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TECHNICAL PAPER PROCEEDINGS
FROM:

64QAM TRANSMISSION OF DIGITAL DATA OVER CABLE AND ALTERNATE MEDIA

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ABSTRACT

Transmission of compressed digital data is a compromise between data rate and signal robustness. In a relatively benign transmission medium such as cable, an efficient modulation technique, such as 64QAM, can be used to optimize the information rate and, therefore, the channel capacity. This paper discusses the results of 64QAM transmission testing. Bit error rates are measured and correlated with channel impairments. The effects of error correction and adaptive equalization are investigated.

BACKGROUND

It has been demonstrated that compressed digital video can be transmitted over cable as a 16QAM signal. However, 16QAM transmission limits the maximum data rate to somewhat less than 20 Mb/s in a 6 MHz channel. The information rate (i.e. - the amount of useful data which can be transmitted) is even lower due to the data overhead which must be added for error correction. In a relatively benign environment such as cable, a significant increase in channel capacity can be obtained by using a more efficient modulation technique in conjunction with error correction which is more appropriate for the medium. 64QAM is one such modulation technique.

A comparison of the efficiency of 16QAM and 64QAM is shown in Table 1. The information rate shown in the table is based on the DigiCipher compression algorithm which is capable of compressing up to 5 NTSC signals into a 13.46 Mb/s data stream. If a low overhead error correction is used in conjunction with 64QAM modulation, it is possible to transmit a total information rate of 26.92 Mb/s or up to 10 NTSC signals in 6 MHz.

Table 1 Comparison of 1QAM and 64QAM

	16QAM	64QAM
Information Rate (Mb/s)	13.46	26.92
Error Correction (Mb/s)	6.05	2.34
Total Data Rate (Mb/s)	19.51	29.26
NTSC Signals in 6 MHz	5	10

DigiCipher, as transmitted via satellite, is a QPSK signal with 2 - 5 NTSC signals modulated on each transponder phase. Therefore, the use of 64QAM for transmission over cable would permit the operator to send the contents of an entire satellite transponder in 6 MHz.

Since the results of previous tests with 16QAM were encouraging [1], it was decided to conduct a series of channel characterization tests to determine the feasibility of using 64QAM.

TEST SYSTEM DESCRIPTION

A block diagram of the test system is shown in Fig. 1. A pseudorandom data generator, internal to the digital modulator, is used as the data source. The digital modulator is capable of generating and transmitting data with both trellis coding and Reed Solomon error correction or with either or both of these error correction techniques disabled. This flexibility permits testing to determine the optimum error correction technique for use in cable transmission.

The IF output of the digital modulator is a double sideband suppressed carrier AM signal centered at 44 MHz with a 3 dB bandwidth of 4.88 MHz. The output is up-converted to the appropriate cable channel using the RF section of a Jerrold Commander VI modulator. The digital RF signal is combined with other cable channels and sent over the system in the normal manner.

At the receiving site, the RF signal is converted to IF using a frequency agile down converter. In order to insure low phase noise, the down converter's local oscillator input was supplied by a HP8644 frequency synthesizer. Spectral purity of the L.O. was maintained by a tunable bandpass filter at the output of the device.

The digital demodulator incorporates display capability for readout of errored seconds. Both raw errors and coded errors are displayed. The errored second data is also output to an RS-232 port in order to permit data logging using a personal computer. The demodulator also contains a 64 tap adaptive equalizer for correction of multipath and group delay effects. The values of the adaptive equalizer coefficients are also output on the serial data port in order to provide data on the nature and extent of echoes resident in the system under test. The PC software is structured such that the error data and the adaptive equalizer coefficients can be stored in separate ASCII files for off-line printout.

TEST RESULTS:

Initial tests were conducted with the system in a back-to-back configuration at the headend. For this test, the RF signal was taken directly from the -20 dB monitor output of the Commander VI modulator. The digital signal level was about 8 dBmV. In this configuration, the bit error rate prior to correction was about 3×10^{-4}. The coded bit error rate remained at zero over a 12 hour test period.

The first sytem test was conducted over two fiber optic links plus a 23 trunk cascade, terminating in a bridger and one tap. Test duration was 15 hours. The digital signal was transmitted on channel A-3 (102-108 MHz). Analog carrier/noise and CTB in the channel were 44 dB and -63 dBc, respectively. Digital signal level at the end of the drop was 7 dBmV. Digital carrier/noise ratio was about 32 dB. The average raw BER was 3.4×10^{-4}. A total of 7 errored seconds were logged during the course of the test run, resulting in an average coded BER of 1.4×10^{-7}. There was no loss of signal during this test. The system operated without errors for 99.99% of the time. It should be noted that there was some interference from FM carriers, resulting in about a 20 dB C/I ratio.

A subsequent test was run over a 15.25 mile AML link. Test duration was about 2 hours, with a total of 8 errored seconds, yielding an average coded BER of 1.6×10^{-5}. The average raw BER was 7.4×10^{-5}, resulting in 99.85% error free operation. The errors which occurred during this test were due to phase noise in the AML hardware. Phase noise, measured at 10 KHz from an unmodulated carrier, ranged from -70 dBc/Hz to -103 dBc/Hz. The received signal level was 27 dBmV, with a digital carrier/noise ratio of 40 dB.

The third test was run over a 24 trunk cascade plus two taps plus considerable internal wiring to the receiving site (a hotel room). Received signal level and digital carrier/noise were -3 dBmV and 22 dB, respectively. The test duration was about 51 hours, during which loss of signal occurred for 65 seconds, resulting in a system availability of 99.96%. The loss of signal may have been due to an intermittent failure of the down converter's power supply which was corrected for subsequent tests.

The final test was run over a cascade of 41 trunk amplifiers plus two line extenders and a total of 22 taps. The digital signal was transmitted on channel 58 (96-102 MHz). Test duration was 19.5 hours. The digital signal level was 11 dBmV. Analog C/N was 41 dB. No CTB or CSO were present on the channel. Average raw BER was 1.3×10^{-4}. There were zero coded errors during the duration of the test. Digital C/N at the start of the test was 32 dB, improving to 36 dB at the conclusion of the test run. This may be attributed to a 50 degree change in ambient temperature on the system during the test period.

Information on reflections and group delay, may be derived from the adaptive equalizer coefficient values. Ten bit coefficients are used in the equalizer, providing a coefficient range of ±512. In order to provide headroom, the equalizer is initialized by setting the 20th tap of the in-phase section to 384 and all other coefficients to zero. The coefficient values transmitted via the serial port are those values obtained after the equalizer has converged.

Adaptive equalizer impulse response plots are shown in Figs. 2 - 5. These plots show the absolute value of the impulse response in dB relative to the initial value of the non-zero (20th) tap. The information presented in these figures shows the results of equalization of both system echoes and group delay as well as correction of deviations from ideal impulse response in the system filters. Group delay in the test hardware was on the order of 6-700 nS and was chiefly due to the IF filter. Fig. 2 shows echo amplitude and phase data for the system in the back-to-back configuration.

The data presented in Figs. 3 - 5 indicates that echoes which were present on all of the subsystems tested were relatively short. If one defines significant tap amplitudes as those exceeding -30 dB, then only about 14 taps of the adaptive equalizer showed significant changes relative to the back-to-back impulse response shown in Fig. 2. This implies that system echoes which were corrected by the equalizer were relatively short. This is not inconsistent with the results of previous analyses and testing [2], [3].

Since the channels used for these tests were at the low end of the cable spectrum, it may be assumed that system echo amplitudes were near worst-case conditions due to near-minimum attenuation in the cable. Nevertheless, the performance of the adaptive equalizer was such as to compensate for the effects of all echoes without much difficulty.

CONCLUSIONS:

Judging from the results obtained to date, 64QAM appears to be feasible for cable transmission. The problems encountered in transmission over AML are indicative of the need for careful design of phase locked loops in both the digital transmission and AML hardware. Adaptive equalization appears to be capable of handling echoes and group delay in both the cable system and the transmission equipment. Additional laboratory and field testing is required in order to determine more conclusively the effects of system impairments.

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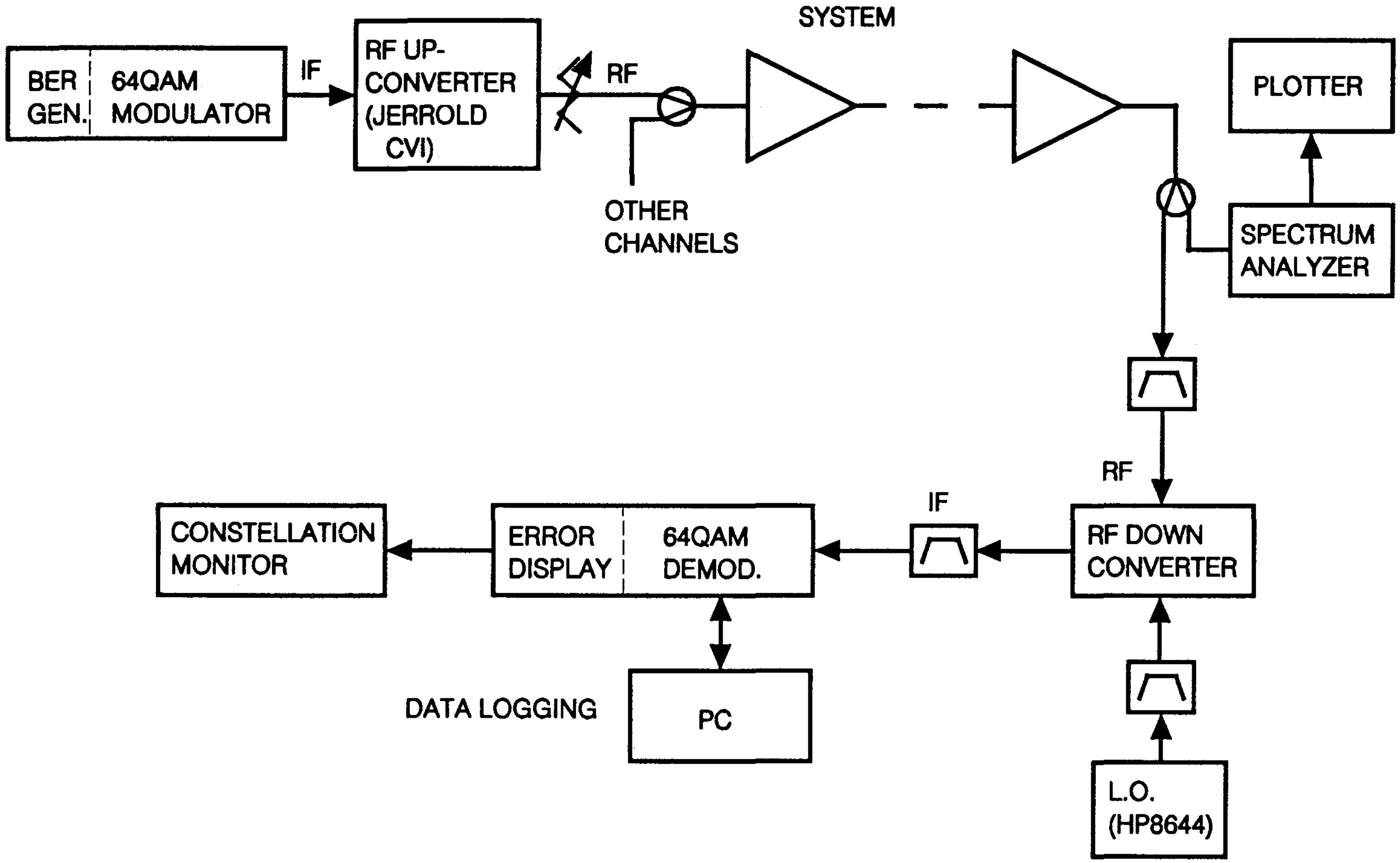

FIG. 1 - 64QAM CHANNEL CHARACTERIZATION - BLOCK DIAGRAM

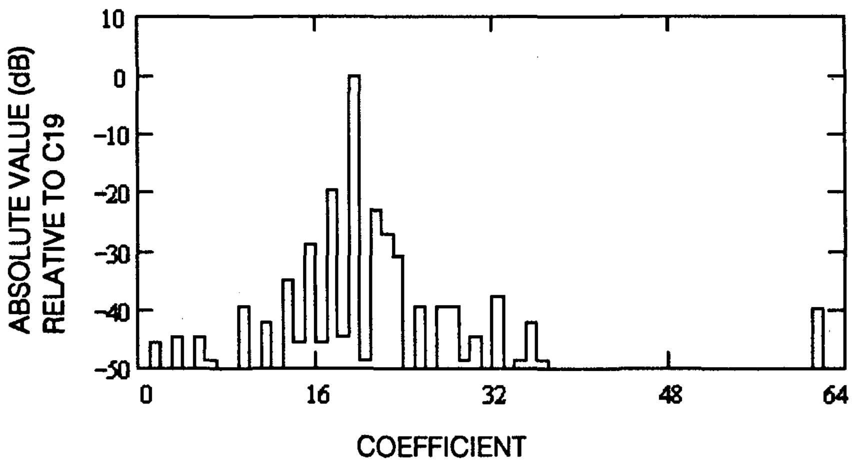

FIG. 2 - ADAPTIVE EQUALIZER IMPULSE RESPONSE - BACK TO BACK THROUGH RF LINK

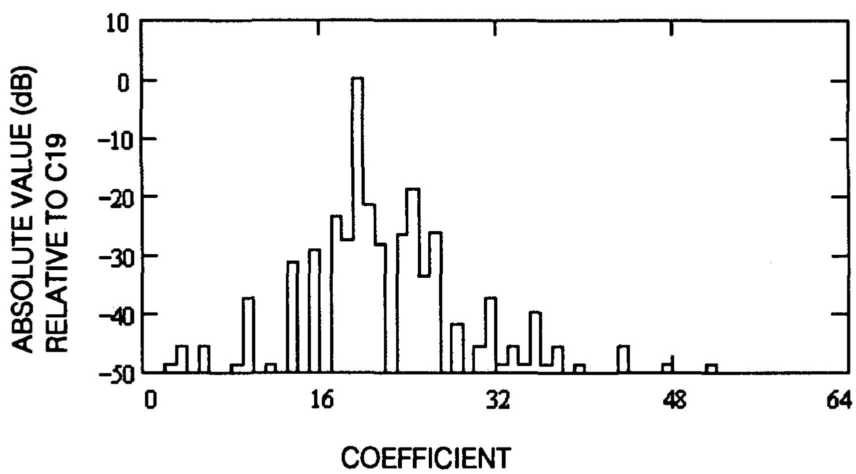

FIG. 3 - ADAPTIVE EQUALIZER IMPULSE RESPONSE
24 TRUNK AMPS + 2 TAPS + INTERNAL HOTEL WIRING

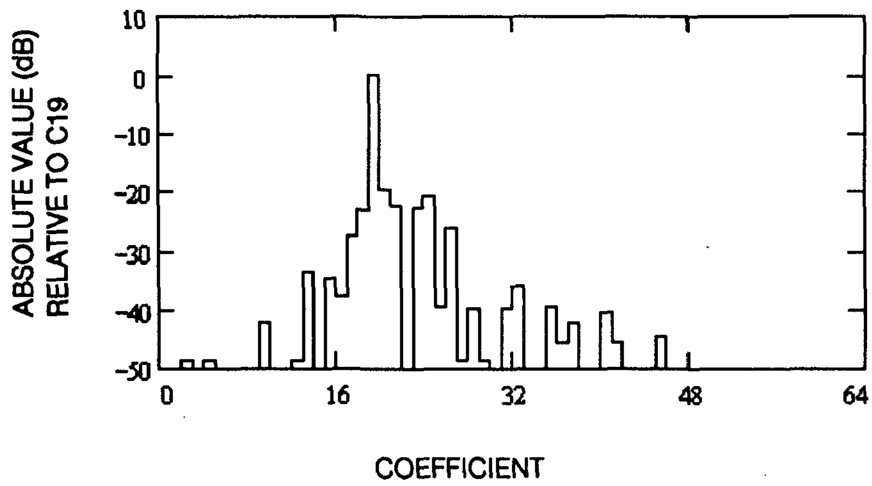

FIG. 4 - ADAPTIVE EQUALIZER IMPULSE RESPONSE
25 TRUNK AMPS + 2 LINE EXTENDERS + 22 TAPS

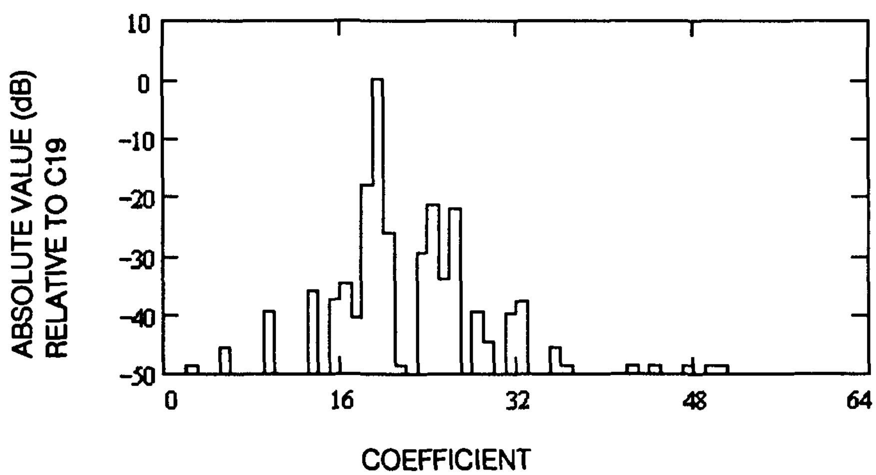

FIG. 5 - ADAPTIVE EQUALIZER IMPULSE RESPONSE
41 TRUNK AMPS + 2 LINE EXTENDERS + 26 TAPS

A Passive Optical/Coax Hybrid Network Architecture for Delivery of CATV, Telephony and Data Services

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Abstract

A number of architectures have been proposed to provide VSB/AM modulated video, digital compressed QAM video and telephony services over a hybrid optical/coax network. The majority of these architectures employ an RF carrier for each individual POTS circuit, which is dynamically allocated to serve only active POTS lines. The disadvantages of this approach include the inherent blocking factor that must be accounted for and the difficulty in migrating from single POTS to a rich menu of enhanced telephony and data services.

The Passive Optical Network Architecture (PON) has the advantage of being able to allocate bandwidth dynamically to any customer on demand. Additionally, as overall network capacity demands grow, the capacity of the network can be expanded incrementally to match increased demand.

A Passive Optical/Coax Hybrid Network (POCN) can be designed which provides video as well as enhanced telephony and data services, while providing all of the economies associated with an optical/coax cable architecture. The optimum economic serving areas for telephone and video based services are remarkably similar.

This paper describes a POCN network, and the economics for providing both CATV and POTS based service.

INTRODUCTION

MSOs today are faced with their most difficult strategic problem in terms of evolution of their network. The challenge is both technical and financial because of the need to plan network evolution to accommodate the non-traditional CATV services in the loop. There are obvious difficulties in implementing a future-proof network without financial implications. The difficulties are, of course, enhanced by MSOs lack of experience in the new services and by recently imposed regulatory constraints.

Rapid fiber deployment in the CATV network using FTF or FSA architecture[1] is providing the necessary infra-structure (bandwidth and network topology) for provision of a rich menu of services by MSOs. These include such new revenue opportunities as Video-on-Demand (using compressed digital video), POTS and data services in the loop. The capability of wireless implementation in a POCN environment offers a major new growth market for network services such as PCS.

PASSIVE OPTICAL NETWORKS (PONs)

The intent of telephone companies (TELCOs) to deploy fiber in the loop for provision of narrow-band telephone and broadband services is well known. For the last decade, TELCOs have struggled with the question: What is the optimal architecture for introducing fiber in the loop (FITL)? Two FITL network architectures have emerged as contenders: double-star FTTH (Fiber to the Home) or FTTC (Fiber to the Curbside) and passive optical networks (PONs).

In double-star ("Active Star") implementation, a high speed fiber feeder connects up to 1,000 subscribers to the CO via a remote terminal multiplexer or concentrator. The fiber drop from the remote node now connects a curbside location (FTTC for serving 4 - 16 subscribers) or directly subscriber premises (FTTH). Some RBOCs have expressed the commitment to a limited deployment of this architecture using new generation Digital Loop Carrier (NGDLC) for implementation of narrow-band services.

Although passive optical networks were initially introduced to improve the economics of bringing fiber closer to the subscriber, several other benefits have since then emerged in some implementations. PONs use passive optical splitters (instead of active remote electronics at the node in an NGDLC implementation) to distribute the CO signals to subscribers.

In it's most common implementation, telephony over a PON uses a TDM technique in the downstream direction to deliver up to 672 DS0 (64 kb/s) channels to subscribers. Figure 1 shows the block diagram of a PON system being currently deployed in the United States.

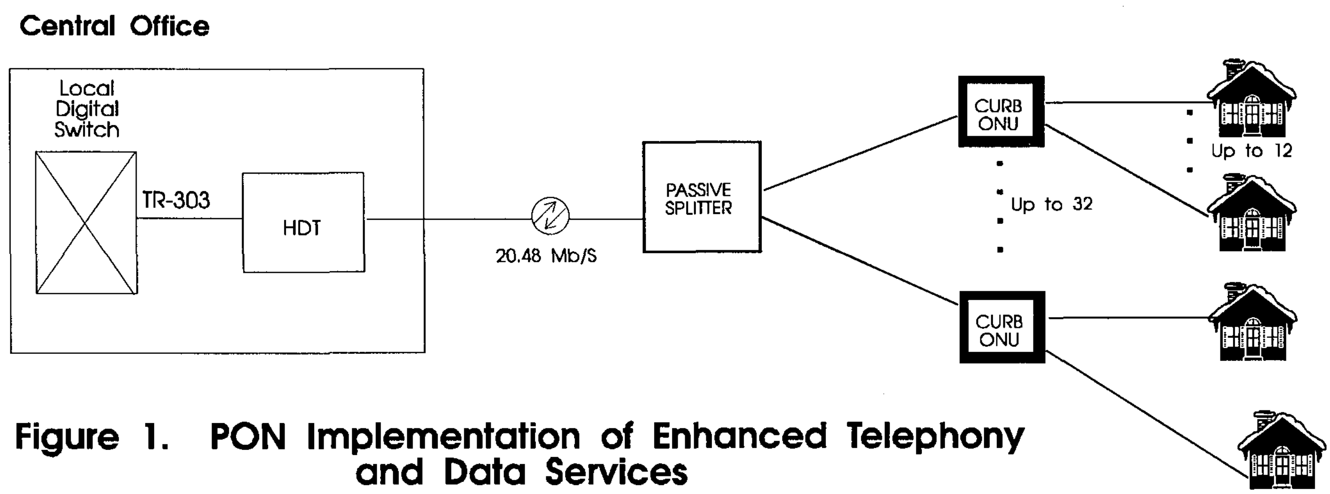

Figure 1. PON Implementation of Enhanced Telephony and Data Services

The Host Digital Terminal (HDT) is the interface between the public switched telephone network (PSTN) and the distribution network. The distribution of bandwidth to subscribers in the upstream direction is accomplished by a TDMA technique(2). Each TDMA system has the capacity of up to 224 DS-0 channels; three TDMA systems may be accommodated by each Host Digital Terminal. The TDMA system operates on the fiber at 20.48 Mb/s.

The optical fibers pass through the passive optical splitters for distribution to the Optical Network Units (ONUs). The number of fibers, and the number and type of splitters, can vary from one system configuration to the next; the optical link budgets are engineered to accommodate a maximum splitting ratio up to 1:128 for narrowband applications.

The deployment of electronics to serve subscribers for telephony and data services occurs at each curb-side location. Each TDMA channel can address up to 128 physical termination devices, hence the 224 DS-0 channels may be shared as needed among the users served by those terminations.

Services available from an ONU are a function of the channel units installed. Channel units for POTS, ISDN, data and other special services are generally available.

PASSIVE OPTICAL/COAX HYBRID NETWORK

The impetus for deployment of Passive Optical/Coax Hybrid Network (POCN) to deliver enhanced telephony and broadband services (entertainment video, VOD) has recently gathered momentum from both major players in the subscriber loop: telcos and MSOs. The recent FCC decision allowing telcos to enter video dial tone business has accelerated their plans for FITL deployment. Thus, the primary driver for telcos for FITL deployment today is new revenue opportunities from the delivery of video dial tone-based services. This is in sharp contrast to original thinking at RBOCs where the primary driver for FITL deployment has been copper parity for POTS. The current FITL strategy at RBOCs appears to be a cost effective deployment of fiber within few hundred feet of subscriber premises using the FSA concept. The drop to subscriber premises is coax which will initially deliver video services. This is a significant difference from NGDLC and FTTC implementations with broadband overlay where two separate drops (wire and coax) are required to deliver telephony and video services. By addition of necessary HDT and CPE, a smooth migration path for provision of enhanced telephony and data services is envisaged.

From the CATV industry side, MSOs are well positioned to implement a POCN for delivery of not only CATV but enhanced telephony and data services. The implementation of FTF architecture in CATV networks has allowed MSOs to begin placing large amounts of fiber close to subscribers. A fiber node serving area in FTF does not exceed a few miles radius (2,000 subscribers). The more aggressive implementations limit fiber serving areas to around 2,000 feet radius (500 subscribers or less). The following table illustrates the sizes of fiber serving areas in various fiber deployment scenarios. Figure 2 depicts block diagram of a POCN for integrated service delivery of CATV and enhanced telephony.

Fiber Serving Area Size (# of Passings)	550 MHz CATV	1 GHz CATV	Enhanced Telephony	Enhanced Telephony, CATV, VOD, PCS
FTF/FSA	1000-2000	200-500		
PON			128, maximum per PON; 4-32 per ONU	
PON with Broadband Overlay				128 (Enhanced Telephony) 16-32 (Video)
FSN				500
POCN				50-100

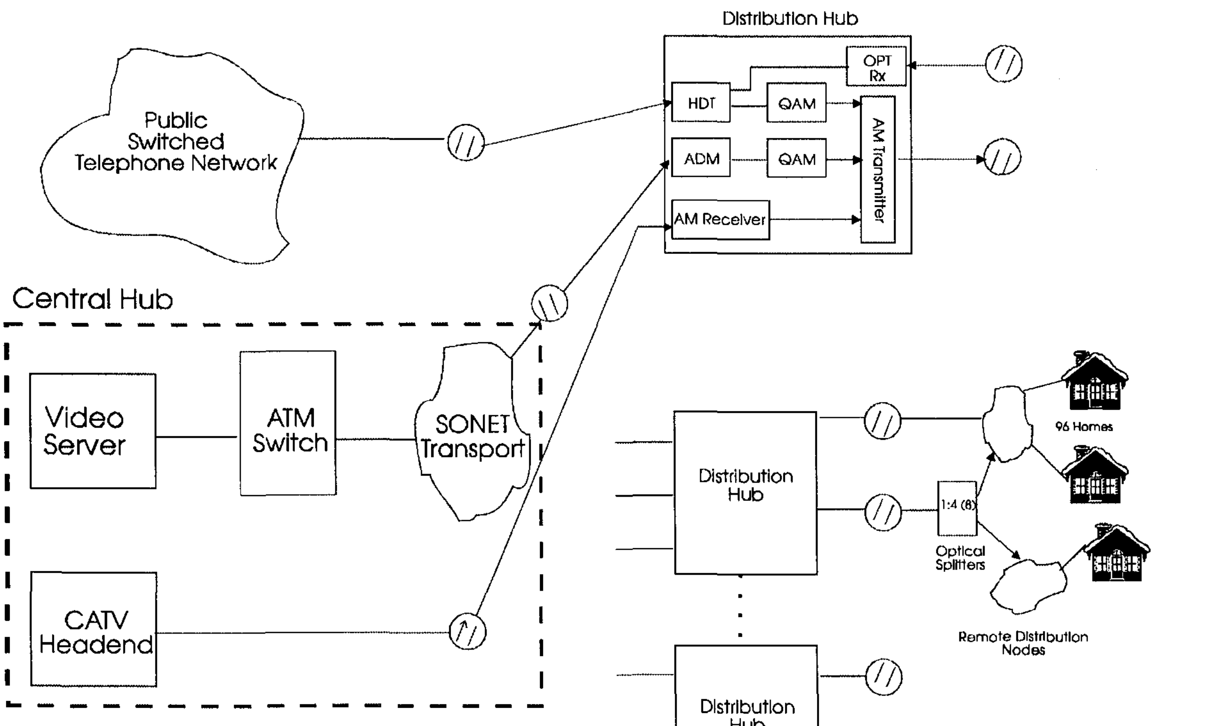

Figure 2. Implementation of Passive Optical/Coax Network

Various frequency plans have been proposed for broadband hybrid fiber/coax networks[4,5]. The Full Service Network proposal[5] from Time Warner recommends the following frequency assignment scheme:

<u>Reverse Path</u>

5-30 MHz — Coaxial plant status monitoring and IPPV carriers.

850-1000 MHz — Digital Services: POTS and data

Forward Path

50-450 MHz	Traditional VSB-AM Cable
450-750 MHz	Digital Services: Video-on-demand, POTS and data

The POCN proposal in this paper is similar in spirit to the FSN and uses the following frequency plan:

Reverse Path

5-25 MHz	Digital Services: Enhanced telephony and data
25-31 MHz	Coaxial plant status monitoring and IPPV carriers

Forward Path

50-450 MHz	Traditional VSB-AM cable
450-600 MHz	Digital Services: Video-on-demand, POTS and data
600-1000MHz	Not required because of narrow-casting and smaller node size

THE CENTRAL HUB

The Central Hub is a regional headend[6], which has the necessary capital intensive equipment including:

1. Conventional CATV (VSB-AM) headend equipment.
2. Video Server
3. ATM Switching
4. SONET multiplexing and transmission equipment.

DISTRIBUTION HUB

A Distribution Hub location serves 10,000-40,000 subscribers via a star network of remote fiber nodes. It receives 50-450 MHz conventional CATV signals in VSB-AM format from the Central Hub.

VOD signals in compressed digital format (MPEG II) and PON downstream channels (20-48 Mb/s) are transported to each hub location using a SONET OC-48 ring. The digital signals in SONET format are converted to 16-level QAM channels in 450-600 MHz band. All the downstream signals are now combined before intensity modulating a linear DFB transmitter. The serving area of a Distribution Hub is divided into fiber distribution nodes, each serving approximately 100 potential subscribers each. The selection of node size is based on considerations involving return signals for enhanced telephony and data services. A 4-way or 8-way optical splitter is used in the

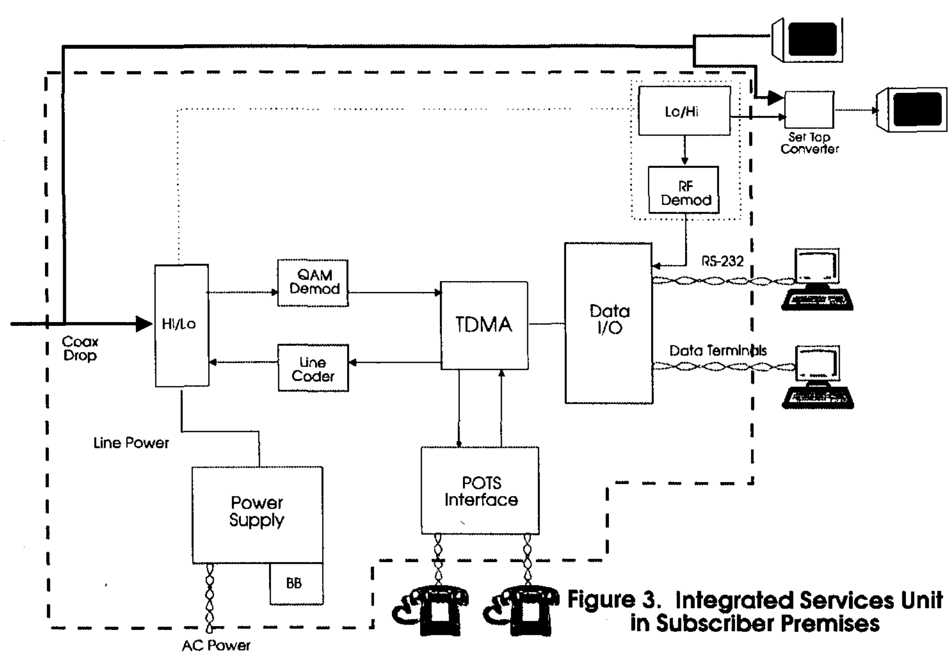

Figure 3. Integrated Services Unit in Subscriber Premises

POCN forward path instead of 1:16 or 1:32 way splitter commonly used in PON telephony networks.

CPE AND RETURN PATH

The equipment in customer premises to provide CATV, VOD and enhanced telephony is shown in Figure 3. The coax drop from the fiber node terminates on an Integrated Services Unit (ISU) in subscriber premises.

The 20.48 Mb/s downstream TDM signal from the HDT is demodulated before delivery to the TDMA module. In the upstream direction, the subscribers ISU's are synchronized to the HDT, so that returning time slots interleave automatically as they move through the fiber/coax distribution network. A ranging protocol from the HDT and a programmable delay element in the ISU's permits synchronization to be achieved between the HDT and subscribers within a serving node(s). Consequently, 20.48 Mb/s TDMA bursts from each ISU are synchronously received in appropriate time slots for multiplexing.

The POTS interface provides all A/D conversion and BORSHT (Battery, Overvoltage, Ringing, Supervision, Hybrid and Test) functions for connection to standard telephone sets. Data terminal devices connect to ISU by RJ-45 connectors. Date I/O module provides network adapter functions for asynchronous data devices (RS-232, etc.) The digital multiplexing and network access functions are implemented by the TDMA circuitry in the ISU. The TDMA output is line coded to shape the output digital spectrum compatible with reverse path characteristics in a sub-split coaxial distribution system.

It is assumed that traditional CATV services, including scrambled premium programming, is received via a cable-ready TV set or a one-way set top converter as appropriate. The reception of encrypted, compressed digital VOD channels will be via a 2-way set top converter with enhanced capabilities such as QAM demodulation, decompression, deencryption and D/A conversion.

For VOD services, there is a need to adopt signalling standard for set top converter units to communicate with ISU.

ECONOMICS

Any system evaluation must include an examination of system requirements for very low initial penetration, incremental expansion, and maximum system capacity.

As previously discussed POCN network minimum configuration provides 224 DS-0 slots (POTS lines) for 128 subscribers. These subscribers may be served from one distribution hub feeding hundreds of fiber nodes. Therefore, at extremely low penetration, the POCN network can be economically implemented albeit requiring more complex provisioning and traffic engineering practices. As penetration grows, the system can be incrementally expanded in 128 subscriber increments. When implemented in advanced fiber/coax cable TV architectures, there is an excellent match between homes served per node and the size of POCN nodes.

Importantly, many MSO's have not decided whether to be in the telephony providers including call routing. Any system chosen for implementation of telephony over a fiber/coax transmission path should not preclude the CATV operator's future choices of telephony service offerings. Unlike alternative architectures, the POCN network is non-blocking. It does not limit the offering of telephone services to single POTS lines. Rather it supports dynamic bandwidth allocation up to a DS1 per subscriber. This allows the CATV operator great flexibility when considering the costs of implementing advanced data and video conferencing to the home. In summary, the POCN architecture is not limited to POTS or conventional CATV, but is rather a means of delivering variable bandwidth for enhanced telephony and a rich menu of broadband services.

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A Point of Entry Interface for 2-Way Broadband Information Delivery

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Abstract

Currently Cable is the dominant provider of Audio/Video entertainment services into the home. But, with the advent of video compression technologies, virtually every company and industry associated with computers and communication is targeting the delivery of A/V entertainment into the home as a future growth market.

The next 20 years are going to be very exciting and many new services will be provided to consumers, but steps need to be taken now to coordinate and standardize the hardware for distribution of information into and within the home. The problems associated with current Cable converters and Cable Ready TVs will seem insignificant when a multitude of information providers are all trying to use the same TV and VCR, and each provider is using a different interface.

This paper proposes a cost effective approach which combines the various distribution methods of external media into a single "Point of Entry" unit. The pluses and minuses of standardization are addressed and recommendations are presented as to what should be standardized and what level of standardization should be implemented. Also, the issues associated with the distribution of signals within the home is discussed presuming that compression, ATV, and multi-media are in the not too distant future.

A marketable interface needs to be cost effective, useful, and easy to use by the consumer. It must also be backward compatible and easily expandable. Methods for solving these problems are proposed.

1.0 Introduction

Addressable Converter Decoders, (ACDs), are typically used in Cable systems when a high proportion of premium channels exist, because it has proven to be a cost effective method of securing and delivering premium channels to Subscribers. But, the problems associated with ACDs are well known, even by the U.S. Congress which passed the Cable Act of 1992[1], as a measure taken for solving the consumer's problems associated with Consumer Electronics, (CE), equipment which is connected to a Cable system using ADCs.

As a result of this legislation several groups have been organized to make recommendations to the FCC as how to comply with the legislation. Two of these groups are the EIA/NCTA Joint Engineering Committee, (technical advisory group open to all), and the Cable-Consumer Electronics Compatibility Advisory Group, (made up of executives from Cable and Consumer Electronics). The primary mission of these two groups is to make recommendations to the FCC and Congress as to how Cable and Consumer Electronics can cooperate to comply with the current legislation.

The Cable legislation targets existing technology. But, there is currently a rapid development in technology and several Cable, Satellite, and telephone companies are now experimenting with and contemplating delivering hundreds of channels of Pay Per View programming to the consumers CE equipment in the near future.

Within the next five years, six important, technological developments which will most likely be introduced to the consumer are:

- 1.0 giga hertz channel capacity using fiber optics,
- High Definition Television,
- Digitally compressed video,
- high power satellites requiring only small dish antennas,
- broadband wired telephone services,
- local area mobile communications, (PCS).

The introduction of these technologies will radically change the way information is delivered to and used by the consumer. The changes, potentially, could make the consumer interface, to the network and CE equipment, unmanageable.

Most of these issues have been investigated by the FCC in their quest of the next generation of Advanced TV, (HDTV). Specifically the S2 subcommittee, (ATSC Specialist Group on Interoperability and Consumer Product Interface), of the ATSC Technology Group on Distribution (T3), has submitted their final report[2] which studied the issues relating to interoperability among the various media that may be employed to deliver Advanced TV (ATV) services to U.S. consumers and the resulting impact on the interface between consumer products and the various media.

The report is detailed and discusses all of the Cable/CE equipment interface issues raised in the Cable Act of 1992 and describes desirable attributes for achieving a good interface. Unfortunately, it was not the mission of the T3/S2 sub-committee to look at existing NTSC CE equipment, but it can be assumed that the basics of solving the problem for HDTV will also solve the problem for future NTSC equipment. For existing equipment, interim solutions are being sought. The period of pain, where we have to live with existing hardware, can be relatively short if a cooperative effort, which is now taking place between the Consumer Electronics and the Cable industries, is successful. This effort should solve the existing problems, presented by the Cable Act of 1992, in a manner which is completely compatible with the solutions for interoperability and the consumer interface to HDTV, (which by the way will be digital).

2.0 The path to a solution

Any solution to the current problems of the consumer's interface to Cable needs to also consider what the home environment will look like five, ten, and fifteen years in the future.

The premise

1. Digital TV is coming,
2. Entertainment will be the major information revenue source,
3. There will be competition from multiple vendors, for the entertainment business.
4. Cooperation and Standardization is needed among participants.

Digital

With the advances in digital compression, virtually all of the HDTV proponents have elected a digital approach and these same techniques are currently being applied to both computer graphics and standard NTSC television. Couple these facts with the ability of digital circuits to get cheaper and more dense year by year, and it is inevitable that the future of home electronics will be digital and digital will be the transmission method of choice. Already Cable is planning to introduce compression of NTSC signals by 1994.

Entertainment

The average annual dollars spent per person in the U.S. for Cable, Home Video, and Records is \$ 180.26[3]. If you have four members in your family you would average $ 721.04 per year for entertainment products in your home.

Entertainment, is what consumers want and are willing to pay for. The demand and revenues for entertainment are more than other information services which are delivered to the consumer. If other information services[4], such as education, are to be financially successful, it would not hurt if they were also entertaining. Consumers appear to have no limit to their appetite for consuming entertainment, and they clearly want to consume large portions of entertainment information in their home.

Cable has been successful, because people want to be entertained and Cable provides a diversity of entertainment products that feed the consumer's appetite to be entertained.

Competition

It is Cable that is currently taking the heat from Congress and the Consumer, but with more networks and service providers gaining access to the Consumer's TVs and VCRs, the heat will intensify for others. Even now, Cable has indirect competition. Broadcast television, video cassette rental stores, video games, radio, recorded music, all compete for the consumer's time and dollars.

Right now other industries are investigating the delivery of entertainment to the home. The allure of being able to send digital pictures, sound, and data to the home cheaply has stirred several corporate giants in the, telephone industry, computer industry, and the aerospace industry, into looking at Cable for new services or with the intent of competing directly with Cable.

The environment is right for competition to flourish. The government wants it, our high tech industries want it, the tele-communication industries want it and now the only question is - will the consumer want to pay for it.

Cooperation and Standardization

Technology is not what makes consumers buy. The attraction to a Subscriber, (a consumer who buys a service), is the content of the programming and not the technology which delivers it. But, it is the technology which enables the consumer to have a greater diversity of entertainment and information services, delivered to their home.

As new technologies evolve, new services are provided, (radio, TV, Cable, satellite, VCRs, compression, ...), and the consumer consumes them all. One service does not appear to displace the other. For example; video tape rentals and VCRs did not stop the growth of Cable.

The new services, and compression will allow virtually an endless array, and will typically require greater participation by the consumer to select, order, and consume the new services. This means that there is a two-way transfer of information between the service provider and the consumer. CE equipment is typically designed "open loop", with no provision for consumer feedback. The amount of information required from the consumer to the service provider is minimal in most cases. It means, however, that for an effective interface to all of the equipment involved in the delivery of the programming, an integrated system approach is prescribed.

An **integrated system approach** is prescribed to solve the consumer interface problems.

But, integrated system approaches require cooperation among the various industries and participants; and they require Standardization.

It is within our grasp to solve the problems plaguing consumers who have to deal with new technology interfacing with old technology. There is a price to be paid to do the job right, but if there are no unfair advantages, then all should benefit - even the consumer.

3.0 Enter the POET.

The current technological and business environment is reminiscent of the 60's and 70's when semi-conductors and micro-computers were emerging. Both of these industries were pioneered by start-up companies and ostensibly ignored by the large corporations. The apparent difference in today's situation is that both big business and government are intensely interested in the future of communication technologies to the home.

An approach which will effectively deal with the future needs to be an integrated solution which addresses the business, technological, and political aspects of future communications to the home. The proposed approach of a Point Of Entry Terminal[5], (POET), considers that future communication services to the home to be able to be integrated together. For example: if an Addressable Converter Decoder could know what channel a TV or VCR was tuned to and the ACD could command the TV or VCR to slave to a desired channel, then most of the consumer's interface problems could be solved , at little cost.

Point Of Entry assumptions

1. Multiple networks connected to the Subscriber's TV and VCR.
2. Increased demand for distribution to the individual, as opposed to the family.
3. Two-way interactive capability with the bandwidth into the home much greater than the bandwidth out of the home.

Physical elements of integrated approach:

1. External networks.
2. Interface between the External and Internal networks,(POET),
3. Internal distribution network, and
4. CE appliance, (ie. TV,VCR, etc.).

The Point Of Entry Terminal, (Figure 1), is the element located between the External service network and the consumer's Internal network and is referred to as the POET.

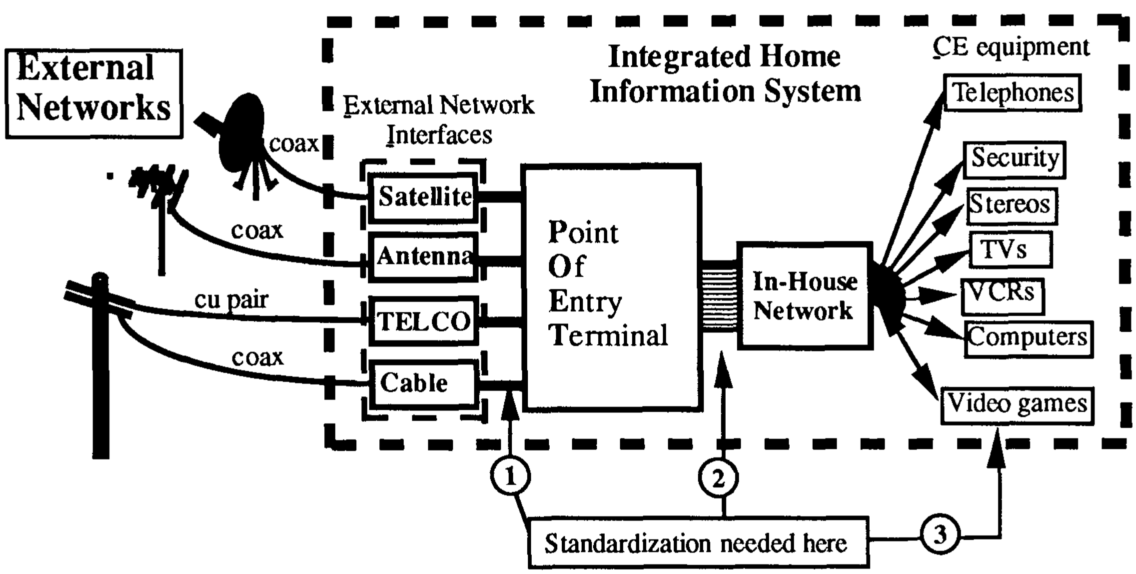

Figure 1. Home Communication System

4.0 Point Of Entry Terminal Requirements:

1. Secure external access to the home	a. The network provider needs easy access to their equipment, b. Access is in a secure external enclosure c. The enclosure is to be independent and secure from other network providers and the consumer.
2. A method of switching or multiplexing.	a. Individual programs or tiers can be selected from any network to any consumer device. b. The control of the switch/ mux needs to be standardized.
3. Two-way interactive communication between the user and the service provider.	a. Transmission into external network needs to be buffered from the consumer network; to prevent the consumer from causing harm to the external network. b. System is asymmetrical, with much more data required to the Subscriber than from the Subscriber.
4. Program security method.	a. Controlled by service/network provider b. Renewable if breached.
5. Compatibility to existing equipment.	a. Analog NTSC b. TVs, VCRs, c. Cable ACDs
6. Modular approach.	a. Consumers can change or upgrade system easily by themselves. b. Wiring to be minimized. c. Interoperability to be maintained.

5.0 In-home Distribution

The connection from the external network to the CE equipment will become more significant in the future of information delivery to and from the home. The traditional role of the in-home distribution network has been to bring the programs to the CE equipment. With the introduction of the remote control an added element was added to the network to control the operation of the CE equipment. Pay Per View, (PPV), programs on Cable have extended the needs of the in-home distribution network an addition step - PPV requires the Subscriber to send information to the Service provider .

The trend, for the consumption of information services in the home, is moving toward more variety and individual use, such as seen by personal audio, wireless and mobile telephones, personal computers, and small screen portable TVs. This individualization of in-home information will need even further enhancements to the distribution network.

And to fully realize an integrated approach to solving the consumer interface problem of the future, CE equipment will require a two-way data port which both talks and listens to the consumer's commands.

It is believed, by several engineers I have talked with, that the utility of the EIA CEBus[6], in the home, is to switch lights, send video from the VCR in the family room to a TV in the bedroom, and other tasks insignificant to the real importance of an in-home distribution network. That is, as an integrator of the home information environment.

One of the key problems of current and future interfaces is that, when working in a system, devices need to talk to each other. The VCR needs to know what the TV is doing and the Addressable Converter Decoder, (ACD), needs to know what the TV and VCR are doing. The problem of the in-home network is not just to distribute audio, video, and data throughout the home, but it is needed to fully integrate various elements of CE equipment into a 'user friendly' system.

Another problem is associated with passing broadband conditional access signals, in the clear, directly to the CE equipment. Service providers want to control their services and do not want to leave the interface to their service completely up to the CE manufacturers. It is important to service providers, how their service is presented to the consumer. The consumer buys directly, (in most cases), from the Service provider. As a result the Service provider has a vested interest in presenting their product in the best way possible. And as there will be many additional competitive alternatives open to the consumer in the future, the way the product is presented to the consumer will gain in importance. This is in contrast to the marketing and sales approach of CE equipment manufacturers who do not sell directly to the consumer, but use distributors and dealers instead. As a result they are not involved in the day-to-day decisions a consumer makes when selecting programming. And, although they wish to make the consumer's job as pleasant as possible when using their product, they have little or no concern for the Service supplier who supplies the consumer with the programs.

The driving force for an in-home distribution network should be the amount of interoperability it provides and it ability to provide a pleasing consumer product interface. Since HDTV and compressed NTSC are around the corner, serious consideration needs to be given to an in-home network which satisfies everyone - service provider, network provider, CE equipment provider, consumer, and let us not forget the Congress (which presumably represents the consumer).

6.0 Standardization is fundamental

There are pluses and minuses to standardization. If done during the period of rapid technological and new service advances, standardizing too early could stymie or curtail growth. But, without standardization each new service and technology wouldn't be compatible with any other and the consumer interface problem would be unwieldy. An additional complication is that service providers would not support standardization of program security if it meant that they could not control the security and change it if they felt the security was being breached.

The major difficulty in the standardization process is that it crosses different business and special interest boundaries. Each industrial group has it own interests and in most cases its own standardization body. There is the EIA, SMPTE, ANSII, IEEE, Cable, etc. And each of these bodies wants the standards to reflect their position and in most cases there are significant conflicts. In an attempt to breach some of these conflicting interests several joint groups have been formed, such as the EIA/NCTA joint engineering committee. This committee established the standard for EIA 563, Multiport that had the potential to go a long way to relieving the problems associated with interfacing Consumer Electronics television receiving devices and Cable Addressable Conditional Access equipment. But, the standard provided a technical solution, and the management of three industries involved, (Cable system operators, Cable equipment manufacturers, and Consumer Electronic equipment manufacturers), did not want to make the mutual investments required to cause the solution to become established.

It might appear that mutual agreement between industries on standardized approaches is futile, considering that more industries are becoming involved every day, (Telcos, computer, satellite, etc.), if it were not for a particular sequence of events.

Specifically:

- The FCC is currently undergoing a standardization process for Advanced TV, which is expected to replace the current NTSC over the next 20 years.
- Congress has enacted the *Cable Act of 1992*, which was inspired by a lack of competition for cable and the inability of the Cable and CE industries to make their products easy to use by consumers.
- The current Administration, (Clinton/Gore), has made the U.S. communication infra-structure a priority.
- The economic environment has caused major U.S. industrial corporations, such as IBM, to re-evaluate their current businesses and to look toward the new entertainment and consumer sectors.

Virtually all standards, except those mandated by the U.S. government, (such as the recent Closed Captioning standard), are voluntary standards observed by a specific industry or group within an industry. Currently there are too many special interest groups to have voluntary standards that work. The demise of EIA 563 (Multiport) is a good example. And if this point is not clear, it should be obvious that in the case of the current FCC standardization of HDTV that many more factors are involved, such as "in the national interest". And industries, such as the telecommunication and computer industries are financially and politically very powerful and it will surely be a significant part of any government mandated standards for the next generation of communication and consumer electronics.

In view of the above mentioned complications; when and where does it make sense to do standardization for a proper integrated interface between the service, networks, and the CE equipment, (see Figure 1)

Standardization locations for Home Communication System

1. Media entrance
2. Distribution network
3. CE equipment.

Media entrance

With several media and service providers available, in the future, it will be important that each supplier has physical access to their network interface, independent from all other suppliers, and that the interface is external to the domicile.

Distribution network

A person's home is their castle and they want flexibility in configuring information services in their own home. In systems of the future the consumer will want to select programs, or information, from a variety of sources. And the location of the source may not even be explicitly known to the user. The user would select a particular program from a library and the location of that item may be in the user's local data base, or in any one of the network services the user may have at their disposal such as - telephone network, Cable network, satellite, wireless, etc.

Consumer Electronics equipment

Consumers do not like being limited to one supplier and very much like going to a variety of stores to buy upgrades to their equipment. They also do not like having a complex installation procedure. In the case of a TV or VCR they would like to be able to, (in the best of all worlds), put the device anywhere they like and be able to use the device with no connections or extraneous installation procedure. We are a long way from the wireless devices, that don't even need power cords, but with existing technology the consumer should not have more than a few simple connections or insertion of a module into a slot, (or equally simple procedure).

It is because of the above mentioned pressures that industries that need to interface will have common relationships. And those that are able to work together at solving the consumer interface problem, will succeed in getting the consumer's dollar. It has been said that Cable is in a monopolistic position because of franchising. But, Consumer Electronics, (specifically TVs and VCRs); also has a monopolistic position because of the NTSC standard. But, consider that with the advent of digital transmission, that the whole genre of computer electronics is also available for audio and video. And if the proliferation of PCs into the home continues, PCs may be the dominant display device and the picture is definitely superior to current consumer NTSC receivers. And you can believe that the information industries, such a computers, will play a significant role in any standardization issues of the future.

7.0 Proposed solution

Three key areas of standardization for future technologies and services are, (in order of importance) :

1. digital interface to the consumer television receiving devices
2. Point of entry interface between the media of the service provider and the in-home network
3. multiplexing, (or switching) method for selecting programs among services

These are not the only areas for standardization, but they are key in respect to how a consumer must interface to a diversity of future services.

The basic configuration shown in figure 1. has three basic elements: the *network interface,* the *Point Of Entry Terminal,* and the *consumer devices.*

The network interface is external to the domicile for easy access by the service provider who owns the network. The interface to the Point Of Entry Terminal is standardized both electrically and mechanically. It is designed in such a way that it can be either a part of the POET or separate.

The POET contains the common elements such as multiplexers, addressable controllers, transmitters , receivers, and modular interface equipment.

Existing consumer devices will require the use of external interface equipment. New consumer devices will have standardized interfaces "built in", for seamlessly interfacing.

8.0 Conclusion

Any long range solutions need to consider both the existing and future environments. Individual industries are unwilling to change their current balance, because they feel comfortable in a known environment. But, change is in the wind and opportunities are abundant. Unfortunately it is the large lethargic corporations and industries which are reluctant to change their *modus-operandi* : and succumb to change. Silicon Valley exist today , because large corporations were not willing to take advantage of the opportunities when semi-conductors and micro-computers first arrived.

It is easy for large corporations to relax and not venture into the unknown. After all they are protected by their monopolies and size. But, technology is advancing, and change is inevitable. And since the changes coming to the communication industry affects the entire nation and inter-relationships between nations, the large corporations have a great influence over the government and by their very nature they will oppose change to protect their own interests.

It may be that the conflicting political, financial, and business interests will inhibit a unified solution. But, the opportunity is there and with technology not willing to stand still, sooner or later an integrated approach will evolve and the eventual winners and losers in the struggle could be a surprise. And if the past is a harbinger of the future - the new corporate giants don't yet exist. The entrepreneurs of these new companies are probably, right now, working for some of the current leaders in the Consumer Electronics, Cable, Computer, and Telecommunication industries. They are working on great new technologies, but their employers, for what ever reasons, are not aggressive in pursuing the market. The researchers will get frustrated and venture off on their own.

CE equipment needs to make significant changes, along the lines of ANSI / EIA 563 (Multiport), if there is any hope of integrating the home information services of the future.

One of the missing ingredients of developing the Multiport standard was intimate contact between all of the interested parties, on a continuing basis. It will probably take another intrusion into the free market by the government, to be able to cause the interested parties to get serious about cooperating.

Standardization

The final report of T3/S2 recommends that "voluntary standards" be adopted by the various interested groups. There are two problems with this approach -

1. voluntary standards usually do not have a deadline and can go on for many years.

2. Voluntary standards are voluntary and there is no guarantee that the "other guy" is going to implement them, then they are doomed from the start.
   Re: Multiport

Therefore, it follows that if progress is to be made, then both HDTV and existing NTSC need mandatory standards if a totally integrated, interoperable, consumer friendly interface is to be achieved.

Acknowledgements

Many of the ideas generated in this paper are the result of many discussions in various committees and with colleagues and associates. The specific opinions and proposals expressed, however, are from the author and do not necessarily represent the opinions of any other individual, group, or company. In fact several of the opinions and proposal go against the majority opinion.

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AC POWERING FOR DIGITAL NETWORKS

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ABSTRACT

Network powering reliability is one of the most fundamental and unfortunately one of the most overlooked areas of system design and operation. Competitiveness with other service providers can be significantly affected by powering reliability, not only in the outside plant but in the office and headend as well.

This paper will explore the key issues facing operators today in terms of improving the powering reliability of their networks.

INTRODUCTION

The Cable Television industry has evolved rapidly into a complex infrastructure of broadband signal trunking and distribution networks for transmission of many different information services. The industry is poised on the threshold of the conversion to digital signal transmission of the majority of existing services. In addition, new services that are much more feasible due to digital technology are being implemented at an ever increasing pace.

The fundamental business issue facing the industry is the ability for Cable Television networks to be competitive in delivery of other services with the existing providers that are already firmly entrenched. One of the most important technical obstacles to the competitiveness of our industry is *network reliability.* Compared to existing providers of Alternate access, Telephony and Cellular, the Cable Television industry has to make significant progress in the design, construction and reliable operation of their systems in order to win over new customers from the competition. As one of the most fundamental issues facing operators for improvement of reliability, system powering is perhaps the area that deserves initially the most attention in the design of new communications networks.

DIGITAL SIGNAL POWERING REQUIREMENTS.

With the advent of digital signal transmission over the cable television network, reliable and uninterrupted powering of signal processing and transmission equipment has become extremely important.

Previously, minor signal interruptions to the cable system were somewhat tolerable because the information transmitted was entertainment video and not necessarily critical in nature (Although some subscribers would argue with this viewpoint). A slight picture roll, or a few second dropout was annoying but not necessarily critical to the subscriber.

In the past, power fluctuations, dropouts and transfer interruptions have been tolerated in many systems. Many locations had only limited or no back-up power capability for the outside plant or the headend. Some locations that had standby power equipment in place experienced poor equipment reliability, excessive maintenance requirements or budget limitations that limited repair or replacement activity.

BANDWIDTH, DIGITAL AND NEW SERVICES.

With cable systems upgrading and rebuilding for higher bandwidth and transmission of digital video and audio, Video on demand (VOD), PCS, pay per view, data networking and other digital signal delivery services, powering reliability is one of the most critical common denominators to the success of the system.

A key factor that has determined a difference in powering requirements is the volatile nature of digital data. Digital data using Asynchronous Transmission Mode (ATM) data protocol (even with error detection) can be very susceptible to power fluctuations that cause signal dropouts. Even if some form of error correction or packet delivery verification is employed, microsecond interruptions in signal flow result in reduced data throughput, higher bit error rates or complete data loss. Even the advanced synchronous "data packet" protocols that have effective error detection and correction can experience reduced data transfer speeds because of re transmission of the same data over again.

These interruptions can cause annoying visual and audible effects for entertainment transmission but can cause critical problems for other services.

SUSCEPTIBILITY TO POWER FLUCTUATIONS.

Several amplifier manufacturers have recently studied the effect of power interruption to their equipment in terms of effect on signal transmission. Their conclusion is that an interruption of power to active devices (or prolonged brownout) for longer than 20 to 25 milliseconds (.025 seconds) will cause a corresponding dropout in signal flow through the device.

AMPLIFIERS AND FIBER OPTIC RECEIVERS.

The problem in the outside plant is interruption of power to the signal processing and amplification circuitry in the active devices.

The "hold-up" time of the filter capacitors in the power supply within the amplifiers could provide several milliseconds of continued operation during a brief power dropout when new. But as they age, especially in warmer climates, the capacitance value typically decreases, and the hold-up time decreases as well. This often results in an amplifier hold-up time that is shorter in duration than the "transfer" interruption caused by of many of the standby power supplies. When certain types of standby power supplies change modes from line to standby or standby to line, an interruption in output power results. It is clear that any momentary power fluctuation that may occur on the utility input can cause standby power supplies to transfer to standby. This is what the power supply is designed to do, but if the transfer time is longer in duration than the hold-up capability of any of the amplifiers, a drop-out of data flow will occur.

Can you imagine a network that provides digital services such as telephony, dropping all phone calls in progress every time the power supplies transfer into standby?

It would be difficult to argue that such a system would be competitive with the existing Telephony providers that utilize DC Uninterruptible power systems in the central office and the outside plant.

An obvious conclusion is the importance of uninterrupted power output from the Cable Television standby power supply for reliable signal transmission. This is true not only in the outside plant but in the headend and office as well.

UNINTERRRUPTIBLE POWER SUPPLIES (UPS).

Uninterruptible power supplies (UPS) have been used by the telephone and computer industries for over 30 years for reliability reasons. These "Double Conversion" UPS units tended to be large, inefficient and expensive. For cable television applications, the typical standby power supply has been acceptable for years because of the aforementioned insensitivity of the network to minor interruptions.

DIGITAL COMPRESSION AND DATA LOSS.

With digital signal transmission, this has all changed. To give an example, any power interruption longer than a few milliseconds to any signal transmission device in a PCN or alternate access system could cause a complete drop and disconnection of all calls in progress within that cell. Any signal dropout of this duration to digital compressed video and audio can cause unpredictable, strange and annoying effects that are presented to the subscriber. Dropouts in other data services such as leased commercial data networks (service provided to inter-exchange carriers) can be catastrophic depending on the error correction system (or lack of), data transmission speed and duration of the signal loss.

Digital compression ratios in excess of ten to one have been advocated by several manufacturers of signal processing equipment. In conjunction with the compression system, high data transmission speeds are to be employed as well to provide the necessary video performance. At these high data rates, even a few millisecond interruption could result in data loss greater than all of the information contained in a several volume encyclopedia!

As many of the local area network engineers have concluded, it is imperative to the data integrity of the network that power be completely uninterruptible.

Many cable operators who are active in system planning for networks that will carry digital data in the near future have recognized the importance of UPS powering for all of the critical signal processing equipment from the headend to the subscriber. With the right design concept, uninterrupted output from a power supply does not require many additional components or extra cost.

POWER SUPPLY DESIGN

Single Ferroresonant

In cable television applications there are basically two standby power supply design approaches; the single ferroresonant transformer UPS and the "two-module" standby.

The single ferroresonant transformer concept for cable powering was introduced over 15 years ago and is available in outside plant standby power supplies as well as UPS for office or headend powering. The single ferroresonant design features two primary inputs (AC line and battery inverter) and one isolated resonant secondary winding output. The output is always connected to the transformer and is isolated from primary side transients and noise by 60 dB. The output voltage is regulated in both AC and standby modes and is consistent in voltage, waveshape, frequency and phase during AC and standby operation. Input power is routed either to the AC input primary from the utility or from the solid state crystal controlled inverter fed by the battery string when operating in standby mode. The circulating energy in the resonant tank circuit on the output winding provides continued output power during the transfer on the primary side from either line or inverter.
This energy storage provides the uninterrupted output in all modes of operation, during transfer from line to standby or standby back to line mode.

Two-Module Standby

The two module approach available from most manufacturers uses essentially two power supplies with their outputs connected to the contacts of a relay. The wiper of the relay is connected the cable system and selects from the output of one or the other power supply outputs depending upon AC or standby operation. In normal line operation, a non-standby ferroresonant transformer power supply provides output power to the cable system. When AC power browns out or completely blacks out the inverter module waits for the output voltage of the ferroresonant power supply to drop below the holding current of the transfer relay (or a sensing circuit) before the relay switches the cable system to the output of the inverter module output. This results in a significant brownout on the output (which can drop end of line actives out of operation) prior to a significant power output interruption of 35 to 70 milliseconds or more before the inverter starts to power the cable system.
According to the amplifier manufacturers, a 20 to 25 millisecond (or less in some cases) interruption is all that is required to drop signal. This effect is much worse at the end of cascade where the actives operate at a lower average voltage and have less hold-up time.
It is important to note that even if a power brownout occurs (not a complete drop-out), distortion levels in the amplifier circuitry can increase to such a level that data flow is interrupted or corrupted.

The other problem with this design is that the transfer from line to standby is not synchronized in phase. The output is switched by a relay with variable switching time and no means to synchronize to the AC line prior to re-transfer after an outage. The inverter frequency is free-running in many of these designs and can vary from 45 to 90 Hz depending on temperature, battery voltage and output load. When operating in standby, these designs can produce a high harmonic square wave output which can cause interference in the subscriber tap. This interference unfortunately also interferes with digital signal through the tap. The interference caused by the rapid rising and falling edges of the square wave output causes a signal blanking of up to 200 microseconds in the tap. This effect can occur in any device with capacitive or inductive elements that respond to the conducted harmonics at several frequencies. Devices designed for higher bandwidth such as 750Mhz to 1Ghz seem to be more susceptible to spurious noise generated by harmonics in the power supply output waveform. Or caused by transfer switching interruptions and phase changes.

OFFICE, CUSTOMER PREMISES AND HEADEND POWERING.

Power reliability is not only important in the outside plant. In most offices now, computers are an integral part in plant design, billing systems, addressability, status monitoring and other applications.

For Telephony and data network services, all of the network switching and routing equipment must be protected.

Cable network connection to local exchange carrier point of presence (POP) as well as connections to inter-exchange carriers require UPS powering for all of the multiplexers, routers, and other digital interface equipment. Usually most central office and customer premise equipment for commercial data services is powered by 48VDC UPS systems on site. A DC UPS system consists simply of a 48 volt DC (24 VDC for Cellular/PCN systems) rectifier with it's output connected in parallel to a string of Gel-cell batteries. In normal operation, the rectifier provides the operating power for the Telephony equipment in addition to "trickle charge" current to maintain the charge on the battery string. When a brown-out or blackout occurs, the battery system continues to power the equipment with no interruption. An inverter or transfer circuit is not necessary, and the corresponding potential transfer delays or interruptions are eliminated.

Even the office telephone system is critical in most systems for subscriber pay per view transactions and needs to be protected from power failure. A few minute power interruption during pay per view peak ordering time can easily result in enough revenue loss to pay for a UPS several times over.

In the headend, new digital equipment is being installed in many systems. From digital advertising insertion equipment, telephony switching and routing systems to microprocessor controlled modulators, receivers and digital music systems. Many of the computer controlled devices will not reset after a power interruption and may require manual reprogramming or fine tuning in order to restore correct operation after interruption. This clearly can be a problem in remote headend or telephony hub site locations where it can take a significant amount of time to get someone on site to correct the problem.

STANDBY GENERATORS

Even installations with standby generators are not immune from problems. It can take up to 50 seconds for an automatic standby generator to start and come up to stable voltage and frequency before transfer of the load to generator. This is assuming that the generator starts up properly the first time, many generators will re-try several times if they are having difficulty starting. This situation can occur often during cold weather in outdoor installations that can increase starting difficulties. Even if the generator starts up properly within 50 seconds or so, most computer based equipment has long since shut down. Interruptions of 8 milliseconds or less can drop out most computers.

In most high density locations, it would seem unacceptable to drop out service to all of the subscribers fed by a particular headend for 50 seconds. Add to this the interruption caused to telephone call routing systems and switching gear for commercial data customers for this duration. Our competition in the telephone industry employs dual redundancy in powering equipment in many locations that are critical to the network switching and routing activity.

Many of the newer cable television headend locations are being designed with power reliability in mind. One approach to powering in the headend is the use of both interruptible and uninterruptible branch circuits for equipment power.

The interruptible circuit is powered by the standby generator and usually consists of the devices that can withstand a momentary interruption in power with no ill effect upon operational reliability such as the following:

Interruptible Circuit;

Most lighting
Air conditioners
Circulating fans
Non-computer based equipment
Other non-critical electrical equipment.

The uninterruptible circuit is powered by a UPS that is also powered by the standby generator. When a power outage occurs, the UPS continues to provide uninterrupted output power to the headend equipment during the start-up delay of the generator. Even if the generator took several attempts to start up (or did not start at all) most UPS systems can provide continued output up to 30 minutes or longer. After the generator starts, the UPS is powered by generator and transfers out of standby mode and immediately starts recharging its battery bank. The UPS provides another significant function while operating from the generator; Voltage regulation and filtering. Most smaller generators that have been used for these types of applications are not very stable in terms of frequency or voltage regulation. When heavy electrical loads are suddenly placed on the generator such as an air conditioner, motor or lighting, the voltage and frequency can sag for many cycles until the generator speed governor and voltage regulator circuit compensate for the load change. The same is true when heavy loads are removed from the generator output, except in this condition frequency can increase and voltage can overshoot or spike until the governor can compensate. During generator operation, the UPS will filter the damaging voltage spikes and fluctuations from the generator output and provide clean power to the sensitive computer equipment connected to the Uninterruptible circuit such as the following:

Uninterruptible Circuit;

Satellite Receivers
Modulators
VTR's
Ad Insertion Equipment
Telephony switching equipment
laser transmitters and receivers
Computer Controllers
Microprocessor Based Equipment
Telephone System
Emergency Lighting

By implementing a dual circuit power system in the headend, the UPS need only be large enough in capacity to provide power to the devices connected to the uninterruptible circuit. This saves both cost and physical size with no sacrifice in reliability of the critical equipment. By coordinating this approach with the electrical contractor during the building design , maximum flexibility in installation of equipment racks powered by each circuit can be achieved. It is important for the designer to pay close attention to electrical grounding details to ensure that both the interruptible and uninterruptible circuits share the same "single point" ground location to eliminate potentially damaging ground loops.

HYBRID TELEVISION AND TELEPHONY NETWORKS.

In the U.K. many locations are currently under construction to provide video delivery as well as telephone service utilizing the same communication network. Traditional 60 volt Ac powered cable television amplifiers and fiber optic receivers are being co-located with 48VDC telephony multiplexers and switching gear. This design approach initially presented several challenges in terms of powering design. To eliminate the cost and size requirements for a dual AC and DC powering systems using traditional equipment, a new design was implemented;

A 60 volt AC output UPS was redesigned to operate from a 48 VDC battery string instead of the typical 36 volt systems used for cable television applications. The battery charger was upgraded for additional output current and to comply with the low ripple, low noise telephony specifications for 48 VDC power. A significant savings in cost was achieved by using one unit to provide both AC and DC UPS functions. The battery charger/ rectifier provides 48 VDC output for the telephony equipment at each node as well as to trickle charge the gel-cell batteries. The 60 VAC output powers the cable television equipment co-located at the node and continues to operate without interruption when utility power is interrupted. The internal DC to AC inverter converts the 48 VDC energy stored in the batteries to the 60 volt quasi-square wave output. With this approach, the cost and size of the equipment was significantly reduced. In all cases this implementation proved less expensive than the previous approach that did not provide any back-up for the 60 volt AC output.

Another power device was also implemented to improve reliability in this network; a "power multiplexer".
In the architecture used in these U.K. systems, there is a telephony node called the "Major Multiplexer" that feeds signal to all of the peripheral subscriber node locations. The Major Mux. is connected to the peripheral nodes via coaxial cable and thus can have access to the 60 volt AC UPS power from the peripheral node uninterruptible power supplies. The Major Mux. may not always be co-located with other node locations and as it is 48VDC telephony equipment it requires a rectifier / battery system to provide back-up power. To save the high cost of a separate utility power location (electrical meter, pedestal etc.) and the cost of a dedicated 48 VDC power supply, the "Power Mux." was designed. This device can accept 60 volt power from up to four directions fed via coax from the power supplies located out in the peripheral areas. The "power mux" selects AC power from one of the 4 input ports and rectifies, regulates and filters to provide a 48 VDC telephony grade power output to operate the major multiplexer. Since all four of the AC power sources are UPS, essentially "quadruple redundancy" for powering was achieved for the telephony node without installing an electrical service, large power supply or batteries. This design effectively increased reliability and reduced cost at the same time. Due to the nature of the telephony service carrying emergency (911 type) calls, the reliability requirements are much stricter than those typically considered for television service only.

CONCLUSION.

Due to the impending change in signal transmission to digital format and the new business opportunities for services in addition to television, the requirements for reliability have greatly increased. AC power problems in many locations can contribute to as much as 30 percent or more of the signal outages if not prevented by adequate power conditioning and protection systems. New services such as telephony, PCN, and data networking are far less tolerant of power related problems than the existing video service. UPS powering systems should be implemented for protection of equipment in all critical locations of the new communication networks. This will help to ensure powering reliability that will assist operators in being competitive in the new ventures.

ADAPTIVE DIGITAL IMPULSE NOISE REDUCER

By John P. Rossi, Intelvideo, Inc.
Thomas R. Jokerst, Cable Television Laboratories, Inc.

Abstract

A newly developed adaptive digital signal processing system capable of eliminating most impulse noise from TV signals is described. Video is analyzed pixel by pixel. If the circuits determine that the pixel under analysis contains impulse-noise perturbations, and no motion is found in its vicinity, that pixel is replaced with an appropriate predicted value. The system cleans up impulse noise, FM sub-threshold noise, as well as video tape drop outs.

1. INTRODUCTION

A problem often encountered by cable television operators is interference in the television signal caused by power line leakages, industrial electrical equipment operating in the vicinity of the receiving site, and other RF energy entering the TV signal spectrum at the receiving antenna. This type of interference usually shows up in the TV picture as bright or dark speckles and streaks, and it is commonly referred to as impulse noise.

Until recently, the only way to clear up this type of interference was to locate the source of the electrical noise and to correct the cause of the problem. In some cases correcting the problem has been impossible, forcing the cable operator to transport video from a remote site or directly from the broadcaster, via fiber-optic or microwave links. Such extreme measures can be very expensive, and in small markets, or isolated sites, they can become economically impractical.

With the encouragement and support of Cable Television Laboratories, Inc., Intelvideo has developed an impulse-noise reduction system that can remove impulse noise from baseband NTSC color television signals and permit cable operators to deliver acceptable quality pictures for channels that otherwise would have been severely impaired by impulse noise.

2. NOISE AND VIDEO CHARACTERISTICS

To understand the operation of the impulse-noise reducer, it is necessary to understand the character of impulse noise. In general, impulse noise is the result of electrical discharges which generate broadband energy at RF. This energy can occur at particularly high levels at frequencies occupied by the VHF TV channels, and of course, broadband energy at RF converts into spikes and streaks in the demodulation process. These spikes can have any amplitude in the baseband video signal. They can have different shapes and either positive or negative polarity. They may have a duration from a few hundred nanoseconds to several microseconds. Some spikes may destroy the video signal of an entire TV line. When the interference is very severe, the picture becomes unwatchable or, at best, very annoying to the subscriber.

The first task in trying to remove this type of noise is to identify characteristics that would permit differentiating the impulse noise from normal NTSC color signals. The most important and useful characteristic of impulse noise is that it usually consists of isolated spikes, uncorrelated with the video signal, and normally uncorrelated from line to line and from frame to frame. Another characteristic of impulse noise is that it often exceeds the normal positive or negative range of the video signal. The third characteristic of impulse noise is that, because it is usually caused by power line leakages, it has a 60 Hz repetition component. This is clearly demonstrated by the fact that this type of impulse noise in a TV picture rolls slowly up the screen.

An NTSC color signal, unfortunately, also exhibits certain characteristics that cause difficulties in differentiating between impulse noise and wanted video. Because of the color subcarrier, a color NTSC signal appears to have a certain degree of uncorrelation from line to line and from frame to frame. This is due to the color subcarrier having 180° phase difference from line to line and from frame to frame. In addition, moving picture details, unless precisely tracked, appear to have the same frame-to-frame uncorrelation that is a characteristic of impulse noise.

The challenge in trying to remove impulse noise is to differentiate between impulse noise and video. The low spatial and temporal correlation of impulse-noise spikes can be used to identify potential impulse-noise errors. But, in addition, one needs to identify moving video details and differentiate between impulse noise and video details.

3. COLOR SUBCARRIER IMPLICATIONS

As mentioned, the presence of the color subcarrier in the video signal reduces pixel correlation, both spatially and temporally, because it causes neighboring video samples to have large level variations. However, samples that have the same color-subcarrier phase do exhibit similar amplitude levels. To analyze NTSC color signals and detect impulse noise using correlation methods, one must either use video samples that have the same color-subcarrier phase, or one needs to color decode, or at least separate, the luminance and chrominance of the NTSC color signal.

To achieve acceptable luminance-chrominance separation, one may use comb filters. Comb filters normally combine video information from two or more TV lines. That means that if video contains a noise impulse, comb filtering will spread that impulse to two or more TV lines. The impulse amplitude will also be reduced, making it more difficult to detect, and secondary impairments may result. More sophisticated comb filters use adaptive processes. An adaptive comb filter can help when the impulse noise is a fairly long streak, making it easily detectable as a luminance signal. But for very short duration pulses, practical comb filters have been found to react too slowly to permit a clean separation of the impulse and the chrominance. In some cases, the adaptive process can cause significant video perturbations.

We looked at a number of adaptive comb filters being used in professional equipment and we also analyzed other patented variations of adaptive comb filters. The hardware-implemented comb filters we tested performed poorly trying to separate impulse noise from chrominance. Some of the more complex comb filters that have been proposed may, on the surface, appear to be able to handle impulse-noise separation, but practical implementation of these systems requires selection of switching thresholds and controlled gating functions that can introduce secondary perturbations. Any error in the luminance-chrominance separation can result in imperfect impulse-noise detection as well as imperfect correction. We decided, therefore, to look for impulse noise in the composite color signal, taking into account the color subcarrier phase variations.

4. NOISE DETECTION AND CORRECTION

To determine whether a particular video pixel has impulse noise or is in error, it is spatially and temporally correlated with surrounding pixels having the same color-subcarrier phase. Thus, looking at a limited spatio-temporal array of video samples, we first define equi-phase samples surrounding the sample to be analyzed. Figure 1 shows such a spatio-temporal array of video samples that have the same color-subcarrier phase (the samples identified with a star). The video sampling frequency used is 14.3 MHz (four times color subcarrier).

Note that the array of Figure 1 has samples from a number of lines from the same field (field 2) as well as from lines of the previous field (field 1) and the following field (field 3). In addition, this relationship repeats every two TV frames. The

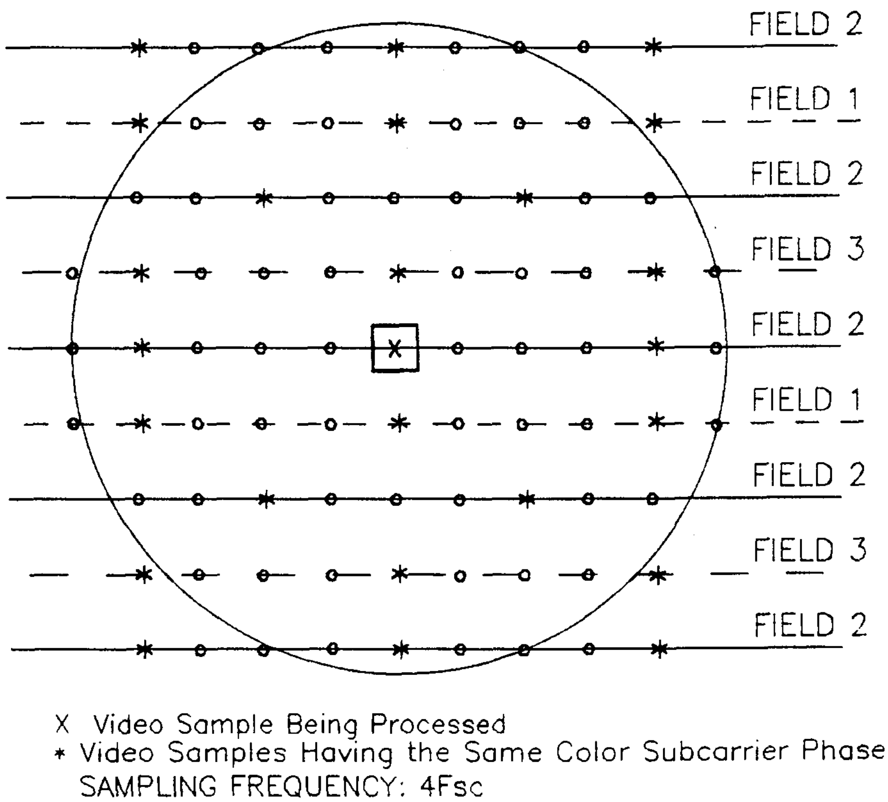


Figure 1. Spatio-Temporal Array of Video Samples

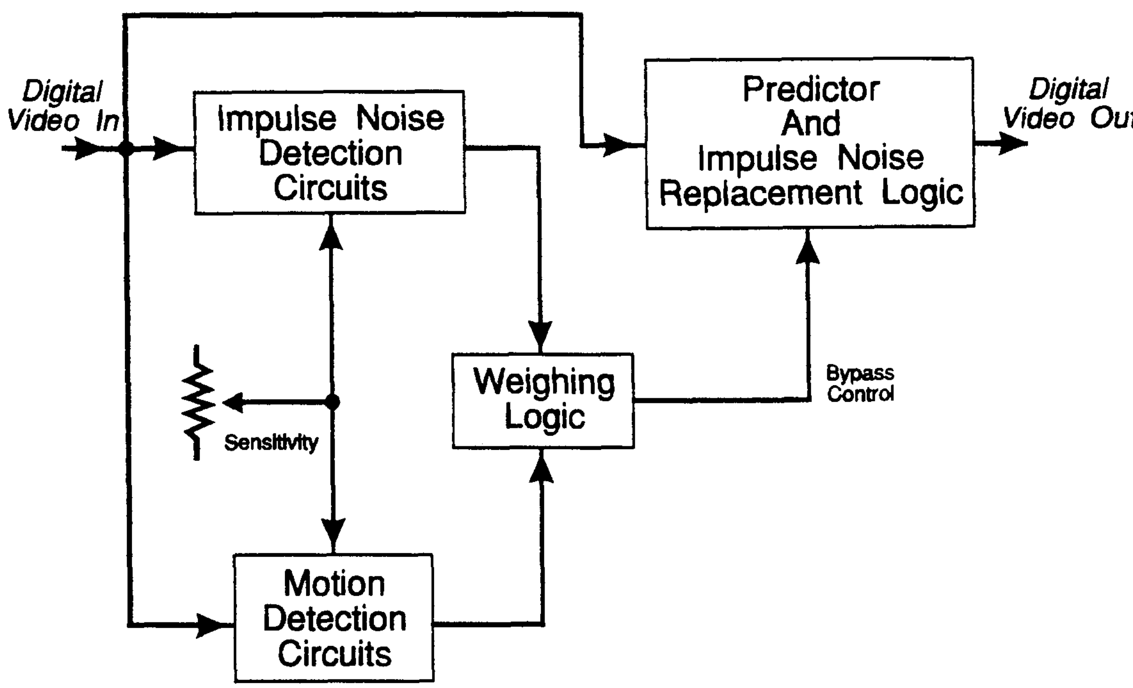


Figure 2. Impulse Noise Reducer - Digital Processor

process of determining whether the sample under consideration (sample X) has impulse-noise perturbation consists of comparing that sample with a number of other equal phase samples (as identified in Figure 1). Using some empirically determined priority rules, one can decide whether pixel X is sufficiently uncorrelated with respect to the other samples and can be labeled impulse noise.

Since moving video details, when analyzed by the same method used for impulse-noise detection, may give the same reading as impulse noise, a different analysis is performed on a number of surrounding pixels from different video frames to determine whether motion is present in the vicinity of pixel X. The process of motion detection is also a correlation process similar to the process used to detect impulse noise. The significant difference here is that pixel X is not included in the motion detection process, and thus the motion detector is not affected by the possible presence of impulse noise in pixel X.

When the noise-detection circuits determine that a given video pixel appears to have an impulse-noise perturbation or is in error, and the motion detection circuits determine that no significant motion exists near that pixel, the decision is made to replace that pixel with a video value that is believed to be the correct level for that pixel had it not been altered by the impulse noise or other perturbations. That value is obtained by predictive techniques using spatio/temporal surrounding pixels. The resulting noise-corrected picture is excellent. Under many conditions, it is nearly impossible to detect residual distortions or impairments that may be introduced by this correction process.

5. SYSTEM IMPLEMENTATION

Figure 2 shows a block diagram of the digital processes implemented in the impulse-noise reducer. Its operation is essentially as already explained. The block diagram has one particular that has not been mentioned yet. That is a sensitivity control. There are, obviously, different levels of impulse-noise perturbations, some are mild, some more severe. In some extreme situations, impulse noise is so severe that the TV picture is practically unwatchable. Under those conditions, the noise detection circuits will easily detect the noise, but the motion detection circuits will also be fooled by the noise into believing that there is motion and thus prevent the noise correction. Thus is necessary for the system to be able to operate at different sensitivity thresholds for both noise detection and motion detection. The sensitivity control shifts detection priority between noise detection and motion detection.

For severe noise cases, the motion-detector sensitivity is reduced so as not to be triggered by impulse noise, while the noise-detector sensitivity is increased so as to permit positive noise identification even as the level of uncorrelation between the pixel under analysis and the surrounding pixels (which may also have some noise) is reduced. This makes it possible to clear up severe impulse-noise conditions. A minor penalty to be paid under those conditions is that the noise-reduction process may introduce some motion impairments. But, given the choice between pictures with severe impulse-noise impairments and pictures with no noise impairments, but some occasional motion artifacts, the choice will always, unequivocally, be for the impulse-noise-free picture. In fact, the quality improvement achieved is so dramatic one needs to see it demonstrated in order to appreciate its effectiveness.

6. OTHER APPLICATIONS AND CONCLUSION

A useful alternative application of the noise-reducer technology is to correct FM sub-threshold noise. This noise appears as bright or black dashes or sparkles on a picture. They are usually caused by a signal reduction of the FM carrier. The impulse-noise reducer has a rather easy time of detecting those types of errors and replacing the errors with a proper video level. Thus one may look at the impulse-noise reducer as a means of extending the

FM threshold in an FM microwave or satellite link. It also can be effective in reducing the impulse-noise effects of terrestrial interference (TI) in satellite TVRO installations.

Yet another use of the impulse-noise reducer is as a tape drop-out compensator. Of course, it is preferred to perform drop-out compensation at the video tape recorder during playback using the drop-out detector control signal. Some tape recorders, however, do not have a drop-out compensator, and one is at times saddled with video signals that contain drop outs. Because the drop outs have characteristics similar to impulse noise, the impulse-noise reducer will automatically detect drop outs and correct them.

The impulse-noise reducer we described is available as a product from Intelvideo. Several cable companies are already using the device to eliminate the effects of impulse noise at some of their worst reception sites. Reports from users of the device have been enthusiastic.

Addressable Decoder with Downloadable Operation

Mack Daily
Zenith Electronics Corporation

ABSTRACT

There was a time when a set top converter could take a non-remote TV and turn it into a wonder of convenience. Now the converter has turned that fancy, hi-tech, 32 function remote control TV into a color monitor.

There is a need to make the converter desirable again, to offer features that a TV set can't support, to make the decoder a convenience.

This paper follows the design of a new CATV converter from the initial marketing concept, to the design that is in production today. It tries to shed some light on the decisions which lead to that gap between what was asked for and what is finally produced.

INITIAL MARKETING CONCEPT

Here's the wish list:

1) Color On Screen Display (OSD).

A new color on screen display will be the user interface. A menu system will allow the user to select options. Instructions for using the converter will be spelled out in plain English (or Spanish) on the screen.

2) Electronic Program Guides.

An electronic program guide will be loaded and updated continuously. This guide will be used as one would use the guide in the Sunday paper. The user finds the day and time and the converter shows what is on. Two weeks of information was deemed sufficient.

3) Messaging.

Messages to groups or individuals can be sent. Anything from "HAPPY BIRTHDAY" to "PAY YOUR BILL" to "DON'T FORGET! THE CONCERT YOU ORDERED IS ON TONIGHT".

4) Flexibility.

Think about the future. The system needs to be independent of the video scrambling system to allow migration from present to future systems.

HARDWARE

Hardware Part 1: Fulfill the List

Referring to Figure 1, a block diagram of a cable decoder is fairly generic if one is concerned only with the operation of the microcontroller.

The tuning microcontroller is the control center. It provides an interface with the user having IR and keyboard for input, LED and OSD for feedback. The tuning micro controls the tuner. Depending upon the complexity of the system, it may have input concerning descrambling. This implies the micro receives and interprets data. With or without the tuning micro's help, the descrambling portion decides authorization and manipulates the video for the desired output.

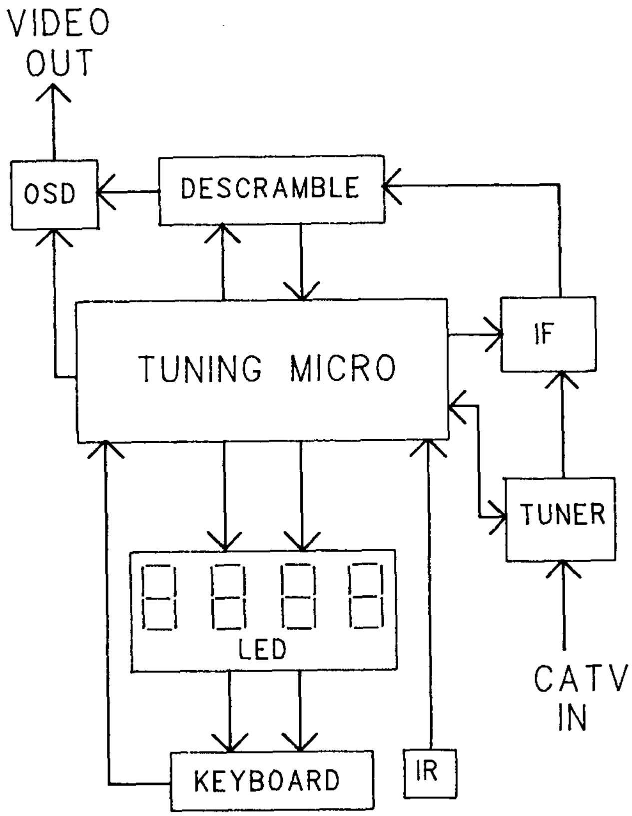


Figure 1
A Generic CATV Converter

Given our generic converter, how do we add the needed features? Easy, leave the present converter alone, it works! We still need all the tuning micro's tasks done, we're just throwing a couple of screens up now and then. An additional microcontroller is needed to control the new electronic program guide, and it needs a large memory in which to store the guide data. If the new micro reads the LED segment drivers of the existing tuning micro while an LED digit is being scanned, it can tell what that digit is displaying. These LED's tell if the converter is authorized, or can buy a program, etc. Using this information, the new micro will be able to show an OSD with a more detailed explanation of the situation. The new micro will receive the IR input, and control the keyboard, as it will be deciding what actions user inputs are calling for. The original tuning micro can be controlled by synthesized IR commands applied to its IR input.

While awkward, this approach could fulfill the requirements. However, it had became apparent that simply switching between watching programs and showing screens wasn't enough. Entering favorite channels and parental control had to be made easier. No one likes current VCR timers. All those connections to the tuning micro drove the pin count of our new micro way up.

It was apparent this system could not have 2 microcontrollers, both programmed to be in control.

<u>Hardware Part 2: A Division of Labor</u>

1) The Conditional Access Microcontroller:

The tuning microcontroller was made a slave, and became the Conditional Access Microcontroller. The Conditional Access Micro controls the LED's, keyboard scanning, and contains whatever video descrambling capability the original tuning micro had. The descrambling duties of the micro vary from scrambling system to system, therefore the Conditional Access Micro is hardware and firmware specific to a scrambling system. The Conditional Access Micro receives in-band data (data which is transmitted within the bandwidth of the tuned channel) as before, but except for program authorizations, the data is passed to a master microcontroller. In fact, the only independent function of the Conditional Access Micro is program authorizations. The decision making process as to whether to descramble is the same as in the original system.

2) The Dialog Processor Microcontroller:

The new master of the converter is called the Dialog Processor. Except for program authorizations, the Dialog Processor runs the show. It can access a large external RAM. This RAM, where program guides and more are stored, has battery back up. An EEPROM provides non-volatile storage of critical data. Parental control and channel tuning information are stored in the EEPROM. The new color on screen display is under the direct control of the Dialog Processor. The display can overlay characters on live video, or generate entire screens.

With a 2-way expansion bus, the Dialog Processor will be able to read and write future accessories. A special accessory now available is a plug-in IR transmitter. The Dialog Processor can transmit low power IR commands, controlling a VCR, TV or whatever.

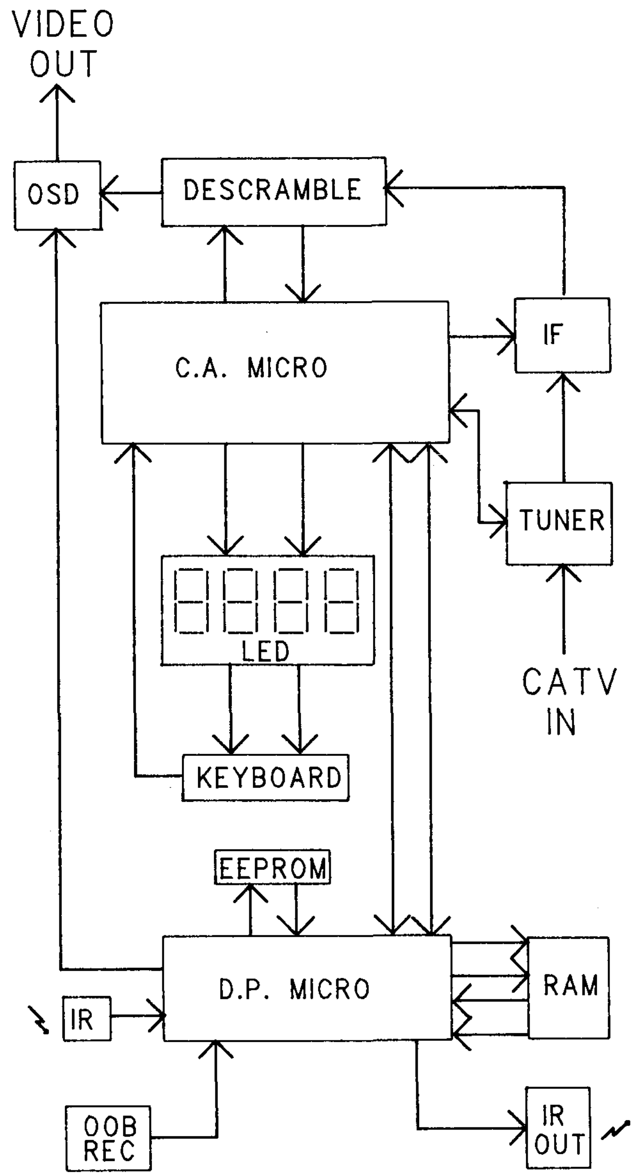


Figure 2
The New System

The Conditional Access Micro is considered just another peripheral by the Dialog Processor. The Conditional Access Micro and Dialog

Processor communicate over a custom 2-way serial bus. This bus allows each micro to determine at what speed it can comfortably send and receive data, but each micro is required to constantly send data, whether it really has anything new to say or not.

The commands passed back and forth were designed to be independent of any Conditional Access Micro hardware. The Conditional Access Micro also takes care of any timing involved with command execution. For example, the Dialog Processor provides the Conditional Access Micro with two displays for each LED digit. The Conditional Access Micro drives the LED, automatically alternating between the two displays.

Tuning information is communicated to the Conditional Access Micro in the form of PLL data. This allows the tuning of any combination of channels. The Conditional Access Micro indicates to the Dialog Processor any keyboard action, as well as any commands sent via the in-band data channel. The task of receiving IR, a function which the original tuning micro had performed, has not been given to the Conditional Access Micro, but rather is done by the Dialog Processor. This speeds IR response by eliminating the Conditional Access Micro to Dialog Processor bus delay.

The Dialog Processor also has an out-of-band data receiver. Out-of-band data is data transmitted independently of the bandwidth of the channel tuned. The format of the in-band data is a function of the scrambling system. For previously existing systems, that format probably has no provision for loading a two week program guide. Even if the guide data can be fitted into the format, speed will be a problem. In the future, the in-band data rates capable with digital video may well overwhelm the Dialog Processor, but for the present even the "penny pinchers" in the marketing department agree that loading a 2 week guide using in-band data at 2 bytes per vertical is too slow.

SOFTWARE

The Need for Flexibility

At this point, we had a hardware system into which we could load and store a lot of data. The restriction was the framework hard wired into the Dialog Processor for displaying the data. Screen after screen could be displayed, but actions within a screen were not flexible. For example, consider the 2 screens shown in Figure 3.

The user hits "ENTER". Do we add channel 7 or 19 if we're highlighting the upper right corner of the screen? How did we get the upper right highlighted in the first place? To code the Dialog Processor to work with either screen is doable, but it has to be planned. Considering the amount of information to be made available, it was certain we would not cover all the options.

The solution is to load not only screens, but the behavior of the decoder with any given input. One option

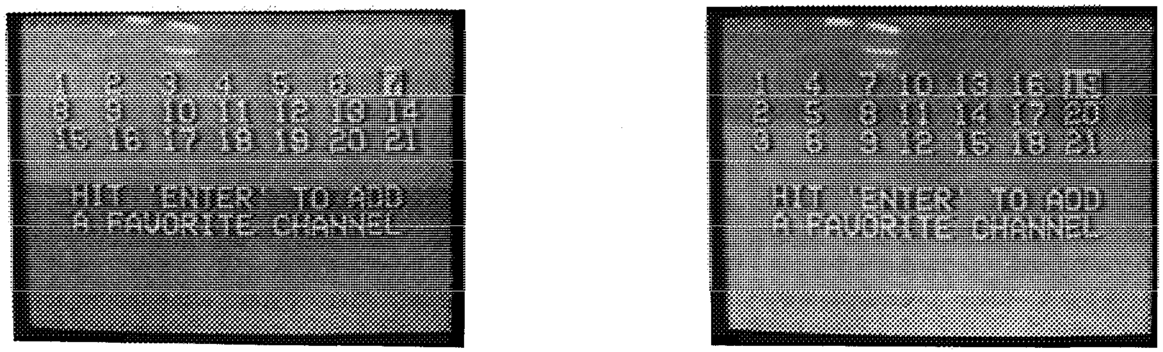


Figure 3
Two Screens for the Same Function

is to load the actual opcodes of the micro. This requires a micro which can run a program out of external memory. It also ties you to micros which will run that code. What about the possibility of loading the wrong code and locking the device in an endless loop? Lastly, who is going to support this code?

<u>The Dialog</u>

In order to avoid the mentioned pitfalls, but gain the needed flexibility, we developed our own "CATV decoder programming language". The Dialog Processor was programmed to interpret the language. The combination of on screen display data and behavior codes was called the Dialog, hence the name Dialog Processor. The interpreter is a firmware function of the Dialog Processor, the dialog to be interpreted is loaded via out-of-band data and stored in the external RAM.

It was necessary to develop an architecture, commands, and the associated tools for program development. There were also two programs to write, the interpreter and the dialog, neither of which could be reliably developed independently.

