very significant advantages:

1. Off the air reception would be improved by substantial elimination of co-channel interference. This would definitely be in the public interest.

2. Since all channels would be on precise frequencies, receiver design, for both off-air and cable could be improved through the use of crystal stabilized frequency synthesizer local oscillators and improved traps on exact frequencies.

3. Cable system performance would be improved since the large majority of carrier triple beats would be zero beats.

4. If a WWV type national standard were employed, sync reference information could be included to effectively gen-lock all transmitters, further reducing the effect of third order distortions.

5. Locally originated channels could also readily be locked to the precise frequencies with the same advantages.

The major problem with the constant interval plan, as with the augmented FCC plan, is the 2 MHz offset of Channels 5 and 6. Initially, for some period of time such as five years, these channels could be put on precise frequencies or phase locked to a 6N + 5.25 MHz comb. (or equivalently all channels to a 2N + 1.25 MHz comb.) while provision is made to ultimately move them up 2 MHz to fit the 6N + 1.25 MHz comb in perhaps 5 to 10 years.

Moving Channels 5 and 6 up 2 MHz would mean the loss of 2 MHz in the FM band, or half of the portion reserved for educational stations. There are currently approximately 250 stations operating in these 2 MHz, most of very low power, and the impact of reassigning them would have to be carefully studied. In the meantime, system operators could move them themselves if receiver tuning or off air does not prove to be a problem. If converters are used, they could be placed in other parts of the band to solve off air problems.

With today's technology, putting all broadcast transmitters, both VHF and UHF, on precise frequencies is very feasible and represents a very cost effective method of achieving a major improvement in our television transmission methods for both off the air and cable reception. Rubidium controlled signal sources are available from several manufacturers with frequency stability which is quite impressive. For example, typical specifications are:

Long Term Stability: $<2 \times 10^{-11}$ per month
Systematic Trend: (typically 1×10^{-11} per mo.)

Short Term Stability: One Second Averages: $< 7 \times 10^{-12}$ rms

Applying the short term stability to Channel 13 one can calculate the frequency error as:

$$(211.25 \times 10^{6})(7 \times 10^{-12}) = .0015 \text{ Hz rms}$$

With this type of stability it would take 666 seconds, or over 11 minutes for a beat to move across a television receiver's screen. It is well known that stationary or very slowly moving interferences are less objectionalbe than rapidly moving ones, and the above stability is several orders of magnitude better than typical quartz oscillators.

The use of individual atomic frequency standards at each transmitter may be considered as a first step toward putting all transmitters on a true precise national standard. A second step might be the establishment of regional "master" stations to which all other stations in the area could be slaved, including sync information. By making all of the blanking intervals in a given region coincident, the effects of sliding frames, cross modulation and triple beats due to sidebands could be even further reduced. Finally, all of the regional master stations could be tied together, establishing a national standard.

In conclusion, our present television system has served the nation well for almost three decades, but has obvious defects in terms of current needs. The above proposal could effect a major improvement for both off-air and cable reception for many years to come. Eventually there will be a demand for a system having higher definition, three dimensional capability and who knows what else. That will require a massive effort by the entire communications industry, but in the meantime we should employ every technical advance possible to improve our present system.

TABLE 1

NOMINAL VISUAL CARRIER FREQUENCY

	1	2		3	
Channel	Nominal FCC Visual Carrier	Constant Interval Carriers		Harmonically Related Carriers	
		n	(6n + 1.25)	n	(6n)
2	55.25	9	55.25	9	54.00
3	61.25	10	61.25	10	60.00
4	67.25	11	67.25	11	66.00
5	83.25	13	79.25*	13	78.00*
6	83.25	14	85.25*	14	84.00*
A	121.25	20	121.25	20	120.00
B	127.25	21	127.25	21	126.00
C	133.25	22	133.25	22	132.00
D	139.25	23	139.25	23	138.00
E	145.25	24	145.25	24	144.00
F	151.25	25	151.25	25	150.00
G	157.25	26	157.25	26	156.00
H	163.25	27	163.25	27	162.00
I	169.25	28	169.25	28	168.00
7	175.25	29	175.25	29	174.00
8	181.25	30	181.25	30	180.00
9	187.25	31	187.25	31	186.00
10	193.25	32	193.25	32	192.00
11	199.25	33	199.25	33	198.00
12	205.25	34	205.25	34	204.00
13	211.25	35	211.25	35	210.00
J	217.25	36	217.25	36	216.00
K	223.25	37	223.25	37	222.00
L	229.25	38	229.25	38	228.00
M	235.25	39	235.25	39	234.00
N	241.25	40	241.25	40	240.00
O	247.25	41	247.25	41	246.00
P	253.25	42	253.25	42	252.00
Q	259.25	43	259.25	43	258.00
R	265.25	44	265.25	44	264.00
S	271.25	45	271.25	45	270.00
T	277.25	46	277.25	46	276.00
U	283.25	47	283.25	47	282.00
V	289.25	48	289.25	48	288.00
W	295.25	49	295.25	49	294.00

*Special consideration must be given to these channels.

TRANSIENT AND OUTAGE ELIMINATION IN CATV SYSTEMS

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The nature of CATV system transients is discussed and the devices used for system protection are evaluated and compared. Methods of employing protective devices to the best advantage of the system are discussed and a multi level field proven protection scheme is presented.

The causes of system outages are explored and the impact of protection schemes on fusing and related outage problems is discussed. It is shown that proper fusing together with judicious protective device application can eliminate all but the most catastrophic outages, excepting, of course, loss of primary power. For outage protection with loss of primary power the various means of standby powering are explored and a new concept in standby power source implementation is presented.

NATURE OF TRANSIENTS AND SURGES IN CATV SYSTEMS

Abnormal operating voltages introduced into CATV systems fall into three basic categories:

1. Short duration (< 10 ms) usually 2 to 20 times normal voltage (caused directly by lightning strikes or lightning induced power surges).

2. Medium duration (10 ms to 1 second) usually 2 to 4 times normal voltage (turn on surges of main power and/or power supplies of the CATV system).