<u>Downloading a Dialog</u>

Hardcoded into the Dialog Processor is the task of out-of-band data reception and the associated memory management of the external RAM. Before being transmitted, the data is sorted into records which consist of a variable number of like sized files. Depending on what is presently in the RAM, the actual addresses into which data is stored will vary from decoder to decoder. Therefore, a dialog will refer to the Nth entry of record X to recover data. In addition to keeping track of where all downloaded data resides, the memory manager coalesces current data to lower addresses. Thus, all available memory resides in a block above an address which the memory manager calculates.

<u>Interfacing the Dialog to the User</u>

The main program loop of the Dialog Processor handles the hardware specific portion of communicating with the OSD chip, the Conditional Access Micro, and other periphery.

While the IR input is sampled and decoded by firmware, a special downloaded record is predefined to contain two IR formats. By loading this record, the decoder may be made to respond to up to 3 IR transmitters. The main loop updates a real time clock and 2 timers which are set by interpretive commands. The inputs from the periphery, IR inputs, and the time-out of the timers, are presented to the interpreter as transitions.

Interpreting a Dialog

Actions taken due to the presented transitions are determined by the dialog loaded via out-of-band data. The Dialog Processor only interprets the dialog, which is changeable.

For a "slide show" type of application, the interpreter is used as a state driven machine. Given the current screen and the transition, the next screen is known. This allows the dialog to change screens by simply supplying a pointer to the new screen. Referring to Figure 4, the screens represent the states. The state number is given in the upper right of the square. An arrow points to the next state, given a transition corresponding to the arrow's label. Any transition without an associated arrow has no effect on the state. Transitions may also be defined to cause an action regardless of the current state. "POWER", for instance, could turn the box off from any state.

This efficient way of stepping allows development of tools with which a nontechnical person may develop their own slide show. The new decoder has 32,512 states available for this type of application.

For any given input, a more complex action may be required. "CHANNEL UP", for instance, requires finding the next valid channel, and communicating to the Conditional Access micro new tuning and LED information. For these types of actions, interpretive commands were developed. The commands are an assembly language code which the interpreter runs.

The interpreter features a design to prevent a corrupted dialog from locking the micro. The dialog is also prevented from modifying itself.

From a dead start, at least minimal functionality was required from the decoder. This basic mode was written as a dialog and at start up it is loaded into the RAM. From that point it is executed as if it were a downloaded dialog. This was not necessarily the most efficient way to code the basic operation, but it allowed testing and enhancement of the interpreter using a real application.

In order to allow for personalized messaging, dialogs are sent with addressing information. A packet may be globally addressed, addressed to members of a specific group, or individually addressed. Each box has a unique address and can be a member of up to 8 groups. A packet may also be encoded and a decoder must be authorized to receive it. Packet trans-

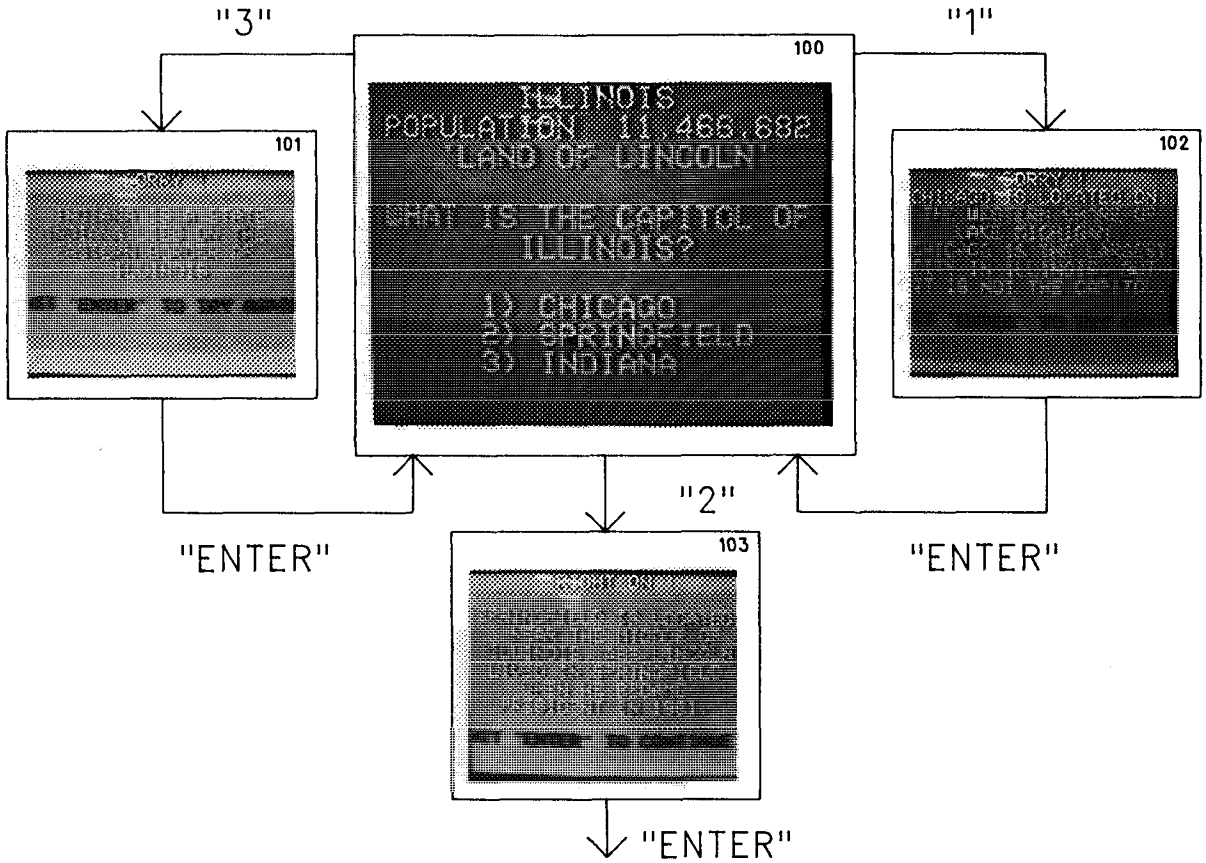


Figure 4
State Transition Diagram

mission includes a 16 bit CRC to prevent accepting bad data.

CONCLUSION

The end result is a field programmable cable box. The box contains 2 microcontrollers. One micro replaces the functions that a tuning micro traditionally performs, ie. tuner control, LED drive, keyboard scan, and any video descrambling control. The second micro has 3 main functions.

First, it manages a large external RAM into which data received from an out-of-band source is stored. This data is referred to as a dialog. Secondly, the micro performs housekeeping tasks of time keeping, and communication with peripherals. Housekeeping also includes collection and indicating the presence of certain events called transitions which may require a response. Thirdly, an interpreter, given a transition and the state in which the box currently sits, performs a corresponding series of instructions indicated in the dialog.

By using state transitions to page through screens, tools have been developed which offer the service provider the chance to design his own dialog. State transitions make efficient use of the available RAM, and require only that pointers from state to state be supplied.

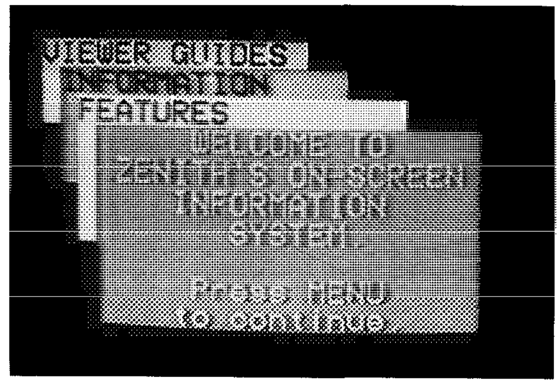
Though not something to be changed recklessly, the most basic operations of the box are downloadable.

The OSD displays a field of text 11 rows by 24 columns. By taking advantage of the colors and characters available, a fairly complex display may be generated. A bit mapped display of either 192 bits X 18, or 96 bits X 36 may also be displayed. A bit mapped display may be scaled horizontally to extend the display across the screen, but the vertical size may not be altered. Examples of a text and a bit mapped display are shown in Figure 5.

The box was designed for 2 weeks of program guides, but it can do more. Stock prices, scores, even download your own games.

A self diagnostic screen indicates both the presence and signal strength of in and out-of-band signals. ROM code revisions of the Conditional Access Micro and Dialog Processor, as well as the size of the external RAM are also displayed. The diagnostic screen is shown in Figure 6.

This design is the result of the work of the entire Zenith CATV department. I think we've designed what marketing really wanted, but were afraid to ask for. The content of the dialog will determine whether the decoder becomes a convenience for the user.



Text Field OSD

Bit Mapped OSD
Figure 5

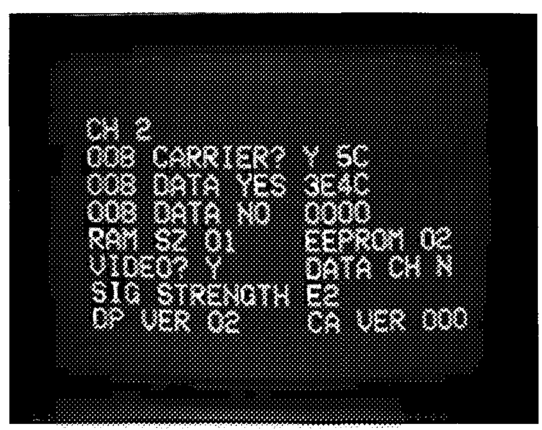


Figure 6
The Diagnostic Screen

Advanced Data Communications Applications for the CATV Industry

By
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and
William E. Cohn
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ABSTRACT

Two way cable plants have traditionally been used to provide interactive television services to home subscribers. The deployment of fiber technology and the impact of digital data services within the cable industry has accelerated the move toward telecommunications and local area networks.

Today's delivery costs for video (broadcast) entertainment services and data delivery remain less expensive via analog facilities vs. digital facilities. Furthermore, metropolitan community cable TV networks already provide ample bandwidth for the delivery of bi-directional services including video, voice, local area networks (LAN), alternative telecommunications access and real time control systems.

Unlike baseband LANs such as Ethernet and Token Ring, broadband LANs based on cable TV technology offer the ability to span large metropolitan areas and can be expanded to support multiple networks on a single cable. Cable systems can be structured as a LAN backbone data architecture to support baseband sub-networks, bridges and routers, and can replace T1 circuits, dedicated and dial-up phone lines.

This paper will provide a technology brief, present case study applications and address the impact and benefits of cable TV data networks.

INTRODUCTION

Can today's cable TV plants support computer networking? Although industry visionaries have begun to look forward to the days when the tree and branch analog cable plant will be replaced by switched digital networks, we should not overlook the existing analog cable TV infrastructure. Although originally designed to deliver broadcast TV signals to home subscribers, it presents an excellent conduit for high speed data transmissions without compromising existing entertainment programming. Broadband-cable TV "networks" already provide ample bandwidth for the delivery of bi-directional services, including video, voice, metropolitan area networks (MANs), and local area networks (LANs). Data and electronic service access may include alternative telecommunication links for businesses using native LAN connections, in-house cable TV operations connectivity, environmental monitoring, real time control, work-at-home "cablecommuting", image transfer, INTERNET and electronic bulletin board access and others. Electronic "data kiosks" could provide personal digital assistant (PDA) users with information downloads. Imagine linking your Apple Newton PDA to a kiosk at a subway station using an infra-red interface and downloading the train map, schedules and fares - over the cable TV plant! Furthermore, computer networks can utilize excess cable TV channel capacity to supplement and expand revenue which benefits the cable operator.

CATV TECHNOLOGY BRIEF

Community cable TV plants are a ubiquitous medium comparable only in geographical coverage to phone companies. Industry estimates indicate that between 50% and 60% of all homes in the U.S. are connected to cable and approximately 80% of all homes in the U.S. can be easily connected. Because cable TV plants are metropolitan in nature, they can support local businesses, municipal governments and community schools.

Broadband-cable TV based data communication systems, when compared to baseband systems such as Ethernet and Token Ring or even telephone data equipment, provide a sophisticated and flexible backbone solution. Broadband-cable TV based LAN systems inter-operate with video or other data transmissions by having an allocated frequency slot on a cable plant as if they were a television channel. The inherent advantage of cable TV systems, is the ability to simultaneously carry multiple services including broadcast video, multiple LANs, point-to-point data, security, image transmissions, video teleconferencing, voice and other value added services on a single wire. This sharing technique is referred to as frequency division multiplexing (FDM). In contrast to broadband-cable TV systems, baseband communication systems use the entire bandwidth of the wire for transmission and reception of a single signal on either copper or fiber based cable.

A review of the existing cable plant architecture shows a frequency domain multiplexing (FDM) system which utilizes multiple 6 MHz channels on a single coaxial wire. Plant capacity has increased over the years through the introduction of line amplifier technology which permits an increase in frequency bandwidth. Cable plant capacities range from 5 MHz to 350 MHz in older systems to plants which support up to 450 MHz. Hybrid fiber/coaxial super trunking systems are gradually replacing the older coax only systems, and are now capable of supporting 1 GHz of bandwidth. The transmission requirement for data is a two-way duplex data path. LAN devices on broadband-cable TV systems utilize one channel for reception (downstream) and one channel for transmitting (upstream).

LAN PROTOCOL FOR CATV

The support of hundreds of computer devices on municipal cable plant requires a contention access protocol that is bandwidth efficient, cost effective, and supports commercial type data services. The plant's tree-and-branch architecture invariably dictates the type of LAN access scheme that can be used. Because the data transmissions on the plant are bi-directional and the span of the system can be extremely long (30+ miles), creating significant transmission delay times conventional baseband LAN access methods cannot be used. Designed as a video distribution system, the plant cannot be modified into a point-to-point configuration, nor can it be fashioned into a ring. Using the given tree-and-branch topology, a Carrier Sense Multiple Access with Collision Detection (CSMA/CD) based broadcast contention system meets the criteria given above. To meet the distance, spectral efficiency and data bandwidth requirements for a commercially viable cable TV LAN, a modified CSMA/CD scheme must be used.

CSMA/CD based LAN interface devices designed for metropolitan cable TV plants utilize upstream channels for transmitting and downstream channels for receiving. Each LAN device sends messages using an upstream channel; the message is received at the headend, translated to a downstream channel, retransmitted and received by the destination device - assuming no two devices transmitted at the exact time. If message "collisions" do occur, it is the job of the CSMA/CD protocol to detect collisions and retransmit until the message is properly sent. To establish this duplex transmission path on the cable plant, a device called a frequency translator is required at the headend.

needs described in this presentation. These products permit the transportation of standard LAN protocols using a broadband cable plant as a data backbone. The plant allows multiple LANs to be added onto a single cable to increase data bandwidth on demand.

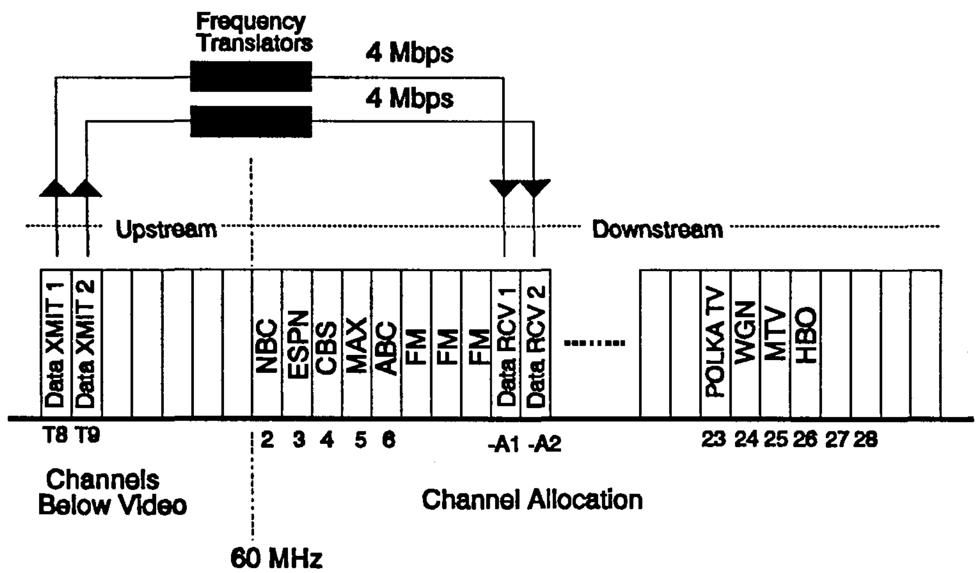

FIGURE 1: Example of LAN Channel Allocation for Cable TV Plants

Because broadband based cable TV LANs operate in the frequency domain, several networks can be operated on a single coaxial cable. Individual LAN backbones are easily configured by assigning different frequency pairs (channels) using one frequency translator device per LAN. This individualized backbone approach permits flexible bandwidth on demand expansion, or segmentation by business, academia or service application.

CATV DATA INTERFACE EQUIPMENT

LAN connectivity equipment for cable TV applications is currently marketed which addresses the diverse data communication Gateway and bridging interfaces between broadband cable and a variety of standardized LAN protocols, including Ethernet and Token Ring are available. General computing equipment which uses asynchronous RS-232 interfaces (ie. printers, terminals, optical code readers, PCs) can also be interfaced to the metropolitan community network.

CASE STUDY APPLICATIONS

Business-to-Business:

Business-to-business data networks which require high speed bandwidth can easily be created on municipal cable TV plants. Using a LAN multi-point architecture, businesses can connect PC based file servers, mainframes and graphic workstations. High speed graphic file transmissions would occur electronically in a matter of seconds. Shared T1 (1.544 Mbps), low speed phone modems (1200-9600 bps) and other multiplexed telecommunications equipment could be eliminated. Figure 2 compares telecommunications data equipment with market ready LAN products available for the cable TV industry.

This problem solving example for business-to-business applications was recently implemented by the Village of Schaumburg, IL in cooperation with Tele-communications Inc. Three data line alternatives were available to the Information Systems (IS) organization: 1) install a private fiber network, 2) use existing low speed point-to-point telephone equipment with multiplexing modems or 3) obtain bandwidth on the municipal cable system's two way institutional network for high speed LAN data transfers.

A new fiber network would be cost prohibitive; a telephone modem/mux system using a digital data service line (typically 9600 bps) performance would not allow high speed connectivity between public service facilities (police and fire); the LAN would provide multipoint connectivity at a 4 Mbps data rate/RF cable TV channel.

Schaumburg Police and Fire Departments use a computer aided dispatch system linked across the institutional network LAN to each Public Service Facility in the Village. The dispatch system operates on a Novell NetWare file server system, which is connected to the backbone using a LAN bridge. The bridge provides an interface from a baseband Ethernet LAN to cable TV plant backbone.

Community Schools (K-12)

The City of Glenview, IL, in cooperation with Tele-communications Inc., is utilizing the institutional cable TV plant to network 7 schools within the district. The district's computer system utilizes Unix based server equipment at each school site, which are then connected to the broadband-cable TV LAN backbone using TCP/IP as the network transport protocol. This computer network supports both instructional and academic applications. Apple Macintosh computers are bridged onto the LAN backbone via an Ethernet-on-broadband media access unit (MAU) connected to an AppleTalk-to-Ethernet bridge. Teachers can share files across the network and communicate using electronic mail facilities.

REVENUE EXPANSION

The cable operator is always looking for new sources of revenue. This is especially attractive if the service can be offered over the existing plant. Many cable operators deployed two-way ready cable plants during the franchise frenzy of the early 1980s. Not many operators found a need for this two-way capability, so it either went unused or was drastically under utilized. The prime reason for this capability was the deployment of residential interactive services. Although the network was apparently ready to handle this traffic, the users did not have a reason to use this capacity. Cable operators were relegated to the opinion that they would either not use the two-way plant capacity or give it a minor role, like plant status monitoring. Early on, operators tried impulse buying technology that could make use of the interactive nature of the plant as an order collection mechanism. Both applications have very small bandwidth requirements. Even in a modest subsplit cable plant only a very small portion of the 25 MHz is utilized. With deployment of fiber optics into the cable plant, this small return path can provide enormous revenue potential. What is an operator supposed to do with this new found upstream path?

	NATIVE SPEED	TOPOLOGY	CONNECTIVITY	COSTS (Equip.= Pairs)	LINE CHARGES	ADVANTAGES	DIS-ADVANTAGES
ETHERNET INTERFACE Broadband-CATV	Local - 10 Mb Backbone - 4 Mb	LAN/MAN broadcast multi-point CATV	School-Inter/Intra Business-Inter/Intra Mfg.-Inter/Intra Tele-commuting Campus-Inter/Intra Residential	Equip. $3990 Instal. $TBD	Per Franchise	Std. Ethernet Interface Performance MAN Coverage (30 Miles) Multi-media Expansion	CATV Channel Allocation
PC LAN CARD Broadband-CATV	4 Mb	LAN/MAN broadcast multi-point CATV	School-Inter Business-Inter Mfg.-Inter Tele-commuting Campus-Inter	Equip. $895 Instal. $TBD	Per Franchise	Performance MAN Coverage Multi-media Expansion	CATV Channel Allocation
LAN BRIDGE Broadband-CATV	MAN - 4 Mb LAN - 10 Mb 16 Mb WAN- 0 - 2.048 Mb	Bridge-LAN/MAN/WAN broadcast multi-point CATV/T1/LAN	School-Inter/Intra Business-Inter/Intra Mfg.-Inter/Intra Campus-Inter/Intra	Equip. $17000 Instal. $TBD	Per Franchise	Expansion LAN Gateway LAN/WAN/MAN Coverage Multi-media	CATV Channel Allocation
RS-232 MODEM Broadband-CATV	38.4 Kb (0.0384 Mb)	Business-Inter Node broadcast point-to-point CATV	Tele-commuting Electronic BBS Residential	Equip. $1390 Instal. $TBD	Monthly $TBD Usage $TBD	Performance Uses CATV Connection Multi-media MAN Coverage	CATV Channel Allocation
T1	1.544 Mb	LAN/WAN leased line point-to-point TELCO	School-Inter Business-Inter Mfg.-Inter	Equip. $9600 Instal. $2400	Monthly $1200 Usage $5/mile	WAN Coverage Voice, Video	Req's Native LAN Bridge Cost-to-Performance Expansion req's 2nd line
RS-232 PHONE MODEM Dial Up Line (Voice)	9600 Kb (0.096 Mb)	Node dial up line point-to-point TELCO	Tele-commuting Electronic BBS Residential	Equip. $600 Instal. $0	Monthly $15 Usage $TBD	Better for WANs	Impacts Voice Line Performance
RS-232 PHONE MODEM Dedicated Line (DDS)	9600 Kb (0.096 Mb)	Node dedicated line point-to-point TELCO	Business-Inter Tele-commuting Electronic BBS Residential	Equip. $1100 Instal. $750	Monthly $200 Usage $0	Better for WANs	Requires 2nd line Performance

FIGURE 2: A Comparison of CATV LAN vs. Telco Data Interfaces

Cable Regulation

The cable act of 1992 has provisions for the controlling of certain tier rates a cable operator may charge his subscribers. If operators end up with a fixed rate structure it may be prudent to investigate other uses of his broadband cable TV plant. The current regulations are aimed at the rates charged to subscribers for video entertainment services. The regulations allow for the incorporation of alternative data services over the cable network.

Return on Investment

Selling excess network capacity on cable for data services is a natural expansion for the cable operator. The single largest investment necessary for a data network is the network itself. The transport mechanism of the network, the cable plant, is already in place. The hardware needed to add data capability is not only available at this time, but at a small investment.

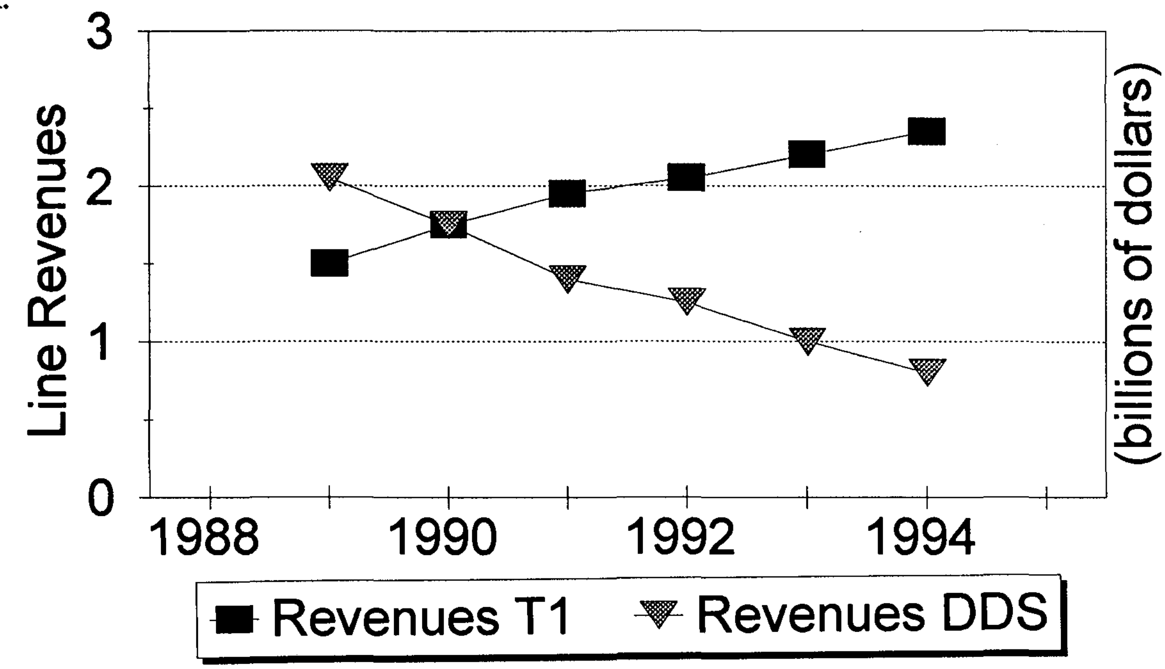

FIGURE 3: Estimated Telco Data Revenues

Estimates of Revenue for Telco Data Services

The graph in Figure 3 demonstrates the revenue opportunity that LAN type data services could present to cable TV operators. In 1993, it is estimated that the revenue from combined digital data services and T1 services will exceed $1B, not including data over voice grade telephone lines, which accounts for an additional revenue stream of about $800M.

CONCLUSION

Many operators are faced with the reality that they are perhaps reaching subscriber saturation levels. As subscriber counts are starting to stabilize, there are fewer areas to extend the reach of the cable TV system economically. The current subscriber is reluctant to add more premium channels to his monthly bill and there is only so much video entertainment a subscriber is willing watch. Therefore, other revenue streams need to be investigated.

An Enhanced Cost Effective Line Shuffle Scrambling System with Secure Conditional Access Authorization

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ABSTRACT

Many systems currently exist to scramble a composite video television picture, but most suffer from both technical and commercial flaws which can seriously compromise performance and security. Most recently, digital compression and transmission of NTSC, PAL or SECAM video has been envisioned as the ultimate answer to video scrambling and protection from theft of service, but the cost of implementation is high. This paper presents an alternative analog scrambling system with the benefits of video digital processing for hard security and concealment without the high costs associated with full digital compression.

A line-shuffling analog video scrambling system, compatible with NTSC, PAL or SECAM systems, is presented which randomly displaces video lines in a video field to render the resulting television image unviewable but capable of being transmitted and received with standard equipment. By utilizing special memory addressing techniques, only one block of memory is required to continuously scramble successive blocks of video, thereby reducing system components and cost. A fully encrypted conditional access system is also included to provide protection against piracy without the need for "smart-cards" to renew security.

INTRODUCTION

Analog video scrambling systems, and their associated conditional access methods have been in existence since the concept of "Pay TV" began in the 1940's. The popularity and longevity of analog scrambling is due primarily to the low cost of implementation. Methods currently used to render TV video unviewable (until authorized) largely rely on suppression or elimination of video scan synchronization to encode the video (sync suppression). Sync suppression is effective but can be prone to theft of service if the timing-location of the suppressed syncs can be easily determined by analysis of video, audio, or in-band decoding data. Sync suppression additionally proves difficult to implement in CATV head-end modulation, terrestrial broadcast re-transmission equipment or subscriber reception equipment due to the lack of synchronization pulses with which to clamp video. Other analog methods, such as rapid video inversion, random line delay or line-cut-and-rotate systems, can be prone to serious residual artifacts due to the scrambling techniques or non-linearity of transmission systems. Such artifacts may themselves become a weakness in the security of the scrambled signal, allowing for simple signal piracy techniques.

There is a need for a high performance, secure, opaque scrambling method that is cost effective and requires no modification to video transmission or reception equipment. A video line shuffling system with secure encrypted descrambling sequence information and conditional access control data has been developed to satisfy those needs. The system, co-developed by DCE and Zenith, is called "DigiCrypt."

LINE SHUFFLE VIDEO SCRAMBLING

Line Shuffle scrambling is a technique whereby video lines are interchanged within a field of video so as to destroy the entertainment value and information content of a television program to an un-authorized viewer. There are basically two types of line shuffling.

The first type, which can be called "Field Line Shuffling", is where a number of video lines are displaced within a whole video field. Field Line Shuffling suffers with the problem that if the number of lines actually shuffled is less than the number of active video lines within the video field (288 for a PAL system), some of the video lines will remain unshuffled during that field. This can cause the scrambling effect to be less opaque than other scrambling methods even though any line chosen to be displaced can in fact be displaced anywhere within the video field.

The second type of line shuffling, which can be called "Block Line Shuffling", is where the video field is split up into "Blocks" of N video lines and every line of video within each block is displaced from it's original position, rather like shuffling a pack of cards (see Fig. 11). However, this method suffers with the problem that any line can only be displaced from it's original position by up to N lines, i.e. the block size. However, in a system where N is variable, this can be a strength, as the density of the scrambling can be selected by the program provider.

Block Line Shuffling

The DigiCrypt system is based upon Block Line Shuffling as it was considered to be the more flexible system and able to offer a higher degree of opacity. However, one drawback of splitting the video field into blocks of N lines is that the PAL, SECAM and NTSC standards do not offer a 'friendly' number of lines per field, making it difficult to select a number for N to comfortably fit whole blocks within the video field, especially considering that N should be a power of two to maximize the efficiency and utilization of the video memory.

For example, if we select N to be 32 and allow 288 lines of active video per field for a PAL system, we get 9 whole blocks per field. However, if we then transpose this format to an NTSC system and allow 240 lines of active video per field we get 7.5 blocks and therefore we find that the last block will wrap-around into the next video field.

This then leaves us with one of two possible solutions. Either we allow a pre-defined number of video lines at the top and/or bottom of the video to be clear (unscrambled) thereby forcing a multiple of whole blocks, or we design the architecture of the system to allow blocks of N lines to wrap-around into the next video field, only pausing to let the field blanking interval through. Although the former is attractive due to the simplicity of design required, it was considered that the latter would render the most flexibility from the system. This would therefore allow any size of blocks and any number of lines per video field, the only consideration then being how many video fields it would take for the shuffling of blocks to return to a field boundary for re-synchronization of encoder and decoder.

In the DigiCrypt system, N is chosen to be either 32 or 128. This enables the system to give a very high degree of opacity, via the 128 line option, or more visibility, via the 32 line option for 'teaser' viewing. It also means that a very cost effective decoder may be produced using a smaller amount of memory, which will decode 32 line block transmissions only, or an "all-singing, all-dancing" decoder which can decode both 32 line and 128 line transmissions using the full amount of memory.

System Overview

The line shuffling system can be used for terrestrial broadcast, satellite, microwave or cable TV applications. Fig 1 shows a typical system configuration transmitting over a satellite link. The transmission side of the system, consists of an encoder and conditional access computer containing a data-base of subscriber authorizations. The video feed, which could typically come from a television studio, is fed into the encoder, digitized by an analog-to-digital converter and then scrambled by Block Line Shuffling. Data coming in from the conditional access computer is packetized, a scrambling seed added, and then the whole message is encrypted and inserted onto four unused lines in the field blanking interval before being converted back into the analog domain by a digital-to-analog converter and transmitted over the satellite link. The scrambling seed is generated from a random number generator within the encoder (possibly a noise source) and is used by the line shuffling algorithm each time a re-synchronization occurs. The "re-synchronization" decision, generated in the encoder, is sent as a signal along with the in-band data to inform all decoders that a new seed should be used to initialize the block line shuffling algorithm.

The reception side of the system in this example, consists merely of a satellite receiver and a line shuffle decoder. The decoder constantly monitors all field blanking interval lines for in-band data, and upon recognition, determines whether it is authorized for the current programming. If it is authorized, decoding starts automatically.

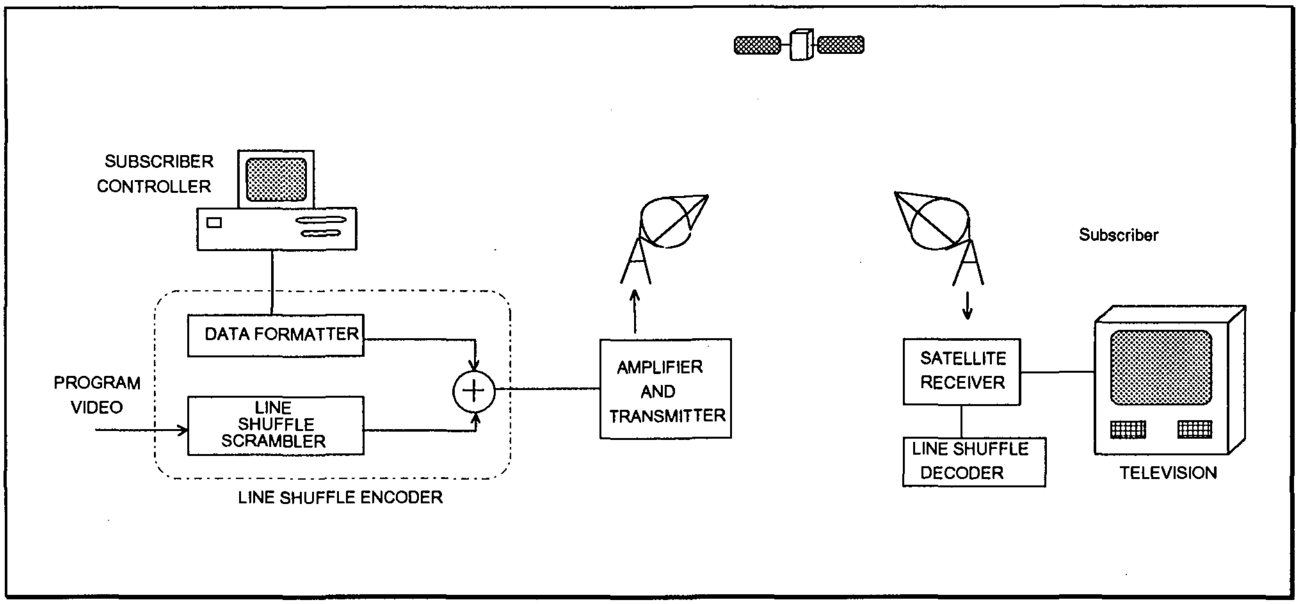

Fig 1: Block diagram of a typical system configuration using Block Line Shuffle Scrambling

Block Shuffling and System Re-Synchronization

Each block of N video lines is shuffled using a Pseudo Random Number sequence which is "locked" between both the encoder and authorized decoder. The "locking" of the encoder and decoder is vital in order for the decoder to reposition the displaced video lines into their original and correct positions. This "locking" is performed by the synchronization pulse every F_n fields, where F_n is a multiple of the number of fields required for the blocks to return to a field boundary. The repetition rate of the re-synchronization pulse will determine how quickly a decoder will lock to an authorized program once it is tuned to the correct channel. From tests, it was found that a repetition rate of between 0.5 and 1 second gave the best result.

Because the re-synchronization is such a vital part of the system, much effort has gone into designing it to be very robust and reliable. Hand-in-hand with the re-synchronization is the transmission of the scrambling seed from the encoder to all authorized decoders - it is all very well for a decoder to recognize the re-synchronization, but if the scrambling seed was corrupted prior to reception, the decoder block shuffling algorithm will be exercising a different sequence than the encoder, and hence the decoder will "drop-out" until the next successful re-synchronization occurs. This then necessitates that the scrambling seed is sent more than once between re-syncronizations to ensure that it has been received properly by the decoder. In fact, the more times the better, although an acceptable balance must be found on the number of times the scrambling seed is sent, as it follows that it will occupy valuable in-band data bandwidth which could be used for other purposes.

From tests, the balance that has been found acceptable is that the scrambling seed is sent 5 times in between re-synchronization pulses, and that the decoder will only accept a scrambling seed once it has received the same seed twice in succession.

System Timing and Field-Blanking Interval

The video to be scrambled is pre-formatted in the encoder in such a way as to make the decoding as simple and cost-effective as possible.

The Field Blanking Interval must not be scrambled due to the in-band data and teletext it contains. Due to delays through the system while scrambling, the Field Blanking Interval has to be stored and then retrieved in the encoder at a time when it is required by the decoder. This is to ensure that the decoder only has to "pass" the field blanking interval without processing it or using any of it's memory.

Fig 2 shows the overall system timing and subsequent delays introduced by Block Line Shuffling. It should be noted that everything revolves around the correct reconstruction of output video from the decoder.

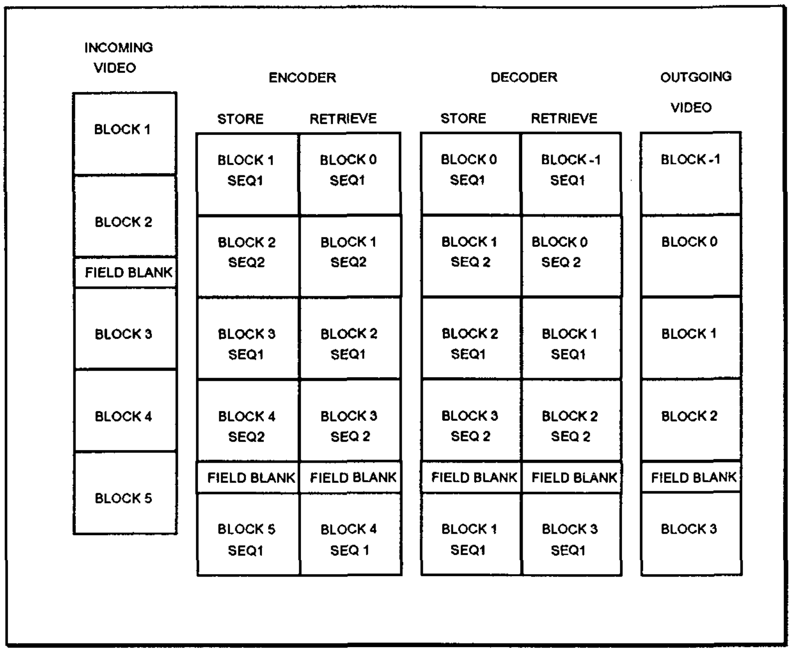

Fig 2: System timing chart

From Fig 2, it can be seen that Block Line Shuffling introduces a delay of:

$$D = (2N + FB_n) \times Lt \quad \text{(seconds)}$$

where: N = Block Size (in lines)

FB_n = Field Blank Size (in lines)

Lt = Line time (in Sec)

Therefore for a 32 Line Shuffle PAL system, where N=32, FB_n=25 and Lt=64 x 10^{-6}:

$$D = (2 \times 32 + 25) \times 64 \times 10^{-6} \text{ sec}$$

=5.696 mSec

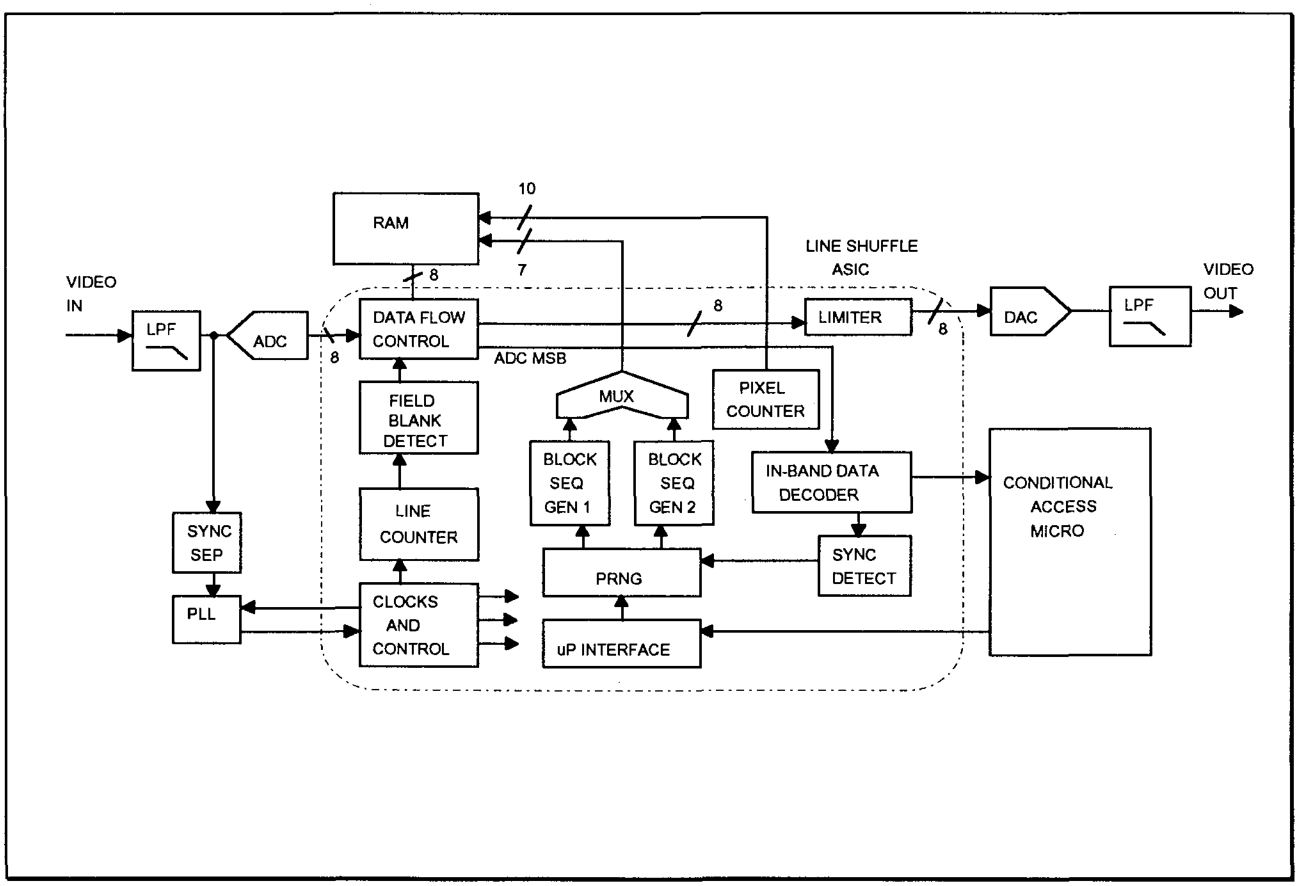

Fig 3: Block diagram of the block line shuffling decoder

The Decoder

The decoder is essentially the heart of the system, as the demands placed on it from the commercial world are high. It should cause no visual picture degradation, be secure from piracy, reliable while decoding, robust in a noisy environment and, most importantly, very cost effective.

Fig 3 shows a block diagram of the decoder, which is built around two fundamental components. The first is the CONDITIONAL ACCESS MICRO which is a full custom integrated circuit containing a Microprocessor, ROM, RAM and secure EEPROM, while the second is an Application Specific Integrated Circuit (ASIC), which is shown as a dotted outline. All blocks within the outline exist as part of the ASIC.

The video input is digitized by an 8 bit analog to digital converter (ADC) and fed into the DATA FLOW CONTROL block which is used to control the flow of digital video. While decoding a line shuffle block, the RAM is first read at it's current address and the resultant byte fed to the LIMITER. The input from the ADC is then written into the RAM for later retrieval. The LIMITER is invoked only if the in-band data lines occupy the first four active video lines and only then to ensure that the in-band data lines do not appear visible on a television set for aesthetic purposes. The output from the LIMITER is then fed to the digital to analog converter, DAC, for conversion back into the analog domain.

The most significant bit of the ADC, ADC MSB, is used as a data slicer and fed into the IN-BAND DATA DECODER, which permanently interrogates the incoming video lines in the field blanking interval to determine whether or not the line contains in-band data. This data decoder can reliably distinguish it's own data from any other known data type, including teletext. Once all four lines of in-band data have been collected, the re-synchronization pulse is removed and the remaining encrypted data sent to the CONDITIONAL ACCESS MICRO. This micro decrypts the data and decodes the packets for configuration information, scrambling seed and user authorizations. If it detects a scrambling seed and determines that the decoder is authorized for the current programming, the micro will write the scrambling seed to the uP INTERFACE for storage and subsequently to the PRNG when a re-synchronization is detected by SYNC DETECT.

The Phase Locked Loop, PLL, locks the whole system to the incoming video line and frame synchronization signals, which are in turn extracted from the video by the sync separator, SYNC SEP.

Decoder Memory Utilization

Because every effort has been made to ensure that the decoder is as low cost as possible, the whole scrambling system has been developed around the decoding process which employs a novel memory management algorithm.

It is usual to have two blocks of memory when changing the order of an incoming data stream, of any sort. The first block is used to write data into, while reading data from the second block in a different order. Once the first block is full, the writing then switches to the second block which by now has been completely read, and reading commences from the first block which is now full of new data.

For example, lets assume that N = 4 (i.e. shuffling in blocks of 4 video lines):

Assuming input video lines of 1,2,3,4......16, suppose we wish to shuffle these lines such that each successive block of four video lines are rearranged according to a new order, i.e.: 1,3,4,2; which we will call sequence S1. The resultant video line output order would therefore be:

1,3,4,2,5,7,8,6,9,11,12,10,13,15,16,14

The simplest way of achieving this result would be to use two blocks of four element memory as in Fig 4:

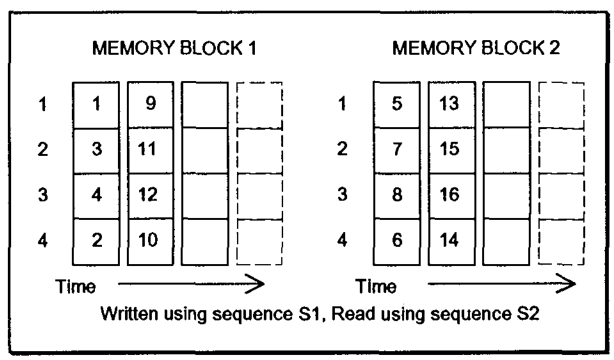

Fig 4

As each new incoming video line is written into the next available memory position of one memory block with a previously known sequence (in this case sequence S1), a video line is read from the memory element of the other memory block using a previously known sequence, different from the first sequence, say

1,2,3,4, which we shall call sequence S2. Once each of the four memory elements of the block being written into is full, the writing and reading exchange blocks. The resultant video line output order is therefore:

x,x,x,x,1,3,4,2,5,7,8,6,9,11,12,10,13,15,16,14

where x is undefined due to the fact that initially, nothing has been written into the memory block where reading commences. From this, we can see that there will always be an inherent system delay.

There is however a more efficient way of producing a very similar result using half the amount of memory than the example just given. Suppose each element, or video line, is read and then immediately over-written using the same sequence, but that now the <u>sequence</u> changes each time all four elements have been completed.

Lets again use the same sequences as the last example, i.e. sequence S1 = 1,3,4,2 and sequence S2 = 1,2,3,4:

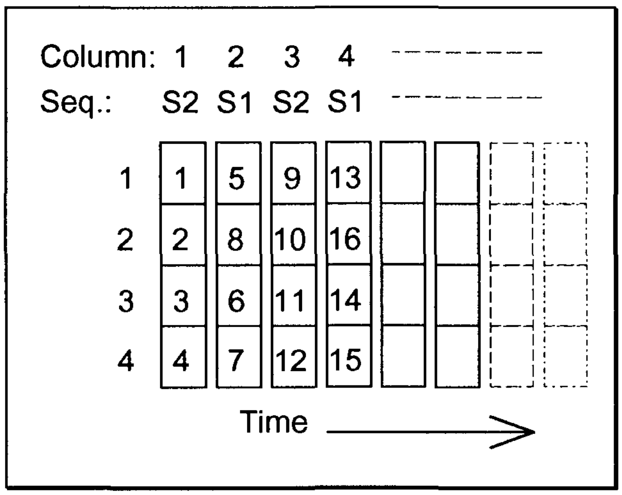

Fig. 5

As the video lines are read from and then written into the memory, it first uses sequence S2, shown as column 1 in Fig 5. After all four memory elements have been stored, the sequence changes to S1, shown as column 2. As each block in the sequence is read, it is immediately written to with the next video line. This process continues, giving the following result:

x,x,x,x,1,3,4,2,5,8,6,7,9,11,12,10,13,16,14,15

As can be seen, this result is slightly different to the two memory element solution, but still very usable. Indeed, this is the process which has been adopted in the decoder, where each data word represents one entire video line and N = 32 or 128.

This single memory solution however, requires a slightly more complex algorithm in the <u>encoder</u>, along with twice the amount of memory, but this is considered to be a justifiable trade-off, as the savings in the decoder are considerable.

<u>Block Shuffling Sequence Generators</u>

In the example given in the previous section, the two shuffling sequences were fixed, i.e. they didn't change from block to block. In a practical design, this would leave the system open to piracy, as a mere logic analyzer would reveal the shuffling order and allow a pirate to descramble the signal.

It is vital therefore that the sequence generators are continually changing in an apparently random and unpredictable way. Pseudo Random Number Generators (PRNG) are therefore utilized to provide this effect. Since it is common knowledge that Pseudo Random Number Generators on their own are completely logical and easily predicted, the sequence generator must be designed in such a way as to utilize Pseudo Random Number generators to form a highly complex, variable and apparently unpredictable algorithm, the basic structure of which is shown in Fig. 6.

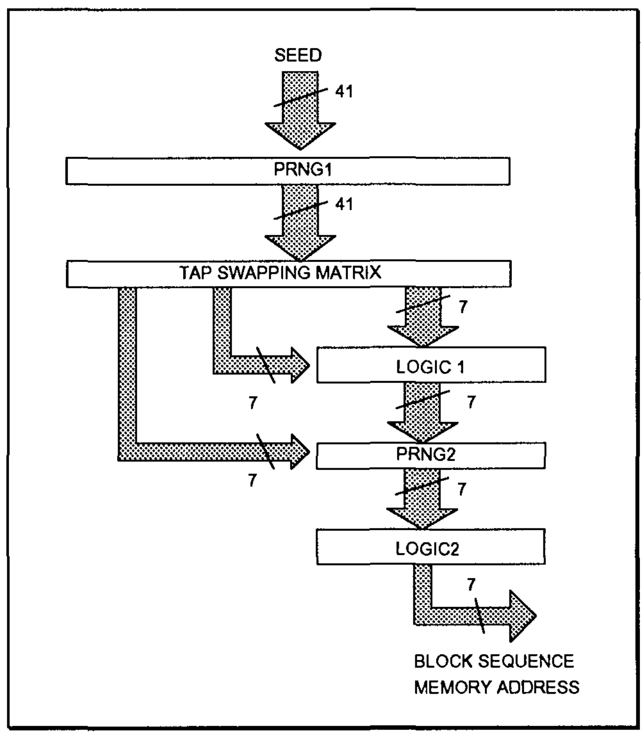

Fig 6: Basic structure of the Block Shuffling Sequence Generator

Whenever a re-synchronization occurs, the next SCRAMBLING SEED is clocked into the generator to provide the initial conditions. The SCRAMBLING SEED is used by PRNG1 which generates a set of completely unique sequences for all subsequent blocks between re-synchronization pulses. The output from

PRNG1 then feeds the TAP SWAPPING block which is used to further "randomize" the result and various taps are then taken and fed into the two LOGIC blocks around PRNG2, the function of which is to produce the actual line ordering sequence, such that for a 32 line block system, the resultant Pseudo Random Number numbers are 0-31 inclusive in a pseudo random order. The entire sequence generator is clocked once per block except for PRNG2 which is clocked every video line.

From Fig 6, it can be seen that each block line sequence is a function of 14 binary inputs, thereby giving 2^{14}, or 16,384 different line shuffle sequences. However, because these inputs change after every block between re-syncronizations, according to a 41 bit PRNG, the number of possible block sequences is:

$$2^{41} = 2.2 \times 10^{+12}.$$

Therefore, the number of block and line sequences that are possible from this sequence generator is:

$$2^{14} \times 2^{41} = 3.6 \times 10^{+16}$$

Also, if a new and unique scrambling seed was used every re-synchronization period of 1 sec, all possible sequences would be exhausted after:

$$2^{41} / 86{,}400 = 25.5 \text{ million days}$$

$$= 69{,}730 \text{ years}$$

In the DigiCrypt system, the SCRAMBLING SEED is assembled from two smaller seeds which together are used to provide the initial conditions for the Sequence Generators. These two smaller seeds are called the "Dynamic Seed" and the "Static Seed".

The "Dynamic Seed" changes every re-synchronization period and is transmitted from the encoder continually to ensure successful reception by the decoders. It's bit size is chosen to render "guess-work" completely ineffective by a potential pirate and yet still maintain a healthy size for the "Static Seed".

The "Static Seed" changes very infrequently and is transmitted from the encoder independently from the "Dynamic Seed". It occupies all other bits that are not assigned to the "Dynamic Seed".

Active Line Only Shuffling

In early developments of this project, it was envisaged that the whole video line should be scrambled including synchronization pulse and color burst, cutting each line just before the falling edge of the sync pulse (Fig 7a). However after much consulting and testing of the system with the BBC, it was felt that shuffling the entire line of a PAL signal could leave a "back-door" open to piracy. This was due to the fact that the color burst of a PAL signal continually rotates through 135° per video field. It was therefore considered theoretically possible, although unlikely, to determine the correct position of a line within a scrambled block by the absolute phase of it's color burst, even though the change in phase of each line with respect to the previous line is only 0.43°.

In view of this, an option to scramble only the active part of the video line was included in the DigiCrypt system (see Fig 7b) such that for systems scrambling a PAL signal, this option could be invoked rendering the possibility of piracy by this means ineffective.

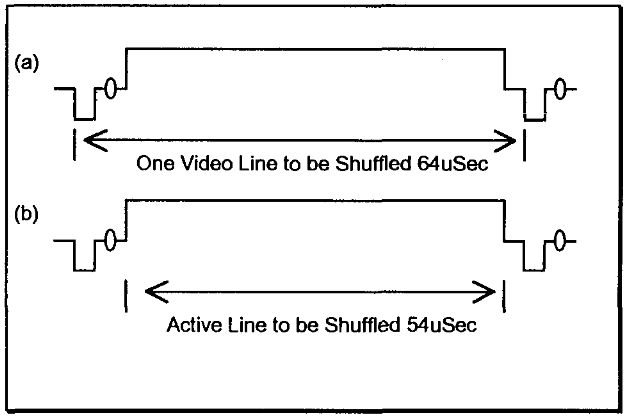

Fig 7: Splicing points for scrambling the video line via Block Line Shuffling
(a) The entire video line 64µSec; (b) The active portion of the video only 54µSec

Active Line Jitter

Active Line Jitter is a process whereby the active portion of a video line, approximately 54 µSec for a PAL signal, is displaced within the same line by a predefined amount, the direction of displacement changing randomly from line to line. Fig 8 shows this effect.

It should be stressed that this type of process is in no way a satisfactory scrambling method in it's own right, but by adding it to Block Line Shuffling, it adds another option which a system operator can invoke at anytime to frustrate potential pirates or to enhance the scrambled video's opacity.

The DigiCrypt system adds Active Line Jitter to it's repertoire with no extra system cost, as once the signal is in the digital domain, processes like this become very simple, using very little logic to realize.

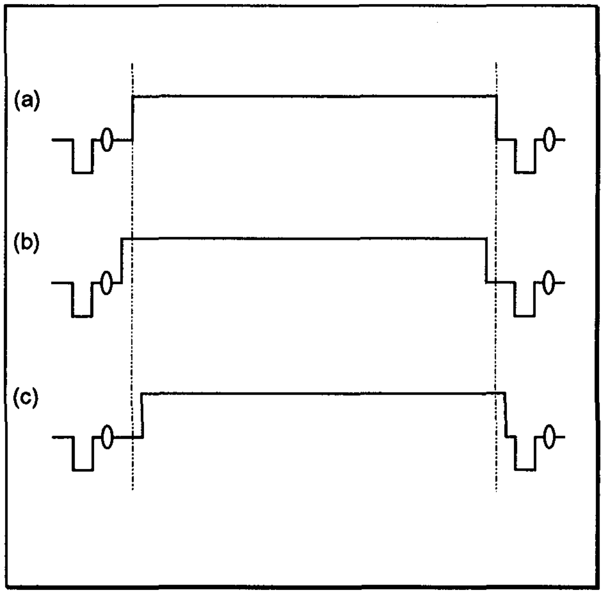

Fig 8: Active line jitter
(a) No horizontal displacement (b) Displacement 1µSec to left (c) Displacement 1µSec to right

The displacement chosen for the system is ±1µSec which is annoying enough to the viewers, and can indeed be used to "tease" subscribers into purchasing more services. However, in order to prevent the video line encroaching into the color burst and/or back porch and consequently impeding the PAL, NTSC or SECAM specifications, truncation of the front and back of the active video line is necessary at the encoder.

The Encoder

The encoder has been developed using Field Programmable Gate Array's (FPGA), for maximum product flexibility and size reduction, allowing the Video Encoder to occupy minimal rack space. 10 bit A/D and D/A converters have been used for optimum linearity, noise and distortion performance, giving very high quality broadcast video.

CONDITIONAL ACCESS

The conditional access system utilized in DigiCrypt is based on an error-protected, encrypted in-band data technique compatible with terrestrial, satellite and cable transmission methods. Each decoder has its own unique identification number and other security passwords and session keys buried within the proprietary Conditional Access Micro in secure non-volatile memory. New session keys may be issued at will by the encryption control system to any decoder by encrypting, with other encryption keys, the in-band data message addressed to the decoder's unique identification number (address). A "scrambling seed", changed approximately every second, and encrypted with one of the variable session keys, is used by the line-shuffling system to determine the correct line order sequence for decoding. Failure to receive the correct "scrambling seed" due to de-authorization or not having correct decryption keys results in a scrambled video display. A second secret "static seed" to be used with the dynamic "scrambling seed" can be changed in the unlikely event that the system is compromised, thus allowing for "renewable" security.

Conditional Access and System Security

The main method of restricting un-authorized subscriber access is via the absence of scrambling seeds being sent from the CONDITIONAL ACCESS MICRO to the ASIC. This means that the security of the system primarily lies with the security of the encrypted in-band data as opposed to the predictability of the block sequence generators. This is due to the fact that without knowledge of the next scrambling seed, a prospective pirate has a chance of 1 in 2^n of predicting the correct seed, where n is the number of bits allocated to the seed, which even for a seed as small as 8 bits would be 0.39%.

In-Band-Data

The in-band data occupies four video lines which can be positioned anywhere within the field blanking interval, or the first four active video lines, which must subsequently be blanked by the decoder. The data system incorporated utilizes 256 bits of digital data to be error-detected and decrypted every video field by the decoder. These 256 bits are split into four 64 bit data packets, each packet being placed on its own predetermined video line. Therefore, in order to transmit all data, four video lines are required and can be located anywhere in the VBI or, alternately, in active video if it is desired to keep the VBI intact for teletext, etc.. The decoder blanks data lines after decoding so that if data must occur in active video it will not be visible to viewers. The data is modulated onto a video line as shown in Figure 9:

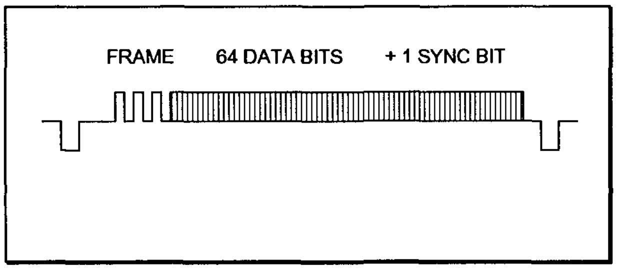

Fig 9: One Data Line

The data consists of a framing code followed by 64 Manchester encoded data bits and one synchronization bit. The instantaneous data rate is approximately 1.2 Mb/sec, significantly lower, and more robust than teletext data. The decoder detects data, over-sampling each data bit 10:1 to correctly identify each bit. Each half of the Manchester encoded bits are tested to be equal and opposite, and an error signal is generated if the result is negative. If eight or more errors are accumulated within a 64 bit packet, it is assumed that the packet under test is not a relevant in-band data packet and consequently "thrown-away". After each packet passes these tests, a 16 bit CRC error check is additionally made on every data packet to insure complete integrity. Finally, after all the error checking has been completed, the data must correspond to one of the valid command structures programmed in the Conditional Access Micro's ROM code in order to be acted upon.

Data Encryption

The four data packets transmitted within each video frame consist of a "global" data packet followed by three "individual" data packets. Each data packet is encrypted independently of the others with different encryption keys. In order to gain access to "scrambling seed" data (which is changed approximately once per second), secret keys must be used to gain access to other variable keys for decryption of the desired data.

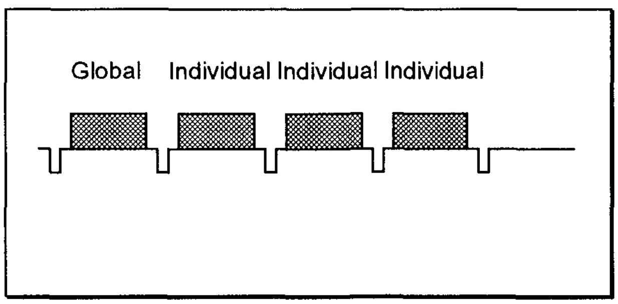

Fig 10: Conditional Access Data Packets

Global Data Packet

The "global" packet contains information of use to all valid decoders, such as local time synchronization, operator customized initialization data, and a variable "program tag" for the video program being received. This packet also periodically contains the "next" dynamic scrambling seed which is necessary for the decoder to use for un-shuffling the encoded video. For security, the "global" packet is encrypted with a 16 bit "session key" which can be changed periodically to a new "session key" previously downloaded to authorized individual decoders via independently encrypted "individual" data packets.

Individual Data Packets:

The "individual" data packets contain information to be addressed to individual valid decoders in the control computer's data-base. With three "individual" packets per field, 9,000 decoders per minute can be addressed in 50 Hz vertical scan rate video systems (i.e. PAL, SECAM) and 10,800 decoders per minute can be addressed in 60 Hz vertical scan rate video (i.e. NTSC) systems. The information in the packet can include commands to authorize (or de-authorize) a decoder for any program tag of any video program to be shown on any scrambled channel. The "individual" packet is also used to download current and future "session keys" to valid decoders to be used to decrypt the global packet.

For security, each "individual" packet is encrypted with a secret 16 bit "address key" unique to each decoder address. Decoder address data in the "individual" packet is also encrypted such that it cannot be identified simply by observing data. There are over 67 million individual addresses available for decoders. Decoder addresses and "address keys" are assigned to each decoder at manufacture and "sealed" into secure non-volatile memory which cannot be altered or read externally thereafter.

Authorization

Decoders are authorized by downloading to each valid decoder, in an encrypted "individual" data packet, a list of "program levels" for which it is authorized. This list is stored by the decoder in secure non-volatile memory for reference. The secure non-volatile memory is integrated on the same IC die with the Conditional Access Microprocessor. When a subscription or "pay-per-view" video program is tuned, the decoder

Conditional Access Microprocessor compares the encrypted "program tag" in the "global" packet with its list of "program levels" stored in memory. If the "program tag" in the encrypted video matches a "program level" previously loaded into the decoder, the decoder passes the scrambling seed (encrypted in the "global" packet) to the descrambling ASIC. This permits decoding of the selected video. If the "program tag" does not match any of the authorized program levels in memory, or if the decoder cannot decrypt the "global" packet (due to not having proper "session keys"), the scrambling seed will not be passed, and decoding of video will not occur. Decoders can store up to 256 unique "program levels" for which they may be authorized at any one time. The decoder also stores two independent encryption session keys which can be changed periodically for security or as a means of de-authorization to invalid decoders.

An example of the use of session keys for de-authorization would be to allow a subscriber to play back and decode a tape of a "scrambled" program through his decoder only for a pre-determined time. At the end of that time period, the decoder will have been loaded with new "session keys" incompatible with the "session key" used to encrypt the data on the recorded tape.

Two-Way Interactivity

The conditional access system also allows for two-way interactivity on cable, fiber or possibly in wireless transmission systems through a PSK RF return data path. The 42 bit return data from the decoder is at a 45Kb/s data rate in a short, pre-defined data packet lasting 1.4 msec. The data is CRC error protected and can be encrypted with a downloaded encryption key. Decoder "status" information, including memory contents, channel tuned, etc., can be transmitted from the decoder to the control computer via polling techniques. This method allows for channel monitoring if required. Additionally, decoders can initiate transmissions for pay-per-view authorization requests, opinion poll responses, requests for information or merchandise, or to request control sequences from a service provider in a video-on-demand system. These operations must be initiated by a subscriber through inputting a proper PIN (Personal Identification Number) which the decoder verifies before transmission of the request. PIN numbers can be changed only through downloading a new number from the control computer at the transmission site.

Such decoder initiated transmissions rely on the short message length and a contention "blind-aloha" methodology to insure that messages do not collide and are received by the control computer. The decoder always expects a response from the transmission center via in-band data whenever it initiates a two-way transmission. If the decoder receives no response within a random-per-decoder time period, the decoder assumes that a "data collision" occurred and re-transmits after another random time delay. This assures that all decoders requesting services via two-way interactivity receive responses within a short period of time. Actual average operational response times in large cable TV systems is under 1 second.

CONCLUSION

A new line-shuffling system for PAL, SECAM or NTSC has been introduced which has the benefits of hard renewable digital security and multi-level encryption without the cost and difficulty of full digital compression and transmission. The system is compatible with existing analog transmission techniques for broadcast, microwave, satellite, fiber and cable applications. The system is also compatible with existing subscriber receiving equipment since the encoded signal is essentially standard NTSC, PAL or SECAM. Performance of the system exceeds that of line cut-and rotate, sync suppression or other analog methods and a novel memory management technique is used to reduce memory requirements and cost. Photographs of the encoded video are shown in Fig 11.

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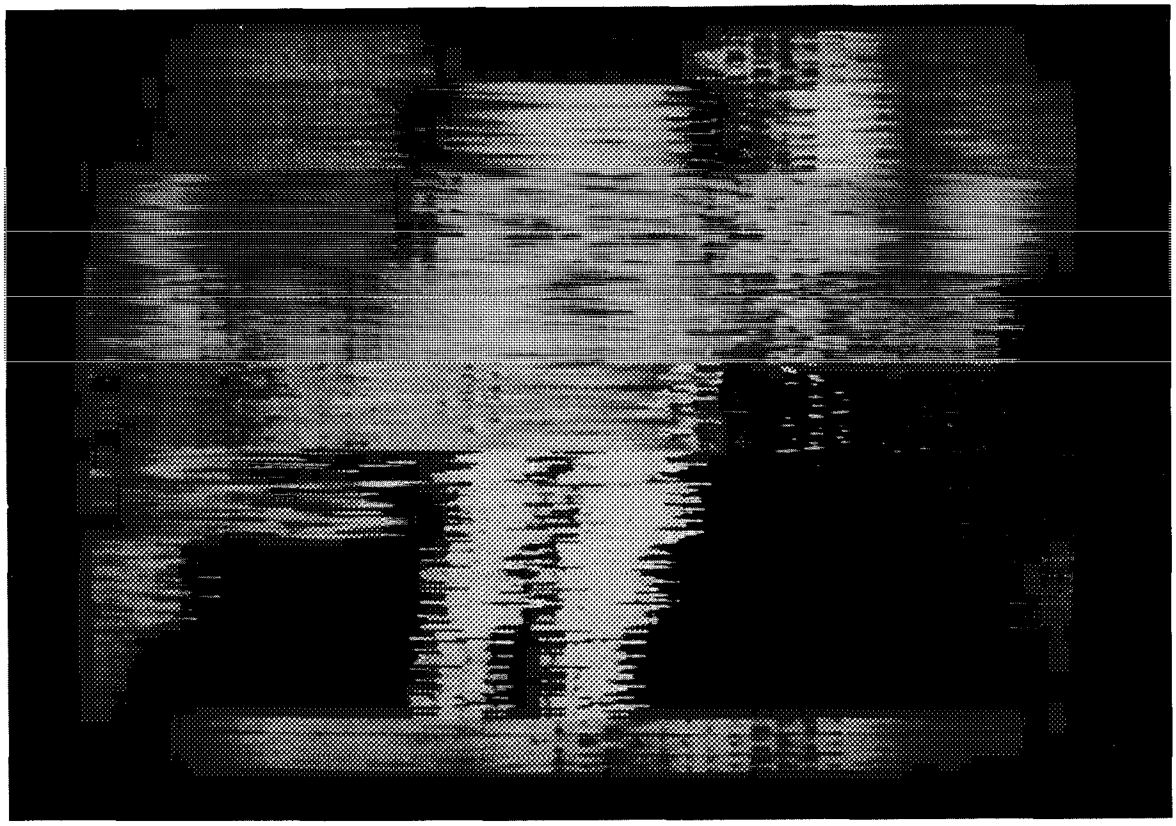
(a)



(b)

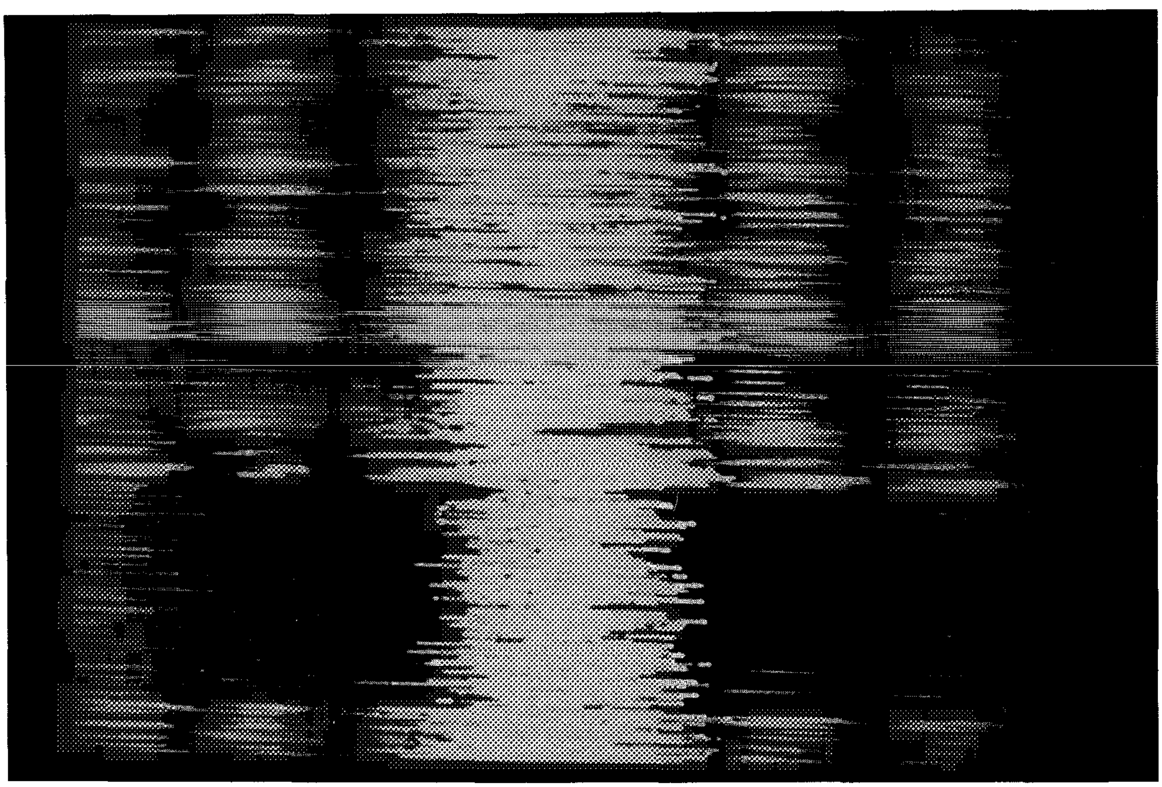


Fig 11 Actual TV Screen Images (a) 32 Line Shuffle (b) 128 Line Shuffle

APPLICATIONS AND DESIGN OPTIONS FOR AN IN-HOME CABLE TV DIGITAL CONSUMER TERMINAL

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Jerrold, General Instrument

Abstract

No longer are we in the cable TV industry focusing our discussions on whether there is a technology available to do digital compression of video for our applications. The technology has been proven, products for satellite transmission exist, and products for cable TV are not far behind. The focus now is more on how the cable TV industry may best optimize the deployment of digital compression. This paper presents various applications for in-home digital consumer terminals along with a discussion of related design options.

APPLICATIONS

What are some of the primary applications that will be enhanced and/or enabled by digital compression? My list would include the following:

* NVOD
* Cable On Demand
* Home Theater
* Multimedia
* HDTV

NVOD

Near video on demand (NVOD) trials have already been performed by Time-Warner in New York (Quantum) and as part of the TCI (VCTV) test in Denver. Both of these activities were done using good old analog video, as will the Viacom - Castro Valley system to be launched later in 1993.

The use of digital compression will significantly reduce the amount of raw bandwidth required for the transmission of the movies to be carried in NVOD applications. If we take for example 10 hit movies (2 hours in duration each) and assume repeated one-half hour start times, the total bandwidth required would be 40 times 6 MHz, or 240 MHz (40 NTSC channels). Utilizing digital compression at a ratio of 10-to-one (achievable for film sourced material), only four 6 MHz channels would be required, or 24 MHz.

The in-home consumer terminal will require the digital transmission and processing circuitry as well as some form of consumer friendly NVOD ordering system. A menu-driven NVOD system will offer movie selection through various database trails, including by genre, start time and titles as well as offer functionality familiar to today's video rental consumers such as pause, fast-forward and rewind.

If an operator wished to modify the menus, an amount of downloadable memory will be required to expand the code in ROM.. Options in this area include battery-backed SRAM (maybe in either 8k Bytes or 32k Bytes increments depending upon the desired flexibility). These options would allow for some degree of menu/screen customization, additional basic functions (akin to favorite channel) along with other potential look-and-feel enhancements.

Cable-On-Demand

As the cable TV industry moves towards providing a greater selection of on-demand services, the segmentation of cable systems into fiber optic nodes serving 500 to 2,000 homes will be prevalent. In a cable-on-demand application, smaller fiber optic node sizes can be used to offset contention issues of anticipated on-demand services. The smaller the number of homes per fiber optic node, the less likely will be the probability of more subscribers wanting access to the cable system than the amount of available channels to that particular node at any given time. Digital compression also can be used to increase the effective bandwidth to each node and thereby alleviate contention issues.

For cable-on-demand, the in-home consumer terminal would need similar functionality as that required for NVOD applications with the possibility of increased bandwidth requirements due to the increased variety of personalized programming options (which could be offset by smaller nodes as mentioned above). It appears likely that the digital consumer terminals will often use 1 GHz tuners to allow for maximum future flexibility

Return path capability may play a more important role as upstream commands will need to be sent real-time in order to interact with switching processing upstream. Both RF and telephone return paths already are offered as options for today's analog systems. The extensive use of fiber optics in cable plant rebuilds has enabled the increased use of RF return paths due to the homerun nature of fiber optic return (node to headend) which simplifies maintenance and enhances performance.

Home Theater

Almost all advertisements for today's premium TV sets include a statement highlighting an S-Video input. Since the digital decompression process utilizes a component signal, it is relatively straight forward to supply an S-Video (Y/C) output on the digital consumer terminal (See Figure 1). Baseband video outputs are expected to be a standard feature.

The quality of the video will be excellent for the digital programs/movies. The digital compression algorithms available today can reproduce pictures at receive locations throughout the cable plant that are subjectively equivalent to the quality provided to the digital encoder. The digital picture quality will not degrade as the receive site is distanced from the headend, as opposed to the typical degradation associated with analog video (i.e. no visible noise or distortion created in the picture due to transmission).

Audio quality will be equally as impressive. CD quality transmission is possible with the proposed digital systems. An issue will exist with regards to the consistency of stereo sound between the RF and component outputs (baseband or S-video) of the digital and analog programs. The analog signals can be transmitted down the cable plant encoded in BTSC. These signals will be provided to the digital terminals' RF output ports for decoding within today's stereo TV sets to provide Left/Right stereo sound. Without a BTSC decoder in the digital consumer terminal, the baseband output of the analog programs can only be monaural.

For the digital programs the reverse is true. The digital programs will be transmitted through the cable plant in Dolby® AC-2 or other similar formats. They will be decoded in the digital consumer terminals and therefore be provided in L/R format to the baseband ports. The digital signals will not be encoded in BTSC and therefore will only provide monaural sound to the RF port.

If the cable operator wishes to provide consistent stereo sound for both analog and digital programs at the baseband ports of the digital terminal, a BTSC decoder for the analog programs will be required. A BTSC encoder will be required for the digital programs if the operator wished to provide stereo for both the analog and digital programs at the RF port.

As with today's analog converters, if certain operators desired to only use the digital consumer terminal for the digital and scrambled analog programs, an RF bypass switch could be utilized. This option would allow the unscrambled analog programs to bypass the terminal and provide RF input to cable ready TVs (provided the TV tuner has adequate performance and bandwidth capability). It should be noted that the consumer would have to go into non-RF bypass mode if they wished to utilize the anticipated on-screen-displays (OSD) and electronic program guides (EPG) to be provided with digital consumer terminals.

Multimedia

Multimedia is an often used term in the trade press and shows. It's used so often and in so many different contexts that I wouldn't be surprised if many are somewhat confused about what it is. Depending upon the perspective of the person describing the term, multimedia is something involved with computers, consumer electronics, public utilities or cable TV. In fact multimedia could be key to all the above and more.

Before the term multimedia appeared a different moniker was used to describe many of the services now included under the multimedia umbrella. The term frequently used was interactivity. While the promise of interactive services always seemed around the corner, the fulfillment of that promise was not fully met for many of the proposed applications.

The cable TV converter provided the possibility of having one device that could act as the controlling interface for much of the functionality promised under interactivity. Current analog converters already perform varied functions such as that of a clock, switched electrical outlet, phone modem and messaging device.

While much is already possible with today's converters, tomorrow's digital consumer terminals will go much further towards enabling multimedia/interactive services. In a digital video environment, the digital data streams transmitting the signals from uplink through headend to the in-home consumer terminal will have the capability to carry data along with or instead of the video/audio services. Over the cable plant, the data can be carried within the video multiplex data stream or out-of-band. One of the limitations of transporting the data in the video multiplex is that the data must be associated with the tuning of a video service. Out-of-band transmission allows for continual reception of the data stream by the receivers in the in-home terminals. Typically today's analog converters contain out-of-band receivers capable of ten(s) of kbps. Due to the anticipated higher volumes of data coming over the out-of-band path, optional receivers up to 1.5 Mbps are planned. The information coming down the out-of-band path will include access control and EPG. Depending upon the processing capabilities within the consumer terminal, the received data can either be processed internally or passed out of the terminal through a port to other devices/modules.

At cable TV shows in 1992 computer software manufacturers provided a glimpse of the possibilities of multimedia. Icon-based operating systems facilitated access to programming and/or information services. These types of operating systems will typically require processing capability and memory beyond that usually found in today's cable TV converters or even that which will be required for baseline functionality in digital consumer terminals.

To provide for ROM and RAM expansion capability, access to the digital terminal's primary microprocessor bus is offered through external ports or internal connectors (processor interface, "PI" port, in Figure 1). Internal connectors allow for the insertion of computer-like modules. These modules could contain state-of-the-art microprocessors, operating systems, user interfaces and memory that would allow for the upgrade of the basic digital terminals. This would allow the cable TV operators to make the upgrade investment only in the cable systems and subscribers' homes where this functionality would have economic justification.

A key component to any multimedia scenario is having the right architecture and tools to enable various third party programmers to be able to create attractive new programs to run on these computer-like converter platforms. Without these programs there will be little incentive for consumers to pay the envisioned premiums for the hardware and services.

What are some of the examples of how a multimedia environment may add value to the cable subscriber? One way could be associated with the watching of music videos. The data sent to the terminal could include the lyrics of the songs being played, information about the artist, ticket information for their next concert and potentially the ability to order the related CD. If a subscriber is watching a baseball game, information about a specific team and/or player could be viewed while watching the game as well as the ability to switch between various camera angles or replays.

Digital compression and processing may not be the technology that makes interactivity a successful business for cable TV, but it should certainly help enable a more accurate determination of consumer preferences/demand.

HDTV

The Federal Communications Commission's high definition TV (HDTV) standard selection process is well underway and has focused on digital techniques. Until the final decisions are made regarding a standard, a likely plan for digital consumer terminals is that they output the decrypted digital signals associated with a particular HDTV program out a port capable of data rates of ten(s) of Mbps. This data would then be delivered to an appropriate digital interface to a digital HDTV television.

SUMMARY

The future is not now, it is already behind us (at least with regards to cable TV's technical capabilities). The challenge ahead is to apply cable's cutting edge technologies like digital compression in a way that optimizes value to cable TV subscribers of today and tomorrow.

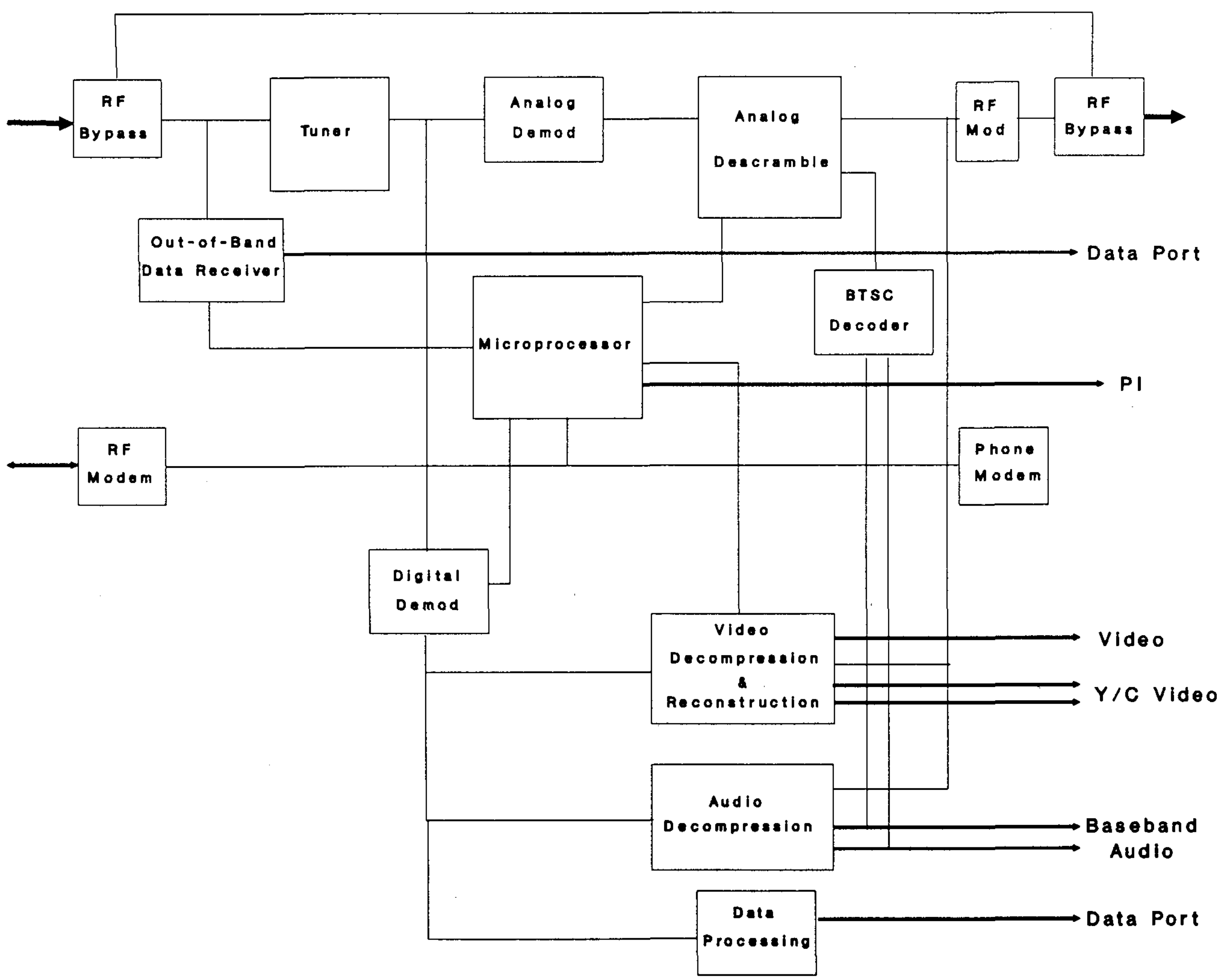

Figure 1 - Digital Consumer Terminal Functional Diagram

CATV BANDWIDTH ASSESSMENT
(A PRACTICAL APPROACH TO SYSTEM DESIGN)

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Abstract

The multitude of upcoming franchise renewals, the resulting need for many cable television system re-builds, and the recent onslaught of evolving technologies, are provoking much discussion among CATV personnel regarding the amount of bandwidth that should be built into cable systems. Many industry leaders are touting 1GHz as the bandwidth of choice, while others are concerned that even 1GHz will not be enough bandwidth to support the incredible amount of services that the future Cable TV operator will want to provide.

Current development of spectrum-saving technologies such as video compression and signal multiplexing, however, may eliminate the need for such an enormous bandwidth. In fact, when utilized in conjunction with an appropriate architecture, 550MHz and 750MHz systems will provide ample capacity, both today and in the future, for the delivery of a wide range of conventional and interactive services.

BANDWIDTH ASSESSMENT

Relative to a system re-build (or new build), there are at least two major technical questions that must be answered:

1. At what bandwidth should the system be designed?
2. What type of architecture should be employed?

When searching for the best answers to these questions, it is easy to be confused by the many factors which play a part in the decision-making process, (e.g., company economics, preparation for future CATV services, product availability, etc.). Since most of the industry discussion relating to system bandwidth is centered around future CATV services, (e.g., telephony-over-cable, video on demand, etc.), it is probably most practical to begin an analysis by taking a closer look at those services.

It is important to understand the types of CATV services that will be available and the amount of bandwidth that each service will demand. Also, because the provisioning of certain services is dependent upon the use of an appropriate system architecture, it is important to understand which types of architectures are conducive to providing particular types of services.

Since a picture is worth a thousand words, Figure 1 (on the following page) will form a good basis for discussion relative to the two questions above.

Bandwidth Segmentation

FORWARD ONLY		
Off Air	60 MHz	10 channels
Satellite Basic	252 MHz	42 channels
Pay Channels (*HBO*, etc.)	42 MHz	7 channels
Analog PPV	18 MHz	3 channels
Near Video On Demand	90 MHz	120 channels
Local Access, Local Origination	18 MHz	3 channels
SUBTOTAL	**480 MHz**	**185 channels**
Digital Music Service	18 MHz	
INTERACTIVE (Forward/Reverse)		
Customer Sig./Status Monitor	6 MHz	
Telephone Service	36 MHz	
Personal Computer Networking	24 MHz	
GRAND TOTAL	**564 MHz**	

FIGURE 1

While the number of channels allotted for each service will vary from system to system, the purpose of this chart is to provide the foundation for a well-informed decision.

Listed in Figure 1 are various services that will be provided by CATV operators, both in the present and in the future. The chart is *not* intended to represent exact bandwidth segmentation for every cable system in the country. Instead, it is intended to be a source of information for those who are concerned with the demand that certain services will place on system bandwidth.

Following are explanations regarding some of the services listed...

Near Video on Demand

Near Video On Demand will allow subscribers to choose from a list of movies, with each movie beginning approximately every 15-30 minutes (or at whatever interval the operator chooses). Generally, because N.V.O.D. is channel-intensive, it makes best sense to employ this service in conjunction with video compression technology. Assuming a compression ratio of 8:1 (a reasonable assumption for movie services) 90MHz can be used to provide the following:

Assuming two-hour movies...

- Each of ten (10) movies can begin every fifteen (15) minutes (80 channels required), and...
- Each of ten (10) movies can begin every thirty (30) minutes (40 channels required).

That's a total of twenty (20) movies in all; each being shown with a relatively small interval of time between successive starts (15-30 minutes). As technology advances and compression ratios increase, more movies can be added with less time between successive starts.

The mathematics here are quite simple. A movie that lasts two hours will utilize eight (8) channels if it is to be shown every fifteen minutes. This results from the fact that there are eight (8) fifteen-minute intervals in a two-hour period. Similarly, if the same movie will be shown every thirty minutes, it will require four (4) channels as there are four (4) thirty-minute intervals in a two-hour period.

The 90MHz of bandwidth can be divided up in many different ways depending on the number of movies to be shown and the intervals between successive starts (e.g., assuming two-hour movies and 8:1 compression, using 120 channels, each of twenty (20) movies can begin every twenty minutes).

What about Video On Demand (as opposed to Near Video on Demand)? While video on demand is certainly a service that will be provided by the CATV operator, video on demand is not so much bandwidth intensive as it is dependent on an appropriate system architecture (one that segments the system by limiting the number of homes per fiber node) and the addition of intelligent headend and subscriber equipment. The headend equipment will be capable of delivering a single movie to a particular subscriber as needed and may incorporate some form of *less-than-real-time* delivery (e.g., forward & store). It is expected that a 2,000-household fiber node will require approximately twenty-four (24) channels dedicated to V.O.D., assuming 60% of the homes passed by cable take basic service and 25% of those subscribe to V.O.D. with a peak usage rate of eight percent. Assuming 4:1 compression, for example, these 24 channels would occupy only 36MHz of bandwidth.

Depending on the compression scheme used, the subscriber demand, and the number of channels available to the operator for the service, many scenarios can be envisioned related to the provisioning of V.O.D. In any case, it can be expected that Video On Demand will require considerably less bandwidth than the 90MHz shown in Figure 1; thereby freeing a portion of the spectrum for use by other services.

It is assumed here that most systems will not find the need to provide a full slate of N.V.O.D. programming ***and*** *a full slate of V.O.D. programming. Delivery of one service or the other would be most appropriate.*

Telephone Service

Telephone service may include a Personal Communications Service (PCS) or may be a standard telephony-over-cable service. In either case, the following will serve to explain some of the applicable math:

Regarding standard telephony-over-cable, one (1) 6MHz channel in each direction (upstream & downstream) will be capable of supporting approximately 375 voice users. Assuming a telephony penetration of 25%, these two channels can serve a 1500-home node (1500 x 25% = 375). Two (2) channels in each direction will support approximately 850 voice users. Assuming 2,000 homes-per-node, these four channels (2 in each direction) will support a penetration rate of about 43%. The 36 MHz in the above chart will support approximately 1,380 voice users. In a 2,000-home node, that equates to a telephony penetration of nearly 70%. *The above numbers relating to voice users per channel are based on a Grade of Service equal to P.01. This equates to a call-blocking probability of less than 1% during the busiest hour of the busiest season (BHBS).*

It is signal multiplexing that allows such a large number of users to use such a small amount of spectrum. The bandwidth requirements for a personal communications service will be similar to those spelled out above for standard telephony-over-cable. As time marches on, and multiplexing and compression technologies improve, it can be expected that these services will require even less bandwidth.

Personal Computer Networking

This particular category covers a wide range of potential services related to data transfer (as with a standard modem). One related scenario might include linking schools together via the cable network to provide a *distance learning* environment. In this way, for example, a local grade school could tap into the library of a local high school or college. Another scenario may include the private, point-to-point interconnection of business users via the cable network.

Products are available today which allow for Ethernet- (IEEE-802.3) type data transfer over standard cable television plant. Current technology allows for a digital bit rate of approximately 10Mb/s to be placed within one (1) 6MHz channel on the cable network. The number of channels required for a particular service will be dependent upon the number of users on the network and the amount of delay time that is acceptable to the users. Overloading the network with users (and therefore data) will result in data congestion. This congestion results in slower transfer of data. Enough bandwidth will have to be provided to accommodate the number of users and their demands on network speed.

Presently, two (2) 6MHz channels (one in each direction) will allow for full, two-way 10Mb/s data transfer; allowing approximately twenty to thirty (20-30) users to share the network without severe delay times. The 24MHz in the chart above will allow for approximately twice that number. The majority of cable operators will likely find most of their success (related to this category) in dealing with point-to-point connections such as schools and businesses as described above. In these scenarios, 24MHz should be plenty of bandwidth to provide for a host of options relating to personal computer networking. Again, as technology advances, the bandwidth requirements related to the provisioning of this service will relax.

Digital Music

The 18MHz allows for approximately thirty (30) channels of commercial-free stereo audio programming to be delivered to the customer. The 18MHz can generally be segregated into smaller portions and be placed in the *roll-off* or FM portions of the spectrum, making it very bandwidth-efficient. The programming consists of a wide variety of music including jazz, rock, country, classical, etc. This technology (known by the trade names *DMX*, *DCR*, etc.) is already being successfully used by many cable operators around the country.

There are those who will argue that the above chart (Figure 1) fails to account for other services that may develop five to ten years from now, and therefore cannot be used to properly assess bandwidth requirements. Figure 2 below serves as a counterpoint to that argument.

Bandwidth Segmentation

(large-scale use of compression)

(shaded) = **compressed 4:1**
(N.V.O.D. = 8:1)

FORWARD ONLY

Off Air, L.O., Access	84 MHz	14 channels
Satellite Basic	**72 MHz**	**48 channels**
Pay Channels (*HBO*, etc.)	**11 MHz**	**7 channels**
Pay-Per-View	**5 MHz**	**3 channels**
Near Video On Demand	**90 MHz**	**120 channels**
SUBTOTAL	**262 MHz**	**192 channels**
Digital Music Service	18 MHz	

INTERACTIVE (Forward/Reverse)

Customer Sig./Status Monitor	6 MHz	
Telephone Service	36 MHz	
Personal Computer Networking	24 MHz	
GRAND TOTAL	**346 MHz**	

FIGURE 2

There are two simultaneous evolutions taking place in the CATV industry:

1. The number and types of potential CATV services are increasing and expanding.

2. Technologies for limiting the bandwidth requirements associated with those services are also progressing.

As technology continues to advance, the use of video compression and other spectrum-saving techniques such as multiplexing will increase. It can be expected that most satellite and pay channels will eventually be compressed, yielding an incredible amount of bandwidth that can be used for other services.

Practical Economics

Before getting caught up in too many arguments about future services, it is worthwhile to take a look at some factors of economics. Relative to system design, and applicable to almost all cable systems, are the following arguments:

1. Any system planned at less than 550MHz is impractical. With all of the recent advancements in electronics, a 550MHz build can be done more cost effectively than a 450MHz build. In fact, according to most sources, 450MHz is a thing of the past.

2. As discussed earlier, in order to be prepared to provide the many future CATV services that will be available, a system design which specifies 2,000 (or fewer) homes per fiber node is most desirable. Fortunately, with the cost of fiber-optic equipment dropping, and the availability of a new generation of specially-designed amplifiers and cable, it has been shown that, in most cases, a Fiber-to-the-Service Area design serving 2,000-home nodes can be implemented at a lower cost than a conventional trunk & feeder design.

If the CATV engineer follows the above logic and agrees that a 550MHz Fiber-to-the-Service Area design is the most practical starting point for today's re-builds, a decision then needs to be made regarding the possibility of incorporating a bandwidth greater than 550MHz. There are three (3) possibilities to consider for design:

1. Build the system at 550MHz with no regard to future bandwidth expansion.

2. Build the system at 550MHz, using proper amplifier spacing and an ample amount of fiber to accommodate easy expansion to a higher bandwidth.

3. Forego the 550MHz design by immediately building a system with a greater bandwidth.

Which is the right thing to do? The best answer to this question will be dependent upon the cable company's economic factors and whether or not the operator feels that he/she will desire to be a provider of such services as telephony-over-cable, distance learning, etc. Community demographics may play as important a role as any in regards to this decision.

In any case, a few points should be kept in mind...

1. As Figures 1 & 2 suggest, 1GHz is more bandwidth than most cable operators need to be concerned with. If a system is to be designed with consideration to a capacity of more than 550MHz, then 750MHz is an appropriate bandwidth to aim for. In Figure 1, the amount of bandwidth between 564MHz and 750MHz can be used for services such as High Definition Television (HDTV), which will require one (1) 6MHz channel per compressed HDTV channel. This extra bandwidth (up to 750MHz) can also be used for various digital data services that the CATV operator may want to provide.

2. A system designed at 550MHz without a true *footprint* for expansion to 750MHz can still be expanded to that higher frequency at some later date. The downside, however is that the operator will pay a huge premium for extra fiber, construction, and high-gain actives as compared with the operator who originally designed the system with future expansion in mind.

3. A system that is designed at 550MHz with the proper spacing and amount of fiber to allow for an easy upgrade to 750MHz will cost approximately 10% more for the initial build. However, expansion from 550MHz to 750MHz will be relatively painless.

CONCLUSIONS

With the advent of such services as V.O.D. and telephony-over-cable, and the continuing development of compression and multiplexing technologies, limiting the number of homes per fiber node is at least as important as (if not *more* important than) increasing system bandwidth.

Relative to system design, decision-makers can regard a 550MHz, Fiber-to-the-Service Area (2,000, or fewer, homes per node) architecture as a starting point for deliberation. From there, the most important decision is whether or not to consider 750MHz. If 750MHz is considered, the operator can either build a 550MHz system that is spaced for 750MHz or the operator can build a 750MHz system in the first place (which will cost about 10% more than a 550MHz system spaced for 750MHz). This decision must take into account both company finances and community demographics. For operators building a system today, it is important to keep the following in mind:

1. Depending on the number of channels currently being used for conventional programming services, and taking into account local demographics, many system operators will find that there is no need to plan for a system capacity beyond 550MHz. Many systems will be able to provide a full slate of conventional as well as interactive programming within that 550MHz.

2. If the operator knows that he/she will want to expand to 750MHz at some point during the life of the system, it may be more economical to build at 750MHz in the first place. Otherwise, the operator pays for a full set of 550MHz electronics now, and has to scrap the entire lot for 750MHz gear in a few years. In a case such as this, an immediate 750MHz build will actually end up being less expensive than the 550MHz build. *While this point may sound obvious, it is often overlooked.*

A 1GHz architecture may make sense for those systems involved in pioneering the development of new technologies, but 1GHz is far too impractical for the overwhelming majority of cable systems. The cost premium for the 1GHz system cannot be readily justified. (In fact, in most cases it is currently more economical to build a dual 550MHz plant than it is to build a single 1GHz plant). Today's cable operators will find much reward, both now and in the future, in limiting their current bandwidth planning to no greater than 550/750MHz.