3. Long duration (> 1 second) usually 2 to 20 times normal voltage (caused by accidental contact between cable system and power system primary or high voltage lines).

Short duration surges usually have a fast rise time, typically 2 μs, and a fall time of 100 μs to 1 ms. Extensive observation by Bell Northern Research teams(1) indicates that 99.9% of all lightning caused surges induced or conducted into coaxial cable had peak voltage less than 1000 volts. Approximately 2% had rise times less than 20 μs or fall times greater than 4 ms.

METHODS OF SURGE ENTRY INTO THE CATV SYSTEM

The prime means of introduction of abnormal operating voltage is by the powering system, although surges can be generated within the CATV system itself. A summary of intrusion points is given below and depicted graphically in Figure 1.

1. Surges introduced via the ac power line having been introduced to the power line by lightning or very high fault currents.

2. Surges produced by the CATV ac power supply when the primary power is switched on and off during power fault conditions.

3. Sheath currents due to lightning or other high level currents such as power faults, which are coupled into the system via any small resistance.

4. Inductively coupled currents which are set up due to lightning or power fault currents, which exist in proximity to the system.

5. Transients which might occur in the amplifier power supply due to power off-on switching.

PROTECTION DEVICES FOR CATV SYSTEMS

There are many surge protection devices now available that can be used in various combinations to achieve a high degree of surge immunity. Some of the more useful devices are discussed below.

1. Miniature Gas-filled Surge Suppressor

These devices offer low capacitance (~2 pF), bipolar clipping for voltages ≳90 V. Lower breakdown voltages are not possible because of the characteristics of Paschen discharge in low pressure gases. Gas-filled surge suppressors have an intermediate response time (~1 μs turn-on time). They can handle large current surges of low duty cycle (~1-5 kA) for 100 μs but do not stand up well under continuous current discharge over 1 A. If their discharge current is limited to ~10 A peak with low duty cycle, they have a long life.

2. Zener Diodes

Zener diodes have intermediate capacitance values (~30 pF for 1 W devices) and relatively fast switching time (~40 ns, depending on junction capacitance). They have low surge current capability (~0.1 A) because of their power dissipation limitations.

Breakdown voltages range from 1 to 200 V and zener diodes are frequently used to trigger other devices which can handle large surge currents (such as SCR's).

Zener diodes can also be used in tandem to provide bipolar limiting to any voltage from 2 to 200 V.

3. Solid State Switches (e.g. Diac, Triac, SCR's)

These devices usually rely on external circuitry (resistors and zener diodes) to provide accurately controlled turn-on. They have moderate power dissipation capability (~100 W) and find wide application for power supply protection.

4. Variable Resistance Devices

a. Varistor

These are metal oxide devices that have a voltage variable resistance. They have high capacitance (~1000 pF) and fair peak current capability (~1 kA for 7 μs). Breakdown voltages range from ~30 to 1400 V. Limiting characteristics are fair.

b. Thyristor, Thyrector, Thyrite

These are mainly silicon carbide devices. They have high capacitance and good surge current capability but poorer limiting characteristics than varistors.

5. Mechanical Switches (e.g. Time Delay Power Relays)

During a power surge these devices disconnect the applied power. They are slow acting (~0.1 to 1 second) and can be programmed to reconnect power to the system after a prescribed waiting time from return of primary power.

SYSTEM PROTECTION TECHNIQUES

Since surges can be very severe and can be introduced at practically any location in the system, it is very desirable to locate protection devices at scattered locations in the system. These should:

1. Minimize and/or attenuate the surge injected into the system.

2. Protect the electronic equipment from any residual surge that inevitably does intrude.

Some of the protection points and methods are listed below:

1. At power input, filtering and a high energy breakdown device to absorb power transients. Attention to grounding to minimize ground coupled transients.

2. At power supply output, where the transformer transients are introduced, use time delay relays and/or energy absorption devices to limit output voltage.

3. At amplifier input and output, gas diodes attenuate transients that otherwise could be capacitively coupled to the RF transistors.

4. At the transformer secondary of dc power supply (which is very vulnerable because of the low frequency direct conduction path to the transformer). This is the only protection point that prevents sheath currents from affecting the amplifier station. Use SPM and filter capacitors for protection.

OUTAGES IN CATV SYSTEMS

1. Causes of System Outages

The basic cause of most system outages is usually abnormal operating voltage conditions - either an excess of it or lack of it. Protection of the system from lightning caused transients and power line surges is highly desirable but if it alone is done, outages will still result. One of the problems is the system fusing must be closely examined and adjusted to prevent nuisance blowing when protective devices are activated, yet prevent loss of stations when catastrophies such as accidental contact of cables with live HV transmission lines occur. With the CATV system fusing properly adjusted the other major outage cause, the primary power source, needs to be examined.

2. Prevention of System Outages

There are several existing techniques for maintaining system power when primary power fails. The technique most used to date employs a dc to ac inverter at the constant voltage supply with two principal variations in the form of a "non-interruptable" and "interruptable" output. There are, in fact, some problems with standby powering as it exists today. A few experiences have been so bad as to generate comments to the effect that the standby system is less reliable than the primary power source!

Some basic considerations on standby powering are as follows:

1. For unattended operation, the standby power source must use some form of storage battery.

2. All batteries produce dc power.

3. Batteries require dc for charging.

4. It would be logical to use these dc features of the battery in conjunction with the amplifier power supply itself, eliminating the need for dc to ac conversion by an inverter, the attendant power loss in the ac distribution system and the additional loss sustained in reconversion of the ac to dc for use by the amplifier.

With this in mind, a new concept in standby powering has been developed which would operate from the raw dc present at the individual station power supply regulator input. Using this point for dc standby power injection, the dc to ac and ac to dc conversion losses are eliminated. Further, upon loss of primary power, the switchover to standby power can be instantaneous with no change whatsoever in the regulated dc output. When primary power is restored, switchover to the float charge mode is also instantaneous and automatic. The raw dc voltage is passed through a simple current limiting, constant voltage regulator to restore the rechargeable batteries to their fully charged condition and hold them under float charge with very little power consumption. The overall concept is depicted in Figure 2.