CATV Channel Characterization for Digital Data Transmission Applications

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ABSTRACT

To transmit digitally compressed video with co-existing analog video over cable television (CATV) systems, the entire CATV bandwidth is frequency-division-multiplexed (FDM) into 6 MHz wide channels. For reliable data transmission, it is necessary to design an adaptive digital equalizer to compensate for the linear distortion effects, for example, the microreflections, introduced in such a 6 MHz CATV channel. This paper describes the characterization of the linear distortion effects as viewed by a digital adaptive equalizer in a 6 MHz CATV channel by developing measurement techniques using existing equipment. In contrast to other proposed techniques, this method has the added advantage of *non-intrusive* characterization of the channel, i.e., it is not necessary to interrupt existing cable service to characterize the channel. The advent of a new type of spectrum analyzer has greatly facilitated our work. Laboratory tests are performed to validate the measurement techniques. Finally, channel measurements are obtained for an in-house cable system.

INTRODUCTION

A typical cable system has a tree-type network structure, originating from the headend, then going through the trunk cable, distribution (or feeder) cable and the drop cable to the in-house wiring, and finally terminating at some consumer electronics equipment [1]. Numerous amplifiers are required to maintain the signal at specified levels. These amplifiers are generally operated in the linear region. The nonlinear effects, for example, the composite-triple-beats (CTB) and the composite-second-order (CSO) products are at least 53 dB below the main signal which is small compared to the NTSC peak carrier-to-noise ratio (CNR) of 43-46 dB. Hence, for testing the performance of digitally modulated signals, it is sufficient to assume that the CATV channel is a time-invariant linear channel with noise, which could be impulsive in nature.

The received signal at a specific consumer site can be represented simply by a sum of variously attenuated multiple reflections of the same signal caused because of improper termination of the numerous taps in the system. Since the channel is assumed to be linear, the effect of these 'microreflections' can be characterized completely by the frequency-response of the CATV channel. In older analog systems, precise channel characterization was not necessary. Crude methods were sufficient to "measure" amplitude response and group delay, such as observing the envelope of a frequency sweep or the base-line of a two-tone burst on an oscilloscope display. These methods are clearly inadequate as digitally modulated signals are added to these older systems.

A conventional network analyzer is capable of measuring the characteristics of a communication channel if both ends are in the same location. However, in a typical cable television (CATV) system, the receiving location may be twenty miles or more from the cable head-end. With the exception of only a few systems, this spatial restriction limits the use of a network analyzer to laboratory simulations.

In formulating the channel characterization technique described in this paper we made certain assumptions about the channel data required to characterize performance of digital modulation techniques over CATV channels. By the time-frequency duality, a channel characterization of X MHz should be able to resolve all microreflections of 1/X μsec or greater. This implies that the general problem of characterizing *all* the linear-distortion effects of the CATV channel is extremely complex, since this implies that the entire channel frequency-response be known. However, for a digitally modulated signal with a specific center frequency, only a 6 MHz section need be known to evaluate the performance of the digital modulation strategy. This channel characterization technique then concentrates only on the characterization of 6 MHz wide channels and, in this respect, is different from other approaches as described in [2], [3].

The other constraint that is assumed is the fact that such 6 MHz channels in most cable channels are already occupied with analog NTSC. It is possible to remove channels from service temporarily, but that may not always be commercially acceptable. Simulated cable plants at any lab fail to generate 'typical' channel characteristics and tests on actual user-sites are required. The technique presented in this paper can be used for *both* the cases when analog NTSC is present or when empty channel space is available, using the same equipment for either case and thus is different from the technique proposed in [3]. One way to characterize a channel even when an analog NTSC channel is being used, is to make use of the recently adopted Ghost Cancellation Reference (GCR) signal used for echo cancellation. This reference signal is sent during the vertical blanking interval (VBI) of analog NTSC. The received signal is then a convolution of the transmitted GCR reference and the channel impulse response. Thus, the channel characteristics are obtained quite simply by dividing the received frequency response by the frequency response of the known reference. It should be emphasized that both the magnitude and the phase-response of the channel is of interest for determining the performance of the adaptive equalizer.

The above 'one-shot' technique of determining the channel frequency response usually has some noise added to it. Using averaging techniques, implemented efficiently using the new HP 89440A vector signal analyzer, it is possible to eliminate this noise, by assuming that the channel frequency response is time-invariant, at least during the total time required for averaging. One problem associated with averaging is the possibility of having a random initial phase-offset for each measurement because of sampling time jitter. This uncertainty causes the amplitude-response to be attenuated at high frequencies. Using the NTSC sync pulse, a stable reference can be generated which has provided sufficiently accurate channel measurements and is limited only by the timing-jitter present in the sync-regenerator circuits of an NTSC receiver. A similar sync pulse can be provided for the case when empty channel space is available.

An inherent problem associated with channel measurements obtained using the existing analog NTSC channels is that the bandwidth of channel measurement is limited to at most 4 MHz because the picture carrier is placed 1.25 MHz away from the band-edge and also because of the presence of the sound-carrier at 5.75 MHz. In fact, the GCR signal, introduced in the VBI of analog NTSC, has a 3 dB bandwidth equal to 4.15 MHz. To determine the frequency response over a 6 MHz bandwidth, an interpolation technique can be used, which is not included here and will be described in [4]. Thus, the output of the channel measurement scheme will be a frequency-response measurement of at least 6 MHz bandwidth obtained either by using empty-channel locations or using the GCR signal in existing analog NTSC channels.

In the next section, the measurement philosophy and setup are described in more detail. Following that, validation experiments performed in a laboratory are described using a simple single-echo channel simulator. Finally, measurements are provided for an in-house cable system.

MEASUREMENT SETUP

As discussed in the previous section, the GCR signal is used as a reference signal to characterize the linear CATV channel. Fig. 1 describes the measurement setup used for laboratory validation tests. For the purposes of the validation tests, the GCR pulse along with the synchronization pedestal was sent repetitively. An HP 89410 spectrum analyzer was used extensively, a description of which follows.

The HP 89410A (dc-10 MHz) vector signal analyzer (VSA) represents a new class of measurement instrument. These analyzers calculate both frequency and modulation domain characteristics from a time-record. The time-record of the desired frequency span is produced by accurately digitizing the input waveform, mixing with a digital quadrature local oscillator and band-limiting with digital filters. Selectable trigger delay and time-record length control the portion of the time-domain waveform that is captured. In addition, time-gating allows a subset of the time-record to be selected for subsequent calculations. The HP 89410A also has an arbitrary source generator.

For the laboratory setup shown in Fig. 1, the HP 89410A arbitrary source generator is configured to send the test signal repetitively. Fig. 2 shows the signal sent by the HP89410A source which consists of a GCR signal on an NTSC sync waveform. This signal is then modulated by the HP 8780A vector modulator, thus resulting in a double-sideband (DSB) modulated signal with the synchronization pulse providing a carrier similar to the visual carrier in analog NTSC. Note that the DSB signal will have a much larger bandwidth than 6 MHz, and is used only for this setup: typically another filter will remove one of the sidebands as used, for example, in an NTSC modulator. For the demodulation, a Tektronix VSB demodulator with sufficiently wide bandwidth filters is used to obtain the signal at baseband. A separate frame synchronization waveform can also be generated by using the HP 1133A. The receiving HP 89410A is then set to trigger on this sync and a time-record is generated which is sufficient to capture the entire transmitted signal, as shown in Fig. 2. This captured time record is then converted to a vector spectrum in the frequency domain. The spectrum contains both amplitude and phase information for every frequency component of the test signal. Fig. 2 also shows the amplitude spectrum of the time-record, which has a small attenuation over the 4 MHz bandwidth.

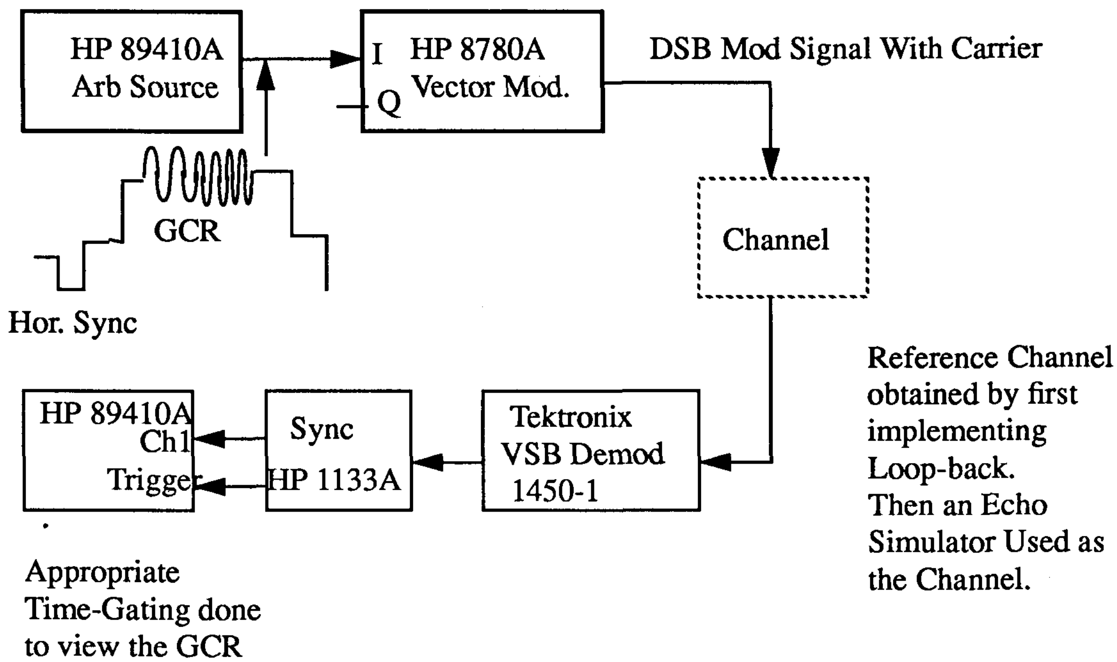

Fig. 1: Laboratory Setup Used for Channel Measurement.

For the purposes of calibration, the reference measurement is made by using a loop-back technique, i.e., the DSB modulated signal is fed directly into the Tektronix demodulator. This ensures that the frequency responses of the different instruments have also been taken into account. Fig. 3 shows the amplitude and phase variations across the entire frequency band. After creating this reference, the spectrum of the channel is measured. Dividing this spectrum by the previously measured reference yields the transfer function of the channel with an arbitrary delay term (phase ramp). The actual propagation delay cannot be measured with this technique: however, in most applications, the delay is irrelevant and only the deviation from linear phase is of interest. If necessary, improved signal-to-noise ratio is achieved by time averaging several measurements. Because the noise is not correlated with the repetitive test signal, the noise averages to zero over time. Due to the use of the HP 1133A sync generator, timing jitter is kept small which allows for such averaging to be done without any degradation to the measurement.

For measurement over a CATV network, when empty channel-space is available, a different arbitrary source generator must be used since the instruments are at different locations. For the case when analog NTSC is present, the trigger for HP 89410A is the frame sync passed through a divide-by-8 counter. This is because the GCR signal is sent with different phases over an eight field sequence to compensate for the dc offset and the color burst [5]. This will be described in more detail in the following sections.

VALIDATION TESTS

To validate the channel measurement technique, a single-echo simulator was used as shown in Fig. 4. The HP 8753 network

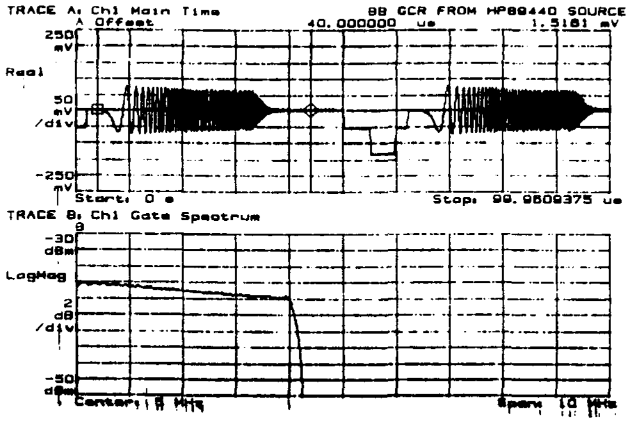

Fig. 2: GCR With the Timing Pulse.

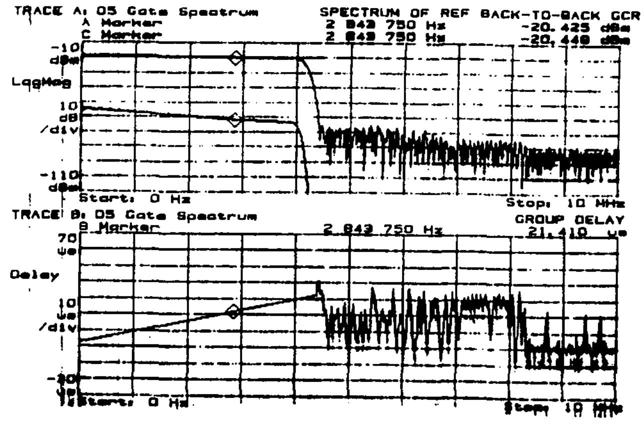

Fig. 3: Reference Amplitude and Group-Delay Response.

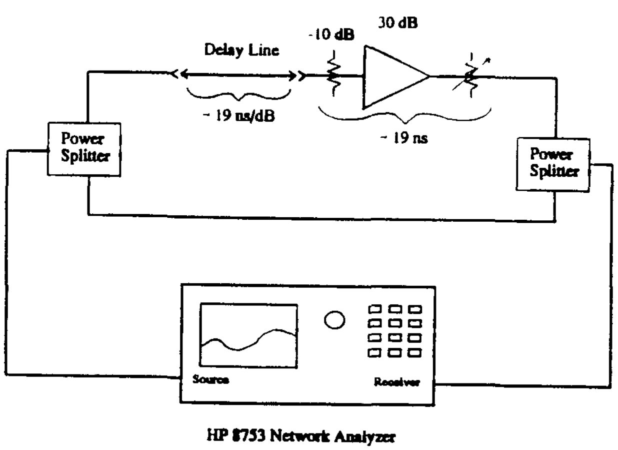

Fig. 4: Single-Echo Generator.

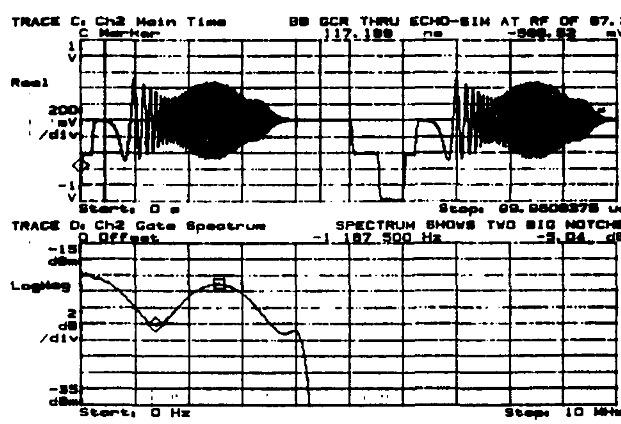

Fig. 5: GCR With a 10 dB Echo at 420 nsec.

analyzer was used to obtain the amplitude and group delay variations across a frequency band of 12 MHz, which is compared with our results.

Fig. 5 shows the GCR pulse received at the HP 89440A when a 10 dB attenuated echo was added to the main signal at a delay of 420 nsec, along with the amplitude spectrum of the appropriately gated time-record. In Fig. 6, amplitude and group delay measurements are shown for a section of 12 MHz bandwidth between 60-72 MHz using the network analyzer. This can be compared with two 4 MHz measurements shown in Fig.'s 7 and 8, between 61.25-65.25 MHz and between 67.25-71.25 MHz. Note that there is a small ripple in the group-delay measurement. This is because the dc offset in the signal was removed by subtracting the signal by a constant and then performing an FFT as can be seen by the expression shown in Fig.'s 7 and 8. Unfortunately, the AGC control in the VSB demodulator was not very accurate and this level jitter caused a ripple in both the amplitude and the group delay response. A simple method of removing this jitter will be described in the next section.

Fig. 9 shows the amplitude and the group delay measurements obtained using the network analyzer when the echo amplitude is 25 dB below the main signal. Note that the peak-to-peak variation in both the amplitude and the group delay is smaller than the 10 dB case. The corresponding measurements using our setup are shown in Fig.'s 10 and 11 which are close to the measurement made by the network analyzer.

CHANNEL MEASUREMENTS

The channel used is as shown in Fig. 12. The sixteen amplifier cascade is part of an in-house cable system with a bandwidth of 50-600 MHz. The output of this cascade was then passed through a 21 dB 8-way splitter, seven of which were unterminated. To simulate possible home-wiring the output of this splitter was passed though another splitter, the attenuation of which was varied between 0 and 3 dB for two different experiments. The other end of the 3 dB splitter was left open-ended.

Fig.'s 13-16 show the amplitude and group delay measurements performed at different bandwidths for the 16 amplifier cascade only. Note the flat spectrum in Fig.'s 14 and 15 for mid-range frequencies of 295.25-299.25 MHz and of 567.25-571.25 MHz. Also note the expected attenuation and increasing ripple for both the low frequncy of 67.25-71.25 MHz and 627.25-631.25 MHz.

Fig. 17 shows the case when the bottom path is selected for the channel shown in Fig. 12, i.e., a 3 dB splitter is used. As can be seen the amplitude ripple for 567.25-571.25 MHz is only 0.5 dB. Finally, in Fig. 18, the amplitude and group delay response for a 0 dB splitter is shown, where an open-ended cable of RG-59 of length 56 inches is used at the other end. This causes a deep null to occur near the 572 MHz frequency, as is seen by as much as 3 dB attenuation in the amplitude response as in Fig. 18.

In most of the figures on channel measurement, the effect of incorrect dc offset is observed clearly at the low frequencies. As explained earlier, this dc offset is because of the AGC present in the VSB demodulator. This dc offset can be removed quite easily by using the HP 89440A delayed trigger mode. The arbitrary source generator is used to send the GCR signal of opposite phases at successive intervals. At the receiver, a synchronization trigger to the HP 89440A is created by passing the frame sync from the HP 1133A through a divide-by-2 counter. The received baseband signal is fed in to both the Ch1 and the Ch2 inputs of the HP 89440A. The gated window for Ch2 is set to be a time-offset win-

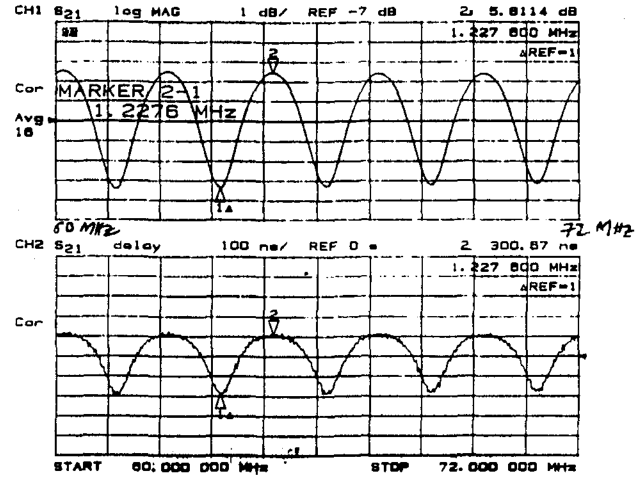

Fig. 6: Amplitude and Group Delay Measurements Using a Network Analyzer for 10 dB Echo.

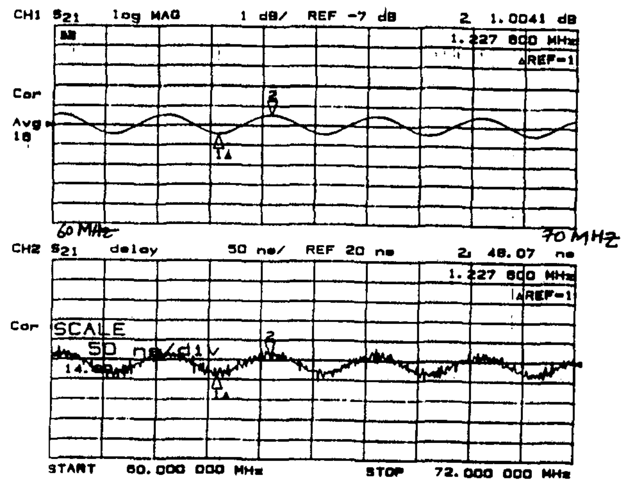

Fig. 9: Amplitude and Group Delay Meas. Using a Network Analyzer for 25 dB Echo.

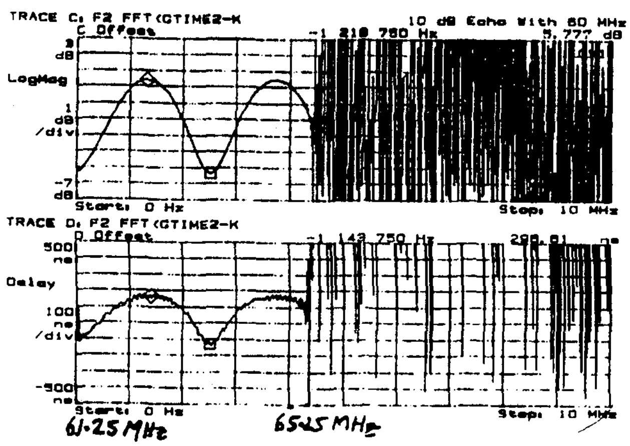

Fig. 7: Amplitude and Group Delay Meas. From 61.25-65.25 MHz for 10 dB Echo

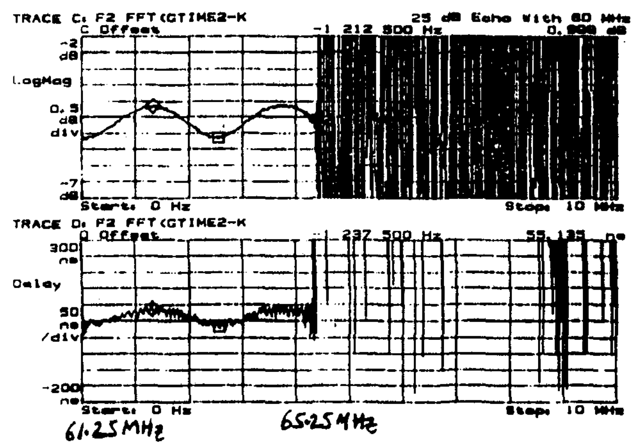

Fig. 10: Amplitude and Group Delay Meas. From 61.25-65.25 MHz for 25 dB Echo.

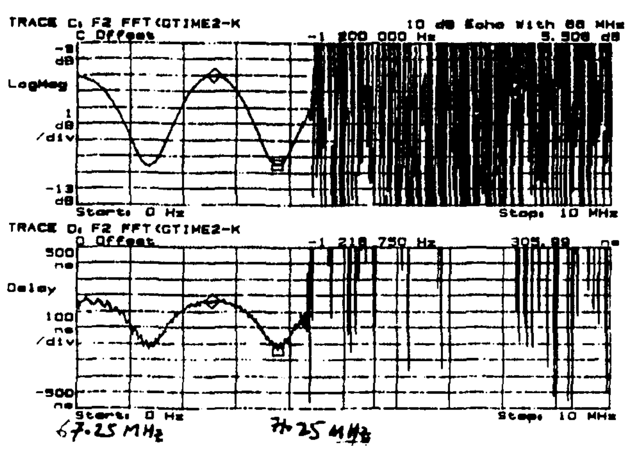

Fig. 8: Amplitude and Group Delay Meas. From 67.25-71.25 MHz for 10 dB Echo.

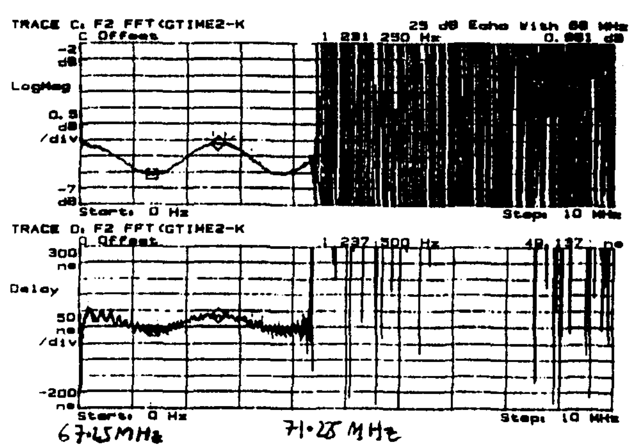

Fig. 11: Amplitude and Group Delay Meas. From 67.25-71.25 MHz for 25 dB Echo.

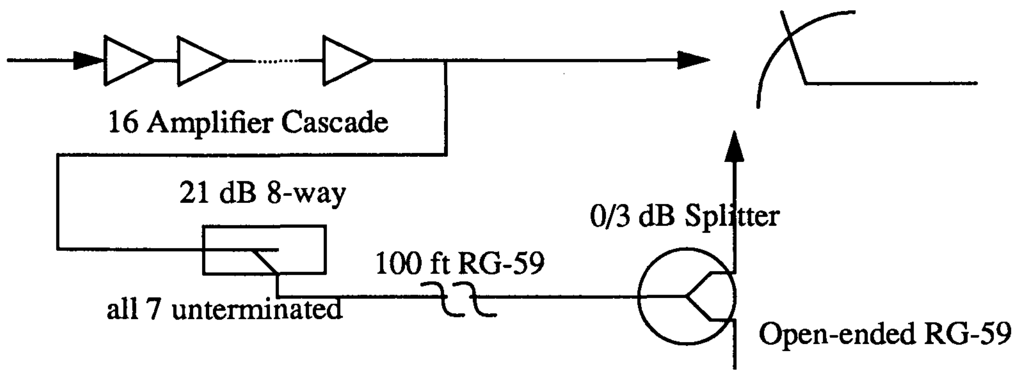

Fig. 12: Channel Setup for CATV Measurement

dow of Ch1 so that now a difference between the gated window of Ch1 and Ch2 removes the dc offset but does not cancel out the GCR. This technique can also be used with the analog NTSC GCR 8-field signal sequence, where the opposite phase is present every fourth field, and, now, a divide-by-8 counter is used. Another technique to remove this dc offset is by observing the trailing edge of the time-gated signal and using the mean value of the samples of this trailing edge to calculate the required dc offset. This trailing edge can be obtained as a time-gated signal on Ch2. A software program which performs such an averaging can be easily written using the BASIC programming options available with the HP 89440A. This investigation will form part of our future work.

CONCLUSIONS

Using the GCR signal, proposed for echo-cancellation, a channel characterization technique is described. Assuming that digital modulation techniques could be used over channels currently used for NTSC, it then becomes necessary to characterize these channel with 6 MHz bandwidth. The channel characterization technique described above allows for non-intrusive channel characterization. The measurement technique was validated in the laboratory by using a single-echo ghost simulator. Some channel measurements are shown with an in-house cable system.

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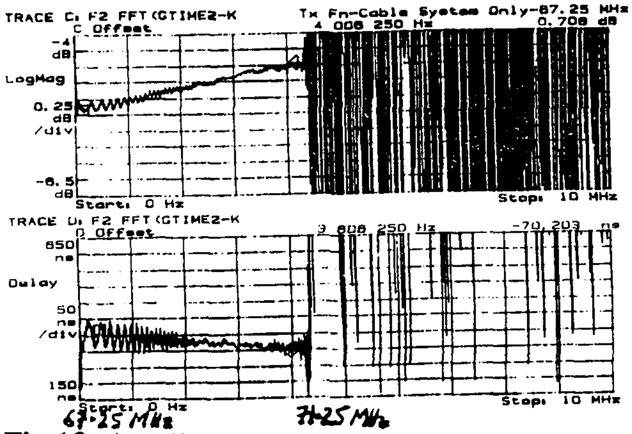

Fig.13: Amplitude and Group Delay Meas. For Just the Cable System- 67.25-71.25 MHz.

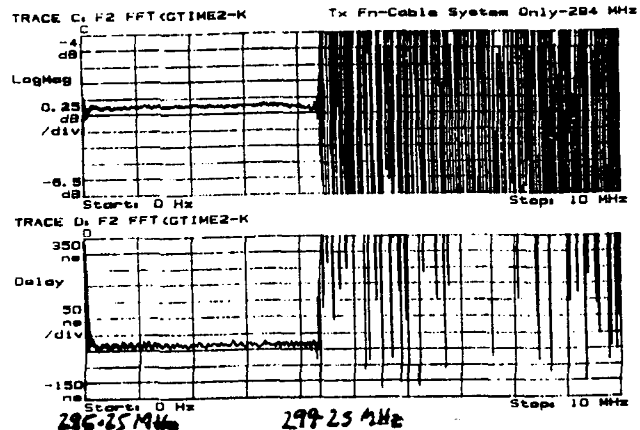

Fig. 14: Amplitude and Group Delay Meas. For Just the Cable System - 295.25-299.25 MHz.

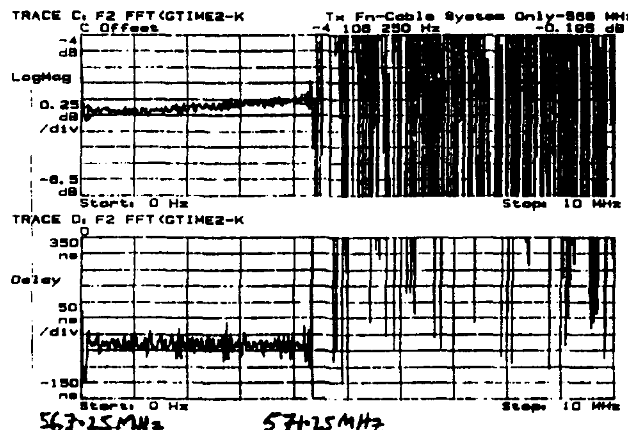

Fig. 15: Amplitude and Group Delay Meas. For Just the Cable System - 567.25-571.25 MHz.

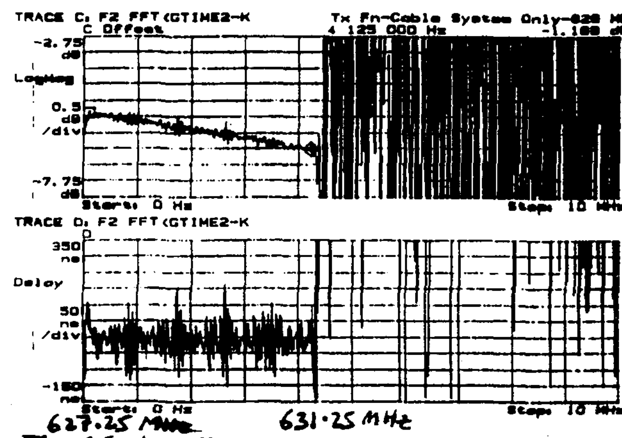

Fig. 16: Amplitude and Group Delay Meas. For Just the Cable System - 627.25-631.25 MHz.

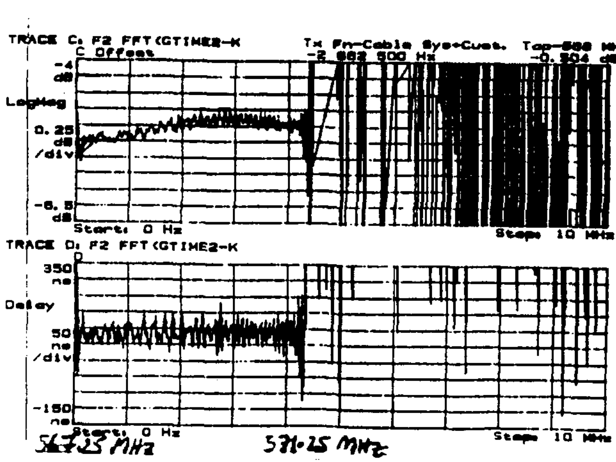

Fig. 17: Amplitude and Group Delay Meas. For Cable System+3dB Splitter-567.25-571.25. MHz.

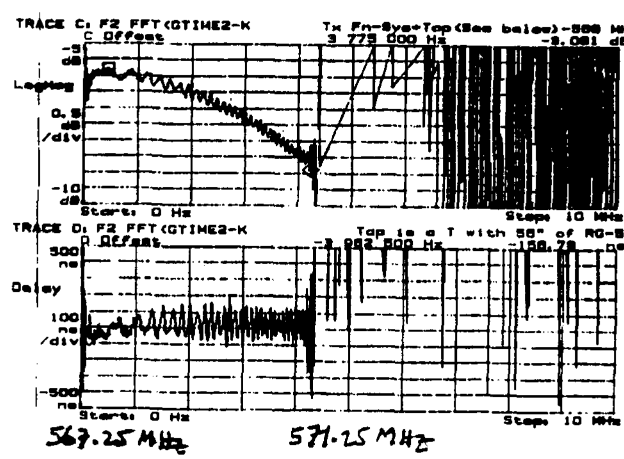

Fig. 18: Amplitude and Group Delay Meas. For Cable System+0dB Splitter-567.25-571.25 MHz.

CATV Digital Compression Systems Interoperability: A Paradigm for the Future

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AT&T - Bell Laboratories

Abstract

Digital video compression is poised for initial CATV deployment in 1994. An important consideration for the cable operator contemplating the deployment of the new digital technology is the interoperability of different vendors' compression systems. Interoperability offers the potential advantages of interworking between different vendors' equipment, increased maintainability and reduced maintenance costs. Most significant is the creation of an extensible digital infrastructure that can readily support future interactive, networking applications.

This paper outlines the major areas that must be addressed to provide interoperability in an end-to-end compression system: the types of video and audio compression employed, specification of transport formats and transmission system characteristics (including signaling channels) for various media (e.g., satellite, coax, fiber), access control and encryption, and equipment interfaces and interconnection protocols.

INTRODUCTION

The notion of interoperability is fundamental to the creation of integrated communications networks supporting a wide variety of services. As CATV networks continue to evolve from analog to digital, from coax to fiber, and from one-way broadcast to two-way interactive services such as Impulse Pay Per View (IPPV), interactive multimedia and Personal Communications Services (PCS), the need for end-to-end system interoperability specifications will intensify.

Traditional CATV systems, based primarily upon broadcast services, have tended to be geographically localized and isolated from other systems. There has been no need to ensure compatibility of equipment deployed in different systems, making incompatibility the rule rather than the exception. Local optimization of equipment and resources has been an appropriate and accepted paradigm. Interoperability between systems — and between the elements that make up each end-to-end system — has not been a requirement.

The traditional CATV architecture is rapidly facing obsolescence with the tremendous increase in the breadth of services that cable operators are now introducing or planning to offer. Interactive and transaction based services will require the capability to support communications between different CATV systems, as well as external communications systems such as public telephone and data networks. The future success of the new service offerings critically depends upon the adoption of a new paradigm of interoperability.

Benefits of Interoperability

In the near term, interoperability offers the cable operator the potential for interconnecting equipment produced by different vendors to create fully operational end-to-end systems. Provided that the necessary conditions — outlined below — are met, source material can be appropriately processed at a point of origination (such as a satellite uplink site), be transported through a network consisting of a variety of equipment and transmission media, and be reconstructed at the receiving end in a manner that is totally transparent to the information consumer.

Operations and maintenance considerations also support the notion of digital interoperability. The new generation of digital equipment will be significantly more complex than today's analog equipment. Moreover, in order to access the received analog signal that will actually be seen by the end customer, the digital bit streams must be demultiplexed, decrypted and decompressed. Standard techniques for testing analog video equipment will be of little help in diagnosing the problems of digital systems.

Testing, maintenance and fault isolation of digital systems will require special equipment with the capability to properly analyze bit streams and provide status and error indications to test personnel. Interoperability will reduce equipment needs to a practicable level and eliminate a needless proliferation of incompatible test gear. Side benefits also include reduced maintenance time and the requisite amount of training required by maintenance personnel.

The first opportunity to adopt the interoperability paradigm is the deployment of the new digital compression technology. Because the new technology encompasses virtually all aspects of an end-to-end system, the equipment that is deployed today will have a long lasting effect and will continue to influence the ability — or inability — of CATV networks to support new services for years to come. Interoperability will greatly enhance future network extensibility and will favorably influence the economics of new service offerings by allowing them to be deployed incrementally, supported by a solid digital infrastructure. Of course, interoperability also demands the mutual coexistence of the new digital technology and the existing analog technology that will continue to be used for many years to come.

Thus, the long term value of interoperability is the capability to grow networks easily and seamlessly to support new services without the need to replace the existing infrastructure of equipment, coax and fiber. In effect, interoperable design criteria can ensure that the digital infrastructure that is first put in place to provide IPPV and EPPV services in the near term can be evolved into digital highways of the future. Through the establishment of appropriate criteria, it will also be possible for CATV systems to interconnect with other digital communications systems, such as Local Area Networks (LANs) and Wide Area Networks (WANs) and even digital telephony networks. The time for the new paradigm has now arrived.

Interoperability Defined

Interoperability may be defined as the design and deployment of consistent functionalities and interfaces throughout an end-to-end information delivery system to ensure operation at an expected level of performance. The most significant characteristic of an interoperable system is the ability to easily accommodate compatible equipment at any point in the communications path from satellite uplink to cable head end to the home terminal. Moreover, an infrastructure of compatible equipment provides a clear path to the future, readily supporting the introduction of new services.

Interface compatibility includes the specification of signal levels and wave forms, bit rates, bit framing and packet formats, protocols and standard message sets. Key dimensions of functional interoperability are compression, encryption, multiplexing, modulation, error correction and other transmission signal processing. Other significant network attributes are signaling modalities, return channel characteristics and the many aspects of access control.

It is important to note that this level of interoperability does not preclude the possibility of advanced, value-added features that can serve to differentiate different vendors' products. Indeed, a truly interoperable digital infrastructure can serve as the vehicle for providing a great variety of new features and services that can be designed in accordance with a well-defined set of interoperability criteria.

DIMENSIONS OF INTEROPERABILITY

Although the new digital technology affects virtually every aspect of system operation and performance, it is important to recognize that it is compatible with the existing infrastructure of fiber, coax and analog transmission equipment. Conceptually, a new layer of digital functionality is being placed upon — and supported by — the present analog CATV plant. However, it is equally important to note that the nature of the new digital overlay will essentially determine the capability to support future interactive services.

The key dimensions of interoperability are the functional elements that determine end-to-end system performance. They include compression, transport formats, modulation, error correction and various other transmission signal processing, downstream and upstream signaling, return channel characteristics, and access control and encryption. The interoperability requirements of each of the key dimensions is described in more detail below.

Digital Compression

Digital compression of video and audio signals constitute the foremost enabling technologies for the new IPPV and EPPV services that will also serve as the foundation for many future services. Many different — and incompatible — compression techniques have been proposed, creating a difficult challenge for cable operators and equipment vendors alike in choosing an appropriate compression technique.

Video compression algorithms can be described in terms of their specific feature sets and their syntax. Features refer to the definition of elements used to represent compressed video and the rules for using these elements to reconstruct decompressed video images. Examples include motion vectors, discrete cosine transform coefficients, quantization matrices and other mathematical constructs that are typically utilized by compression algorithms. Syntax is the set of rules used to efficiently represent the various elements in a binary form that can be decoded by an appropriate digital receiver. Similar comments also apply to audio compression algorithms.

Fundamental to digital CATV interoperability is the use of video and audio compression algorithms, or families of algorithms, with common features and syntax. A digital cable converter will not be capable of decoding a compressed video or audio signal that has been compressed with an incompatible compression algorithm. In addition to various proprietary compression schemes that have been proposed, considerable effort has been expended in the development of digital compression standards. Most notable in the context of CATV is the MPEG2 standard.

An interesting aspect of MPEG2 video compression is the proposed support of distinct "profiles", each corresponding to a specific feature set. Different profiles may be best suited to different applications, based on required functionality and cost considerations. For example, the creation of a profile optimized for CATV applications has been proposed. All profiles will employ the same syntax and some profiles may include other profiles as subsets. Nevertheless, for interoperability any particular MPEG2 decoder would have to support the profile (or a superset of the profile) used by the video encoder.

Essential elements for compatible video compression include the syntax and feature set, as well as the range of compressed bit rates supported and any constraints that are placed upon compression parameters, such as motion vector ranges or limits on receiver buffer sizes. In addition to feature set and syntax, compatible audio compression requires definition of auxiliary data channels and specification of any built-in error correction parameters, such as those that are built into some existing algorithms. However, as discussed below, interoperability is better served by including error correction with medium specific transmission equipment and logically separating the compression and transmission functionalities.

Transport Formats

Associated with the introduction of digital compression technology is the deployment of a new digital overlay to the existing analog infrastructure. The definition and specification of every aspect of this digital overlay is critical to interoperability and system extensibility.

Because every bit in a digital communication system appears superficially to be indistinguishable, formats for organizing digitally encoded information must be established. The definition of these transport formats can either facilitate or severely limit the future networking potential of CATV systems, including the ability to interwork with other communication networks.

Closely associated with the transport format definition is a plethora of issues related to timing, framing and synchronization of bit streams, means for associating and synchronizing video, audio and any associated data within a bit stream, and many more related concerns. There is also a number of issues related to separating digital streams associated with different points of origination and recombining them for targeted redistribution. Broadcast based approaches are generally not amenable to supporting this type of networking.

Flexible networking is also needed to support different bit rates associated with varying degrees of compression and to accommodate the different capacities of various transmission media, including satellite, coax and digital fiber. Moreover, flexible networking and extensibility to future services demands the use of compatible transport formats that can be used regardless of the actual transmission media, as discussed more fully below.

All the issues noted above must be satisfactorily resolved in order to ensure interoperability. The definition of transport formats is another area of active standardization activity, particularly within MPEG2.

Digital Modulation and Error Correction

Digital compression and transmission lead naturally to the use of digital modulation techniques. Particular forms of modulation may be more or less appropriate for a given transmission medium, depending upon the fundamental limitations of that medium. It is essential to note that the type of modulation technique is logically independent of the transport format specification. Specifically, in the case of IPPV services, all bit streams must ultimately be decoded by a large number of home terminals, regardless of the route by which the digital programming actually traverses the system. It is therefore imperative that medium specific transmission equipment be designed to serve as digital highways that transport bits *without* altering their transport format. This logical separation of functionality is a cornerstone of system interoperability.

Forward Error Correction (FEC) techniques are also designed to accommodate the transmission limitations of a specific transmission medium, such as degraded signal to noise ratio or channel dispersion. The particular technique employed and the specific number of error correction bits that is used can vary significantly between, for example, satellite and cable transmission. Interoperability demands that the medium dependent error correction functionality be logically separated from the medium independent transport format.

The interoperability of transmission components requires not only compatible modulation and error correction techniques. Transmission equipment must designed to a common set of specifications, including well-defined external interfaces and input and output signal characteristics.

Transmission Interfaces

Transmission interoperability requires common specifications for the various interfaces that exist within an end-to-end system. At the most fundamental level are physical interfaces, which are specified by physical connectors, acceptable ranges of signal levels and wave form variations (defined by masks), impedance levels, spectral shaping, frequency plans and channelizations supported. Additional measurable signal characteristics that must also be specified for compatible operation include frequency and phase stability over time and temperature, the degree of permissible linear and nonlinear distortions, and bit stream jitter generation, transference and tolerance, to name but a few.

Return Channels

The introduction of interactive services will necessitate the specification of *all* the interoperability dimensions described above for *both* downstream and upstream channels. Consideration must be given to the natural evolution toward greater upstream capacity, the impact of transmission performance upon interactive services, and the protocol aspects associated with interfacing to other external networks.

Signaling Channels

In addition to their physical interfaces, transport formats, and modulation and error correction techniques, signaling channels are characterized by their protocols and message sets. The minimum requirement for interoperability is the adoption of a standard set of protocols that can support any type of control message. The prospects for interoperability will be further enhanced with the definition of a basic set of universal control messages that apply to all foreseeable applications. Examples could include commands for initializing the state of the home terminal, performing built in self tests, and so on; and creating queries for operational status or consumer usage information on an addressable terminal basis.

Access Control and Encryption

Security and access control are essential to the viability of value-added services. At present there is no single access control standard, although most approaches utilize the same basic principles. The existence of a number of proprietary access control systems is perhaps the greatest barrier at present to complete system interoperability. What is needed is a more general framework which encompasses all existing systems as well as potential future access control schemes.

A minimum requirement for system interoperability is the logical separation of access control from the other end-to-end system functions. In addition, as in the case of signaling, interoperability would be aided by a set of standard interfaces, including connectors, signal levels and so forth. The establishment of a basic protocol scheme would provide a further means of communicating access control messages of any desired format *without* compromising the security of a system. These factors are important to the development of low cost home terminals with universal access control capability.

Digital encryption is a fundamentally simple operation involving only the performance of a logical "exclusive or" of the data to be encrypted with a secure pseudo random sequence that can be updated in near real time. The paramount issue here is the absence of a standard relationship between the encryption process and the transport format. This subject is also being addressed by the MPEG2 systems working group, along with the definition of transport formats.

THE ROLE OF STANDARDS

Interoperability is also facilitated by the development of industry standards and adherence to these standards in equipment design and operation. Although a number of standards already exist for digital video and audio formats, most other important aspects of an end-to-end digital CATV system have not yet been standardized. As noted above, many interoperability aspects of particular relevance to the CATV industry will be addressed by the emerging MPEG2 standard, which is presently being defined by the International Standards Organization (ISO) in conjunction with the International Electrotechnical Commission (IEC). MPEG2, which is an extension of the MPEG1 standard, encompasses video and audio compression and transport formats (known as "systems" in MPEG parlance).

A major issue with any evolving standard, including MPEG2, is the timeliness of final standardization and subsequent availability of low cost VLSI implementations in relation to perceived market needs for deployment. Although short term deployment of non-standard technology may address immediate opportunities, this approach carries the risk of creating a digital infrastructure with limited extensibility to support future applications.

SUMMARY

The deployment of digital video compression systems marks the dawn of a new era for the CATV industry. The new technology will create a digital overlay, supported by the existing analog plant, the characteristics of which will critically determine the ability of cable operators to introduce future services. Many new interactive, two-way services will require the ability to interoperate with other systems, including other types of communications networks.

Thus, with the new digital era comes the opportunity to adopt a new paradigm of system interoperability: a paradigm with a path to the future.

CATV Distribution in A Fiber-in-the-Loop System Utilizing External Modulation

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Abstract

We report results of a video distribution system designed to be deployed in an integrated telephony and television distribution system. This system has been developed to be cost competitive with conventional solutions. The architecture is based on a combined Passive Optical Network - Fiber In The Loop system (FITL): a telephony PON system (Interactive Service) and a television PON system (Distributive Service). The two services are designed to be co-deployed. The video overlay described here can provide up to 50 channels of PAL video. The combination of analog TV distribution and interactive services could be accomplished within a single pedestal.

INTRODUCTION

The cost effective provision of both distributive (am-vsb CATV) and telephony services to the building or pedestal using an integrated fiber optic network is an attractive development for both CATV and telephone companies. This paper describes such a system, developed for large scale deployment in Germany.

In the video distribution system, a high-powered fiber optic transmitter serves many remote optical network units (ONUs). From a headend or central office site, each externally modulated diode-pumped Neodymium Yttrium Lithium Fluoride (Nd-YLF) transmitter feeds up to 64 ONUs located in pedestals or buildings. A tree and branch coaxial cable network distributes the video signals beyond the ONU.

Telephony services are provided over a normal loop at a distance of up to 1000 feet from the ONU. Customers can be provided with Plain Old Telephone Service (POTS), ISDN basic access (BA) and primary rate (PR), and leased lines. The downstream direction uses time division multiplexing (TDM), and the reverse direction uses time division multiple access (TDMA).

A single fiber cable can be used to carry the video and telephony to the ONU , which provides both services.

SYSTEM OVERVIEW

Link description - number of remote sites

The complete video system provides up to 50 channels of PAL broadcast video to subscribers from a Headend through a passive optical network (PON) to as many as 64 distant units (DU or ONU).

Link description - video

Each transmitter has either two outputs each of 12-14 dBm or 4 outputs each of 11-12 dBm. In a typical system, a minimum received power is - 5.5 dBm, giving a link budget of 17.5 dB for each output of the four output transmitter. This allows each output of a four output transmitter to be split 16 ways, each path having typically 2 km of fiber. In this way one transmitter can serve up to 64 ONUs.

Link description - telephony

Each PON tree can provide up to 384 DS0 (64 kbps) channels, with each ONU serving up to 30 subscriber lines. As described below, the optical transmission scheme uses wavelength division multiplexing to enable bidirectional traffic on a single fiber.

VIDEO DELIVERY

Transmitter

The transmitter utilizes external modulation of a c.w. light source, thus separating the functions of light generation and light modulation. This allows the use of high power, low noise optical sources such as the Nd-YLF laser (1) in combination with a zero-chirp modulator such as the Mach-Zehnder waveguide modulator (2).

The combination of a narrow linewidth source and a chirp-free modulator avoids the problems associated with direct modulation ofdistributed feedback lasers (d.f.b.). These include: interferometric intensity noise from fiber backscatter and reflections (3); cavity induced CSO distortion from reflections (4); dispersion induced CSO (5); and, optical amplifier gain slope induced CSO (6). In addition, considerably higher transmitter output powers are available than from present d.f.b. lasers.

The external modulation provides very low chirp and immunity to interferometric intensity noise. The use of feedforward error correction provides very low CSO and CTB, allowing transmitters to be cascaded if required.

Transmitter Design

Optical feedforward (9, 10, 11) is a straightforward analog of electrical feedforward (8). The design of the transmitter is shown in Figure 1. The main optical source is a Nd-YLF laser (1). This is modulated by a balanced-bridge lithium niobate interferometric modulator (12). An error signal is derived by splitting off a small fraction of this modulated light onto a photodetector and comparing this with a sample of the electrical input signal. This error signal is amplified, delayed and then converted to an optical signal by means of a d.f.b laser. This optical error signal is combined with the main signal in a 50:50 coupler in such a way that the error signal cancels the distortion in the main signal.

Two separate feedforward correction circuits are implemented, one for each output of the modulator.This has two benefits. First, the modulator need not be symmetrical in its distortion, and, second, two separate delay adjustments are available to facilitate operation at multiple receive sites.

YLF laser

The light source is a diode- pumped YLF laser operating at 1313 nm. The pump source is a 2 W diode laser, derated to 1 W operation. This laser has an extrapolated MTBF of over 1 million hours. Fiber-coupled output power exceeds 135 mW.

Modulator

The light is modulated by a lithium niobate modulator. This has a +/- 0.5 dB bandwidth to beyond 606 MHz. The modulator has a typical excess loss of below 3.5 dB, and two equal optical outputs, giving a total insertion loss of 7.5 dB per output. Under 50 channel PAL operation at 5%/channel modulation depth, the modulator CTB is ~ 45 dB. The system is designed to reduce this to below 70 dB.

Predistortion and Optical feedforward using dfb correction sources

Linearization is provided by a combination of electrical predistortion and optical Feedforward. It should be noted that because, feedforward uniquely cancels distortions of every order and indeterminate phase, it can be readily combined in this way with any electrical or optical predistortion techniques.

A feature of feedforward is that the error signal is a small proportionof the total signal. Therefore it can show high optical noise without significantly contributing to the overall carrier:noise. Similarly, the distortion of the error signal represents distortion of the distortion, and is a secondary effect. For these reasons, low grade d.f.b. lasers can be used as the error correction source without the noise and distortion limitations mentioned above for systems using d.f.b.s only.

Performance

Each transmitter provides two outputs of 20 mW each, or four outputs of 16 mW each. Measured with 50 PAL c.w. carriers at 5% /channel + 30 FM channels at 4 dB down, the measured CSO is better than 70 dBc and CTB better than 69 dBc.

The transmitter is monitored and controlled using a microprocessor. An external RS485 interface provides full status and alarm monitoring. In addition a timed 3-level optical shutdown and start up is initiated by an external laser safety shutdown (LSS) input. This is controlled by the microprocessor and monitored by a second microcontroller, to ensure reliable operation.

The optical receiver for the video is co-located in the pedestal with the telephony. A typical receiver for this application has a 8 pA/rt.Hz equivalent input noise. The measured optical distortion is less than -70 dBc (second order) and -75 dBc (third order) for a two tone, 40% /tone, test at 0 dBm input power.

Link budget

The system is designed to operate with a minimum link budget of 18 dB for a minimum CNR of 46 dB (5 MHz), with CSO of 62 dB and CTB of 57 dB. Measured results, reported below, are considerably better than this.

TELEPHONY DELIVERY

Forward link

The optical line terminal (OLT) is located near the local exchange. All subscriber information is fed into the OLT, and distributed through the PON to the ONUs. The OLT accepts input lines in multiples of 2 MBit/s and converts them to an internal interface format for maintenance and control. These are then multiplexed and transmitted to the optoelectronics by the bit transport system (BTS). The data steams for both directions are multiplexed on the same fiber by using different wavelengths - 1550 nm for downstream and 1300 nm for the return.

The BTS additionally provides automatic ranging to monitor the path delay of each optical link. Finally, the BTS automatically monitors and controls the transmitted and received power of each link. The ONUs access the allocated Time Division Multiplexed (TDM) time slots and provide the required services to the customer in multiples of 64 kbit/s. Up to 30 POTS lines can be handled by one ONU, and the network management system allows up to 32 ONUs per BTS.

Return Link

The ONU transmits in the reverse direction (upstream) using Time Division Multiple Access (TDMA). Data collision is prevented using an automatic ranging procedure which compensates for the signal delays of the optical routes.

VIDEO RESULTS

Measured results for 50 PAL c.w. carriers + 30 FM channels are shown in Table 1. The launch power was 12.6 dBm and received power -8.5 dBm, giving a link budget of 21.1 dB. This was achieved using 6.4 km of fiber followed by passive loss. Measured modulation depth was 5.07%/channel. The distortion is not corrected for the noise floor. At -2 dBm received, all distortion values were measured at better than 69 dBc.

CONCLUSION

We have described an integrated video/telephony fiber in the loop system. This system is based on co-located passive optical networks for video and telephony. The video transmission system utilizes high power externally modulated transmitters with feedforward error correction. The telephony system uses TDM/TDMA transmission, with bidirectional transmission over a single fiber. There are a number of good reasons to consider this approach to system design. The coaxial part of the video system beyond the ONU could provide a conductive path for AC power for both video and telephone hardware. Interactive video services could employthe telephony for upstream communications requirements, saving the cost of redundant upstream systems. Deploying both video and telephony lines simultaneously would result in a significant reduction in construction costs over independently deployed systems. Finally, the ability to capitalize on future opportunities like digitally compressed video, multimedia and computerized information services can best be addressed by the combined strengths of a combination video (large downstream bandwidth) and telephone (switched) system.

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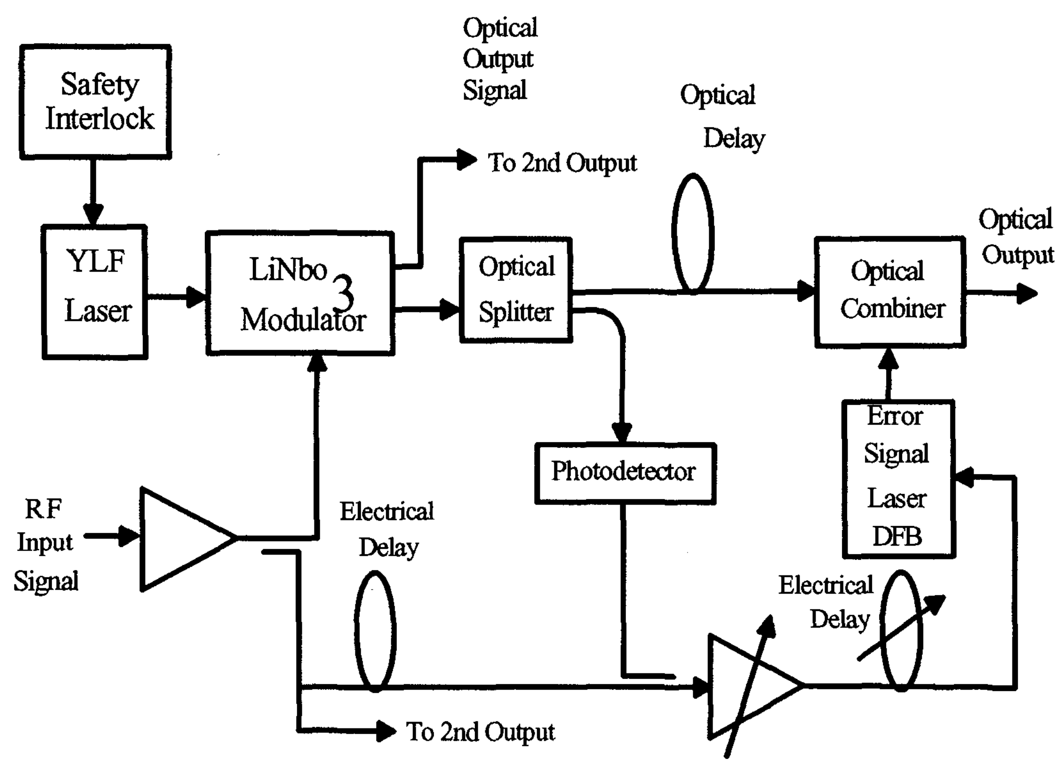
Table 1. Measured Results For 50 PAL c.w. carriers + 30 FM channels

-8.5 dBm received:

	k2 (48.255 MHz)	s37 (431.247 MHz)	k37 (599.246 MHz)
CNR (dB)	46.5	46.4	46.8
CSO (dBc)	70	68.2	68
CTB (dBc)	-	68.4	66.2

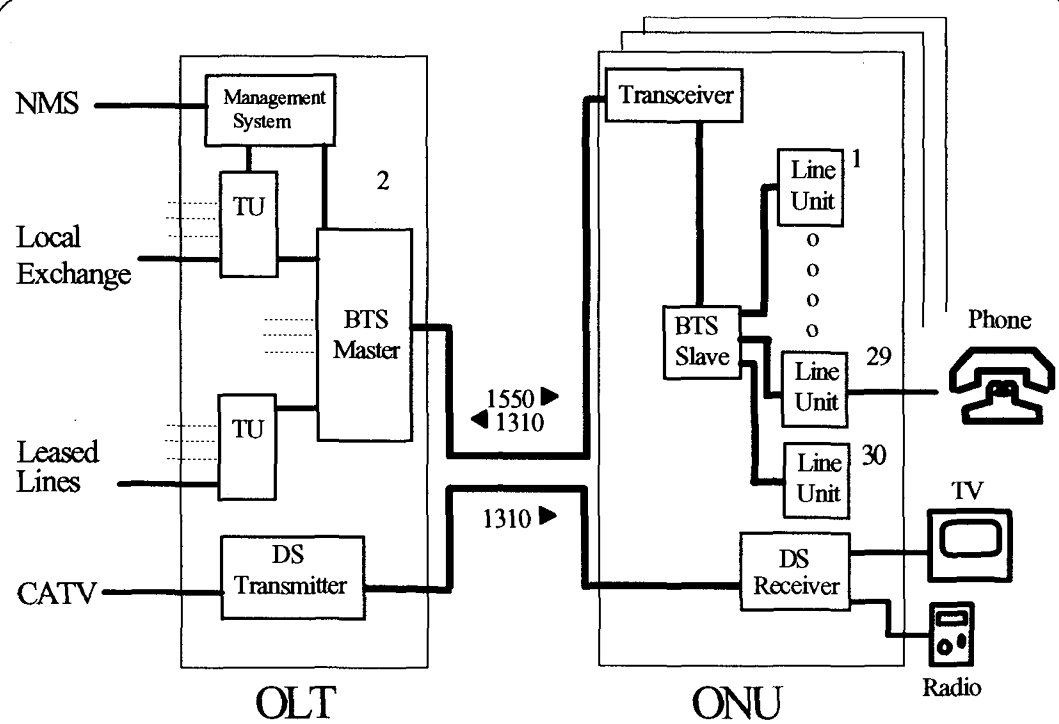
-2 dBm received:

	k2 (48.255 MHz)	s37 (431.247 MHz)	k37 (599.246 MHz)
CNR (dB)	52.1	51.8	51.9
CSO (dBc)	72.7	71.3	71
CTB (dBc)	-	71.5	69.3



External Modulation Laser Transmitter

Figure 1



BTS = Bit Transport System
OLT = Optical Line Terminal
ONU= Optical Network Unit (16 per OLT)
TU = Tributary Unit
POTS = Plain Old Telephone Service (30 per ONU)

Figure 2

Combined Video and Telephone Network

COMPARISON OF MICROWAVE PROPAGATION AT 13, 18, AND 28 GHZ

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ABSTRACT

Recent FCC regulatory proceedings have opened up the 18 and 28 GHz bands for certain types of multichannel television distribution. It is, therefore, of some interest to CATV operators to compare the atmospheric propagation characteristics of microwave transmissions at 18 and 28 GHz with the more familiar 13 GHz CARS band. The effects of multipath and rain attenuation at these frequencies are reviewed and the method of predicting path performance is summarized. Pertinent examples delineating performance limits of existing systems are given.

INTRODUCTION

The calculation of microwave system performance is relatively straightforward when applied to free space. Formulas are available to describe the free space attenuation and the antenna gains from which the received power is calculated when the transmit power is given. This net propagation loss can also be envisioned as a percentage of the transmitted beam energy which is intercepted by the receiving antenna. The transmit beam spreads with distance at an angle Θ. The area of the receiving antenna could then be compared to the transmit beam area for the path distance L. Further losses due to antenna inefficiencies and waveguide are then added to the net free space loss to predict the power at the input of the receiver.

The situation is somewhat more complicated when a terrestrial path is considered. Not only must one assure oneself that there is no actual blockage of the path, i.e., "line of sight" must be established, but also there must be adequate clearance so that interaction between the electromagnetic beam and an object close to the center line of the path will not lead to a significant modification of the free space propagation prediction. The required clearance to avoid diffraction effects is given by the Fresnel zone formula for $0.6F_1$, the radius of a narrow ellipsoid of revolution with the path center line as an axis. However, in the presence of large "flat" surfaces such as bodies of water or sides of buildings, one must also investigate the possibility of reflection in the area of overlap between the transmit beam and the "receive beam". Such a reflection would interfere with the direct, on-axis, propagation. For the very small angles of reflection typically encountered, the surface need not be very flat to be an efficient reflector. A common experience is the reflection of light from the asphalt as one is driving along the highway. Clearly, the surface is orders of magnitude rougher than the wavelength (1/2 micron) at optical frequencies, yet the mirage effect is very evident. Similarly, at microwave, even cultivated fields with near uniform height vegetation can act as a highly reflective surface at small angle of incidence.

Another consequence of the terrestrial environment is that the curvature of the earth's surface comes into play. If there were no atmosphere, the earth bulge would be simply accounted for just as any other potential obstructions along the path. The atmosphere, however, complicates matters further since it does not have a uniform density as a function of elevation. As a result, it acts as a lens which normally bends the electromagnetic beam slightly downward as it travels between the end points of the path. One speaks of an effective earth radius and a corresponding K-factor to describe this effect.

A more serious consequence of the atmosphere is that conditions change. The most obvious change is rain which causes a sharply increasing attenuation of the electromagnetic beam as the frequency increases. A not so obvious effect is caused by changes in the K-factor and the formation of atmospheric inversion layers which can lead to multipath propagation interference.

RAIN ATTENUATION

Attenuation due to rain is described by the equation

$$\gamma = kR^{\alpha} \qquad (1)$$

where γ is the specific attenuation expressed in dB/km, k and α are constants dependant on frequency and polarization, and R is the rain rate in mm/hr. Figure 1 shows the results at 13, 18.3, and 28 GHz for vertical polarization and also for horizontal polarization at 28 GHz.

It is clear from this result that rain attenuation is approximately twice as severe at 18 GHz as at 13 GHz and 3 to 4 times as severe at 28 GHz. Moreover, horizontal polarization results in 20 - 25% greater attenuation than vertical polarization. Note that these comparisons are in terms of dB/km, i.e., "twice the attenuation" is not just a factor of 3 dB, but a much larger number dependant on the total path attenuation. The constants used in plotting Figure 1 are derived from the rain model given by the International Radio Consultative Committee (CCIR)[1].

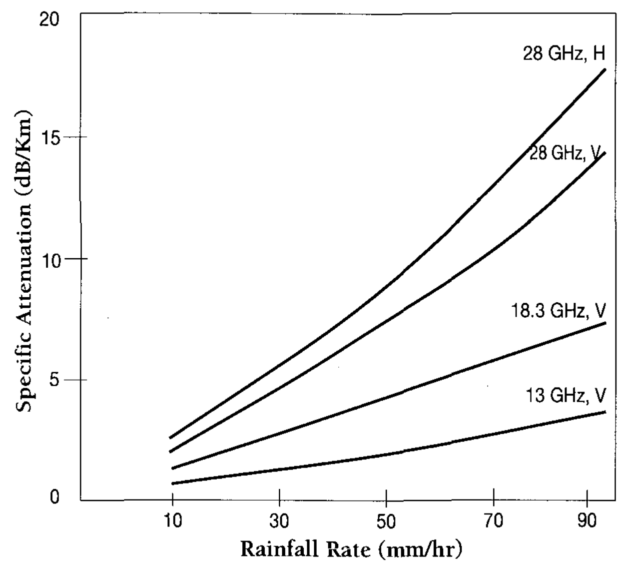

FIGURE 1
Specific Attenuation vs Rainfall

The path attenuation is obtained by multiplying the specific attenuation, equation (1), by an "effective" path length. This length differs from the actual path length because in actuality, the rain rate varies along the path. In particular, for very high rain rates, the storm diameter is usually less than the path length. In the CCIR model[2], the path length reduction factor is given by

$$r = L_{eff}/L = 1/(1 + L/L_o) \qquad (2)$$

where L_o is a parameter that depends only on $R_{0.01}$. Figure 2 shows the path length reduction plotted as a function of path length for three different rain rates.

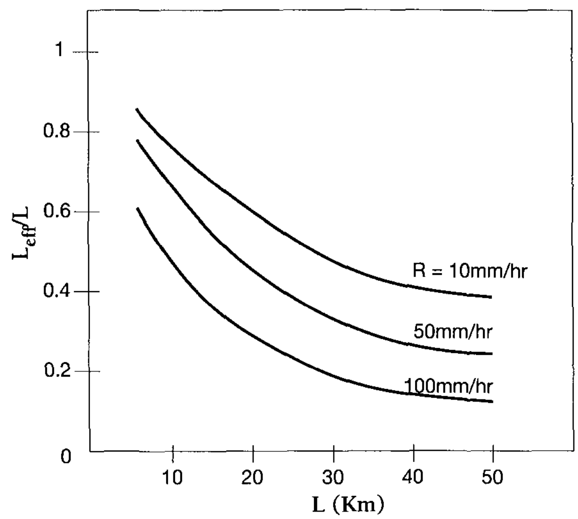

FIGURE 2

Path Length Reduction Factor vs Path Length

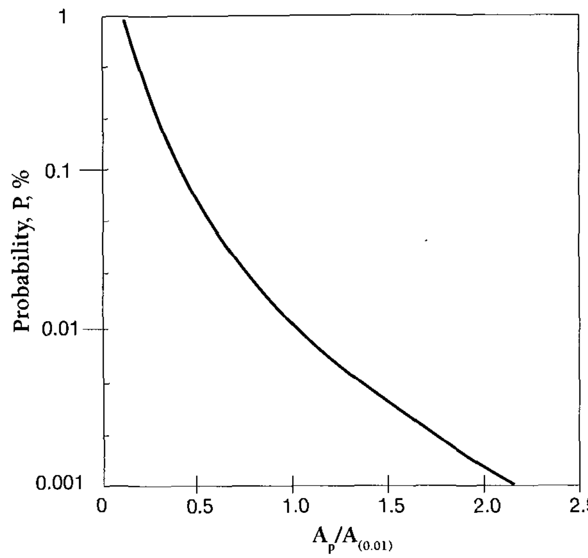

FIGURE 3

Fade Probability vs Normalized Rain Fade

The total path attenuation exceeded for 0.01% of the time is obtained by multiplying the specific attenuation in Figure 1 by the path length and the path length reduction factor from Figure 2. In general, the attenuation thus calculated is not equal to the available fade margin. To obtain the probability for a rain fade equal to or greater than the available fade margin, the equation

$$A_p/A_{0.01} = 0.12\ P^{(0.546 + 0.043 \log P)} \qquad (3)$$

is utilized. Figure 3 shows the relationship in graphical form. For instance, if the available fade margin, $A_p = 0.6\ A_{0.01}$ then the probability for such a fade is 0.04%. Note the steepness of the curve, i.e., a 10% change in attenuation in dB results in roughly 40% change in probability of occurrence. Equations (1), (2), and (3) constitute the present CCIR rain attenuation prediction method.

The notation $R_{0.01}$ denotes a rain rate which is equalled or exceeded 0.01% of the time during an average year. Since the attenuation is tied directly to the rain rate, it is important to distinguish between the total amount of rain which falls in an hour at a particular point, and the "instantaneous" rain rate expressed in mm/hr. For practical purposes, a 1 minute measurement interval is close enough to instantaneous to adequately describe the actual fluctuations of the path attenuation with time. Unfortunately, there are very few locations in the United States where 1 minute rain rate measurements have been made. In the absence of such long term statistical information, the CCIR offers either rain climate zones which are associated with a tabulated rain rate for various probabilities of exceedance, or 0.01% rain rate contour maps[3]. Figure 4 shows the CCIR contour map portion for the United States.

The above CCIR path attenuation calculation, into which the value of $R_{0.01}$ is entered, is considerably simpler than another model[4] which was cited in earlier CCIR reports and which was utilized until recently for predicting path attenuations. On a world-wide basis, the latest CCIR model appears to be most accurate[5]. However, comparison of the CCIR path attenuation prediction to measured path attenuation values is most accurate when the actual rain rates are used. Year to year rain rate variability as well as place to place variability within a relatively small local area can be expected to result in rms deviations of the probability in excess of a factor of 2. For this reason some caution is recommended in applying these formula. One way to build in conservatism into the calculation is to assume horizontal polarization even when the actual implementation will be with vertically polarized antennas.

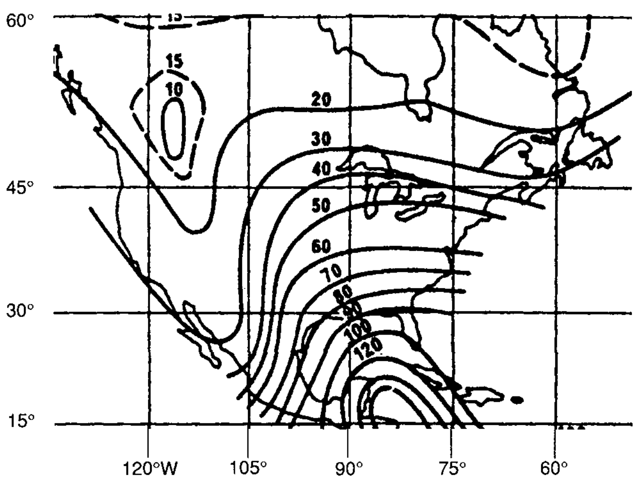

FIGURE 4
CCIR .01% Rainfall rate, mm/hr

MULTIPATH ATTENUATION

The general CCIR equation for the probability of multipath attenuation in the worst month is given by[2]

$$P = K_m Q f^B L^C 10^{-A/10} \qquad (4)$$

where A is the multipath attenuation in dB corresponding to the % probability, P, at which A will be equalled or exceeded. With B=1 and C=3, equation (4) takes on the form of the Barnett equation[6] which has been used heretofore for path reliability predictions. In equation (4), f is the frequency in GHz and L is the path length in kilometers. The CCIR suggests a form of the equation [2] which is

$$P = K_m L^{3.6} f^{0.89} (1 + \varepsilon)^{-1.4} 10^{-A/10} \qquad (5)$$

where ε is the absolute value of the inclination angle between transmit and receive antennas in milliradians. The value of K_m for overland paths in non-mountainous terrain is

$$K_m = 10^{-6.5} P_L^{1.5} \qquad (6)$$

where P_L is the percentage of time that the average refractivity gradient in the lowest 100m of the atmosphere is less than -100N units/km. Maps of P_L for four different months are given in Reference (3). For the USA, worst month values of P_L range from about 8 to 30% depending on location. To convert from worst month to yearly probability, one still has to multiply equation (5) by a climate and terrain related factor b which ranges from 1/2 to 1/8.

Aside from the variability of the parameters, the most striking attributes of equation (5) are the steep dependence on path length and the fact that a 10 dB change in fade depth corresponds to a factor of 10 change in probability (a 3 dB change in A would result in a factor of 2 change in P). True atmospheric multipath is therefore a concern only on relatively long paths. Equation (5) is valid only for fades in excess of 15 dB. The deeper the fade, the more frequency dependant it typically becomes. This can be understood by multi-ray models in which the rays interfere with each other through phase cancellation. Since even small atmospheric changes would affect the relative phase shifts, one can expect that deep fades will vary rapidly with both time and frequency.

By contrast, defocussing or beam bending phenomena can result in shallow fades which are relatively slowly varying and independent of frequency. These take place at the same time as the true multipath. The direct beam energy is thereby reduced and makes the signal more susceptible to phase cancellation by reflected beams either from atmospheric inversion layers or the ground.

When the reflected beam comes from the ground, K_m in equation (6), increases. A minimum factor of 3 increase is suggested. The same holds true for over-water paths. On the other hand, in mountainous terrain, a factor of 4 decrease applies to equation (6).

For broadband signals typical in multichannel AML applications, the best way to overcome multipath type phenomena is through careful path engineering which avoids ground reflections even under unusual K-factor conditions. Another technique, which has been proved useful in the past when fading was in fact encountered, is to tilt the antennas slightly upward. This sacrifices a few dB of fade margin, but matches better the propagation conditions during fade-prone atmospheric conditions. As a result, the path availability was greatly improved. In general, however, AML applications have encountered multipath in only a very small percentage of cases and the path predictions have been too conservative. It is expected that the use of equation (5) will more accurately incorporate local factors and thereby avoid costly over design.

REPRESENTATIVE SYSTEM EXAMPLES

Figure 5 is a schematic representation of a CATV system utilization of AML. In this simple example, there are 4 paths, each 30 km (18.6 miles) long. The single rack AML-SIBT-121 transmitter[7], the highest power broadband unit available, has been used in a number of CATV system upgrade applications of a similar nature. Generally, the paths are of unequal lengths and the splitting network associated with the broadband transmitter is optimized to take this factor into account, thereby providing additional power to the longest path. Thus, the example given in Figure 5 is in one sense a worst case 30 km application.

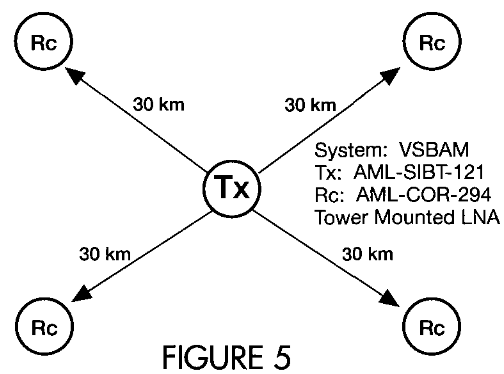

FIGURE 5

Typical 13 GHz CATV Application

It is assumed that the application involves carriage of 49 channels even though the same AML system could, of course, accommodate up to 79 6-MHz-wide channels as well as the FM broadcast band within the 12.7 - 13.2 GHz band. The assumed channel loading is selected to match that of the assumed LMDS 28 GHz system so that a more valid comparison can be made. In actuality, SIBT's are presently utilized to carry up to 77 channels in systems previously serviced by a lesser channel count AML-STX-141 high power array.

The 13 GHz application, as well as the 18 and 28 GHz applications, assume that the propagation factors are average, i.e. $R_{0.01}$ = 50 mm, P_L = 19%, ε = 2 mr, and b = 1/4 are the parameter values inserted in the rain and multipath attenuation equations.

Figure 6 shows the result of the calculation. The fade margin to 35 dB C/N is 22.5 dB when a 65 dB C/CTB requirement is imposed on the overall microwave system. As seen, multipath and rain probabilities are nearly equal at 0.016% each. At larger path attenuation, rain dominates. The two probabilities are additive since multipath type phenomena are precluded during rainfall when the atmosphere is well mixed.

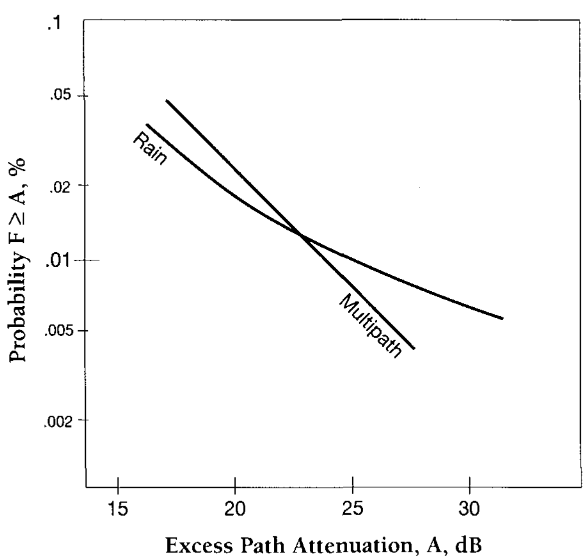

FIGURE 6
Average Rain and Multipath on 30 km path at 13 GHz

Figure 7 illustrates a typical SMATV application. A cluster of nearby sites is serviced directly by the high power outdoor transmitter. One path, however, is 10 km long, and a repeater is used to feed the signals to a second cluster of receive sites. This is the performance limiting path. The regulatory limitation sets the number of available 6 MHz-wide channels to 72, but 49 channel loading is again assumed to match the LMDS system. The SMATV system need not drive a large cable plant. As a result, the specification for the microwave system is relaxed and a 58 dB C/CTB is acceptable. The clear weather C/N, fade margin to 35 dB C/N, and path availability are also less than for the previous CATV application. Because the path is much shorter, multipath plays a near negligible role but the probability of rain fade is significantly higher.

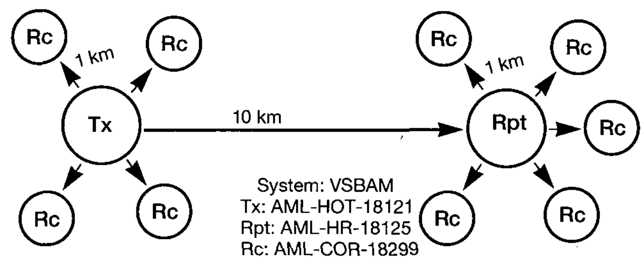

FIGURE 7
Typical 18 GHz SMATV Application

Figure 8 shows the 28 GHz LMDS application. In this case, the transmit antenna broadcasts the signal in all azimuth directions and only the receiver utilizes a directional antenna. Table I summarizes the antenna and microwave path parameters for the three systems. Note that the antenna beamwidth angle at 28 GHz is significantly larger (37 mr vs 8 mr) than for the 13 and 18 GHz point to point links. This makes the receiver more vulnerable to interference from nearby transmitters utilizing the same frequency band. Of course, the fact that the system is FM helps ameliorate the potential interference problem.

In all three cases, the possibility of ground and nearby building reflections must be taken into account as indicated by the beam diameter for the path length L. Actually, for the 13 GHz and 18 GHz point-to-point links the largest diameter of interest is at distance L/2 since the receive beam and transmit beams must overlap, but the diameters, although then somewhat smaller than the 28 GHz case, would still dictate care in path design.

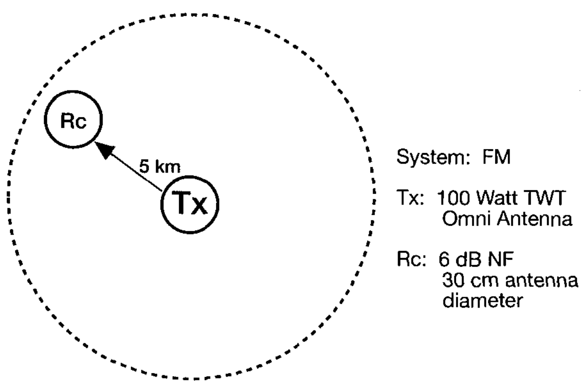

FIGURE 8
Typical 28 GHz LMDS Application

The comparison of far field distances shows that with only 30 cm aperture at 28 GHz, the distance at which the beam begins to spread with angle $\Theta = \lambda/D$ is quite small. As a consequence, any passive reflectors utilized to establish line of sight between the transmit antenna and the receive antenna must be significantly larger to avoid further propagation loss. At the same time, a small passive reflector beam width in the near field is normally too small to service more than a single receiver.

The Fresnel zone clearance criteria are not particularly onerous in any of the three examples.

TABLE I
Antenna/Path Characteristics

Frequency (GHz)	13	18.3	28
Wavelength, λ(cm)	2.3	1.6	1.1
Ant. Diameter, D(m)	3	1.8	0.3*
Path Length, L(km)	30	10	5
Beam Width, $\Theta=\lambda/D$(mr)	7.6	8.9	37
Beam Diameter, ΘL(m)	228	89	185*
Far Field, D^2/λ(m)	391	202	8.2*
$0.6F_1$, at midpoint (m)	7.9	3.9	2.2

*Receiver only

Table II summarizes the system performance for the three cases under consideration. Obviously, the CATV application has much greater range, but it also results in a higher quality signal and better system availability. The quality comparison is made in terms of baseband S/N to be able to compare to the 28 GHz FM system performance and includes all sources of noise including intermodulation noise (CTB) and phase noise. As previously indicated, atmospheric multipath plays a significant role only for the 30 km CATV example. At 18 GHz, and especially at 28 GHz, it is entirely insignificant. Rain, however, is a serious problem at the highest frequency. Note also that the availability limit for FM represents loss of signal, while for the VSBAM 13 and 18 GHz systems, the pictures are noisy, but still watchable even below 35 dB C/N.

TABLE II
System Parameters

Frequency (GHz)	13	18.3	28
Range (km)	30	10	5
C/CTB	65	58	56(1)
S/N	55	51	51(2)
Fade Margin (dB)(3)	22.5	14.5	17.5
Availability, %(3)	99.97	99.91	99.92

(1) Equivalent value with FM improvement
(2) Limited by CTB
(3) To 35 dB CN for VSBAM. To FM threshold for 28 GHz system.

SUMMARY

All three multichannel microwave video distribution systems can deliver good quality pictures, but the best path reliability and signal quality are possible with the 13 GHz system despite its use at greater distance. This result not only reflects the availability at this frequency of high power solid state broadband transmitters utilizing advanced dual feed forward linearization technology, but also illustrates the serious increase in rain attenuation, particularly at 28 GHz. Multipath plays a role only for longer path distances, but uncontrolled reflections from the ground or nearby buildings can cause interference in any of the systems. This, and the question of nearby frequency reuse in broadcast systems, needs further assessment for 28 GHz systems. Small size passive repeater utilization is only possible at very short distances and must then be limited to single receivers unless additional propagation loss can be accommodated.

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COMPARISON OF PROPOSED ATV SYSTEMS

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Abstract

The Federal Communications Commission appointed an Advisory Committee on Advanced Television Service in 1987 to determine if an ATV system should be recommended for adoption as the United States standard. The Committee has developed requirements and laboratory tested the proposed systems to select the best system for the United States.

In February 1993, after reviewing the results of the tests and analysis, plus proposals for improvements, the Committee determined that none of the systems could be selected. It further determined that the four proposed digital transmission systems should have their proposed improvements incorporated and then be retested. The results of the lab tests and their impact on the cable industry are outlined in this paper.

BACKGROUND

In 1987 the Federal Communications Commission (FCC) impaneled the Advisory Committee on Advanced Television Service (ACATS) to develop information that would assist the FCC in establishing an advanced television (ATV) standard for the United States. The committee, through its various sub-committees and working parties, has developed a list of desired attributes for the ATV service, produced the procedures to determine the ability of proposed systems to meet the desired attributes, reviewed proposed systems to determine if they should be tested and tested those systems which appeared to be capable of providing ATV quality pictures and capable of meeting the required transmission characteristics.

Of more than 20 systems or subsystems originally proposed, only six made it to the development point where they could be tested. One of the systems, an enhanced NTSC system, was withdrawn from consideration by its developer shortly after its laboratory tests were completed. The five remaining systems were tested and analyzed to determine if any were acceptable for recommendation as a standard. Four of the systems used a digital transmission format and the fifth system used an analog transmission format.

The five systems that were tested and analyzed, in the order in which they were tested, are:[1]

1) The Narrow-MUSE system, proposed by NHK which developed the original 1125-line high definition studio production system. This system utilized a 6 MHz analog transmission technique. The video format was 1125 lines, 2:1 interlaced, with a 60 Hz field rate.
2) The American Television Alliance (General Instrument and Massachusetts Institute of Technology) DigiCipher system used a 32 QAM carrier to transport a 1050-line, 2:1 interlaced, 59.94 Hz field rate signal.
3) The Zenith/AT&T Digital Spectrum Compatible-HDTV (DSC-HDTV) system used a digital 2/4 VSB modulation technique to transport a 787/788 line, 1:1 progressively scanned 59.94 frame rate signal.
4) The Advanced Television Research Consortium (David Sarnoff Research Center, Thomson Consumer Electronics, North American Philips, NBC, and Compression Labs) - Advanced Digital - HDTV (AD-HDTV) system used two separate 32 QAM

channels (within 6 MHz) to transport a 1050-line, 2:1 interlaced 59.94 Hz frame rate signal.

5) The second American Television Alliance system Channel Compatible DigiCipher (CCDC), used a 32 QAM carrier to transport a 787/788 line, 1:1 progressively scanned 59.94 Hz frame rate signal.

The aspect ratio of all systems was 16:9.

The laboratory tests began on July 12, 1991, with the Advanced Television Research Consortium's Advanced Compatible TV system and continued at about two-month intervals by the other systems. The Advanced Compatible TV system was withdrawn from consideration after its tests were completed and it will not be considered here. The test results of major interest to the cable television industry are the impairment levels at which a specified impairment just becomes visible in the picture (the threshold of visibility). These carrier-to-impairment levels will be cited in this paper. After the threshold of visibility, the signal quality degradation of the digital transmission systems is very rapid, while the analog transmission system has a more gradual degradation after the threshold.

The five ATV system results were compared by the Advisory Committee to determine if one system could be recommended for adoption as a standard.

TEST RESULTS

Carrier-to-Noise Ratio

The carrier-to-noise ratio is one of the major design limitations for a cable television system. As the number of amplifiers in cascade increases, the carrier-to-noise degrades. Television viewers are becoming increasingly critical in their acceptance of pictures with noise present. The 1958 TASO tests determined that a 30 dB signal-to-noise was considered "somewhat objectionable;" a similar test in 1983 determined that a 40 dB S/N produced the same rating while a 1992 CableLabs' study[2] determined that current viewers consider a 45 dB S/N to be "slightly annoying." Many cable operators are designing systems to deliver an end-of-system S/N ratio in the mid 40s to meet the demands of their customers. The ATV signal delivered to the subscriber's home must be at least as noise tolerant as NTSC signals to avoid having to rebuild the cable system.

The noise bandwidth of the various ATV systems are greater than the 4 MHz bandwidth used for NTSC systems. In order to compare the various systems most easily, the noise bandwidth has been normalized to 1 Hz. The 45 dB C/N for NTSC in 4 MHz becomes a C/N_0 of 111 dB in 1 Hz.

The most noise-tolerant ATV system was the Channel Compatible DigiCipher system with a C/N_0 of 83 dB at the threshold of visibility. The DigiCipher and DSC-HDTV systems were next at 84 dB followed by the AD-HDTV systems at 86 dB. The N-MUSE system was determined to be "slightly annoying" with a C/N_0 of 100 dB. (The ATV digital transmission systems normally show no indication of impairments until a certain level of impairment is reached. As the impairment is increased beyond that threshold point, the picture quickly becomes unusable for normal viewing. The analog transmission systems exhibit a more gradual degradation in quality as the impairment level is increased. The values above give the threshold point for the digital systems and the "slightly annoying" value for the analog N-MUSE system.)

Composite Triple Beat

A second major design consideration for cable television systems is the composite triple beat (CTB) ratio. This impairment limits the number of amplifiers in cascade and is used in determining the output levels of the amplifiers. The NCTA Recommended Practices, Second Edition, suggests a performance objective of 53 dB for NTSC signals. Some of the ATV systems have been designed to operate in the presence of NTSC signals by incorporating notches in the receiver, splitting the channel around the NTSC visual carrier, etc., and are expected to have good CTB performance because the CTB products generally fall on or near the NTSC visual carrier.

The best performance in the presence of CTB was the DSC-HDTV system with a threshold at a C/I of 11 dB. The next best performance was obtained with the AD-HDTV system at a C/I of 16 dB, followed by N-MUSE with a C/I of 27 dB, DigiCipher with a C/I of 31 dB, and CCDC with a C/I of 33 dB.

All of the tested ATV systems performed significantly better than NTSC in the presence of CTB. When the CTB improvement and the C/N improvements are considered, it is expected to be possible to operate these signals at lower levels than the NTSC signals and still provide high quality pictures to the subscribers.

Composite Second Order

Composite second order (CSO) distortion products have had a reduced impact on system design consideration since the introduction of push-pull amplifiers. This impact has increased with the introduction of AM fiber optic links which typically have a degraded second order performance. The beat product typically falls about 1.25 MHz above the NTSC visual carrier and the ATV signals do not normally protect that area from unwanted energy. Most rejection of the beat product would be due to the action of the equalizer in the receiver.

The best performance was exhibited by the CCDC system with a threshold C/I of 12 dB followed by the DigiCipher system with a C/I of 16 dB. The DSC-HDTV system was next with a threshold C/I of 20 dB, the AD-HDTV systems with a C/I of 21 dB and the N-MUSE system with a threshold C/I of 38 dB.

As with the CTB results, the ATV systems were significantly more tolerant of the CSO distortion than NTSC and this impairment should not pose a significant problem when introduced into the cable system.

Hum Modulation

The power supplies in cable amplifiers do not normally contribute significant hum modulation to the amplified signal. However, in instances when the voltage feeding the power supply drops sufficiently low, the unit may go out of regulation and begin to create significant hum modulation. NTSC television sets are fairly immune to the effect of hum modulation and will not display the effect until the modulation reaches about 3%.

The four digital transmission systems were very tolerant of hum modulation and did not display any effect until the modulation was above 10%. The N-MUSE signal reached threshold at only 1% hum modulation.

The digital ATV transmission systems will not have any problems operating on cable systems designed to provide hum-free NTSC signals. The N-MUSE system is more susceptible to hum interference than NTSC and may have a problem on marginal cable television systems if the level of hum modulation is just below the NTSC threshold of visibility.

High Level Sweep

Most cable television operations utilize some form of high level sweep to maintain the frequency response of their systems. The original sweep systems made use of a signal about 10 dB above the visual carrier which was quickly swept across the band of interest and the detected result displayed on an oscilloscope. The visual effect in the picture was a small number of lines on the screen turning white. If the sweep signal were only turned on for brief periods, the subscribers might not notice and few would complain.

The N-MUSE system reacted in a similar manner to NTSC with a few lines being blanked. The four digital systems were more severely impacted as they lost sync and froze the picture or displayed errors in the video.

Cable operators would have a significant problem if the high level sweep signal were used on systems with a digital ATV transmission system. The N-MUSE would have problems comparable to the NTSC signals.

Phase Noise

Phase noise is generated in synthesized oscillators and imparted to signals during the heterodyne process. NTSC receivers are fairly immune to the effects of phase noise and no specifications have been set for phase noise contribution by processing equipment. Digital transmissions are generally more susceptible to phase noise interference. It may be necessary to set minimum specifications for frequency conversion equipment to ensure the total phase noise in the cable systems and customer's equipment does not exceed the capability of the receiver to handle the distortion.

The CCDC, DigiCipher and DSC-HDTV systems all exhibited the effect of phase noise at a C/PN_O of 82 dB while the AD-HDTV system threshold was 84 dB. The N-MUSE system was extremely sensitive to phase noise and exhibited a threshold of visibility at 106 dB.

The cable industry needs to review design criteria for heterodyne equipment used in the systems to ensure the signal delivered to the subscriber can be used by the ATV receiver to produce quality pictures. It may be necessary to replace poorer performing equipment.

Residual FM

Small amounts of power-supply ripple in synthesized oscillators can result in significant amounts of frequency modulation of the carrier. The NTSC receivers can tolerate a large amount of residual FM before exhibiting any degradation in the picture. The cable industry has not been very concerned about residual FM. However, it is expected that digital transmission systems may have problems with residual FM.

The CCDC and the DigiCipher systems had a threshold of visibility at just under 6 kHz of residual FM. The DSC-HDTV system threshold was at 1.2 kHz, the AD-HDTV system threshold was 0.6 kHz and the N-MUSE system threshold was only 0.1 kHz.

The systems showed significant sensitivity to residual FM and will either have to have significant improvements in their performance or the synthesized oscillators used by the cable industry will have to have very little residual FM.

Channel Change Speed

Cable television subscribers are used to very quickly skimming through the channels to determine which show or shows they wish to watch. When channels are scrambled, the subscriber gets upset if the channel does not unscramble almost immediately upon being tuned. ATV systems must exhibit a similar speed in tuning and producing a picture, if subscribers are to be kept happy.

The CCDC, DigiCipher and DSC-HDTV systems all produced an identifiable picture in under a second, but the time increased when the signal was subjected to significant impairments. The AD-HDTV system required between 2 and 6 seconds to produce an identifiable picture while the N-MUSE system took over 8 seconds to produce an identifiable picture.

The fastest systems, at under 1 second, may be fast enough while the other systems would most likely meet with resistance from the public.

Basic Picture Quality

The picture quality of the proponent systems was compared against an 1125-line studio quality reference picture. Non-expert viewers rated the pictures to determine if there was any significant degradation in picture quality when passed through the compression-decompression process. The test material consisted of a number of still scenes and a computer generated graphic still, video camera motion scenes, transfers from film using a video camera and a computer generated motion scene.

The AD-HDTV and DigiCipher systems performed better than the other systems when processing the video camera-generated motion sequences.[3] When the material transferred from film was observed, the DigiCipher and AD-HDTV performed best, followed by N-MUSE, then CCDC and DSC-HDTV. CCDC and DSC-HDTV performed best with the graphic motion sequence, AD-HDTV and DigiCipher were next best, and N-Muse performed the poorest. The systems performed equally well with the material transferred from stills and with the graphic still. Experts viewing the various scenes commented that, while the systems performed very well, they did not feel that the quality was adequate for acceptance by the general public. It was felt that some characteristics of the compression process, while not noticed during the initial viewing, would become annoying after longer periods of observation.

CONCLUSIONS

The proposed ATV systems are able to operate in the presence of higher levels of impairments of typical concern to the cable industry, i.e., random noise, second and third order distortion and hum modulation. The systems are less tolerant of phase noise, residual FM and high level summation sweep. All of the systems exhibited some artifacts in the basic video quality which are expected to be of concern to the average viewer.

The Advisory Committee, after reviewing the results of the lab tests and entertaining proposals for improvements to the proposed systems, decided that the N-Muse transmission system could not be expected to improve to the capability of the digital transmission systems and it was removed from consideration. The four digital systems are to have the improvements which were proposed and accepted by the Committee implemented so they can be retested. The retests are expected to start in May 1993 and take about six weeks per system after which one system will be recommended for field tests.

The selection process, while requiring a significantly longer time than was originally expected, is working toward the adoption of a very high quality ATV service. It is imperative that the cable industry participate fully in the process along with CableLabs to ensure that the system selected works well on cable as well as over the air.

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CONDITIONAL ACCESS AND ENCRYPTION OPTIONS FOR DIGITAL COMPRESSION SYSTEMS

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Abstract

The development of digital transport of television signals marks a change from traditional approaches for "secure" distribution using analog scrambling technology. The all-digital nature of these signals makes hard encryption of all program services and network information possible, and thus our expectations for good security performance over long periods of time in future digital compression systems is high.

At the same time there is much effort today to standardize elements and subsystems of this new technology, such that maximum benefits accrue from interoperability with related developing technologies and markets. This paper discusses the issues surrounding encryption in digital compression systems, and explores the possibilities for encryption standardization in certain areas of the transport level. Included are comments on replaceable "Smart Card" and "Processor Card" approaches and benefits.

INTRODUCTION

The consumer and commercial business and entertainment television industries have now some twenty years of experience in the design, fielding and operation of privacy/conditional access systems. Many methodologies have been developed for terrestrial, satellite and cable distribution for both broadcast and point-to-point applications.

For entertainment distribution, true encryption techniques were introduced in the early 1980's. Since that time there has been a steady increase in the adoption of encryption techniques, leading (eventually) to a better awareness in, and utility of proper application of cryptographic technology.

Except for very high cost systems that could afford total digitization of the audio and video material, virtually all existing systems have employed techniques that use the "randomizing" capabilities of encryption to deterministically "scramble" analog program components, and reorder or otherwise reassemble these components at the receiving end. Examples of this are line shuffling, cut-and-rotation, and random inversion of video.

The fundamentally analog nature of the above randomizing approaches has problems. For example, in most implementations (but not all) enough recognizable information remains in the received programming to sometimes not satisfy desired requirements of a good conditional access security system—namely that the scrambled information contain no useful remnants of its original form, and that reconstruction of the signal not be possible by examination of the scrambled waveform alone. (For a good treatise on desirable attributes of security systems, see reference [1].)

In addition, the ways in which the need for security systems developed and solutions evolved have resulted in a plethora of different systems which are not only incompatible with each other, but also with other types of equipment used at the source, transit, storage or display chain. (Most obviously evidenced by the consumer environment situation, and the resultant quagmire of "opportunities" to be solved there.)

Today we find ourselves at the crossroads of a technological digital revolution; one where participation in going forward forces decisions to be made that involve significant departures from previous generation technology. This change begs the examination of opportunities to attain improvements over the current situation in several areas, such as consumer friendliness, compatibility and interoperability, improved security,...all topics where some degree of standardization has important potential. One of the more controversial areas is standardization of conditional access. The all-digital nature of compression systems provides at least the technical opportunity for future-friendly advances in this area.

STANDARDIZATION

The experiences of our industry with encryption products over the past decade has left a trail of both positive and negative reactions throughout the operator/user base. In addition the esoteric nature of cryptographic technology, in combination with the veil of secrecy that surrounds most products tends to shroud reality from view. The result is that decisions regarding the whole subject become driven in part by sound technical judgments and part by emotion.

The very mention of "standardized conditional access" in the wrong circles will frequently be met by cries of eventual disaster. Yet many who have studied the issue from a neutral position have concluded that when theory and experience are applied properly, there are indeed procedures and structures that can be implemented to provide some basis of commonality in future generation systems. Note the many non-military implementation standards used by the U.S. government and the longevity of the DES algorithm, for example.

The motivation for the consideration of standardization develops primarily from compatibility and interoperability issues. More and more relationship and interdependency exists today between heretofore unrelated markets. This trend will dramatically expand. The merging of the television and computer industries into a "multimedia environment" is in the sights of many wishing to put to use the broadband highways that lie in our future. The growth accomplished by these new markets will be throttled by interoperability issues.

Surrounding digital compression developments are significant efforts to define standards. Driven primarily through the International Standards Organization (ISO), the global unification of digital television program generation, editing, storage, retrieval, transport and display is leading to a set of agreed upon methodologies for audio and video compression, and transport of complex multiplexes of associated data and ancillary digital services. These standards, known as "MPEG-2," cover the primary areas of audio compression, video compression and transport. They will serve as the guides to international utility of future systems for most industrial and consumer applications.