Although the total number of standby power sources will be larger with this approach than inversion at the ac supply, the inherent simplicity and efficiency of this approach appears to offer greater reliability and cost effectiveness, especially for standby powering critical runs of existing equipment. Normally these standby power source units would be placed at all critical trunk locations and possibly selected external bridgers. When a power failure is localized, it also affects power to subscribers in the nearby distribution area. Therefore it would appear unnecessary to provide standby powering for line extenders. The fundamental purpose of standby powering is to prevent a local outage from causing the remainder of the system to be without signals.

SUMMARY

CATV system equipment damage caused by transients and surges can be eliminated for all but direct lightning hits, however, good system grounding and construction techniques are a MUST. How extensive a protection scheme is incorporated depends on the severity of lightning in the area, local power system characteristics and terrain.

Outages caused by transients and surges can be prevented by proper equipment protection and system fusing. Outages caused by loss of primary power can only be eliminated by use of a standby power source that is omnipresent and omnipotent - especially critical on the main trunk line. A new concept in standby powering has been presented for this application for consideration.

REFERENCE

(1) "Lightning Surges in Open Wire, Coaxial and Paired Cables", E. Bennison, et al, International Conference on Communications Proceedings, Philadelphia, 1972.

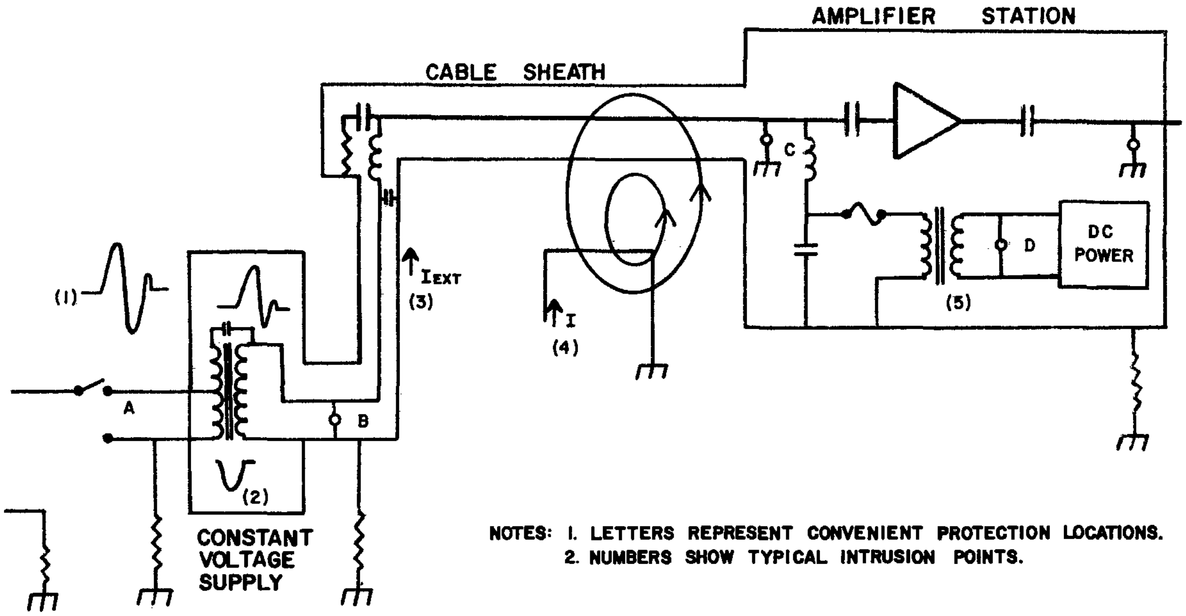

FIG. 1. SCHEMATIC REPRESENTATION OF TRANSIENT INTRUSION INTO THE C.A.T.V. SYSTEM.

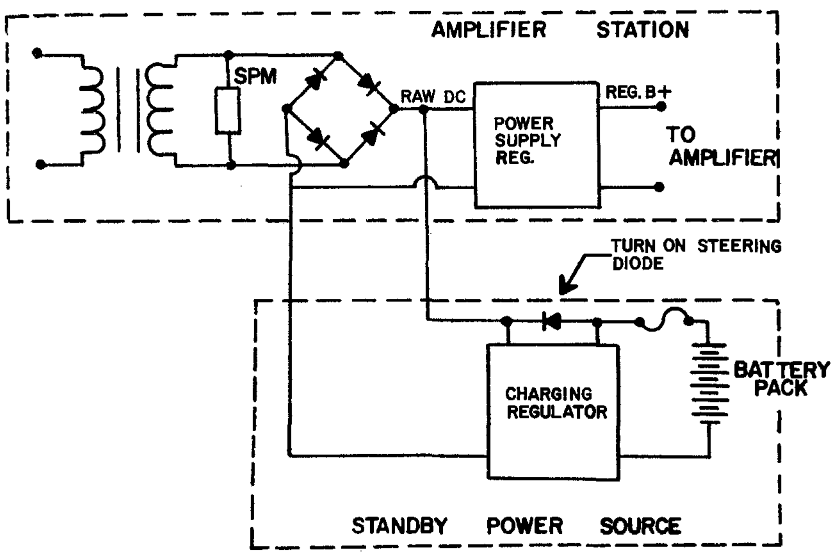

FIG. 2. BLOCK DIAGRAM OF SPS STANDBY POWER SOURCE CONCEPT.

TRANSIENT CONSIDERATIONS FOR CATV SYSTEMS

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ABSTRACT

This paper deals with the damage and outages caused by both natural and man generated transients which are a major, very costly problem for CATV system operators. The paper is divided into 3 categories:

1. The nature of transients
2. Source of transients
3. The prevention of damage and outages from transients

The emphasis in the paper involves an analysis of how transients get into the cable systems. These are categorized in such a manner as to enable analysis and preventative measures to be taken.