In the transport area, the work has led to the development of a working draft which defines:

- Program Stream—A grouping of audio, video and data elemental components having a common time relationship, and being generally "associated" for delivery, storage, playback, etc.

- Transport Stream—A collection of program streams or elementary streams (video, audio, data) which have been multiplexed in a non-specific relationship for purposes of transmission.

While discussions are continuing at the time of this writing, these "system layer" efforts are aimed at providing a basic data structure, the "semantics and syntax" of a data stream, that can serve as a common format for local and broadcast transmission.

Entities working within the ISO MPEG-2 System Layer Group have agreed to a number of basic structural elements that are expected to become part of the system layer syntax. Fundamental to this structure is that the transport stream will be "packetized"; that is, consist of packets of data (sizes of the packets are in the 130 byte to 192 byte range) containing digital information from a single elementary stream or data type. The packets will each be preceded by a "header" of up to 4 bytes of packet-specific information such as packet ID, clear/scrambled indicator, even/odd key, continuity counter and other information. The "generalized" digital nature of these packets makes for very flexible opportunities in the area of encryption and conditional access, and the packets can be easily and singularly protected (scrambled) throughout their distribution and routing "life."

In order for the digital television market to fully and freely develop, it is very important not only that specific audio and video compression techniques be codified, but this transport area as well. The requirements vary greatly between various applications for digital storage media (DSM) and direct broadcast satellite (DBS), for example. Yet it is essential that easy movement between such mediums be available. Many factors come into play, such as timing, program stream reconstruction, synchronization, de/remultiplexing, (re)packetizing, and of course the need for encryption in certain applications.

It has been an objective of the ISO systems working group to limit the extent of "specification" to a minimum...to define only as much as is generally agreed to provide meaningful interoperability. The remainder of this paper discusses the implications of encryption on interoperability, and the issues regarding separation of systems and long term security.

CONDITIONAL ACCESS RECOMMENDATIONS

Both the European (through the CCIR) and the North American (primarily through the ATSC) communities have considered the issues surrounding conditional access standardization, and both have extensive expertise and experience in the subject matter. The conclusions and recommendations of both groups are very similar [1],[2]; that:

> *conditional access systems can be designed according to fundamental theoretic principles and implementation procedures such that different systems can share certain common security elements without compromising security.*

It is helpful to observe the CCIR's definition of "conditional access," and note the two key elements which comprise it [3]:

- **Conditional Access System**—Within a television distribution system, the means to selectively provide television programs to specific individual subscribers. The system includes means to track access for accounting purposes.
- **Scrambling***—Alteration of the characteristics of a broadband video/sound/data service (i.e. television program or service) in order to prevent unauthorized reception of the information in a clear form. The alteration is a specific process under the control of the conditional access system (sending end).
- **Access Control**—The function of the conditional access control at the sending end is to generate the scrambling control signals, and the provision of information to enable authorized users to descramble the program or service. The availability of this information is controlled by the conditional access system, between the transmitter and receiver(s); thus information is structured in secure messages multiplexed with the signal itself.

So *conditional access* is the total envelope of mechanisms which are responsible for delivering information to selected receivers only.

In the context of system implementations and the above definitions, one notes that there is a natural segmentation between the requirements of a system's transport layer hardware-level *scrambling* elements and the addressing/authorization *access control* elements of almost any proto-typical system. In fact, the above distinct processes have become systemic to modern broadband system security approaches:

> The information (programming) to be transmitted is secured by scrambling (encrypting) the data during transit,
>
> The access control delivers to the decoder commands and procedures associated with who,

* The European Community has maintained the term "scrambling" as associated with the operations performed on the digital content of elemental streams and/or other raw services data. This is a holdover from the analog world where signal components were scrambled in the traditional sense. The U.S. community is adopting this terminology, which is convenient in separating the security mechanisms/algorithms used in the access control channel from those of the transport level data packet.

where, and when a decoder is allowed to unscramble the information and deliver the program.

In practice systems get very complex, and many factors must be considered. Assuming the scrambling process is done correctly from a cryptographic standpoint, it can be made very straightforward; essentially mechanical or generic. Access control is an area, however, where one finds much of the distinction between systems: how fast, how often, how user-friendly, how operator friendly,....It is in this domain that we find many of the processes that define a system's "personality" as well as those that control program access: PPV/IPPV procedures, cryptographic key distribution, all addressability processes, latency/synchronization factors, etc. Subscriber management systems, headend control systems, and system data channel(s) are dedicated to these functions, and *they are all unique to different system implementations.*

But what *can* be thought of as common are system services, especially if one considers that an MPEG-2 compressed version of a movie *can* be universally coded (the program stream), no matter what system is carrying it, or digital storage device is saving it. The scrambling of the signal is what has been recommended by the ATSC and CCIR as a factor that can be standardized on. The access control remains unique to each respective system, responsible for providing enabling parametric information (keys, etc.) to common descramblers.

SCRAMBLERS

The most straightforward method to secure a digital signal when presented in a bit serial fashion is simple modulo 2 EXOR of the data with a stream of random data. Of course the random stream cannot be literally random or the information will be thoroughly and permanently encrypted forever. For this reason, "pseudo random binary streams" (PRBS) are utilized...they look random to anyone not having certain "key" information.**

The basic premise that a *pseudo* random stream employed to scramble data can be essentially as secure as a truly random stream is a fundamental notion of modern cryptographic doctrine. When cryptographic systems are compromised it is not that this doctrine is at fault, it is that the design or the use of the PRBS generator is flawed, or (more often) that the other conditional access element, "access control," has broken down.

The basic argument that it is possible to standardize on the scrambler without compromising security is that all systems employ PRBS generators, or they can be modeled that way, and that no "good" PRBS generator is any better

** This approach is commonly used with a "private key" or symmetrical encryption approach which works well for high speed encryption and decryption. There are other techniques for encrypting information. The access control channels of most systems typically use other/additional techniques (e.g. public key cryptosystem attributes) to ensure that factors such as message authentication, message replay, and other kinds of spoofing, etc. are appropriately handled. These techniques are system-unique.

than any other "good" PRBS generator. That is to say if a given PRBS generator qualifies as good it must have certain qualities, and these qualities certify that it can be employed to generate pseudo random data that will be as random as any other generator of that quality.

Modern theory and experience, along with capabilities of today's digital electronics, allow the design of PRBS generators (and techniques for employing them to insure their inherent randomness is exploited) that meet nicely the requirements of today's systems. By accepting the qualification of "good" above, one has no argument that the scrambler/descrambler hardware cannot be standardized. This is a difficult notion to accept both intuitively and emotionally, and it may be a lost cause to expect it to be accepted. (Indeed, should the qualification process for defining "good" be flawed, the result could be disastrous, and that argument cannot be ignored.)

Ideally, to make everyone comfortable it would be nice to be able to change the scrambler if needed. The concept of changeable security leads to the next section.

ACCESS CONTROL AND REPLACEABLE SECURITY

Most newer system designs today employ (or will employ) some type of replaceable security hardware. This approach provides for the placement in a replaceable card or module some or all of the circuits associated with access control. Several systems in Europe have relied upon "smart card" technology for this capability.

Smart cards occur in four types [4]:

1. Small Memory Cards—Pay phone, gas station credit use,
2. CPU/Memory Cards—Banking, health care, pay TV, gaming use,
3. Large Memory/PCMCIA Cards—Sub-notebook, handheld computers,
4. "Super" Cards—Type 2 or 3 with on-card keyboard, displays.

The last type is not always technically a "smart card" in the sense that it might not follow the ISO 7816 or PCMCIA standards for physical size and I/O. It is included in this discussion for completeness, and to indicate where the state-of-the-art is progressing. In addition, there are other types of replaceable modules that have been developed and used for the computer, entertainment and security industries that provide functionality similar to smart cards.

But in the general sense of "changeable security" (which will become ubiquitous), with recognition that the access control portions of conditional access systems will most certainly remain unique among vendors, what all such approaches provide is an alternative to building into the decoder hardware permanent, and therefore potentially tamperable, security-related parameter storage and/or functional processing elements. The security card allows replacement of the access control functions of a system, or at least the cryptographically sensitive aspects of the access control, such that should it ever be necessary to update or change the system in this area, it is possible to do so.

The major trade-off surrounding system design employing replaceable security cards is the decision about how much goes into the card? It turns out to be a question of economics. Security cards can cost from $2 to $30. The cost penalty for changing out a large system's population of security cards may well turn out to be less than the cost of tolerating piracy! But the degree of freedom allowed nevertheless has given the replaceable card a large popularity at this time, and the hard costs associated with more card functionality for fewer dollars continues to drop.

A natural breakdown between the access control and scrambler functions that constitute conditional access is to place the core "descrambler" circuits in the decoder hardware VLSI, and the system-specific (critical) access control functions in the replaceable card. One has to study carefully then the activity that takes place at the card interface to ensure that information available there, assuming total knowledge of what's in the decoder hardware, will not allow compromise of the system.

It would be better yet to place both descrambler and access control functions in the security card, but this can get cost prohibitive. The structure of the digital compression multiplex and packetization of elementary streams described above which may be concatenated and encrypted (scrambled) with different keys gives rise to a need for very sophisticated and high-speed logic in order to maintain operation at data rates to 50 or 60 Mbps! This kind of performance is not feasible in inexpensive replaceable cards, in combination with the demands that this would place on the card I/O and associated receptacle.

SUMMARY

The developing transport level definition of the MPEG-2 System Layer will result in a structure easily availing itself to a marriage of vendor-unique access control, and industry-wide common scrambling. Many implementation variations are possible, allowing the specific needs of each system designer/user to decide what form solutions are to take. Relative "levels" of security and risk assessments thereof can thus be weighed and appropriate requirements accommodated.

There are many advantages in having interoperable scrambling in the broadcast and storage arenas; this paper has not attempted to make those arguments. (References [1] and [2] are recommended reading for these discussions.) In the end, however, there will continue to be controversy, and commercial factors will dictate what the industry decides to do. But it is felt that there *are* compelling technical methods for how interoperability can be accomplished, and that these need to be (unemotionally) discussed.

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CONDITIONAL ACCESS FOR COMPRESSION SYSTEMS: DESIRABLE ATTRIBUTES AND SELECTION CRITERIA

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Abstract

During the next few years, cable systems will apply digitally compressed video technology to provide a vastly expanded selection of programs and services to subscribers. The cable industry has a unique opportunity to apply fresh thinking to requirements for conditional access and security in the digital era, having lived for almost a decade and a half with addressability applied to analog signals.

This paper discusses the process and criteria by which alternative conditional access methods and architectures can be evaluated, and suggests desirable key attributes and features. The industry should not place on its systems/hardware suppliers the entire burden of assuring security, functionality and compatibility. A fresh approach to permit system operators and programmers to thoroughly evaluate security, in particular, should be an essential part of the process.

INTRODUCTION

As the cable industry moves to 500-plus channels of digitally compressed programming, the requirements for conditional access will evolve far beyond the tiered addressability presently in use. A new generation will be required of subscriber equipment, and new thinking about control methodology, compatibility, and security to protect services of ever increasing value. The introduction of the new technology also provides the opportunity to address conditional-access issues in a co-ordinated way, and to seek industry consensus on some of the major factors.

Just because digital compression employs exciting new technology is no reason to be complacent about making sure that its implementation is directed properly. The involvement of the industry's major suppliers doesn't preclude firm direction from the operators and programmers whose businesses will be dependent upon successful operation of the technology. Experience with satellite scrambling and cable addressability should teach us that there is much to be gained by planning ahead.

- Widespread theft of satellite delivered programming has taught that encryption of digital (audio) signals is not automatic proof against piracy - secure handling of the authorization process is key.
- The functionality of cable addressable systems has always seemed to involve a struggle to catch up with market needs - there never seems to be quite enough tags/tiers to deal with the latest PPV offering.
- Addressable converter-descramblers brought in new ways to market cable services and to create additional value - but along came a new set of compatibility issues.

Digital compression brings with it the possibility and promise of a major improvement in security. In principle, encryption of a digital data stream can be much more secure than scrambling of an analog video signal - but only if the authorization system is designed properly. **Encrypted digital compression does not automatically equate to highly secure.** Similarly the introduction of an all new compressed delivery system will not automatically equate to the functionality appropriate to deliver new services and with compatible operation with TV receivers and VCR's.

An initiative must be taken by the cable's operators and programmers to set out clear requirements for security, functionality and compatibility. It may be useful to refer to the Advanced Television Systems Committee (ATSC) conducted study of desirable attributes and features of conditional access for high definition television (ref 1). ATSC created a list of attributes and features for the guidance of ATV proponents, and to be used as a checklist in evaluating conditional access aspects of proposed systems. Similarly, the development of conditional access requirements for digital compression systems, soon to be introduced, is essential to assure early introduction of secure products with hoped-for features and compatibility of operation. The development of digitally compressed home terminal will represent very substantial investments in engineering and customized components on the part of the industry's vendors. Resolution of these issues should occur **now**, before the first new products are deployed.

OPPORTUNITY AND INDUSTRY PROCESS

Industry focus on digital compression is driven by a sense of urgency related to competitive threats. Much of the activity has centered on development of compression algorithms and digital transportation layer protocols. At a time when these issues are being resolved, the industry has an opportunity for a thorough examination of security, functionality and compatibility issues associated with conditional access.

For many years, proprietary (and largely incompatible) scrambling designs have dominated the marketing of addressable set top cable converter equipment - somewhat to the cost and disadvantage of operators. When digital compression systems are introduced, there is no reason to allow this to recur. It should be possible to develop a commonality of approach which will allow for multiple vendors, and yet assure operators of system level control over security.

At some point in time it may be possible and appropriate to build some portion of the digital channel selection, decompression and control functions into TV receivers and VCR's. Such an evolution will require development of standardized interface specifications, leaving replaceable, critical control elements still at the discretion of operators and programmers.

Possibly sooner than many of us have thought, the compression system will also serve as a platform for the delivery of computer services requiring high bandwidths; indeed the national cable infrastructure is probably the ideal vehicle for driving computer networking at the consumer level.

What is proposed is a co-ordinated industry effort to establish requirements for conditional access in the areas of:

- **security**
- **functionality**
- **compatibility**

A comprehensive listing of desirable attributes and features for each of these aspects of conditional access should be developed, together with a methodology for evaluation. The work should be spearheaded by cable system operators and

programmers whose services will be delivered and controlled by the new generation of digital equipment.

SETTING GOALS

Security

Conditional access systems, once deployed, will be subject to piracy attempts. Indeed, almost any security technology will have the possibility of being broken at some point in time. The cost of piracy must be made very high in relation to the perceived value of pirated programming and services, and, anticipating that some kind of security breach will eventually occur, the system must be capable of recovering from compromise at minimal cost. To the extent that existing cable and satellite scrambling and encryption systems have been defeated, it has in almost every case been by modification of home terminals (set-top-decoders) already provided for legitimate access to programming; attention to the physical aspects of security will always be important. To the extent that security can ultimately be designed to reside in replaceable components (e.g. smart cards), the industry must be satisfied that the cost of cloning and distributing unauthorized devices is extremely high. It is essential that cable operators retain control of whatever equipment the replaceable element plugs into. It may also be necessary that provision be made for electronic countermeasures to be sent over some alternate physical path such as telephone line.

Security Attributes

- The conditional access system must permit recovery from **any** security compromise.
- Security should be contained entirely in the delivery and processing of encrypted keys.
- Access to any one program or service should not facilitate unauthorized access to any other.
- Provision should be made for local cable system intervention and control of satellite delivered programs.
- Operation must be secure even when the threatening party has total system information.
- The ability should exist to exchange key security components at minimal cost.
- It should be non-feasible to recover clear information or control signals by real-time inspection of the encrypted data stream.
- Subscriber hardware should be physically secure to prevent the replacement of components critical to security with other readily available components. Critical security components (e.g. smart cards) should not be accessible to outside probing.
- The cost of cloned devices or components should be much greater than the deferred service cost.

Functionality Issues

As compared with most analog addressable systems, some of the primary issues affecting functionality for conditional access with digital compression are:

- The much larger numbers and variety of channels/program choices/tiers/ program packages/and other digital services to be controlled. Control of high speed data services for personal computers should also be considered.
- Need for multiple operator/programmer control.

- Provision for interactive program requests.

- Requirements for high speed authorization and deauthorization.

- Control of delivery of encryption keys.

- Logistics of using exchangeable security components such as smart cards.

(Smart cards are certain to be an element of conditional access systems. But smart cards on their own are not the total answer to secure conditional access. Cards must be designed to be totally immune to outside probing - a requirement not to be taken lightly. Program code and data storage memories within smart cards should be encrypted, and any attempt to discover the value of the keys used should result in erasure of the card's contents. Operational security requires a lock-interaction between the smart card and the device into which it is connected. The card should be locked using an algorithm from the first unit into which it is plugged, causing the smart-card to be un-usable in any other unit.)

Compatibility Issues

Bringing 500-plus cable channels into a subscribers home introduces new challenges for the configuration of conditional access terminal equipment. When first introduced (projected to be in 1994), digitally compressed signals will be decompressed and restored to analog NTSC format for connection to existing television receivers and recorders.

Configurations to achieve this will include set-top tuner/decompression boxes, point-of-entry devices, and decompression devices at a node removed from the subscribers premises.

Compatibility provisions of the cable Act of 1993 constitute a serious challenge to the industry's use of analog addressability. Some of the unique characteristics of digitally compressed programming provide both a new set of potential problems, and also an opportunity - with careful planning - to try to "do things right." Rather than a set of suggested attributes, the following are some of the compatibility issues to be confronted.

- Availability of a large number of channels (perhaps greater than 500) is likely to lead to provision of programs at multiple time slots. The process for the subscriber to select a program/time slot is likely to be menu driven, and will not likely resemble channel selection as mostly used today. Universal remote control program selections will likely need to accommodate such new ways of perceiving digital program selection, and additionally, control TVs and VCRs.

- Digitally delivered programming will be almost artifact free (certainly fee of cable system analog distortions such as cross modulation, beats, etc.) Putting the digitally delivered image into a TV screen free from the noise and distortion inherent in TV timers will be a challenge.

- Anticipation of digitally compressed program delivery is bound to affect consideration of solutions to the industry's present issues of compatibility in delivering analog signals. There is, for example, no digital equivalent of clear signal delivery with interdiction. Some form of set-top device is certain to be required for delivery of digitally compressed programming for many years.

- Compatibility with digitally compressed high-definition programs will also be an issue, once a U.S. standard for HDTV is selected.

EVALUATION METHODOLOGY

Evaluation of proposed conditional access technologies should give first priority to security. If security is compromised early, it is difficult and expensive to patch it later.

It is essential that a conditional access technology survive security challenges over the entire life of the technology, meaning more than the expected service life of the subscriber terminal; it is important that security can be assured for as long as the compressed signal format remain in use.

In order to achieve the maximum confidence in security, the process of evaluation and selection of a secure conditional access system should start with the assertion that "this is a decision completely separate from the selection of compression technology (or the selection of compression system vendors)" (ref. 2).

Similarly, the evaluation of functionality and compatibility should be separated from decisions regarding compression algorithms, transport layers, and vendors.

It is important that the evaluation process include independent outside expertise - including individuals and companies with insight into the non-conventional methods favored by signal pirates in the past. The industry's twenty year experience with scrambling and encryption reveals that systems have almost always been circumvented by employing short cuts in ways never imagined by the original system engineers. Security of encryption algorithms or of smart cards is only a part of the equation; total system security is the only thing that ultimately matters. It is also essential to the evaluation process that would-be suppliers provide complete disclosure, including **all** details of systems, the results of their own and independent security analyses, and their own knowledge of potential threats.

CONCLUSION

Conditional access objectives for security functionality and compatibility need to be established **now** by the operators and programmers who will commit their businesses to the use of digital compression technology in coming years. An industry process can and should be initiated to specify desirable features and attributes, and to communicate these requirements to industry vendors. As digital compression systems are proposed by vendors for introduction, the industry needs to be satisfied that security and other goals have been met by independent and exhaustive evaluation.

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ACKNOWLEDGMENT

The Advanced Television Systems Committee (ATSC) developed and published in 1992 a list of Conditional-Access System Characteristics appropriate to advance television (HDTV) systems. The approach taken in the present paper is based in part upon the work reported by ATSC.

Consumer Friendly, History, Hopes, and the New Cable Law

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Abstract

This paper reviews attempts at improving customer convenience when connecting their TV receiver to the cable television system. The Cable Television industry now must comply with a new Law which mandates much of what has proven impractical to impliment for cost conscious customers and MSO's. Some ideas will be presented as to how some of these features could be accomplished and where possible FCC intervention could preclude them.

Cable Television has always attempted to be consumer friendly. Cable came into existence because people who lived too far from the major cities of the country where Television was broadcast also wanted to to benefit from the available programming. The cable operators were often the owners of the local appliance store. They could, and often did, sell and install tall towers with antennas and rotators, or stand the expense of installing cable, and thus become a cable operator. Cable was, and still is, more friendly than most other delivery methods. When almost all of the television was delivered by the three Networks, cable systems had multiple duplication of Network channels. I remember a system where multiple channels were carrying the three networks. When asked why, the operator related that at 11 P.M. there were ten different late movies. Normal cable and amplifiers delivered the twelve TV channels on their normal channel frequencies. Some systems carried the high band channels in the sub channel area (before systems became two way) and then block converted them to high band. That is why the sub channels are numbered T7 through T13. Channel converter boxes started out because of an environment that we are experiencing anew today. In New York City, the TV reception was always a problem because of the ghost problem. The problem was double trouble because the transmitters were on the highest building, The Empire State Building. With the cable system delivering the signals on channel, many of the receivers had direct pick up (DPU) on the 300 ohm twin lead or into the tuner. Teleprompter, the system operator, used a channel converter to move any selected cable channel to an unused off air channel, usually channel 3. An interesting side note here, even off air channels using an antenna were improved using this technique against DPU. Cable systems generally converted off air channels to fill all 12 available channel slots, a situation that not all television receivers accommodated without interference. In the early 1970's the need for more channels, including UHF channels now carried on the cable system, prompted using the 9 mid band channels. At this time the real problems started. Only the DuMont TV receivers with their continuous tuners could access those 9 channels. Cable companies were not allowed to sell converters to the consumer, but had to supply them to access the channels. Early converter manufacturers attempted to supply cost effective converters to the cable operators. Some had wafer switch tuners and others had push-buttons. Interestingly, double conversion tuning quickly became standard. This mainly because of cost and performance. Since the levels into the converter were not too low, and most channels were of the same amplitude magnitude, double conversion worked well. Shielding against DPU in converters was better than TV receivers and coaxial shielding was maintained through to the TV receiver. Consumer friendliness was evident in that at least one manufacturer supplied the control part of the converter on the end of a 25 foot wire. Push-button tuning was achieved for initially 30 channels using 15 buttons and a two bank switch. Later versions extended to 36 channels using 12 buttons and a three bank switch. One manufacturer developed a frequency synthesized converter with a wired remote control with digital entry. Remote control TV receivers started to come into vogue in the late 1970's and in markets where the cable converter could be sold to the customer (Canada), true cord-less remote controls using ultra-sonic sound were developed. Since the control was more or less digital, calculator type entry, the number of tunable channels grew. In the early 1980's lower cost cord-less remotes were developed using Infra-red technology.

To go back into the early converter years, Pay television also became legal. Since TV receivers could not tune some channels, and there were few pay services available, early pay systems used "privacy" as a security method. They put the pay service where no one could tune it. The pay converter had a button or switch position that tuned to the pay channel frequency. Needless to say, that method of securing channels didn't last too long. As a more consumer friendly, but more operator costly approach, the operator drove a truck to the non-subscribers home and inserted a signal depriving trap into the CATV drop cable. This is a method that is still in use today in certain areas especially for services that are highly penetrated. As the number of pay channels increased and the penetration of those services decreased, it became desirable to find other methods of access control. In some cases, for low penetration services, an additional carrier was added to the channel to overload the T.V. receiver circuitry and "jam" the signal. A nice side benefit of this technique is that the audio usually is jammed along with the picture. Subscription to the service requires a special trap be installed to remove the jamming carrier. This is not too secure a method since illegal traps are easy to procure. Even with these disadvantages, traps can be a good way for a small system to control a channel. Small is important because every change requires a truck roll, and the jamming carrier adds to the cable system to the same extent, or worse than, adding another channel to the system. In either case the system may require more trucks and need to hire more installers than some alternatives. A variant of this method is called "interdiction". Basically a local jamming carrier is added either at the tap or at the point of entry into the home, to preclude watching the jammed picture. As a cost reduction and to minimize the use of illegal traps, one oscillator may be shared time wise between a number of channels. Of course the time the carrier isn't sitting exactly at the correct frequency the sound, and maybe the picture, can be usable. Since good jamming requires relatively accurate jamming carrier levels, either the jamming oscillator or the whole signal ensemble on the cable must be gain controlled. To supply only the lifeline signals, and not the extended basic tier, this technique could be used to jam the extended basic tier. Unfortunately the basic tier is the lowest cost tier, and now one has to add an expensive box to supply that lowest cost service. Interdiction has been offered for a long time and has not been accepted mainly because of a multitude of problems, including: security, frequency range, effectiveness of masking, resolution of who powers the unit (consumer or cable system?), radiation problems etc. As the number of pay channels increased and the number of people taking the additional services became a smaller part of the total, it became necessary to either buy more trucks and hire more installers, or scramble the additional premium channels. Most operators selected scrambling the additional channels as they simultaneously expanded their channel capacity. This meant a descrambler in the home of those subscribers taking pay services. Some operators continued to use traps for the heavy subscribed services and only install descramblers in the low penetration services. This still meant truck rolls for changes. Some attempts were made at addressable taps, which allowed the operator to turn off service if the subscriber elected to terminate service. The problem here is that every subscriber on the system has to have an addressable tap, and someone has to supply its' power. Even with this, there is no control over the pay signals. It becomes necessary to have some access control for those customers desiring to buy a pay service.

One other access control method whose concept is being selectively demonstrated is the broad-band descrambler. Conceptually this unit can be installed at the point of entry to the home and selectively descramble all the authorized channels. Until more information as to which scrambling techniques are accommodated, potential piracy issues, powering, economics etc. are considered, the impact cannot be assessed.

This more or less brings us to where we are today. If a subscriber desires to take the basic service, and no pays, they get a cable installed into the home and their TV and VCR can tune and record whatever they want. If they desire a pay service that is scrambled, a descrambler must be installed. Depending on the subscribers viewing and recording habits, if a VCR is included in the customers system, either two individual descramblers are required or a "Watch and Record" configuration incorporating two converter-descramblers in a common housing is required.

There have been attempts at other methods such as placing a box on the side of the house into which addressable traps are placed. The box must be large enough to contain a trap for all the channels that are desired on the system. At the same time, they must be installed in all the homes in the system. If that isn't the case, then a truck roll is necessary anyway so why go to the trouble. If traps are to be used, it is generally better to have them up in the air on the cable or locked in a pedestal rather than on the consumers' home.

Presently the cable operators are trying to make changes to their channel line-ups and systems to meet the requirements of the new "CABLE LAW". The Government has directed the FCC to generate rules to make CABLE more friendly, and lower cost if possible. They also encourage competition. One of the more difficult problems to be solved is that "lifeline service" which dictates that the normal off air channels in the channels' service area to be included, as well as Public broadcast Service (PBS) and public access channels. This lifeline service is supposed to be low cost and actually the minimum service necessary to get the cable into the house so that premium channels may be purchased. There have been various attempts so far at how the pricing is done. In one case, the lifeline cost is 80% of the former "Basic" service tier where all the service was either basic or premium. In the new tier arrangement, all the satellite services were put into the extended basic tier. This roughly 60 % of the basic service channel allocation cost only 20 % of the subscriber rate. In another case, the operator has taken another stand in that 50% of the rate is for the lifeline and the remaining for the extended basics. It would appear that neither of those allocations included any thought of paying for the carriage of the off-air stations, a feature of the law, since in both cases the total cost of the combination lifeline and extended basic is the same as prior to the partitioning. There was no charge listed for the installation of the channel reduction equipment necessary for lifeline only service. Justification for either case could be made based on how much the local operator has taken advantage of local ad insertion as a source of income. Depending on how the court cases decide the "must carry" etc. part of the law, the off air stations may be able to demand carriage at some place in the spectrum where they have been all along or would enhance their viewing. An example, if channel 47 UHF has been carried on cable channel 47, and is now in the lifeline tier, one cannot merely trap (low pass filter) all channels below a threshold frequency for those subscribers desiring lifeline only. This would mean moving channel 47 elsewhere. That may or may not be desirable, depending on the feelings of the UHF station operator.

Indications are that scrambling is becoming the choice for extended basic and premium carriage. This is because trucks cost money, drivers cost money, and "Pay on Demand" type programming is becoming more popular. Based on converter shipments, straight pay is in a decline while Pay Per View (PPV) and Impulse Pay Per View (IPPV) is increasing in use. Some new developments are making this environment more friendly. One of the present developments is "Electronic Program Guide" with easier channel selection incorporating retuning. Another is the two tuner converter becoming available. A third, and too early to see how it will fare, is the TV receiver, VCR descrambler interface. This came to us earlier as the IS-15 interface and now is EIA-563. This is an access control device that permits the TV receiver to do all the tuning and display functions while the descrambling is done in an external box connected to a socket on the TV or VCR. There is activity in the committees to update the standard to incorporate the hooks necessary to accommodate the expected digital compression and new On Screen Display (OSD) features expected soon. This activity has become very serious in that the Cable industry is attempting to help the FCC in solving the problems given to them by Congress.

One area that the Cable Law has not addressed but will have a significant effect on how systems operate is the introduction of digital programming. While the products in use so far only deliver signals to the head end for transmission to customers by conventional methods, equipment to carry compressed digital signals directly to the home on CATV will be delivered to cable operators next year. The exact services to be offered are not quite established yet but a number of major programs are being considered. In service now are systems which use satellite to bring to the cable head end, programming previously delivered on multiple FM Satellite channels, four to six programs compressed into one digital channel. At the head end the signals are de-compressed and delivered to cable customers by normal access control means. Because of the premium nature and large number of channels of programming, most are probably using addressable converters. In the near future, those same programs will be delivered in digital form to the home. The fact that four or more channels are delivered on one channel means that in order to receive any of the signals, a converter-decompression box will be required. Another programming variation being considered is the Video on Demand (VOD) and Near Video on Demand (NVOD) concept. In the NVOD scenerio, it has been proposed that with the ability to compress ten movies into one channel, the same movie be given ten successive start times so that a 90 minute movie would have 9 minute intervals between starts. Statistically a person would wait an average of 4 minutes for their selected movie to start. During this time they could be retuned to a preview channel of similar type movies. When their movie selection start time came by, they would be switched to the appropriate movie start. In the true VOD scene, channels or really sub divisions of channels could be assigned as required for a movie as ordered. These converter-decompression boxes are probably not what the Cable Law conceived as consumer friendly. Actually the features that these converters have often exceed what the TV receiver offers, but a television receiver without a converter is disadvantaged. The comments related to the ability to Watch and Record, and view Picture in Picture previously discussed still apply to digital compression. The digital signals require tuning capabilities that exceed those presently available in present day converters and television receivers. The definition of a cable-ready tv receiver will have to change substantially to be called digital-cable-ready. Changes will be necessary in the television receiver and the EIA-563 interface adapter plug to work with digital compression.

The FCC has discovered that the authors of the "CABLE LAW" never considered how the activities necessary to enforce the law would be paid for. The FCC is now considerating a mandatory contribution from the cable systems to pay for this activity, which will subsequently be passed onto the cable customer. If the FCC forces the basic tier rates down, and Cables competition thinks that there is a great amount of money to be gained by supplying programming in competition to the CATV system, it would appear that the CATV operator with cable already installed should be able to supply that same programming at equal or less cost. In fact, if cable is not able to make money overall, the operators will be forced out of business. It is doubtful that this would happen without a fight.

The idea of competition to the Cable industry is incorporated into the name of the "CABLE LAW". Whether the FCC dictates that the conditions imposed on the competitors to Cable are the same that the Cable industry must meet remains to be seen. As a point of interest, CATV franchises pay about $ 800 million yearly to the cities in which the franchises exist. In the popular vernacular, would the alternate suppliers of premium programming also be expected to contribute a percentage off the top of their income? It is interesting to consider that the Cable System must supply the local off air channels unmodified (not scrambled or advertising changed) to the cable home, Public Broadcasting channels included. Up to one third of the channels must be these and public access (City Government,etc.) channels. Will the alternate (competition) TV signal supplier also have to supply this service? If a competitive supplier can supply only the Pay-Per-View channels, will it be permitted for the Cable TV Company to supply only that type of material? With Cable systems being built with fiber to the node, a premium only service could be created in competition with itself. In fact, some dual cable systems presently have basic on one cable and premiums on the other. Is it allowed to sell only the premium? If it is allowed to do so, do the other performance issues spelled out in the law apply?

This paper has attempted to present some history of cable friendly issues as well as some of the techniques that can be employed to meet the law and still not create problems beyond what the customer had. There are more issues being discussed in Industry sponsored committees that attempt to solve the problems that we have been working on for years.

DIGITAL BROADBAND DESCRAMBLING TECHNOLOGY - A COMPATIBLE ACCESS CONTROL SOLUTION TO THE EVER-GROWING CONSUMER ELECTRONICS INTERFACE PROBLEM.

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ABSTRACT

Digital Broadband Descrambling ("DBD") is a newly developed digital technology for simultaneous on-channel processing of a large number of TV signals. It utilizes advanced Digital Signal Processing ("DSP") methods for effecting low cost broadband access control signal security compatible with most addressable converters in use today and thus will provide economically viable option for cable system operators to provide their subscribers with a truly "subscriber friendly" cable service while distributing scrambled video signals on the cable plant and avoiding the need for set-top descramblers.

Unlike existing "single-channel-at-a-time" descrambling technologies, the DBD technology simultaneously descrambles and provides all authorized channels in the clear by broadband selective coherent injection at RF and thus enables subscribers to enjoy all the features of their cable ready TVs and VCRs in a whole-house service, including built-in VCR programming functions, remote controls, watching and recording from different scrambled channels simultaneously or consecutively, and viewing multiple channels at once (picture-in-picture). Furthermore, the DBD devices will pass into the home all other unprocessed channels including digital compression signals, thereby allowing compatibility with future digital transmission.

INTRODUCTION

In the evolving competitive multichannel video distribution environments, Cable operators who adopt broadband access control methods relying on the intrinsic broadband capability of simultaneous multichannel VSB AM television signals are likely to reap powerful strategic benefits in offering tiered cable service: This technical advantage to Cable may remain the only *sustainable* differentiating feature over service provided by other multichannel video providers, such as a DBS operator, who unlike Cable, will have no choice but to employ set-top decoders. These competitors will thus require the use of multiple decoders for VCRs and additional outlets, while offering no relief to the ever-growing consumer electronics interface problem.

Unlike set-top descramblers currently in use, the DBD system does not employ single channel filtering or video demodulation-remodulation circuitry and thus introduces no measurable frequency response distortions or artifacts in either the video or audio signals of the descrambled or non-blocked channels. Therefore, video and audio quality at the subscriber's TV terminal is virtually that which is provided at the subscriber drop, facilitating compliance with recent FCC technical standards.

The following sections describe in relative detail the digital signal processing technology developed by Multichannel Communication Sciences, Inc. ("MCSI") for Broadband Descrambling applications. The descriptions herein describe but a few implementation versions and further cost reduced implementations are likely. The advent of lower cost digital signal processing VLSI used in digital cellular telephony and in the personal computer industry opens a new era for implementing low cost broadband systems that can be added to the cable operators' arsenal for dealing with the consumer electronics interface problem.

BROADBAND DESCRAMBLER PRINCIPLES

Multichannel Processing by Coherent RF Injection

Since the object of a broadband access control system is to provide all authorized channels to the subscribers in a clear form, and only certain channels must be descrambled, and hence modified, the approach herein seeks to avoid any single channel filtering or tuning techniques but rather focus on techniques that involve broadband signal addition in such a manner as to modify (descramble or further scramble and deny) only selected channels. From the outset, it is instructive to observe that many of the baseband and RF sync suppression scrambling formats constitute a linear modifying process in the radio frequency domain. In many cases this linear process is active only during the blanking intervals in which sync suppression occurs. This means that for each of these scrambling process, there exists an additive RF signal pulse of the appropriate duration, onset time, amplitude, frequency and phase, such that when it is added to the scrambled RF signal, it results in an RF television signal with normal synchronizing signals, and hence one that is unscrambled.

Figure 1(a) depicts the signal during the Horizontal Blanking Interval ("HBI") in a baseband sync suppression system. As can be seen, the normal sync signal is suppressed at the scrambler by adding a baseband offset signal of a predetermined magnitude (typically 70 IRE) during the HBI which results in the suppressed sync signal shown by the broken line. In this example, the active video signal is unmodified. Thus, in the inverted modulation scale of the RF domain, the HBI gated offset level at baseband is equivalent to the subtraction of the RF pulse shown in Figure 1(b) from an otherwise non-scrambled RF television signal. The frequency and phase of this RF pulse is equal to those of the picture carrier of the television signal. Hence, in order to restore this baseband sync suppression signal to it's unscrambled mode, one can add a coherent RF pulse train with the horizontal synchronizing repetition rate, coinciding in time with the HBI as shown in Figure 1(b), with the appropriate amplitude and in phase with the picture carrier so as to obtain an unscrambled signal. During the active video time, there is no RF signal injected.

Such addition at RF, hereinafter termed "Coherent RF Injection", must be effected with sufficient precision in amplitude, phase and timing so as to obtain essentially an unscrambled signal. For example, a baseband suppression of 70 IRE units using the standard television modulation scale, means that the in-phase coherent RF injection level required to effect descrambling must have an amplitude corresponding to 44.75% of the peak RF level of the non-scrambled portion of the signal. Moderate errors in the level of such injected RF pulse may not affect the proper synchronizing of the television receiver for satisfactory viewing of unscrambled programs, but may cause minor errors in the black reference level of the television set. This is because most sets establish their black video reference level by sampling the 0 IRE level during the color burst period. However, generally accepted video specifications allow for fixed errors of up to $\pm$ 3 IRE in black level, well below the 7.5 IRE setup level. These fixed error levels are permissible and are undetectable for all practical purposes. Based on this permissible amplitude error, it can be shown that the required accuracy of coherently injected RF signals for descrambling can be characterized by an ideal errorless injection signal accompanied by an injection RF phasor error of magnitude not exceeding -27 dB as compared to the desired injected RF signal. Similarly, a phasor error limited to -27 dB in the injection phase of the RF pulse results in maximum deviation of the combined picture carrier phase of less than $\pm 1.3°$ during the HBI. This is well within the requirement limiting the phase error to $\pm 3°$ due to Incidental Phase Modulation ("ICPM") so as not to cause perceptible intercarrier audio buzz or MTS stereo distortion[1]. As will be subsequently appreciated, this -27 dB permissible error level facilitates a robust and low cost embodiment of a broadband generator for simultaneous injection for a plurality of channels.

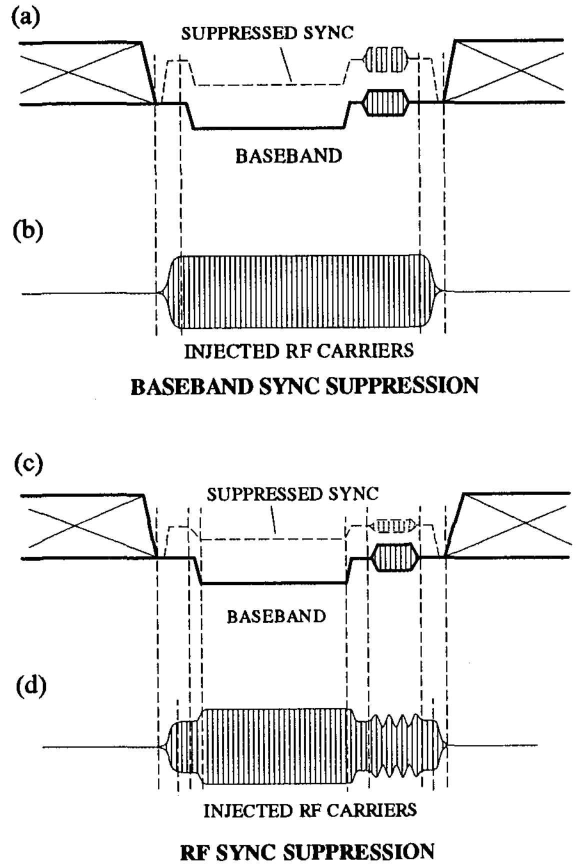

Figure 1. Descrambling by Coherent RF Injection. Signals during the HBI.

The baseband video sync suppression transitions at the scrambler as shown in Figure 1 take place over a time duration not exceeding two hundred nanoseconds, consistent with a standard television video bandwidth of 4.2 MHz. Upon descrambling of such signals, it is preferable to match these transition times when the sync offset level is removed at the descrambler by coherent injection of an RF pulse shown in Figure 1(b). Here, the onset and termination periods of the injected RF pulse would have durations that would preferably each be no longer than two hundred nanoseconds. However, if the pulse shape of the injected RF envelope of Figure 1(b) is attempted by means of an amplitude pulse modulator with video bandwidth, the fast rise-times and fall times would generate double sideband spectral broadening of up to 4.2 MHz above and below the picture carrier frequency. The upper sideband content of this injected signal will be contained within the desired normal television bandwidth as transmitted in Vestigial Sideband ("VSB") Modulation. However, since the injected signal is assumed to be combined with the received signal in a broadband combiner, the lower sideband of the injected signal may interfere with a lower adjacent television channel and in particular with it's audio subcarrier located only 1.5 MHz below the picture carrier of the descrambled channel.

If, instead, longer transition times are assigned for the injected RF pulse so as to limit the spectral broadening of the amplitude modulated pulse to less than 1.5 MHz, the descrambled video signal will contain front and back porch transients with durations lasting several microseconds. These slow transients may invade the leading edge of the horizontal synchronizing signal or the active video time of the descrambled signal, thereby delivering a degraded video signal to the subscriber, which may cause false horizontal sync or unstable video clamping action by the television set.

The above-mentioned conflicting requirements in the frequency domain and in the time domain, can be resolved by turning to the very method which allow fast video transitions in television transmission without undue lower sideband spectral expansion, namely, the use of VSB modulation techniques for the transitions of Figure 1 prior to the RF combining with the scrambled signal. This will allow the television receiver to process the upper sideband containing up to 4.2 MHz wide spectrum associated with fast baseband transitions while limiting the lower sideband expansion to well below 1.5 MHz and thus prevent the associated interference to the lower adjacent channel. An elaboration on the digital RF circuit embodiments which facilitate such VSB spectral shaping of the injected signal will be discussed in the sections below.

The coherent gated RF injection described above can be useful for purposes other than descrambling. Provisions can be equally made for implementing signal denial techniques on a channel by channel basis for non authorized subscribers. In contrast to the descrambling case, in an example signal denial case, the coherent gated RF injection of Figure 1(b) can be effected in opposite phase to that of the picture carrier of the television signal, thereby further suppressing or nulling the synchronizing signals and optionally, with sufficient injection level, even reversing the resultant RF phase of the received television signal during the HBI. This method results in enhanced security for unauthorized subscribers since it denies "pirate" decoders the ability to reconstruct the sync signals and further causes phase discontinuity in the intercarrier audio detector of the television set, thereby introducing disturbing audio buzz and further audio noise masking in some television sets. It should be understood that coherent RF injection for sync denial of the type described above must also be gated during the HBI using VSB transition modulation so as to prevent interference to the lower adjacent channel that may otherwise be clear or authorized for descrambling.

Thus far, processing of the television signals at RF by coherent injection was discussed in a context of a single channel. Clearly, the main reason to use RF injection techniques is to offer simultaneous processing of this novel type for a plurality of channels. This means that coherent injection should take place at each frequency for which either descrambling or further scrambling denial is required.

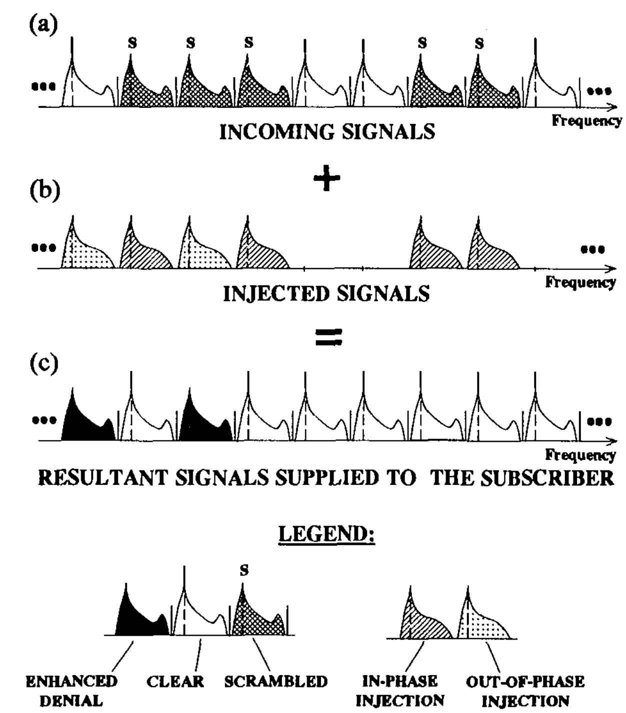

Figure 2. Descrambling and Enhanced Denial by Coherent RF Injection of VSB Shaped Signals.

Figure 2(a) depicts a portion of the broadband spectrum of the incoming signal carried on the CATV system entering the multichannel broadband descrambler. The channel spacing is 6 MHz. As can be seen, the spectra of each television signal appears asymmetric about its picture carrier frequency, as it is upper sideband VSB modulated. In Figure 2(a) one can observe two types of channels being transmitted down the CATV distribution plant. The first type, designated by clear patterns, represent all the non-scrambled channels for which the majority of subscribers are authorized and thus require no further processing at most subscriber locations. The second type of channels carried is the sync suppressed scrambled channels, designated with the letter S and a cross-hatched pattern. In the example of Figure 2 the assumption is made that the subscriber has purchased subscriptions for the premium scrambled channels corresponding to all scrambled channels except the third channel from the left, and has not obtained a subscription for the first channel from the left, transmitted in the clear. Consequently, the required RF injection spectrum corresponding to this subscription configuration is depicted schematically in Figure 2(b). Each signal in Figure 2(b) is assumed to be generated simultaneously within the multichannel descrambler installed at the subscriber's drop point of entry and combined in phase lock with its respective transmitted counterpart picture carrier of the same frequency in Figure 2(a). The broadband composite signal of Figure 2(b) is coherently injected and thus linearly combined with the broadband incoming signal of Figure 2(a) to form the composite broadband signal depicted in Figure 2(c). This resultant signal is subsequently provided to the subscriber for his/her viewing pleasure. The injected signals of Figure 2(b) consist of VSB injection signals with time domain profiles of the type depicted in Figure 1(b) or Figure 1(d). The injected RF signals for the second, forth, seventh and eighth channels from the left are all injected in-phase with respect to their corresponding incoming scrambled signals, thereby effecting simultaneous descrambling and resulting in clear channels in Figure 2(c), the signal provided to the subscriber. In contrast, the injected RF signals for the first and third channels from the left are injected out of phase, thereby causing sync null or other signal denial effects such as sync phase reversal. These are the television signals depicted in solid black on Figure 2(c), which are not viewable or otherwise useful to the unauthorized subscriber. However, because of the broadband characteristics of this combining system, they are fed in their further scrambled mode to the subscriber along with all other clear signals. Since the fifth, sixth and ninth channels are originally transmitted in the clear, and the subscriber is authorized to receive them, these channels require no further processing and therefore no signals are injected in the corresponding channel slots.

Because the injected signals of Figure 2(b) all have identical temporal profile as that of Figure 1(b), their simultaneous generation as a group can be made much simpler if they are all required at the same time, that is if the HBI of all television signals in the channel group of Figure 2(a) coincides in time repeatedly. This relative timing coincidence condition among this group of video channels means they must be "frame synchronous". This condition can be accomplished at the CATV headend for each channel in the group by means of video frame synchronizers providing video outputs genlocked to a master video synchronizing source.

It will become apparent in following discussions regarding embodiments of the multichannel injection signal generator that another appreciable simplification in the subscriber injection generator can be realized if channel groups intended for such processing are grouped in coherent relationships as in IRC or HRC systems, at least within that portion of the band constituting the groups of channels that are being processed by a Broadband Descrambler. This simplification is related to the fact that under such conditions, the composite RF signal of Figure 2(b) can be mostly derived from periodic signals with fundamental periodicity equal to the Incremental frequency separating any two nearest channels within the group (6 MHz). This RF coherence condition can be effected at the CATV headend by phase locking all modulators in the channel group to an appropriate coherent group comb signal.

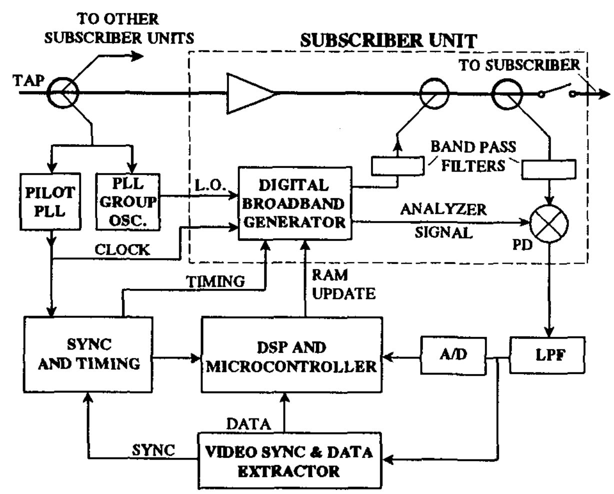

Figure 3. Simplified block diagram of a broadband descrambler.

As indicated above, each channel RF injected pulse must have correct amplitude and phase that matches the level and phase of the corresponding incoming signal. To that end, the broadband descrambling system of Figure 3 is constructed to accomplish such result in a digital feedback scheme as explained below. The assumption is made that the headend video frame synchronization and group coherent carrier phase locking is effected as discussed above. The broadband incoming signal containing all transmitted channels arrives at the input tap. A portion of the broadband signal power is coupled to a broadband amplifier whose output signal corresponds to Figure 2(a). It is then combined with the injected signals correspond to Figure 2(b), that are generated by the Digital Broadband Generator ("DBG"). Each of these injected signals has a temporal profile in video synchrony with the HBI. This coherent combination results in the composite signal of Figure 2(c) at the subscriber port.

The Digital Broadband Generator is a low cost RF generator capable of generating a plurality of incrementally related VSB or CW signals situated on an arbitrary subset of a 6 MHz frequency grid centered about a center local oscillator frequency, the signal of which is feeding the DBG via the L.O. line. The PLL Group Oscillator is locked to the picture carrier of the center channel of the group while the clock frequency may be obtained by using a pilot PLL locked to a low level CW pilot carrier transmitted from the headend at a frequency such as 72 MHz. The clock frequency required by the DBG is an integral multiple of the incremental channel separation frequency such as 144 MHz or 72 MHz.

A special case that can be controlled in the generation capability of the DBG is the generation of a single CW signal in phase coherence with any of the channels within the group, wherein a precise phase control is possible. This signal is used to provide the Analyzer signal shown in Figure 3, feeding a synchronous detector (PD). The DBG is used during the VBI to sequentially generate two quadrature analyzer signals on each channel being processed (Analyzer I and Q). The phasor analysis results from the Integrate & Dump LPF are sampled at field rate by the A/D and then fed to the Digital Signal Processor ("DSP") as sample inputs to the digital phasor tracking algorithm implemented by the DSP. The results enable the update of the RAM content in the DBG, so that the composite waveform generated by the DBG matches the phase and amplitude requirements for each processed channel. In a similar manner, the Analyzer signal can be set for coherent detection of video sync and data during the VBI of any channel within the group. The Sync & Data extractor is used to establish video frame synchronization of the system, so as to synchronize the coherent injection processing as well as VBI data reception of any designated channel within the group.

The Digital Broadband Generator

In general, the generation of a pulsed VSB signal at any given frequency can be accomplished either by passing a double sideband AM pulse through a vestigial sideband filter or by an equivalent phase and amplitude modulation of a sinusoidal carrier signal. The latter method[2] employs the Hilbert Transform of a high pass baseband component of a pulse. Accordingly, it can be mathematically shown that two envelope signals used for quadrature modulation of a carrier yielding a desired VSB pulse shaping are given by *C(t)* and *S(t)* shown in relation to the pulse width during an HBI in Figure 4. The signal *C(t)* is the modulating function of the in-phase component of the carrier and *S(t)* is that of its quadrature component.

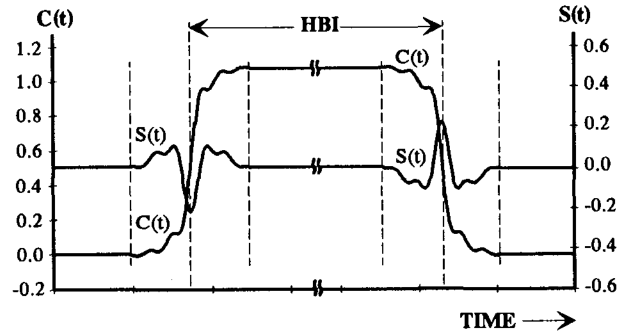

Figure 4. Quadrature modulation components required for VSB generation of the signal in Figure 1(b).

Hence, given a carrier frequency ω, a VSB shaped pulse about that frequency can be represented by a signal *f(t)* given by

(1) $$f(t) = C(t)\cos\omega t + S(t)\sin\omega t$$

In order to see how a plurality of incrementally related VSB signals can be *simultaneously* generated with a low cost digital structure, we turn to Figure 5. Figure 5(c) shows a block diagram of a Digital Broadband Generator comprised of two sets of RAM, D/A converter ("DAC") and low pass filter ("LPF") feeding a broadband quadrature modulator. The baseband signals feeding the two quadrature inputs are functions of time designated hereinafter as $B_1(t)$ and $B_2(t)$ and are digitally generated by the corresponding DACs, based on the contents of their respective RAMs. The low pass filters provide antialiasing filtering, clock signal components rejection and out-of-band harmonic rejection. The clock signal driving the DACs and the RAMs also advances the RAM address generator, causing the appropriate RAM data contents to be loaded sequentially into both DACs respectively. The clock frequency is set so that it is a sufficiently large integral multiple of the fundamental frequency increment between two adjacent channels. For example, in a 6 MHz channel spacing system, one might

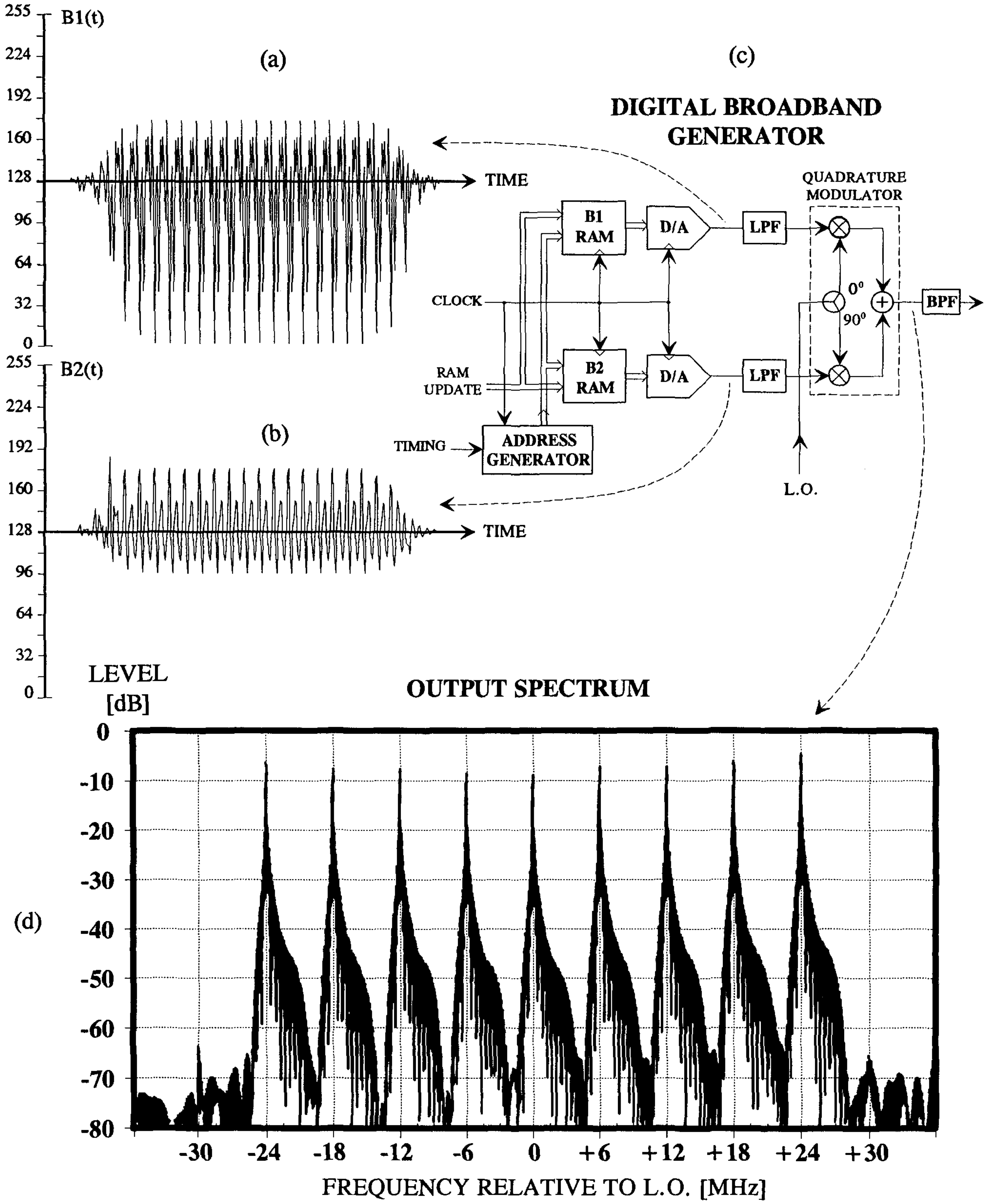

Figure 5. Example of a Digital Broadband Generator operation.

select a 72 MHz clock frequency, thereby allowing digital generation in each quadrature path, baseband signals with frequencies approaching the Nyquist rate of 36 MHz, while a 144 MHz clock will allow a baseband frequency approaching 72 MHz. Because the spectrum generated by the quadrature modulator contains both an upper sideband and a lower sideband, and because practical low pass filter designs limits the useful baseband frequency to less than the Nyquist rate, one can easily generate injection signals for a 9 channel group (for a 72 MHz clock) or 19 Channels (for a 144 MHz clock). Because high speed triple video DACs with clock rates exceeding 150 MHz are employed in a growing number of personal computer displays, their rapidly declining costs allow modular implementation of several Digital Broadband Generators. For example 4 such D/A packages provide 6 Digital Broadband Generators with processing capability for up to 114 channels.

Initially, note that for the generation of incrementally related CW output signals at RF, the required signals $B_1(t)$ and $B_2(t)$ in the DBG must be each a linear combination of sinusoids with frequencies that are integral multiples of 6 MHz. In this CW case, these signals are generally given by:

$$(2)\quad \begin{aligned} B_1(t) &= \sum_{k=0}^{k=N} x_k \cos(2\pi k\frac{t}{M}) + y_k \sin(2\pi k\frac{t}{M}) \\ B_2(t) &= \sum_{k=0}^{k=N} u_k \cos(2\pi k\frac{t}{M}) + v_k \sin(2\pi k\frac{t}{M}) \end{aligned}$$

where the Fourier coefficients x_k, y_k, u_k, and v_k determine the desired amplitudes and phases of the RF CW carriers. This is due to the linearity and superposition principle of the quadrature modulation process. Hence, during period of times within which a steady amplitude and phase is generated, $B_1(t)$ and $B_2(t)$ are periodic waveforms with a 6 MHz periodicity as shown in the center portions of the time waveforms in Figure 5(a) and (b). This allows for a discrete time representation of these periodic signal with M samples (wherein $M = f_{clock}/6$ MHz). Therefore, the RAM address generator need only scan repetitively through M RAM addresses denoted by a discrete time index t in order to generate an arbitrary CW frequency grid at the DBG's output.

At the RF domain, each generated CW carrier at the output can be resolved into two quadrature components I and Q. The index k shall be used here to designate the baseband order of the 6 MHz harmonic corresponding to the separation of the specific carrier in question from the L.O. center frequency carrier on which the group local oscillator is locked. Thus, for any given baseband frequency index k (up to a value of N), there are two RF sideband components (phasors) that can be generated, corresponding to two distinct channels. The situation is illustrated schematically in a phasor diagram of Figure 6.

With an arbitrary RF phase reference coordinate system in Figure 6, I_k^+ and Q_k^+ correspond respectively to the in-phase and quadrature components of the upper sideband RF injection signals of frequency index k, while I_k^- and Q_k^- correspond to those of the lower sideband of frequency index k. Accordingly, for each baseband frequency index k, the baseband Fourier coefficients of Equation (2) are related to the RF phasor components by:

$$(3)\quad \begin{bmatrix} x_k \\ y_k \\ u_k \\ v_k \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & -1 & 0 \\ 1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_k^- \\ Q_k^- \\ I_k^+ \\ Q_k^+ \end{bmatrix}$$

In this manner, an arbitrary set of RF phasors can be generated by the DBG with only M samples in each RAM. As will be shown below, the generation of arbitrary set of VSB modulated phasors will require a slightly larger memory array: It is based on employing the method of Equation (1) for each phasor and combining it with Equations (2) and (3). That is, given the phasors' desired quadrature components I_k^+, Q_k^+, I_k^- and Q_k^- represented by a 4 entry column vector, and given the desired VSB shaping for each carrier characterized by the envelope components $C(t)$ and $S(t)$, the baseband signals $B_1(t)$ and $B_2(t)$ represented by a 2 entry column vector for each sample time t is given by vector Equation (4).

The I_k^+, Q_k^+, I_k^- and Q_k^- phasor values' representation within the DSP for the computation of Equation (4) will be set in accordance with the desired processing action on each channel, based on the subscriber's subscription status, as addressed to the subscriber device and received in the data stream of the VBI. In the case $k=0$ both sidebands degenerate into two halves of a single center carrier, for which Equation (4) reduces to an equation for 2 entry vectors and a 2x2 matrix. The parameter t is the discrete time variable assuming integer values corresponding to a sequential RAM address value having three sectors in the RAMs: Two non-periodic sectors corresponding to the VSB "rise" and "fall" transition waveforms for all generated carriers, and a pair of M sample sectors holding only one cycle of the periodic CW portion of the generated carriers. In the example of Figure 5(a) and (b), the transition intervals

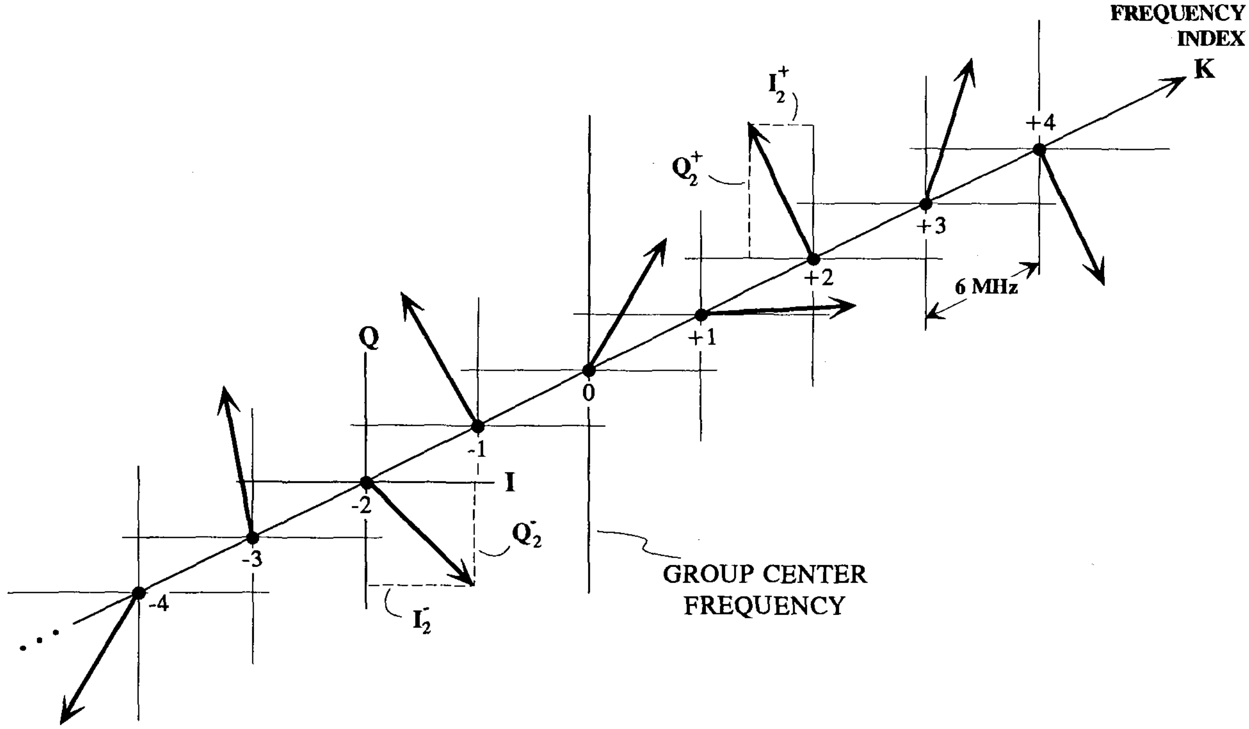

Figure 6. Multichannel RF Phasor Diagram

from 0 to the CW steady state each correspond to a record length of 60 sample bytes assuming 72 MHz sampling rate, while the steady state periodic sector contains only 12 samples bytes. Figure 5(d) depicts the resulting frequency power spectrum at the output of the DBG if all 9 VSB channels are generated. As can be seen, one can achieve an acceptable VSB spectral shaping about the picture carrier with this relatively short sample sequence. Of course, any other selection of a subset of these nine signals can be made and inserted in the DSP calculation in accordance with Equation (4).

$$\begin{bmatrix} B_1(t) \\ B_2(t) \end{bmatrix} = \sum_{k=0}^{k=N} \begin{bmatrix} \cos(2\pi k\frac{t}{M}) & \sin(2\pi k\frac{t}{M}) & 0 & 0 \\ 0 & 0 & \cos(2\pi k\frac{t}{M}) & \sin(2\pi k\frac{t}{M}) \end{bmatrix} \begin{bmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & -1 & 0 \\ 1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} C(t) & S(t) & 0 & 0 \\ -S(t) & C(t) & 0 & 0 \\ 0 & 0 & C(t) & S(t) \\ 0 & 0 & -S(t) & C(t) \end{bmatrix} \begin{bmatrix} I_k^- \\ Q_k^- \\ I_k^+ \\ Q_k^+ \end{bmatrix} \quad (4)$$

Another feature provided by the digital signal processing capability is the ability to select the functions *C(t)* and *S(t)* based on a precise computation of spectral nulls provided around the audio subcarrier frequencies, thereby ensuring that the broadband injected VSB signals do not interfere with the audio portion of the signals. In general, these stringent attenuation specifications are not required on frequencies which only affect the *video portion* of adjacent channels. Here, much more relaxed attenuation specifications are needed since the resultant adjacent channel crosstalk effects are video frame synchronous for a contiguous group of channels and thus introduce only small coherent and synchronous transient modifications at the edges of the HBI. These HBI edge "mini-transients" are far more benign in comparison to the artifacts introduced by any set-top descramblers' sync restoration circuit. Special mathematical design tools were developed at MCSI to optimize the functions *C(t)* and *S(t)* so that a proper balance exists between the base requirement of fast baseband equivalent video transition on the desired channel, and adequate adjacent channel spectral overlap rejection, while maintaining the shortest possible memory array for the VSB transitions, so as to minimize the number of DSP calculation cycles per frame.

By proper calculations of phasor increments, essentially in accordance with Equation (4), and based on the required generated values of I_k^+, Q_k^+, I_k^- and Q_k^-, the Digital Signal Processor shown in Figure 3 evaluates the required samples $B_1(t)$ and $B_2(t)$, and stores them in the DBG RAMs via the RAM Update data bus. The numerical values of the trigonometric functions and the predesigned envelopes $C(t)$ and $S(t)$ are stored in a ROM inside the DSP, wherein the usual ROM space savings are realized by taking advantage of the symmetry and sample degeneracy features of these functions. The calculation and phasor tracking of Equation (4) is performed for all processed channels at video frame rate. Thus, the system maintains its injection and analysis waveforms in a fixed phase and amplitude relationship to the incoming signals by closing a phasor control loop for each processed channel. This is done by successive analysis and corrections, thereby tracking any slow relative phase or amplitude drifts in the CATV distribution system or any of the components in the subscriber unit such as power splitter, directional coupler, the broadband amplifier or any of the components within the broadband generator which may affect the relative injected phasors as compared to the incoming channel phasors. This feedback method lends particular robustness to the Broadband Descrambler device which may be subject to extreme environmental conditions.

As explained above, the phasor tracking process is performed by use of the Analyzer signal generated by the DBG for phasor measurement, whereby the injection and Analyzer functions are time-shared in accordance with a predetermined video timing schedule. It is possible to time-share and perform measurements during time periods in which no descrambling or RF injection is required. These measurement or phasor analysis periods would preferably be within the VBI, or during time intervals in which no active video information is present, therefore providing a fixed received reference for the picture carrier amplitude and phase.

Figure 7 shows the RAM address timing for the DBG during an HBI injection pulse and during a portion of the VBI, wherein two quadrature Analyzer signals are generated. One of these RAM records for the Analyzer may also be used for synchronous detection of data in the VBI. The RAM contents required in order to receive a selected channel is the same as that which is required to generate a single carrier, coherent with that channel's received carrier.

In order to perform the injection and analysis in coordination with the group video timing, a vertical frame reference data provides for vertical frame synchronization by the use of a sync/data detector, resetting the timing chain circuitry via the sync detect line. The address

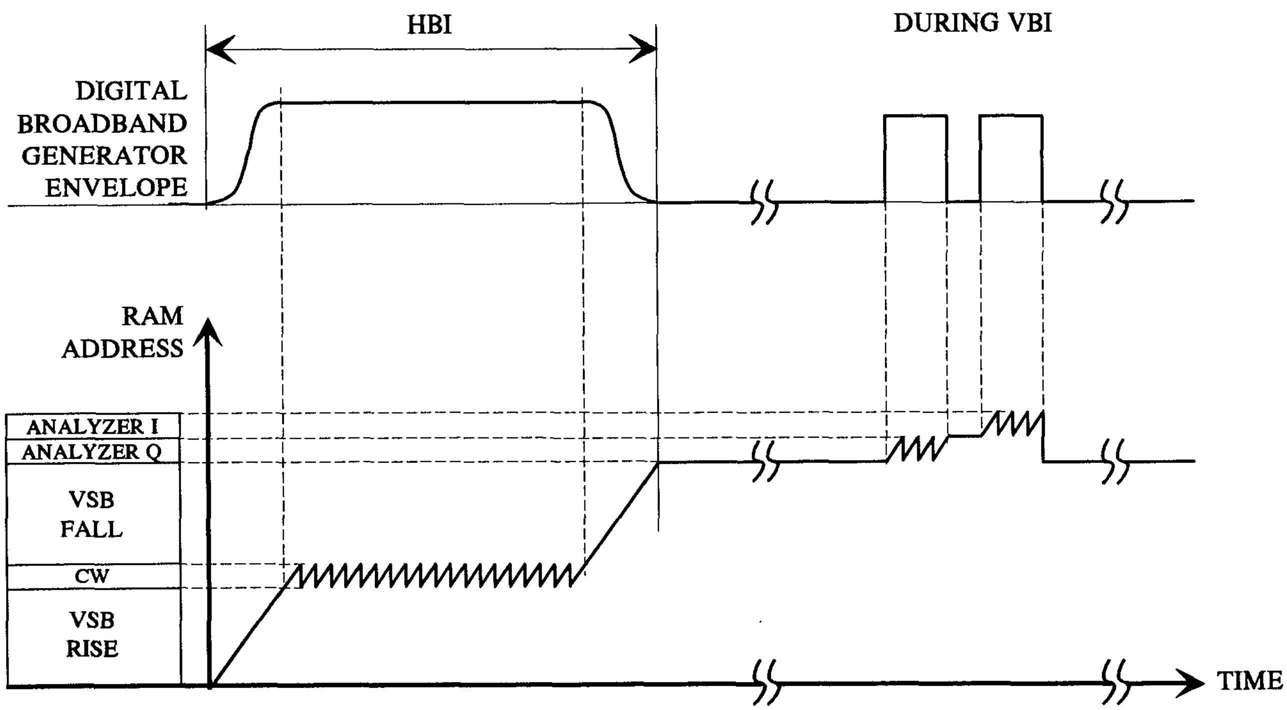

Figure 7. Digital Broadband Generator RAM Schedule

generator is provided with the proper reset and preload signals from the timing chain circuit so as to scan the proper RAM memory locations containing the appropriate data records for the synthesis of the injection signals and the analysis signals as required.

Enhanced Scrambling By Video Folding

It is worth noting that sync suppression descrambling only requires injection during the HBI. Therefore, the DBG can be used during the active video line to generate other fixed injection signals of levels randomly varying from frame to frame during the active video time so as to provide an additional security based on random "video folding". This new scrambling method can be implemented by effecting gated coherent injection at the headend using some fixed set of injection values governed by a cryptographic keystream control for individual channels. At the descrambler, opposite coherent injection signals governed by keystream control are injected simultaneously on authorized channels, thereby descrambling these channels based on precise phasor adjustment similar to that used for sync recovery. Because the injected signal at the headend can be in opposite phase, video inversion on only a sector of the screen may take place (Video Folding), further frustrating any existing "pirate" descramblers. Figure 8 shows the method of scrambling, wherein one of four predetermined levels in Figure 8(b) are randomly selected on a frame by frame basis. As can be seen in Figure 8(d) an unaided TV set will receive a baseband signal that is partly inverted in luminance and in chrominance, and RF phase reversals are likely to frustrate the intercarrier audio detection. Video inversion constitutes a special case of Video Folding, as it corresponds to a folding axis of 0 IRE.

It can be appreciated that while a Broadband Descrambling system can be rolled out over an extended period because of its compatibility with existing sync suppression systems, the Video Folding scrambling mode can only be used on channels for which all authorized subscribers have a Broadband Descrambler installed. However, it is possible to use Video Folding as means of local denial of otherwise clear signals. Since the random injection is confined only to the active video period, the method is highly secure because it is virtually impossible for the pirate to obtain an estimate or a guess absent the knowledge of the particular injection level being used in for each frame, since it is impossible to separate between changes in folding point and changes due to program material.

In this Video Folding operation mode, the DBG RAM records must be configured to provide VSB

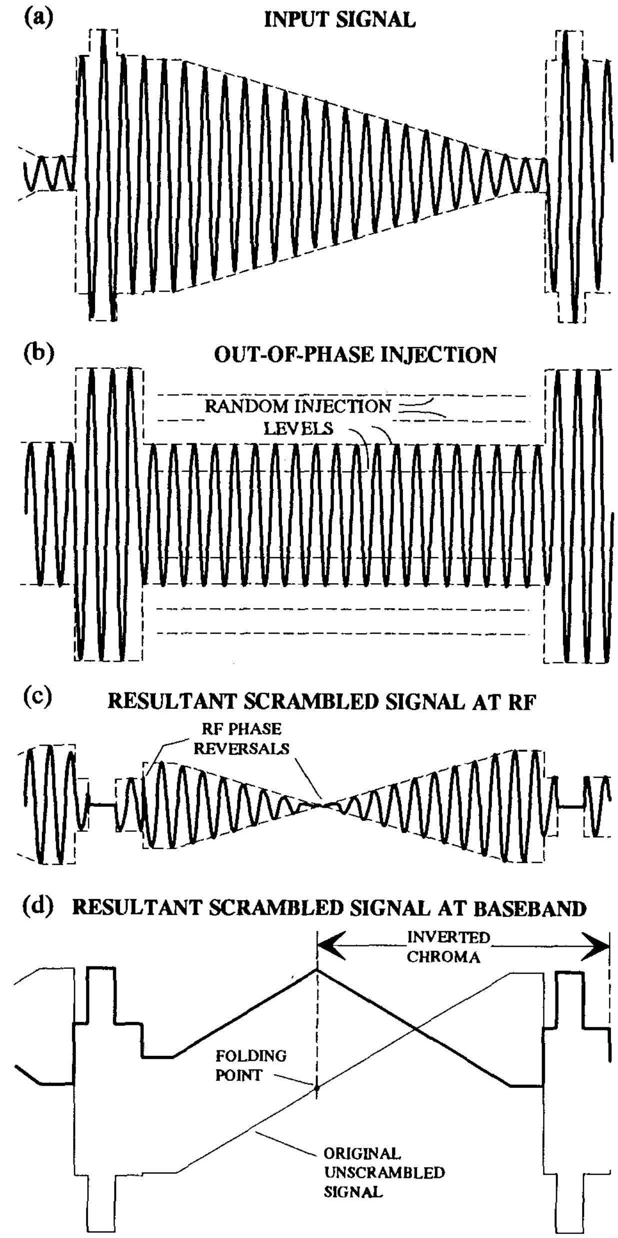

Figure 8. Random Video Folding or Inversion Scrambling

transitions from an HBI injection phasors to active video CW injection phasors on certain channels with different levels of injection. These transitions from one set of phasors to the next is effected by storing RAM samples corresponding to a superposition of values derived from an equation similar to Equation (4).

Descrambling of Dynamic RF Sync Suppression

Figure 1(c) shows a baseband representation of an RF sync suppression HBI. Figure 1(d) depicts the required coherent injection signal for descrambling. Due to the scrambler attenuation at RF, all signal components are in need of injection including a portion of the color burst. As can be seen, six RAM records are required for generation of the picture carrier portion of the injection signal as opposed to three in the baseband sync suppression case. Although it may be possible to generate the missing burst signal by VSB generation about the picture carrier, this approach is expensive in memory because of the poor congruence between the color subcarrier frequency and 6 MHz.

An alternative solution is based on the fact that all upper sideband color subcarriers in a frame synchronized video sources are also incrementally related at RF with 6 MHz spacing. Hence they can be generated and injected separately using a DBG local oscillator gate-locked on the RF component of the color burst of the center carrier channel. In a manner similar to the picture carrier tracking, all injected color burst phasors required are measured and tracked preferably during the VBI. Since all RAM records are recalculated by the DSP every video frame, injection matching the 6 - 10 dB suppression dynamics can be provided on a channel by channel basis. An additional group keystream informing the broadband descrambler at the beginning of each frame the suppression level for each channel must be added to an addressable control stream. Such control stream can be made secure through encryption.

Use of Time-Shared DBG

In applications in which no processing is required in the active video period (sync suppression), it is desirable to be able to use the Broadband Generator in a time-sharing mode, whereupon several channel groups may be processed sequentially, thereby increasing the total number of channels processed by a single DBG by switching the frequency of the local oscillators feeding the DBG to the center frequency channels of each group. This operation mode is generally possible in this video application since the required processing (and injection) time per line is limited to the HBI, which duration is less than one forth of the total horizontal line time. Thus, at the headend, groups of channels are video synchronized in a staggered manner so that their HBI's do not overlap. This is shown schematically in Figure 9(a). Time intervals shown in gray provide a guard interval, during which no injection is required, for switching the center carrier local oscillators among the four channel groups A through D.

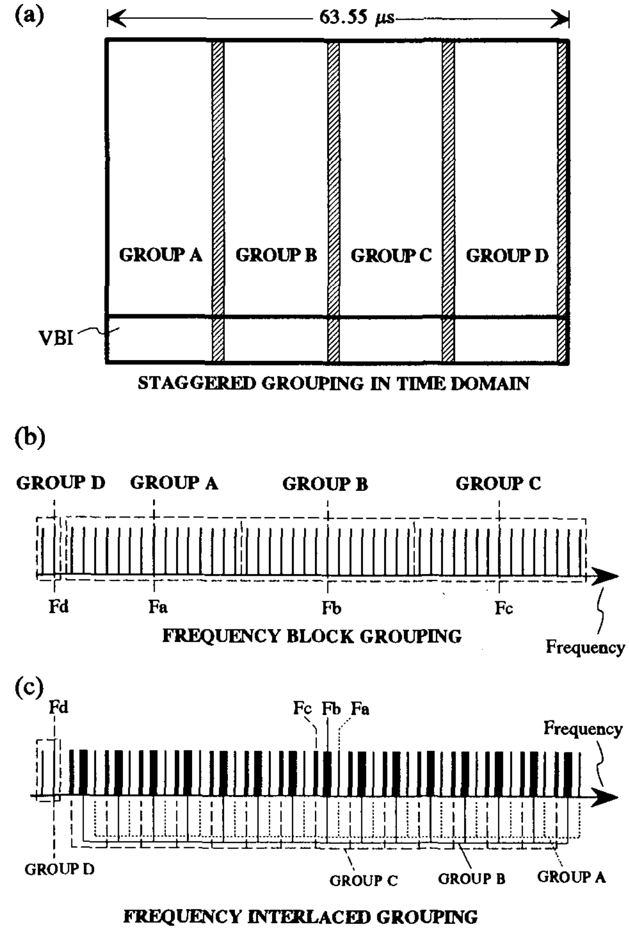

Figure 9. Video Frame Staggering for Time-Shared Utilization of a Digital Broadband Descrambler.

Two possible frequency arrangements for channel assignments for each group are shown in Figure 9(b) and (c) respectively. The first utilizes the frequency block grouping, requiring lower DAC speeds for the same number of channels per group. However, at the expense of faster DACs and RAMs, the frequency interlaced grouping of Figure 9(c) offers potential savings in filtering and frequency swing of a VCO which might be used for the switched local oscillator. In both configurations, the same Digital Broadband Generator performs the required processing for each channel in the four groups by coherent injection during the HBI of every channel. This operating mode requires 4 times more memory containing the required records for each group based on subscription.

IMPLEMENTATION AND OPERATIONAL ISSUES

Hardware Configurations

For the purpose of clarity, Figure 3 shows a single DBG operating on a fixed center frequency. In practice, however, it may be desirable to allow the flexibility for remotely configuring the center frequency of the DBG and perhaps provide several DBG's for processing a larger number of channels. Low cost application of "High Side" 900 MHz center frequency DBG's generating signal groups that can be down-converted to any contiguous channel groups in the CATV band are possible by the use of a "high-side" L band variable frequency synthesizer. Furthermore, using this "high-Side" conversion scheme, a single agile "high-side" Local Oscillator (VCO) can be used with a single time-shared DBG, resulting in spectral processing coverage for up to 4 groups in a manner described in Figure 9(b). Finally, future implementations of DBGs with large channel groups of as many as 60 channels per group can be anticipated with recent commercial availability of GaAs 14 bit D/A converters with sampling rate capability of up to 1 GHz.

Particularly noteworthy is the potential for low cost implementation of Broadband Descrambling in a Multiple Dwelling Unit (MDU) devices incorporating 4 or 8 subscriber ports. In this case, many subsystems such as power supplies, enclosure, DSP, VCO's and data reception can be shared among subscriber units resulting in a cost per subscriber that is significantly lower than that of using addressable set-top converters.

Typical Applications in Tiered and Pay Services

As explained above, the same subscriber processing platform including the DBG can simultaneously descramble some channels, while locally denying others by further scrambling using Sync Null or Random Video Folding as described above. A typical example might illustrate the economic and operational benefit of this approach:

Assume, for example, that today a cable system with 50,000 basic subscribers carries 30 basic channels in the clear and 10 scrambled channels for which addressable descramblers are required. Assume further, that there are 20,000 addressable subscribers in the system and the operator wishes to unbundle the 30 channel tier and offer a Statutory Basic tier of 13 clear channels and the other 17 satellite cable programming channels are to be configured as Expanded Basic. Assume further that only 1000 subscribers (2%) opt for the Statutory Basic without the Expanded Basic. If the operator elects to retier by scrambling all 17 satellite delivered channels, he must purchase addressable converters for 29,000 subscribers (roughly 38,000 set-tops including AO's) and convince his current non-addressable subscribers to accept set-top installations *before* the transition to scrambling. Alternatively, the operator may opt to supply the 1000 Statutory Basic subscribers with band reject traps. This solution suffers from truck roll costs, inflexibility and even outright impossibility of handling the broadcast (Must Carry) channels within the Statutory Basic tier while still effectively trapping all other 17 channels without excessive trap cascades and the resultant signal degradations.

In contrast, compatible Broadband Descramblers can be supplied to the 1000 subscribers of the Statutory Basic tier and they can be addressed for denial of all 17 Expanded Basic channels, while providing these subscribers with full access to scrambled channels on an addressable basis. This can be done without Buy-Through requirements and without the need for addressable set-top devices. As the system employs such Broadband Descramblers, set-top descramblers can be replaced by Broadband Descramblers over time, and an economically graceful migration to full Broadband Descrambling for analog signals can be effected with allowance for digital services pass-through to the home. Hence, the use of Broadband Descrambling can provide the lowest cost and most subscriber friendly solution for dealing with the post Cable re-regulation tiered access control environment.

Installation and Powering

The DBD can be installed at any point, from the pole or pedestal to the side of the house or any other point of entry to the subscriber premises. Also possible, are indoor locations such as the basement, garage, attic or even internal "set-back" devices behind the TV set. The power requirement of Broadband Descramblers may be in the range of 3-5 Watts per subscriber, and therefore a subscriber premises wall mount power supply can feed the device via the coax line. In more external installations, CATV plant powering may also prove to be an attractive powering mode.

Security

Although during the phasing-in period of a compatible migration into cable systems employing sync suppression scrambling the operator will be precluded from employing the new enhanced DBD security features as described above, immediately upon deployment of DBD, other security measures will be available. These measures are local denial on otherwise scrambled channels for subscribers in known pockets of piracy. This will ensure that pirate boxes that are able to illegally descramble existing formats are rendered useless due to the enhanced denial processing that further scrambles the channels to which that subscriber port is not entitled.

Some in the cable industry have expressed concern about the reduction of security in cases where groups of channels are made frame synchronous. Their concern is that the availability of sync timing for one channel supplies the pirate with sync information for other channels. Implicit in this concern, is the assumption that pirate decoders could be constructed to tune to one channel and supply a sync recovery signal for another. This folklore concept may be held by those who are apparently unaware of programmer's operation practices due to which many channels on every cable system are already frame synchronized, and have been so genlocked *for years on every cable system.* The satellite uplink facilities in Hauppauge, New York transmit over a dozen of the most valuable cable channels in video frame synchrony due to "House Genlock" Sync. For example, the following Viacom channels are all frame synchronized to one sync source: *Showtime, Showtime 2, The Movie Channel, Flix, Viewer's Choice 1, Viewer's Choice 2, MTV, VH-1* and *Nickelodeon.* Similarly, the Time-Warner uplink in Hauppauge transmits the following signals in frame synchrony: *HBO, HBO-2, HBO-3, Cinemax, Cinemax 2, Comedy Central* and *USA Network.* Every cable system carrying these channels is doing so in frame synchrony for many years. Yet, after all that time, no dual receiver pirate decoders obtaining sync from one channel to illegally descramble another have been discovered. The fact is that none of these hypothetical pirate decoders are likely to ever materialize, presently or upon the introduction of DBD, because it is much easier for the pirates to employ simple means for illegally modifying existing addressable descramblers to permanently enable them to descramble every premium channel available on the cable system.

CONCLUSION

The specific ability of low cost digital generation of simultaneous multichannel VSB signals with essentially arbitrary amplitude and phase in video synchrony and RF coherence with incoming signals, allows one to provide simultaneous processing of a large group of television channels in a Broadband Descrambler for the purposes of access control. Because the Broadband Descrambler employs an additive broadband processing, it will pass into the home all other unprocessed channels including digital compression signals, thereby allowing compatibility with future digital transmission decoders that are not deployed at the subscriber premises' point of entry.

A Broadband Descrambler can be made compatible with most existing sync suppression scrambling formats and therefore can be installed in a gradual and economically graceful manner. Because Broadband Descramblers can simultaneously descramble incoming scrambled channels while at the same time denying other clear channels, it will constitute the lowest cost method to provide tiering without Buy-Through requirements while providing full compatibility between cable systems and subscriber consumer electronics equipment.

ACKNOWLEDGMENT

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DIGITAL COMPRESSION IN TODAYS ADDRESSABLE ENVIRONMENT

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ABSTRACT

The introduction of digital compression technology to today's addressable system presents a host of new challenges to the industry. With the ability to deliver a vast array of information and entertainment, operators will be faced with the need to easily and seamlessly integrate the digital signal access control within the confines of a relatively mature addressable system environment. While much of the navigating and control will be defined by the user interface in the home terminal, the overall integration of the digital system will also be important to avoid confusion by the consumer.

This paper will address the control system architecture required to enable the variety of services possible, while maintaining the simplicity consumers have become accustomed to in today's addressable environment. The focus will be on the headend and system implications, but will briefly touch on the in-home terminal user interface issues. All aspects of the interface, including video, audio, and data, will be covered.

INTRODUCTION

The cable headend has changed a great deal over the past twenty years. Initially, the headend served nothing more than to receive signals from off air broadcasts and then process the signal for transmission through a cable plant to subscribers who were unable to receive the broadcast signal. Over the course of time, the complexity of the headend has increased as signals are received from off-air antennas, satellites, microwaves, and fiber links, as well as locally originated signals. With 50+ channels of analog video in many of these systems, coupled with scrambling technology and addressability, the need for clean and simple headend interfaces has become critical.

The advent of digital compression will bring about a whole new landscape for the system operator. 500+ channels of video, along with a multitude of data services, will become the norm in the late 1990's. Some of these interfaces will be completely within the control of the operator, while others are likely to be passed through without requiring any intervention. As this convergence of video, voice and data through the headend is inevitable, it is important to step back and review the fundamentals of digital video, the element enabling the convergence, before analyzing the impact on headend and system architecture.

DIGITAL COMPRESSION

Digital compression allows for the carriage of more than one video signal in a standard 6MHz NTSC bandwidth channel. This process was first studied by the video entertainment industry as part of the research toward High Definition Television (HDTV). With an HDTV signal containing at least four times as much information as a standard NTSC signal, compression was all but a necessity for carriage within 6MHz. By applying the same technique to NTSC signals, multiple NTSC signals can be carried within the bandwidth of one NTSC analog signal.

The process of video compression involves several phases. To begin with, the analog signal is divided up into a large number of video pixels. Each pixel is then converted into a numeric value resulting in a signal approaching 100Mbps of information (audio and data packets are included). Transmission of this signal, even using a very robust modulation technique, would require about four standard NTSC signal bandwidths. Therefore, compression is required even to achieve signal transmission of 1:1.

Various techniques of compression are available, with the most promising being discrete cosine transform (DCT). In the DCT process, small areas of information within each frame are compared for similarities. These redundant similarities are then eliminated, leaving only the differential information. By further applying color and motion compensation techniques, the amount of information required to represent similar portions of successive picture frames is reduced.

With only the differential information remaining, a further reduction in the amount of data required is achievable through various mathematical techniques. One such process, Huffman coding, assigns short data codes to frequently repeated data and long data codes to infrequent information. After applying this process, error correction is added to the signal to ensure operation of the system at low carrier-to-noise (C/N). The level of sophistication of the required detection and correction circuitry varies between the cable and satellite environments due to the nature of the transmission media (cable is more rugged since it is a closed environment).

The net result of the completed compression process is a signal with a data rate as low as 2Mbps (2% of original signal). The actual data rate will vary over time, depending upon the source of the material, film versus live motion, and the degree of redundancy in the video. Because the system allows for statistical multiplexing of the combined signal, this data rate will vary over time on a real-time basis.

The complete compressed signal in the General Instrument DigiCipher™ system consists of approximately 30Mbps of information. In the cable environment, the error detection and correction requires about 3Mbps of the data, leaving approximately 27Mbps for the compressed video, audio and data. Access control and encryption is embedded within the signal in the compression process. User feature control can be included in the data, or may be it video, audio, or data. Block A represents the process at the satellite uplink facility, while block B contains the satellite receiver and transcoding equipment required at each cable headend. "C" is the converter in the home. Each of these areas will be expanded upon below.

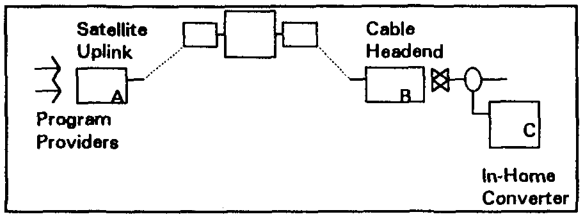

Figure 1 - System Block Diagram

A. Satellite Uplink Facility

The satellite uplink facilities in use today can be readily adapted for digital compression. At these facilities, analog signal will be converted to digital by feeding each signal through the compression process previously outlined. If the plan is to carry six (6) signals within the one transponder all six (6) signals will be fed into the compression system and will be statistically multiplexed with one another, either in total of separately between the I and Q phases. The access control and encryption information is then added to the signal. Each video service within the multiplexed signal can be encrypted with a unique key and can therefore be authorized on an individual basis. If desired, however, the complete multiplexed signal can be encrypted with a single key. Such a process could reduce the cost at the headend and might be viable in certain applications (e.g. NVOD).

Before transmission, forward error detection and correction is added to the signal. As the result of the nature of satellite environment (low C/N, high interference), a complex error correction circuit must be added. The resultant signal is then fed into a QPSK modulator for transmission (FM) over the satellite link.

Figure 2 shows the complexity of the satellite encoder. Due to the real-time requirements, a fully redundant sytem is required. While this significantly increases the cost, on a per subscriber basis the impact is minimal.

B. Headend Facility

The purpose of the cable headend in a digital environment is basically the same as today: receive the signal and process for transmission over the cable network. Instead of analog integrated receiver descramblers (IRD's), digital IRD's capable of decompressing one video signal within each transponder will be used. As compression over satellite will occur before compression over cable, the output of the initial IRD's will be 6MHz analog signals. This signal is basically identical to that from an analog IRD and will be processed similarly at the headend (see figure 3).

With digital compression over the cable plant coming on line in 1994, the utilization of compressed video over satellite for such services as NVOD will explode. With up to ten (10) compressed signals per transponder, the number of individual IRD's and QAM Modulators could become unmanageable. Therefore, a modular approach to the headend system will provide the most cost and space effective solution. This rack-mounted frame with cards, called an Integrated Receiver Transcoder (IRT), will allow for one card per video signal, containing both the functionality of the IRD and a modulator (QAM) as well as acting as an interface to local addressable controllers and cable FEC generator.

Access control for the headend IRD is generated at the uplink facility. The design of the DigiCipher system allows for pass through of the access control signal at the headend or for a new access control signal to be added at the headend. In the first case, only basic transcoding equipment is required at the headend. The basic transcoding cards demodulate the satellite QPSK signal, strip off the satellite error correction and add the lower cost cable error correction, and then modulate the cable QAM signal. This system provides the lowest cost solution for bandwidth efficiencies, but is subject to higher security risks due to lack of segmentation.

The second approach to cable compatibility offers the greatest degree of operator flexibility, growth potential, and security. In this segmentation transcoding approach, the satellite access control is removed from the incoming signal and replaced with system-level access control. This control information can be generated from the addressable control computer resident in virtually every addressable system or could be provided on an individual system level basis over the satellite. With local access control, the same controller which operates the analog converters in the system will drive the digital converters, thereby enabling a smooth transition and not requiring any change in billing operation.

In the future, local system compression will also be an integral part of the overall system. The local compressor will operate similar in nature to the satellite system compressor, multiplexing various analog signals into a single digital data stream. As local ad insertion on digital signals requires the same expensive compression system at the headend (or potentially on a regional basis), it is envisioned that no local insertion will occur in the initial deployment of digital compression. Once this capability becomes cost effective, the segmentation transcoder will be enhanced to enable insertion at a given data rate. As the compression signal maybe statistically multiplexed in many applications and the data rate may vary over time, the local insertion system will need to be designed to operate in a very flexible mode.

Figure 4 shows a typical headend with digital compression signals being received and processed, along with local insertion and access control.

C. <u>In-Home Converter</u>

The in-home converter will receive and demodulate the signal, and decompress the appropriate video. Because of the installed base of analog scrambling systems, the decompression converter will also tune and descramble analog signals. This backward compatibility functionality will enable a smooth transition to digital and permits a single converter solution. Access control will be provided over a single out of band data stream, including authorizations for both analog and digital signals. The user feature set of the converter will expand upon those found in today's analog converters. While the myriad of potential features is beyond the scope of this paper①, it is likely this converter will more appropriately reflect the convergence of a computer into the converter. With the power of digital compression, the need for an operating environment which facilitates navigation and control will be imperative.

COMPRESSION IMPLEMENTATION

The implementation of compression in a cable system will be dictated by the services which adopt the technology. While the advantages of digital compression to the system operator are tremendous in terms of picture quality improved bandwidth utilization, and enhanced security, the costs of the compression system will limit its initial applications to those services which dictate these characteristics the most. Multi-channel pay-per-view and near-video-on-demand services are likely to become the first major adopters of compression because they are nationally delivered, do not require local ad insertion, and will require the highest video/audio quality in order to obtain top dollar from the subscriber. A fifty (50) channel NVOD service will require an operator to purchase transcoding equipment for each of the channels. If this service is offered with a club fee to subscribers, only a small percentage of subscribers will require a decompression converter initially. As the service grows in popularity additional converters can be added on an incremental basis without obsoleting the entire installed base. As the cost of the compression technology is reduced over time, additional services will be carried digitally compressed on the cable system. In each case, digital converters can be added incrementally without disrupting the analog system already in place. With local system control and full backward compatibility, introducing new services will be comparable to how analog services are added today.

The digital compression system will also bring about an extremely cost effective means for delivering data services. As each 6MHz bandwidth will contain several 9.6KBps data channels, various "interactive TV" data services, such as electronic program guides and augmented video services, will benefit from the new delivery means. While many unsuccessful attempts have been made to market such services, digital compression coupled with fiber optics, have eliminated these technical obstacles and brought about, an environment which will readily facilitate consumer testing.

VIDEO ON DEMAND

One potential service which has received a great deal of attention lately and which will dramatically change the headend of the future is video on demand (VOD). VOD is a broad category which encompasses not only movies on demand, but a vast array of on demand information and entertainment. By digitizing video signals and using a defined packetized data structure, the opportunity exists to move blocks of digital information, video, audio, or data, amongst various devices. Information can be stored digitally on high capacity disks and then retrieved on a real-time basis with digital file servers. As the information is requested and retrieved from the server, a packet switcher will route the data to the proper subscriber on demand. The introduction of this approach to on-demand information will dramatically impact the interfaces in the headend, from access control to the billing system. The architectural considerations in the client-server concept requires a paper unto itself and will not be addressed here. Needless to say, however, that the choice of such an architecture will require stringent evaluation as it will alter the operation of the system forever.

SUMMARY

The era of digital technology is upon us. Beginning in 1994, digital compression technology will be integrated into today's addressable environment through an evolutionary process. A variety of new services will be developed to expand the on line capabilities in video, audio and data. To facilitate the integration, careful planning must be undertaken to ensure the transition is seamless to customers. Because this is a new technology within the cable environment, all aspects of the delivery system from the uplink facility to the in-home converter will be affected. By utilizing analog backward compatible converters, subscribers will easily transition to the digital technology.

The DigiCipher™ digital compession system enables a variety of headend configurations, from full pass through of the compressed signal to complete local control. It also allows for the addition of new data services to be integrated into the system at the headend, either from a local file server or from a nationally delivered data service. The end result of such capabilities will be a highly flexible environment in which both the operator and the ultimate customers, the subscribers, reap significant benefits.

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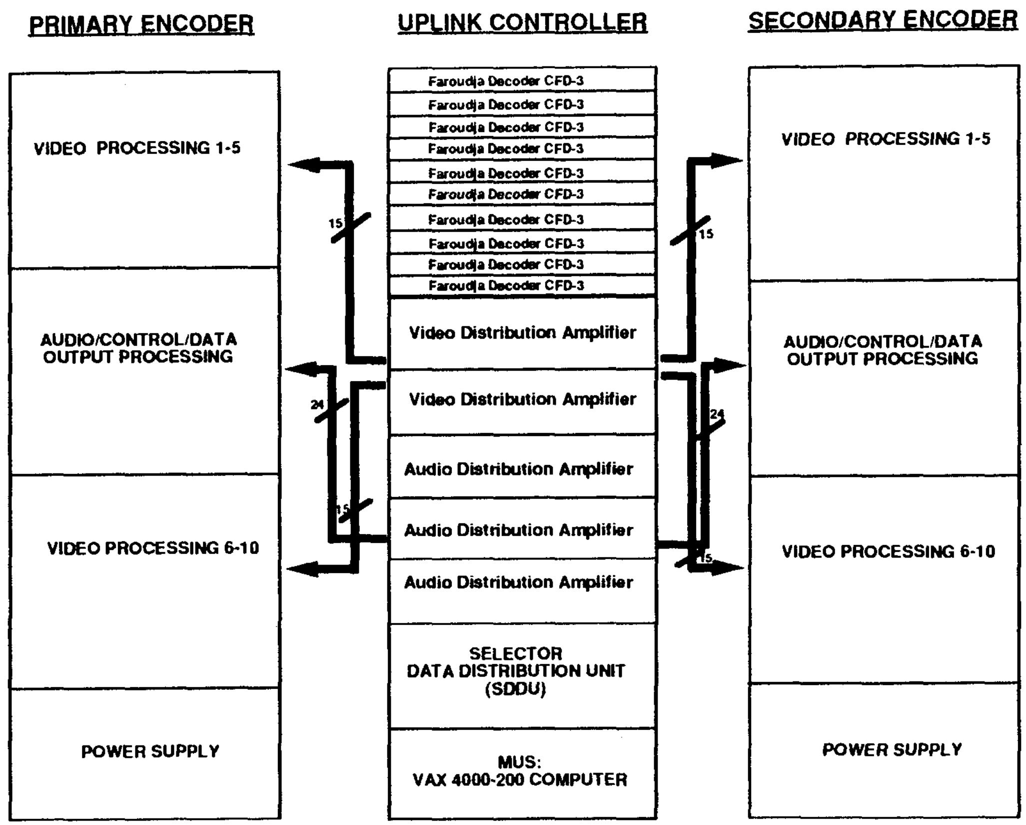

Figure 2: Satellite Uplink Encoder

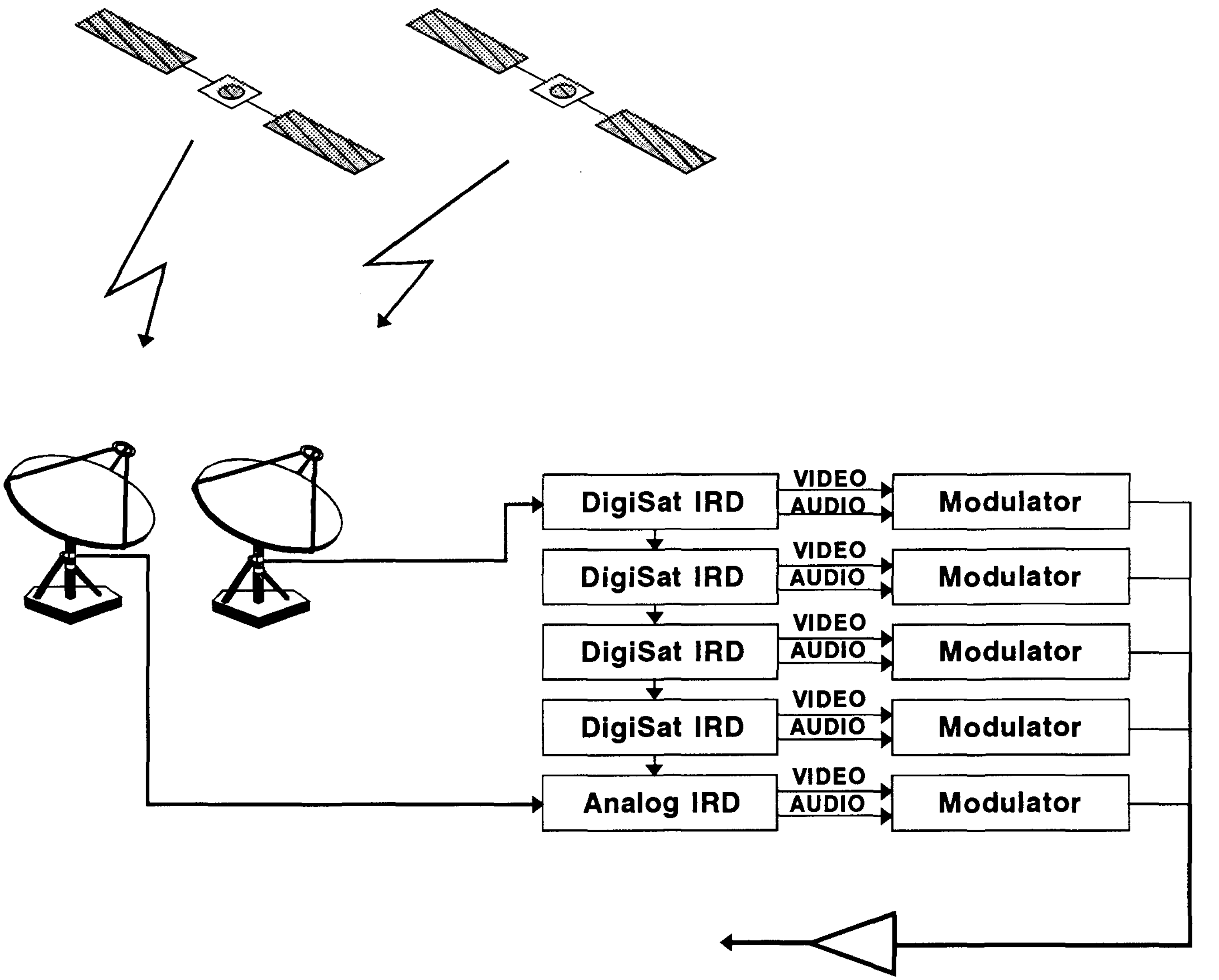

Figure 3: Digital/Analog Headend

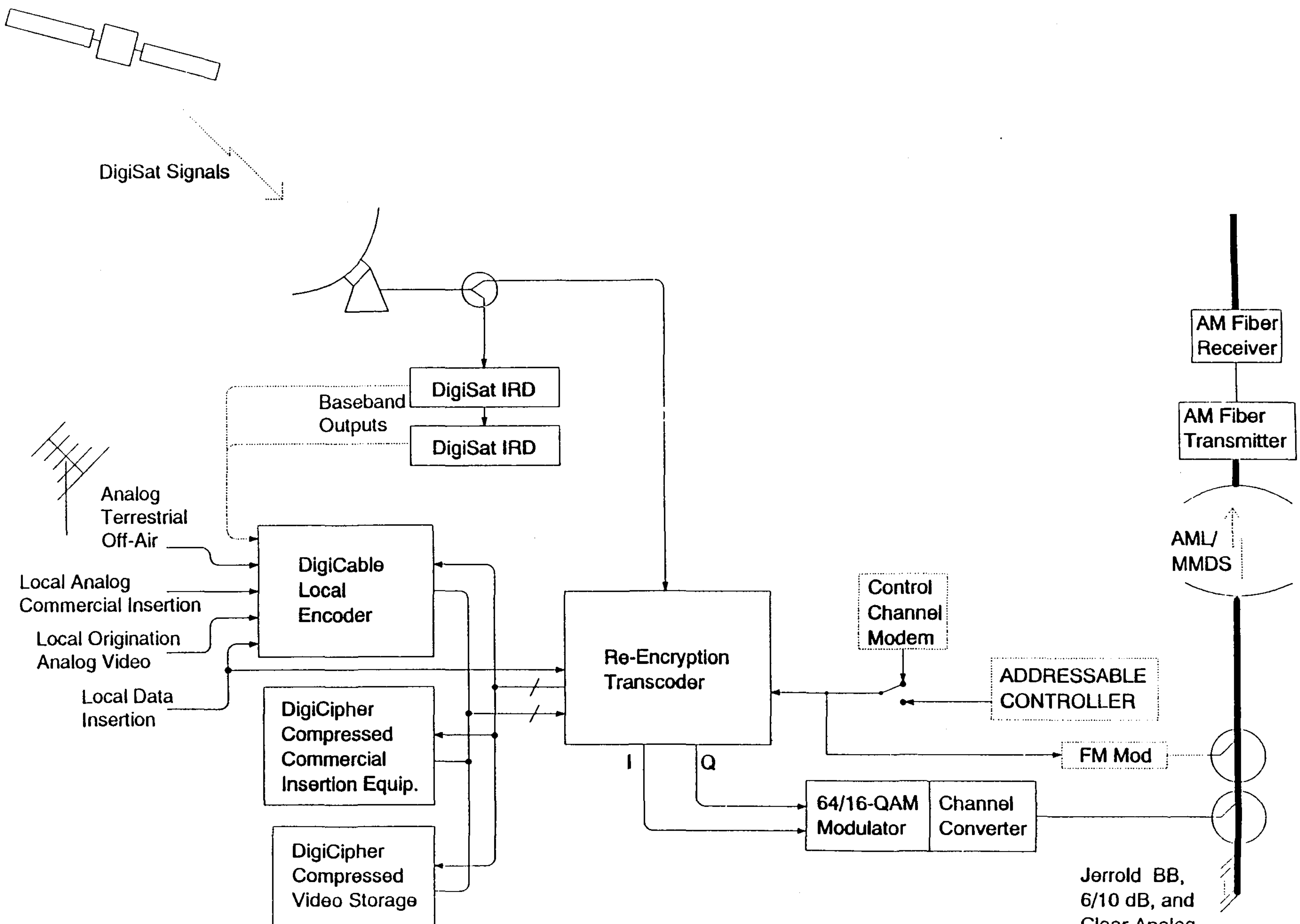

Figure 4: Digital Signal Processing

DIRECT PICKUP INTERFERENCE IN A WORLD WITHOUT CONVERTERS

by

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Abstract

Cable companies introduced converters into the homes of cable subscribers in the mid-sixties to eliminate direct pickup interference (DPU). As cable services expanded, converters were redesigned to increase the tuning range of television receivers from the original twelve channels. Since the converter was effectively a gateway for receiving programs that emanated from the headend into the consumer's television set, the redesign also provided control over conditional access.

New conditional access control systems such as interdiction, broadband descrambling, or Multiport, when used with cable-ready TV receivers, do not require the use of converters. At the same time, however, there appeared to be an indication that this combination of new conditional access control systems with an apparent proliferation of cable-ready television sets would substantially eliminate the protection against DPU provided by the converter.

This paper reports on a study commissioned by CableLabs to determine the extent of the DPU problem which may result in a cable television environment operating in the spectrum of 50 mHz to 550 mHz, without converters.

The study predicts that if the present trend of replacing converters with a different type of conditional access control, and the present design of cable-ready television receivers continues, 26.5% of urban/suburban television households will experience DPU problems from VHF television stations if they are served by cable television. The combined transmissions of VHF and UHF television stations in the 50 mHz to 550 mHz band would cause 47.8% of urban/suburban televisions households to experience DPU problems if they are served by cable television.

INTRODUCTION

Direct pickup interference (DPU) is a particular form of ingress wherein off-air broadcast signals interfere with signals delivered on the same channel via the cable system. DPU was recognized as a serious potential problem from the earliest days of cable television. The problem was temporarily solved by the introduction of CATV converters. Those new converters, built with shielded input circuits impervious to DPU, replaced the TV set tuner.

Responding to the growth of CATV channel capacity and the expanding subscriber base, the consumer electronics industry developed "cable-ready" TV receivers and VCR units. These receivers and VCR's were capable of tuning to all the channels in the CATV spectrum without the need for a cable channel converter. This family of cable-ready equipment included new viewing, recording, and remote control features.

In homes where converters were required to descramble programs, the consumer could not use the desirable features built into the new cable-ready receiver. Where it was possible to remove a converter installed to serve a cable-ready set, the consumer's cable-ready TV receiver often began to experience DPU.

Equipment manufacturers, multiple system operators and CableLabs have been searching for conditional access control methods that would allow the consumer to enjoy all the special features of the new cable-ready TV equipment. Traps, interdiction, Multiport decoders, and broadband point-of-entry control devices are being tried, but the DPU problem persists.

DPU DEFINED

Direct Pickup Interference (DPU) is the name given to a class of co-channel interference caused by the mixing of (1) the desired signal, which enters the TV receiver through the input terminals, and (2) the undesired signal, which enters the TV receiver through one or more other paths. Classically, co-channel interference is caused by the TV receiver antenna's reception of two different signals sharing the same channel.

There are two distinct types of co-channel interference: **coherent** signal interference and **non-coherent** signal interference.

Coherent co-channel interference is caused by the mixing of two signals transmitted on the same carrier frequency, but not necessarily in time-phase with one another. Examples of over-the-air coherent interference are (a) reception of two different TV stations operating on the same channel and locked in frequency, and (b) reception of two or more signals from the same TV station by a direct path from the transmitting antenna and from one or more longer reflected signal paths.

Coherent DPU may occur in a TV receiver connected to cable when TV station signals are carried "on-channel" in an area of high ambient signal strength. Coherent interference manifests itself as one or more ghost images superimposed on the primary or desired image. The per-ceptibility of these ghost images is determined by the strength of the interfering signal with respect to the desired signal and the phase difference between the signals. The strength of the interfering signal determines the contrast of the ghost. The phase difference determines the offset or placement of the image on the screen and affects the visibility of the ghost.

Non-coherent co-channel interference is caused by the mixing of two signals transmitted within the same TV channel but at a different carrier frequency or frequencies. Over-the-air non-coherent interference is caused by (a) reception of two different TV stations operating on the same channel, (b) reception of a harmonic from a two-way radio system or an FM station while the TV receiver is tuned to a TV channel, or (c) reception of spurious signals from electrical machinery while the TV receiver is tuned to a TV channel.

Cable non-coherent interference occurs when the TV receiver is tuned to a cable channel whose frequency spectrum is used locally for over-the-air TV broadcasting, two-way business radio operations, or FM broadcasting.

Non-coherent interference generally manifests itself as alternating light and dark bands which may move through the picture. The contrast between these bands and the desired picture is determined by the relative strength of the desired and undesired carriers. Non-coherent interference can also cause other presentations, depending on the type of signal.

During the early years of television broadcasting, 1945 through 1965, extensive research was conducted into co-channel interfer-ence to determine the minimum required spacing to avoid interference between stations utilizing the same channel. Studies conducted by Mertz indicated that coherent interference becomes imperceptible at desired-to-undesired signal ratios of 40 dB. The work of Mertz was followed by Lessman who found perceptibility present at desired-to-undesired signal ratios of 36 dB. Other studies and published reports from JTAC, TASO, CTAC, RCA, and CBS generally agree that desired-to-undesired signal ratios of 35 to 40 dB are required to avoid coherent co-channel inter-ference. To avoid non-coherent co-channel interference the desired-to-undesired signal ratios must be even higher than for coherent interference. In 1949, the Joint Technical Advisory Committee (JTAC) to the FCC reported that for non-coherent interference without "offset carriers", interference is noted when the undesired signal is less than 55 dB below the desired signal. This 55 dB ratio was confirmed by studies conducted by members of the Cable Technical Advisory Committee (CTAC) to the FCC, concerned with cable broadcasting, over twenty (20) years ago. More recent literature generally accepts desired-to-undesired signal ratios of 55 to 60 dB in order to avoid non-coherent co-channel interference.

THE STUDY

In January 1992, CableLabs asked Stern Telecommunications Corporation (STC) to undertake a study to answer the following question:

What is the extent of the DPU problem that may result from the use of cable-ready TV equipment in a 550 mHz environment without converters?

STC undertook to answer this question by a combination of research -- both a literature search and laboratory experimentation. The literature search included reports of investigations into the cause and effects of co-channel interference, as well as documentation and analysis of DPU complaints from cable subscribers.

For laboratory experimentation, measurements were made of the shielding efficiency versus frequency of a representative sample of recently manufactured cable-ready TV receivers.

In addition, a computer model, designed for this project, was developed. The model analyzed variables of field intensity contours from multiple sources and related the resultant product with census data to develop household counts subject to a specific field intensity value.

METHODOLOGY

Evaluating the potential extent of DPU interference required first that a geographic area for measuring these phenomena be defined. STC chose to use the television industry's designated market areas (ADIs), generally agreed to as the basis for reporting and evaluating program viewership. Using ADIs gave us access to the on-line or published databases that report on television household distribution. For our sample we chose the top ten television ADI's, representing approximately 30% of US households. Furthermore, these ADI's represent a number of different population distributions in relationship to the site of broadcast transmitters. This varied population distribution made possible the extrapolation of results for urban and suburban America.

Having defined the geographic area for assessing the extent of DPU, we established the criteria for determining the number of households that might be subject to this interference. Whether or not a given household experiences perceptible DPU, and the severity of this interference, is determined by many factors.

1. The ambient field strength of the interfering signal with respect to the desired signal;

2. The TV receiver's ability to shield against the undesired signal;

3. The location of the TV set in the dwelling;

4. The channel or channels being viewed;

5. The number of TV sets in a dwelling.

The model considering all of these variables would not only have been unwieldy, but would have required information on the distribution and DPU immunity of all television equipment -- data that is not available. The model chosen defined a DPU "trigger point" of a field strength of 100 mV/meter, making the assumption that all households located in an area with this predicted field strength or greater were assumed to have the potential for DPU. Consideration of variations in the shielding efficiency of different television receivers was not included in the model.

The 100 mV/meter (100 dBu) level was selected after two research efforts were completed. The first was an examination of field service records from several cable television system operators. Their records show a dramatic change in the number of complaints related to DPU as the ambient field strength approaches 100 mV/meter. The second effort was the review of results obtained from our laboratory tests of shielding efficiency on several current model television receivers. The tests showed that each set exhibited visible DPU interference on at least one channel when immersed in a 100 mV/meter

Note

The chart that follows, "DPU Potential in Top 10 ADIs" shows the results of the computer model analysis. The variations in the percentage columns reflect the siting of and the number of television transmitting stations in each ADI.

For example, Detroit has no UHF-TV transmitting service operating at frequencies below 550 MHz, and ADIs 8, 9, and 10 have significant UHF-TV operation below 550 MHz.

SUMMARY OF FINDINGS

- Over twenty years ago engineers in CATV and the consumer electronics industry stressed that DPU posed a serious threat to the growth of the cable TV industry.
- Records compiled by a number of CATV system operators showed DPU complaints from subscribers located in VHF television station ambient fields of 80 to 100 dBu.
- Twenty-five years of laboratory testing shows that DPU problems may occur with desired-to-undesired coherent signal ratios of 35 to 40 dB and with desired-to-undesired non-coherent signal ratios of 55 to 60 dB.
- STC's laboratory tests on a sample quantity of TV receivers in current production demonstrated that all receivers may suffer from DPU from 100 dBu ambient non-coherent sources on all channels.
- Laboratory tests by STC on a sample quantity of TV receivers in current production demonstrated that all receivers may suffer DPU from 100 dBu ambient coherent sources on at least one channel.
- STC's computer modeling predicts that 26.5% of all urban/suburban house holds in the USA, or 18,438,000 households, may be subject to DPU from VHF television stations.
- The same computer modeling predicts that 47.8% of all urban/suburban house holds in the USA, or 35,671,000 households, may be subject to DPU from the combined transmissions of VHF and UHF television stations oper ating at 550 mHz or below.

DPU POTENTIAL IN TOP 10 ADIs
(50 to 550 MHZ)

Area	Total Number of TV Households	Percentage Subject to 100 dBu or Higher	
		VHF	UHF+VHF
New York	6,944,400	26.0%	38.2%
Los Angeles	4,807,700	15.1%	45.4%
Chicago	2,860,600	28.5%	51.8%
Philadelphia	2,642,500	32.4%	58.2%
San Francisco	2,164,100	37.3%	42.3%
Boston	2,045,100	14.0%	40.1%
Detroit	1,712,600	42.1%	42.1%
Dallas/Ft.Worth	1,676,700	15.9%	66.6%
Washington	1,638,900	38.5%	62.6%
Houston	1,447,800	33.5%	62.7%
TOTAL	27,940,400		

Average percentage:	**28.3%**	**51.0%**
Average Percentage Weighted by Number of TV Households:	**26.5%**	**47.8%**

Distributed Processing Encoder for Pay Per View

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ABSTRACT

This paper describes a distributed processing encoder for efficient conditional access control of Pay Per View (PPV) events. The encoder provides rapid deauthorization of subscriber terminals at the end of each PPV event. This permits immediate reuse of a program tag without loss of signal security. This encoder becomes an active part of a distributed intelligence conditional access control system in the CATV headend instead of the conventional passive encoder systems currently in use.

INTRODUCTION

Addressability provides individual control of multiple programs on a single channel. This is accomplished by assigning a unique controlling element (TAG) for each program segment. Initially a tag was assigned to a single premium service or tier of services. Traditional practice uses a separate tag for each premium service and each program segment of a PPV service. Not only should the tag be different, but a sufficient amount of time should have passed since the tag was last used, so that all decoders last authorized to use the tag are now deauthorized. The twenty tag Z-TAC system initially provided more than ample tag capacity for multiple premium and tiered services along with limited PPV offerings.

Over the past few years, the market for recurring PPV has exploded. The need for additional tags has placed a strain on the conventional tag management methodology of controlling programs.

IN-BAND ADDRESSING OVERVIEW

Spectrum conserving in-band addressing is used by the Z-TAC system to provide the conditional access control of individual programs. The Zenith Command Series System Controller sends the decoder authorizations for all premium services, PPV events, and attributes. This global list of decoder authorizations is optimized for recent transactions and data is sent continuously in parallel through all encoders in the system. This same data stream is used to provide remote encoder control and realtime two-way Z-View transaction control.

The system transmits the tag authorizations in four separate RAM group packets of 5 tags each. This is accomplished by transmitting three decoder authorization packets per Vertical Blanking Interval (VBI). The decoder requires four separate data packets to update its full twenty tag authorization profile. There are approximately 10000 packet slots per minute available. Transmitting one RAM group at a time gives a system throughput of approximately 2500 decoders per minute for full authorization via global data.

PAY PER VIEW ENCODER

The RAM group data format, to communicate the individual authorizations provides the means of communicating different data on specific channels. This independent data approach to controlling PPV, allows each PPV encoder to optimize the control of the decoders on its channel.

The PPV Encoder is allocated a particular program tag which is used for each PPV event scheduled on its assigned channel. Subscriber decoders are authorized in a normal fashion by the conditional access control computer; however, the PPV Encoder captures and stores in memory a list of all decoder addresses authorized for a PPV event on its channel. At the end of the event and through subsequent events, the encoder transmits rapid deauthorization commands to all decoder addresses that have been previously authorized for any PPV event on its channel. Since this list of subscribers is typically small in comparison with the global circulation list, deauthorization occurs rapidly, allowing immediate reuse of the PPV event tag assigned to the channel.

PPV transactions , whether from the Management Computer Interface, direct Automatic Number Identification (ANI) input, or Z-VIEW realtime interactive two-way, are processed by the Command Series Controller. The controller maintains the schedule of events, tag assignments, and advance buys. As decoders are authorized for a specific program, the decoder address and its RAM group profile are captured by the PPV encoder. Each PPV encoder keeps a list of decoder addresses authorized for the current program showing on its channel as well as the current program showing on the other PPV channels in its RAM group.

Each PPV encoder independently keeps a list of decoder addresses which have ever purchased a program on its channel. When the current program ends, the current decoder addresses become the highest priority deauthorization output. The decoder addresses are aged as additional programs are shown on a PPV channel. During a single program the 10,800 decoder addressing slots are optimized for the authorization of those who purchased the current program, the deauthorization of those who recently purchased a program on this channel or within this RAM group, and finally deauthorizations are sent to all decoder addresses which have ever been authorized on this channel and are not authorized for the current program.

A load shedding algorithm is used to ensure that each PPV encoder will "to thy own self be true". As additional decoder addresses are added to a "blockbuster special event" the encoder will dynamically reallocate the 10,800 decoder addressing packet slots and 64,000 active decoder address capacity to the event.

Current marketing information indicates that 80% of the PPV transactions come from 20% of the subscriber base. The current buy rates indicate that the PPV loading is 5% for the first showing and decreasing thereafter. An aggregate of 64,000 decoders can be active on the five channels within one RAM group. This PPV capacity can handle even the largest of subscriber systems.

FUTURE USES

The distributed intelligent in the encoder and the capability of circulating different decoder address lists on each channel opens the door for two-way channel monitoring. Unique system defined lists of decoder addresses could be assigned to each channel and polled independently.

CONCLUSION

By maintaining a list of decoders as they are authorized and aging that list as additional programs are shown, a collection of all decoders who have ever been authorized for any program on a given PPV channel are maintained in the encoder. This negative PPV list is sent, independent of the system controller global circulation, by the encoder during each event. This multilayered approach to deauthorization of tags, ensures the exclusive use of a single tag to a single PPV program maximizing the recycling of a scarce resource.

DROP SYSTEM AND COMPONENT PERFORMANCE: EMERGING REQUIREMENTS IN A HIGH BANDWIDTH, 64 QAM DIGITAL WORLD

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ABSTRACT

Digital modulation techniques and refined terminal devices are rapidly becoming available, paving the way for a whole new world of communications and entertainment services to the home. An unanswered question is whether existing drop components and systems are capable of effectively transmitting this digital superhighway traffic. This paper reports on the testing of 64 QAM modulated signals over typical and less-than-ideal drop systems. Also, from a joint Raychem/CableLabs sponsored indoor cabling project, important performance criteria, such as shielding effectiveness and return loss, are reported on for a variety of drop components. Sources of these components include electrical contractor distributors, consumer retail outlets, and typical CATV operator vendors. Digital signal transmitted through drops containing these products show significant Symbol Error Rate degradation, requiring the Carrier to Noise levels to be well maintained. Furthermore, many products being installed today can allow considerable levels of noise into the system, reducing any 'safety (fade) margin' in the Carrier to Noise ratio. Recommendations for insuring a reliable Residential Communications Network are offered.

INTRODUCTION

The CATV industry is rapidly bringing forth improved customer service, picture quality, and multiple service offerings as competition and the ability to fill a broad range of demands grows. Plans for new services and revenues, such as implementing high bandwidth networks and high symbol rate digitally modulated signals, are placing great demands on all parts of the CATV network. Much work has been concentrated in fiber and distribution portions of the network. Until recently, less attention has been placed on the drop. The time is rapidly approaching when the drop, consisting of all components of the system from the tap to the TV set, must meet minimum performance and reliability metrics to assure clean signal. Much can be done in the composition of the drop to improve the quality of CATV under existing AM transmission. Digital compression will further add to the technical considerations of the drop system and will require a substantial general increase in awareness of component performance and reliability.

In the outside area of the drop, the effects of improper installation and corrosion of components are well recognized problems. These problems can be addressed directly with proper component selection and training.

The indoor area of the drop has its own set of issues. Electrical performance requirements are similar to the outdoors, however, component selection and installation practices vary greatly. The operator has little control over these variables due to the wide range of purchasers and installers of equipment, including system operators, CATV contractors, home building contractors, and homeowners.

This paper addresses practices that should be considered for improved drop performance and reliability. There are concerns that the existing drops, particularly the indoor portion, will not always maintain a discernible signal to the TV set. Test results of 64QAM digital signal transmitted over typical and less-than-ideal drop systems are reported.

In addition, individual component performance is characterized to understand product impairments that can contribute to overall drop failure. Products analyzed consist of 'generic' and 'premium' types of cables, connectors, and splitters from retail, electrical supply outlets, and CATV industry vendors. The paper is organized as follows:

1) The magnitude of drop-related problems known in today's analog systems,

2) the technical considerations of an effective drop in a high bandwidth, digital world,

3) the performance of currently available products with respect to these characteristics,

4) actual test results of 64 QAM signal transmitted over drops, and

5) recommended practices for the Residential Communications Network, which should perhaps replace the 'drop' designation, which has connotations of lower levels of acceptable quality, service, and revenues.

STATE OF THE 'DROP' TODAY

The Drop Network

The drop, consisting of all components from the distribution multi-tap to the television set, can have many variations. The ideal drop would be one that has few components from tap to TV, minimizing reflections and cumulative leakage and interference. However, the operator has little control over the inside of the house and many subscribers purchase and install their own equipment. Drops can range from that shown in **Figure 1**, the typical CATV drop with few devices, to that in **Figure 2**, the less than ideal drop. It is not clear how typical the 'typical' drop actually is, as the data above suggest that a substantial number of subscribers install their own equipment.

For example, cables sold at retail outlets often do not have bonded foil and have very low braid counts. Connectors are often tool-less, yet craft sensitive to a degree that often results in poor shielding effectiveness. Splitters often have poor isolation and return loss, as will be shown below.

Problems in the drop

In recent years, the scope of indoor connector problems and service calls due to indoor versus outdoor drop problems has become better understood due to improved tracking and studies. Studies from several systems, performed within the last five years, show the magnitude of the problem as experienced today.

To get a sense of the scope of the indoor problems, one can refer to NCTA studies[1] conducted across three systems of varied geographic and demographic character. Upon examination of all trouble calls (217 total hardware-attributed problems), **Figure 3** shows a large percentage of calls (80%) were caused by drop hardware problems.

Within the drop, **Figure 4** shows that 60% of the problems were indoor related. [In a separate study[2], **Figure 6**, a CLI audit was conducted at an eastern seaboard location. Signal leakage problems were indoor related in 53% of the instances].

Outdoor problems either were due to loose connectors or were unspecified, both likely related to the actual installation of the connectors. This suggests that a connector or drop system that eliminates craft error, and reduces the number of accesses to the F-connector, would reduce outdoor trouble calls. Many of the remaining connector problems were likely corrosion related, a common connector design issue.

Figure 5 illustrates the proportions of the various types of service calls related to the drop. Of the indoor-related problems, a large portion (26%) were related to equipment purchased or installed by the customer. Implementation of programs that help to control subscriber purchases and installation practices have great potential for reducing trouble calls.

Of the in-home components not installed by the subscriber, but by the cable operator, the largest percentage of problems were connector related (25%)(see **Figure 5**). A substantial percentage of service calls (6%) were specifically due to loose connectors.

In a third study[3] of drop-related signal leakage, it was found that:

- 57% of indoor problems were connector related
- 43% of indoor problems were subscriber related
- 70% of indoor connectors were found loose.

The CableLabs Intra-Premises[5] study confirms these results and based on their broad industry survey, the two primary causes of in-home trouble calls are: 1) subscriber related equipment and 2) loose connectors.

Summary

The studies cited above yield different results, yet there are recurring trends in their findings:

1) Over half of the drop problems/service calls are related to indoor products.

2) Connectors account for between 25% and 60% of drop service calls and leakage.

3) Loose connectors are ubiquitous in systems, accounting for half of the connector-related problems.

There is a strong correlation between loose connectors and signal leakage in both the field and the lab. **Figure 7** shows the difference for in shielding effectiveness for standard swivel connectors when loose versus when tight.

The recurrence of loose connectors shows substantial opportunity for improvement in design. One potential solution to this problem is to use connectors that cannot be put on or behave in a 'loose' manner. The other is to train installers well and extensively.

TECHNICAL CONSIDERATIONS FOR FUTURE NETWORKS

The previous section outlined the state of the drop today and problems that require improvement. What are the future implications of sending digital signal down existing drop system.? First we must examine the nature of digital signal processing and potential drop component performance implications.

Nature of Digital Video Transmission and Compression

Proposed methods of digital transmission use two fundamental concepts to send information. The first, compression, uses redundancy elimination schemes to reduce the number of bits required to deliver quality video. The second, bandwidth efficient modulation, increases the bit rate for a given frequency spectrum using special modulation encoding schemes (e.g. QAM).

To increase the number of bits per hertz, digital signal processing must be specially modulated to allow fast data transmission and bandwidth efficiency. Many proposed systems are considering 64 Quadrature Amplitude Modulation (QAM). The RF carrier is digitally modulated with multiple states designated by discrete amplitude and phase combinations. As the QAM level rises, however, the immunity to noise and interference is greatly reduced, because the symbol states are closer together, and therefore more difficult to discriminate.

Figure 8a shows a 64 QAM 'Constellation', where each cluster represents a state. I and Q scales are used where the two axes are separated by 90 degrees. In a vector from the center point to any state, the amplitude is represented by the length of the vector and the phase by the angle made with the positive I axis.

For 64 QAM, each state and each symbol transmitted represents 6 bits of information. There are sixty four possible combinations of a six bit long series of 0's and 1's. Each of these 6-bit word combinations is represented by a state in the 64 state constellation. With 16 QAM, there are 4 bits per state. For 256 QAM there are 8 bits per state ($2^{(\text{bits per state})}$ = QAM level).

The constellation shows many symbols that pass through the I/Q plane over time. In the ideal case, each cluster would appear as a single dot, for clear distinction of symbol states. The greater symbols deviate from the decision state, the more likely the receiver is to make errors determining the transmitted state. This is known as a symbol error. Symbol errors due to reflections or multipath often distort the clusters into oval or diamond shapes.

Another way to look at the closing of cluster gaps, is to use the 'eye' diagram, **Figure 8b**. The constellation looks at symbol transmission in the phase-amplitude plane, whereas the eye diagram looks at the I or Q amplitude versus time.

To reduce the effects of these impairments, adaptive equalization, echo cancellation, and forward error correction can be incorporated into the system. At the receive end, adaptive equalization filters out many impairments, particularly those that are stable and unchanging. Echo cancellation, a bi-directional bit stream identification and cancellation scheme, is used to minimize reflection effects. To further reduce errors, Forward Error Correction addresses the presence of impulse noise and other transients. To the extent that these circuits cannot filter out impairments, the drop network must keep their effects to a minimum.

SER Versus C/N

One of the more informative measurements is the Symbol or bit Error Rate (SER). If plotted versus the Carrier to Noise ratio, as shown in **Figure 9**, the allowed external impairment level can be estimated. The power of this measurement is in its ability to estimate the robustness of a given system, representing the transmission capability, a function of electrical design, of components or systems. This information indicates the contribution that the unit under test is making on the degradation of SER, and the corresponding Carrier to Noise ratio needed to achieve a desired SER.

Today's transmission equipment operates effectively with $1x10^{-10}$ or better SER using Forward Error Correction (FEC). Performance is 'degraded' at $1x10^{-6}$ SER and is rendered 'unusable' at $1x10^{-3}$ SER. Interfering noises must not raise the noise so high as to break the C/N threshold corresponding to these levels. Threshold breaks come in the unpleasant form of cracking and popping in audio, and broken, frozen and/or total picture loss in the video.

IMPORTANT DROP PERFORMANCE CHARACTERISTICS IN A DIGITAL ENVIRONMENT

Component effects on the digital signal can be characterized in two ways. One is transmission effects, such as reflections, that are due to the electrical transmission character of the components. The second type includes those effects that decrease the actual Carrier to Noise level, such as attenuation and interference (signal ingress and impulse noise).

Transmission Effects

Transmission impairments often result in distortion of constellation cluster shapes. These are fairly steady (except for special cases such as 'channel surfing', see below). The SER curve is primarily a representation of the transmission effects, setting the benchmark for noise avoidance.

Reflections

Microreflections are typically measured in the CATV industry by the 'Return Loss' method. Reflections can result in the reflected signal interfering with forward signal causing standing waves, constellation cluster distortion, and increased SER.

Port to Port Isolation

Without good port-to-port isolation in splitters, interference of one downstream reflected signal can affect the other. This can combine with other microreflections to distort and enlarge constellation clusters, increasing SER further.

One such combination comes from the practice of 'channel surfing', a rapid changing of channels in search of the preferred program. Reflections received at a television set often come from an adjacent TV connected to the same splitter. As the adjacent set is being changed, the reflections that are not well isolated at the splitter may well travel toward the other terminal, causing an error burst.

Carrier-to-Noise Effects

Although the acceptable Carrier-to-Noise level based on SER versus C/N curves appears to be quite acceptable, there are often many sources of noise that components must be able to withstand.

Signal Ingress

Signal ingress is measured by Shielding Effectiveness. When the Shielding Effectiveness of components degrades, external RF interference decreases the Carrier-to-Noise ratio causing an increased potential for threshold crossing.

If signal ingress occurs, error bursts may result. Examples of strong transient RF sources are two-way radio, pagers, cellular signals, or multipath geographic reflections.

If the ingressive signal is due to multipath, the terminal receives a secondary signal that is slightly delayed relative to the primary signal. For analog, the result is ghosting. For digital the result is frequency-selective fading because of signal cancellation or inter-state interference due to time delay.

Impulse Noise

Impulse noise can be induced by electrostatic discharge, machinery, electrical arcing, lightning and other system transients. Effects of localized activation of electrical equipment near the drop has been shown to impress approximately 7 dB of additional noise across the drop frequency spectrum.[4] This is likely to vary significantly depending upon the situation. Significantly high field Impulse Noise measurements have been mapped by NYNEX for ADSL applications and were found to cause 50% receive errors for Telco applications.[9,10]

Attenuation

Though the Signal to Noise ratio can drop quite low in digital systems and still provide excellent quality, recommended operation levels should be strongly adhered to. Maintaining high carrier levels to the drop without inducing noise, will assure a higher 'safety margin', allowing ingress and impulse noise to be impressed upon the system without affecting picture quality. If the carrier is allowed to decrease, failures will not be as forewarning as the gradually degrading analog signal. A pictures will look fine until the threshold is met, at which time it is destroyed.

Implications of Higher Bandwidth

High bandwidth systems are being proposed at anywhere from 1 to 1.2 GHz. Both higher attenuation and greater signal leakage are experienced with increased bandwidth. Greater signal leakage occurs with higher frequency because the shorter wavelengths are more difficult to shield with decreasing wavelength interfaces. Reflections are also affected by high frequency, making maintenance of the impedance match more difficult with decreasing wavelength.

Due to the attenuation and tilt characteristics of most products at 1 GHz and the need for reduced actives in the distribution plant, it is important that the capabilities of drop components are understood. Most systems design or have taps in place with outputs of 10 +/- 5 dB. With FCC regulations requiring 0 dB to the video terminal, all products going into the home, regardless of source, should be the industry's concern. Estimates of the number of TVs per home vary, but 2 to 4 sets are common. The existence of multiple set homes requires that the indoor drop have good shielding to minimize cumulative leakage and low attenuation in order to serve all terminals with adequate levels.

PERFORMANCE OF TODAY'S DROP PRODUCTS

Considering the above implications, how well do existing components rate? Several of the existing products have been evaluated out to 1 GHz. The products were purchased from a cross section of CATV industry, electrical supply store, and retail outlet sources. The CATV products tested are those popular among Cable operators. The electrical supply sources are those from which electrical and home building contractors might purchase. Retail outlets are all chain retail stores tailoring to the hobbyist or 'do-it-yourself' customer. The tests performed, and the drop component tested is indicated in the table below.

COMPONENT	TEST
Cable	Shielding Effectiveness Signal Transmission (Attenuation)
Connectors	Shielding Effectiveness
Jumpers	Shielding Effectiveness
Splitters	Return Loss, Port to Port Isolation, Phase Shift vs Frequency

Splitters

A total of six splitters were tested for Return Loss, Port to Port Isolation, and Phase characteristics. Most of the splitters were specified for under 600 MHz. One premium CATV industry 1 GHz splitter was also evaluated. Though most splitters were rated for lower than 1 GHz, all were tested to the full spectrum to understand what they would be capable of if exposed to all frequencies. Two of the splitters were CATV industry products, while the other four were retail products. The construction and performance of the splitters placed them naturally into the following four groups:

1. Premium Retail
2. Standard Retail
3. 600 MHz CATV
4. 1 GHz CATV

Return Loss

The six splitters tended to naturally fall into the four categories of curves based on Return Loss results. Representative curves for each of these categories are plotted in **Figure 10**.

Return Loss Summary

Splitter	550MHz	1GHz
CATV 1 GHz	-22 dB	-25 dB
CATV 600	-21 dB	-5 dB
Premium Retail	-13 dB	-19 dB
Standard Retail	-7 dB	-5 dB

Performance varied over a wide range from approximately -5 dB to -25 dB. At 550 MHz, the CATV industry splitters (at -20+ dB) were approximately 7dB better than that for the premium retail splitters, and approximately 13dB better than that for standard retail splitters. The return loss of the CATV splitters over their specified frequency range was significantly better than that of the retail splitters. The 600 MHz rated CATV splitters rated as well as the 1 GHz up until the specified (600 MHz) frequency.

Port-to-Port Isolation

The port to port isolation of the splitters over their specified frequency range exceeded 20dB for all six splitters tested. There was no more than a few dB difference between the level of isolation for the retail splitters versus the premium versions. **Figure 11** shows all the results on one graph, as they all fall below 20dB.

A typical directional coupler demonstrated a return loss of approximately 20dB and a port to port isolation of approximately 30dB over a frequency range of 10MHz to 600MHz **(Figure 12)**. In cases where the isolation of existing splitters does not effectively isolate unwanted reflections and noise, a directional coupler should be considered. In homes where the indoor architecture is home run and the signals into the home are sufficient, this may be an approach worth considering. (That is, if improved splitter isolation is not available).

Phase Changes

The effect of phase noise can be significant with regard to QAM modulation schemes. Although not yet fully understood, phase related non-linearities and phase shifts through shared passives may be important. Though adaptive equalizers can accommodate a substantial degree of phase distortions and reflections, this data is included for reference purposes.

The phase shift for the CATV splitters, that is, the change in phase occurring as signal passes through the component, was close to a linear function of frequency. The retail splitters, on the other hand had a widely varying phase shift. Typical plots are shown for a premium CATV splitter **Figure 13** and a standard retail splitter **Figure 14.** All measurements were normalized to the reference standard, a cable sample with a Regal F-81. The F-81 was exchanged for the splitter in each test.

The other measurement regarding phase is the measurement of the phase shift of input to output versus the phase shift as signal passes into one output and out the other. This simulates the difference of signal phase that a television might see as a result of a forward signal that is coupled with reflections from an adjacent terminal, such as a TV or converter with poor return loss. Plots show very different phase change characteristics in this case, **Figures 15 and 16.**.

Connectors, Cable, and Jumpers: Shielding Effectiveness

The components tested and summary of shielding effectiveness testing are listed in **Table 1**. In all, 16 connectors, 12 cables, and 7 jumper products were evaluated.

Components were tested using the Transverse Electromagnetic Method (TEM) of shielding effectiveness testing (**Figure 17**). Three of each of the samples were tested. Each sample was measured and rotated 90 degrees in the chamber to achieve four measurements per sample.

Results summarized in **Figure 18,** are divided into connector, cable, and jumper categories. Connectors did not show as much variation in shielding as the other categories, although some variation occurred with values at 72 +/- 8 dB. Cable samples differed substantially more, measuring 84 dB +/- 16 dB. Jumpers, showed the highest variability and lowest performance as a group, measuring 52 +/- 19 dB.

For a given cable, various connectors showed little difference in shielding effectiveness, whereas cable shielding varied significantly. This shows that the effect of cable is far stronger than the effect of connectors on the F-interface shielding effectiveness. Again, the greatest variance and poorest performance category were the jumpers.

Connectors

Twist-on connector performance is comparable to the crimp connectors, depending upon design. Of the retail connectors, the two-piece crimp versions consistently performed as well or better than the one-piece versions. This was interesting, as there is a perception that the two-piece connector is of much lower quality. When these are installed properly, as done for this test, they perform quite well.

The problem lies in the substantial care to get that proper installation. None of the connectors were sold with crimping equipment. This is not a problem in a test lab but the homeowner is not likely to be as adequately equipped. The two piece connectors took extra care to get the crimp ring into place. Twist-on versions did not require tools but they did take extra care to assure that the dielectric of the cable was flush with the connector mandrel face.

Cables

Cable shielding, as mentioned above, varied significantly. There is some correlation in shielding to braid coverage, but other factors are involved. For example, the best performing cable, out-shielding even the CATV industry quad cable, was a 60% braided electrical supply house sourced cable. Also, a 9% coverage cable did shield better in this test than several cables ranging from 30 to 67% coverage. The 9% braid sample did have good aluminum tape coverage of the dielectric. The high percentage braid coverage cables tend to have better shielding, but the presence of tape and other factors may be of equal significance. This should be taken into accout when considering a construction-based standard.

Jumpers

The jumpers tested all had low braid counts and in two cases had no tape over the dielectric. Both cases where no tape was used had very poor performance. The other low rating performers had low braid count. It is suspected that, in part, poor shielding can be attributable to assembly techniques. Due to the high speed at which some low cost jumpers are manufactured, proper assembly may be compromised. Inspection is also difficult due to the over-molded construction used by many of the manufacturers.

Jumpers are sold for application after the set-top, typically for use between the VCR and television set. However, these are now found installed and will continue be installed between the wall plate or subscriber-installed splitter and the set-top.

Cable Signal Attenuation

Signal transmission tests revealed that the attenuation for the CATV products were substantially better than those from other sources, (**Figure 19**). Throughout the retail and electrical supply sourced products the 6 had lower attenuation than the 59 as expected. However, the CATV 59 was better than even the retail/electrical supply -6 products. In fact, at 1 GHz the CATV industry cable shows 8 dB attenuation as compared to a retail -6 cable attenuating almost 12 dB. Again, as with shielding characteristics, attenuation should not be based too readily upon the construction of the cable (in this case whether or not the cable is '59' or '6').

SUMMARY OF PRODUCT PERFORMANCE FINDINGS

The level of performance necessary for drop components will no doubt vary depending on ambient conditions. However, considerations of potential problem areas have been outlined. The data given here can serve as a reference to performance of existing products. The best way to determine component performance levels required is to conduct or refer to actual digital field studies and determine tolerance levels. Conclusions based on the product performance evaluations are listed below:

1. Extra precaution should be taken when purchasing jumpers. Workmanship and/or quality of construction affect the quality of the jumper shielding performance.

2. When properly installed, most connectors will shield comparably. Care must be taken to assure connectors are installed properly, as tools rarely are sold or recommended with retail connectors. All connectors tested in this study were carefully installed.

3. An unexpectedly wide variation in shielding effectiveness exists between various cable brands. If a minimum cable construction is to be specified, the tape construction as well as the percentage coverage should be included. The best standard would involve actually testing samples. Shielding cannot be accurately predicted based solely on the existence of tape or the braid coverage.

4. Cable attenuation, as with shielding effectiveness standards, will be substantially more reliable if based on actual measurements of products as opposed to construction. For example, some -59 CATV industry products attenuate less than -6 retail products.

5. Port-to-port isolation for all categories of splitters was better than 20 dB. For optimal port-to-port isolation, the use of the directional coupler (better than 30 dB) is recommended.

6. The return loss of retail products are significantly lower than the industry products. This may pose a threat to signal encoding, depending upon effectiveness of error correction, echo cancellation and adaptive equalization techniques..

DIGITAL DROP SYSTEM TEST RESULTS: 64QAM TRANSMISSION

Several drop configurations were tested to determine the range of digital signal impairment that may be expected. Constellation charts, eye diagrams and SER (Symbol Error Rate) versus C/N (Carrier to Noise) information were utilized.

A Line Diagram of the test setup is shown in **Figure 20.** Signal generation and analyzer equipment operated at 50 MHz. Frequency was upconverted to 850MHz to simulate levels that may be expected in future networks. The symbol rate was 5MHz, hence a 30 Mbit/s transmission rate. Baseband filters were not used in order to be able to attribute impairments to the drops under test. Results are therefore probably slightly worse in actual practice, for it is likely these would be used.

The reference SER vs C/N curve, **Figure 8**, shows the effects of transmitting through the test equipment alone. The lower level curve represents the theoretical ideal, where the right curve is the actual. At $1x10^{-6}$ SER the there is little (2 dB) discernible additional requirement, or 'implementation margin', in the Carrier to Noise ratio.
Two models, encompassing a broad range of conditions that the signal will experience, are reported on here. One is the best case, with the so called typical drop architecture shown in **Figure 1,** utilizing higher grade products. The other is the worst, 'less-than-ideal' case, modeled after the drop in which the subscriber has installed several retail products, **Figure 2.** The drop components used in each model are listed below. 'CATV grade' represents products which are popular among system operators. 'RL' represents approximate Return Loss at 850 MHz.

Best Drop

- Cable, 150 feet CATV grade -6
- Ground Block, 17-18 dB RL rated
- Cable, 5 feet CATV grade -6
- Splitter, 1 GHz rated, 23 dB RL
- Cable, 30 feet CATV grade -6
- Wall Plate, 15 dB RL rated
- Cable, 5 feet CATV grade -59

Worst Drop

- Cable, 150 feet CATV grade -59
- Ground Block, 12 dB estimated RL
- Cable, 5 feet CATV grade -6
- Splitter, 600 MHz rated, 10 dB RL
- Cable, 30 feet CATV grade -59
- Wall Plate, 15 dB RL
- Cable, 3 feet retail
- Splitter, standard retail, 6 dB RL
- Cable, 25 feet retail -59

Note: The carrier in the worst drop case attenuated almost 20 db from the tap to the TV set.

In the ideal drop case, the SER vs C/N graph, **Figure 22,** shows very little implementation margin (1 dB), versus the test equipment reference. The Carrier-to-Noise ratio thus required is approximately 26 dB at 10^{-3} SER and 29 dB at 10^{-6} SER. From the Constellation and Eye Diagrams, **Figures 23 and 24**, we see that in this ideal case, the drop has a constellation with very tight clusters.

In the worst case, 'less-than-ideal drop', deviation from theoretical is about 5 dB, which is substantial (See **Figure 25**). Thus for an error rate of 10^{-3}, almost 30 dB C/N is required, and for 10^{-6}, 37 dB C/N is needed! Though significant, drop signal *usually* reaches the TV set well above this. Note the constellation diagram, **Figure 26**, showing the more scattered nature of the state clusters. The diamond shape of the clusters show that the increased distortion is due to reflections. In the eye diagram for this case (**Figure 27**), ripple in the left side of the eye opening reduces the time and degree of symbol state separation, and is due to reflection perturbations.

To determine the cause of the reflection and impaired signal, attenuation pads were placed between the two splitters. The effect of doing this was that it not only attenuated the carrier, but also the reflection. As a result, the reflected signal is reduced into the noise floor and the carrier is lowered. The eye diagram in **Figure 28** shows that ripples were no longer discernible. The signal versus time proves to be noisy but it is ripple free (a constant width, yet noisy trace). The difference in results, due to attenuation between splitters, suggests the problem is with standing waves between these two low-grade passives.

When the splitter ports were terminated with 50 feet of cable and a Television set, SER increased significantly, depending on the channel. The phase of the reflected signal changed as a function of the channel setting. Receivers would ideally be able to correct for fast-changing, multi-reflections.

Effects that can close the Carrier-to-Noise safety, or 'fade' margin, include impulse noise and ingress. As shown above, the effect of loose connectors can greatly decrease the shielding effectiveness of the connector and hence close the threshold margin. Impulse noise, which can give a wide range of hits to that margin[4,9], could add to the ingressive noise due to the loose connector combined with strong ambient RF.

With the effect of attenuation, especially at high frequencies, the carrier degrades substantially, directly effecting C/N. Low attenuation cable will reduce low carrier problems, as will proper engineering of the feeder-line-to-drop transition.

CONCLUSIONS

Digital transmission through the cable drop network looks very promising, though care must be taken to assure positive results. The following findings, regarding the state of cable systems and components today, should be understood and addressed.

1. Indoor cabling practices are a major cause of existing trouble calls, primarily due to
   - Loose connectors (also a major problem outdoors)
   - Subscriber installed products

2. Indoor component performance is substantially lower than that of outdoor. Shielding and return loss performance of many of the products that are likely to be in homes are extremely poor compared to the CATV operator products. Specifically,
   - Jumper shielding effectiveness is consistently very poor.
   - Cable shielding is varies widely.
   - Cable attenuation is varies widely.
   - Retail splitter return loss is poor.
   - Construction of the cable, such as braid coverage and 59/6-designation, is not always a reliable indicator of performance quality.

3. Based on tests of random bit generated 64 QAM digitally modulated signal, the drop does not appear to pose a major barrier to compression based services.

   - In the worst case, the drop will likely need a Carrier to Noise level of 30-37 dB to assure adequate signal (for 10^{-3} and 10^{-6} SER, respectively).

   - Although 64 QAM is very promising, in-home practices may pose a threat in cases where sufficient Carrier-to-Noise is threatened, especially if

     1. Engineering precautions are not taken to assure consistently adequate carrier levels.
     2. Retail splitters and other passives are used excessively, causing extreme reflections and carrier degradation
     3. Connectors are not tightened, especially in high ingress areas.
     4. Impulse noise is excessive. Combinations of the above scenarios will increase the chances of exceeding the threshold.

RECOMMENDATIONS

Based on test results and the many variables to consider, (none of which is insurmountable), the following recommendations are offered.

I. Work to control practices and products used in all areas of the drop. Standards must be rapidly implemented in the industry. The In-Home Cabling Sub-committee of the SCTE, CableLabs, and the NCTA are currently addressing quality practices. The SCTE, for example, has a three phase approach that should be supported:

   1) Publish a consumer guide for the electrical contractor and homeowner, to be provided by the CATV operator.
   2) Publish a comprehensive technical manual of practices.
   3) Create a 'Stamp of Approval' process for retail products.

   A comprehensive plan for awareness building in all industries is included in the CableLabs Intra-premises Study.[5]

II. Avoid splitting in the home. Home Run Architectures should be used whenever possible. All unused ports should be terminated to 75 ohms.

III. Sufficiently high carrier levels should be maintained. This is important to do proactively, as there will likely be little warning based on picture quality that will alert the operator that signal is degrading.

IV. Appropriate components should be used.
- Connectors should ideally:
  1. Eliminate craft sensitivity and be designed in a way that they can not be put on in a 'loose' manner.
  2. Rarely be connected/disconnected, perhaps permanent where practical (mostly outdoors), to statistically reduce the chance of a loose connector installation
  3. Be sealed, as this will reduce the chance of ingress due to corrosion.

- High bandwidth, low Return Loss splitters, splices, and passives should be phased into the drop network.

- In the home, circuit protection should be considered to reduce the chance of impulse noise problems.

V. Consider utilizing decompression and analog conversion at a Demarcation Box/Residential Gateway. This could do some or all of the following:

- Keep digital signal from entering the home
- Assure robust signal into the home through simple, low bandwidth amplification
- Remove unwanted set-tops from the home and share electronics cost of boxes
- Provide controlled security.

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Figure 1
Today's Typical/Ideal Drop System

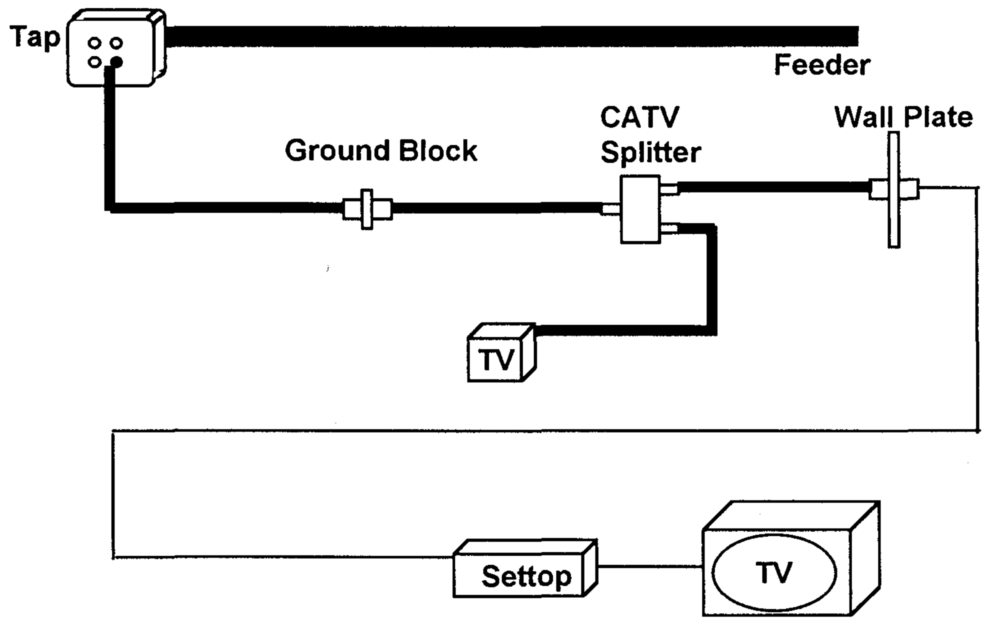


Figure 2
The Less-Than-Ideal Drop System

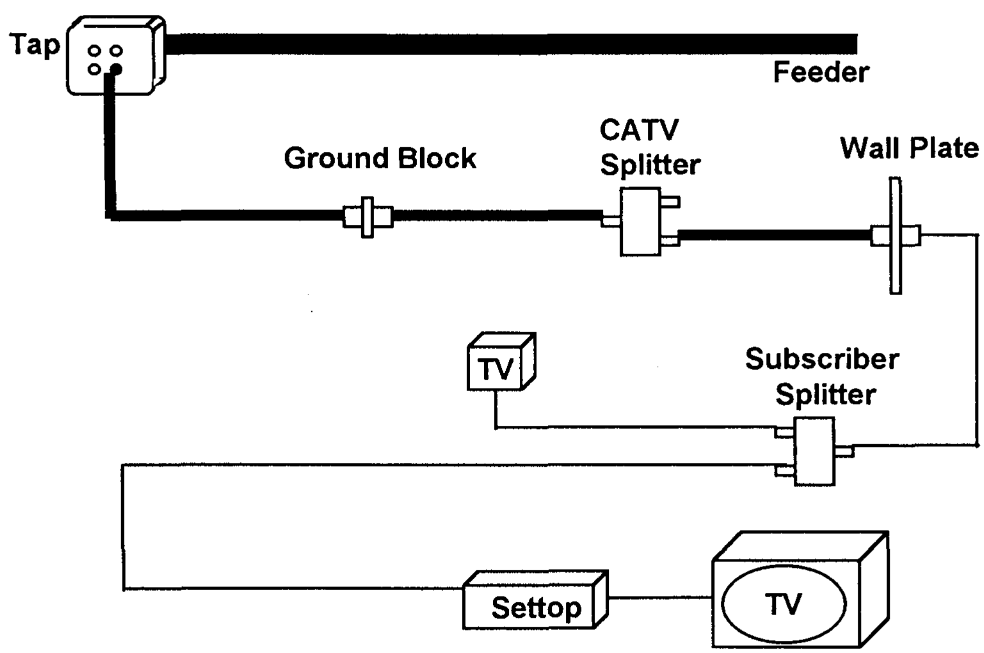


Figure 3
Summary of All Service Calls

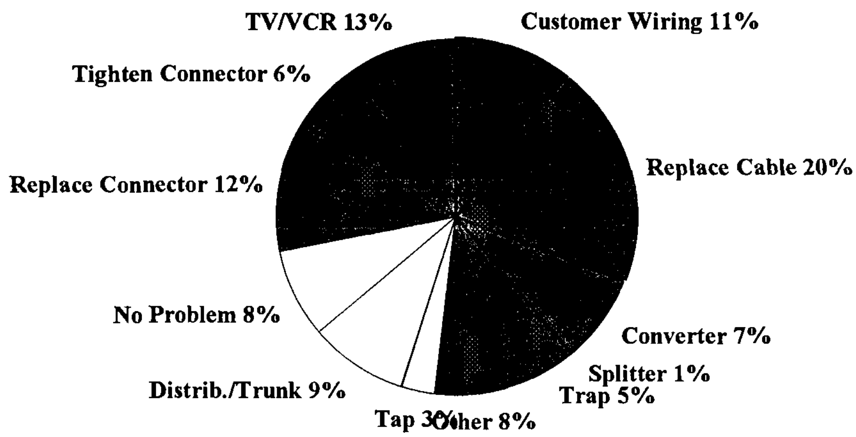


Figure 4
Drop Service Calls Only

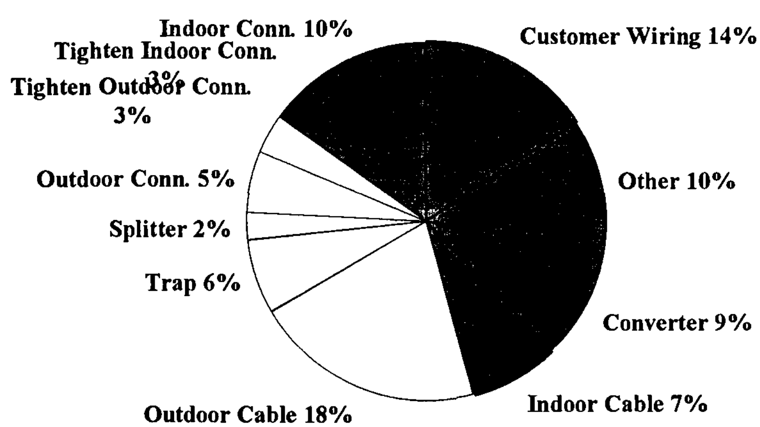


Figure 5
Indoor Service Calls Only

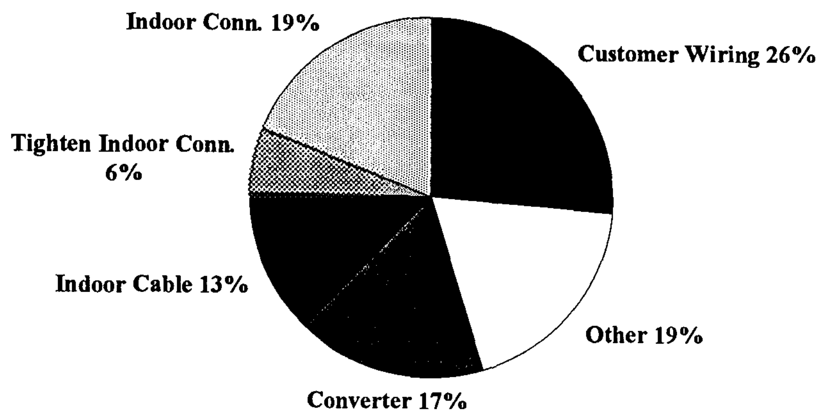


Figure 6
CLI Audit Study

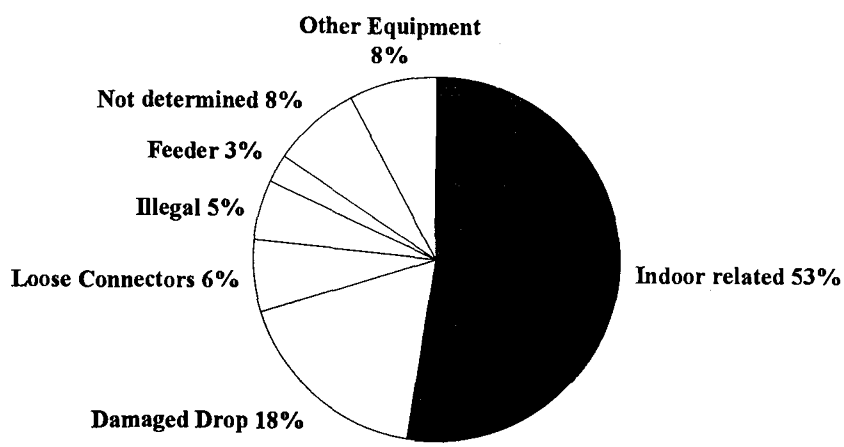
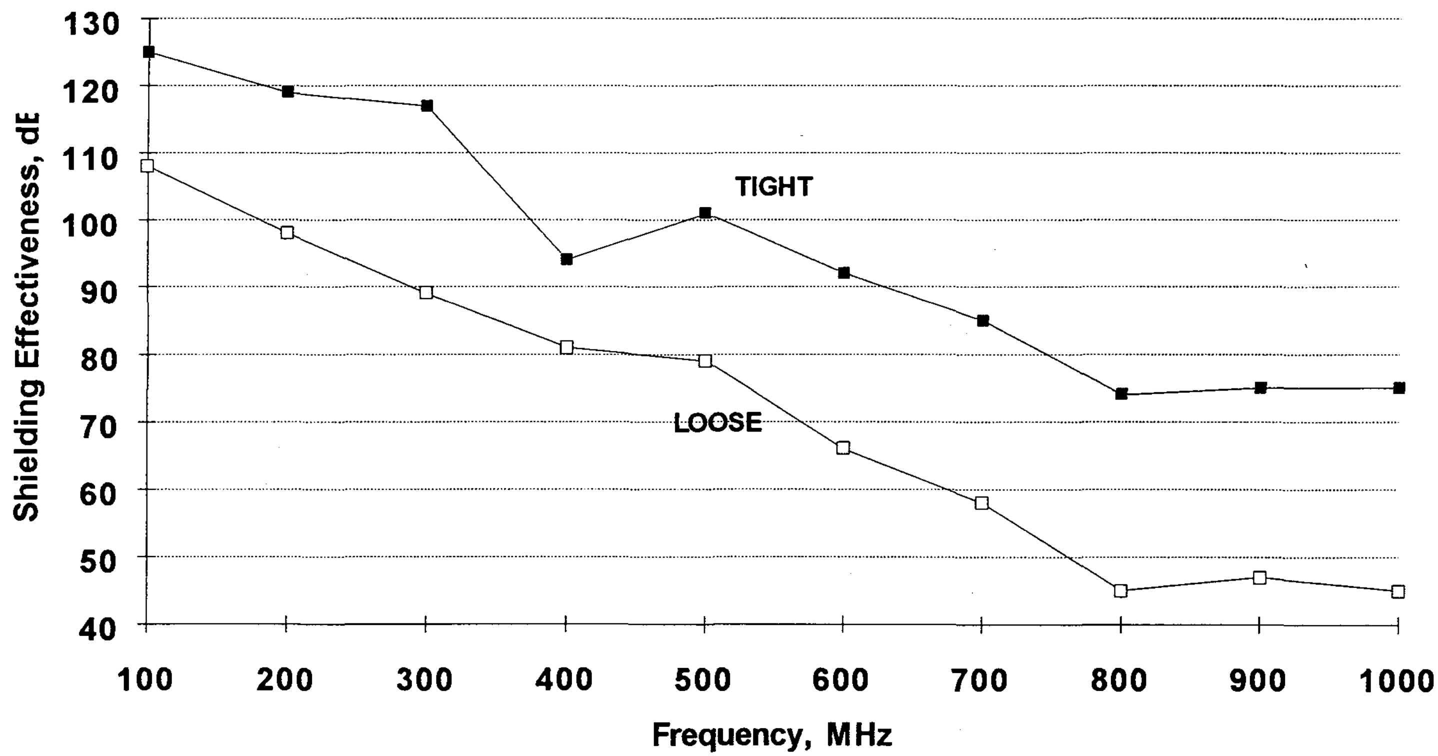


Figure 7
Shielding Effectiveness
Standard Swivel Connector



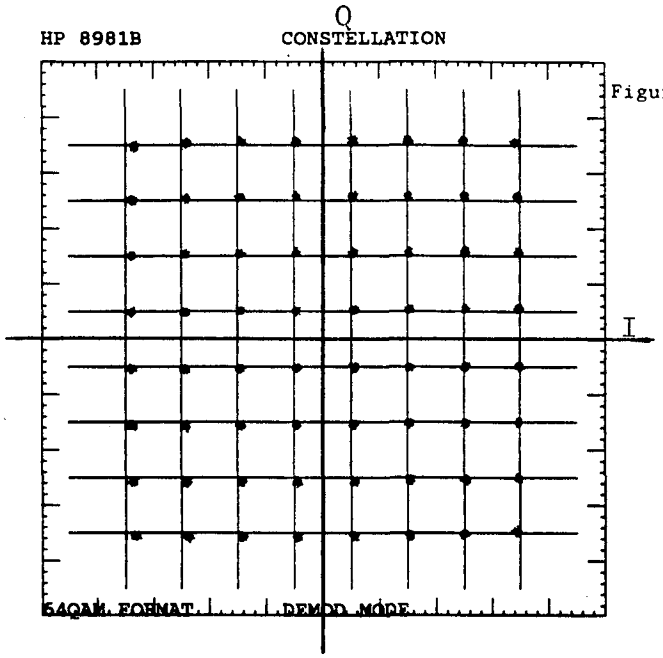


Figure 8a.

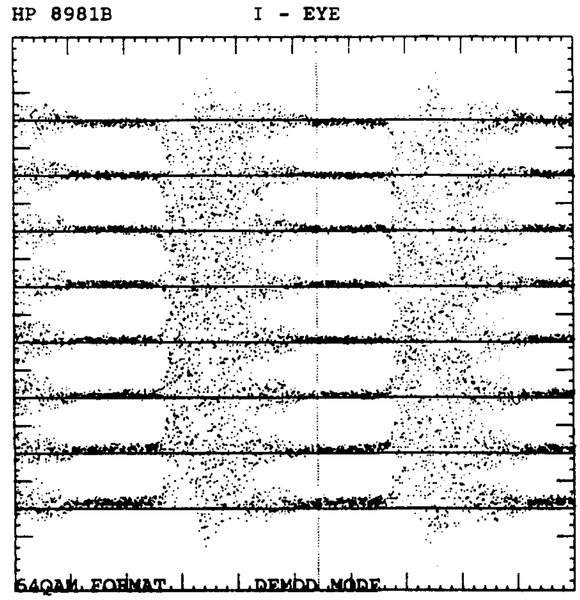


Figure 8b.

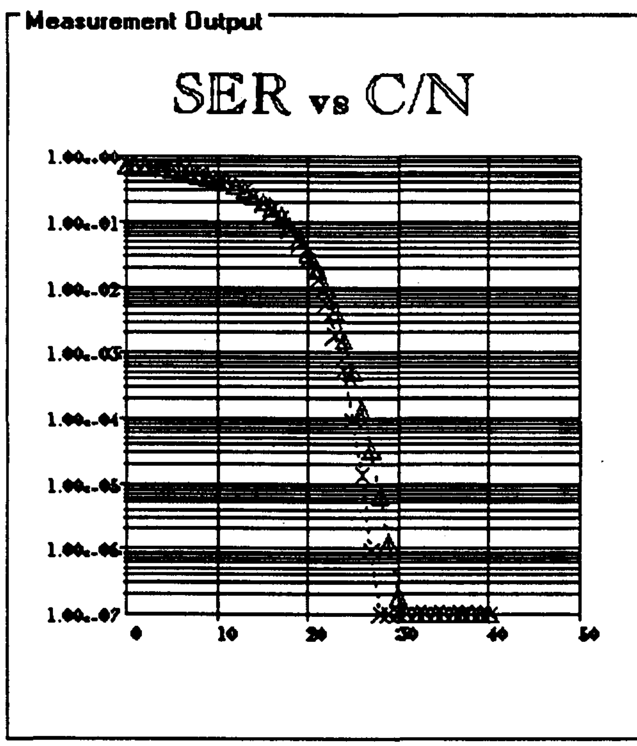


Figure 9

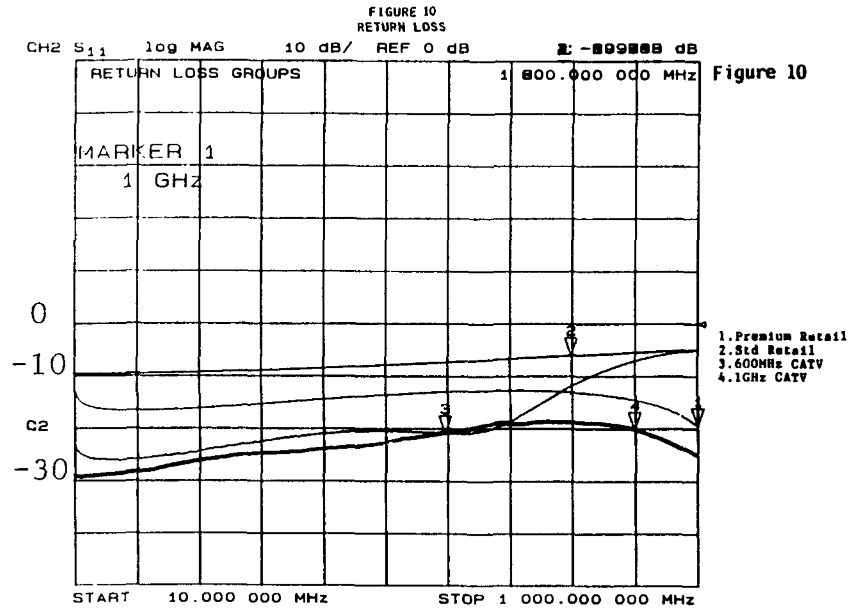


Figure 10

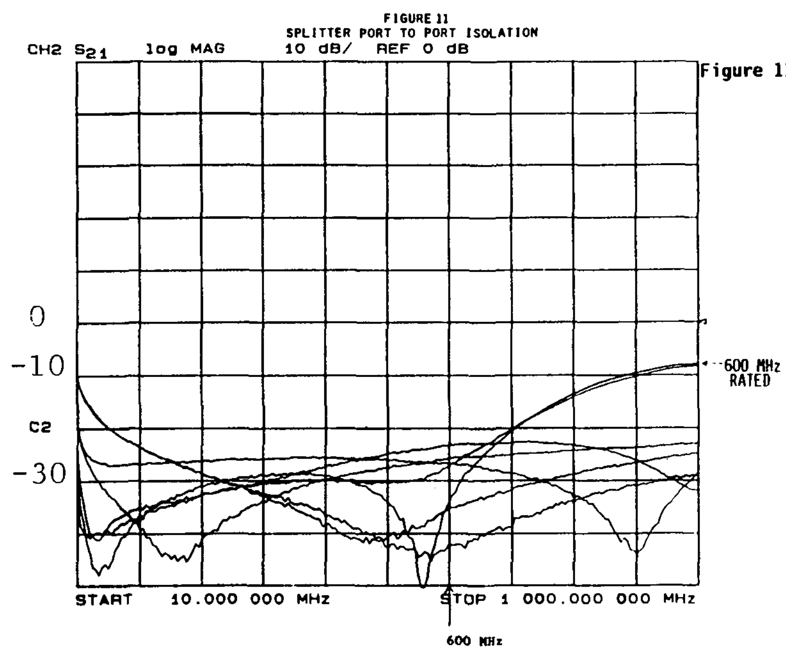


Figure 11

FIGURE 12
DIRECTIONAL COUPLER PORT TO PORT ISOLATION

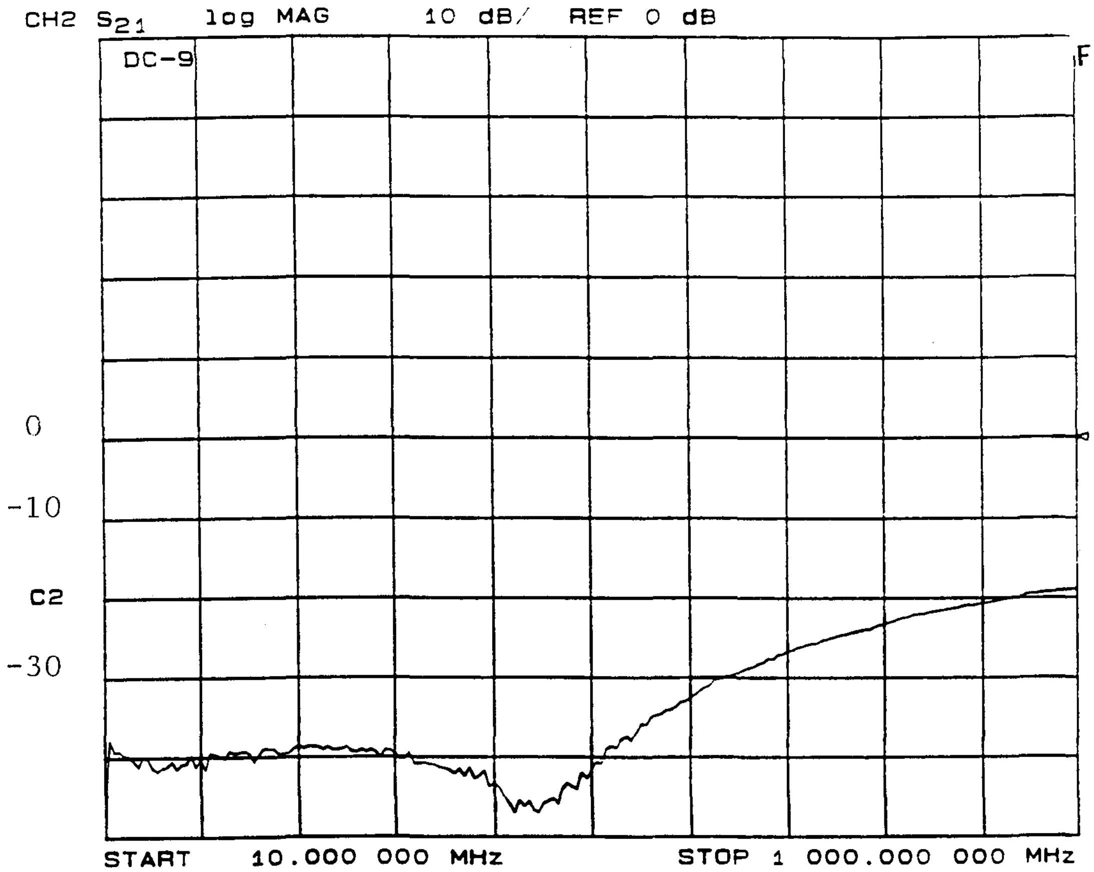


Figure 12

FIGURE 13
PHASE SHIFT THROUGH SPLITTER
PREMIUM CATV PRODUCT

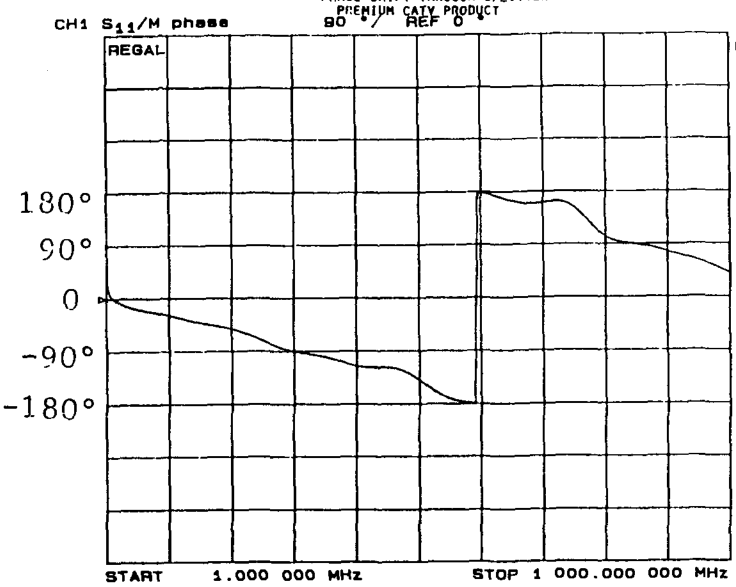


Figure 13

FIGURE 14
PHASE SHIFT THROUGH SPLITTER
RETAIL PRODUCT

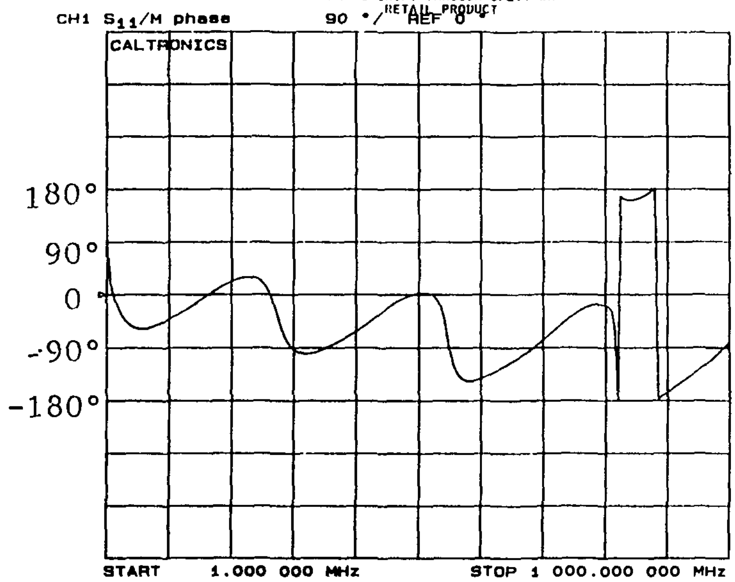


Figure 14

Figure 15
Retail Splitter Input Phase vs "Reflected" Adjacent Port Phase

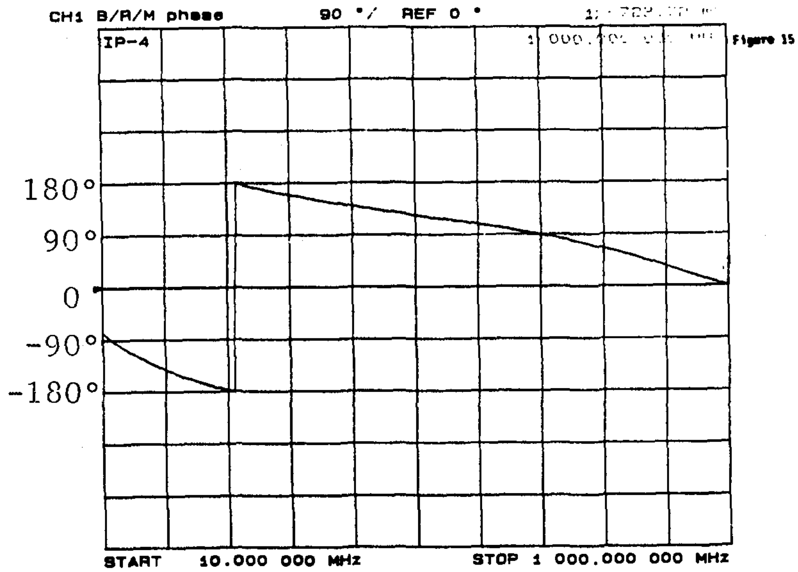


Figure 16
Low Grade CATV Splitter
Input Phase vs "Reflected" Adjacent Port Phase

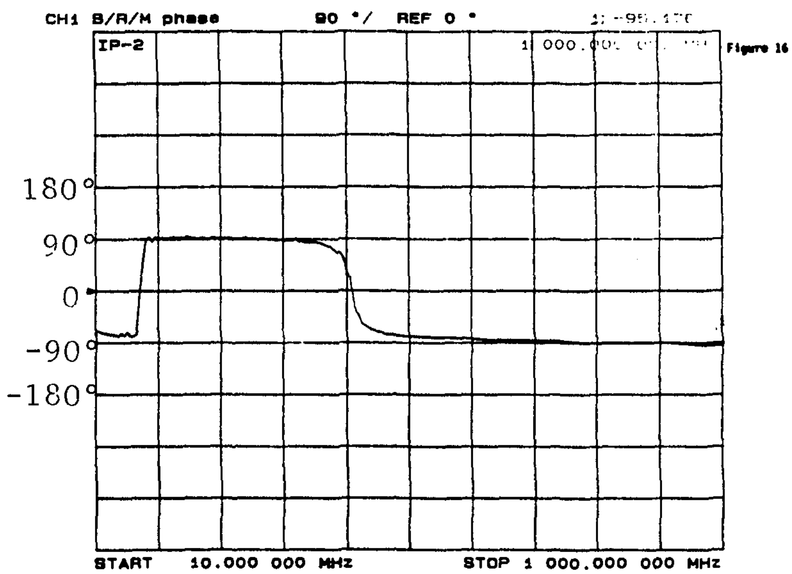


TABLE 1

Summary of Products Tested	
Source	**Style**
CONNECTORS	
Retail A	59 Crimp, Two Piece
Elect. Supply A	59 Twist on
Retail B	59 Crimp, Two Piece
CATV A	6 Crimp, 1 Piece Universal
Elect. Supply B	59 Crimp, Two Piece
CATV B	59 Crimp, One Piece Universal
CATV C	59, One Piece Universal
Elect. Supply C	6 Twist on
Retail C	59 Crimp, Two Piece
Retail D	59 Crimp, Two Piece
CATV E	6, One Piece Universal
Retail E	59 Crimp, One Piece
Retail F	59 Twist on
Elect. Supply D	6 Crimp, One Piece
Elect. Supply E	59 Crimp, One Piece
Retail G	59 Twist on
CABLES	
ElctSup A 6-60%	6, 60 %
CATV A 6-Quad	6-Quad
Retail A 59 33%	59, 33%
CATV B 6-60%	6-60%
Retail B 59-59%	59, 59 %
Retail C 59-35%	59, 35 %
CATV C 59-Quad	59-Quad
ElctSup B 59-9%	59, 9%
Retail D 59-30%	59, 30%
Retail E 59-33%	59, 33 %
CATV D 59-67%	59-67%
Retail F	6
JUMPERS	
Retail A	59
Retail B	59 Gold
Elect. Supply A	59
Retail C	59 Regular
Retail D	59
Retail E	59 Gold
Elect. Supply B	59
SPLITTERS	
Elect. Supply, IP1	2 way splitter
CATV, IP2	2 way splitter
CATV, IP3	2 way splitter
Retail, IP4	2 way splitter
Retail, IP5	2 way splitter
Retail, IP6	2 way splitter
CATV, IP7	3 way splitter

Figure 17

Line Diagram
Measurement of Shielding Effectiveness, TEM Method

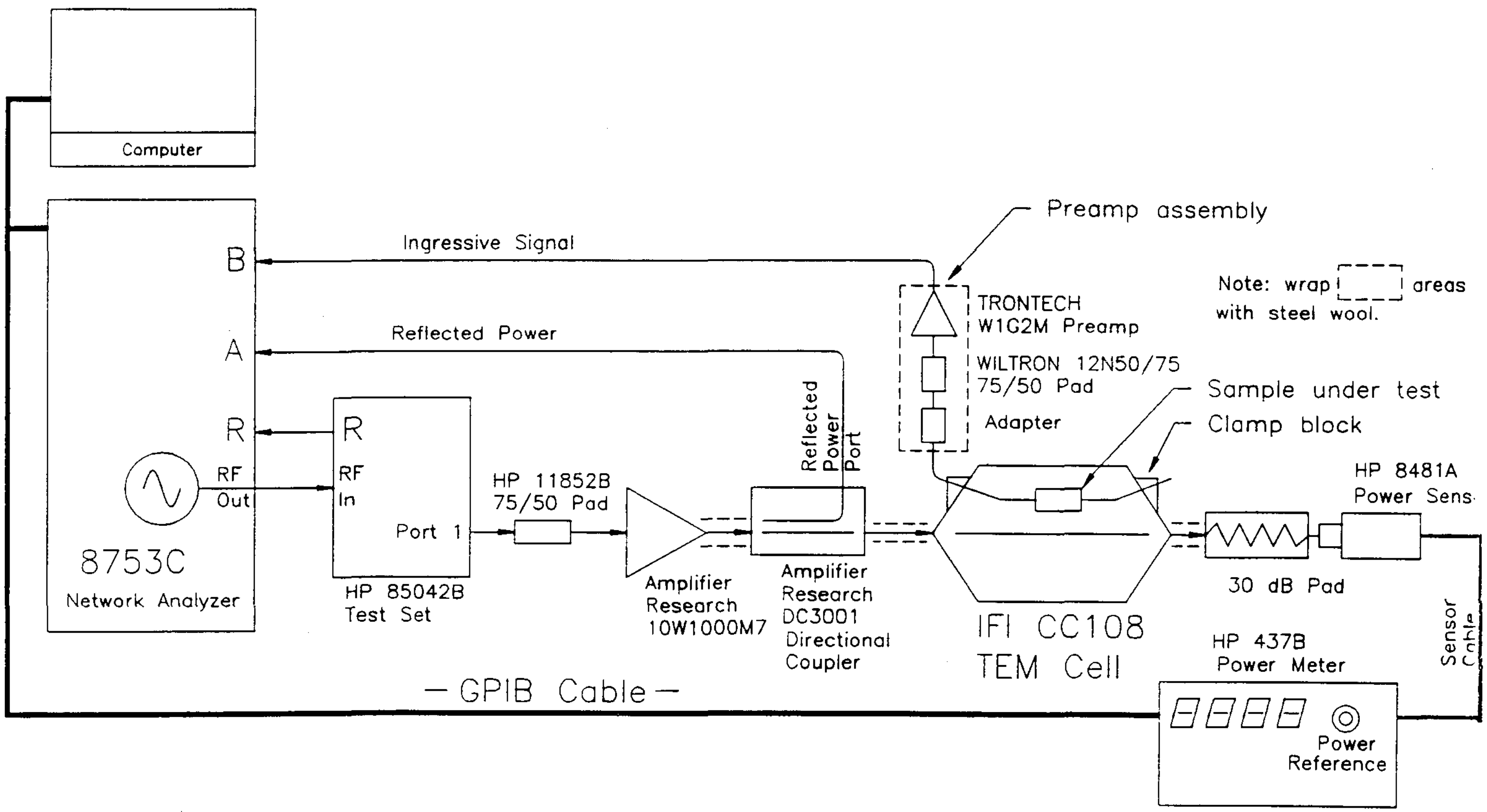
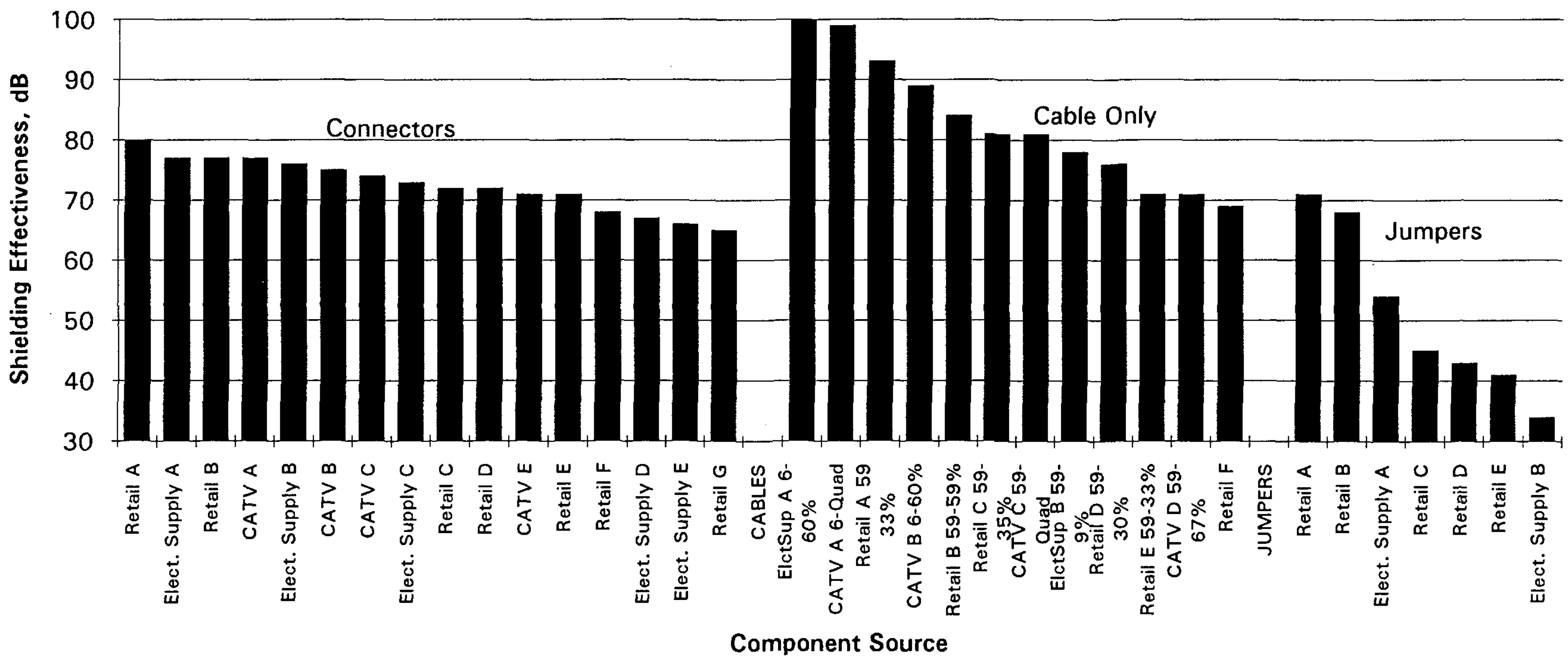


Figure 18
Shielding Effectiveness Summary
Shielding at 1 GHz, TEM Method



Retail: Retail Outlet
Elect. Supply: Electrical Supply, likely home contractor source
CATV: Major CATV MSO Vendor

FIGURE 19
Cable Attenuation
At 550 MHz and 1 GHz

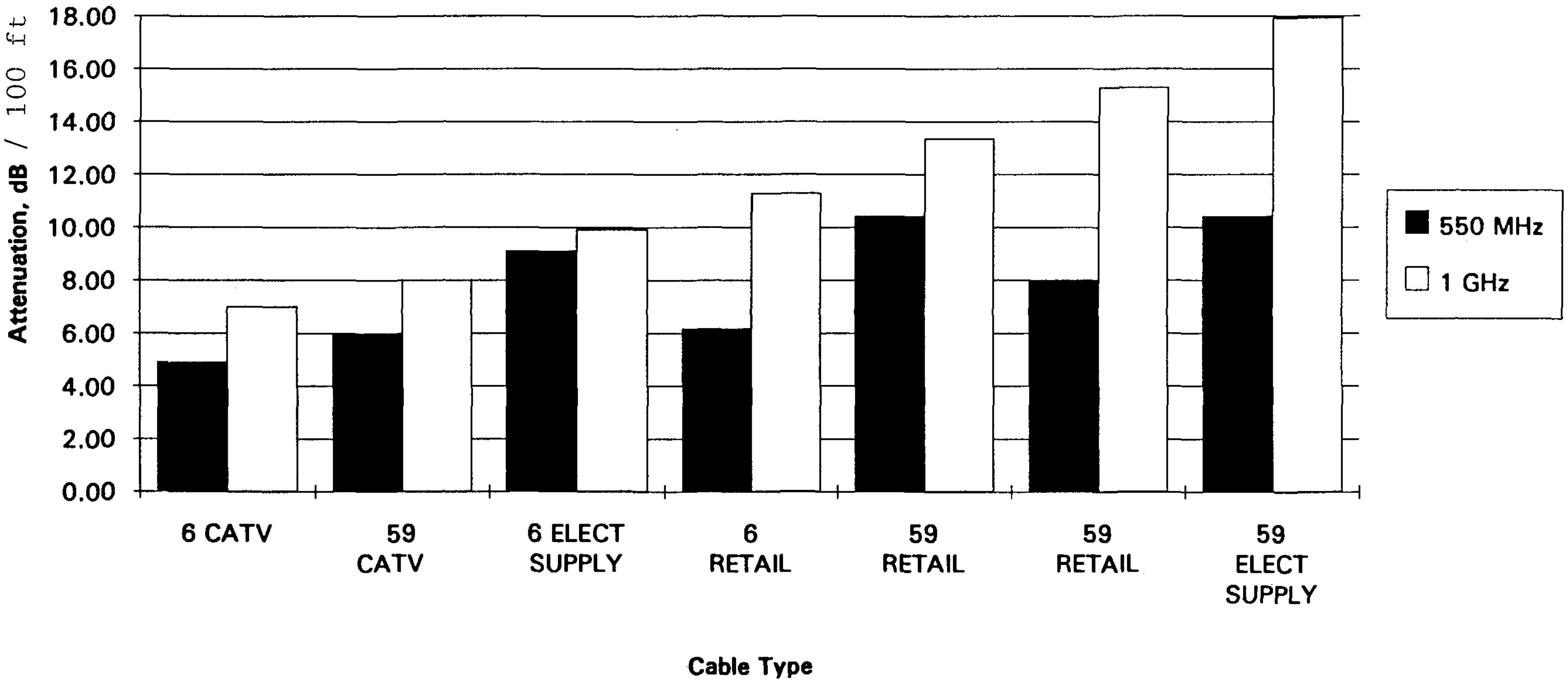


Figure 20
Digital Modulation Test Line Diagram

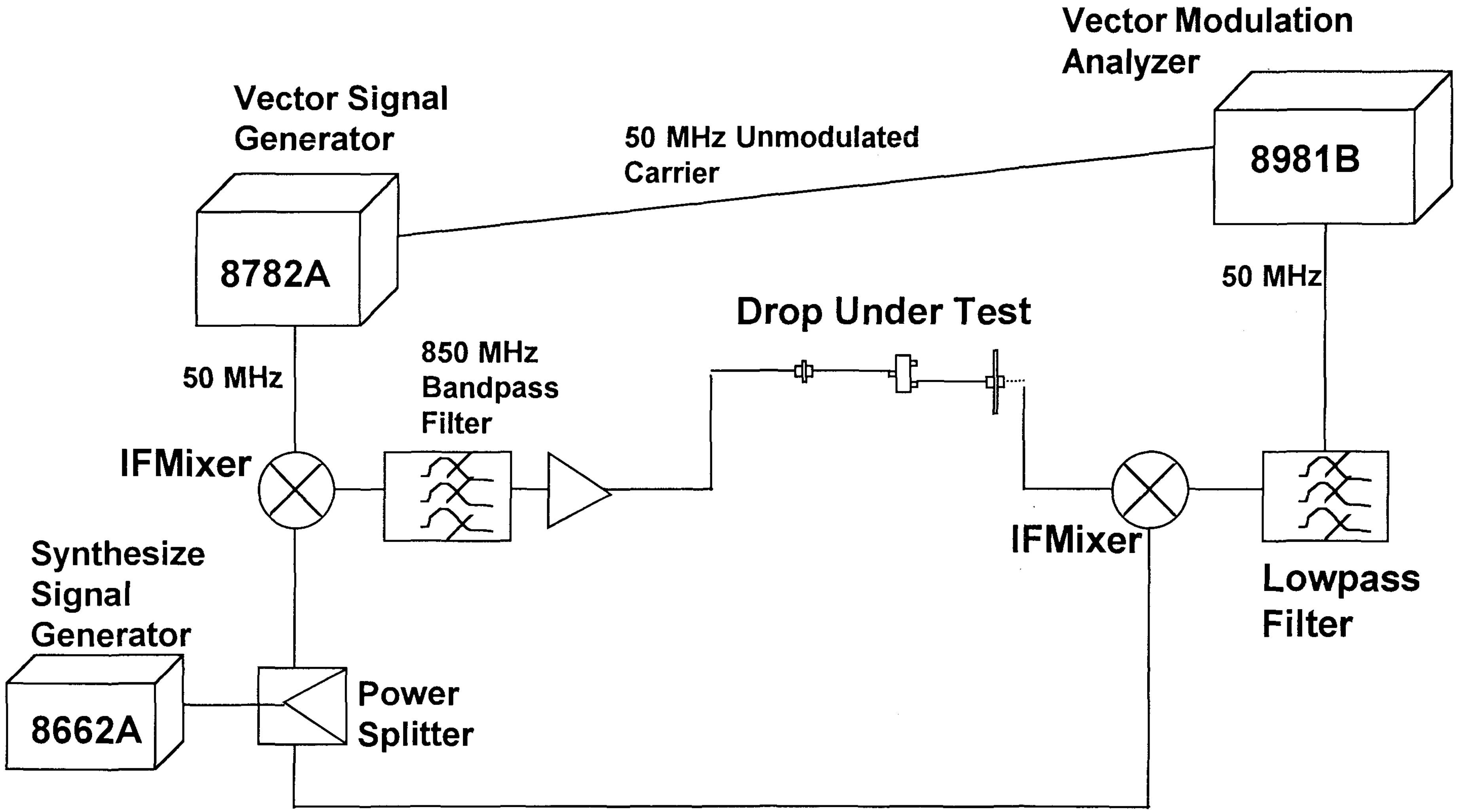
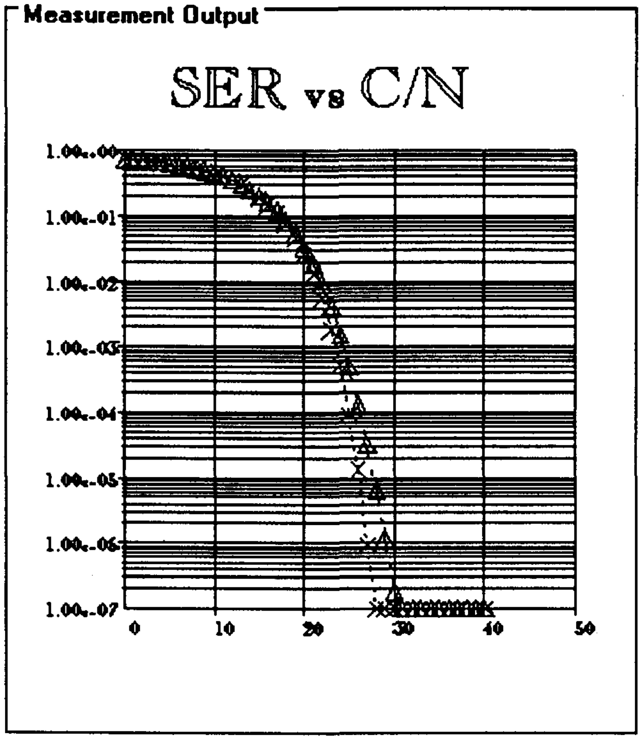