Protective devices are discussed in some detail including the characteristics and limitations of these devices. The major solution discussed in regard to preventing transient damage is the grounding system as used conventionally and as it might be used to improve the grounding action. The solutions discussed in the paper have been based on experience of systems as observed over the past two years.

INTRODUCTION

Damage and outages caused by transients are a major and very costly problem for CATV systems especially for those located in areas of high transient activity.

The problems created include those caused by any system outage; the main ones being customer complaints and dissatisfaction; the added time and expense of maintenance crews.

In addition, a considerable amount of equipment damage can occur. RF transistors by their nature are very susceptible to damage. To a lesser extent, power supplies, splitters, directional couplers, filters and power chokes can be damaged by transients.

For purposes of discussion, we can separate the subject into the following categories:

1. Nature of transients
2. Source of transients
3. Prevention of damage and outages from transients

THE NATURE OF TRANSIENTS

The damage caused by transients can be appreciated if we look at the nature of transients, i.e., rise time, duration and particularly the magnitude of the currents and voltages.

Direct lightning strikes have had the following recorded:

Current:	10,000 amps avg. to 260,000 amps maximum
Rise time:	12,000 V/usec
Voltage:	72,000 V
Waveform Definition:	6 x 20 is a standard test waveform for typical lightning strikes

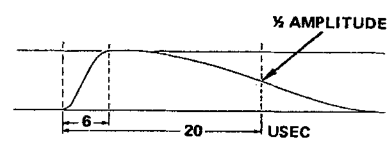


Figure 1

The first number is the rise time, the second is the time to decay to 1/2 amplitude.

Power line surges resulting from load switching transients can range from one usec to the larger part of a second. Currents of 2000 amps and voltages of 15,000 volts are not uncommon.

Higher and lower values for transients can be cited, however, when compared to the 24 volt transistors we use, the magnitudes are formidable.

THE SOURCE OF TRANSIENTS

We can classify transients into two types.

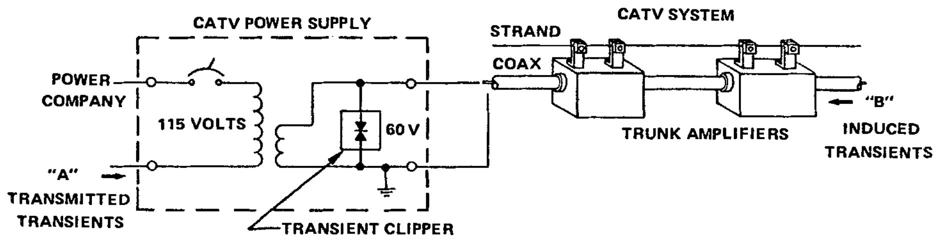


Figure 2

A. Those which enter the system via the 60 Hz pole mounted A. C. power supplies. These transients are present on the power line and enter through the 115 volt primary. These power surges are usually present where heavy industrial loads are being switched. Automatic reclosure of power company circuit breakers also create transients to the power supply. Lightning can also be a cause. It is interesting to note that power interruption for less than 5 seconds is not classified as an outage by many power companies. In a typical power company, there may be 2,500 per year of these short duration non-classified outages which cause transients.

Ferro-resonant type power supplies due to their nature can cause a transient as high as three times rated output voltage when turned on.

Protection for these transmitted type transients can be provided by several types of devices.

B. The other type transients are those which are inductively coupled into the strand or coaxial sheath of the CATV system. These may be caused by power line faults, load switching, lightning and atmospheric effects.

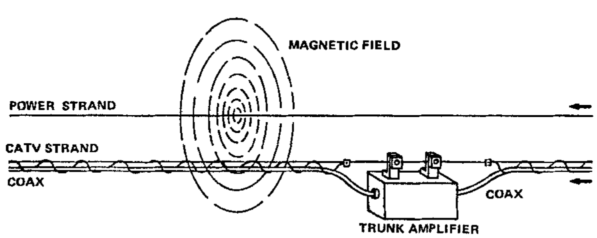


Figure 3

Inductive coupling shown in Figure 3 occurs due to current in a conductor (such as the power strand) creating a magnetic field which cuts (or couples) another conductor (in this case the CATV strand). A voltage is generated in the CATV strand which will cause a current to flow. These currents in both the power and CATV strand flow to the best ground point or points.

Both transients and steady state voltages can be inductively coupled when neutral (strand) or unbalanced currents flow in parallel conductors.

The most important consideration for system protection from this type of transient is a good grounding system.

PREVENTION OF DAMAGES AND OUTAGES FROM TRANSIENTS

Theory is interesting but most important, what are the practical methods a system operator can use to protect his system against transient outages.

Protection for those transients entering from the A. C. power supply is relatively simple. The Transient Clipper, used and field tested by Theta-Com, has proven to be quite effective.

Let us look at how the Transient Clipper protects the system from transients which enter through the power supply.

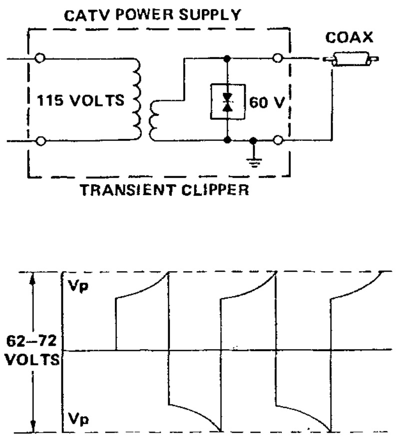


Figure 4

The typical waveform from a ferro-resonant supply is shown in Figure 4. The peak value is 62 to 72 volts at full load and no load respectively. The Transient Clipper is connected across the 60 volt (RMS.) terminals and will conduct when the peak voltage exceeds 91$\pm$ 10% in either a positive or negative direction. This is done by a network of avalanche (zener) diodes. The voltage and current characteristics of the transient clipper and three other devices are shown in Figure 5.

Ferro-resonant type power supplies (which are used by the majority of CATV systems) produce a voltage transient of 2 to 3 times rated voltage when turned on. This will decay to normal in 2 or 3 cycles of the 60 Hz frequency. The Transient Clipper will clamp these at a lower voltage than the spark gap type devices. The spark gap units at times would not turn off due to the power supply short circuit current. When they do not turn off, they will destroy themselves by melting solder joints in the associated circuitry. The Transient Clipper does not have this problem as it turns off at approximately 91 volts peak.

The basic circuit device in the Transient Clipper has been used in airborne electronics equipment to protect voltage sensitive components from large voltage transients. The device was tested in the Theta-Com Engineering laboratory and subsequently installed in several systems that were experiencing severe transient problems.

The resulting reduction in transient damage and outages has been dramatic in most cases.

Time delay relays which allow time for transients to pass before connecting power to the cable system have been used with good results. The Transient Clipper will perform the same function and operates much faster.

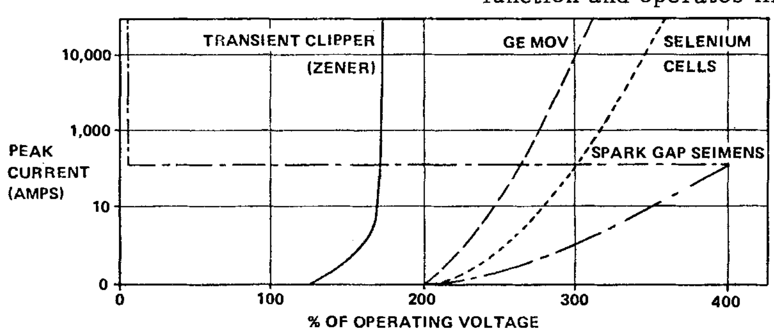


Figure 5

Characteristics of The Transient Clipper

The sharp curve (zener characteristic) allows the breakdown voltage to be set reasonably close (130%) to the operating voltage. Other devices used start at 200% and some go to 400% voltage before complete breakdown. When the Transient Clipper conducts, it clips above 91 volts but does not present a low impedance or short circuit as does the spark gap device. The turn on and off time is very fast at 10^{-12} seconds (one millionth of one microsecond). It has a peak pulse power dissipation rating of 15,000 watts and a peak pulse current rating of 300 amps. The small size of the Transient Clipper allows it to be easily mounted in the power supply housing.

Protective devices such as fuses, surge suppressors, transient clippers, over-voltage circuits are necessary and useful to protect equipment, but, they many times create a secondary problem by causing a system outage in the process.

Protection against type B(see Fig. 2) transients which enter from the strand is more difficult. The most important element for protection is a good grounding system. The grounding system should minimize the magnitude of the transients before they reach the equipment and protective devices. This will reduce the fuse type outages to a necessary minimum.

General Ground System Considerations

The resistance should be as low as possible. Wetter soil and higher clay content will have lower resistance. OSHA requires 8' ground rods. Multiple ground rods can be used to provide a lower resistance.

In addition to resistance, the inductance of the ground lead is a factor. A high inductance will produce a high transient voltage. Lower inductance can be provided by multiple leads, woven copper straps are also quite effective.

Antenna Site

1. The mast should be higher (preferably 10') than the antenna.
2. Heavy copper conductors should run from the top of the mast to the ground system instead of depending upon the mast for conduction.

In extremely dry soil, a good ground is difficult to establish. Methods that have been used are: several buried radial 100-200' copper conductors, large masses of scrap metal such as car radiators have been buried 4 to 6' deep to provide a ground.

Cable Distribution System

The generally recommended considerations for good grounding should be followed.

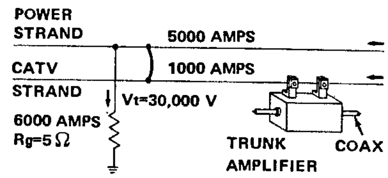
Ground resistances on the order of 5 ohms are desirable. Good grounds in dry climates may be impossible to establish.

The commonly used practice of obtaining a ground by "strapping" the CATV strand to the telephone or power company strands has in many cases created transient problems for the CATV system.

There are three grounding situations shown in the diagrams below which are significant. In all three situations it has been assumed that the surge current in the power strand is 5000 amps and a surge of 1000 amps has been inductively coupled into the CATV strand and coax sheath. A ground resistance of 5 ohms has also been assumed.

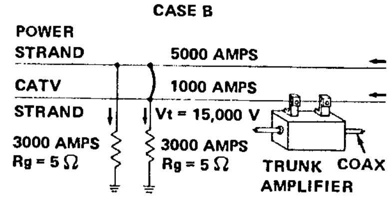
In case A shown below, the CATV strand is "strapped" to the power strand and the sum of 5000 and 1000 amps flow through the common ground resistance of 5 ohms, producing a voltage at the amplifier case of 30,000 volts.

CASE A



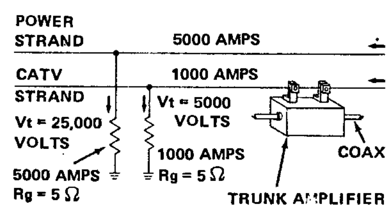
In case B shown below, a separate ground lead and rod have been installed on the CATV strand which is still strapped to the power strand. The total surge current of 6000 amps divides equally between the two grounds and produces 15,000 volts (3000 amps x 5 ohms) at the amplifier housing. This is a 2 to 1 improvement over case A.

CASE B



In case C shown below, the strap has been removed from the power strand, allowing the surge current in each strand to follow the separate grounds installed on each system. The 1000 amps in the CATV strand will produce 5000 volts (1000 amps x 5 ohms) at the amplifier housing. This is a 6 to 1 improvement over case A.

CASE C



The above is intended to illustrate the problems that can be encountered in grounding systems and the importance of low ground resistance. There are requirements, in many instances, to be strapped to power grounds. However, some systems having consistent transient problems were able to cure them only by removing the strap.

The magnitude of the currents and voltages are chosen only to illustrate the circuitry involved. Other factors such as cable resistance and inductance affect the magnitude of the transient voltage at each amplifier. Analysis of equipment damage has shown that voltage transients of over 2000 volts commonly reach the equipment.