Figure 22 - Best Case Drop



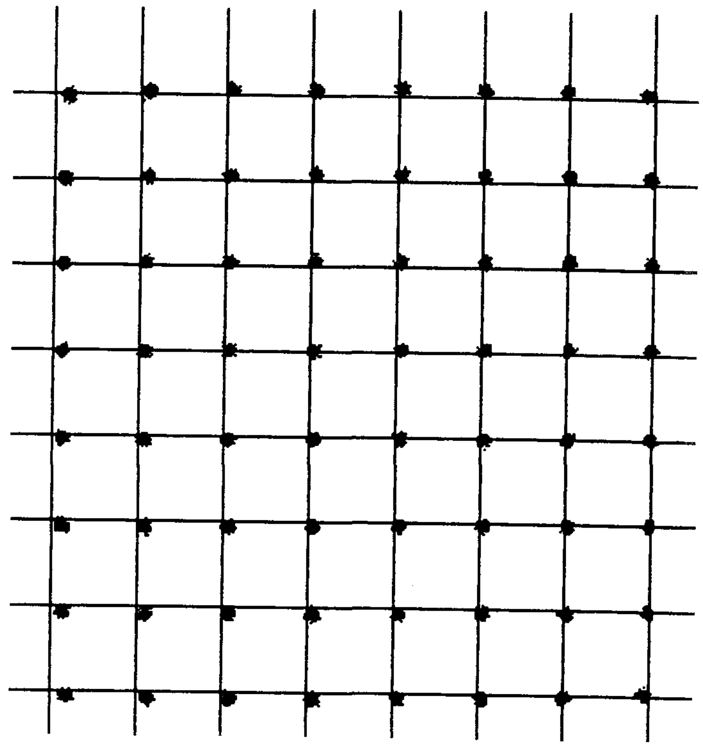


Figure 23
Constellation

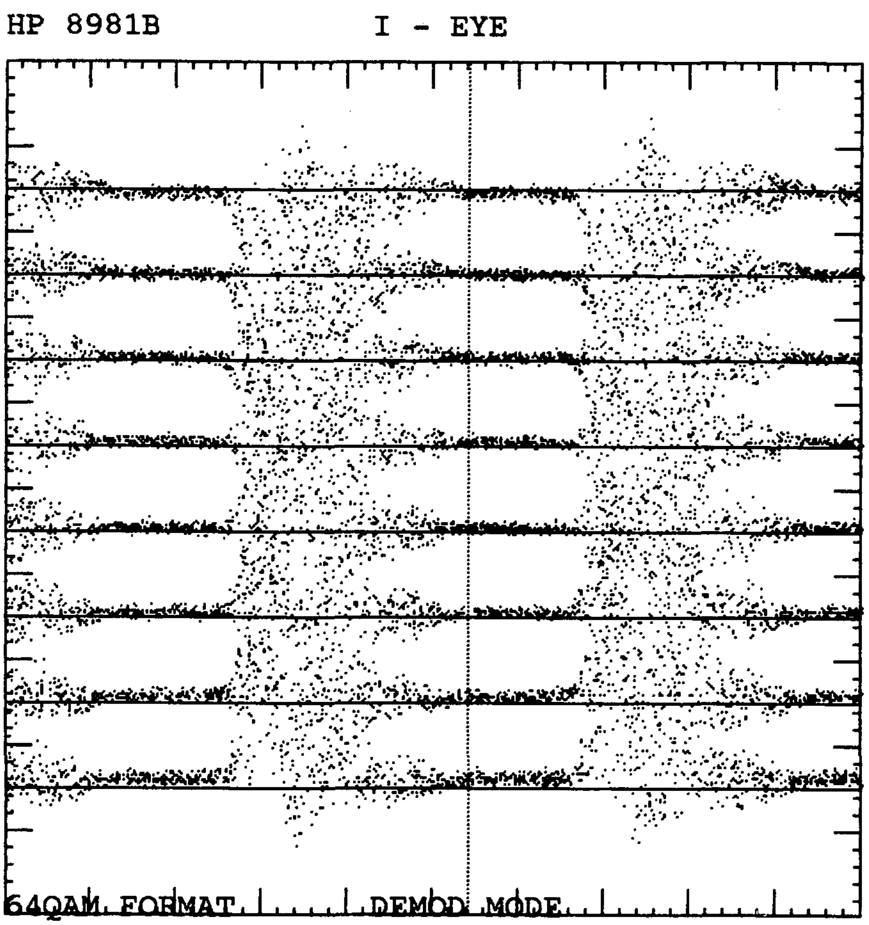
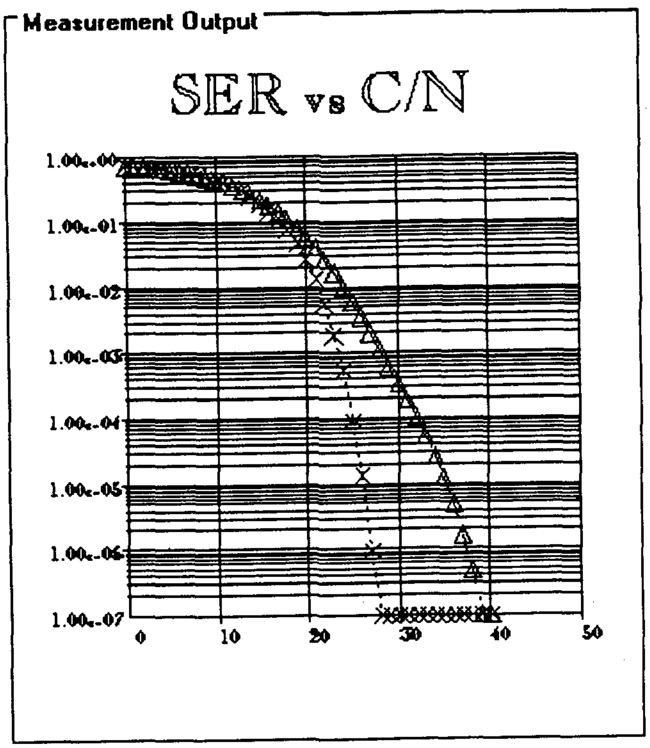


Figure 24
Eye Diagram

Figure 25 - Worst Case Drop



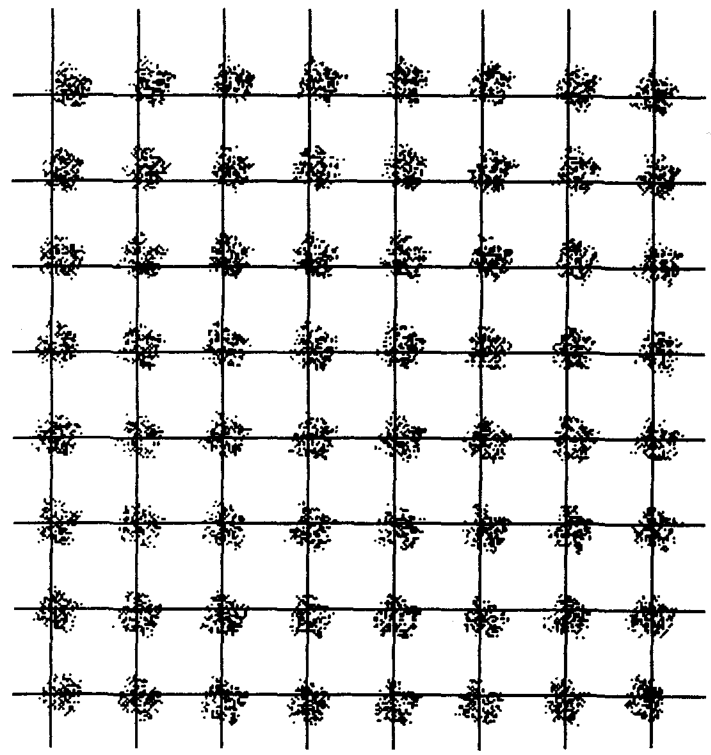


Figure 26
Constellation

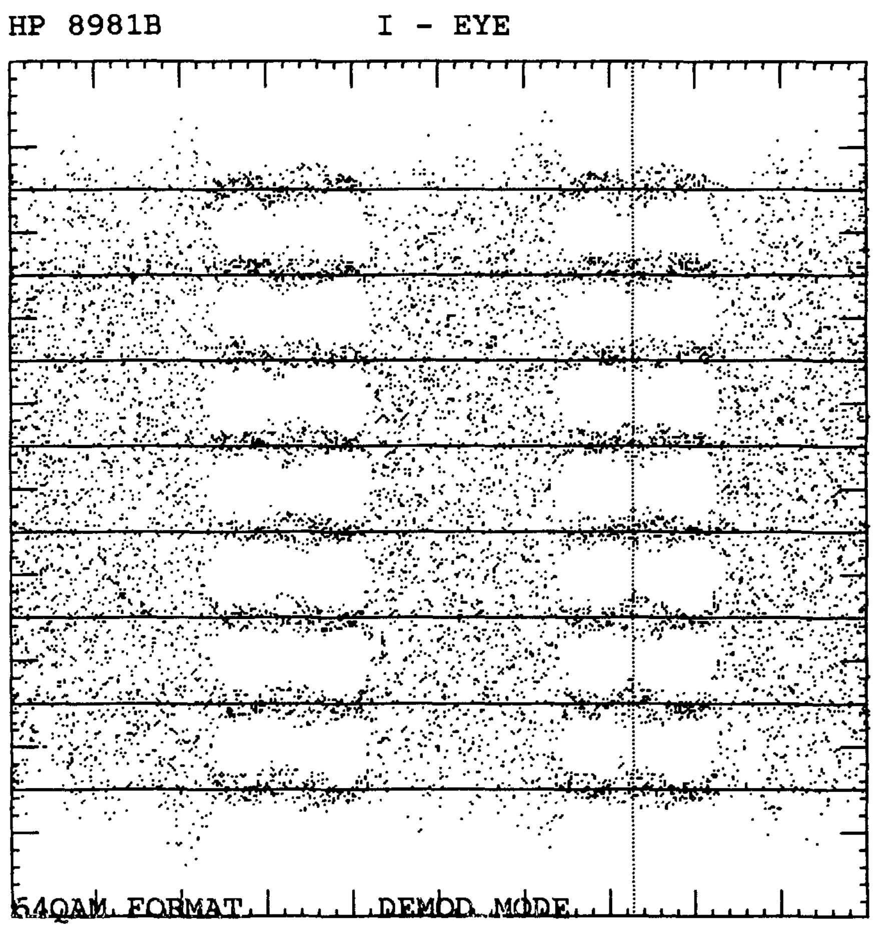
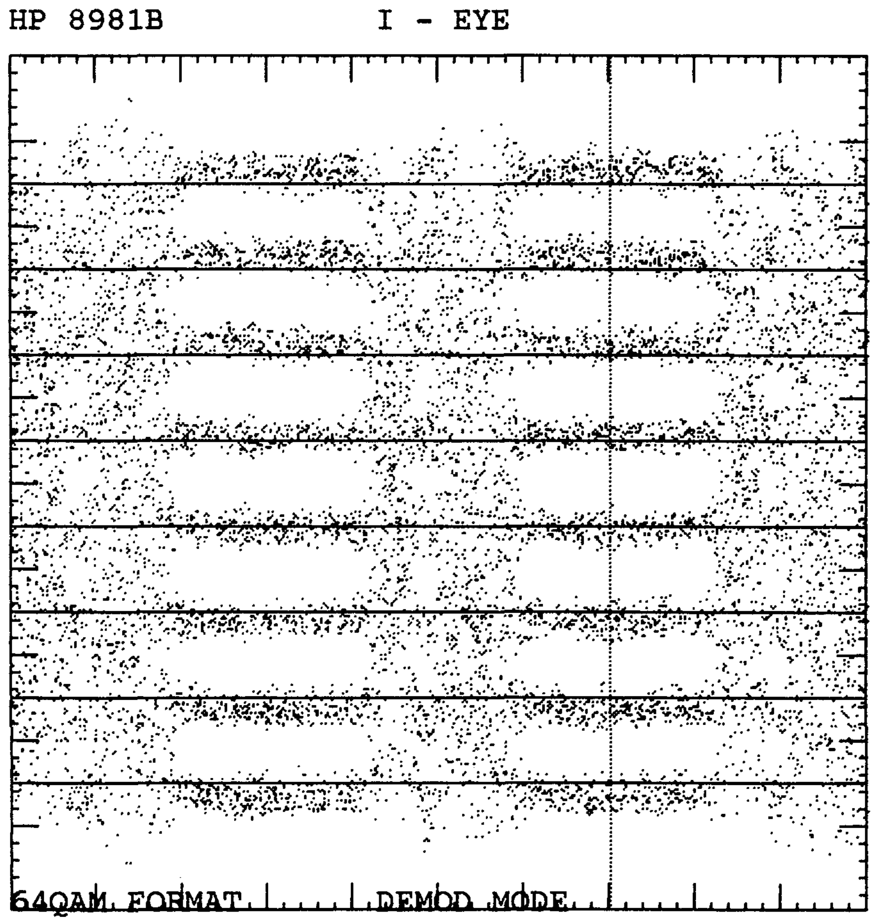


Figure 27
Eye Diagram

Figure 28

Worst Case
Attenuated Between Splitters
Note wider eye opening from attenuated reflections



Effects of Multiple Splice Reflections in Fiber Optic AM CATV Transmission Systems

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ABSTRACT

Reflections in fiber optic AM CATV transmission systems are an important source of noise. Mechanical splices always introduce some reflection, which is a function of temperature. For two splices, the degradation in Carrier to Noise Ratio (CNR) is related to the magnitude of the co-polarized reflections. For multiple splices, the CNR degradation is related to the sum of the reflection contributions from every combination of splice pairs in the system, as well as reflection from Rayleigh scattering. The reflection induced noise also depends on laser characteristics, such as chirp and modulation index. Measurements using two reflections show excellent agreement with theory. Measurements using eight Fibrlok™ mechanical splices at temperatures ranging from -40 C to +80 C confirm the theory for the multi-splice case, with only minor decline in system CNR.

INTRODUCTION

Single-mode optical fiber is currently used as the backbone transmission medium in many AM CATV applications. The fiber link is typically 10 to 30 km long, with splices approximately every 2 km. These splices can introduce noise into the system in a variety of ways. In the absence of reflections, both mechanical and fusion splices can introduce modal noise if the splices are close together[1] as might be the case for laser pigtails, cable repairs, or patch panels. If the splices have some reflection, interferometric phase-to-intensity conversion from a pair of reflections can convert laser phase fluctuations to intensity noise[2].

We are primarily interested in the effects of splice reflections on system noise. While both fusion and mechanical splices typically have low reflections at moderate temperatures, reflections from mechanical splices may become important at extreme temperatures. Reflections occur at a change in index of refraction. The reflectance of a mechanical splice is the sum of the two reflections, which occur at each fiber/gel interface, and an interference term, which describes either constructive or destructive interference between the two reflections within a splice. The index of refraction of the gel is a function of temperature, and thus the reflectance of mechanical splices varies with temperature. Moreover, as a splice expands and contracts with temperature, the interference term will vary as well. Other factors, such as end angle, surface quality, and splice loss reduce the amount of reflected light that is captured by the fiber core. The reflections can be reduced in a variety of ways, such as using angled cleaves or improved index matching gels. By developing a model for multiple splice reflections and their influence on noise, system performance can be predicted for actual splice reflections. This will aid in determining whether a mechanical splice is suitable for fiber optic CATV systems.

SINGLE CAVITY CASE (TWO SPLICE SYSTEMS)

In a system that has two splices, the splices will form a reflection cavity. In this case, the total system noise consists of the baseline noise and the noise introduced by the cavity:

$$CNR_{sys} = -10\log\left[10^{-CNR_{cav}/10} + 10^{-CNR_{base}/10}\right]. \quad (1)$$

Here CNR_{sys} is the total system noise, CNR_{cav} is the noise introduced by the cavity and CNR_{base} is the baseline noise of the system without the cavity. CNR_{base} will be limited by multipath interference caused by double Rayleigh backscatter[3].

The CNR of the cavity (CNR_{cav}) can be determined by measuring CNR_{sys} and CNR_{base}, and calculating the "backed out" CNR_{cav}. Thus,

$$CNR_{cav} = -10\log\left[10^{-CNR_{sys}/10} - 10^{-CNR_{base}/10}\right]. \quad (2)$$

The measured CNR_{cav} can be compared to a theoretical model[4]:

$$CNR_{cav} = 10\log\left[\frac{\sqrt{2\pi}}{8}\frac{m^2}{R_{12}}\frac{B_{½}}{B_N}\right] \quad (3a)$$

$$= 10\log\left[\frac{\sqrt{2\pi}\, m^2}{16\sqrt{\ln 2}}\frac{B_{FWHM}}{B_N}\right] - \mathcal{R}_{12} \quad (3b)$$

where:

CNR_{cav} is the theoretical CNR of the cavity,
$B_{½}$ is the 1/e bandwidth of the laser spectrum,
B_{FWHM} is the full width at half maximum of the laser spectrum,
B_N is the noise bandwidth for cable TV (4 MHz),
m is the modulation index,
R_{12} is the ratio of the twice reflected power to the main signal power at the receiver,
$\mathcal{R}_{12} = 10\ \log(R_{12})$.

Equation 3 assumes that the splices are separated by at least several meters of fiber, and that the reflected light has the same polarization as the non-reflected light. Equation 3 also assumes a Gaussian optical spectrum with a width much larger than the CATV modulation frequency. This results in a flat noise response over the band. A small correction factor must be used to correct for the Gaussian line shape of the noise introduced by a narrow line laser. For a narrow line laser, and carrier frequency f, the CNR will be given by

$$CNR_{cav} = 10\log\left[\frac{\sqrt{2\pi}}{16\sqrt{\ln 2}}\frac{m^2}{R_{12}}\frac{B_{FWHM}}{B_N}e^{2f^2\ln(2)/(B_{FWHM})^2}\right] \quad (4)$$

The width of the laser diode spectrum, B_{FWHM} or $B_{½}$, is dominated by the laser chirp. The chirp is a shift in the wavelength as the drive current changes. Thus the width of the laser spectrum will depend on the level of modulation. The chirp characteristics of laser diodes vary widely from device to device.

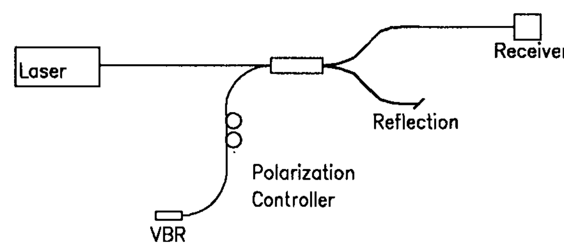

Figure 1. Experimental setup for the single cavity test. Two reflections were placed on opposite ends of a coupler. The fixed reflection is a cleaved fiber immersed in oil, and the variable reflection is a Variable Back Reflector (VBR). Figure 5 shows the measurement system.

Experiment:

Our experimental setup is shown in Figure 1. The reflection cavity consisted of a coupler with one end cleaved and immersed in index matching oil (with an index chosen to provide the appropriate level of reflection), and the other end spliced to a variable back reflector (VBR). The polarization controller was adjusted for maximum system noise, which occurs when the incident and reflected waves are co-polarized. The $\mathcal{R}_{12}$ term includes round trip cavity losses through the coupler, taking into account the coupler insertion loss. We used two different lasers: one high chirp, and one low chirp. The laser spectral widths were measured using a scanning Fabry-Perot interferometer at the rf drive levels used in the test. The spectral widths of the lasers were $B_{FWHM} = 6180$ MHz and $B_{FWHM} = 780$ MHz for the high and low chirp lasers, respectively. A CATV multi-channel generator produced 42 CATV carriers, from 55.25 MHz to 325.25 MHz. We measured CNR_{sys} and CNR_{base} with a spectrum analyzer for both lasers at three frequencies (55.25 MHz, 187.25 MHz, and 325.25 MHz) with a variety of cavity reflection levels. We then plotted the computed backed out CNR_{cav} from Equation 2 along with the theoretical CNR_{cav} from Equation 3. We found excellent agreement with theory (usually within ±2dB) for $\mathcal{R}_{12} > -70$ dB. For very small reflections, $CNR_{\text{cav}} > 65$ dB. In this case, CNR_{sys} and CNR_{base} are nearly equal, and Equation 2 becomes very sensitive to measurement error. Equation 3 gives a reasonably accurate estimate for the effects of a reflection cavity on CNR.

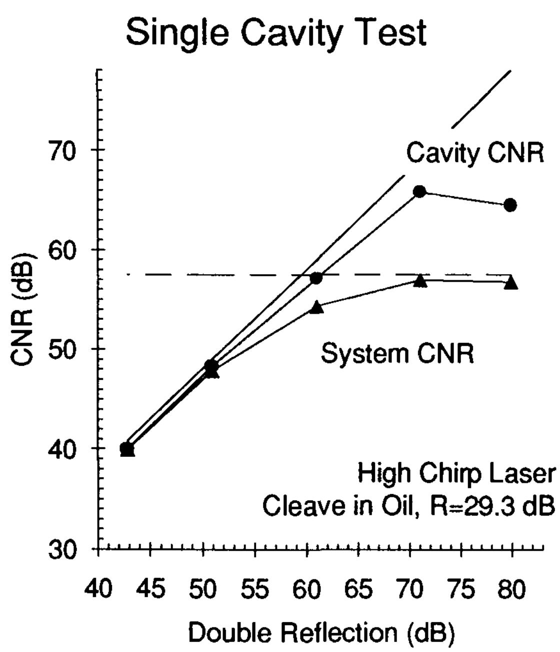

Figure 2. Single cavity results for a high chirp laser at 187.25 MHz. The dashed line is CNR_{base}. The solid line is the theoretical CNR_{cav}. The circles and triangles are measured values for cavity CNR and system CNR respectively.

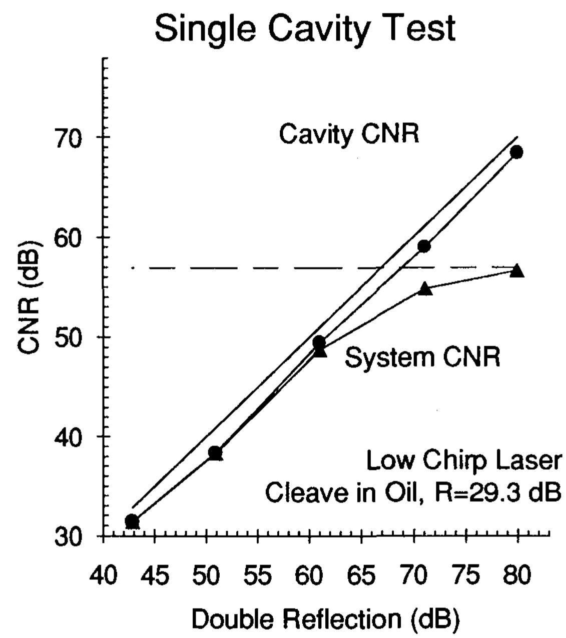

Figure 3. Single cavity results for a low chirp laser at 187.25 MHz. The dashed line is CNR_{base}. The solid line is the thoeretical CNR_{cav}. The circles and triangles are measured values for cavity CNR and system CNR respectively.

Figures 2 and 3 show typical results from our experiment. The baseline is the measured result for the system without a reflection cavity. As R_{12} decreases, the system CNR approaches the baseline. Figure 2 shows the result for a high chirp laser and Figure 3 shows the result for a low chirp laser. The cavity introduces more noise with the low chirp laser than with the high chirp laser just as Equation 3 predicts.

Equation 3b shows that CNR can be improved by increasing the laser modulation (m), or by using a higher chirp laser (B_{FWHM}).

Both of these effects were confirmed by our measurements. If high chirp lasers are selected, CNR degradation due to reflections is substantially reduced.

Our main interest with Equation 3b is the $\mathcal{R}_{12}$ term. CNR introduced by the cavity follows $\mathcal{R}_{12}$: a 1 dB improvement in $\mathcal{R}_{12}$ results in a 1 dB improvement in CNR_{cav}. Note that $\mathcal{R}_{12}$ is almost independent of the positions of the two reflection points. The only dependence on position is due to the round trip cavity losses from fiber attenuation. Thus widely separated splices are slightly better than closely spaced splices, ignoring Rayleigh scattering.

MULTIPLE CAVITY CASE (MULTIPLE SPLICE SYSTEMS)

For multiple cavities, the noise term can be described as a summation over all of the terms generated by the double reflections[5]. Each cavity will add by Equation 1. Combining with Equation 4 we get

$$CNR_{cav} = 10\log\left[\frac{\sqrt{2\pi}\, m^2}{16\sqrt{\ln 2}} \frac{B_{FWHM}}{B_N} e^{2f^2 \ln(2)/(B_{FWHM})^2}\right] - 10\log\left[\sum R_{mn}\right] \tag{5}$$

Here, the subscripts n and m refer to the individual splices, and the summation is over all possible cavities formed. For N reflection points, there are $N(N-1)/2$ terms in the summation: for 8 splices there are 28 terms. Each R_{mn} includes both reflections and the round trip cavity losses. For reflections R_m and R_n,

$$R_{mn} = \frac{1}{2} R_m R_n 10^{-2\alpha \ell_{mn}/10}, \tag{6}$$

where α is the fiber loss in dB/km and ℓ_{mn} is the separation distance in km. The factor of ½ is included to account for random depolarization by long pieces of fiber[6]. If the splices are closely spaced, this factor will not be included. Using Equation 5, we can compute the CNR for any combination of splice reflections.

For convenience in reporting results we define an "Average Reflection":

$$R_{ave} = \left[\frac{\sum_{n=1}^{N}\sum_{m=n+1}^{N} R_m R_n}{N(N-1)/2}\right]^{1/2}. \tag{7}$$

This is the average of the $R_m R_n$ terms.

Effects of Rayleigh Backscatter:

For a system with small reflections, the fiber Rayleigh backscatter will be much larger than the splice reflections. Light reflected from a splice will see Rayleigh backscatter from the fiber between splices in addition to the other splice reflections. The summation in Equation 5 becomes:

$$\sum R_{mn} = \sum_{m=1}^{N-1}\sum_{n=m+1}^{N} \tfrac{1}{2} R_n R_m 10^{2\alpha \ell_{nm}/10} + \frac{S\alpha_s}{4\alpha'}\sum_{i=1}^{N} R_i\left[\left(1-e^{-2\alpha' \ell^+}\right)+\left(1-e^{-2\alpha' \ell^-}\right)\right]. \tag{8}$$

S is the amount of scattered light captured by the fiber (S=.0015 at 1300 nm), α' is the fiber loss coefficient $[\alpha' = \alpha \ln(10)/10]$ and α_s is the Rayleigh scattering coefficient, i.e., the fraction of light lost due to scattering (for an ideal fiber, $\alpha_s = \alpha' = .076\ \text{km}^{-1}$)[3]. $\ell^{\pm}$ is the length of fiber in the link in the forward (+) or backward (-) directions from the splice. If the splices are evenly spaced by distance $\Delta\ell$, $\ell^+ = \Delta\ell(N+1-i)$ and $\ell^- = \Delta\ell\, i$.

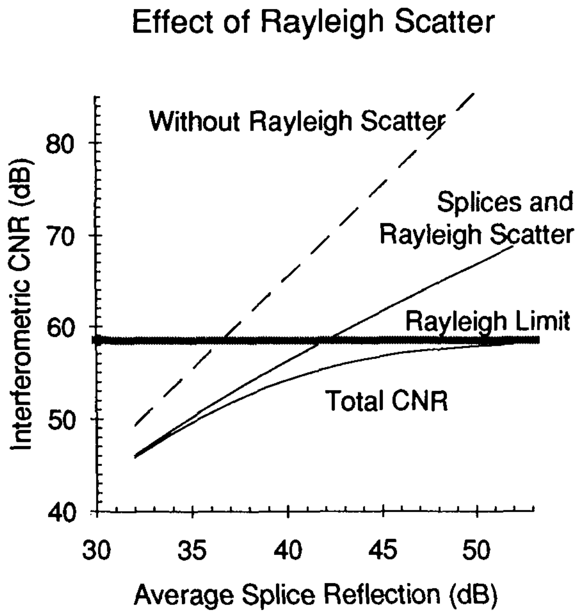

Figure 4. Interferometric CNR for an eight-splice system with and without Rayleigh scatter. The horizontal line is the limit of system CNR due to double Rayleigh backscatter in the absence of any other reflections, for the system used in our test. The total interferometric CNR approaches this limit.

Figure 4 compares the results for an eight-splice system, with and without the Rayleigh scattering terms from Equation 8. The result for the case ignoring Rayleigh scattering is a straight line (dashed in Figure 4). Including Rayleigh scatter adds a slight curve to the line and reduces CNR (the middle curve). The horizontal line is the limit of system CNR due to double Rayleigh backscatter scatter in the system under test (B_{FWHM}=1040 MHz, m=0.063, length=20 km). Using this value as the limiting CNR_{base} in Equation 1, gives the total interferometric CNR, the bottom curve in Figure 4. At very small reflections, Rayleigh scattering dominates the total noise term. As the splice reflections become large, Rayleigh scattering becomes less important, and the total CNR approaches the dashed line asymptotically.

Multi-splice experiments:

Our experimental setup for the multiple cavity test is shown in Figure 5. Nine 2.2 km spools of fiber were spliced together by eight Fibrlok™ mechanical fiber optic splices. All cleaves were made with a high quality York cleaver, and the cleaves were checked for flatness and angle using an interferometer. All cleave angles were less then 1°, ensuring the highest possible reflections in the splices. (This was done to generate worst case noise in the system.) The splices were stored in a splice tray and placed in a temperature cycling chamber. An OTDR was used to measure the splice

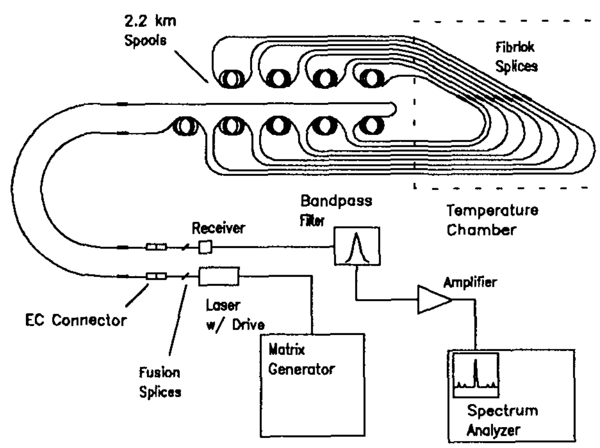

Figure 5. Experimental setup for the multi-splice experiment.

reflections at each temperature: -40 C, -20 C, 0 C, 20 C 40 C, 60 C, 80 C. The measured values for $\mathcal{R}_{ave}$ [$\mathcal{R}_{ave}$=10 log(R_{ave})] and ΣR_{nm} from Equation 8 at each temperature are shown in Table 1. Room temperature values are not shown because the reflections were too small to be seen with the OTDR. Again, a CATV multi-channel generator produced 42 CATV carriers, from 55.25 MHz to 325.25 MHz, and we measured CNR_{sys} with a spectrum analyzer for both lasers at three frequencies (55.25 MHz, 187.25 MHz, and 325.25 MHz) at each temperature. We used the room temperature measurement (essentially no reflections) for CNR_{base}. We also measured system noise for a continuous 20 km piece of fiber at room temperature with a very similar result. The spectral widths of the lasers were $B_{FWHM} = 6180$ MHz and $B_{FWHM} = 1040$ MHz for the high and low chirp lasers, respectively.

Temp	$\mathcal{R}_{ave}$(dB)	ΣR_{nm}(dB)
-40	-39.1	-62.2
-20	-41.8	-65.1
0	-47.7	-71.4
40	-50.3	-74.2
60	-45.2	-68.7
80	-42.2	-65.4

Table 1.

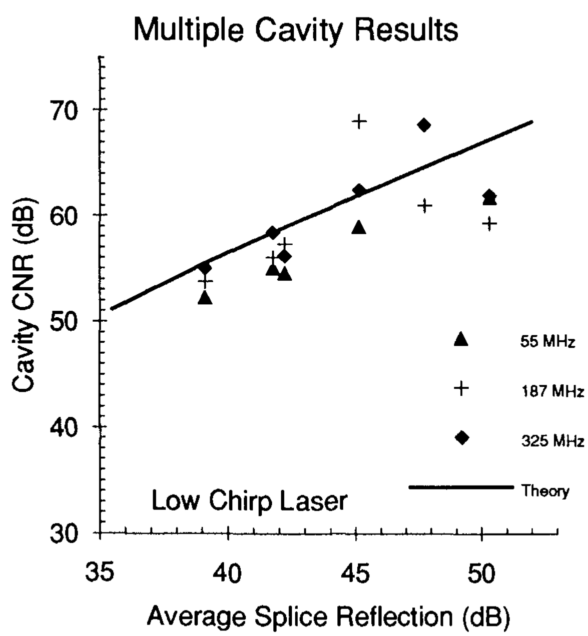

Figure 6. Measured and theoretical results for cavity CNR using a low chirp laser (1040 MHz linewidth). The theoretical result was calculated at 187.25 MHz. Theoretical curves for other frequencies are very close to this result.

We computed the CNR expected from the multiple splice test and compared the results to the measured values. Reasonable agreement with theory was achieved; the largest deviation in CNR_{sys} between theory and measurement was less than 1 dB. For the high chirp laser, CNR_{sys} was very close to CNR_{base}, so that the effective multi-cavity CNR_{cav} was very large (>60 dB). Results for this low chirp laser are closer to the predicted values, since the CNR_{cav} is lower than with the high chirp laser. There is some frequency dependence of the computed results, and the measured results follow the same trend.

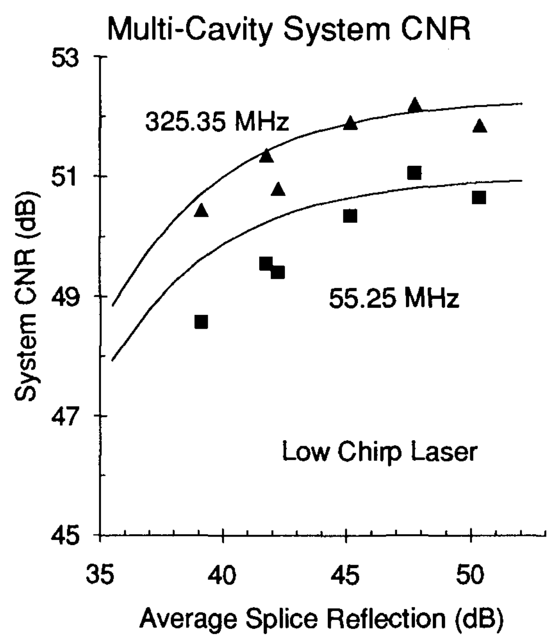

Figure 7. Measured and theoretical results for system CNR using a low chirp laser (1040 MHz linewidth).

Figure 6 shows the CNR_{cav} as a function of average splice reflectance for the low chirp laser. Figure 7 shows the measured and calculated results for the system CNR as a function of average splice reflectance for the low chirp laser. The calculated results agree well with the measurements. Figure 8 compares the two lasers that were used. The high chirp laser system can tolerate much larger reflections before a serious degradation in performance occurs.

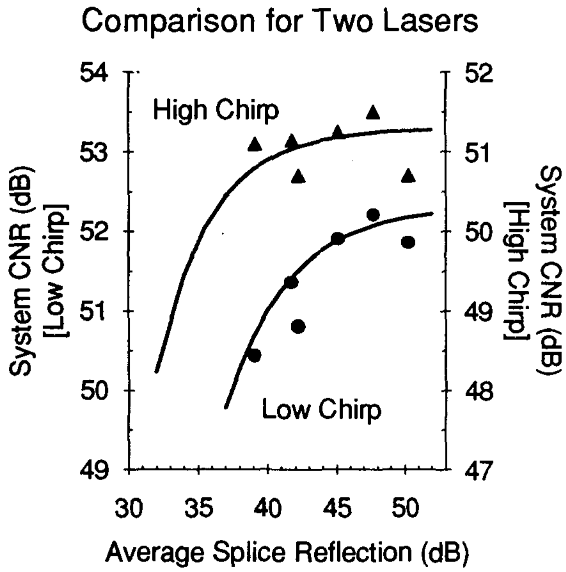

Figure 8. Measured and theoretical results for two lasers. The low chirp laser had a 1040 MHz linewidth; the high chirp laser, 6180 MHz.

Figure 9 shows the effect of changing the number of splices in the system and changing the spacing between the splices. The splices are spaced evenly throughout the link. A larger spacing between splices increases both the Rayleigh scatter and the round trip loss, so the net result is very little length dependence. It is important to note that the cavity CNR is much better if a high chirp laser is used. Cavity CNR with N splices and the low chirp laser will be worse than the cavity CNR with the high chirp laser and 3N splices. With eight splices in the system, the cavity CNR remains above 59 dB even for very long lengths, if a high chirp laser is chosen.

SYSTEMS WITH COUPLERS

Our single cavity test used a coupler to introduce controlled reflections. In an actual system, couplers may be used to construct a passive distribution network. Reflections in such systems introduce some interesting system noise effects that have not been discussed previously. These effects result in some new considerations for network design. A coupler can act as an effectively one-way reflective

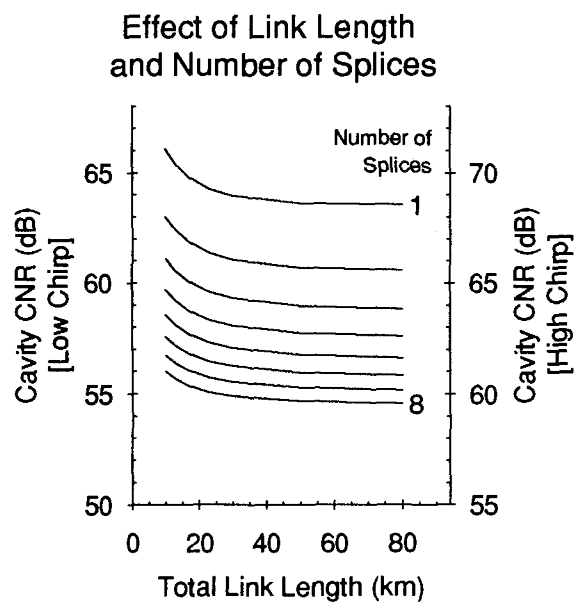

Figure 9. Theoretical results as a function of total link length for different numbers of splices. The splices are evenly spaced within the link. The calculation used a carrier frequency of 55.25 MHz and a splice reflection of -39 dB. The laser linewidths were 1040 MHz and 6180 MHz for the low and high chirp lasers, respectively.

element. That is, light travelling in one direction sees a reflection, but light travelling in the other direction does not. As a result, the locations of the reflection and the coupler become very important.

Consider a system containing a coupler with an unterminated output port. This port will generate a reflection of -14.7 dB (with a perfect cleave). Since the light must pass through the coupler twice (with a 3 dB insertion loss in each direction) the total reflection will be -20 dB back toward the laser. Since the lasers are typically isolated, the feedback into the laser will not be problematic unless the reflection is very large. Thus this single reflection will not be a problem if the coupler is several meters from the laser. However, if the coupler is far from the laser, the fiber between the coupler and the laser will reflect some of the light by Rayleigh backscatter. In this case there is a reflection cavity with reflections of -20 dB and -32 dB, degrading CNR. This shows that the location of the coupler is important and there is an advantage in placing the coupler close to the laser. On the other hand, if the coupler has an unterminated input port, the situation is reversed, and the coupler should be placed near the receiver.

This position dependence is confirmed by experiment. A coupler with a variable reflector on one of the output leads was placed in the system near to the laser. The unused input lead was terminated with low reflection. The system noise in this case was independent of reflection level even for reflections as high as -4.2 dB. When 2 km of fiber was spliced between the laser and the coupler, the noise became sensitive to the magnitude of the reflection. For a reflection of -4.2 dB, the backed out CNR_{cav} was approximately 50.5 dB. For a reflection of -15.4 dB the CNR_{cav} was 57 dB.

In a similar experiment, the unused output port was terminated and the unused input port had a reflector. When 6.4 km of fiber was placed between the coupler and the receiver, the noise level became sensitive to the reflection. For -4.2 dB reflection CNR_{cav} was 46.5 dB and for -15.4 dB reflection, CNR_{cav} was 54.1 dB.

In an installed system, the unused input ports can be permanently terminated with low reflection ends. The return loss for a factory terminated 3-port coupler is typically in the range of -45 dB to -55 dB. The output ports however, may need to be reconfigured or repaired. In such circumstances the reflections could easily be -14 dB when fibers are disconnected or cleaved. This condition could cause excessive noise in receivers attached to the coupler's other output legs. Thus in a passive video distribution network, designers and installers need to be aware of how reflections in one output leg can affect the noise in other output legs.

CONCLUSION

The model presented in equations 3 and 5 is useful for predicting the system noise effects from splice reflections. The most accurate results were cases of the smallest CNR_{cav},with decreasing accuracy as CNR_{cav} increases. When calculating the effects of small reflections on the system noise, Rayleigh scattering terms must be included to get accurate results. For cases of very small reflections, the contributions from equations 3 and 5 are very small and other effects dominate. Since our measurements were made over several hours, or in the multiple cavity case two days, the measurements could be influenced by a variety of other factors: laboratory temperature, operator consistency, instrumentation drift, repeatability of the connectors on the sources, feedback into the laser, and others. Several measurements taken at room temperature over the course of the two days of testing show variations in CNR_{sys} of up to 0.3 dB.

The laser linewidth is an important consideration for the design of a low noise CATV system. A large FWHM laser spectrum (several GHz) is advantageous for the reduction of noise. The noise introduced into current CATV transmission systems by reflections in the fiber link will be minimal for $\Sigma R_{mn} < -65$ dB, and will be negligible for $\Sigma R_{mn} < -70$ dB even for a low chirp laser. For a high chirp laser, no substantial CNR degradation will occur even with relatively large reflections. With proper engineering, system design and installation, reflection induced noise will be minimal.

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EXTENDED SERVICES IN A DIGITAL COMPRESSION SYSTEM

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Abstract

The coming of digitally compressed video opens the door to a variety of new services that up to now were either impossible or impractical to deliver over broadband RF systems.

The data stream of digitally compressed signals that delivers high quality video and audio services is equally at ease delivering any number of additional services, such as interactive video guides, multiple promotional channels, and sophisticated advertising and shopping services.
The cable system operator can now offer these services because digital compression makes it possible to send still frame images, low bit rate video, and teletext within a single stream.

This paper explores how digital compression makes the expansion of the services possible.

INTRODUCTION

Digital compression allows not only more of the traditional video and audio services, but also opens up the possibility of new services never before feasible.

These new capabilities also add new complexities. The use of the new features requires a system design that is both flexible and easy to use. Logical grouping of related services is needed. Higher levels of automation in both playout and generation of playout schedules are required.

In this paper, we will first look at some new services that are possible with state-of-the-art compression systems being developed to meet the emerging MPEG2 standard. We will then explore some tools and techniques needed to implement these new services. At the end we will illustrate how these techniques can be utilized to build the hypothetical shop at home service.

Digital delivery systems offer a wide range of features that can extend the impact of a conventional television signal:

any number of different audio languages can be sent with a given video service,

a large number of high speed teletext services can be supported,

auxiliary data services can be associated with a video channel, providing interactive on-screen displays, and

wide screen(16x9) pictures are possible, with the decoder cropping the picture to 4x3 format under the direction of commands embedded in the digital bit stream.

Also, many new features can be offered that were previously not practical:

the ability to receive and display single frame images accommodates many new or extended services, such as shop at home, classified ads, and electronic "yellow pages." The digital system provides a major extension of the current classified channel. In current systems, the user is at the mercy of the single, fixed rotation of slides. The user has no control over what is seen and may have to wait many minutes to see something of interest. Digital technology provides the opportunity to transmit a catalog of pictures and text, allowing the user to select items of interest.

For example, as many as 100 or more high quality full screen still frames per second can be transmitted, along with associated text, providing an on-line catalog of advertisements.

Interactive, user friendly program guides will incorporate still frame images or even short, low-resolution video clips. (As many as 50 short video clips could be run in parallel in a 6 MHz band, each using 1/9 of the screen.) Teletext overlays can prompt the viewer for selection of specific clips and display of explanatory text. Work on interactive text-oriented program guides is under way at many companies. Using these techniques they can be extended to be multimedia guides.

Video games can be downloaded, similar to a previous system in which games were downloaded from the cable into commercially available video game decks.

Encyclopedias and other references may be kept on-line for ready access. Pictures and text can be mixed into a common interactive data stream. This allows reference materials to be kept current, where CD-ROMs and books run the risk of becoming obsolete. Services can charge on a pay-as-you-go basis, making the service much more affordable than the purchase of an entire encyclopedia. This opens up a much wider customer base than would be otherwise available. More information can be found in Reference 2.

Of course, in a two-way system, all of these features can become interactive. In a one-way system all information needs to be sent repeatedly, since the source has no way of knowing what information the users may want to look at. In a two-way system, with even a very slow return channel, such as a 1200 baud asynchronous link, the information provider can determine what information is requested at any time, filling the data channel with only information that is likely to be needed.

While the advent of digital video systems opens the door to a number of new and exciting opportunities, it also presents a number of new challenges to the system operator. With new capabilities come new complexities. Figuring out how to make the best use of the huge available bandwidth will not be a trivial task.

For example, instead of transmitting up to 70 or so video services, the system of the future will be able to carry several hundred channels. The method of selecting a channel is no longer so straight forward, either. For the most part, channel assignments are standardized. Channel 42 is almost always found at 331.25 MHz. These standards are no longer relevant in a digital video system. The system needs to provide more than just an indication as to what frequency each channel is; it also needs to assist in allocating the resources within each carrier.

Most systems that transport subscriber video services offer a limited number of options for configuration of the video service. For instance, BTSC stereo allows the operator to transmit one stereo audio channel and a single, mono, secondary audio. Satellite systems such as D2-MAC and B-MAC offer a wider, but still limited set of options. Digital systems will allow a virtually unlimited set of options. The operator can decide how many audio services to attach to a single video service. Each audio service can have its own characteristics. It is also possible to turn the tables and attach a single audio service to a number of video or teletext services. The channel usage can be optimized by sending the unique components once and sharing them among different services. The digital system must provide the tools necessary to create this array of service packages efficiently.

The digital video system will also be dynamic in nature. Specialized services will come and go on a regular basis. The concept of "virtual channels" will become widespread. The services accessed by a specific channel can change frequently, allocating resources where they are needed most. The digital video system must have the capability of tracking these changes transparently. The subscribers should never know they are no longer watching the same electronic signal from one moment to the next.

One of the required tools in the digital video "toolkit" is a flexible channel mapping system. It must allow the operator access to the flexibility of the digital system while limiting the complexities of using the system.

CHANNEL MAPPING

Let us introduce several terms we use in the following text: a datastream file, a map, and a table.

A datastream file is a sequence of bytes that is transmitted repeatedly as a sequence of packets on a single Service Identifier (SID).

A map is used to describe the structure of the whole transport system (Global Channel Map) or structure of one band (Band Channel Map). Each map is subdivided into groups of related entities which are called tables (Channel Map Table, Service Map Table). Each map is transmitted under one SID and usually contains more than one table.
There are two channel maps that are transmitted separately in two datastream files: the Global Channel Map and the Band Channel Map.

To make our explanation simpler, we will associate the Global Channel Map with one satellite and Band Channel Map with one transponder. In real satellite implementation that may be the case, but the digital transport system can be implemented in several different ways. Similarly, the global map may be an entire cable bandwidth and the band map represents a 6 Mhz band.

The Global Channel Map is a master directory for the entire system. It provides a reference that the receiver can access at any time to find out where services are located.

The Global Channel Map is transmitted as a single datastream file. It consists of a numbers of tables, transmitted in order: a single Band Map Table, followed by a single Channel Map Table, followed by

multiple Service Map Tables, as shown in Figure 1.
Note that we need only one Global Channel Map per system. (For example, if we have two systems on one satellite we would have two Global Channel Maps).

The Band Map Table indicates how to find a particular frequency band, without providing any specifics about the services it carries. The Band Map Table contains one entry for each band on the transport system. In our example of the satellite system, each entry in the Band Map Table contains one entry for one transponder.

The Channel Map Table describes each of the available, user identifiable, entertainment or information channels. The receiver can store as much or as little of the channel map information as desired. Any information not stored can be retrieved at any time from the data streams. The equipment can trade off the cost of additional memory against the added channel acquisition time that might be incurred.

The Service Map Table describes a set of services that together comprise a particular channel.

There are many different service types that can be described by the Service Map Table. Some of the more conventional types are video with audio, video with stereo or second sound, audio only, and teletext. A single video service can be matched with any number of audio services, allowing multiple languages for a single video source. We can also conceive of a single audio track shared among multiple video signals. This can be useful, for example, if different views of an event are provided for the viewers to select. The ability to define new service types and send them out via service maps allows the system to evolve and grow as new requirements and new services are designed.

Each band has a system channel which is used to carry the Band Channel Map. The Band Channel Map is a subset of the Global Channel Map. It has the same structure as the Global Channel Map, but it is smaller since it relates to only one band. In our example, we can say it covers only one transponder. The SID for the Band Channel Map is unique.

MAP UPDATES

The large number of possible services can generate a dynamic system, with services coming and going on a regular basis. Changes to the system configuration need to be handled cleanly and communicated to the entire system.

The Global Channel Map Updates are carried as a separate datastream file on the system channel, using a unique SID. The idea is to convey the changes in the system to the receiver. The datastream file structure is almost identical to the Global Channel Map file shown in Figure 1, but with the addition at the beginning of the file of the header information shown in Figure 2. The structure of the Band Map Table, Channel Map Table, and Service Map Tables stays the same, keeping in mind the following. If no updates are to be made, the Band Map Table will be empty (Number of Bands = 0), the Channel Map Table will be empty (Number of channels =0), and the service map tables are omitted.

Band Map Table

Band Data (Id etc.)	Frequency	FEC Data	Satellite Data

Channel Map Table

Channel Data (Id etc.)	Band	Alternate Channel	Access Control

Service Map Table

Service Data	Access Control Data

Figure 1. The Global Channel Map consists of band, channel, and service map tables.

Map Updates

Time Stamp	Band and Channel Map Data

Figure 2. Header Information is the crucial part in updating the maps.

CONDITIONAL ACCESS

Besides the techniques of channel mapping digital compression system can also provide secure Conditional Access to services, so that viewers receive only the services for which they have paid. Recent advances in microcomputer technology and cryptology make reliable Conditional Access possible.

Conditional Access is a broad topic. We will briefly outline three major functions that conditional Access serves in a digitally compressed system:
Scrambling/Descrambling, Entitlement Control, and Entitlement Management.

The Scrambling/Descrambling function makes a program comprehensible only to viewers who subscribe for it. Every component of the program (service, in our terminology) can be scrambled separately. The descrambling is done in the receiver and is based on a secret parameter called the Control Word (CW).

The Entitlement Control Function provides the information about conditions required to access the program and accompanies the encrypted secret parameters. This information is packed in dedicated messages called Entitlement Control Messages (ECMs).

The Entitlement Management Function distributes the entitlement to the receivers.

The Scrambling/Descrambling function is usually done in hardware. Since Control and Management functions require use of complex cryptographic algorithms, they are done using a Smart Card . The Smart Card is detachable microcomputer the size of a credit card.

SHOPPING

The channel mapping system provides a tool kit that can be used to build the advanced user features we have already looked at. For example, we can build a hypothetical shop at home service.
Such a service might use a combination of many of the service types that have been described. The shopping service is accessed by selecting a particular channel number, just the same as selecting a conventional television channel. Our service will be assigned to channel 200, the CAble SHopping channel (CASH).

We will define channel 200 as a teletext channel. When channel 200 is selected, a text/graphics screen is displayed welcoming the user to the system and providing an index of available departments within the cable "store." Each department is represented by a channel number. For example, Sporting Goods can be viewed by selecting channel 210. Channel 210 lists a directory of categories within sporting goods, such as Baseball or Skiing. The contents of the selected category can vary from channel to channel and also with time on a specific channel. The Skiing channel, for example, might have a short clip of full motion video, showing a skier going down the slopes. This might be followed by still frame pictures of various pieces of ski equipment, one at a time, with a prompt to purchase the displayed merchandise. Once the user reaches this level of specialization within the shopping system, the system returns to a sequential access to views of a limited number of related items available for purchase. Ordering can occur by telephone, as it is today, or by entering a sequence on the keypad, similar to ordering an impulse pay-per-view event.

Impulse purchases would be collected by a store and forward technique, in most cases. With careful manipulation of the channel map, each category of merchandise can be allocated a time slot of active video to be intermixed with text and still frame screens. A single service channel can be used for several full motion video clips. The channel map control system allocates the single video source to several different channel numbers. For example, a single video might be shared between all categories within the sporting goods department. Each of nine categories might be allocated one minute time slots on a rotating basis. Alternatively, a single service could use most of the available video time to demonstrate the main sales item, similar to the current shopping shows. Other categories would still be available for inspection and purchase, using the still frame and teletext modes.

This method places a heavy burden on the channel mapping system. The channel map might be updated every minute. It is critical that the changes be performed cleanly. The network does have the luxury of maintaining complete control over how the switches are made. This provides an opportunity to use fade to black to mask any disruptions in the video display. This is an application where sending repeated "I" frames will provide real benefits.
The delay for displaying the newly selected video service will be only as long as the time needed to receive and decode a single frame. In this example, the security system does not pose a problem for rapid channel switching, since all of these activities fall within a single service. If any security is required, the same scrambling control can be used for the entire service.

CONCLUSION

The digital video system of the future affords the possibility of a whole new range of video and audio related services. The CASH shopping channel is just one of many examples of how this new technology can be put to work. With this increased capability comes increased complexity. Careful design of the implementation tools for the digital video system will provide the operator access to the capabilities of the system without making it so complex the features will never be used.

As standards for the compression and transport of video and audio signals fall into place, attention needs to focus on establishing a set of conventions for the configuration and operation of these systems.

ACKNOWLEDGEMENT

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FLEXIBLE DATA STRUCTURES AND INTERFACE RITUALS FOR RAPID DEVELOPMENT OF OSD APPLICATIONS

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Abstract

On Screen Display (OSD) used in CATV subscriber set-top decoders can be used for many different interactive viewer information services such as Schedule Guides and Sports Scores. Allowing for the required flexibility and functionality of Interactive Information Services, an OSD decoder system must use flexible redefinable data structures and interfacing rituals. This mandates downloadable behavior and data , not just downloadable screen images.

Decades of Information Systems (IS) software development on mainframe and personal computers have shown that mere reprogramability is not enough. IS applications must evolve almost constantly. Staying responsive to user needs while avoiding development bottlenecks requires that IS systems be built from standard parts customized by parameterization and/or non-procedural specifications rather than custom hand-crafted code. Examples would include Relational Databases and Application Generators.

These IS productivity techniques can be applied directly in headend computers, and scaled to fit within the OSD decoder. Zenith's HT-2000 decoder system applies both techniques to rapidly develop and then deploy Interactive OSD Information applications.

SUPPORTING OSD INTERACTIVE INFORMATION APPLICATIONS

A typical first exposure to On Screen Display capability is a VCR. Cryptic flashing lights on a control panel are replaced by cryptic text instructions displayed on the screen.

To be fair, the text messages aren't all that cryptic. They are just unfamiliar, and expert consumers had already learned how to do everything with the control panel.

For non-expert users, the VCR's features are more accessible. There just aren't any new features. Existing features just had a new, more "user friendly", front end.

While an OSD set-top decoder can certainly be made more user friendly, the real potential is in entirely new features such as Schedule Guides. These new Interactive Information Services can be standalone, or integrated with video programming.

An interactive OSD information application allows the viewer to obtain specific information when they want it. Selection and timing is under viewer control. The requested data is presented on screen, possibly on top of specific video programming.

When designing Zenith's HT-2000 decoder and its headend computer, the OSD Information Gateway, several requirements were identified. Each is discussed in one of the following sections: The Need For Flexibility, Downloaded Data, not Images, and Integrated Control

These points led to the conclusion that a downloadable decoder was needed to allow easy development and evolution of new applications. It was also important to allow for easy deployment of new applications.

THE NEED FOR FLEXIBILITY

Correctly predicting exactly what information is required for Interactive Information services is next to impossible.

For example, a Schedule Guide application has far more open questions than you might expect:

- Will viewers want to find movies by theme and/or actor? Will the data be available?
- Should the schedule be presented in a two-dimensional grid, or a tabular listing?
- Will viewers want information on all channels, or only the movie channels, or only the PPV offerings?
- How much information do viewers want for each movie? The title, two lines, four pages, the actors, the director? Do they want to search by date, rating, price range, director, theme and/or copyright date?
- Would people prefer a long schedule with minimal detail, or a shorter one with more information? Which is worth more to them?
- Should PPV offerings be listed with Pay TV movies or separately? What about movies on non-pay channels?
- How would a staggered start Video on Demand channel be shown in the Schedule Guide? What about a pure Video on Demand service?
- Is the Schedule Guide a premium service, or a method of promoting PPV?

Moving past the schedule guide, what other services will be required: stock quotes, horoscopes, sport scores? Will Baseball fans want just the final score, or a complete box score?

Even more complex than identifying the information to be presented is deciding exactly how it will be presented and which keystrokes the viewers will use to access it.

A well defined user interface combines User Rituals with User Myths . The user rituals are patterns of input required to do certain things. Pressing backspace to erase the previously typed character is a common computer user ritual.

A user myth is an explanation, in user terms, of what each input key or sequence does. Clicking the left mouse button in a certain screen region is "pushing a toggle button".

Consistent user rituals and myths make an interface easy to work with and understand. An interface that requires raw memorization of arbitrary input and output sequences is very difficult to learn and user unfriendly.

Predicting in advance what rituals viewers will find difficult, and which they will find frustrating is even more difficult than knowing what information services they want.

It would be impossible to correctly define all of the information and interface rituals required for these various services. Even with something as 'obvious' as the schedule guide, the answers are just not reliably available.

You don't know. I don't know. That marketing consultant who wants to sell you the answers doesn't know either. None of us **can** know for the simple reason that the viewers themselves don't know.

Conducting a survey won't do any good, no matter how large your sample is. The viewers can only give you their **guesses**. The viewers themselves won't know until **after** they have started using these services.

A survey conducted before the introduction of the remote control might have projected little interest in remote controls, since people only change channels a few times an hour. "Zappers" did not exist.

We are attempting to provide tools for viewers. As with those who designed automotive or computer input devices, we can only propose options. We must wait to find out which options consumers will find useful and/or become accustomed to, and which they will find annoying.

Accommodating consumer interests requires flexibility, and constant adaptability. Would a supermarket manager buy a check-out system that dictated how merchandise be shelved for the next ten years? Why should a Cable Operator accept an OSD decoder that locks in the format of the Schedule Guide and other OSD services?

The nature of the information displayed, the format it is displayed in, and the interactions the viewer goes through to access them will all **need** to change during the lifetime of any OSD decoder.

To meet these needs we must be able to actually redefine the behavior of the decoder from the headend without modifying the decoder.

DOWNLOADED DATA, NOT IMAGES

How the OSD decoder receives and **uses** its information is critical to allowing flexible creation, and evolution, of these and other user-friendly features.

A Schedule Guide, for example, could be viewed as nothing more than many pages of schedule information. Rather than waiting for the information to scroll by, the viewer can now Page Up and Page Down on their own.

Doing so would sell the potential of an OSD decoder short. Separating data reception and storage from display allows flexible efficient implementation of many desirable features. Examples are given in the following sub-sections.

Tiering

Services such as Sports are likely to be tiered. Only subscribers to these services would be able to display this data.

Even within a given application, there could be levels of service offered by tiering. A "basic" Schedule Guide might only provide detailed movie descriptions for tonight's PPV offerings. A "premium" Schedule Guide tier would provide complete descriptions of all movies.

Since decoder RAM space will always be limited, it would be desirable to have the decoder only store data for which it was authorized. For a given RAM capacity the decoder would be limited in what tiers it could be authorized for, not in what tiers were available to it.

Conditional Display of Data / User Filtering

Unwanted information is clutter. It gets in the way of valuable information. The information displayed should adapt to individual viewer preferences. Insisting that every household receive detailed movie descriptions for an Adults Only service would probably not be desirable.

You may view a Schedule Guide as a value added service or as a promotional device. In either case information about channels a viewer will **never** want to watch is undesirable.

If the Schedule Guide is viewed as a premium service, an annoying one will not be worth as much. If the Schedule Guide is a promotional feature, you want the viewer to concentrate on promotions for things they are likely to buy.

Multiple Indexing of the Same Data

In many applications the same data could be found in different indexing orders or via alternate User Rituals.

The same movie may be found in a PPV index, in a Schedule Grid, a time-oriented listing, a channel-oriented listing, a theme index, an actor index, or even a Director index.

The box score for the Chicago White Sox vs. California Angels game could be reached via either "Chicago White Sox" or "California Angels".

Redundant Display for Convenience

Sometimes an application displays information it normally edits on another screen for the viewer's reference.

The fact that a channel is locked out via Parental Control should be displayed not only on the Parental Control screens, but on the Schedule Guide display as well.

Programs scheduled for automatic taping might be flagged in Schedule Guide grids and listings.

INTEGRATED CONTROL

Schedule Guide data should interact, not just be a passive display. The viewer should be able to do things with it. While browsing through a Schedule Guide the viewer should be able to select a given program and then do any of the following:

- Request a more detailed description.
- Tune to that channel immediately.
- Request an IPPV purchase of that program.
- Schedule an automatic taping of that program.

When tuning to a new channel, the decoder could display the channel number, name, and information about the current program.

Parental Control and Favorite Channel maps could reference channels by name. Parental Control could be extended to lock-out or exempt specific **programs**, rather than whole channels.

Opinion surveys and/or home shopping applications could use the two-way transmission capability to interact with the headend.

Application Co-existence

While working on each separate OSD Information Application it would be easy to forget that the Viewer is likely to view their set-top Decoder and television as one unit. And the primary purpose of that unit is to watch television, not check stock quotes.

One aspect of "integrated control" is the ability to toggle between the OSD Information Application and watching the viewer's program.

Remote control layout and software conventions should make it easy for the user to flip in and out without having to start over from scratch every time they re-enter an application.

Conditional Access

Any Schedule Guide application should be integrated with the decoder's Conditional Access system. It should be able to display IPPV ordering instructions, transmit two-way IPPV orders, and give viewer feedback on confirmed IPPV authorizations and authorized subscription channels.

Virtual Channels and Interactive Television

Many applications require "virtual channels". In these applications the decoder is tuned to an alternate channel without bothering the viewer with the details or changing the displayed channel number.

Examples would include Barkering, staggered start PPV Video "On Demand", interactive television, video back-drops for messaging systems, and targeted advertising. The ability to tune the decoder becomes just one part of the OSD applications "message".

DON'T RE-INVENT THE WHEEL

While the information, and viewer rituals for accessing it, are unstable, the possible sources of this information are even more varied and subject to change. A flexible OSD Decoder Information Service must display unknown data in unknown formats that is originally captured by Headend equipment from unknown sources.

Responding to rapidly changing highly flexible requirements is not an easy process. Making the OSD decoder downloadable allows new services to be developed after the decoder is already in the field. It does not make developing those services any easier.

We need a way of developing and evolving new decoder features. We have to be able to integrate the new features with existing features. Lastly, we have to be able to test and deploy the new features without constantly disrupting customer's use of the decoders and the features they already enjoy.

These are not new problems. They have plagued software development for several decades now. Methods of coping evolved to deal with these problems include Prototyping, Relational Database Management System (RDBMS), Report Generators GUI Screen Painters, and Revision Control.

Rather than re-invent the wheel, we should examine these solutions to see what lessons can be applied to the developing Interactive OSD Information Services.

Prototyping vs. Specification

As a rule, Software developers are much better at correctly implementing something than we are at knowing what it is we should be implementing.

The most serious "bugs" are not incorrect algorithms. They are incorrect features. The software functions "perfectly." It just doesn't do anything that is of any particular use to anyone.

The first attempt at solving this problem was **The Specification**. The Specification has taken many forms: long narrative descriptions ("Victorian Novels"), contract-like "rules," flowcharts, data-flow diagrams, structure charts, data structure diagrams, state transition diagrams and the latest fad: object oriented diagrams.

Software Developers can spend a great deal of time debating the relative merits of **Methodologies**. A Methodology specifies how The Specification is developed, what must be in it, and how it is translated into a working system.

Methodologies are most often compared and contrasted with a near religious fervor. However, they almost all make one critical assumption - the "User" already knows what is required.

Evaluating interfaces described on pieces of paper is a very difficult task. The format of the Specification, let alone which icons are used in what Diagramming conventions hardly matters if the user is only reporting their hunches.

When a user has never used a system exactly like this, there is really no alternative but to let the user actually test a prototype of the system. Nothing can match a 'hands-on' test drive of the actual interface for identifying problems with it.

Most interactive user interfaces are now prototyped and/or developed with tools that allow the displays and input rituals to be rapidly updated.

Prototyping and/or rapid deployment of modified interfaces is extremely vital to the development of Interactive OSD Information Services for several reasons:

- A screen that looks fine when sketched on a paper memo, or even drawn on a PC graphics program, may look terrible when shown a real television set.
- Viewers interact using a Remote Control and/or set-top keypad. These are very different from a PC keyboard.

Relational Database Management Systems

Relational Database Management Systems (RDBMS) manage data for IS applications. Professors build entire careers out of debating the fine points of Relational Database theory with each other, so I'm not certain how much can be explained in a page or so.

A RDBMS organizes data into Tables. Tables are said to have Rows and Columns.

Each Row is a record, or one instance of data. A "Programs" table would have one row for "The Empire Strikes Back".

Each Column represents one thing that is known about each instance. It is an attribute of each record. Columns for the "Programs" table could include "Title" or "MPAA Rating".

Tables do **not** include any "repeating" data. You cannot have a "Stars" column that lists up to six different stars. Instead a separate table lists **each** star for **each** movie.

Tables reference each other only by value. Some of the Columns in Table X can be used to search Table Y. Table X does not have anything like a pointer or Record Number for Table Y.

These conventions avoid data that is massively entangled both with code and itself. The dependencies have been limited and cataloged. This separation allows migration to new definitions of the systems data without having to rewrite **every** piece of code that uses that data.

An OSD decoder can benefit greatly from similarly standardized data structures. Headend computers supplying data to the OSD decoder, such as the HT-2000 system's OSD Information Gateway, can use an RDBMS to store the original data and to map its translation into the downloaded data.

Report Generators

Report Generators use RDBMS standardization to allow reports to be specified in a non-procedural fashion.

A Non-procedural report specification states what information should be in the report, and how it should be formatted. It does not specify **how** the data should be retrieved, sorted and formatted.

When applicable, specifying something in non-procedural format has proven to be far faster and reliable than writing procedural specifications.

Non-procedural specifications also allow hardware upgrades. The same results can be achieved under new hardware. The same procedures may not translate as easily. Later OSD decoders are likely to have more RAM and higher resolution display devices. These decoders would co-exist with older models. Non-procedural specifications will be shared.

GUI Application Generators

GUI (Graphical User Interface) applications that run under such platforms as Windows and Presentation Manager can be very difficult to code. GUI Application Generators slash development time by allowing non-procedural specifications to combine standardized components for a new interface.

Use of common building blocks is not just a convenience. It is **desired** for its own sake. Conventions such as list boxes, drop-down combo boxes, checklists, pull-down menus and radio buttons are valuable not only because they reduce coding time but because they make it easier for the computer user to learn how to use the application.

Maintaining a common "Look and Feel" for OSD Information applications is even more important than for PC applications. Viewers have less motivation to work their way through a strange input ritual. While being flexible, the development system for OSD Information applications should encourage use of standard input and display mechanisms.

Revision Control

Even before software developers identified the need to prototype systems, they knew that systems already in use had to modified.

Developing systems is hard enough. Modifying systems that are already in use is considerably harder. Many of these problems are still relevant to OSD information applications:

- Interfaces must evolve. Even new features should feel familiar to old users.
- User edited data should be maintained.

- For many systems operations must continue even while the system is upgraded.
- Many items may change for a new feature: the data sources, how data is stored, and the code to use the data. Changing all of them **at the same instant** is unrealistic.
- New code sometimes blows up, requiring an immediate **rollback**.

SCALING THE WHEEL TO FIT

RDBMSs and the other techniques described are all very powerful tools. Re-inventing the wheel is always a waste. But a set-top decoder with an 80386 is overkill, expensive overkill.

As currently defined and implemented, these tools would not fit in a set-top decoder. The wheel already exists, but it doesn't fit. However the approach does not have to be abandoned, just scaled to fit.

The HT-2000 decoder would need a processor capable of accessing considerably more than 64KB of RAM. No matter how you compress it, you can't fit much of a Schedule Guide in 64KB, let alone any other features.

Additionally this processor would have many other responsibilities:

- Accept input from keyboard.
- Accept input from IR remote.
- Control the OSD chip.
- Tune the decoder.
- Control other outputs: IR out, LEDs, Volume, video blanking, audio mute, any two-way transmitter and any expansion port.
- Manage a small amount of self-edited data. This data would include favorite channels and a user PIN for IPPV purchases and Parental Control.
- Interface with the Conditional Access system. To enhance security this was kept a separate module in the HT-2000 decoder.

The processor would not have to do anything that complex with the data. There are no square roots, or regression analysis to be performed. Vast processing speeds are not needed, just the ability to do simple things with vast amounts of data.

The most powerful affordable candidates were derivatives of 8-bit processors that could look at anywhere from 512KB to a few Megabytes. However it is typically only visible in 64KB chunks. This increases memory management complexity. Many had built-in help for IO interfacing, such as UARTs.

Downloading Safely

A downloadable OSD decoder's behavior is controlled by the data packets sent to it from the headend. The "code" it is executing is updated over the cable downstream, rather than by distributing new ROMs.

On the HT-2000 project the downloaded behavior is called the "Dialog". Once a Dialog has been written it would remain in use indefinitely. This might be a few days, a few weeks, or a few years.

The other data downloaded is the Dynamic Data. This data changes on a daily basis, or possibly more frequently. Schedule Guides, actual weather information and sports scores are all Dynamic Data.

By contrast, the Dialog is what knows how to use the Dynamic Data.

Downloading dynamic data is relatively simple and risk free. The worst that can happen is that the information is wrong. The information has a limited lifespan. It will be updated and/or deleted soon.

Errors are also relatively innocent. If a movie title is "Star Warx" a few viewers will notice and get a minor chuckle.

Downloading dialogs is considerably riskier. An undetected error might cause the decoder to do something various obnoxious such as jamming the volume to full or refusing to tune where the viewer want to tune.

It is imperative that Dialog downloads be as reliable and resilient as possible.

Downloading dialogs over a cable plant to thousands, or even hundreds of thousands, of decoders presents several problems.

In a one-way plant there is no way to acknowledge a successful download, or request a new download. Even in a two-way plant the upstream capacity might not allow each decoder to individually acknowledge the download.

Bad downloads are unavoidable. Whatever is downloaded can and eventually will be garbled at one or more points in the distribution chain:

- Error detection codes are very powerful, but only a partial solution. Fewer than 1 undetected error in 10,000,000 sounds very secure. But if you have 200,000 decoders talked to 1000 times a day it means 20 irate customer calls each and every day.
- Operational errors can occur. The dialog may have been restored onto the headend computer from a faulty tape or floppy disk.
- Software errors are inevitable.

If bad downloads are unavoidable the question becomes, can you fix it? The only way to **guarantee** that is to ensure that **nothing** you can download could prevent the decoder from accepting **another** download.

This requires that the OSD decoder essentially have "two minds". One accepts downloads. The other **is** downloaded. Nothing the second mind does can interfere with the first mind's ability to accept further downloads.

There are four valid approaches to this:

- Some processors allow two virtual programs in the same processors. Usually dubbed Supervisory and User mode, these processors ensure that User mode code cannot interfere with Supervisory code.

  This would be a perfect solution, except that this feature is generally not available in the processors affordable enough to place inside a set-top decoder.
- Two processors. This is essentially a hardware simulation of the above. It takes more power and is nearly as expensive.
- An External watchdog timer could force termination of RAM stored code and return to ROM based code. This is more feasible, but still costs money and takes up board space.
- Interpretive code. The downloaded behavior does not truly gain control of the processor. The ROM based code simulates a processor that executes the downloaded code.

Interpretive code was chosen for the HT-2000 decoder. In addition to its safety features, interpretive code offers other advantages:

- Processor independence. Later versions of the decoder can be implemented on a more powerful processor, possibly with extended instructions while maintaining full backwards compatibility at the binary level.
- More compact downloads. Because the "machine code" is designed for OSD applications it can be more compact than native machine code would have been.
- Interpretive code can be restricted from updating data under control of the headend computer. This would be more difficult under the other solutions.
- Interpretive code can have other safeguards, such as ensuring that it will listen for fresh user input regularly, in addition to being re-downloadable.
- Hardware dependent code, such as device drivers for handling input and output, can be placed in the interpreter. Essentially, the interpreter becomes the equivalent of a PC BIOS. Later revisions of the hardware can handle hardware interfacing differently without having to recode the downloaded applications.

State Driven Display Painting

The decoder's display painting primitives should support non-procedural generation of displays.

It should be optimized to allow static receptive elements to be specified easily and efficiently, while still allowing complex data dependent displays.

The HT-2000 decoder decides what to display by a current Dialog State. In a given state the decoder will have a recognizable display and respond to inputs in a specific way.

Making display logic state based helps reinforce an important principal of graphical user interfaces: if the program/system now **acts** differently it should **look** different.

Basically a state is what the viewer would think of as a given display. The data displayed there might change, but it is recognizable. One state can be "typical schedule guide page". All pages of the schedule guide act the same way, and display the same type of data in the same format. Only the specific data is different.

The viewer will recognize a Schedule Grid as a given display no matter which page they are on, or what day they tune to the Schedule Grid. It has a certain "look", and the viewers will know what they can do when the screen has this "look".

DATA MANAGEMENT PRIMITIVES

A full RDBMS is clearly beyond the horsepower of any 8-bit processor. A more realistic set of standard data management capabilities would have to be selected.

Many factors had to be considered:

- ROM space was even more tightly constrained. Device interfacing, such as IR input handling, would have first claim on ROM space. Standardized data primitives would have to be implemented in very compact simple code.
- There will always be more uses for RAM. Feature tiering will require different decoders to hold different data.
- The decoders were in a heavily distributed environment. Most customers would be running one-way Cable plants. This meant that updates would not be acknowledged.

Certain RDBMS features were too expensive to implement in the decoder. We found ways to do without those features, or to provide the same service in the OSD Information Gateway rather than the decoder itself.

An RDBMS allows the same data to be fetched in many different formats. While this allows portions of the application to view the data as appropriate to its needs and how the data was defined when it was coded it does carry a heavy run-time penalty.

This penalty is high enough that most RDBMSs allow the source code to be compiled to match the actual data format, rather than binding at run-time. There would certainly be no need for run-time binding within the OSD decoder.

RDBMSs also allow the data format to be redefined without losing existing data. You can add new columns to a table, or re-arrange existing columns, without losing any current data.

The code to support this in the decoder would simply be too complex. Instead we decided that the original data would always be stored in a RDBMS on the OSD Information Gateway. The new data would simply be re-downloaded in the new format.

Many applications have data that expires at a specified time. Schedule Guides are just the most obvious example.

When all the decoders are deleting the same records it actually makes more sense for the headend to tell them to delete those records.

In this way "garbage collection" code can execute in a more powerful headend computer, rather than in each and every separate processor.

Record Sets

An RDBMS minimizes inter-dependence of records by using "content" addressing. An employee record does not have a pointer to the physical location of their Department. Instead it has a key value that can be used to search for and find the Department record.

This sort of capability is crucial to a distributed database system. It was scaled down for the HT-2000 decoder by turning RDBMS tables into **Record Sets.**

Each Record Set contains many fixed length records. Each record is much like a record, or row, from a RDBMS table.

Each record would also contain many fields. These are essentially the same thing as a RDBMS column or attribute.

The downloaded dialog simply asks for a specific record from a specific record set. That record may be in different locations for different decoders. Indeed if memory capacities have been varied based on individual option tiering, they will be. The application code does not need to understand this.

The size of each record, and the number of records allowed is defined for each Record Set. Additionally the record set may have an optional key field used to sort all of its records with.

Sorted Record Sets are kept in sorted order. Updates are merged into the Record Set based on the key value at the beginning of the record. Old records, such as yesterday's schedule, are deleted by key range.

Sorted records sets are used to index with user meaningful data. Schedule records sorted by date, time and channel would be a prime example. The downloaded dialog looks for the Schedule Record for a specific channel and time, not a specific memory location.

Unsorted record sets are really just optimized sorted Record Sets. They have a one or two byte 'key value' that is not physically stored with the record. Instead it is implied by which slot of the record set the record is placed within.

Unsorted record sets are most useful when dealing with things that can be numbered in a tight range. Examples would include visible identifiers such as Channel numbers, and internal identifiers such as Program Numbers. Internal identifiers would be obtained from sorted Record Sets.

Splitting the schedule information like this into two separate Record Sets allows the same Program Information to be used for a single movie no matter how many times it is in the schedule.

Placing data in the database **once,** no matter how many places it is referenced from, is one of the most crucial aspects of Relational Database theory. It is critical to efficient data handling and standardized handling of distributed updates.

The Record Sets of the HT-2000 decoder maintain this essential simplification with only a handful of easily implemented data manipulation primitives: virtual memory, record sorting and direct indexing.

An Example Schedule Guide in Record Sets

Suppose that schedule information is available from an outside source. The records each describe all of the times a particular channel shows a given movie. A record might be formatted as follows:

- The Service Name.
- The Movie Title.
- A comma separated list of actors.
- The Movie Length.
- The dates and times it will be shown.

This data would be normalized into OSD Information Gateway RDBMS tables:

- Each **Service** row would specify an available service.

- Each **Movie** row would give information on one specific movie no matter how many times it was shown.
- A **Showing** row would specify that Movie **X** was being shown by Service **Y** at a specific time. If the same movie was shown seventeen times there would be seventeen Showing rows referencing it.
- A **Starring** row would specify that Actor **R** appeared in Movie **X**. If Movie X had five listed stars there would be five Starring rows referencing it.

During the final translation into Record Sets we would attempt to further compress the data. Long keys values used as foreign keys may be replaced by short keys that index into an unsorted Record Set, for example.

Referential Integrity

One of the key features of a RDBMS is **Referential Integrity**. This feature ensures that if a **Pending Order** record has a **Customer Num** and a **Part Num** that there are matching **Customer** and **Part** records identifying who that customer is and what the part is.

The OSD decoder's data primitives must ensure that a **Schedule Record** reference to a **Program Num** is not referencing a non-existent one.

The highly distributed nature of a one-way Cable system presents a major challenge here. Unlike an RDBMS, the OSD decoder cannot just reject a Schedule Record that references a bad Program Number.

In a one-way Cable plant the OSD decoder has no way to complain. Putting up an OSD error message to the effect of "Illegal foreign key in update at 13:47 on 4/21" would be extremely user unfriendly.

Instead, we have to ensure that the Program record is added before the Schedule record by controlling the order in which the OSD decoder will **accept** them.

INFORMATION DISTRIBUTION

The OSD Decoder is just the last step in a complete OSD Information Service. Many other components are involved in a complete system.

Zenith's HT-2000 system has the following components:

- The **OSD Information Gateway** is responsible for downloading the OSD decoders. This requires it to collect all of the data to be downloaded from various sources first.
- Various **Data Providers** supply data to the OSD Information Gateway. Many of them are supplying the data in a standard format, rather than talking specifically to the OSD Information Gateway.
- A separate **Conditional Access Controller** manages Pay TV security. It is likely to have associated equipment such as Encoders and Receivers. Because HT-2000 was built upon the existing Z-TAC system, the Controller had to remain separate to provide continued support for customers who had not yet fully converted to HT-2000 decoders.
- The Cable Operator presumably has some form of **Management System** which is typically a separate computer. Typically the Management Computer would be connected to **either** the OSD Information Gateway or the Conditional Access Controller, but not both. Commands would then be routed to the correct computer.

Data would first be captured or accepted from a Data Provider. Conceivably the Management System could also provide some data.

Some configuration data, such as Channel line-ups would be entered directly on the OSD Information Gateway using GUI front ends.

From either source the data would be placed into RDBMS tables.

Reports, developed using Report Generators, could be run on this data.

GUI front ends, developed using GUI Application Generators, allow review and correction of any errors in the data. While data would typically not be hand inspected, the Cable Operator should always retain the ability to review any information before it is sent out to their customers.

The data may then have to be **prepared** for download. This process may involve some compression of data. For example, the same phrases may be found in many different movie descriptions. In order to preserve decoder RAM space the OSD Information Gateway will attempt to minimize the number of separate times it downloads the text "thrilling adventure" or "heartwarming romance."

The data is then **exported** from the database. This involves final translation of the data into Record Sets and the required download packets.

The data is received by the decoder.

The viewer may then have the dialog display the desired data.

CREATING NEW SERVICES

Developing a new interactive application for an OSD Decoder would involve several steps. The exact ordering of these steps, and some of the boundaries between them could vary depending on the development tools and procedures adopted. The specific steps presented here are for Zenith's HT-2000 OSD Decoder and OSD Information Gateway.

Defining the Editable Data

All information downloaded is ultimately derived from the OSD Information Gateway's RDBMS tables. A new application will typically require the addition of new tables. Enhancements to existing applications may need no additional tables, or only additional columns for existing tables.

It may be desirable to allow high volume data with rapid turnover to bypass the Relational Database. Zenith's OSD Information Gateway allows this option, but still pretends the data came from the RDBMS.

This standardizes handling of the data, and allows the by-pass decision to be deferred until after the application has been developed and tested when solid performance data is available.

Defining the Downloadable Data

The data that will be available to the dialog must be designed. This requires deciding how the data will be formatted and sorted, and what Edited data it is derived from.

In addition to deciding what the data will look like, the Application Designer must decide **which** data will be available to which decoders.

In some cases the supporting data will already exist -it is just being indexed or ordered differently. In other cases new RDBMS tables and/or columns will have to be specified.

Each Record Set can have many Record Set Revisions. The first version of a Record Set may have been missing a field, or it may have included a field that turned out not to be required.

Both Record Set Revisions can co-exist in the same OSD Information Gateway. The "Data Design" details how each Record Set Revision is formed from RDBMS tables.

Record Sets changes may be related. Schedule records and Program Information records might both be changed at the same time. The old versions work together just fine; the new versions get along even better - but you can't mix the two.

The Data Design also specifies which Record Set Revisions can be used together. This specification is called a Record Set List.

The Data Design is itself stored in RDBMS tables.

Specifying the Downloaded Dialog

The **Dialog Editor** is a GUI Application Generator for HT-2000 dialogs. It allows a Dialog Author to develop an interactive application, dubbed a dialog, that works for a specific Record Set List.

The Dialog Editor allows screen images, called "Forms", to be organized in Sections and populated with input and output fields.

Each Form consists of a static screen image and dynamic displays associated with fields. Fields can display data from downloaded Record Sets and/or decoder variables.

These can be combined to form complex expressions. A field specification might be the equivalent of "The name of the Program shown on the Channel in variable X no earlier than then Time in variable Y."

The Dialog Editor also allows the Author to specify **Transitions**. Essentially each transition specifies what **Response** there is to each **Input** event when the dialog is 'focused' on each given input field.

A Dialog Editor 'input focus' matches the Decoder's concept of 'state'. A dialog is in a given 'state' when a given input field has focus. Some 'forms' have invisible 'input fields'. For example, we pretend there is an input field when the decoder is turned off.

Input events include IR Remote keypresses, keyboard input, Conditional Access status changes and time-outs.

A **Response** may invoke a routine that is allowed to modify decoder variables. It can also specify a new state/input focus.

The Dialog is then compiled. The compiled dialog can be distributed to many different OSD Information Gateways.

Dialog Preparation and Download

At each site the Dialog can be prepared for downloading. This step can allow optimization of downstream downloading capacity and decoder RAM to meet site priorities.

The prepared Dialog can then be downloaded to decoders. The new dialog "takes over" from the previous dialog in the decoder. It can then preserve as much of the old state as possible.

With minor dialog changes, there may be no disruption at all to the viewer. Even in more significant code changes the new dialog will be able to let the viewer keep watching and/or taping whatever they were watching.

A Complete Update Scenario

Suppose a new feature has been proposed. In order to explain it a Dialog using no new dynamic data is prototyped with the Dialog Editor.

This dialog could start with the current dialog as a base, or be nothing more than a stand-alone stub of this single proposed new feature for demonstration purposes.

Creating static forms and transitioning between them the Dialog Author "storyboards" the new application. No real data is displayed, but a user will be able to get the "look and feel" of the proposed feature.

The prototype dialog can be compiled, prepared and downloaded to a set of test decoders. Working with actual decoders the Dialog Author and/or his/her reviewers find changes they want to make to the dialog.

This process continues until the storyboarded version is considered polished enough for use.

The Dialog Author would then decide what downloaded data was required to support the application. In many cases the data will already be available in the pre-defined Record Sets.

In other cases new Record Set Revisions will have to be defined and placed in new Record Set Lists. This is when the development process shifts from Dialog Authoring to Data Designing.

As wonderful and powerful as RDBMS concepts are, they are still very tricky. A Data Designer will need far more training than a Dialog Author.

The Dialog Author would specify the new Record Set Revisions and how they are formed from existing edited tables.

Occasionally the required data will not already be part of a pre-existing edited data. In this case the new RDBMS tables and/or columns must be specified. Frequently the RDBMS can be used to fill in new columns with default values based on other columns.

Data capture routines must be developed and/or modified to capture the new data. This step can be very simple if the data source uses a standard interface. When capturing data from a pre-formatted source this step would take a bit longer.

GUI front-end programs that access the modified RDBMS tables will have to be modified to access the new data. However, because of the Client/Server architecture they can continue to use the data in the old format without modification.

Even after updating the format of the RDBMS tables, the current Record Set Revisions will still be supported. Their data will be downloaded without change; they simply ignore the new data.

Once the edited data is defined, the downloaded data can be defined and a new Record Set List exported to the Dialog Authoring system.

The Dialog Editor can now be used to refine the dialog to use the actual data rather than being a simple storyboard.

After extensive testing, the new feature would reach the point where a field trial can be attempted. If anything goes wrong with the field trial the system can be quickly rolled back to the prior dialog. The OSD Information gateway is still fully capable of downloading the old dialog and the data in the format that it requires. The system can be rolled back.

An Alternate Update Scenario

It would be just as valid to start with a new source of data that has become available.

After figuring out how to capture this data, the Data Designer would determine how to store this data in normalized RDBMS tables.

Data Designers could then enumerate useful Record Set Revisions using this data.

Dialog Authors would then attempt to write new Dialogs after selecting the Record Set List that seemed most useful to them.

SUMMARY

Development of Interactive Information Services for OSD Decoders will be an ongoing process as the market adjusts to what information consumers desire and how they wish to access it.

Staying responsive to these changing requirements mandates that the set-top OSD decoder be downloadable.

Downloadability alone merely allows new applications to be developed. More powerful features are required to support rapid development and non-intrusive deployment of new applications.

Zenith's HT-2000 decoder system is an example of a complete development system for Interactive OSD Applications.

The OSD Information Gateway is developed under a Client/Server architecture using GUI Application Generators and the OS/2 RDBMS.

Data is captured and normalized into RDBMS tables. Data can be merged from many sources and even operator edited. Other RDBMS tables control the translation of this data into downloadable Record Sets.

The HT-2000 decoder uses a state driven interpretive model with built-in primitives for screen painting and data manipulation. It accepts downloaded behavior without risk of becoming permanently frozen by a defective download or excessively disrupting viewers.

GHOST CANCELLATION FOR CABLE HEADENDS

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Abstract

Multipath reception, of ghosting, has been a significant problem with broadcast NTSC television. Recent activity has resulted in the establishment of the Koo Ghost Cancellation Reference (GCR) signal as the American standard[1]. A new product which uses this signal has been developed for cable headends. Its use gives a significant improvement in picture quality for subscribers. This paper will discuss the new GCR standard and a practical system developed which uses this signal.

Introduction

The GCR needs to meet many specific requirements for high quality ghost cancellation. To meet these needs a new class of signals where developed. These signals have many important properties of which high energy and flat spectrum are most significant.

The processing algorithm in the receiver must make maximum use of the GCR properties to get high quality and cost effective cancellation. The GCR does not mandate a particular processing but certain properties such as flat spectrum and flat time domain envelope which were developed as desirable transmission characteristics also allow for efficient processing at the receiver. The algorithm presented below was developed to process GCR with a fixed point DSP and very efficient algorithms and hardware. The processing at the receiver must be able to handle the wide variety of the channel characteristics possible. This is best done if one algorithm is used regardless of the type of channel distortion. Some of the different aspects of distortion include distinct ghosts, smeared ghosts, inphase ghosts, quadrature ghosts, pre ghosts, post ghosts, distortion and smearing of the main signal, demodulation phase offsets, and sampling phase offsets. To have an algorithm change for different channel distortions would not be realistic given the number of different types of distortions and the multitude of combinations in which they can occur.

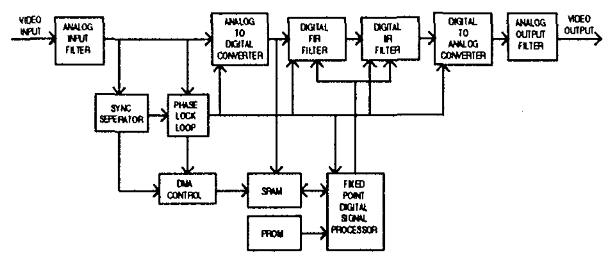


Figure 1 Ghost Cancellation System

The overall system is shown in Figure 1. The digital filter allows flexibility in the placement of the multipliers in its FIR and IIR parts. The architecture has been optimized for ghost cancellation balancing complexity, chip size, cancellation quality, and ghost statistics.

The remaining part of the hardware includes the analog input filter, analog output filter, analog to digital converter, digital to analog converter, sync separator, PLL, RAM, ROM, DSP, and programmable logic devices for controlling the GCR capturing. All of these are standard parts.

This system must work equally well in broadcast and cable environments without knowledge in the receiver in which environment it is located. The extensive testing done by broadcasters[2][3][4] and the cable industry[5] shows the effectiveness of the system.

GCR Signal

The GCR is defined by the following equations[6][7]

$$f(t) = \frac{1}{2\pi}\int_{0}^{\Omega}\left[A\cos\left(b\omega^2\right) + Aj\sin\left(b\omega^2\right)\right]W(\omega)e^{j\omega t}d\omega$$
$$+\frac{1}{2\pi}\int_{-\Omega}^{0}\left[A\cos\left(b\omega^2\right) - Aj\sin\left(b\omega^2\right)\right]W(\omega)e^{j\omega t}d\omega$$

$$W(\omega) = \int_{-t_1}^{t_1}\left(\frac{1}{2\pi}\int_{-\Omega_1}^{\Omega_1}e^{j\gamma t}d\gamma\right)\left(\frac{1}{2}+\frac{1}{2}\cos(ct)\right)e^{-j\omega t}dt$$

where A, b, Ω, t_1, c, Ω_1 are real parameters. These equations were formulated to have specific properties required to properly characterize the transmission channel. These include:

- **High signal energy.** High signal energy allows good characterization of the channel and high speed cancellation in a noisy environment.
- **Flat spectrum.** Flat spectrum allows complete and high quality equalization of the entire video signal.
- **Smooth phase characteristic.** Smooth phase minimizes sensitively to many distortions.
- **Non-cyclic Property.** non-cyclic property is extremely important for ghost/echo cancellation and channel equalization.
- **Windowed $\frac{\sin(x)}{x}$ auto correlation.** This is a widely used function and it can easily be processed by many existing algorithms and processing methods.
- **Flat time domain envelope.** A flat time domain envelope maximizes transmitted power and minimizes nonlinear and clipping distortions.
- **Short time duration.** A short time duration minimizes the impact on VBI resources.
- **No limit to cancellation range.** Range of cancellation should be an option of broadcasters and receiver manufactures.
- **Properties insensitive to digital processing.** Video is an analog signal whose properties should be unrelated to digital processing of that signal. This includes digital sampling rate and data lengths in FFTs.
- **Signal should not mandate processing at receiver.** A range of ghost cancellation products from the professional level to the consumer level will be made. Flexibility in processing at the receiver will allow each product to meet the cost and quality requirements of each market. Flexibility in processing allows the quality of cancellation to improve as new signal processing algorithms are developed.
- **Qualitative indicator of transmission distortion.** The envelope of the signal is sensitive to multipath reception. The envelope of the signal allows a visual indication of the existence of a channel distortion transfer function.

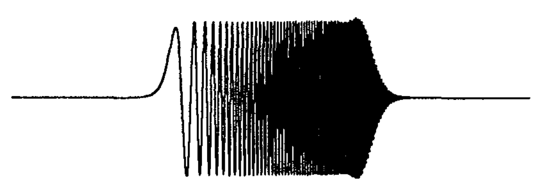


Figure 2 GCR Signal

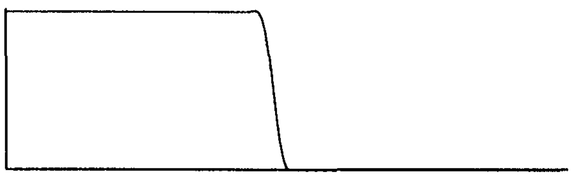


Figure 3 GCR Spectrum

The GCR is transmitted in an eight field sequence of changing polarity (+,-,+,-,-,+,-,+) on a 30 IRE pedestal. The GCR spans from -10 IRE to +70 IRE.

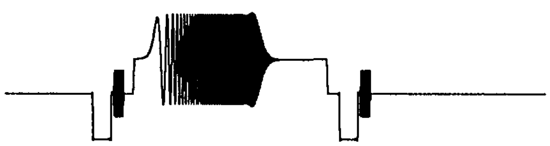


Figure 4 Positive GCR And Video

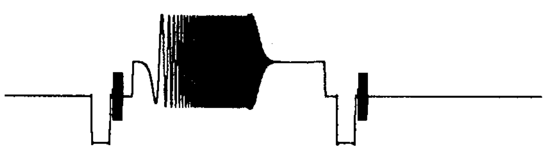


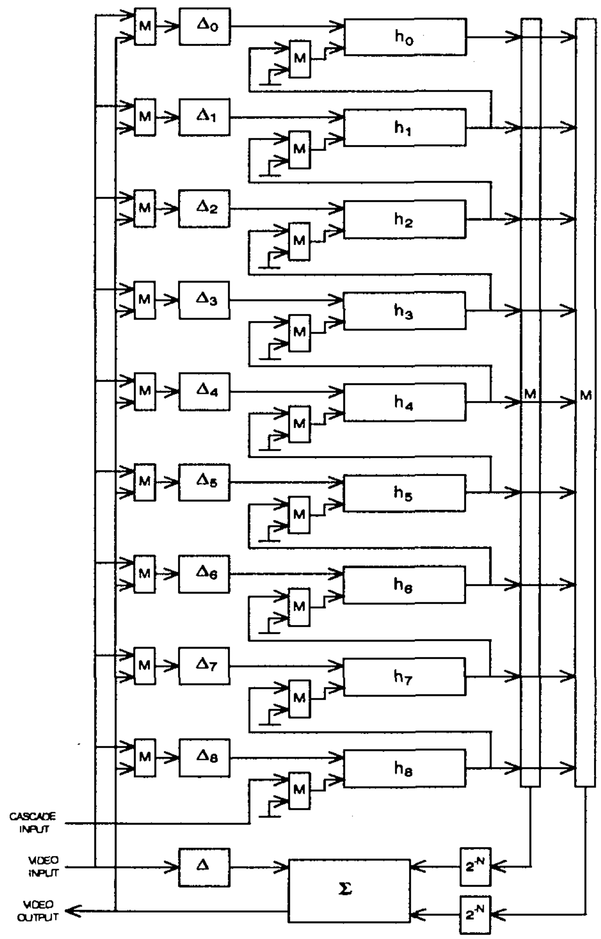
Figure 5 Negative GCR And Video

As stated above the GCR does not mandate particular processing. The description that follows is for the system currently implemented and is only one of many possible filters and algorithms.