History of Typical System Experience

1. Area of high transient activity.
2. Trunk line of 5 miles on power line poles. All poles grounded with butt plates.
3. CATV system was strapped first, last and tenth poles to power strand.
4. Transients induced voltages on CATV strand and tripped amplifier over-voltage protection which consistently blew fuses.
5. Separate grounds were installed at each amplifier and each adjacent pole. This gave significant improvement.
6. Some outages continued until straps were cut from power strand.
7. No outages for several months during last storm season.

Protective Devices

Spark Gap Surge Suppressor -

1. Used extensively directly on RF line to protect transistors. They are the only device with sufficiently low capacitance that can be used on coax center conductors without affecting the RF signals.
2. Firing time varies with transient rise time. At 500V/microsecond firing time is approximately 2 microseconds. At 100V/microsecond firing time is 5 to 10 microseconds.
3. Firing point usually 200% of rated voltage to allow device to turn off.
4. Low impedance during conduction creates transient on ferro-resonant supplies. Can create a sustained short due to continued arcing. (A 35 amp follow on current rating will prevent this).
5. Voltage across the device can rise to 400% of firing voltage during ionization and prior to arcing.
6. Specifications

Siemens P/N	Firing Volt.	Peak Surge Current
B1-C90/20	90 $\pm$ 20%	5 KA
B2-C145	145 $\pm$ 20%	5 KA

Follow On Current	Insulation Resistance	Capacitance
20A	10K	2 pf
35A	10K	1 pf

Silicon controlled rectifiers -

1. Breakdown to low impedance.
2. Are hard to turn off.

Metallic Oxide Varistors (type of selenium) protector) -

1. Fire at 200% of rated voltage.
2. Will not take surges of ferro-resonant supplies.

Transient Clipper -

1. Is a bipolar (back to back) power type avalanche or zener diode.
2. Clamps at a fixed voltage level @ 130% rated voltage.
3. Does not break down to low impedance.
4. Fast firing and fast recovery.
5. Used across secondary of system power supply.
6. Responds to peak voltage.

Fuses -

1. Protect circuit devices such as rectifiers, transformers, etc. but not transistors.
2. Slow acting. Slow blow fuses are used to prevent nuisance tripping.
3. Firing time is in the order of 1 to 5 milliseconds to 1/2 second.

Thermal Breakers (Sylvania P/N ESB710E3A) -

1. Used in bridger legs in series with fuses to prevent nuisance fuse outages due to momentary shorts during tap installation.
2. Has been used in place of fuses. Has a slightly slower firing time. Contact could weld shut. Series fuse should be used.
3. Cycling on permanent short can affect other bridger legs.

Crowbar Circuit -

Used in the amplifier D. C. power supply to sense D. C. overvoltage which may be caused by transients. Zener fires an SCR which clamps DC voltage to low level and blows DC fuse.

Thyrite Pellet Arrestor -

Used across primary of power supply to reduce transient load on primary. Basically a high current device.

Time Delay Relay -

1. Used across power supply to sense over-voltage and take power off cable system for fixed delay time and until transient has passed. 10 - 20 seconds.
2. Mechanical device.
3. Slow acting on initial transient.
4. Has proved effective.
5. Transient clipper should be more effective.

Coupling Capacitors -

1. On amplifiers, smallest capacitance value usable as a blocking capacitor will limit transients.
2. On passives, 500 volt capacitors are preferable. Actual breakdown and test voltages of capacitors are compared below:

Life Rating	Test Voltage	Actual Breakdown Voltage
200V	600V	2100
500V	1500V	2500

CONCLUSION

Transient problems vary considerably in different systems and in various parts of each system. An exact analysis is difficult due to the expensive instrumentation task which would be necessary.

An upgrading of the grounding system, use of transient clippers, surge suppressors and proper coupling capacitors should solve the majority of transient problems.

TWO-WAY SYSTEM EXPERIENCES

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Cablenet International Corporation and Coaxial Scientific Corporation have been operating a per program pay television business in Columbus, Ohio, since June of 1973, using a two-way cable system. This system utilizes technology developed by Coaxial Scientific Corporation which greatly reduces the home terminal cost, simplifies system maintenance, and increases reliability. In the past two years of operation, CSC and Cablenet have gathered a substantial amount of information on two-way system design, construction, balancing, performance, and maintenance. The practical experience gained in the course of operating the two-way CATV system over the last several years will be discussed. An analysis of signal intrusion, noise accumulation, system hum, and system impulse noise problems and their solutions will be among the topics discussed. In addition, day-to-day operation procedures developed by CSC and Cablenet for two-way systems will be discussed. The experience gained demonstrates that two-way CATV is now economical and practical for not only per program pay television but also other services such as fire, intrusion alarm systems, opinion polling, and interactive data transmission.

Coaxial Scientific Corporation has been operating a two-way Pay Television System in Columbus, Ohio for the past 2 years. This system presently consists of approximately 1,500 subscriber terminals and 200 miles of active two-way cable plant. This system uses a unique data transmission technique which was described in last year's NCTA convention. In brief, the system utilizes Code Operated Switches which are located at each bridger amplifier in the cable system. These switches control the flow of upstream signals into the trunk line from each bridger area. (See Figs. 1 & 2) This approach makes possible an inexpensive frequency division multiplex home terminal unit and significantly reduces RF intrusion problems.

In this paper I will describe the two most significant problems we faced in our two years of operation and their solutions.

The first problem faced by the two-way CATV operator is the level instability of upstream signals. Instability arises not from temperature variations as they do in downstream cable plant, but from poor distribution plant integrity, and more significantly, from poor housedrop integrity. We have found that well over half of our operating problems have been due to level variations caused by corrosion in F type fittings in subscriber housedrops. In order to keep subscriber return levels to within an acceptable range, we have found that several things are required.

1. System Design. It has been the philosophy of CATV system designers that upstream signal levels will fall in line when a system is properly designed for downstream signals, and any variations that may result can be compensated for by providing a home terminal with a variable RF output level. In theory this approach works fine. In practice however, it has serious drawbacks. A CATV system so designed results in variations in upstream levels between home terminals in a bridger area of approximately $\pm$ 8 db. It is no problem to provide a home terminal unit which has a 16 db RF output level range to compensate for this difference. However, since it is possible to compensate for most distribution plant and drop problems by turning up or down the RF level control of the home terminal, many faults are masked. In a large number of cases we have discovered that terminals will suddenly and radically change their level at the headend over time due to poor cable integrity in the plant or the subscriber housedrop.

Therefore, we have determined that it is necessary to establish extremely tight specifications for return levels from subscribers' homes to the cable system headend. Our upstream plant is designed so that a signal inserted at the end of any feeder line will arrive back at the headend within $\pm$ 3 db of a specified reference level. In order to accomplish this, some small sacrifices in VHF system design may be required, and as a result, trunk to feeder ratio may suffer slightly. Our experience is however, that the sacrifice is insignificant.

During the system design phase theoretical upstream losses between amplifiers are calculated and the required upstream gain for each amplifier is calculated and noted on the system map. For upstream plant, it is not practical to label amplifier input and output levels as is typical for downstream plant. This is because several feeder lines converge at one amplifier location and each feeder line will have a different input and output levels. In fact, in some systems, as many as 10 or 12 different input and output levels would have to be recorded at the upstream bridger station. (See Fig. 3) Instead, the loss for each cable segment between each amplifier is noted and the gain of each amplifier is noted. To compute the input and output signal at an amplifier from a particular feeder, the gains and losses from that feeder are added and subtracted by the field technician to arrive at input and output levels.

2. Plant Balancing. The CATV technician balances the upstream plant by using a fixed-tuned 11 mhz field strength meter together with an 11 mhz portable test oscillator (PTO). The PTO is located at the end of the longest feeder and the technician, using his 11 mhz field strength meter, follows the cable back to the bridger, measuring the signal level at end amplifier location. Discrepancies of over 2 db from theoretically calculated gains and losses are noted and problems corrected before proceeding to the next segment. The same procedure is followed on each feeder until the entire bridger area has been completed. The system is then ready for installation of end of line test oscillators. Trunk balancing is done in a similar manner. However, since trunk upstream amplifiers request both level and slope adjustment, balancing is done at 32 mhz as well as 11 mhz.

3. End of Line Test Oscillators. Once the system design has been completed and the system constructed and balanced, small line-powered CW oscillators are installed at the end of each feeder in the system. These oscillators are inexpensive and are placed inside subscriber tap housings. Their output stability is ± 1/2 db over the temperature ranges encountered in the CATV plant. End of Line Oscillators (ELO) are preset for an output level of + 20 dbmv. A spectrum analyzer is used at the headend to make certain that each of these oscillators arrives back within the specified tolerance. This serves as an immediate check on upstream plant performance.

4. Home Terminal Installation. When home terminals are installed the same procedure is used. Each home terminal has been preset to + 36 dbmv output level and must be received at the headend within ± 5 db of the reference. If it is not, a technician is dispatched to troubleshoot the subscriber's housedrop. If the terminal is within the ± 5 db range, its RF output level is adjusted by the installer to the system reference level at the headend.

A computer program is used to automatically scan each of the ELO levels and each of the home terminal levels and to report significant variations from normal. By taking care that levels are carefully set up prior to the installation of home terminals, system maintenance and fault location become substantially easier.

The second major problem area in operating a two-way cable television plant is that of radio frequency intrusion or RFI. The sources of RFI are many; international short-wave broadcasts, amateur radio operators, citizens band operators, and harmonics from various electrical devices such as neon lights and industrial machinery. These signals enter the coaxial cable through many points. From our experience, the greatest problems are encountered with intrusion into improperly tightened connectors and broken cable sheaths. Intrusion has also been noted into subscriber drops, but in general, the intrusion levels are well below those caused by distribution system faults.

As mentioned above, the use of Code Operated Switches in the cable system greatly reduces the intrusion problem. This is for two reasons. First, only a small section of the cable plant is contributing intrusion to the system at any given time since only one Code Operated Switch is in use at a time. And secondly, when intrusion does reach intolerable levels the COS allows the operator to localize the sources of the intrusion to a relatively small section of cable plant. The first step in localizing intrusion, therefore, is to enable each COS and note the area or areas where intrusion increases.

RF intrusion is very difficult to measure in absolute terms. This is because the sources of the intrusion are of varying intensity. It is not practical to generate a standard intrusion source since intrusion will vary with frequency and distance of the source from the cable plant. In addition, no frequencies are presently authorized by the FCC for such use. Therefore, the task of tracking down such intrusion can be a difficult one.

Prior to attempting to use a cable plant for two-way, we have found it necessary to have our technicians go through each area of the plant checking each connector for corrosion and proper tightening. This step is not necessary if adequate safeguards are provided in the specifications to the cable system contractor and if the system has been well maintained for signal intrusion since construction. However, in dealing with even a well constructed cable plant, we found that a connector-by-connector check in this system prior to any attempt to balance the upstream plant or document upstream levels is worthwhile.

We have devised two techniques which make the process of locating intrusion easier. We have discovered that intrusion of signals at VHF frequencies generally correlate with intrusion at subband frequencies. The relationship is not 1 to 1 but an increase in the intrusion of a VHF signal will correlate to an increase in subband intrusion. Therefore, when our CATV plant is first balanced and made ready for two-way operation, the intrusion of a strong local FM radio station carrier is measured at the end of each feeder line and entered in the system documentation. Typically, the FM signal would be 40 to 50 db below the lowband video carrier levels for a properly operating cable plant. Should that level rise significantly it is an indication that there is a cable sheath or loose connector problem in that segment of plant. In order to use this technique, the technician simply goes to the COS area where the intrusion problem exists, then goes to the end of each feeder within that COS area (usually there are a fewer than 10 feeder ends per COS area) and measures the FM carrier at each feeder and compares it to the documented level. When an intrusion level is found to be incorrect, the technician works backwards toward the bridger until the level is again normal. He has then isolated the problem to a single amplifier span. A connector-by-connector check of that span of cable then reveals the source of the intrusion.