Digital Filter

The digital filter of the ghost cancellation system consists of two custom filter chips[8]. Figure 6 shows the filter architecture. Each chip has nine sections of twenty tap transversal filters with programmable delays. In the first chip the filter sections have the flexibility to be placed dynamically anywhere in either the FIR or IIR filters. The filter sections of the second chip can be placed at any time delay in the IIR filter. The FIR filter is used to cancel pre ghosts, main signal distortion, and close post ghosts. The IIR filter is used to cancel post ghosts.

The flexibility in placement of the multipliers is achieved by programmable delay lines and programmable multiplexers. The multiplexers control placement of each twenty tap transversal filter section in either the FIR or IIR filters. The delay lines select the location within the filter. The goal of this flexibility is to have the multipliers where they are needed. While the flexibility does require overhead, analysis indicated that allocating chip area to the overhead was more useful than devoting the same chip area to more multipliers. Architectures based on fixed placement of multipliers have been found to require many more multipliers to achieve the same level of performance.



M = Programmable Multiplexer
Δ_i = Programmable Delay For The i^{th} Section
h_i = 20 Tap Programmable FIR Filter

Figure 6 Digital Filter

Algorithm

Figure 7 outlines the algorithm used and Figures 10 through 16 show an example graphically. The ghosted GCR is first captured into memory. Capturing is done with a circuit based on frame counters to guarantee the alignment of pixels when averaging is done on the data from successive fields. This GCR is then processed by the DSP to remove the color burst, sync, and pair-wise constant signals on the video lines before and after the GCR. This is continued through at least one eight field sequence. The number of eight field sequences captured can either be dependent on the signal-to-noise ratio of the received video or kept constant.

The GCR is then processed to get a channel impulse response model. This is accomplished by cross correlating the received GCR with a stored GCR. Use of cross correlation to get the channel impulse response is possible because the received GCR is the channel impulse response convolved with the transmitted GCR and the auto correlation of the GCR is a windowed $\frac{\sin(x)}{x}$. Therefore the cross correlation output is the channel impulse response with the bandwidth of the GCR. For computation efficiency this step is done in the frequency domain using a FFT of the received GCR, multiplication with the conjugate of the frequency domain representation of the stored GCR, and an inverse FFT of the result. This is all done on a standard fixed point microprocessor with a 16x16 multiplier. The flat time domain envelope and flat frequency domain spectrum of the GCR are the keys to the ability to use a fixed point processor with a FFT of 2048 points. The stored GCR has a slightly wider bandwidth than the transmitted GCR to prevent a double rolloff which would occur in the correlation step if the same bandwidths were used (although it is not absolutely necessary in many echo cancellation signal processing). This is shown in Figure 8. It is important to note that the b parameter in the modified stored GCR is the same as that of the transmitted GCR so that both GCRs have the same phase characteristic. The extra bandwidth preserves the energy in the transition band to allow for a good channel equalization in this region.

When the GCR is present in the transmitted signal, the location and value of the peak of the channel impulse response model can be expected to occur within a small defined region. If the peak is within the expected region the GCR is assumed to be present and the algorithm proceeds normally. If the peak is not within the expected region the GCR is assumed not to be present and the algorithm is restarted without updating the coefficients in the digital filter. The expected region is small so that there is not a significant chance of false detection.

A modified LMS algorithm[9] is then used to adapt the FIR filter. The initial condition of the filter for the adaptation is an impulse. This LMS algorithm averages the gradient estimates over the size of the FIR filter to get the best gradient measurement and updates coefficients only once per loop. Sixteen adaptation loops are performed. The reference used for the LMS algorithm shown in Figure 9 is the cross correlation of the ideal transmitted GCR and the stored GCR.

The IIR filter coefficients are obtained by convolving the FIR filter coefficients with the channel impulse response model. The FIR filter should correct for all pre ghosts, main signal distortion, and close post ghosts. Therefore the output of the convolution contains the main signal and post ghosts. The convolution output after the main signal are the coefficients for the IIR filter. No further adaptations of the IIR filter are required. This single step for the IIR coefficients is desirable because the size of the IIR filter makes multiple adaptations computationally intensive. There is no attempt to check the stability of the IIR filter. Extensive field testing has shown this to be of little value. The IIR filter starts shortly before cutoff point of the FIR to compensate for imperfect behavior of the FIR adaptation at the cutoff point.

Up to this point the processing has assumed a multipliers exist at all locations in time over some interval. Mapping from a idealized filter with multipliers at all locations to a sparse filter which exists in hardware is then accomplished by determining the allocation of the filter sections to either the FIR or IIR filters and determining the delay value for each section. This determination is done using an algorithm placing multipliers at locations where the coefficients are the largest. The coefficient values from the full filter are then copied to the sparse filter. Setting of the shift registers and scaling of the coefficients is done to get maximum use of the dynamic range of the filter while preventing overflows. Finally the coefficients are downloaded to the filter during the vertical interval. The whole process is then restarted with the capture of the GCR signal.

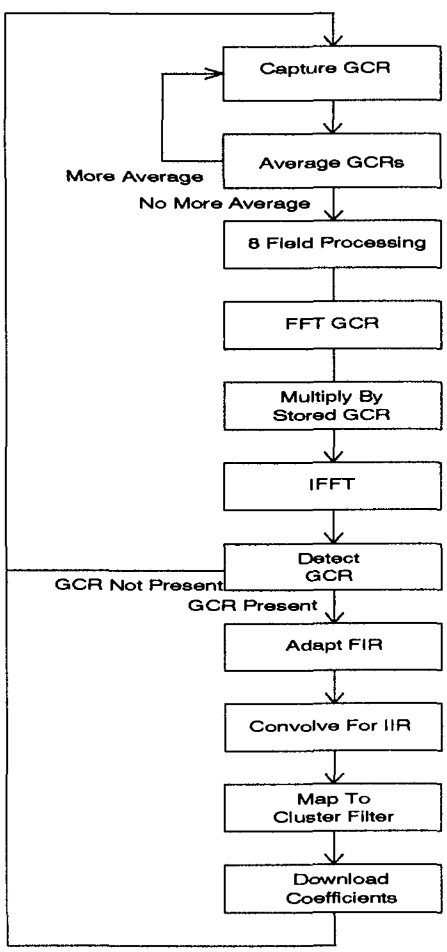


Figure 7 Flowchart Of Algorithm

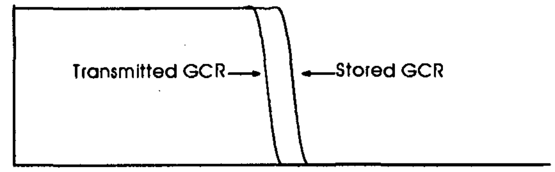


Figure 8 GCR Spectrum

Figure 9 LMS Reference

Figure 10 Ghosted GCR And Video

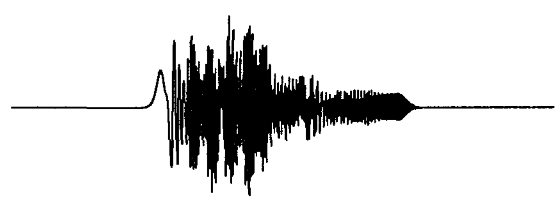


Figure 11 Ghosted GCR

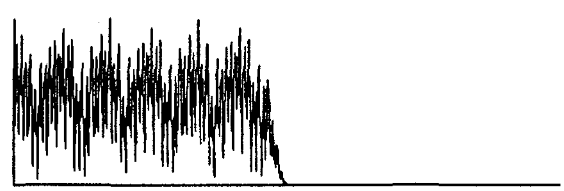


Figure 12 Spectrum Of Received GCR

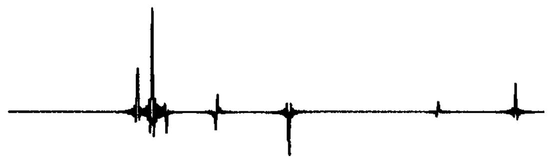


Figure 13 Channel Impulse Response

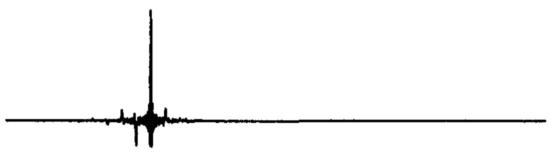


Figure 14 FIR Coefficients

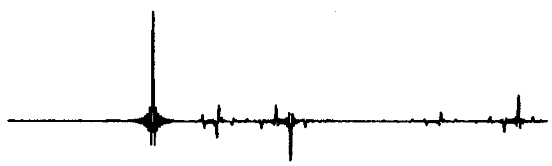


Figure 15 Convolution Output

Figure 16 IIR Coefficients

Conclusion

The GCR is a unique signal was designed to meet the specific requirements of ghost cancellation of television. The performance of the ghost cancellation system using this signal has been found to be excellent. The flexibility in allocating filter sections to any location in the filters has been key to getting high performance from the filter resources. The flatness of the spectrum of the high energy GCR has been found indispensable in allowing the algorithm to be implemented in a fixed point processor while maintaining high quality and high speed ghost cancellation. The theoretical basis of the algorithm which makes no assumptions about the characteristic of the channel except linearity allows the algorithm to perform effectively over a wide variety of channel characteristics.

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INFRASTRUCTURE FOR PCS TELEPHONY

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Abstract

This paper discusses infrastructure issues and requirements for the provision of Personal Communications Services (PCS) by non-traditional telephony providers such as cable TV (CATV) operators . PCS infrastructure includes items such as switching, OAM and mobility management. Many non-traditional PCS providers do not currently possess such switching, network and OAM capabilities as are currently in place for LEC and Cellular systems.

INTRODUCTION

The objective of this paper is to discuss the infrastructure requirements for CATV provided wireless telephony, touching briefly upon potential deployment options and evolution strategies. It is important to realize that the North American telecommunications industry is undergoing tremendous change , as PCS spectrum becomes available, as wireless/fiber/coax technologies are deployed, as business alliances occur and as the regulatory environment unfolds. As recent CATV PCS trials and FCC filings have proven, cable TV companies are poised to enter the telephone business.

There are many aspects to providing telephony and PCS services. While PCS is often equated with wireless access, this is not necessarily the case. Personal Communications Services are oriented towards allowing the user to originate or receive calls anywhere on the network and allowing the user some measure of control over their service parameters. For the new entrant, providing PCS will first involve dealing with basic telephony areas such as acquiring directory numbers, selecting subscriber features, billing and switch operation. PCS is incremental to this basic telephony infrastructure including aspects such as mobility and enhanced service management.

PCS telephony infrastructure can be divided into the areas of switching, OAM (Operations, Administration and Maintenance), mobility management, auxiliary services and 'other'. The switching function requires consideration of PSTN connectivity, routing, directory numbers and features. OAM includes maintenance, provisioning, inventory billing and performance. Mobility management concerns radio handoff between cells as well as tracking the user between switches and across the network. Examples of auxiliary capabilities are directory assistance, voice mail and operator service. 'Other' areas not directly related to making or receiving calls, are overhead activities such as yellow pages, bill collection, staffing and vehicles. All of these infrastructure items may be the direct concern of the CATV PCS provider or handled by leasing or partnership arrangements. This paper will focus upon the switching, OAM and mobility aspects of PCS infrastructure.

PCS telephony is expected to involve a multiplicity of players, each bringing a different set of advantages and capabilities to the PCS industry. The types of companies expected in the business include Local Exchange Companies (LECs), cellular companies (cellcos), cable TV companies (CATV), Interexchange Carriers (IECs), paging companies and new entrants. Alliances are forming, as could be expected, between players having complementary capabilities. Examples are IEC/cellco/CATV alliances where the IEC provides the toll network, the cellco provides switching and the CATV operator provides the access distribution. A PCS provider may also choose to lease facilities from a non-allied company, perhaps until such time as they could purchase their own facilities.

The multiplicity of players involved in the PCS industry requires capability at several levels. These levels are the access area, the switching area and the network area. See Figure 1. Access providers require wireless, coax, fiber and interface technologies. Switching providers need wireline, wireless, local mobility and possibly partitioning capability. Network providers need PCS databases and inter-switch PCS signaling.

Furthermore, each player in the PCS business will not accept unnecessary dependencies upon other players. For instance, a CATV company will desire the ability to changeout RF technologies without waiting for network standards development. An optimum partitioning between network, switch and access areas is essential to provide this decoupling. Such a decoupling will allow PCS providers to work with a variety of switch and network configurations, allow multivendor solutions and provide high performance systems. Careful interface definition is critical in this regard.

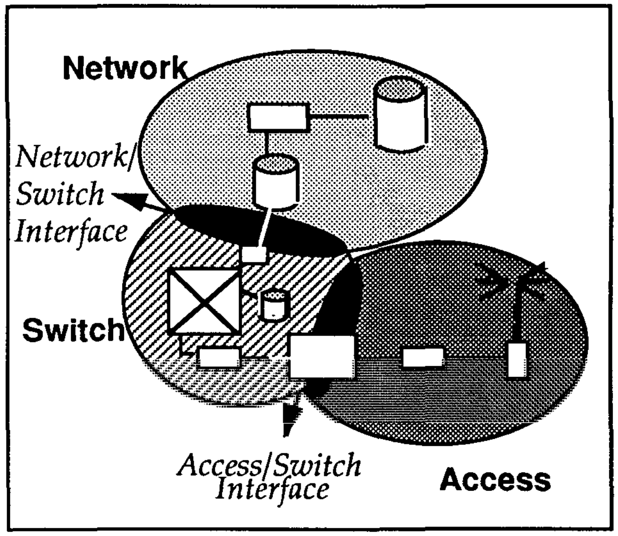

Figure 1. General PCS Architecture

SWITCHING

Switching characteristics (eg. translation, routing, billing and features) for basic telephony are well understood. What is significant are those requirements particular to CATV PCS. An initial view of CATV PCS switching requirements is as follows:

• shareable: there may be several new entrants in a given city who may wish to share the startup costs of a switch or there may be a separate company which would own and partition the switch for interested parties. The switch should also be shareable in the sense of regulatory colocation.

• scaleable: initial low subscriber penetrations will have a higher per subscriber cost.It would be desirable that this could be mitigated by a modular approach. Initial subscriber densities will be sparse as well which would mean that the switch would be serving a large geographical area.

• wireless service mix: a reasonable subset of the hundreds of residential and business features should be available to the wireless PCS subscriber.

• applicable to both wireline and wireless users: the PCS concept covers both fixed and mobile terminals. Wireline services are still required in those areas where spectrum is not available or where the CATV company is providing services such as high speed data.

• decoupling from access media and air interface detail: the subscriber's switched services should be independent of whether the access backhaul is copper, fiber, coax or wireless. The OAM overlay concerning access hardware detail should be layered away from subscriber services.

• OAM overlay: OAM should be layered and provided via common channel signaling so that the CATV PCS provider is not forced to integrate all OAM (especially access maintenance) with switching. And,

• standard interfaces: switch interfaces should be layered, standardized and use generic modern instruction sets.

MOBILITY

PCS mobility is complex. However, there are still fundamental requirements which can be derived.

Mobility should be layered. There are three general layers:

i) mobility inherent in radio management: this is neighborhood handoff . It may be caused by the user moving between adjacent cells of the same base station, by shadowing (eg. a truck drives between handset and primary antenna) or by interference. Such handoffs may occur rapidly and their messaging does not generally percolate up to the switching layer.

ii) access mobility: handoff where more intelligence is required because the user is moving between some sort of system boundaries although still subtending a single switch/PBX. An example would be campus mobility. And,

iii) network mobility: handoff between switches which involves the use of network level protocols and databases.

Mobility should be provided via optional layered modules. For instance, a PCS provider may not choose to provide network level mobility as a service but may very well wish to acquire neighborhood or campus mobility products. It should be realized that network and national mobility are not synonymous. Interswitch mobility within a single large city would still require network level signaling.

OAM

Operations, administration and maintenance (OAM) involves all aspects of running the system to provide service. Operations includes items such as customer management, installation and performance monitoring. Administration includes functions such as provisioning service, provisioning equipment, inventory and billing. Maintenance includes repair and preventative activities.

The extent of PCS OAM performed by the CATV company depends upon the access implementation chosen as well as by the CATV company's decision to operate their own switching and auxiliary functions. For instance, choosing to provide in-home cordless telephone coverage would require dedicated attention on a per household basis, whereas outdoor shared neighborhood coverage would involve a reduced number of units to administer. However outdoor units, subject to weather, could be individually more expensive to maintain.

OAM is computing intensive. The ability of CATV PCS platforms to evolve and to interwork with those of potential business partners is critical. Standards and layered implementations are required. Common channel signaling (CCS) is required so that OAM messages specific to a given service/transport provider can be routed to the appropriate center. CCS based OAM also allows the CATV company some autonomy as opposed to being locked into one vendor or partner's OAM system.

ECONOMICS

Economics for CATV PCS are based upon figures from several sources. Many models are available to determine PCS system costs. Relative values illustrated in Figure 2 are based upon average representative figures.

Switching

One of the initial questions which the PCS provider must decide is whether to buy or lease local switching products. Leasing is assumed to be from a non-affiliated company.

An examination of public domain telecommunication company annual report data (ie. LEC or cellco) provides one with some of the inputs which would be required to decide what potential leasing charges would be. Parameters such as the Cost of Goods and Services (COGS) provide the operating costs which a leasor would hope to recoup. It is critical to consider whether the leasor would provide OAM and other overhead services as these are costs which the CATV company would itself have to absorb anyway. It is also important to consider the different traffic rates that CATV PCS may load onto a given type of switch as well as the increased OAM that may be associated with sophisticated PCS services.

OAM

OAM costs were based upon an average of public domain annual report data and other literature. This includes functions related to the cost of providing service and does not include other per subscriber expenses such as depreciation.

One should be aware that literature showing wireless OAM costs to be lower than existing wireline does not take into account the additional investment and education that the new entrant would have to incur. Many overhead activities such as those mentioned in the introduction are required in order to become a telephony provider.

Mobility

Costs for mobility are extremely variable as they depend upon the architecture chosen. The degree of layering between access, switch and network mobility functions will determine the amount of messaging, processing and speeds required. Even the particular air protocol chosen impacts the cost of mobility as a comparison between AMPS and GSM interfaces will show.

Mobility costs were divided into access mobility and network mobility. Access mobility is that subtended by a single switch. Network mobility is interswitch. The model chosen assumed that access mobility did not interact with the network. This is not necessarily the case with some systems currently under standards development.

Economics Conclusions

A comparison of cost components for CATV PCS is shown in Figure 2. The key result is that switching and OAM costs are, in general equal to or greater than the access portion. Mobility is a smaller cost element and could perhaps be left as a service option until revenues are sufficient to drive this additional investment.

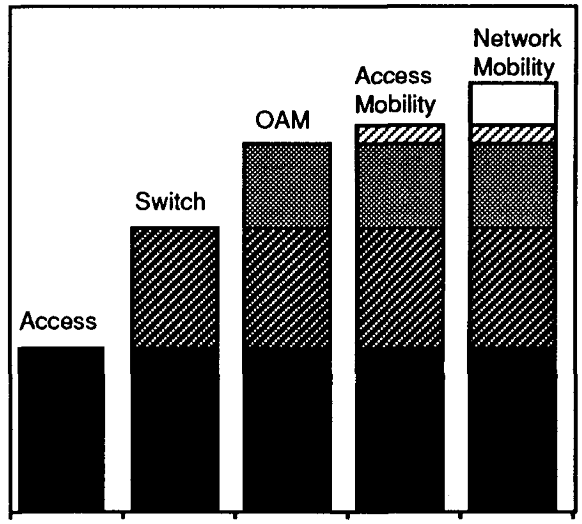

Figure 2 - Relative Cost Components per Subscriber

General Conclusions

Conclusions arising from an examination of the infrastructure requirements for new entrants in PCS telephony are that:

- the cost of switching and OAM could be greater than or equal to the access hardware capital investment.
- standard PCS switch interfaces are essential.
- the feasibility of switch ownership during initial deployment will depend upon the leasor's strategy to recoup investment and offer overhead services.
- the OAM costs of PCS for a new entrant could potentially be lower than existing wireline. However, PCS services will require more intensive administration and the new entrant will

have to learn overhead activities associated with telephony service. And,

• mobility capability should be layered, optional and standardized.

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INTERCHANNEL AUDIO LEVEL VARIATIONS—A PROGRESS REPORT ON EFFORTS TO SOLVE THIS PROBLEM

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If you ask subscribers and operators, one of the most frequently mentioned "technical irritants" is the variation in audio levels as channels are surfed with the remote control. The problem comes up at city council meetings and other places at the most inappropriate times! When I first began to discuss it at NCTA Engineering Committee meetings, many of my colleagues displayed a look of hopelessness. I have felt for many years that the problem is a series of problems compounded by complex interactions of variables over which you may or not have control! The NCTA Engineering Subcommittee on Quality Sound has been logically analyzing the problem, and we are making progress. The purpose of this paper is to discuss progress toward our goal of reasonable uniformity among channels that can be achieved by head end technicians using test equipment.

LOOKING AT THE "SYSTEM" END TO END

The first step is to look at the entire transmission chain from studio output to the subscriber's speaker. Figure 1 illustrates the various elements of the system, and where the critical adjustments occur. It is important to note (one of the root causes of the problem) that the only part of the link governed by "standards" is the final loop from head end to subscriber. For this portion, the FCC has mandated in rule 73.1570 that television audio shall modulate the FM subcarrier no more that 25kHz PEAK for monaural operation. Note that the FCC has defined a PEAK value, not a "0 VU" value, not an "average" value, not "peak to average ratio," but PEAK modulation. Although technically legal, no cable operator in his right mind would intentionally use any other standard for television sound. So, as a starting point, it is important to realize that most cable modulators have a device to indicate when peaks of 25kHz are occurring. Wouldn't it be nice if one could set the level necessary for 25kHz modulation with TEST EQUIPMENT using a standard reference signal?? This is our goal.

The significance of achieving this goal can be put in perspective by considering the fact that the cable program sources represented by this work represent 184,273 individual audio level controls in cable head ends! (Excluding any stereo!!) I lovingly refer to this as the "AMP" or Audio Misadjustment Potential factor.

FOCUS ON SATELLITE DELIVERY

Data taken by the subcommittee verified that wide audio level variations exist as received at the head end. The subcommittee did some investigation of both the FM subcarrier delivery system as well as VideoCipher. After a series of tests the group unanimously arrived at a recommended practice of 185kHz peak for FM subcarrier transmissions to represent 100% modulation. The old reference of 237kHz is simply too wide for many of today's receivers to handle, while a value of 75kHz does not produce adequate audio signal to noise ratios in many cases.

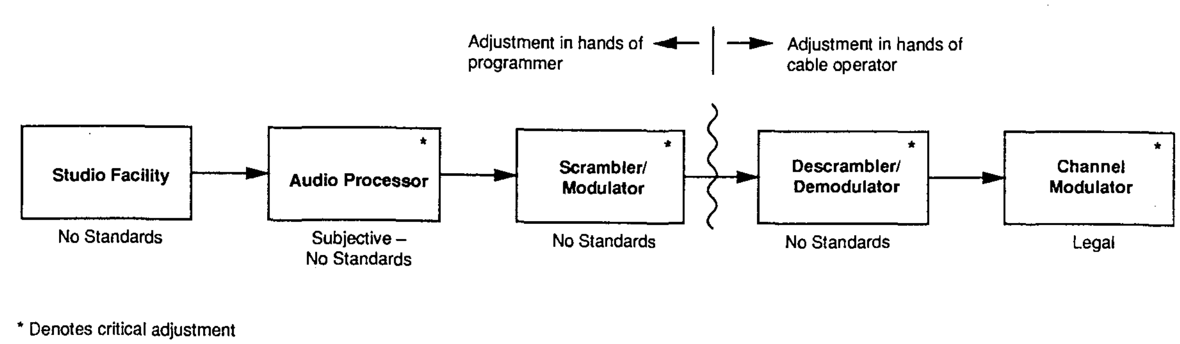

Figure 1. Cable TV Sound Block Diagram—a Program/Operator Team

In the case of VideoCipher, the "reference" system defines maximum audio level as approximately +16dBm just prior to clipping. Note that a "reference" system as defined by the manufacturer includes a 6dB pad on the input to the scrambler. Since there are no standards, the next best thing (we thought) was to ask the programmers to tell us what they considered to represent 100% peak modulation, as defined by FCC rule 73.1570. For FM subcarrier transmissions programmers were asked to provide a deviation value. For VideoCipher transmissions, programmers were asked to provide a value in dBm relative to the GI reference system that represents 100% peak modulation. Responses from programmers representing 29 satellite delivered sources were received. As we suspected, the answers confirmed an amazing variation. There are FM subcarrier transmission with peak deviations ranging from 75kHz to 237 kHz, a 10 dB spread! In the VideoCipher world, the range is from 0 dBm to +16 dBm, a 16 dB variation! A considerable amount of time was spent reviewing each response to make sure that the answer was indeed correct. This was time well spent! As you can see from figures 2 and 3, there is indeed a wide variation in admitted peak levels among programmers.

As an editorial comment, we as an industry should have insisted on defining recommended practices in this area 15 years ago instead of letting it go. The subcommittee encourages developers of the next satellite delivery systems to help set the practices up front.

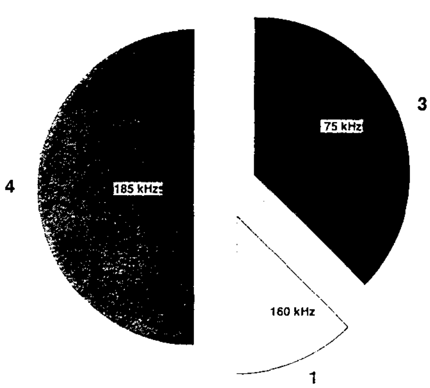

Figure 2. Reported FM Subcarrier TV Sound Peak Deviation

THE BIG HEAD END EXPERIMENT

Armed with peak program level knowledge as provided by the programmers, the next logical step was to set up a head end using these values, good test equipment, and procedures. The head end at CableLabs was volunteered for this experiment. In May of 1992, a technical team from the ranks of programmers, MSO's, and vendors spent 2 full days calibrating the head end. Each IRD was calibrated using a GI furnished scrambler to produce unity gain throughout the system. Each FM subcarrier demodulator was set for unity gain with respect to the recommended deviation of 185kHz. Seals were then placed on all audio adjustments on all IRD's. So, at this point, we had a rack of precisely calibrated receivers and descramblers.

The modulators for each cable channel were then adjusted to produce precisely 25kHz deviation when driven with a signal exactly equal to the level each programmer said should equal 100% modulation. This was done using Bessel Null techniques to insure high accuracy. (At the end of the experiment, we dubbed ourselves the Bessel Null Boys.) Calibration was verified using a precision modulation monitor. It was interesting to note that the little red "peak" indicators on the modulators were consistently within 1dB of being totally correct.

The calibration process of our reference head end also emphasized the need for a regular calibration source available by satellite so that technicians can duplicate our efforts without the

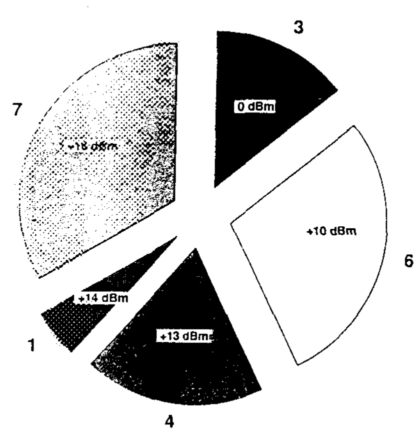

Figure 3. Reported VideoCipher Peak Program Levels

need for exotic test equipment. To that end, our subcommittee is working to establish a weekly precision audio reference test signal that will be available via satellite at a civilized hour of the day. We hope to have this in place and operating this year.

MONITORING THE RESULTS

One channel on the system was used as a continuous reference with a precisely calibrated 400Hz tone at 25kHz deviation. This would serve as a benchmark to insure credibility of results. The entire CableLabs head end was then carefully monitored using a portion of an "AudioRider" system. This system looks at all channels sequentially and records the audio level data in memory. Both peak level as well as "opinionated loudness" information are recorded. One full month of data was taken on the entire system.

Figure 4 is a print out of out reference channel that produced a deviation of precisely 25kHz. Having a print out of this channel for each of the 30 days of the test insured that nothing in the monitoring set up had drifted.

Figures 5 and 6 represent two of the Denver off air channels. These are interesting in that we did not have anything to do with modulation level since heterodyne processors were used. It is also interesting to note the consistency within the channels and between the channels. This same comparison can be made for 4 of the 5 available off air sources.

Now for the cable channels.....

Figure 7 represents a cable programmer who produced a "signature" of the correct peak deviation on a consistent basis. Figure 8 represents a cable programmer who in consistent, but slightly higher in level that he thought he was. Figure 9 represents a cable programmer who is consistent, but lower than he thought he was. Figure 10 represents one of several cable sources with somewhat inconsistent peak level control. It should be noted that Figures 4 thru 10 are from the exact same day.

The identity of channels is deliberately confidential at this point at the request of programmers, of whom several have diligently contributed to this effort. It should be pointed out that there is a sincere desire on the part of many in the programming community to understand the issues and contribute to the solutions where it can be done in a manner consistent with their corporate goals.

The data collected on all 29 channels fills 3 huge binders. As of this date (Mid April, 1993) we are in the process of sharing the data with each programmer along with initial interpretations of the data. The easy issues to solve will involve those programmers who are consistent, but obviously not "peaking" at the level they initially thought. Harder issues to deal with involve the subjective arena of audio processing. Our subcommittee will be sponsoring a processing seminar for the satellite programming community later this year.

Spot checking of the monitoring system reveals that all remains precisely calibrated over one year after the initial data was collected. One interesting observation was the apparent significant (4dB) increase in level of a major well respected programmer. When brought to their attention, the level increase was verified, but there was no obvious reason. This points out the obvious need as a part of the long term process of a central Cable Quality monitoring service to alert programmers when their technical parameters are beyond established limits.

This subcommittee work is rewarding in that the subject seems so simple, yet there are so many subtle variables to make the task nearly impossible. Precise knowledge of peak levels is just the beginning. Issues such as processing, local commercial insertion, etc. are also very complex and will require continuous effort to understand and quantify. Our work will continue until such time as we can provide technicians with a written accurate guide to enable them to perform head end audio adjustments using test equipment and industry accepted calibration methods.

ACKNOWLEDGMENTS

The author would like to thank those individuals and their companies that have contributed significantly to the subcommittee effort, in particular the working group known as "The Bessel Null Boys" Mike Aloisi, Ken Cannon, David Eng, Max Morales, Paul Resch, John Vartanian, and Frank Wimler.

The staff at General Instrument VideoCipher Division also deserves a special thanks for their contribution to the effort.

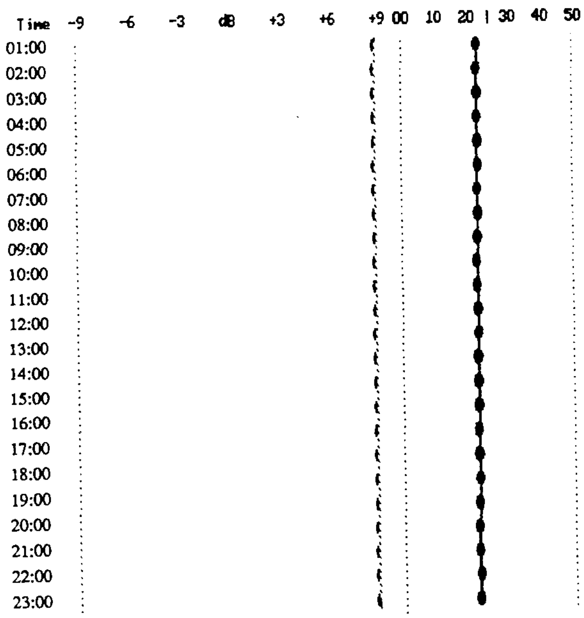

Figure 4. Reference Channel with 400Hz Tone at 25 kHz Deviation

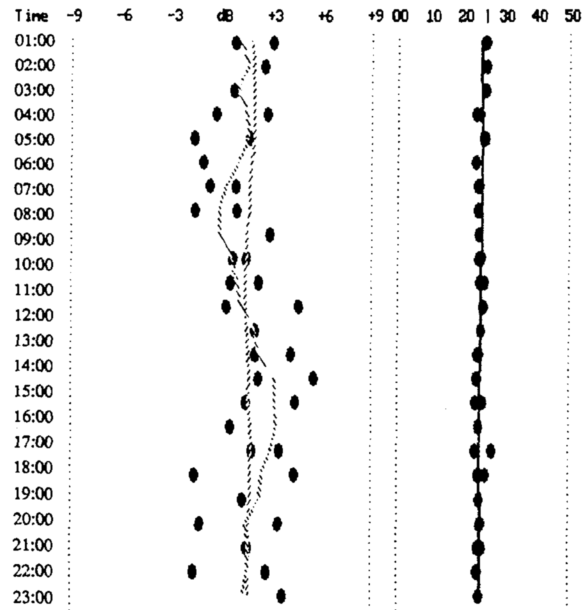

Figure 5. Off-Air Broadcast Station #1

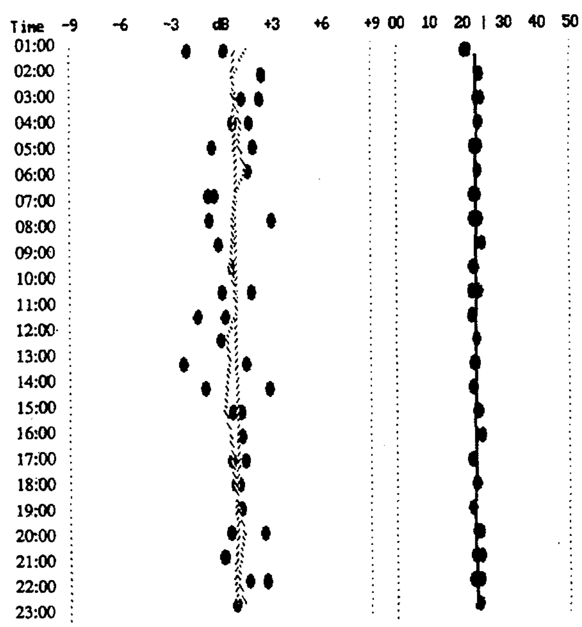

Figure 6. Off-Air Broadcast Station #2

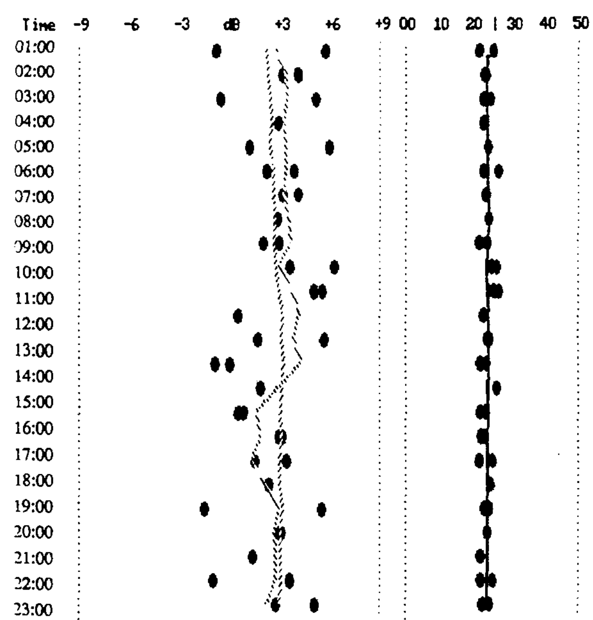

Figure 7. Cable Service with Correct Deviation

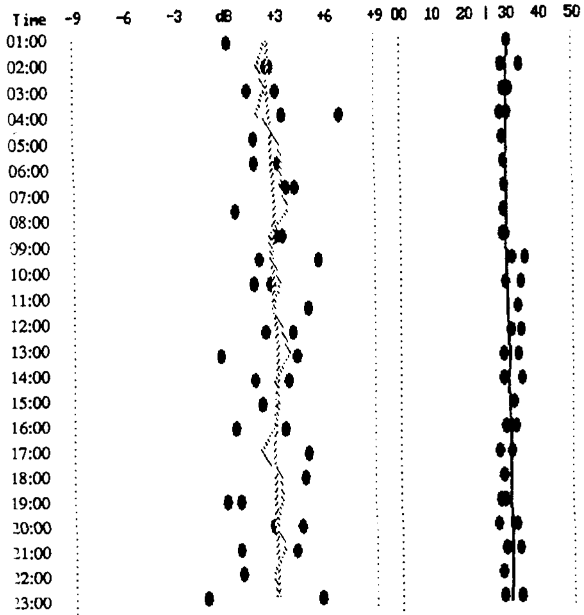

Figure 8. Cable Service with High Deviation

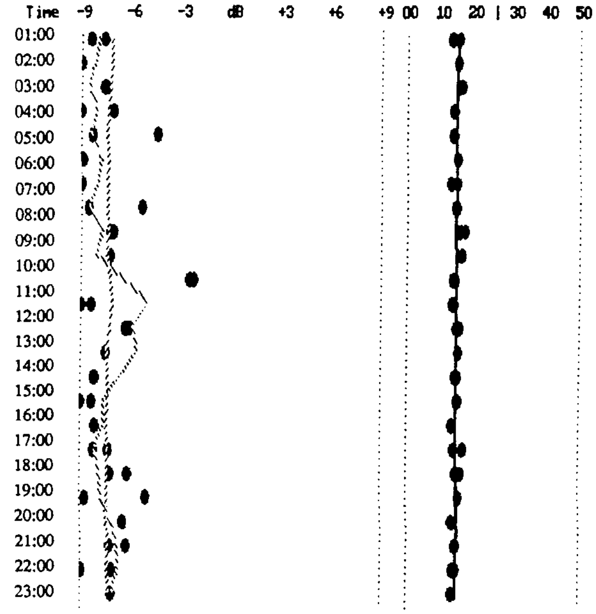

Figure 9. Cable Service with Low Deviation

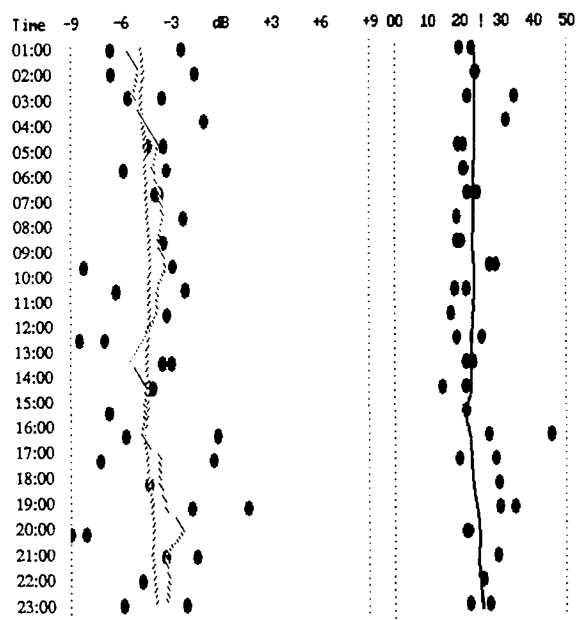

Figure 10. Cable Service with Inconsistent Peak Deviation

MEASUREMENT OF CT2 SIGNAL PERFORMANCE OVER CABLE TELEVISION FACILITIES

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ABSTRACT

Most cable operators are intrigued with the Remote Antenna Driver (RAD) concept which utilizes the CATV plant to transport digital cordless telephone (DCT) traffic and provides widespread coverage economically. Last year CT2Plus, an enhanced version of CT2, was chosen as the Canadian standard for DCT. Rogers Engineering has been involved in examining the feasibility of RAD transported CT2 signals for over 18 months. This paper describes the Rogers' testing of the RAD transported CT2 signal, and discusses the experimental results on RF ranging, multiple-users test, channel capacity limitation, radio coverage overlap, system noise in the upstream path, and benefit of antenna diversity.

INTRODUCTION

Rogers Engineering has been examining the performance of RAD transported DCT signals since 1991. Initially, we used the Ferranti equipment. The Ferranti equipment used a proprietary protocol and did not conform to the Common Air Interface (CAI) standard. As CT2 CAI equipment from GPT, Motorola, and Northern Telecom became available, we incorporated them into the evaluation.

Last year Rogers Engineering published a paper on the subject of PCS transport over cable. It discussed two alternatives of using stand-alone base station and the RAD approach. Based on certain traffic requirements and penetration assumptions, we made cost comparison between the two approaches and proved the feasibility of RAD. Rogers Engineering has conducted extensive tests on the RAD transported CT2 signal over cable. This year we would like to extract a few of these exciting tests and share our research and development experiences on PCS with other cable engineers.

RF RANGING TEST

A historic event occurred in July, 1991. Rogers Engineering received the first batch of RAD prototypes and successfully confirmed that the unchannelized RAD and channelized RAD worked - the unchannelized RAD were units which equipped with Automatic Gain Control (AGC) and processed the DCT spectrum in a 4 MHz block; the channelized version processed the DCT signal in four contiguous block of 1 MHz and the AGC action of each 1 MHz block operated independently. Coverage performance of RAD transported DCT signal was compared against the coverage of a DCT base station.

The evaluation criteria employed on ranging tests are subjective ratings. Subjective quality is graded on a five-point scale with: 5 being excellent voice quality with no audible impairments, 4 being very good audio quality with minimal impairment, 3 being usable audio quality with moderate impairments but consistent radio-coverage, 2 being audible but often requiring repetition to carry on a conversation and the radio-coverage is marginal, and 1 being audio quality unusable, existing radio link may drop and the radio-coverage is at the fringe. A quality of 0 implies no radio-coverage.

We conducted the RF ranging tests in various environments to verify the performance of RAD, to explore the optimum placement of RAD, to evaluate the propagation characteristics of shopping mall, residential areas, and office tower, and to predict DCT coverage at 860 MHz.

Figure 1 shows the coverage comparison between a stand-alone DCT base station and a RAD. The coverage range and subjective quality rating of the RAD was comparable to the DCT base stations. However, the subjective quality in a multiple RADs environment, particularly the overlap area between two adjacent RADs, was not satisfactory. This shortcoming will be discussed further in a later section.

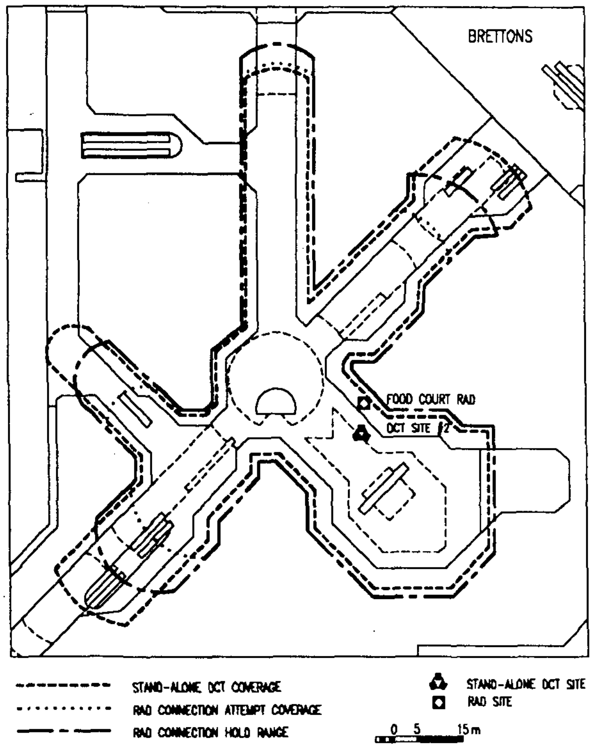


Figure 1 Coverage Comparison between a DCT and a RAD

MULTIPLE USERS TESTS

The ranging test discussed in the previous section included only a single user. Multiple-user tests were conducted in the Burnaby shopping mall in Vancouver. These tests were carried out with as many as five users employing two methodologies: line formation and cluster formation.

In the line formation, four stationary users were arranged progressively farther away from a RAD to encompass the entire coverage range. A roamer traversed from the RAD throughout the coverage area. Subjective qualities perceived were monitored by all the users on signal quality, signal interference and calls dropped. In cluster formation, the four stationary users were confined to a small area at a fixed distance from the RAD. Again, the roamer travelled throughout the coverage area. All users monitored their own voice quality and signal degradation. The test was repeated by changing the distance of the cluster of stationary users from the RAD.

The following summarizes briefly the results. In line formation, the stationary user at the fringe area experienced difficulty maintaining a link; other users had no dropped links. The roamer did not have a strong effect on the link quality of other stationary users. In cluster formation, the fringe boundary of the mobile user depended on the location of the cluster, and may be limited by power handling capability of the RAD. Also in areas where signal quality deterioration occurred, remaining stationary improved the performance.

These tests were initially conducted using the Farranti equipment. Later, the Motorola equipment was used to confirm that similar findings were obtained. Nonetheless, there were slight discrepancies between the Ferranti and Motorola results. These discrepancies related mostly to the specific equipment rather than to the number of users.

CHANNEL CAPACITY LIMITATION

Rogers Engineering conducted a stress test on RAD to determine the maximum number of users a RAD system can support simultaneously.

Two Motorola six-channel, telepoint base stations were used and were synchronized together by configuring one as a master and the other as a slave. The system consisted of two telepoint base stations, a RAD/RASP pair, one trunk amplifier, one bridger and one line-extender. The test was conducted at the Rogers Engineering office at 853 York Mills. Twelve radio links were initiated with eleven handsets in fixed locations and one mobile. The locations of the stationary handsets are shown in Figure 2. A spectrum analyzer plot is shown in Figure 3 with the 12 CT2 channels. This particular plot was captured at the RASP's upstream cable signal port and composed of two traces, A & B. Because of the TDD nature of the CT2 signal, a single plot of the analyzer would not show all the channels. Therefore, two plots that were sampled with one millisecond offset were overlaid to show all 12 channels. The results indicated that the mobile handset experienced strong interferences when it was in motion and was more than 35 feet away from the RAD. However, other information obtained from Motorola indicated that the base stations alone could support only 13 airlinks simultaneously. Therefore, further testing would be required to verify whether any channel capacity limitation was imposed by the use of the RAD/RASP equipment.

Figure 2 Locations of Stationary Handsets

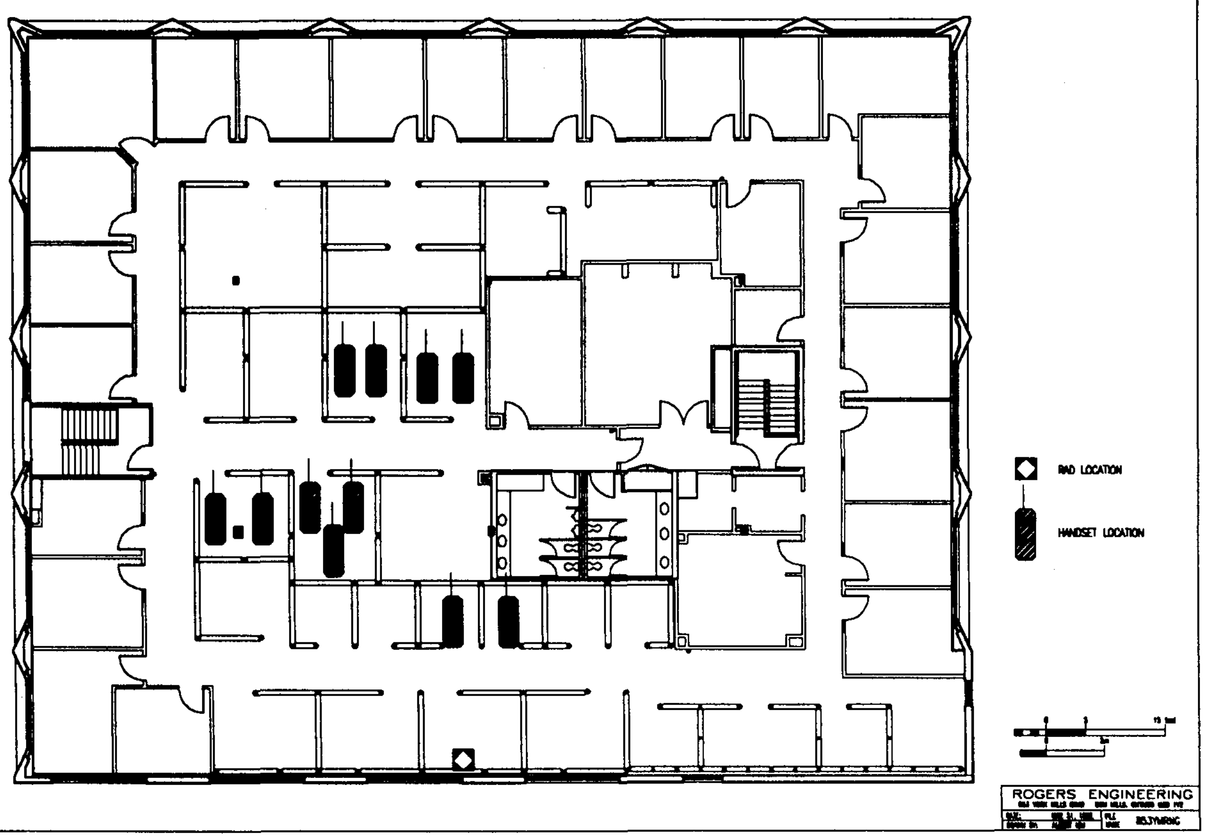
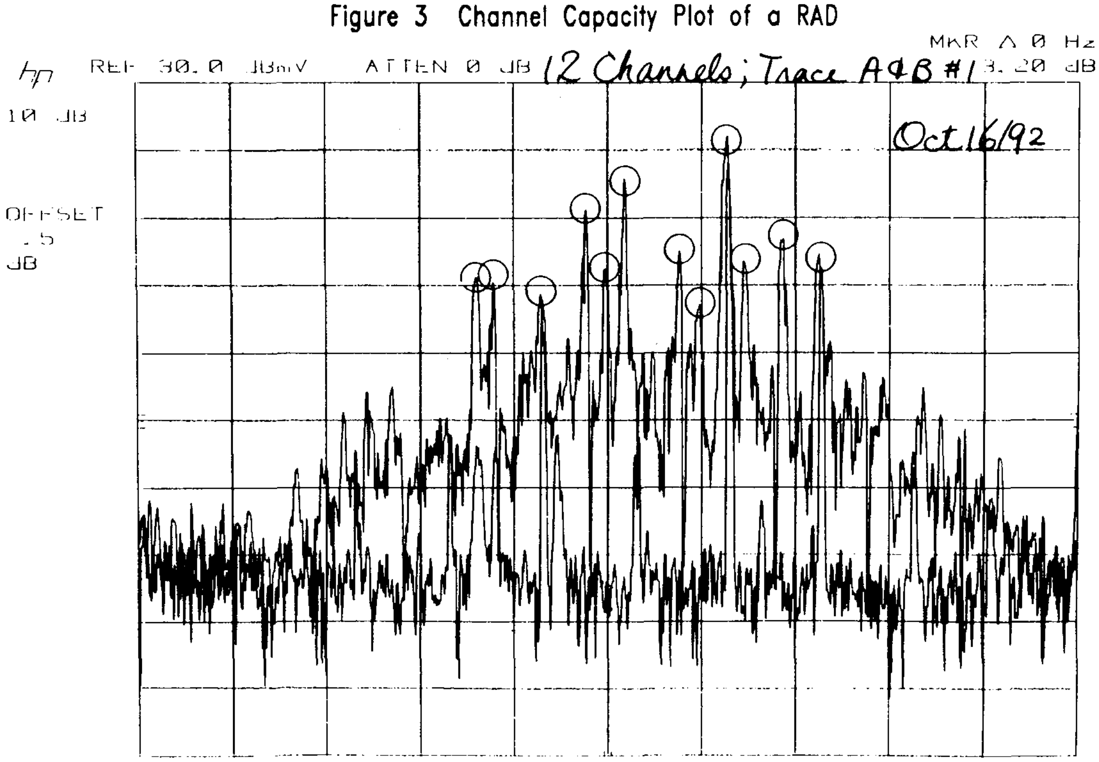


Figure 3 Channel Capacity Plot of a RAD



RADIO COVERAGE OVERLAP

Earlier ranging tests done in Vancouver had clearly demonstrated that the voice quality of a user in the overlap area was degraded. As the user got closer to a RAD, the distortion gradually vanished. Since the mall environment did not lend itself to troubleshoot this kind of technical problem, a similar test must be carried out at an alternate location in an attempt to duplicate the voice quality distortion that happened in the shopping mall. The distortion occurred only when the handset was between two RADs. It was most intense in the area where the radio coverage was equally served by both RADs. The distortion exhibited itself as frequent mutes, clicks, and squawks. We had a mystery; what caused the degradation?

Tests were done at 853 York Mills to explore the symptom of the overlap distortions. Two RADs were installed on the second floor of the Engineering office: one on the east side and the other on the west side. Service coverage of each RAD was determined individually using RSSI measurements. Coverage test was repeated with both RADs operating simultaneously. Figure 4 and 5 show the RSSI profile of each RAD. Figure 6 shows the common overlap area where unacceptable distortion was observed. Careful observations were also made on the radio signal in the overlap region. Figure 7 is a plot made at a location in the overlap region on the south side of the Engineering Office. It was captured by a monopole antenna connected directly to a spectrum analyzer RF input port. The Time Division Duplex (TDD) packet from the base station processed by the two RADs exhibited a few deep notches within a millisecond. Those notches were not observed when a single RAD was in operation (see Figure 8). Further investigation disclosed that instantaneous cancellation due to phase error of the two RADs caused the frequency notches on the TDD packets. The instantaneous cancellation of two carriers having different phases caused the constant mutes, clicks, and squawks in the overlap region.

Figure 4 RSSI Profile of RAD on the East Side

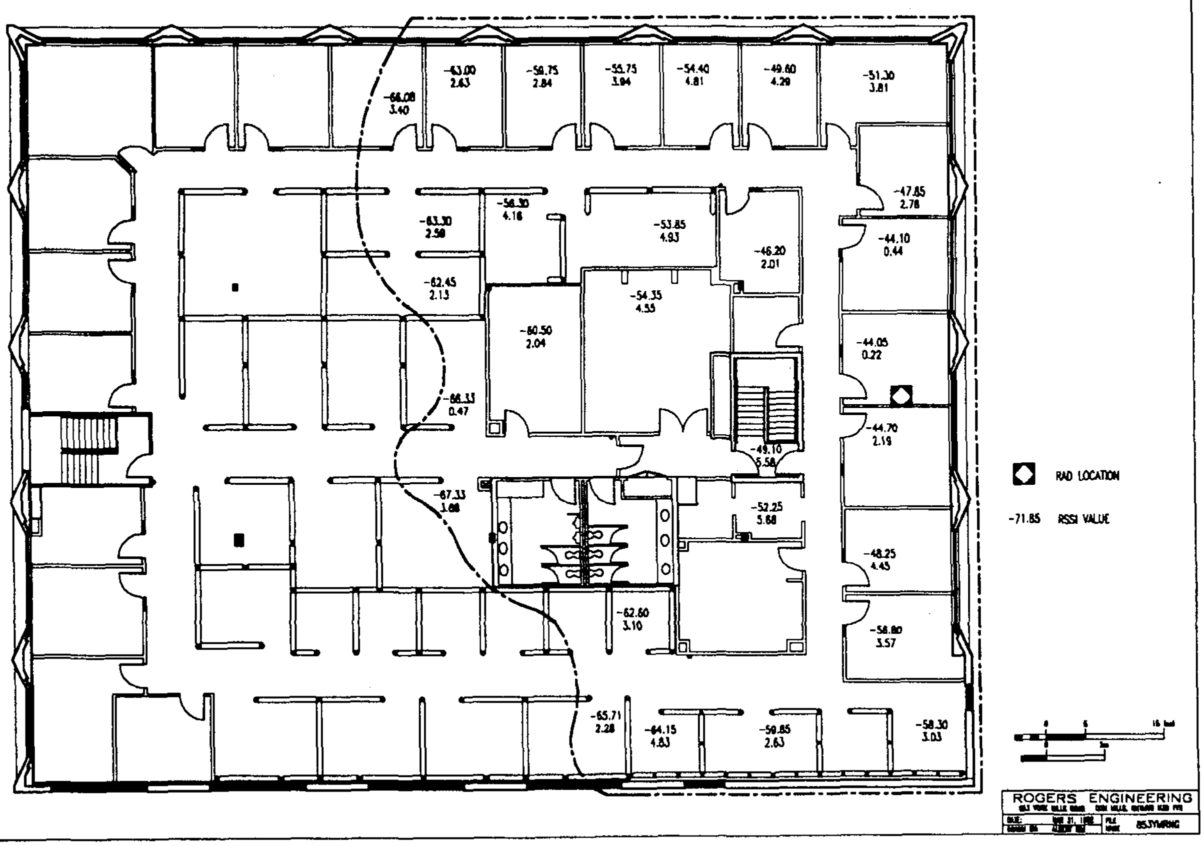


Figure 5 RSSI Profile of RAD on the West Side

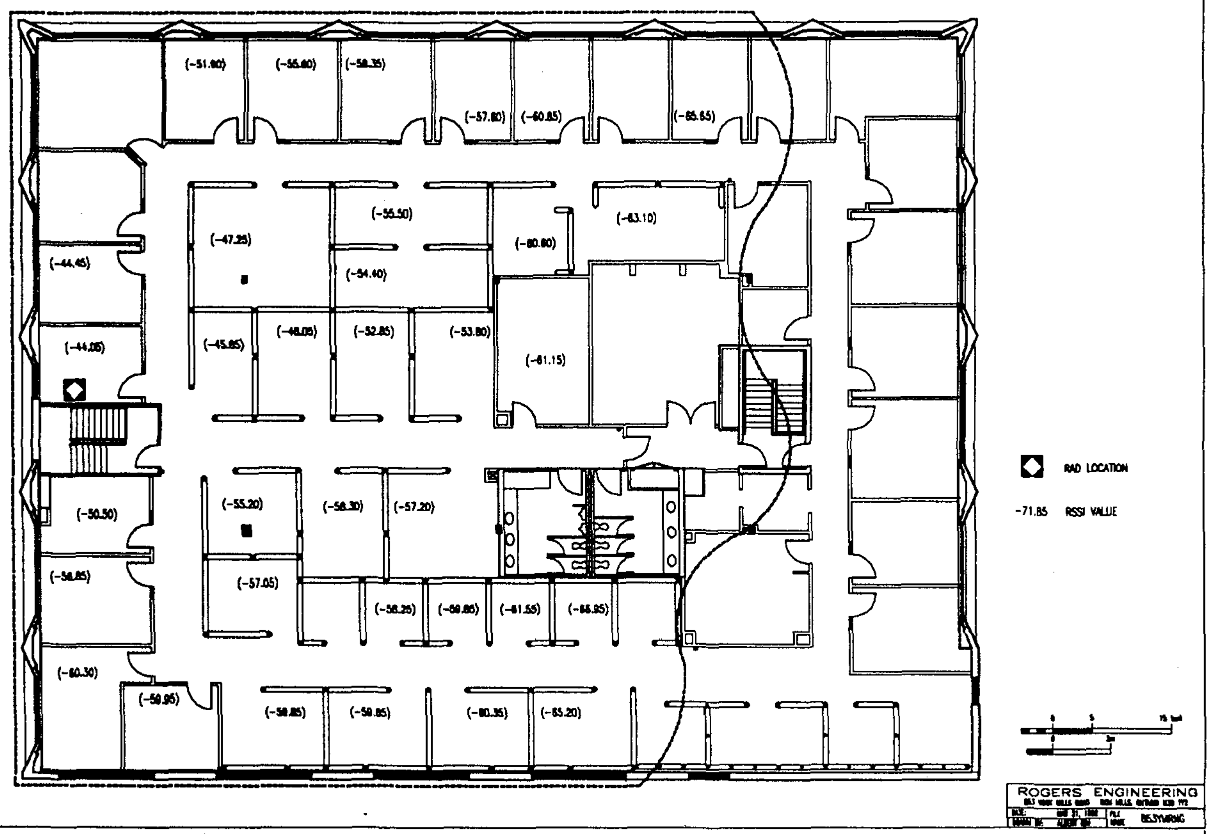
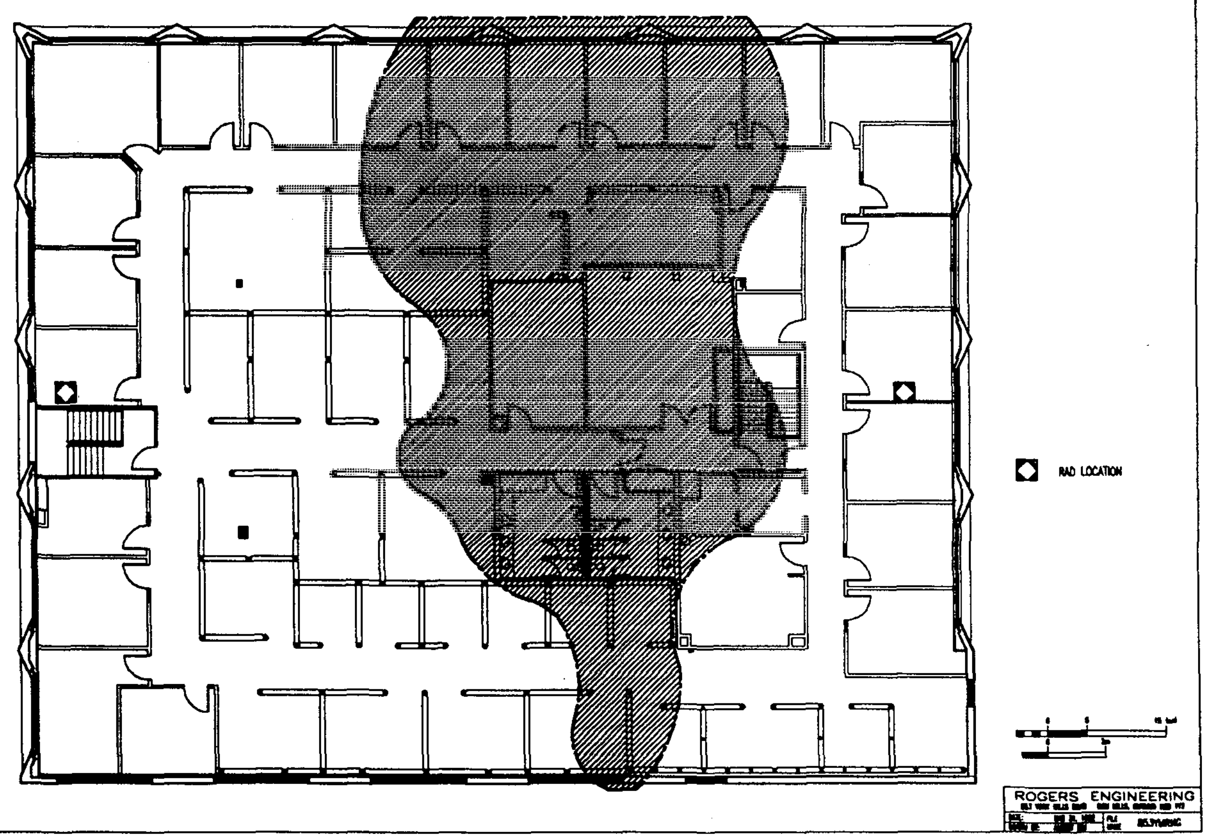


Figure 6 Radio Coverage Overlap of the RADs



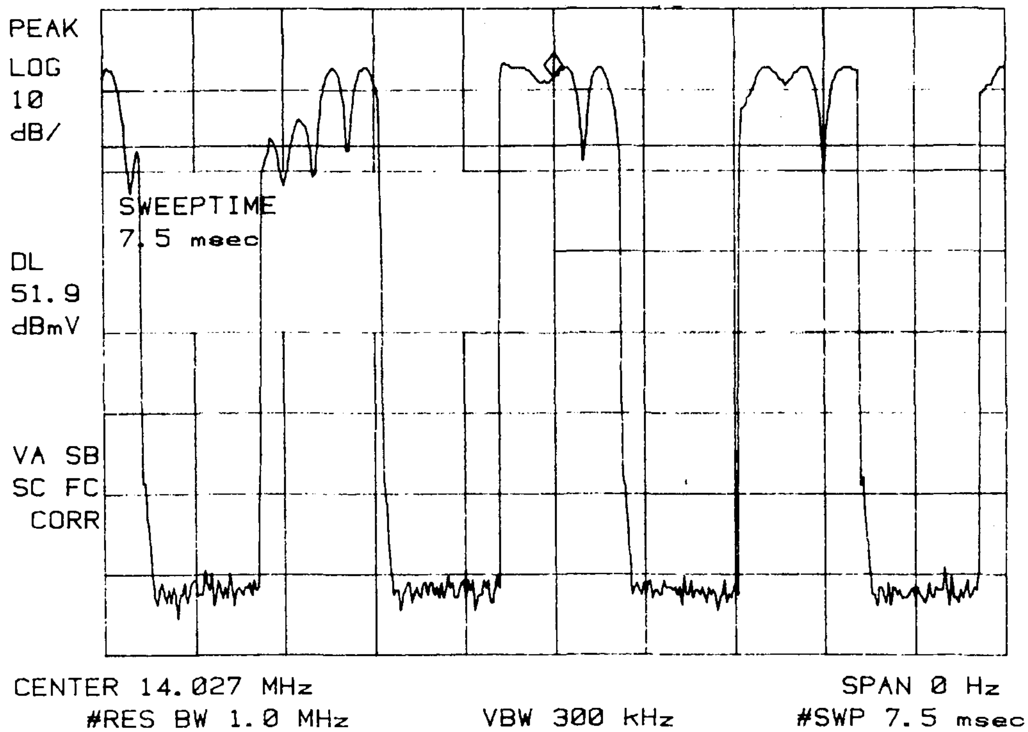


Figure 7 Spectrum Analyzer Display of the CT2 Signal in the Overlap Area

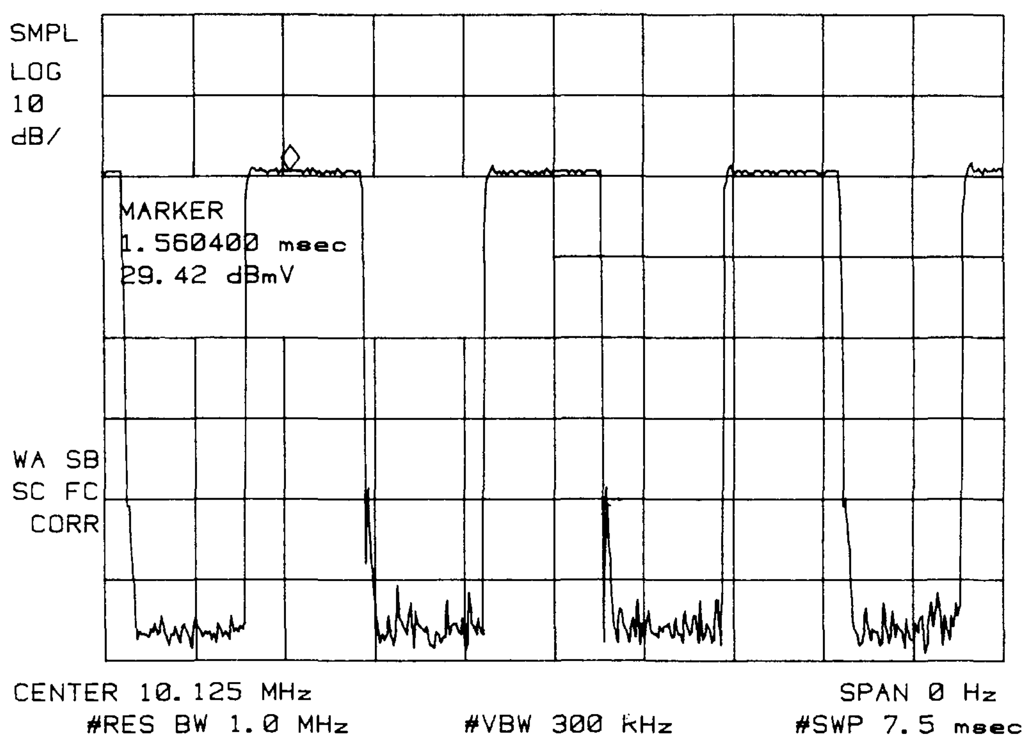


Figure 8 Spectrum Analyzer Display of the CT2 Signal with only One RAD Active

The phase noise of the combined signal of the RADs was so severe as to render an unusable service. Indeed, excessive phase noise of the synthesizers caused the problem. How do we determine the amount of phase noise that can be tolerated to give acceptable quality? Phase noise characterization was done at 853 York Mills. Four signal generators were used to replace the six internal synthesizers of two RADs, RAD A and B. Figure 9 shows a block diagram of the setup. The RADs shared the same local oscillator signals from the generators, except for the 909 MHz local oscillators. On RAD A, phase noise was generated using a video noise generator to frequency modulate an RF carrier. The noise was band-limited by an audio amplifier to cut off any high frequency. The audio amplifier also provided sufficient drive to modulate the CW carrier of the generator. A similar arrangement was made to the 909 MHz local oscillator of RAD B. The level of phase modulation was increased or decreased by the modulation control on the 909 MHz generators. Subjective measures was used to determine the amount of phase modulation considered acceptable. Tests were repeated to confirm the selected level was consistent with previous measurements.

SYSTEM NOISE IN THE RETURN BAND

The conventional way of bringing video back from a subscriber location to the headend involves only a single distribution path activated. The upstream noise comes mainly from that one single distribution. However, in the scenario of providing PCS signal transport, all the distributions will be active. The system noise level in the PCS return spectrum will depend on the number of RADs installed in the cable plant. Given the number of RADs deployed, we can calculate and predict the contribution of noise from a system.

In addition to system noise, there is also noise coming from ingress. Ingress contamination may be a limiting factor on the return path. The feasibility of using RAD for CT2 transport hinges on the transmission quality of downstream and upstream signals. We need to find out the existing level of man-made ingress in the return band. One of the tools employed by all cable operators to control ingress is the ground level CLI patrol. A ground level CLI would ensure the shielding integrity of the cable plant and prevent infiltration of ingress. Rogers Engineering and CableLabs have developed simple computer software which permits automated monitoring of the return ingress. Figure 10 shows a bar graph of the processed data. The vertical axis shows the absolute level in dBmV, and the horizontal axis identifies the particular area. The black bar represents the signal pick-up by a reference antenna and the white bar shows the ingress level recorded by the measuring instrument. "All-on" is the contribution of ingress from all distribution areas. "All-off" means trunk only. "NE" means the north-east area only, and a numeric of 505 means the ingress from a single bridger location identified as 505. It requires a minimal amount of off-the-shelf software and hardware to use this program. Initial findings indicated that power supplies appeared to be weak points. The amplifiers Rogers Cable used have a power injection port. The power injection ports may have permitted a moderate amount of HF permeated into the return system.

BENEFIT OF ANTENNA DIVERSITY

Published data has shown that antenna diversity in an indoor environment will provide an additional 10 dB of fade margin. In other indoor and outdoor ranging tests conducted by Rogers Engineering, the observed multipath excursions of an outdoor parking lot were not as widely varying as those seen in the shopping mall environment. Rogers Engineering believes that outdoor propagation dynamics and the severity of multipath is not expected to be as severe as indoor. By comparing the performance of PCS with antenna diversity and without diversity in a distributed antenna system, the degree of improvement will indicate the necessity for implementing diversity into future RAD systems. The tradeoff in implementing diversity necessitates twice the spectrum in both the forward and reverse directions. Rogers Engineering plans a diversity test for the end of March, 1993. We expect to make available results of the diversity testing at the convention.

Figure 9 Phase Noise Test Setup

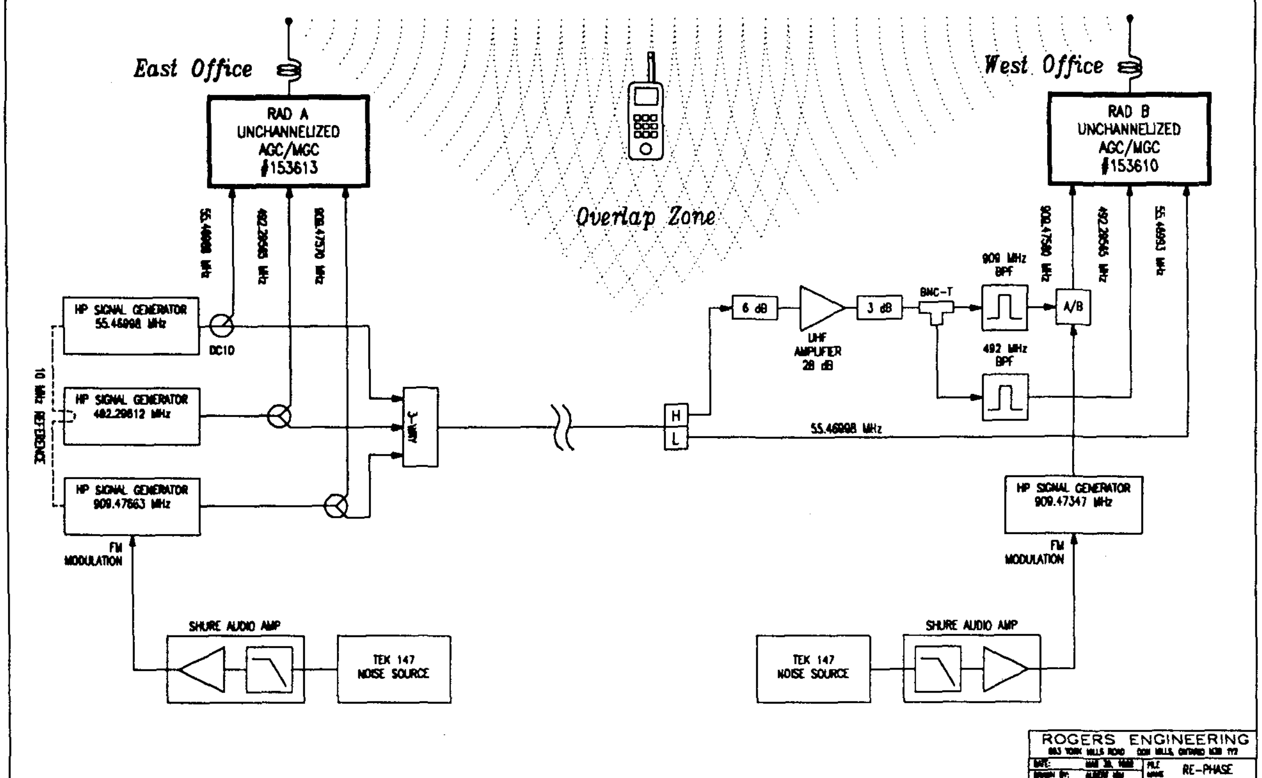
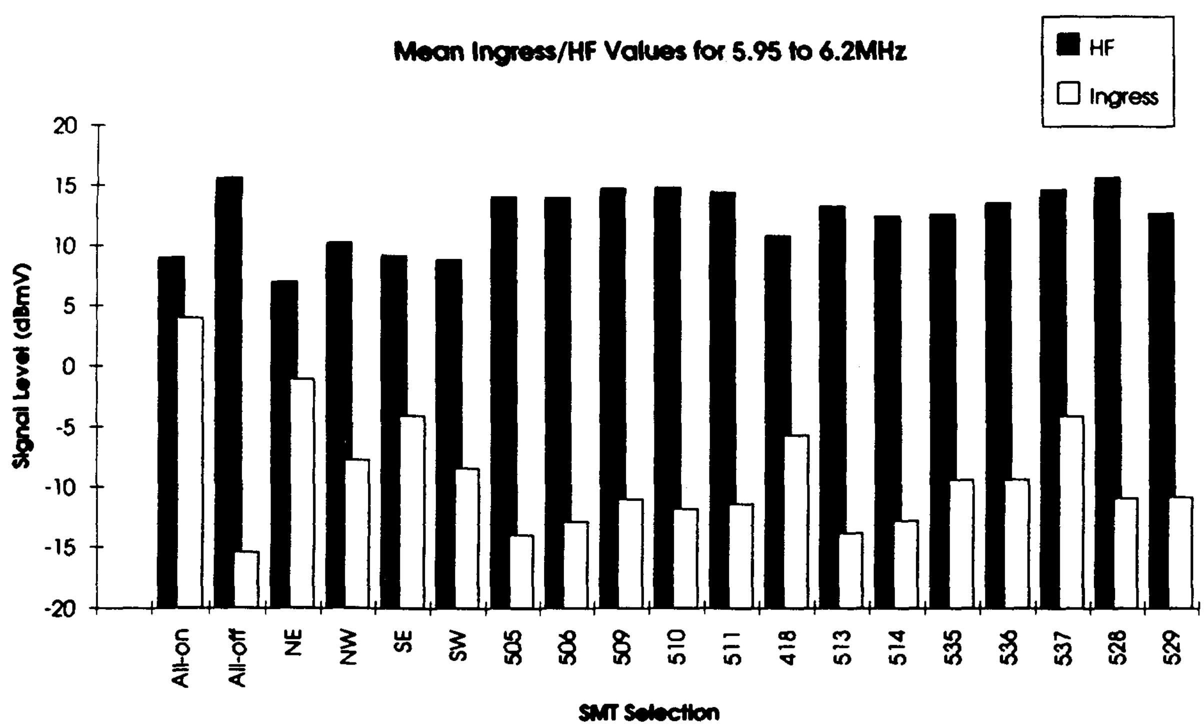


Figure 10 Processed Data of the Return Ingress



CONCLUSIONS

As the prospect of PCS unfold, it becomes apparent that the cable industry has a significant role to play in the success of this new and innovative technology. It is the intention of Rogers Engineering and CableLabs to assess the strength and weakness of a cable supported PCN infrastructure and to study the full impact of future PCN service to the cable industry.

ACKNOWLEDGEMENT

The authors would like to thank Rogers Cable Vancouver and Rogers Cable Toronto for their assistance in upgrading the cable plant and conducting the various propagation tests. The technical support from Motorola and Northern Telecom is vital to the tests of RAD transported CT2 signal over cable. The evaluation of antenna diversity is sponsored by CableLabs, and the cooperation of Cablevision Systems in Woodbury in providing the Lynbrook system as test bed is greatly appreciated.

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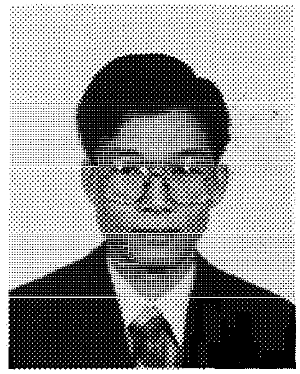

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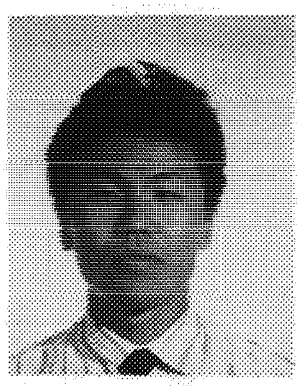

Albert Kim received his B.A.Sc. from University of Toronto in Electrical Engineering in 1988. Upon graduation he joined Rogers Engineering, Toronto, Ontario, and is currently a Staff Engineer in the Advanced Engineering department. He has engaged in the fiber optic architecture design and system deployment into the CATV systems. Since 1990, he has focused on developing and testing systems for transporting PCS services on CATV networks, specifically the distributed antenna concept that is realized through the development of the Remote Antenna Driver (RAD). Mr. Kim is a registered Professional Engineer of Ontario and is a member of the IEEE.

Methods for Picture Quality Improvement : Aspects on Co-channel, Random, and Impulse Noise Cancellation

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ABSTRACT

With the industry wide adaptation of the Ghost Canceling Reference (GCR), commercial products for high quality video ghost cancellation have become practical for the cable operators at their headend. However, co-channel interference accounts for as much as one third of all reception problems. Further, both impulse and random noise related picture impairments are a concern for quality conscious operators. With the cost of high speed digital signal processing becoming more affordable, innovative and powerful real time processing techniques can now be applied for enhancing picture quality.

While mathematical modelling of co-channel interference is at its conceptual stage, it is well known that the primary impact on the picture degradation is related to carrier beat and horizontal line frequency harmonics. Significant improvement of co-channel interference impairments can be handled by addressing these problems.

Expensive studio quality products are available today for the reduction of both impulse and random noise impairment. These devices employ a combination of frame storage, impairment detection, and impairment concealment using substitution and/or averaging techniques.

With the progress being made in digital video compression and HDTV many of these techniques can be re-examined with the economy of the cable operators in mind. This paper examines the status of the technical community in these challenging areas.

INTRODUCTION

This paper describes specific methods for picture quality improvement for motion video in television signals with respect to co-channel, random, and impulse noise impairments. The first section deals with the effect of co-channel impairments and application of transversal filters for improvement. In the next section, a non-linear digital filtering technique is introduced, and its application in impulse noise filtering is explained. A recursive filter for random noise filtering is then introduced along with motion detection techniques for reducing the artifacts of such filters on video signals. Finally, the paper concludes with a proposal on a complete video enhancement system that applies the techniques discussed in the paper.

CO-CHANNEL INTERFERENCE SUPPRESSION

While co-channel interference would seem to be difficult to suppress due to the constantly-changing characteristics of the interfering signal's picture content, the most visually perceptible interference component is a "beat" which is the difference in RF carrier frequency between the desired and the interfering signals. Considering the frequency tolerance of each carrier plus the specified frequency offset (if any), the frequency difference can exceed 20 KHz. The simplest form of co-channel interference suppression could therefore be a sharp notch filter tuned to the interfering carrier.

In practical applications, the beat frequency varies constantly due to small changes in carrier frequencies; a sufficiently sharp notch filter is difficult to realize at RF; and the filter skirts may interfere with the desired signal.

These limitations may be overcome through the use of state-of-the-art digital transversal filters operating at baseband, such as those used for video echo cancellation. These adaptive digital filters are reconfigureable to follow a changing beat frequency, and they also permit additional filtering for removal of line-rate (15 KHz and harmonics) components in the interfering signal.

As in the echo-cancellation system, while the baseband video filtering must be done in real-time, the interference analysis and filter coefficient calculation may be done "off line" using conventional DSP processors and algorithms which operate at speeds which are inappropriate for real-time video applications. A real-time capture buffer permits the analysis routines to operate at a reduced speed appropriate to the echo's rate of change; typically, the filter coefficients are updated every two to eight seconds. This performance level would also be appropriate for the detection and suppression of beats generated by the co-channel interference.

NOISE REDUCTION USING NON-LINEAR SIGNAL PROCESSING

Impulse noise in video signals can come from film scratches and dust, film grain, drop-outs, tape noise, cross color and cross luminance . Application of common digital filters, like transversal and recursive, does not usually produce desired impulse noise reduction without band-limiting the video signal as well. *Median filtering* of video signals provides a powerful alternative for noise filtering in these cases. A median filter provides error concealment by detecting a picture element that is disturbed by noise and substituting it with a picture element from the neighborhood that is less disturbed. Non-linearity in a median filter comes from the fact that a substitution is done rather than averaging. Non-linearity in a signal processing chain generally produces distortions, harmonic waves, and other defects; however, three dimensional median filtering utilizing statistical linkage of neighboring picture elements is found to be suitable for video signal improvement without visible artifacts. It is also suitable for disturbances due to bit errors or drop-outs.

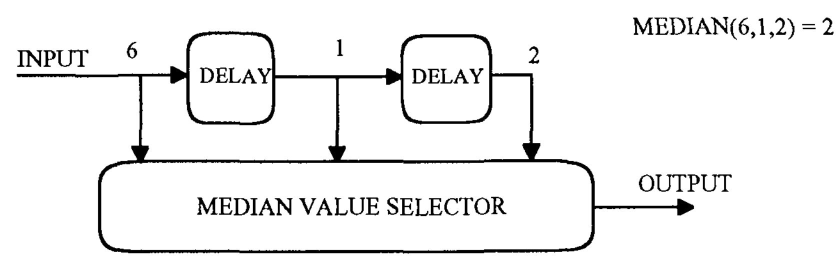

FIGURE 1: ONE DIMENSIONAL MEDIAN FILTER

Block diagrams of a first order median filter and its response to an input with a spike are shown in Figures 1 & 2. Properties of a median filter are better analyzed in time domain as frequency domain will not make much sense. As can be seen from the figures and from the functional properties, the transfer function for a step response of a median filter is unity, and its impulse response is zero. While a conventional low-pass filter affects the rise time or overshoot, a median filter

FIGURE 2 : IMPULSE NOISE SUPRESSION IN MEDIAN FILTER

response is dependent on the input signal waveform with unity transfer function or "zero" transfer function; here the zero transfer function will result in substitution establishing a correlation of adjacent picture elements that were lost or disturbed due to noise.

The application of a one-dimensional median filter, while providing a noise reduction of about 3 dB, also attenuates higher horizontal spatial frequencies and presents aliasing problems. Most of these problems are overcome in a two dimensional median filter where picture element susbstitution is influenced by both horizontal and vertical neighbors. The selection of adjacent picture elements from a cross-shaped window is known to give a good compromise between noise filtering magnitude and undesirable aliasing effects. This is due to the fact that any horizontal or vertical structure or outline in a picture automatically produces unity transfer function (or transparently passes through) in a median filter. If the window were to be a square, this would not be the case resulting in artifacts. The two types of windows for two dimensional median filtering and their noise reduction factors are shown in Figure 3.

A three dimensional median filter further reduces the artifacts as the central value is correlated in horizontal, vertical, and in time. The temporal filtering in this case generally will not produce smearing effects of moving pictures as there is no feedback; further as temporal direction assumes an extreme amplitude rank in the filter window, the median value sought is closely correlated to local surroundings. However, the median filter does have a problem in the case of moving pictures with high content detail; this may not be a big factor due to the fact that there is reduced local resolution in the eye while observing motion. In any case, 2 to 1 interlacing in television signals produces motion aliases for high vertical frequencies.
The resolution of three dimensional median filter can be improved by using sub-pixel averaging for neighboring signals. Here a sub-pixel value is determined by interpolation and can be thought of as an FIR filter in the horizontal direction, a line comb filter in the vertical direction, and a frame comb filter in the temporal direction. By special design of the filter window, even regular disturbance

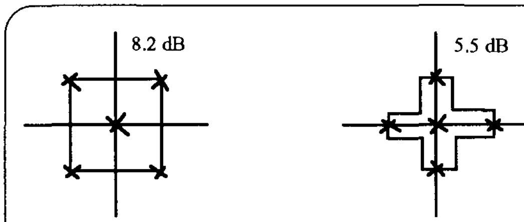

FIGURE 3 : MEDIAN FILTER WINDOWS

structures like cross color and cross luminance can be suppressed.

NOISE FILTERING USING LINEAR SIGNAL PROCESSING

The addition of noise to a video signal happens at the source (e.g. thermal noise in a camera), the transportation system (e.g. signal-to-noise ratio of distribution amplifiers), and by the receiver circuits. Noise reduction can be accomplished in video signals without any impairment to spatial resolution by averaging successive pictures. Such an averaging amounts to a temporal low-pass filtering which is easily implemented using digital transversal filters as shown in Figure 4. The noise reduction factor can be increased simply by adding many picture delay elements.

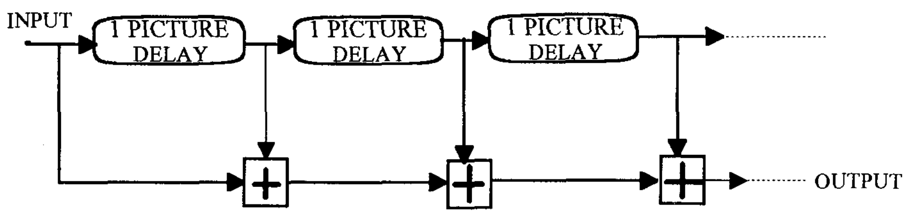

FIGURE 4: DIGITAL TRANSVERSAL FILTER FOR NOISE REDUCTION

Alternatively, a recursive filter that requires a single picture element delay can be used as shown in Figure 5. Here a fraction K of input and a fraction $1- (1/K)$ of the previous output are combined to form the present output. Notice that when $K = 1$, the effect of temporal low-pass filtering is eliminated and the input is transparently passed to the output. Noise power reduction around 8 dB can be achieved for a K value of four.

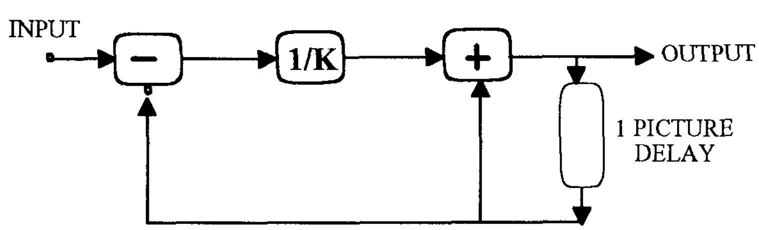

FIGURE 5 : RECURSIVE DIGITAL FILTER FOR NOISE REDUCTION

The filters shown in Figures 4 & 5 perform adequately for still pictures; however, smearing effect similar to long persistence picture tubes will occur for motion pictures, making these simple approaches generally unacceptable. By using motion detection techniques, the digital filtering circuit shown in Figure 5 can be modified to include a control circuit that produces a smooth variation of factor K from the set value to unity at areas of the picture where a degree of motion is sensed. A block diagram of a filter that compensates for motion while accomplishing noise reduction in stationary areas is shown in Figure 6.

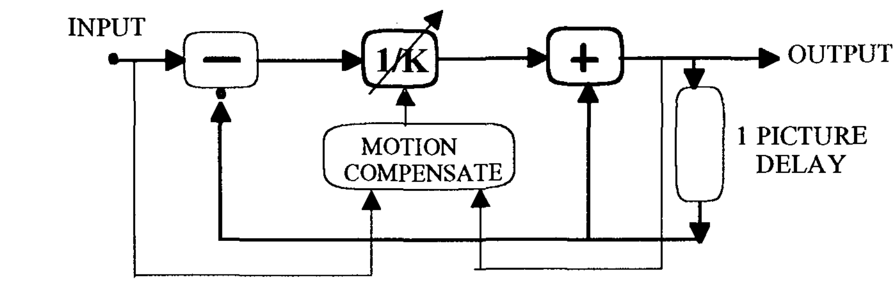

FIGURE 6: NOISE REDUCTION FILTER WITH MOTION COMPENSATION

The motion detector works on the principle that when adjacent pixels are averaged, the probability distribution of white noise which is Gaussian will have its variance shifted due to movement amplitudes in picture. The spatial filter that forms an equal-weight sum of ***n*** terms , triggers a control function for ***K*** which provides a smooth variance to unity from the set value, thus reducing the effect of noise reduction filtering in areas of motion.

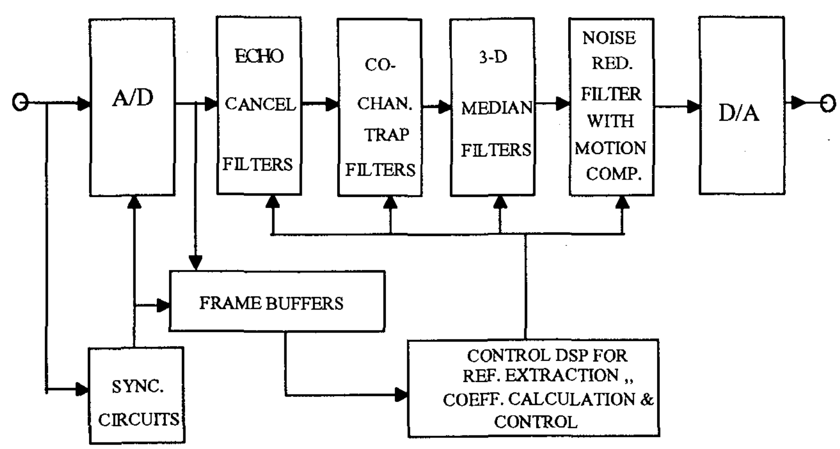

FIGURE 7 : A COMPLETE VIDEO ENHANCEMENT SYSTEM

A COMPLETE VIDEO ENHANCEMENT SYSTEM

A complete video enhancement system that can be built on top of a Philips VECTOR Video Echo Canceller is shown in Figure 7. Such a system adds only incremental cost to the existing hardware while providing extensive performance enhancements. The additions to the current echo cancelling system are the co-channel trap filters, 3-D median filters, and possibly a noise reduction filter with motion sensing and compensation. The co-channel trap filters can be realized using the same powerful and flexible integrated circuits used in the VECTOR product. These filters are programmable in both FIR and IIR configurations, and contain an extensive number of taps for complex transfer function implementation. Algorithms for co-channel beat product trap filters are currently under investigation. The addition of a three dimensional median filter will provide noise reduction but will require hardware for a real-time frame memory architecture. Hardware for noise reduction using linear filters with motion detection and controls is under consideration.

REFERENCES :

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[2] Paul M. Embree & Bruce Kimble: "C Language Algorithms for Digital Signal Processing", 1991, Prentice-Hall, Englewood Cliffs, New Jersey 07632

[3] Sandbank, "Digital Television", 1990 John Wiley & Sons Ltd. West Sussex PO19 1UD, England

[4] Craig B. Greenberg, "Ghost Cancellation System for a High Energy GCR", IEEE 1992

MULTIRATE ALL-DIGITAL MODEM FOR SUPPORT OF UNIVERSAL MULTIPLEX TRANSPORT LAYER FOR DIGITAL COMPRESSION

TV/COM International
16516 Via Esprillo
San Diego, CA 92127

Fred Harris*
Systems Engineer

Tony Wechselberger**
Executive Vice President

Abstract

With the approaching adoption of digital compression and the supporting development of transport systems to effect the delivery of all-digital television, there is intense activity surrounding the search for low cost but high performance modems for digital signals. This paper discusses recent advances in the state-of-the-art of modulator/demodulator technology for the satellite channel. An all-digital modem implementation is described, yielding benefits of near-theoretical performance, low cost, high reliability and variable rate operation from 1 to 60 Mbps.

INTRODUCTION

Video and audio signals can be compressed to obtain varying levels of quality extending through the progression of SIF, VHS, NTSC, CCIR-601 and HDTV, via successively increasing bit rates. Data streams from a number of video and audio signals (compressed at data rates required for their specified quality) can and will be transported in a number of different ways. They can be merged in a full bandwidth (TDM) data transport which requires a versatile multiplexing scheme or transmitted in a single carrier per channel (SCPC) mode using bandwidths appropriate to each selected data rate.

It would be highly advantageous to have a flexible system modulator/demodulator arrangement such that equipment (especially receivers) could be easily reconfigured to operate across a wide spectrum of data rates. Such an *all-purpose* modem must be capable of operating with transponder signals of full bandwidth as well as with the unique bandwidths of the different SCPC signals which may, during operation, be reassigned to different center frequencies by the satellite carrier in response to changes in transponder loading.

An all-purpose modem required to support delivery of digital video and other services can be characterized by the following requirements:

- capable of rapidly switching and acquiring carrier frequencies,
- capable of (automatically) varying the occupied bandwidths,
- capable of varying the data processing (throughput) rate,
- operate in the presence of multiple adjacent channels,
- operate in the presence of terrestrial interference,
- must yield throughput performance equal to the maximum capacity of present and planned transponders,
- must be low cost.

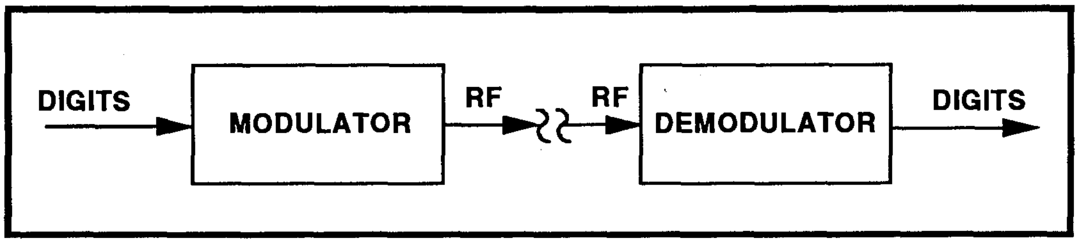

Figure 1
Generic View of Modem

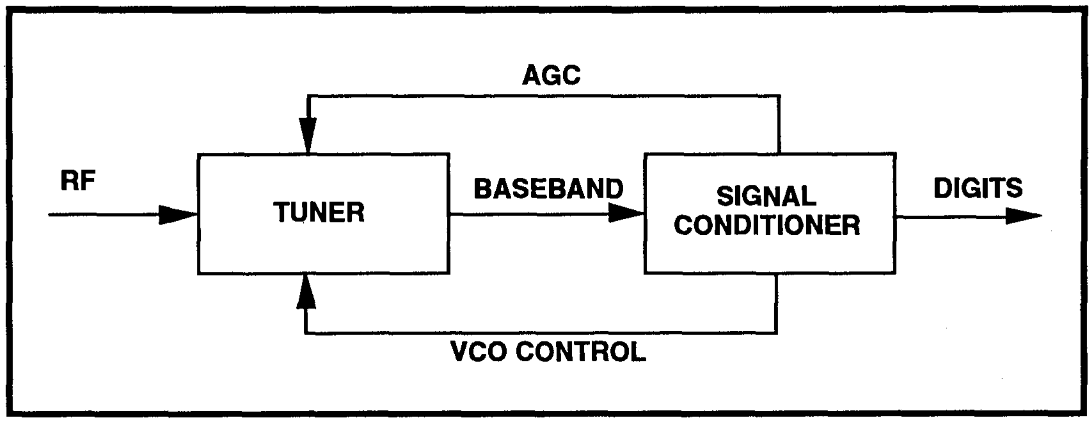

Figure 2
Modem Sub-Block Partition

THE MODEM

From a general perspective, as indicated in Figure 1, modems can be visualized as RF-to-digital transducers operating at the lowest layer of a transport system. This transduction process entails two distinct transformations: RF-to-Baseband and Baseband-to-Digits. To aid in understanding this transduction process it is convenient, as indicated in Figure 2, to partition the modem into two main sub-blocks: a tuner and a baseband "signal conditioner." The tuner isolates and extracts the signal bearing carrier from the channel and performs the RF-to-Baseband transformation.

The baseband signal conditioner processes the analog waveform extracted from the channel (by the tuner) and performs synchronous demodulation with the aid of carrier and timing information derived from the received waveform. The digital output of the baseband signal conditioner is the quantized (soft decision) sample values formed at the output of its matched filters. In developing DSP-based solutions, this second transformation (Baseband-to-Digital) is accomplished by an analog-to-digital converter (ADC) located somewhere in the signal conditioning processing chain.