The second technique which simplifies the tracking down of intrusion is based on the fact that loose fittings or broken cable sheaths result in VSWR problems. At VHF frequencies the problems may have little or no effect on signal levels. However, in a subband range where cable losses are low, a poor match can result in a large effect on upstream levels received from subscribers' terminals or End of Line Test Oscillators. As mentioned previously, we install End of Line Oscillators at the end of each active feeder. These devices provide a reference at the headend for proper operation of the cable plant. When a signal intrusion problem is noted, the level at each ELO within that COS area is measured. Generally, one or more of the ELOs will be incorrect in level due to the reflection set up by the mismatch at the point of intrusion. A technician is then dispatched to the area or areas where these level variations are noted and the intrusion entry point is tracked down as described above.

Using these two methods we have been able to successfully and quickly track down all the intrusion problems that have cropped up in our system.

Through the use of the COS approach and using the techniques described in this paper, we have been able to make the job of two-way plant maintenance practical and inexpensive.

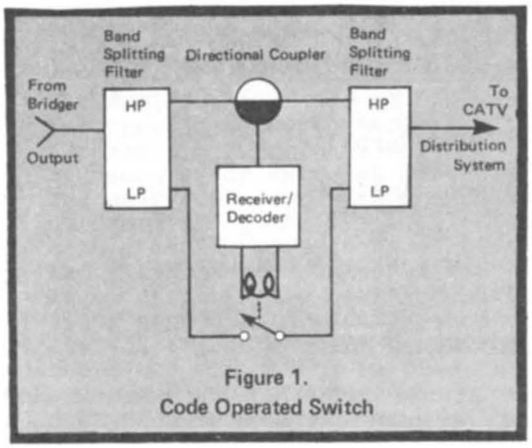

Figure 1.
Code Operated Switch

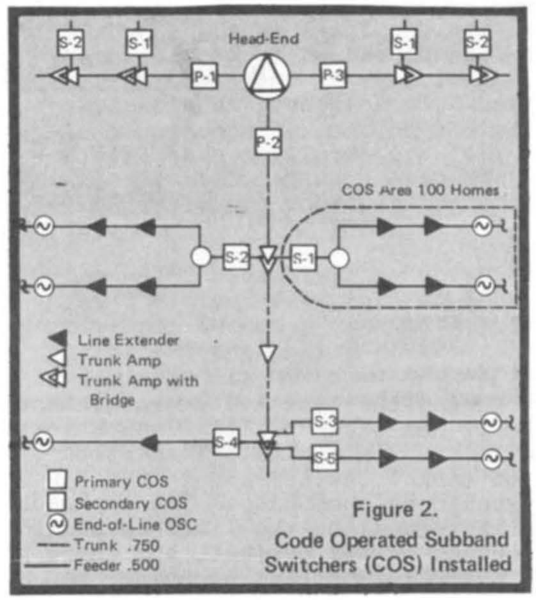

Figure 2.
Code Operated Subband Switchers (COS) Installed

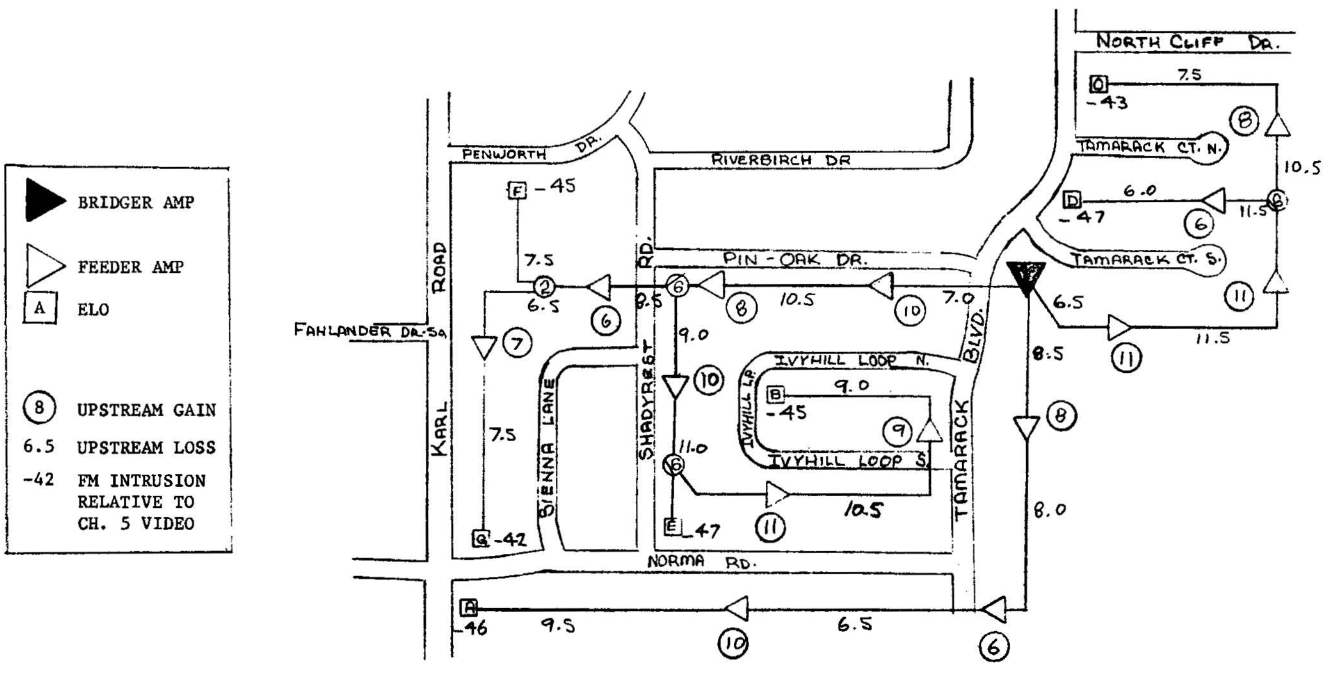

FIGURE 3. TYPICAL UPSTREAM DOCUMENTATION

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