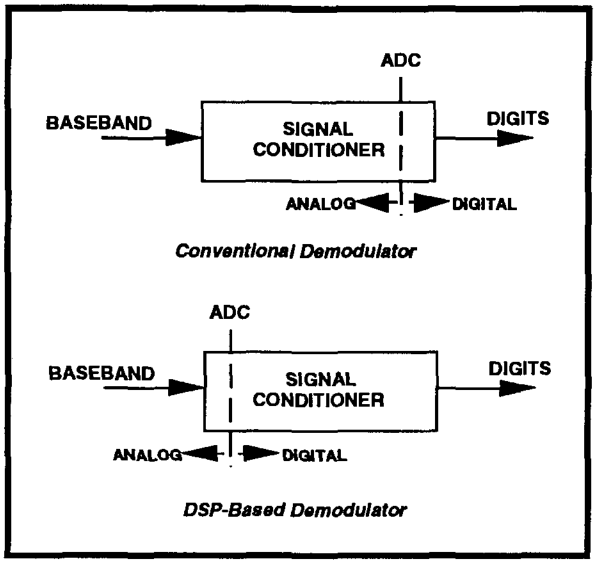

Figure 3
ADC Insertion—Conventional & Modern Modem

The ADC is the boundary between the analog processing and the digital processing performed by the signal conditioner. Traditionally, as shown in Figure 3, this boundary is near the end of the baseband signal conditioning chain. In light of dramatic cost reductions in ADC and digital signal processing technology (alluded to in the next section), there are significant advantages to moving this boundary toward the beginning of the chain. In fact, by placing the ADC at the very beginning of the sequence we have a full DSP-based signal conditioner modem, and solutions to the requirements characterized above in developing an all-purpose demodulator become available as an extra benefit.

THE DSP MODEM

The cost of performing signal conditioning by digital signal processing techniques, measured for instance in *dollars per million integer operations*, has fallen two orders of magnitude in the last five years. This rate of cost reduction appears to be persisting, and we can expect another two orders of magnitude decrease in the next five year period. By comparison, the cost of signal conditioning with traditional analog components, measured in *dollars per MHz*, is changing very slowly (Figure 4).

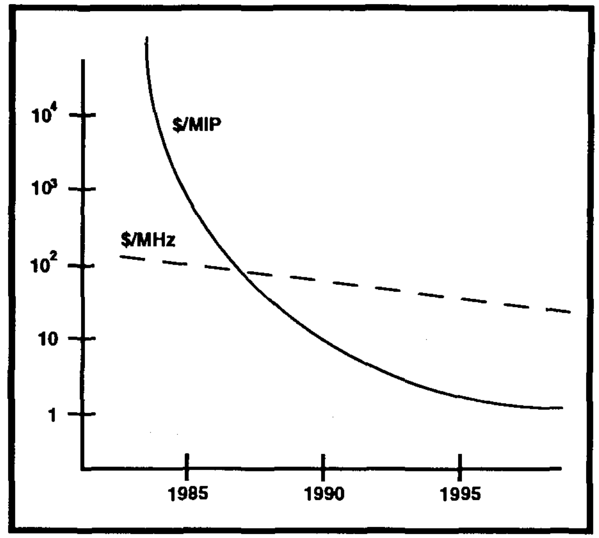

Figure 4
Cost Performance of Analog & Digital Processing Components

The DSP-based modem described herein performs nearly all of the signal conditioning functions of a conventional modem with combinations of application-specific hardware and processor-based software. These functions include:

- automatic gain control,
- timing recovery,
- carrier acquisition,
- bandwidth and sample rate reduction,
- matched filtering,
- soft decision quantization.

The only function not performed via DSP in TV/COM's first generation DSP-based modem is the quadrature down-conversion which uses standard analog mixers with a DAC controlled VCO. A block diagram of the DSP-based modem is presented in Figure 5.

The basebanded I-Q pair is low-pass filtered by analog anti-aliasing filters. The bandwidth and out-of-band attenuation of these filters are selected to avoid spectral aliasing and spectral distortion of the out-of-band and in-band spectral components respectively of the maximum bandwidth signal presented to the modem. The modem's ADCs operate at 60 MHz, the input sample rate corresponding to two samples per input symbol at the current maximum data rate of 60 Mbps.

For signals of lower data rate, hence lower bandwidth, the modem operates in a *multirate resampling mode*. Conceptually, it operates a set of digital resampling filters to reduce the input bandwidth to that of the desired input signal and then resamples to the desired two samples per symbol sample rate. "Resampling" is performed on an ASIC chip automatically according to DSP techniques that allow the actual sampling process to be fixed at 60 MHz, but yield "effective samples" according to selected lower rates.

Samples at the reduced data rate are then processed by a digital matched filter to obtain output samples matched to the transmitter waveforms and bandwidth. In the receiver hardware described here, the bandwidth reducing filters, the resampling and the matched filters are implemented in a proprietary architecture as a polyphase filter process in which resampling and matched filtering are all performed digitally on-chip.

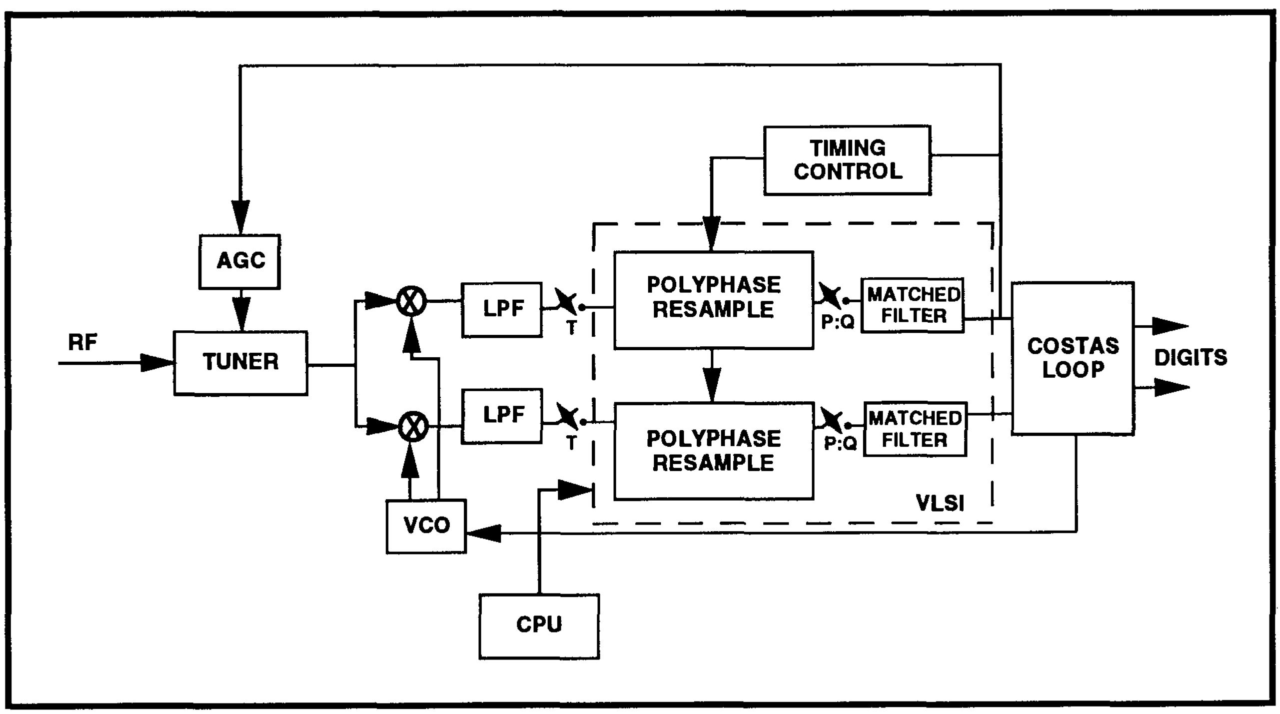

Figure 5
Block Diagram—Multirate All-Digital Demodulator

The polyphase filters are also used in the timing recovery loop. Since phasing of the input time samples is allowed to be *asynchronous* with the input symbol boundaries, a mechanism must be provided for their alignment. A traditional approach would have the timing loop control the VCO sampling clock. Using a VCO to change clock phasing has a significant impact when multiplexing the output of multiple modems which might be required at a head-end for instance.

Polyphase filters capable of down-sampling can also be used for up-sampling. This enables the timing recovery loop to use the polyphase filters to effectively *re-phase* the input sample positions to the desired output positions, again, all on-chip.

As versatile as the DSP filtering process is, it can be made even more so by taking advantage of on-chip design procedures which permit arbitrary gain and phase characteristics. This enables us to imbed the gain and phase corrections required to equalize the analog filters of the demodulator. Thus, through all-digital design, this demodulator simultaneously provides capabilities for bandwidth reduction, resampling, spectral equalization, matched filtering, and time recovery phasing.

As a consequence of architectural structures which yield the versatility identified above, the DSP-based modem is characterized by remarkable flexibility and exhibits performance levels extremely close to theoretical limits.

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* TV/COM International consultant. Principal of Tiernan Communications, Inc., a consulting firm specializing in digital television systems design.

** Mr. Wechselberger has held various positions with TV/COM International since 1980. His staff supports all of TV/COM's cable, satellite, and compression engineering initiatives and he is responsible for a number of key patents. Before joining TV/COM, Mr. Wechselberger was with the General Dynamics Electronics Division. He holds B.S. and M.S. degrees in Electrical Engineering and has published and lectured extensively in the fields of TV Signal Security, communications, and encryption.

National Cable Television Association
ENGINEERING COMMITTEE UPDATE

Tom Jokerst, Chairman

Wendell Bailey, NCTA Staff Liaison

CHAIRMAN'S MESSAGE

The past two years have posed many challenges for everyone in the cable television industry, not the least of which was the NCTA and the industry's technical community. Certainly the members of the NCTA Engineering Committee have been active with numerous issues such as technical reregulation, the '92 cable bill and the explosion of new technology applications in our video delivery business as well as in new business opportunities. The Engineering Committee continues to be involved in new technologies as well as with issues that relate to our everyday operations such as improving the quality and consistency of video and audio that is delivered to our headends by satellite programmers. Ongoing efforts have made progress with the updating of our satellite recommended practices as well as new recommended graphic symbols for fiber optics systems. I wish to recognize the significant efforts that were made by members of the Quality Sound Subcommittee, Satellite Practices Subcommittee, Standards/Recommended Practices Subcommittee, the EIA/NCTA Joint Committee and the Liaisons with the NEC, NESC and COST.

It is worthwhile to note that all of the subcommittee and liaison participants are comprised of volunteers from the various sectors of our industry. Their efforts contribute to and benefit this great industry that has grown from traditional CATV systems to a developing nationwide broadband infrastructure, and that is unparalleled to that found anywhere else in the world.

The following pages will provide a detailed background on the Engineering Committee, its charter, NCTA staff participation and subcommittee and liaison organization. There will also be individual reports from the various subcommittees on their activities during the past year or two. Please take the time to review these and direct any comments or inquiries to the NCTA Science & Technology department.

BACKGROUND

The National Cable Television Association (NCTA) has, since 1952, represented the diverse and growing cable industry before Congress and Federal agencies, in courts of law and before state regulatory agencies. As the principal trade association of the U.S. cable television industry, its members comprise cable television system operators, equipment manufacturers, program suppliers and several ancillary service providers.

Members are provided with forums -- newsletters, committees and an annual convention/exposition, where they may exchange information on developments in the industry and maintain liaison with other industries, societies and groups. The NCTA Engineering Committee is one such forum. Two-day, bi-monthly meetings held mainly at NCTA's Washington DC headquarters, attract 50-75 top level member and non-member cable engineers from all over the country. Subcommittee chairmen reports form an important segment of each agenda.

STAFF AND SUBCOMMITTEES

To the extent that it is able to identify issues of common concern to members, NCTA strives to propose or recommend ways to address these issues. The NCTA Engineering Committee, its subcommittees and staff liaison department -- Science & Technology -- play a vital role in this continuing process. When an area of concern has been pinpointed, the Engineering committee often turns to or creates a subcommittee to address the concern. Following the compilation and analysis of a combination of original testing, research, literature reviews and survey results (every effort is made to solicit technical input from all affected interests) subcommittees report their findings to the Engineering Committee. The Committee then reviews and approves final documents and/or recommendations before NCTA acts on them -- in some cases, publishing and distributing a printed product -- though, as you will read in the following reports, often a subcommittee fills an educating, liaison or monitoring function for the Committee and no published documents results.

CHARTER

The policies of the National Cable Television Association are determined by the Board of Directors. To assist in policy formulation in technical areas, the Board establishes an Engineering Committee. The duties of the Engineering Committee are:

1) To respond on a timely basis to Board requests for advice and recommendations on technical matters.

2) To forward to the Board advice and recommendations on technical matters which the Committee perceives as having an effect on the policies of the Association.

3) To advise the Board of technical developments and innovations which the Committee perceives as having an effect on the policies of the Association.

4) To advise the Board of technical developments and innovations which the Committee perceives as having an effect on the future courses of the cable business.

5) To assist the technical staff of the Association as requested.

6) To represent NCTA by establishing liaison with international and national technical groups.

The activities of the Committee shall include, but not be limited to:

1) Regular review of FCC dockets, Notices of Inquiry, Notices of Proposed Rulemaking, etc., having impact upon the technical operation or construction of cable television systems.

2) Liaison with appropriate outside technical organizations, associations and professional societies.

3) Liaison with international organizations, associations and professional societies whose work may have an impact on the industry.

Membership on the Committee shall be open to all technically oriented employees of members of the National Cable Television Association who are interested in the work of the Committee. The Chairman of the Board of NCTA appoints the Chairman of the NCTA Engineering Committee. Individual voting members are then appointed by the Chairman of the Board of NCTA after consultation with the Chairman of the Engineering Committee.

Notice of meetings shall be sent to all members of the Committee and also sent to interested, qualified parties. Attendance is open to all members of the cable industry's engineering community who are NCTA members.

ACKNOWLEDGEMENTS

Participation in subcommittee work and Engineering Committee meetings are some of the cable engineering community's most challenging but rewarding endeavors, requiring unusual professional dedication and acumen. NCTA's Science & Technology department joins Engineering Committee chairman Tom Jokerst in applauding subcommittee chairman and members for unstinting and outstanding service to the cable industry.

For current information about the NCTA Engineering Committee, call (202)775-3637 or write to Wendell Bailey at NCTA, 1724 Massachusetts Ave., NW; Washington, DC 20036.

For current information about subcommittee or liaison activities, contact the individual chairmen or liaisons. #

SUBCOMMITTEES

HDTV (High Definition Television)
Satellite Practices
Standards/Recommended Practices
Signal Leakage
Quality Sound
In-Home Wiring
ad hoc Tech. Stds. Testing Procedures
EIA/NCTA Joint Committee
ARRL/NCTA Joint Committee
SCTE/NCTA Joint Committee

LIAISONS

Society of Cable Television Engineers (SCTE)
-Bill Riker 215/363-6888
National Electrical Code (NEC)
-Jim Stilwell 215/885-6350
National Electric Safety Code (NESC)
-Jim Kearney 703/444-1800
Institute of Electrical and Electronic Engineer (IEEE) -Lawrence Lockwood 703/920-3795
Advanced Television Systems Committee (ATSC)
-Bernard Lechner 609/924-7545
CableLabs -Claude Baggett 303/939-8500
NIST -Bruce Weintraub 301/294-7606
COST - Richard Annibaldi 614/876-0771

SUBCOMMITTEE REPORTS

QUALITY SOUND
Chairman: Ned Mountain
tel. #: 404/623-0096

Charter: To investigate all aspects of developments with respect to television sound and advise on likely interaction to cable systems. Issues such as surround sound, stereo, "Bose" sound, and "holographic" sound.

Accomplishments and goals: the subcommittee has been active the past year with a primary emphasis on continued investigation of the cable industry's audio level issues. Achievements include: 1) survey of satellite programmers to collect data on peak program levels. Data was obtained representing 26 satellite delivered services. 2) first known attempt to set up a headend using data provided by the programmers and test equipment. This was done by a small working group consisting of Mike Aloisi (Viacom), Paul Resch (Disney), John Vartanian (HBO), Ken Cannon (Scientific Atlanta), David Eng and Max Morales (CableLabs), and Ned Mountain (Wegener). Members from General Instrument also contributed significantly to this effort by providing a scrambler to enable us to precisely calibrate our reference headend. 3) collection of audio level data on all 26 channels for a one month period. 4) private meetings with several programmers to discuss this data. 5) sharing of preliminary results with the full NCTA Engineering Committee.

Work continues in this area with the following tasks planned for completion during 1993. -- 1) providing the full test data to all participating programmers along with preliminary findings about the data. 2) presentation of an Audio Processing Seminar for all satellite programmers to discuss the role of broadcast grade processing in our operating practices.

As chairman, I want to personally thank my subcommittee members for their work during the past year. It has been a challenge, yet a pleasure to have our diverse opinions and ideas all in sincere cooperation toward understanding and solving this longstanding problem.

STANDARDS/RECOMMENDED PRACTICES
Chairman: Dick Shimp
tel. #: 1-800-336-9681

Charter: To establish or identify field measurement practices quantifying a range of actual cable system operating conditions.

Accomplishments: In 1989, under chairman Mike Jeffers, the subcommittee issued the second edition of the text NCTA Recommended Practices for Measurements on Cable Television Systems. A supplement to the second edition is set for release in 1993 which will cover two areas: 1) fiber optics measurements and graphic symbols, and 2) amendments to existing measurements (jointly published with NATOA or the National League of Cities) due to the FCC's 1992 technical standards testing procedures and requirements.

EIA/NCTA JOINT COMMITTEE

Co-Chairman: Doug Semon
tel. #: 510/463-0870 VM #350

Charter: To establish and maintain dialogue between the cable and consumer electronics industries for studying and resolving engineering matters of common interest.

Background: The "Joint Committee" was formed in 1982 and has met regularly for the last 11 years. Doug Semon succeeded Dr. Walt Ciciora as the NCTA's co-chair in May, 1991; Mr. William Miller of North American Philips Corporations continues to serve as the EIA's co-chair. About the same time, Mr. Ralph Justus of the EIA replaced Tom Mock, who had served the committee since its inception. The close association with CableLabs has continued under the guidance of Mr. Claude Baggett, who serves as the Joint Committee's recording secretary. For the last two years, the Joint Committee has met every two months without exception.

The purpose of the Committee is twofold. First and foremost, it is a forum for communication and the exchange of ideas, problems and opportunities between the EIA and the NCTA. The Committee's secondary role is setting of voluntary standards related to the interconnection and performance of consumer electronics devices to cable systems. Certain provisions of the Cable Act of 1992 (dealing specifically with the consumer interface) have given the Joint Committee a renewed sense of purpose. As a result, the Committee has volunteered to provide technical guidance to the special FCC Advisory Group that the EIA and NCTA formed to deal with these requirements of the Cable Act.

Accomplishments: The Joint Committee's first voluntary standard was IS-6, which defined the frequency channelization plan which we know today. Until this time, cable channel designations varied among manufacturers, resulting in confusion even within the cable industry itself. Today, compliance with IS-6 is universal among manufacturers, although it is not uncommon to find printed literature still using pre-IS-6 designations for midband and superband channels.

Following the success of IS-6, the Committee took on the problem of receiver RF performance in the cable environment. The result of this work, IS-23, deals primarily with direct pickup interference (DPU), tuner overload from the pure number of cable signals at the input, and local oscillator leakage from the tuner. Despite agreement within the Committee itself, IS-23 never made it to the Recommended Practice stage. It is appropriate to point out, however, that many consumer electronics manufacturers have substantial improvements in the area of RF performance because of this work.

Perhaps the best known (and least successful) accomplishment is RS-563, also known as IS-15 or MultiPort. This standard is paradoxical: it is a field-proven technical standard but it never gained widespread acceptance among cable operators or consumer electronics manufacturers. At one time, MultiPort descramblers were available from some, but not all, traditional addressable scrambling system manufacturers.

The most recent standard developed by the Committee is an extension of IS-6 to 1 GHz. This action has been approved by the full Joint Committee and is currently waiting approval from all EIA member companies. Full standard status is expected by midyear.

Future Activities: As mentioned above, the Committee is currently addressing several possible solutions to the "customer-friendly" mandate of the Cable Act of 1992. Among these are a renewed and revised MultiPort, broadband descrambling and interdiction systems, a national scrambling standard, and others. The Committee is also discussing another extension to IS-6 that would define "sub-channel" identification of compressed signals, and continues to address those issues surrounding the concept of "cable ready" including DPU and other RF performance areas.

Of greatest importance, however, is that the Committee continues to be the only official vehicle for maintaining an open dialog between engineers in the cable industry and the consumer electronics industry. This ongoing teaching and learning process may represent the best chance for ultimately solving the consumer interface dilemma. Even if the two industries have dissimilar and sometimes conflicting business goals, they do have the same customer base. The EIA/NCTA Joint Engineering Committee continues to believe that both industries benefit most from providing these same customers with the best, easiest to use, technically sound and economical solution that can be devised. **That is our joint goal.**

ARRL/NCTA JOINT COMMITTEE
Chairman: Robert V.C. Dickinson
tel. #: 215/691-0100

The Amateur Radio Relay League (ARRL) /NCTA Joint Committee was formed in 1983 and has been involved with coordination of the Cable and Amateur Radio communities in CATV signal leakage matters. In the early days the committee did some investigation of the signal leakage mechanisms in the field. This exercise was informative and became the basis for ongoing cooperation between the organizations. In the past several years the committee has been involved largely with addressing specific situations where amateurs have been dissatisfied with the performance of cable operators and vice versa. These efforts have been aimed primarily at preventing each specific situation from escalating to a complaint to the FCC. The committee is often able to coordinate the solution of the problem at hand.

The work of the committee has, in part, contributed to the improvement in relations with the amateurs and hopefully in achieving greater awareness on the part of the cable operators. The cable industry has made great strides in attitude improvement toward the "hams" and is to be commended for its efforts.

At present the work of the committee continues to address specific complaints as they are brought to its attention by both cable and amateur parties. There have been only a few complaints in the last 12 months. These have been largely resolved through the efforts of Roger Pience and the Chairman. The ARRL has shouldered its responsibility and the entire effort remains cooperative and effective. At present the active members are Brian James of CableLabs, Roger Pience of NCTA, Ned Mountain of Wegener Communications, the Chairman, plus Hugh Turnbull, Atlantic Director of the ARRL and other ARRL associated amateurs whom he recruits as required.

We expect the activities of the committee to continue at about the present level so that additional members are not currently needed, however, in case of emergency, there are several long time volunteers who can be called upon to assist.

SIGNAL LEAKAGE
Chairman: Charles L. Cerino
tel. #: 215/981-7654

Charter: The functions of the Signal Leakage Subcommittee are as follows: 1) Inform and educate the cable television industry about regulations and interpretations relating to the Federal Communications Commission Rules (47CFR), Part 76 - Cable Television Service, Subpart K paragraphs 76.610 through 76.616 on signal leakage performance criteria. 2) Maintain a good working relationship with the Federal Communications Commission's Cable Television Branch personnel. 3) Take appropriate action to resolve related issues between the industry and the Federal Communications Commission when they occur. 4) Report all activity to the NCTA Engineering Committee.

Accomplishments and Goals: Since the creation of this subcommittee, under Ted Hartson, many interpretations of the FCC regulations were drafted. The industry was educated to the requirements through many NCTA and SCTE sponsored seminars conducted by members of this subcommittee. Key to effecting the change in the industry was maintaining a good working relationship with the FCC. Future plans call for the continuation of process as outlined in our charter as well as interface with the SCTE CLI subcommittee. Interested parties are welcome to contact the chairman.

HIGH DEFINITION TELEVISION (HDTV)
Chairman: Nick Hamilton-Piercy
tel. #: 416/391-7226

Charter: This subcommittee on HDTV was formed by the NCTA Engineering Committee in 1987 to closely follow the rapid developments taking place in HDTV technology; to interpret what impact the transmission of HDTV signals would have on cable television distribution networks; to determine what is needed to accommodate these signals; and to liaise with the various proponents on HDTV systems on the unique requirements of cable/microwave/satellite transmission.

Accomplishments 1992/1993: The Subcommittee's prime focus over the last reporting period has been on supporting the cable testbed testing of the various HDTV proponent systems conducted by CableLabs at the Advanced Television Test Center. The Subcommittee provided expert viewers to assist in detecting visible impairment thresholds and other criteria.

In early 1992, the industry embarked on a program to evaluate the effectiveness of various ghost cancelling equipment reference signals. Subcommittee members participated in the testing. Subsequently, a North American reference signal standard was chosen and a major manufacturer provided headend quality equipment to this standard. Early production units were obtained by the Subcommittee members and were subject to rigorous in-field testing which proved the technology is quite successful for completely removing ghosts in a headend environment.

The Subcommittee reviewed various digital and ATV test plans developed by CableLabs and provided input. In particular, the group helped develop the cable segment for the planned over air testing of the selected ATV proponent system. Testing to this plan is anticipated for mid to late 1993.

Several members of the Subcommittee are also participants on various CableLabs Subcommittees and in that role augment the HDTV Subcommittee work through such projects as digital transmission testing on cable in preparation for NTSC digital video compression services and future ATV services and inputting to the MPEG standards activity.

The expected role of the Subcommittee through 1993 will be "watching brief" on the final selection of an ATV system and the introduction of digital transmission of NTSC and ATV services. Subcommittee members will be called to assist in the final ATV system field tests anticipated to occur in late 1993.

IN-HOME WIRING
Chairman: Larry Nelson
tel. #: 704/324-2200

The subcommittee continues to examine the needs and requirements for the in-home portion of the cable plant and ways of articulating them to a growing group of non-professional installers -- building and/or electrical contractors and homeowners.

This subcommittee was formed in recognition of the increasing complexitites associated with cabling homes due to the growing availability of low quality materials, home automation systems, and the added technical and service performance responsibilities to the operator.

The ways and methods endorsed by this subcommittee will in no way be directed at influencing operating policy decisions of any operator.

SATELLITE PRACTICES
Chairman: Norman Weinhouse
tel. #: 818/884-3105

Nineteen hundred and ninety-two was a year in which two new satellites were added to the constellation serving cable systems (Galaxy V and Satcom C4). In addition, two older Satcoms were retired and were replaced in their original orbital slots by new more powerful satellites (Satcom C3 and C5). The transition to the new and replacement satellites appears to have been relatively smooth although there were numerous programmer changers in satellites, transponder numbers, and polarization. During the year, the Satellite Practices Subcommittee attempted to appraise the main committee of these changes. The programmers did a great job of notification to affiliates which made the transition relatively painless.

A "Good Practice Bulletin" was generated in 1992 and distributed to cable programmers in an attempt to obtain better uniformity of video levels. That bulletin was titled "Establishing and

Maintaining the FM Deviation in Satellite TV Transmissions to Cable Systems". It contained a recommendation to include COMPOSITE and COMBINATION vertical interval test signals (VITS). It also contained detailed instructions to uplink operators on methods to adjust for the proper FM Deviation in the satellite link.

An addendum to that bulletin will be sent sometime in 1993 to further assure video level uniformity and to guard against overmodulation.

ad hoc TECHNICAL STANDARDS TESTING PROCEDURES
Chairman: Sid Fluck
tel. #: 303/939-8500

The subcommittee, comprised of system operators and test equipment manufacturers, was first established when the FCC released its Notice of Inquiry on cable television technical standards in April 1992. The group was tasked with writing new testing procedures that would comply with anticipated FCC rules requiring annual cable system performance testing. Meetings and teleconferences began in January 1993 some weeks after the FCC released clarification and reconsideration of the rules in late 1992.

Achievements: creation of relevant updates to the NCTA Recommenced Practices for Measurements on Cable Television Systems (2nd ed.). Following a vote by the full NCTA Engineering Committee and acceptance by NATOA, the measurement techniques will be jointly published by NATOA and NCTA and distributed widely. Registered holders of the 2nd edition, NCTA Recommended Practices notebook will receive the updates by the end of the year.

SCTE/NCTA JOINT COMMITTEE
acting chairman: Tom Elliot
tel. # 303/267-1344
alternate: Tom Osterman
tel. #206/623-8670
This joint committee was formed in the Spring of 1992 to investigate power quality and its relationship to subscribers' picture quality. Its goal is the specific engineering evaluation of power supply characteristics in relation to digital and analog signal processing equipment.

Regional Interconnect Networking
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NEXT GENERATION CABLE NETWORK ARCHITECTURE

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ABSTRACT

Today's cable network is migrating from the traditional tree-and-branch topology originally designed for point-to-multipoint video entertainment to a star, tree-and-branch topology with a robust, dynamic capability for a wide range of applications beyond video entertainment. One of the major research efforts at CableLabs is focused on leveraging this newly evolving topology so that it can support applications such as multimedia and personal communication services (PCS).

The cable network is positioned to deliver digital signals that will reside above analog spectrum and to provide analog and digital fiber within the same sheath. This will allow the transparent transport of multimedia and PCS applications.

This paper addresses the concept of the regional hub, which provides connectivity to regional and national networks; the transport and interface requirements for analog and digital video entertainment and new applications; the attributes of interactivity and bi-directionality in cable's network design; and reliability and system performance over cable's infrastructure.

1.0 INTRODUCTION

Technology relative to new applications, like multimedia and PCS, is on a convergent path that has led to the integration of audio, data, video and graphics. Converging technologies make it possible to access a great deal of information through the use of a single system or the integration of a number of systems. Many of these advancements are occurring in parallel with advancements in cable network design.

Cable's broadband capacity will make the transport of these services technically feasible and economical. It is the cable network that is the missing link to myriad multimedia applications now being developed by the computer industry, by the consumer electronics manufacturers, by publishers, and by the motion picture industry. PCS will be economical on cable's infrastructure because of the cable network's robust, dynamic bandwidth. The differences between applications are distinct and the requirements are as unique as the implementation. However, cable's infrastructure can provide a common platform for all these new applications.

2.0 THE REGIONAL HUB

Currently, in any given region, it is likely that there will be more than one cable operator with one or more headends serving a portion of that geographical area. Service is provided independent of other operators, even though the cable operators may obtain some or most of their source material from the same programming providers. Hence, a duplication of satellite feeds, off-the-air equipment, and microwave facilities is required to secure this source. This plant might be shared across several headends in the same region owned by the same cable operator, however, usually not with other adjacent or separate cable operators in the region. This situation is further complicated by the fact that most operators provide functionality that duplicates that of other cable operators for video storage, advertisement insertion, etc. The result is slow implementation of new service opportunities.

A solution is the regional hub. A regional hub is a centralized facility that is tightly coupled to a dual ring network topology to interconnect headends located in a common geographic region. The dual ring topology may interconnect a single cable operator's headends or the headends of any number of MSOs operating in adjacent serving areas. A regional hub could be owned by a predominant cable operator in the region, a third party, or some other arrangement.

Centralization of capital-intensive investments for a range of advanced functionalities at the regional hub allows the cable operators to spread the investments across a wider base. It also provides a platform for offering a common set of functionalities to large and small operators. It allows multiple cable operators to share the additional revenue streams as well as the investments and risks associated with providing the advanced applications. This is particularly important because of re-regulation and the introduction of costly advanced-feature functionality.

In addition to the regional hub, cable's next generation architecture will include fiber nodes. Fiber nodes represent a new addition to the network as fiber is migrated further down in cable's network architecture. (See Figure 1 and Figure 2.) This incremental migration of fiber will minimize the need for a total network rebuild. This architecture was conceived to take into consideration a wide variety of network types so that no operator's network is made obsolete.

2.1 Functions of the Regional Hub

The regional hub is a centralized, shared facility that can serve many functions. It allows cable operators to negotiate programming arrangements in bulk that will potentially reduce programming costs. This is particularly important as a means of minimizing overall operating costs.

The regional hub can serve as the platform for:

- advanced television
- bulk program distribution
- storage facilities for network-distributed video on a regional basis
- mass storage for multi-channel pay per view and multimedia applications
- advertisement insertion facilities
- compression/decompression of video source
- advanced program guide for multi-channel systems
- PCS switching and cross-connecting facilities
- multimedia distribution
- automated network management capabilities

The regional hub also provides cable operators with a centralized platform of advanced systems for performing rapid prototyping of more advanced applications. As these applications are "proven in" and demand and revenue streams grow, advanced systems can be gracefully migrated down from the regional hub down to the headend, then from the headend to the fiber hub and, eventually, from the fiber hub to the fiber node. The regional hub can provide an access point to other networks including:

- local exchange carriers
- inter-exchange carriers
- alternate access carriers
- satellites
- microwave
- cellular
- off-the-air broadcast
- PCS providers

2.2 Applications

A range of multimedia applications is being considered as part of the requirement for interactive services. In order to characterize the transport and interface requirements of these applications, it is necessary to evaluate each application independently. A brief list identifying generalized application categories is provided below:

- education
- cable-commuting
- entertainment
- professional

- home shopping
- customer services
- information services
- wired and wireless telephony

2.3 Ring Interconnection

The regional hub provides an interface to other networks and to the headends in its region for real-time and non-real time programming source and control access. (See Figure 3.) This keeps the interconnection point at a higher hierarchical level and allows the cable industry to utilize protocols that are suited to cable's transport requirements. The interconnection of the regional hub to the headends will be through a dual ring topology.

The dual ring consists of analog and digital fiber facilities that are broadband, "self-healing," and bi-directional. The fiber cable contains digital and analog fibers in the same sheath. (Microwave may be used where fiber is uneconomical or inexpedient.)

The dual ring topology of choice is a dual ring, with one ring running clockwise and the other counter clockwise. This builds in considerably higher reliability and increases mean time between failure (MTBF) when compared to a star topology with fiber distributed between the regional hub and the headend.

The ring topology interconnects large and small cable operators to a wide variety of advanced applications, such as multimedia, PCS, wired telephony, and cellular radio, over a regional area (e.g., an entire metropolitan area). The ring protocol suite will be discussed in Section 2.12.

Many of the ring transport facilities already exist and can be leased through a competitive access provider (CAP) or a metropolitan area network (MAN) provider. Alternatively, they can be owned by a cable operator or a consortium of cable operators, by other transport providers, such as a local exchange carrier (LEC), an inter-exchange carrier (IXC), or by other private long haul carriers.

2.4 Systems Redundancy

With the centralization of advanced functionality in the regional hub, it is critical to have duplicate copies of systems, such as mass storage, video servers, and switching, since an outage of any system will have an impact on many headends and, subsequently, a large number of subscribers. Because the regional hub will provide service to large regional areas, it is important to provide redundancy not only on advanced systems but on primary and secondary regional hubs on the ring infrastructure. (See Figure 4.)

2.5 Secondary Backup of the Regional Hub

As advanced functionality is moved higher in the network hierarchy, redundant regional hub functionality becomes more important to avoid single points of failure on the ring. This means duplicate copies of each advanced and gateway system are necessary in order to avoid single points of failure. Secondary locations that mirror the functionality in the regional hub are necessary to ensure that if the regional hub is out of service, cable operators can still provide uninterrupted service to the subscriber base. (See Figure 5.)

2.6 Gateway to Other Networks

Since the regional hub facility serves as a gateway to other network types, i.e., the inter-exchange carriers, local exchange carriers, and other public and private networks, the gateway will initially have systems that are compatible with these networks. For example, interoperability with a network using synchronous optical network (SONET) would require SONET equipment with a gateway to the protocol in use on the regional hub ring infrastructure.

Over time, a series of specifications will be developed that identify the interface requirements of the regional hub. The need for systems that directly interface with other networks will be replaced by a need for equipment that complies with the protocols and systems used on the regional hub dual ring infrastructure. (See Figure 6.)

2.7 Tightly Coupled Rings

To cover a larger geographical area and to reduce the price floor of the advanced functionality of the regional hub, rings are coupled. The interconnection of tightly coupled rings to the main ring extends the reach of the regional hub and offers access to the same complement of advanced functionalities. This extended coverage allows for interconnection of many headends in a regional area. Testing will determine what radius the ring can support. For example in the state of Colorado, the main ring could serve an area such as Denver with coupled rings extending north to Boulder and another ring reaching south to Colorado Springs. Along the way, other, smaller systems interconnect the ring. (See Figure 7.)

2.8 Avoiding Single Points of Failure

The coupled rings interconnect with the primary ring in two different locations to avoid single points of failure. This ensures that the same level of performance and reliability exists on the secondary rings as is provided on the main ring. (See Figure 8.)

2.9 Links to Adjacent Headends

An additional point of interconnection is provided through a link to adjacent headends. This link ensures connectivity to the regional hub dual ring infrastructure in the event of a headend outage or other catastrophic circumstances. (See Figure 9.)

2.10 Virtual Ring

The regional hub design lays out a virtual ring to provide physical route diversity between the fiber hubs which are subtended from a single headend on the regional hub ring. (See Figure 2.) The link between the headend and the fiber hub is the primary path. However, a secondary link between adjacent fiber hubs provides an alternate route to ensure connectivity between all fiber hubs and the headend. This capability is possible through the physical connection between the adjacent fiber hubs and a manual or dynamic cross-connect functionality at each fiber hub.

In the event of a fiber cut or an outage on the link between the headend and the fiber hub, an alternative path is provided through an adjacent fiber hub with active linkage to the headend. This linkage allows for continuity of service during a cable cut or link failure. The transfer from the primary fiber system to the alternate route can be provided through manual or automated systems, such as a cross-connect.

Virtual ring capability is not extended below the fiber hub because of the cost and the limited number of subscribers served by the fiber node, i.e., 200 homes passed.

2.11 Capacity on the Regional Hub Ring

The capacity of the ring infrastructure is determined by the fiber count, the bit rate, and the ratio of digital compression. The number of fibers in the fiber sheath is determined by the types of traffic and applications.

2.12 Transport Protocols

CableLabs is currently assessing various protocols to develop a matrix mapping their various parameters. This will provide CableLabs with the tools needed to select the appropriate protocols and interfaces that are well suited to cable's requirements.

Protocols that show promise include IEEE 802.6, known as distributed queue dual bus (DQDB); IEEE 802.6, distributed queue random access protocol (DQRAP); frame relay; SONET; IBM

PARIS; and fiber distributed data interface (FDDI) with some form of layer two, asynchronous-transfer-mode- (ATM) like, fast-packet functionality. It is possible to use attributes from each protocol to facilitate the most efficient delivery from the regional hub to the home, either from an end-to-end basis or within the ring itself. The need to minimize cost and complexity will determine the selection of an appropriate suite of protocols.

An area of concern with the use of ATM is the fact it discards lost packets. If a particular ATM packet is critical, such as in digital video compression, this may result in the loss or degradation of the picture at the subscriber's display. On the other hand, the loss of cells should be negligible in a fiber-based ring system and in the hybrid fiber/coax distribution. ATM may be a good transport mechanism in the ring and on the fiber portion of the cable distribution plant, but its use all the way to the home requires further analysis.

While economics will play a major role in determining when or if ATM will become feasible for transport on the ring or in the local distribution, another determining factor is the type of traffic being carried. A determinant in this transition is likely to be when some unknown threshold is achieved in which traffic on the network migrates from a constant bit rate (CBR), fixed bandwidth to a variable bit rate (VBR), bursty data characteristic. Until that threshold occurs, it is likely that synchronous transport of traffic on the regional hub ring and the local distribution will suffice.

2.13 Business Access

The original research and development of the regional hub architecture focused on providing service to the residential subscriber. However, recent interest in serving the business customer has stimulated CableLabs research to focus on the best approach to meet this potential opportunity while continuing to evolve the network for residential applications and services.

While a virtual ring serves to provide physical route diversity, a virtual private ring network functions as a physical overlay for business applications. The virtual private ring network may reside in the same fiber sheath as the virtual ring, but the virtual private ring network will provide transport solely to business traffic. (See Figure 10.) A virtual private ring network uses a ring topology that interconnects the business customer at specific points of access through a separate transmission facility. Physically this links the business traffic to the regional hub ring through the headend. This approach provides the business customer with connectivity to areas served by the regional hub and with access to the public switched telephone network (PSTN) and private networks.

A different scenario has fiber hubs or fiber nodes as points of access for business traffic to cable's infrastructure, instead of a dedicated virtual private ring network. In this set up, the fiber hub or node is deployed at the business customer's facility and linked to the regional hub ring through a virtual network to the headend. These fiber hubs and fiber nodes are dedicated facilities in the sense that no residential services are provided from the fiber hub or node through the transport facility supporting this traffic. (See Figure 11.)

2.14 Regional Hub Serves as Gateway to National Infrastructure

Because the regional hub is centrally located within given geographic regions, it is a logical gateway for state and national network interconnections. The interconnection of regional hubs in a statewide configuration is already underway in one state (Pennsylvania) and other states are considering this type of infrastructure. The regional hub can also serve as a gateway to local regions for the national infrastructure.

2.15 Regional Hub Implementation

The initial deployment of the ring is likely to take the form of back-to-back multiplexing at each of the headends subtended from the regional hub. Functionality will be provided in early implementation through the sharing of resources already deployed in one or more locations, i.e., one headend may provide advanced television signals to multiple headends through the ring topology, while another headend may offer advertisement insertion to the same group of headends owned either solely or through several cable operators. (See Figure 3.) As the regionalized concept evolves, a single location will be identified as the regional hub with the collective functionality centralized for efficient utilization and operation.

Implementation may occur more rapidly if a single cable operator is considering linkage of many headends to the ring and centralizing functionality, as opposed to an operating environment where more than one cable operator is involved. The latter would necessitate establishing business and operating agreements, prior to implementation.

2.16 Regional Hub Migration

The migration to this network architecture is graceful in that it provides a path to the future without stranding existing network capital investments. For example, cable operator #1 may choose to migrate the fiber node concept over time. Cable operator #2 may choose to migrate to 500 homes passed now; while cable operator #3 may migrate to the fiber hub and go no further. Obviously, the more closely the cable operator follows the network architecture migration path, the greater the functionality and revenue opportunities possible.

2.17 Benefits of the Regional Hub

The regional hub architecture concept is based on the philosophy of the original tree/branch topology, i.e., share as much of the infrastructure as possible before dedicating transmission facilities to each individual subscriber. Here are some of its advantages:

- centralized advanced functionality lowers price floor for services on a shared basis
- centralized advanced functionality allows for consolidation and elimination of some headends
- connectivity to regional markets that have typically been fragmented markets for the cable industry
- access to advanced intelligent network capabilities
- centralized human resources and reduced operating expenses
- an alternative to switching functionality and interconnections with public and private networks
- a platform for shared access to mass storage for multi-channel pay-per-view and multimedia applications
- a platform for information services providers to introduce new services and test the market in a large geographical area
- access at a single point of interconnection is available to other network providers, such as IXCs, LECs and private networks
- a platform for rapid prototyping of new technologies and services

A major advantage of the regional hub concept is that it allows flexibility in transitioning through new technologies and unproven marketing schemes. The initial commitment is only in one place, the regional hub. As success feeds growth, and demand and revenue streams increase for specific services, advanced functionality may be migrated further into the infrastructure closer to the subscriber.

As an example of this process, if mass storage costs are estimated to be $2 million for each headend for multi-channel pay per view, and a given regional hub ring provides access to 30 headends, the total cost for mass storage for these headends is $60 million. In order for the regional hub to be cost effective, the costs of the regional hub and the ring infrastructure must be less than the distributed functionality. Obviously, the aggregate of the cost savings associated with additional advanced functionality further supports the implementation of the regional hub. Of course, centralized functionalities also imply shared risks and benefits for cable operators using the concept.

3.0 TECHNICAL CONSIDERATIONS

Research at CableLabs is focused on resolving network issues to position cable as a transport provider of analog and digital video entertainment, multimedia, and PCS applications. There are a number of technical challenges which are discussed below.

3.1 Interactivity/Return Path

Most cable systems are able to provide bi-directional capabilities. The downstream direction can exist in available spectrum from 50 to 550 MHz and on some new systems, 50 MHz to 1 GHz. The return path, or the upstream direction, typically is limited to 5 to 30 MHz and it will serve as an interim solution until more efficient approaches are available.

The need for additional return path spectrum has led to research in designing a passive coaxial network, a parallel coaxial network design from the fiber node to the home, and a mid-split system. The passive coaxial design focuses on the elimination of all the active components in the network so that the spectrum for upstream requirements can be allocated in a dynamic fashion based on fixed or variable transaction-based requirements.

Applications such as PCS will require bi-directional functionality and some form of switching and control. Switching, as referenced here, should not be limited to traditional switching techniques. It may be as simple as multiplexing or more complex approaches, such as fast packet, may be appropriate.

A challenge for the cable industry is to clear a block of frequencies that can be allocated to multimedia and PCS applications. Locating large blocks of unused spectrum is a challenge since most cable operators utilize most or all of their system's existing spectrum. Channel alignment is largely a marketing issue that is not technical in nature because channels are lined up with those used by local broadcasters and others. Ultimately, however, a tiered approach to common channel line up will aid in the allocation of spectrum in a more uniform manner for each cable system nationwide.

3.2 Switching Requirements

PCS and wired telephony require switching functionality. Two approaches to switching are being considered: (1) traditional class 5 central office switching with centrex capabilities and (2) distributed switching. The centrex solution offers each cable operator or headend access to only the number of lines required for paying subscribers. As each operator's customer base grows, additional lines can be accessed without having to purchase more hardware. If an operator's customer base decreases, the number of lines can be reduced. Since the centrex system can be partitioned, security is not an issue.

The distributed switching approach offers the cable operator a "pay as you go" deployment methodology that adds switching fabric as customers join the network incrementally.

3.3 Bandwidth and Channel Capacity Requirements

Bandwidth is considered to be another limiting factor for multimedia applications on cable. In cable's existing and future designs, the view of multimedia is for highly asymmetric conditions, with the downstream bandwidth requirements greatly exceeding the upstream requirements.

Initially, one or two channels will handle the upstream demand. As demand increases, however, more cohesive plans for additional upstream spectrum must be developed to maintain pace with multimedia developments. These plans include migration of fiber further down the infrastructure, improvements in laser technology (that allow more than 100 channels on a single fiber), the passive coaxial network that supports dynamic allocation of bandwidth, and digital compression. (Section 3.7 discusses the additional impact digital compression has on multimedia.)

3.4 Throughput

Throughput for PCS can be managed with traditional telephony approaches, however, multimedia applications will require coding techniques to efficiently utilize the broadband bandwidth of the network.

The Multimedia and Hypermedia Expert Group (MHEG) is developing coding for multimedia to manage throughput on the transport infrastructure. Interleaving may be necessary for audio and video sequences. This coding is needed to determine if sufficient throughput on the network or storage capabilities is available for real time or non-real time transactions.

Ethernet applications over cable requiring 10 Mbps throughput are already available within a 6 MHz channel. Moving Pictures Experts Group (MPEG) applications will require bandwidth ranging from 1.5 Mbps to 100 Mbps. Other algorithms are being developed that will allow for throughput capabilities at 20 to 30 Mbps on a single 6 MHz channel.

3.5 Performance and Reliability

The migration of fiber deeper into cable's infrastructure improves network performance and reliability. This is largely due to the reduction in the number of active components in the network, i.e., amplifiers and line extenders. The largest improvement is achieved through the deployment of fiber from the headend to the fiber hub. This reduces amplifier cascades to no more than four amplifiers and two line extenders between the headend and any home. Further installation of fiber from the fiber hub to the fiber node provides only marginal improvement in network performance and reliability because the number of remaining active components eliminated can only be less than six. Future designs will seek to eliminate the active components on the coaxial plant entirely and add amplification at the residential unit. These migratory changes will result in continued improvements in performance and reliability.

Initial research indicates that a dual ring topology is preferred over a star topology because of a dramatic improvement in MTBF. The star approach yields a five-month MTBF, whereas a dual ring topology exhibits a 60.2-year MTBF.

The investment in the additional link to create the dual ring topology obviously has tremendous pay off. Because of its advantages, this technology could also be applied between the headend and the fiber hub. A summary of the results of this research will be made available in the near future.

3.6 Network Management

The existing approach to network maintenance is not reliable enough to support multimedia and PCS applications. For example, the practice of removing an amplifier from service to test its integrity cannot be tolerated with these new applications. The passive coaxial network makes it easier for the cable operator to eliminate this component and to introduce an automated, dynamic approach to network management from a centralized facility, such as the regional hub. This can lead to additional quality improvements and operating-cost economies.

Implementation of network management will evolve in three distinct areas: (1) dual ring topology, (2) cable distribution with two components, i.e., the virtual ring for route diversity and the local distribution over the coaxial, tree/branch topology, and (3) the virtual private ring network for business transport and access.

3.7 Digital Transport and Compression

Applications like multimedia, PCS and wired telephony will require digital transport over cable's infrastructure. In the digital domain, it is likely the reference will continue to be a 6 MHz channel. However, over time, the reference will be a function of compression and bits per second as related to a channel.

Digital compression will have a significant impact on the digital video component of multimedia. For example, using 150 existing downstream channels with 70 channels devoted to digital transport, a 10:1 digital compression scheme will produce 700 digital channels, with the balance of 80 channels remaining analog. For cable operators who choose to offer digital source over existing 550 MHz systems, the spectrum can be allocated with analog programming residing between 50 to 300 MHz and the digital source between 300 to 550 MHz. At 10 to 1 compression, this split will provide over 400 digital programming choices coupled with over 40 analog programming choices simultaneously.

In the initial stages of digital video, compression facilities will be located at the satellite uplink facility with decompression functionality at the home. However, the next migration of compression and decompression will likely occur at the regional hub.

3.8 Synchronization

Some form of global synchronization is necessary for multimedia applications. Synchronization is used to correct the multimedia application when unacceptable delays occur in the transport of the various data streams.

Digital video compression is only one of at least four components of multimedia (audio, data, graphics and video). While algorithms of up to 10:1 are being used for digital video, schemes for audio and data communications are likely to use a different compression algorithm. From a transport perspective, this may mean four separate signals or a single bit stream, and it obviously represents increased complexity. With these signals residing in different compression formats, a lossless network compression scheme will be necessary in addition to the compression formats already applied to MPEG.

In addition, the audio component must be synchronized with the digital video to ensure lip synchronization. Bit stuffing while an application is idle may be required. This approach assumes a dedicated channel for each user, which may not be feasible. A more likely approach on a cable infrastructure is to allocate bandwidth dynamically for each session.

If synchronization is the responsibility of the computer and consumer electronics manufacturers, then this requirement may be innocuous. If, however, it is a function of the network, then it is likely that no single synchronization plan will be achievable without a worldwide protocol. This is largely due to the dissimilar characteristics of transport providers and storage capabilities, along with the various stages of functionality that may reside within these networks, i.e., digital and analog and other divergent functionalities. This requirement is likely to be the source of great debate for some time to come.

3.9 Video Coding and Systems

It is desirable to design a decoder that is low cost, with the majority of expense and complexity in the encoder. The encoder will initially reside at the satellite uplink with a migration to a cable regional hub that serves multiple headends in large geographic regions.

3.10 Mass Storage

Typically, transport rates exceed the processing capabilities of most computer systems. The variability between speed of transport and of processing necessitates storage on a large scale. To minimize the cost of mass storage systems, it will first be essential to locate storage capabilities as high as feasible in the infrastructure, such as at the regional hub. Studies indicate that as the demand for video source increases, it will be necessary to migrate the storage capacity lower in the infrastructure from the regional hub to the headend, for example. For cable systems, mass storage may be shared among multimedia and other applications, such as multi-channel pay per view.

The economics of the storage problem will probably drive the final resolution of the mass storage dilemma. Mass storage in a compressed mode is an alternative to storing uncompressed video source. This method simplifies the network interface and ensures that the network is essentially transparent. It also would reduce the need for additional decoding and encoding functionality at the regional hub and the headend. Instead, the encoding and decoding functionality could reside at the satellite-uplink facility and in the home.

3.11 Security/Privacy

The use of a dual ring topology to access the regional hub and the headends raises issues of security and privacy of information. Several approaches can be implemented including customer-owned encryption or a scheme that is inherent within the cable infrastructure.

3.12 Data Stream Protocol

An open protocol is critical to the success of multimedia, PCS and other information services. Many of the technical attributes described above are being developed by CableLabs. This research focuses on an out-of-band data stream protocol that provides for constant bit rate, low-speed and high-speed protocols in predetermined frequencies common to participating cable systems, and variable bit rate capabilities that dynamically allocate spectrum over unused portions of the cable spectrum. Spectrum allocation will address the downstream and upstream paths for these applications. The data stream protocol in many cases emulates the inband capabilities of the vertical blanking interval (VBI), however, at higher data rates.

A low-speed protocol will support services such as an advanced program guide and low-speed multimedia applications. The low-speed component of the data stream protocol provides for a range of bit rates from 19.2 kbps to 1.5 Mbps.

A high-speed protocol is intended to support MPEG 2 type applications for multimedia. These data rates will include 10 Mbps with multiples of 10 Mpbs, i.e., 20 and 30 Mbps.

3.13 Administration, Operations and Support

Administrative, operations and support functionality, such as operator services, billing and signaling system 7, could be contracted on a third-party basis until demand justifies cable's provisioning of these capabilities internally. For example, these services could be acquired through negotiations with an IXC or IXCs, in turn for a reduction in access charges.

4.0 THE HYBRID FIBER/PASSIVE COAXIAL NETWORK

Coaxial-based systems are common throughout North America. The all-coaxial cable design is migrating to a hybrid fiber and coaxial network design when systems are upgraded or there is new construction. Both designs deliver analog signals.

Fiber is being deployed because it enables a substantial improvement in system performance and reliability through its low-loss, increased passband characteristics, and significant reduction in the number of active components. This greatly increases downstream passband capability.

4.1 Fiber Hubs and Nodes

In the hybrid fiber and coax system, fiber cables are provided from the headend to fiber hubs that are centrally located among about 2,000 homes passed. (See Figure 12.) These hubs feed fiber to nodes that serve 200 homes passed. Thus, 10 fiber nodes are served by a single fiber hub. (Figure 2 illustrates the hybrid fiber and coaxial cable system network architecture hierarchy.) The connections between the headend and the fiber hubs and the hub-to-hub interconnections provide "virtual" ring capability and true physical routing diversity.

The fiber node improves system performance, reliability, and flexibility and reduces operating costs. By using a fiber node to bring fiber closer to the subscriber, we may be able to eliminate active components, i.e., amplifiers and line extenders, in the coaxial, tree/branch portion of the network. This means that the signal that is transmitted from the fiber node must be strong enough to reach the home without amplification. The signal then is amplified at the home by a low-noise amplifier (LNA). The specifications of the LNA are currently under development at CableLabs.

4.2 Low-Noise Amplifier

The LNA would not only amplify the signal, but serve as a line of demarcation between the network and the home and protect the cable system from noise generated within the home. (See Figure 2 for the LNA in the home.) It also would support an increasing number of television sets, VCRs and other display systems in the home. The LNA could be integrated into the consumer electronics interface that may be part of the converter or set-top box, or it could be a separate device attached to the side of the home.

Amplifiers and line extenders have been necessary in existing networks, but they represent a bottleneck in re-allocating spectrum for return path transport. Once the active components of the coaxial plant are eliminated, the bandwidth on the coaxial transmission medium can provide additional spectrum for upstream requirements on a transactional basis. CableLabs is examining methods to dynamically allocate spectrum through the use of an LNA in the home on a passive coaxial network design. (See Figures 13 and 14.) This functionality of the LNA may ultimately be integrated into a home server or point of entry device.

4.3 Parallel Coaxial Network Design

An interim step to increasing bandwidth on the return path is the deployment of parallel coaxial plant with amplifiers directed upstream. (See Figure 15.) Access to the parallel coaxial transmission facilities will be provided to subscribers desiring interactive services. This will minimize the noise funneling effect on the return path.

4.4 Local Distribution Transport Protocols

One protocol that shows promise is the IEEE 802.6, DQRAP. While this protocol is in the development stages, it appears to be far more efficient than Ethernet for the tree/branch topology with multiple points of contention. Each branch on the tree/branch topology is a single point of contention. The drop appears as a LAN connection to the bus infrastructure. DQRAP is a slotted protocol that allows multiple attempts without denying access to all users attempting to access the network in the same time slot. This protocol promises to support the delivery of video entertainment and other information services from the headend to the home, on an end-to-end basis.

Since DQRAP is a physical layer protocol, it may well provide the necessary physical transmission functionality needed to support ATM. As was pointed out earlier, lost cells are likely to enter into the use of ATM over the tree/branch, coaxial network, either in a passive or active coaxial infrastructure. The loss of cells should be negligible in the hybrid fiber/coax distribution. While ATM may be a useful protocol higher up in the infrastructure, use of ATM over DQRAP will require further analysis to determine the feasibility over the tree/branch, coaxial component of the local distribution.

Migration of ATM into the local distribution of a cable network is dependent on technical and economic considerations. Even more important, when traffic that is fixed bandwidth, constant bit rate, is dominated more by variable bit rate, bursty applications, it begins to impact the traffic congestion and contention on the infrastructure. Initially, ATM is likely to be implemented on the regional hub dual ring for PCS and multimedia applications and the virtual private ring network for business applications. However, the use of ATM for voice remains an issue due to packet fill and corresponding delays in transmitting voice in a fast-packet environment.

4.5 RADs at Fiber Hubs and Nodes

The fiber hub and fiber node are candidates for housing a remote antenna driver (RAD) in the cable network. The RAD is a distributed radio antenna technology that provides service to PCS cells. The RAD design takes advantage of bandwidth on the cable infrastructure while centralizing complexity higher in the cable infrastructure at a remote antenna signal processor (RASP) or base station translator. This approach allows the cable operator to deploy these RADs at locations like the fiber node without the distributed complexity used in other approaches to PCS.

4.6 Fiber to the Fiber Node

As it becomes more economical, fiber (4 to 10 fibers in a sheath) will be deployed from the fiber hub to the fiber node, with each fiber node serving no more than 200 homes passed. Since the fiber hub and fiber node do not have switching or multiplexing functionality, no concentration of transmission facilities currently exists at the fiber hub, with each fiber hub serving approximately 2,000 homes passed. As a result, 40 to 100 fibers transit from the fiber node to the headend

Eventually, as the traffic migrates from a predominantly fixed bandwidth analog network to a hybrid analog and digital network with variable-bit-rate, bursty transactions, some form of switching may be distributed to the fiber hub or fiber node from the regional hub or headend. As a result, concentration may be used that would free up many of the fibers between the headend and the fiber hub for other applications, including the virtual private ring network for business access.

4.7 Distributed Switching

Studies indicate that most of the calls made in the local distribution of the PSTN do not go beyond the area served by a remote switch. As the demand increases for new applications, such as PCS and wired telephony, distributed switching will need to be deployed at the fiber hub or fiber node in cable's infrastructure to support these call patterns.

5.0 INTERFACE REQUIREMENTS

CableLabs is represented on various American National Standards Institute (ANSI) work groups and other fast-track standards organizations that establish the appropriate interface standards for multimedia and PCS.

Before multimedia becomes a common fixture in our society, the single most important attribute to be addressed is an interface platform that must be simple and transparent to the end user. Currently, a proliferation of interfaces exists in the computer, consumer electronics, and information provider industries.

The initial interface from cable network to multimedia applications may be through a data port on the set-top converter. A more desirable approach to this interface, as far as the cable operator is concerned, will likely be some form of multiport, such as an IS-15 protocol approach, which is integrated into the back of the computer system or the consumer electronics device.

For the computer industry, the transport provider should focus on interfaces that already exist and are well understood. CableLabs' focus will initially be on the attributes of the physical, data link, and network layers in an effort to position for whatever interface standards may be adopted for multimedia applications. However, it will be necessary to understand the transport layer and other higher layer attributes relative to specific applications. This will ensure that cable is compatible with multimedia interfaces as they are defined.

MPEG may play a significant role in simplifying the interface requirements for multimedia applications. The series of MPEG standards addresses digital compression and decompression relative to motion picture and audio source used in computer systems.

A common air interface for PCS will be required and is being developed by standards organizations (Telocator, T1A1, T1E1, T1P1 and WIN Forum) of which CableLabs is a member.

6.0 REGIONAL HUB FIELD TESTS

CableLabs regional hub field tests are structured as a series of small tests. They will examine the following:

- redundancy levels on the dual ring facility and possibly on the equipment in the regional hub
- measurements of distance limitations
- coupling of rings
- delay, echo, and frequency shifting at the headend
- the need for amplification on the dual ring
- throughput capabilities
- bandwidth requirements
- measurement of BER
- security, and other relevant tests.
- evaluation of the number of nodes that are achievable on a ring using frame relay
- analysis of a series of protocols

Another important aspect of the field tests is to show that the architecture is independent of the transport medium but that transport is dependent on the bandwidth requirements of the various applications. As part of this experiment, compressed digital video will be tested through a microwave link. The following list summarizes field tests scheduled for 1993.

6.1 Boston

The Boston regional hub which will be used in testing consists of a fiber link that is soon to be upgraded to a SONET fiber infrastructure. It will serve as the backbone for the field test. The field test will focus on advertisement insertion, centralized PCS switching, and cable-commuting applications.

The potential participants of this field test include Continental, Time Warner, TCI and Cablevision Systems. The advertisement insertion test will involve insertion of advertisement into existing programming from a regional hub to one or more headends. The switching for the PCS field test would use the Teleport 5ESS with base stations placed on the Continental and Time Warner systems. Another application will address cable-commuting, using DEC and LANCity equipment to provide a 10 Mbps Ethernet link over an existing 6 MHz channel.

These applications are directed toward validating the interactive capabilities of the dual ring infrastructure coupled with two or more headends linked to a centralized switching facility on the ring or coupled to the ring.

6.2 Northeast

The field test activity tentatively slated for the Northeast will test the notion of tightly coupled rings, and the use of SONET as a physical layer transport with specific attention directed toward the add/drop capabilities of the SONET equipment. Another possible application will include advertisement insertion. One potential candidate for this test is Adelphia and their CAP affiliate, Hyperion.

6.3 Seattle

Potential cable participants for a field test in the Pacific Northwest later this year are TCI and Viacom. Because TCI and Viacom already have established a separate entity to provide advertisement insertion, this appears to be an excellent location to test this functionality on the rings.

The rings transit over the greater Seattle area and interconnect TCI and Viacom. The ring transport is likely to be provided by a competitive access provider, as yet undetermined.

The topology will consist of two rings tightly coupled at a point in north Seattle. One ring will cover the region around Lake Washington. The other will provide the transport between Snohomish County and the city of Seattle.

6.4 Toronto

CableLabs and Rogers are currently examining the possibility of testing centralized network management for the dual ring infrastructure and the local distribution on an existing cable system. Another likely candidate would be advertisement insertion.

7.0 RESULTS OF THE REGIONAL HUB FIELD TESTS

The initial field test results will be evaluated by CableLabs staff and the CableLabs Technical Advisory Network Development Subcommittee. After a thorough analysis, the data will be made available to CableLabs member companies.

8.0 AREAS OF FUTURE FIELD TESTS

Future tests will include the following areas: the migration of fiber from the hub to the node, the virtual ring for route diversity between the headend and fiber hubs, and the virtual private ring for business access and interconnection of the regional hub to other networks, such as interexchange carriers, local exchange carriers, and private networks.

9.0 CONCLUSION

Cable's next generation network architecture will provide a uniform structure for migrating network designs. While the migration path may differ from one cable operator to another, ultimately it will provide a common structure that will serve to position cable for future revenues and business opportunities. It will allow cable to increase functionality and reliability, to eliminate active components in the coaxial plant, and to migrate functionality to a lower level in the network hierarchy as demand increases.

The regional hub concept allows rapid prototyping of new services, shared investment and benefit, uniformity of network access for large and small operators, and interoperability with other networks.

With the migration of fiber into cable network designs, improved reliability and signal quality and increased capacity are yielding many opportunities to transport new applications and to explore many new business opportunities.

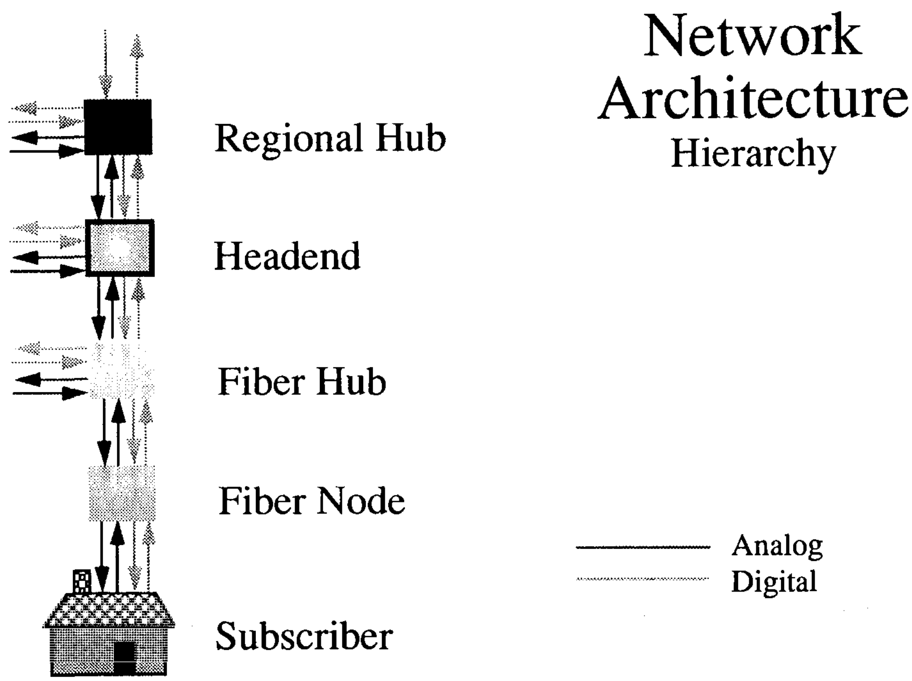


Figure 1

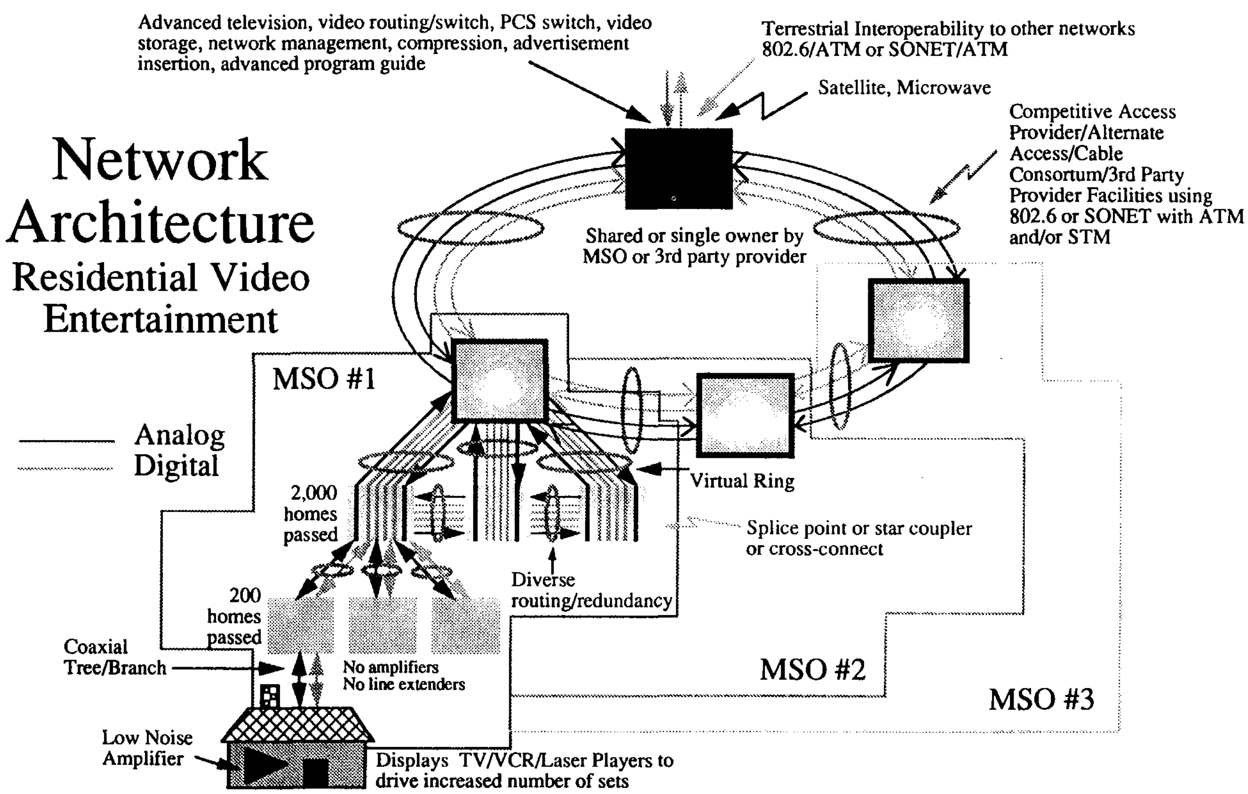


Figure 2

Network Architecture

Regional Hub Concept

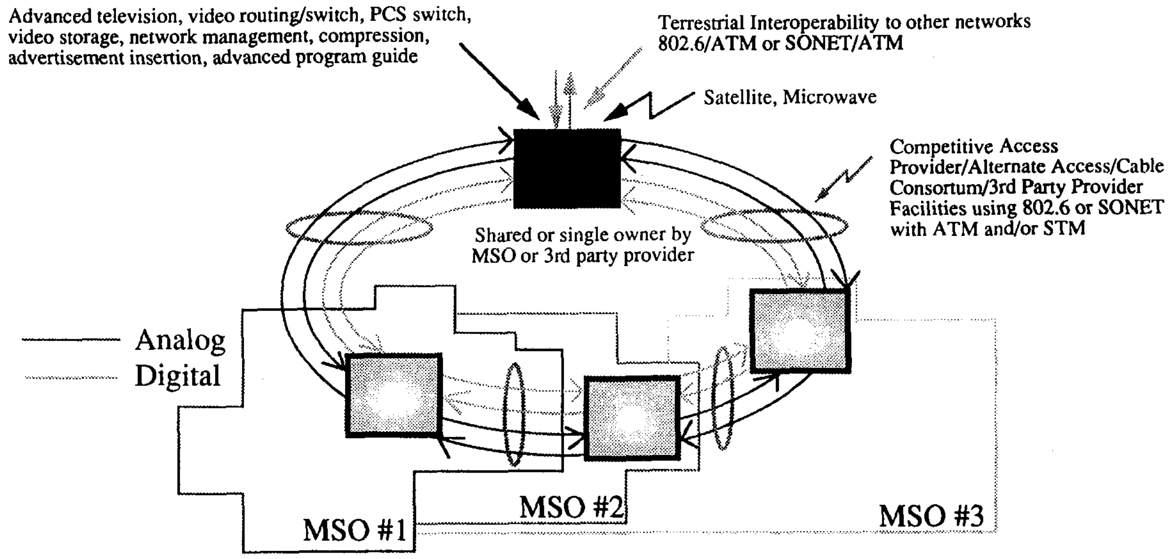


Figure 3

Network Architecture

Systems Redundancy

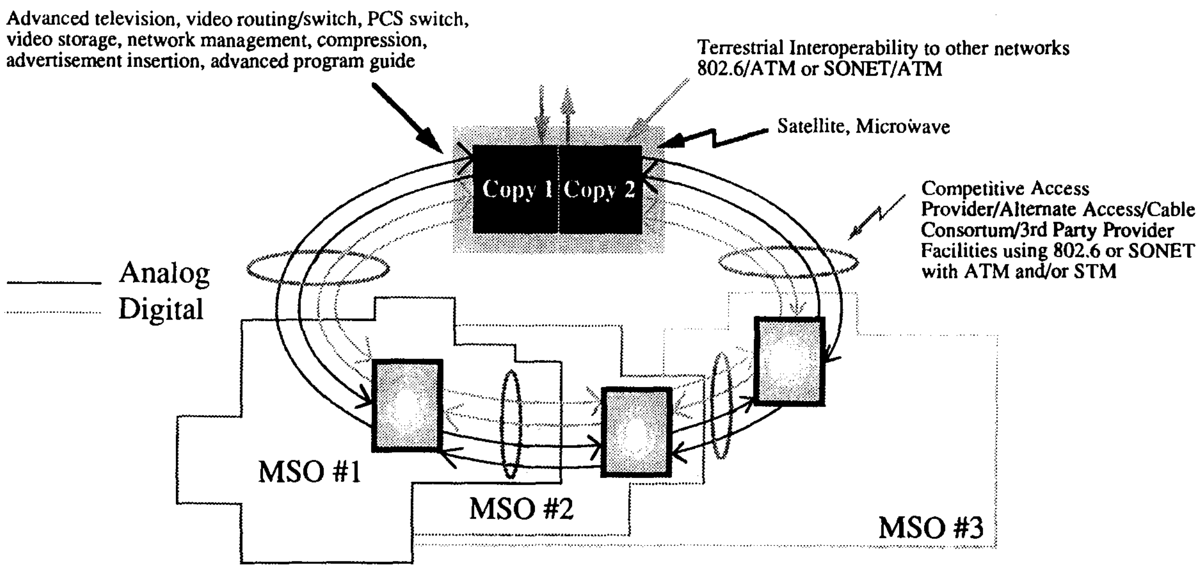


Figure 4

Network Architecture

Regional Hub Distributed Redundancy

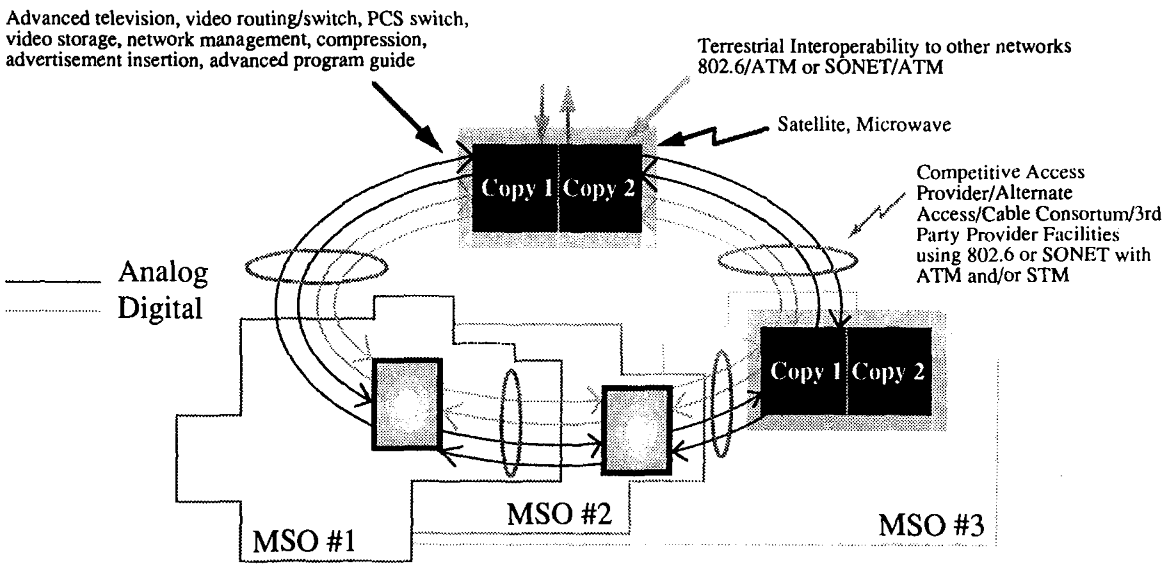


Figure 5

Network Architecture

Regional Hub Gateway

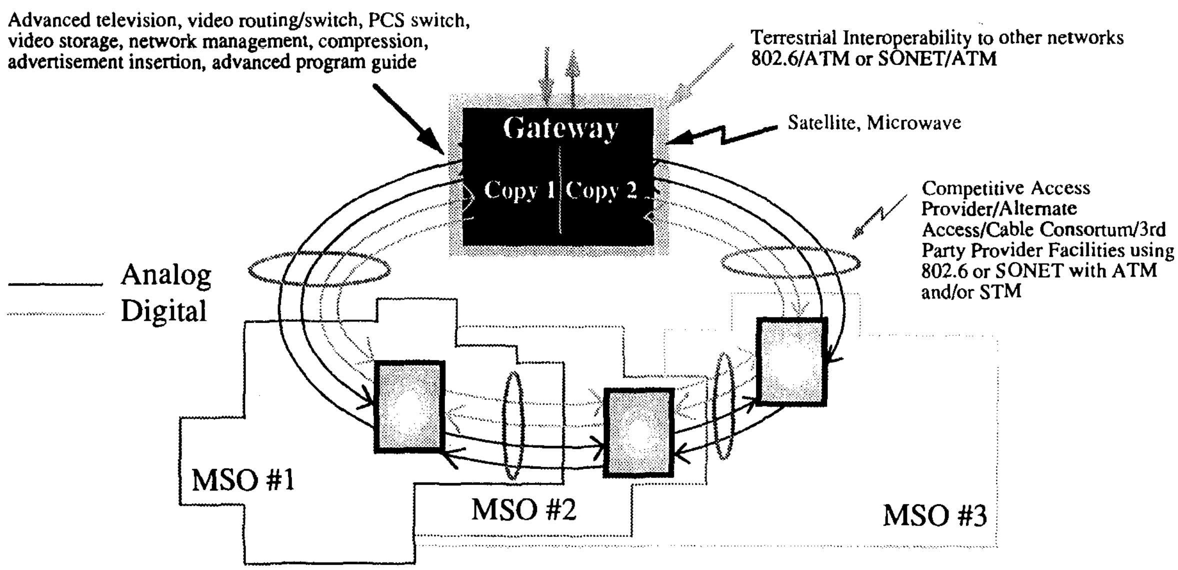


Figure 6

Network Architecture

Coupled Rings

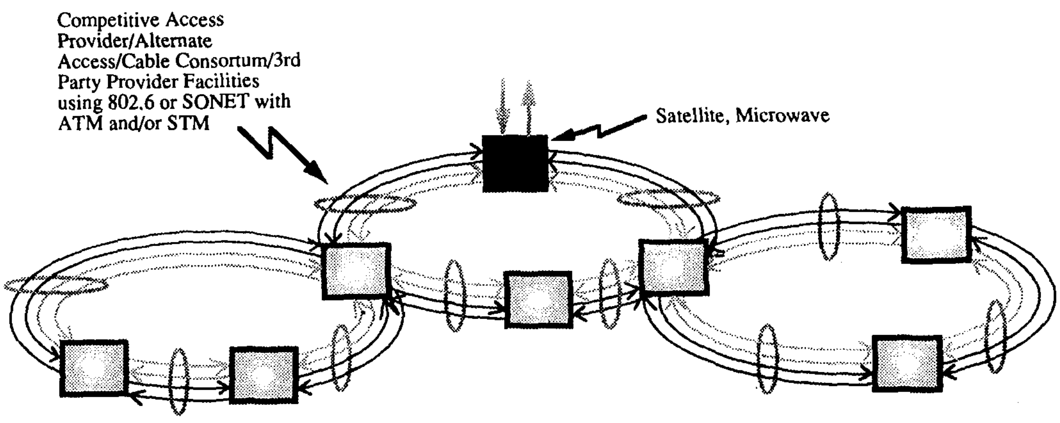


Figure 7

Network Architecture

Avoiding Single Points Of Failure

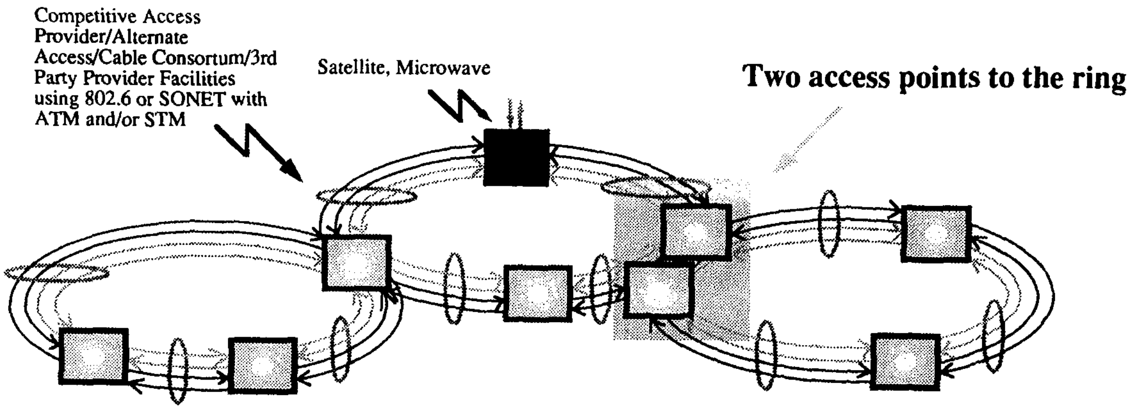


Figure 8

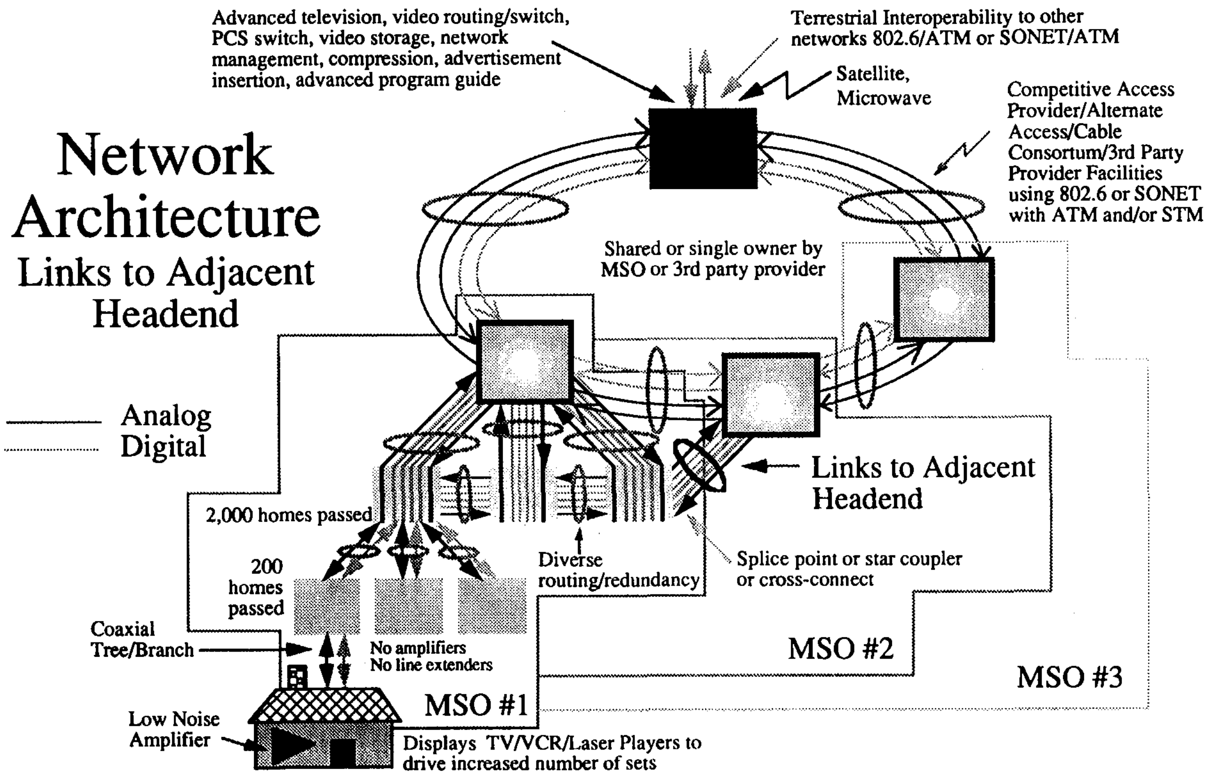


Figure 9

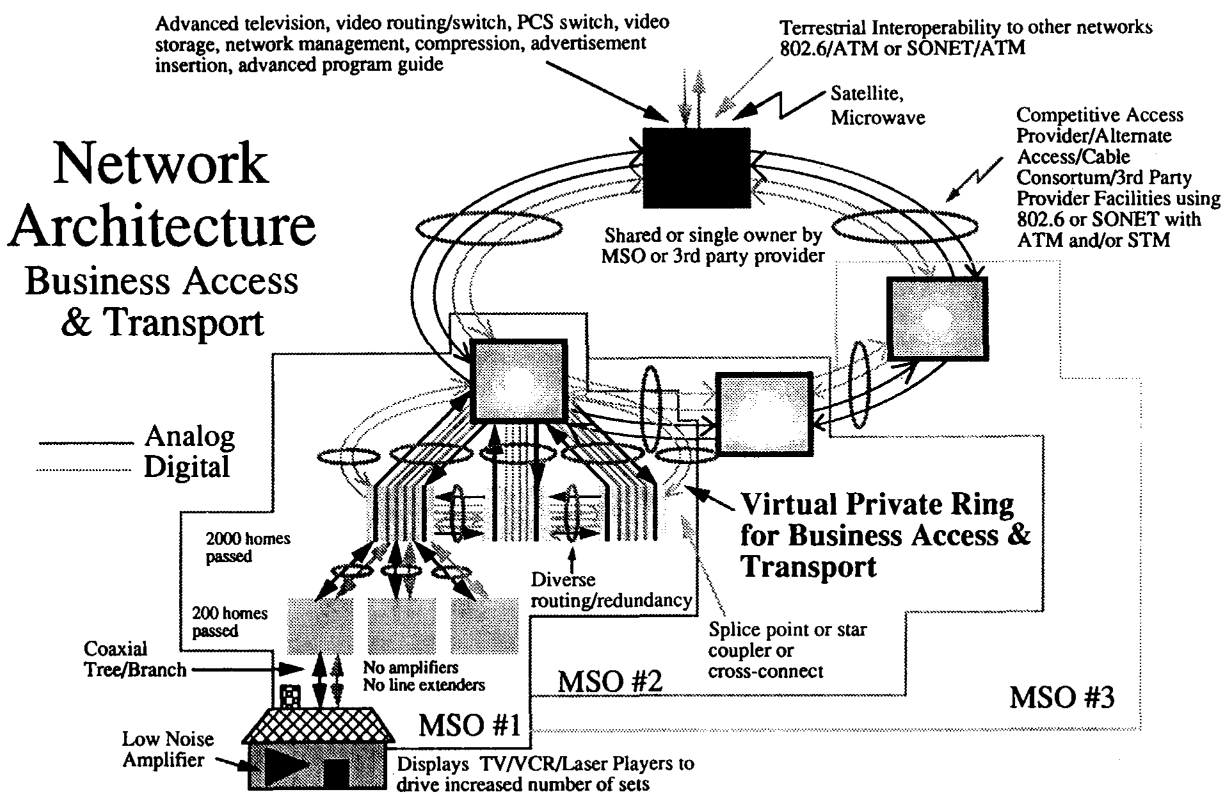


Figure 10

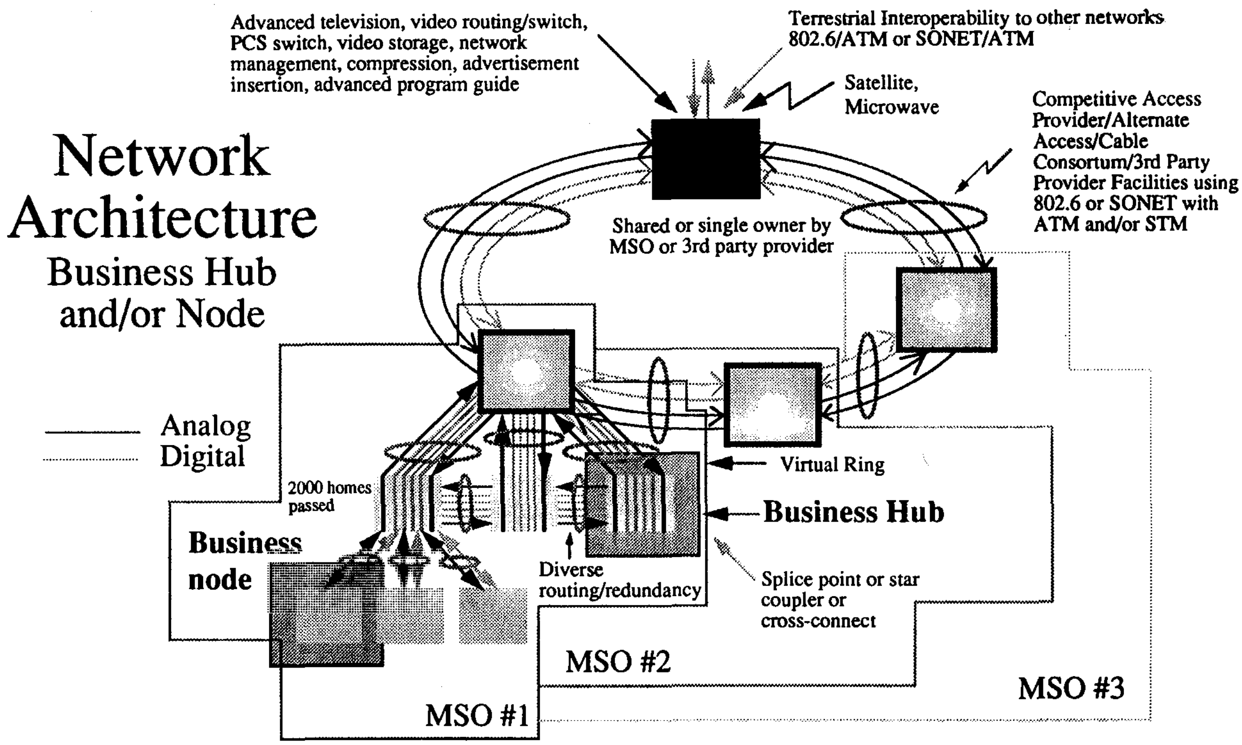


Figure 11

Network Architecture

Network Migration - Existing

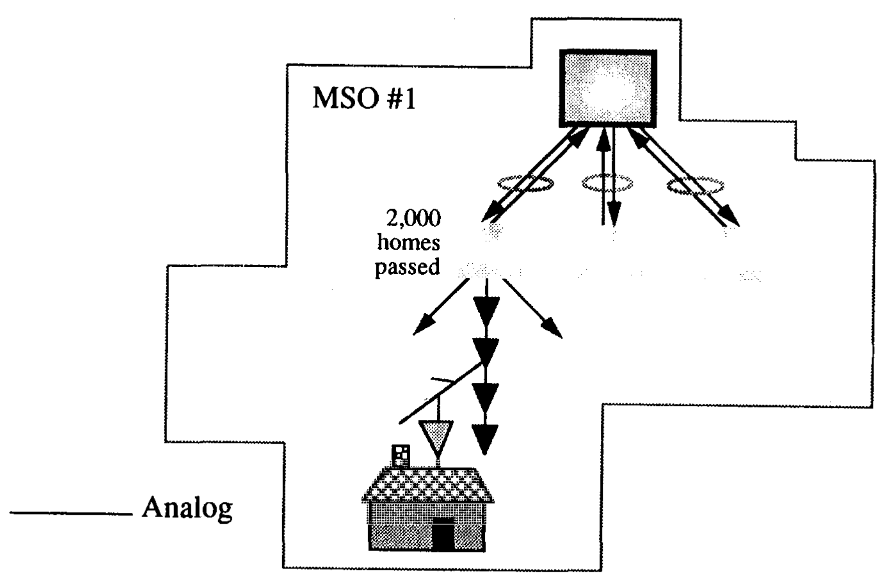


Figure 12

Network Architecture
Passive Coaxial Network Design

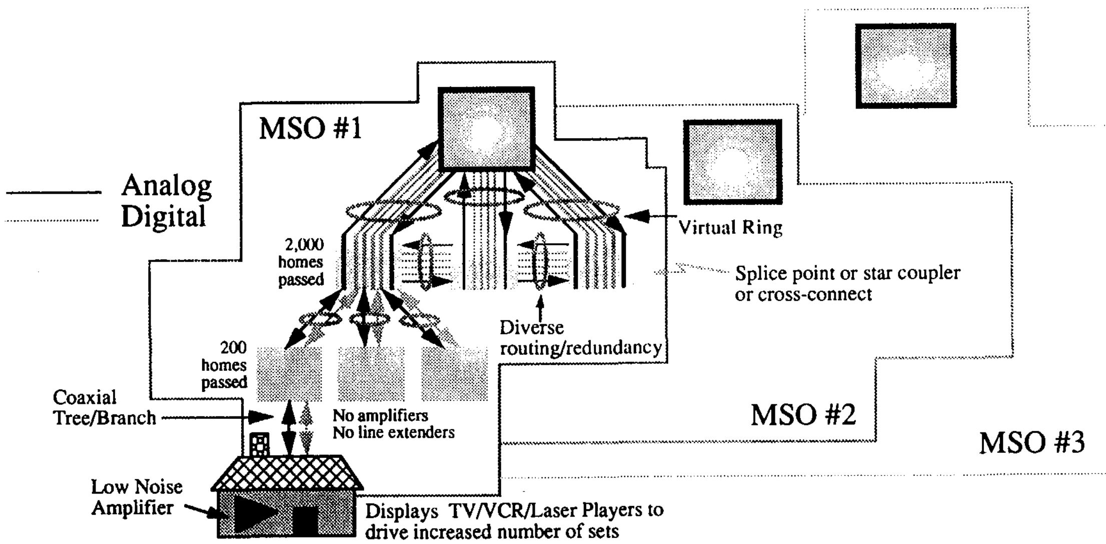


Figure 13

Network Architecture
Network Migration - Passive Coaxial Design

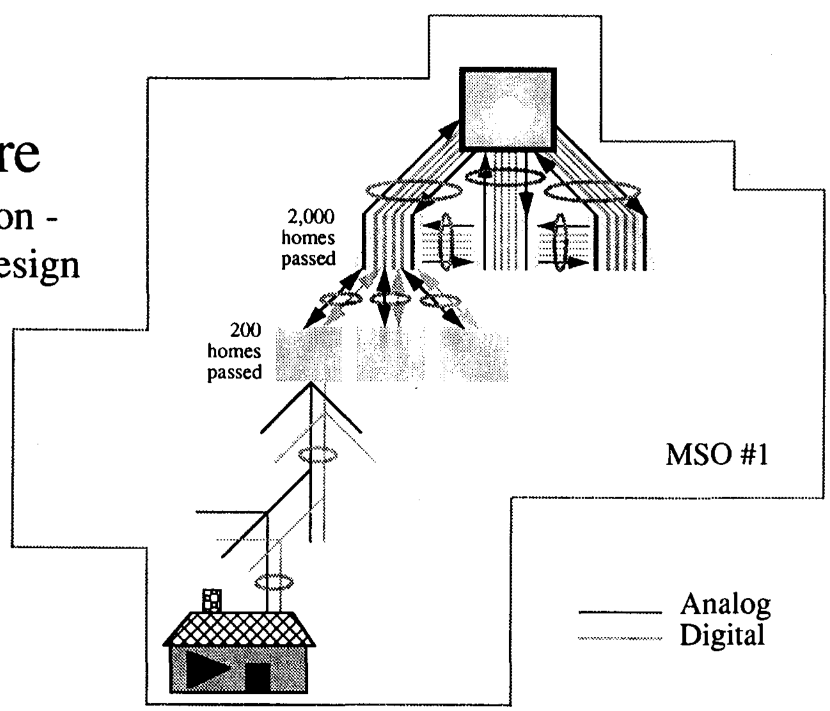
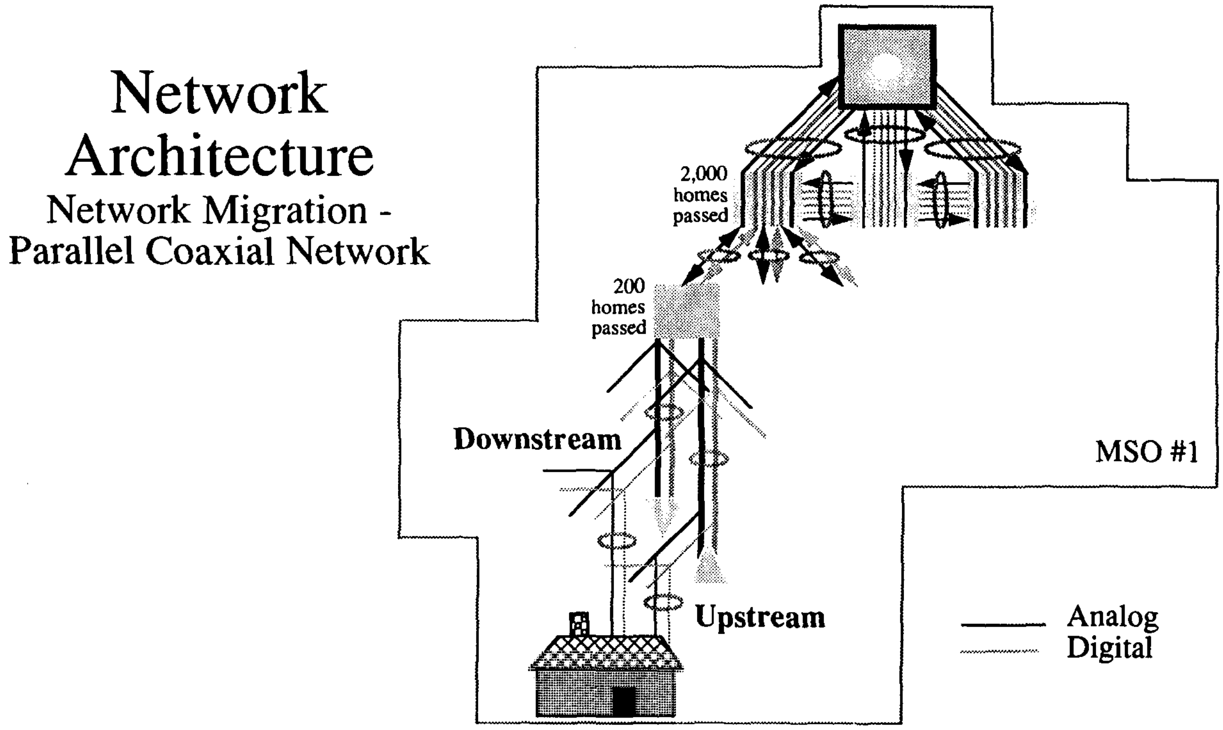


Figure 14



Network
Architecture
Network Migration -
Parallel Coaxial Network
2,000
homes
passed
200
homes
passed
Downstream
Upstream
MSO #1
Analog
Digital

Figure 15

PERSONAL CABLE TELECOMPUTING
enabled by
COMMUNITY MULTIMEDIA
NETWORKING

Jim Albrycht
Digital Cable Television
Digital Equipment Corporation
Maynard, Massachusetts 01754

Abstract

The cable television industry is capable of being a full telecommunications provider as it evolves it's infrastructure into an all digital highway. Both the telephone and computer industries are suggesting their networking models of traditional point-to-point and extended distributed local area network technology become part of the cable industry solution.
- *CATV is positioned to create the multimedia networking model for the '90s as a...*
- *Full Telecommunications provider...*

This paper looks at a computer network model interconnecting integrated personal cable modems with personal computers and television systems in a community setting within the Digital Community Multimedia Networking Architecture (CMNA).

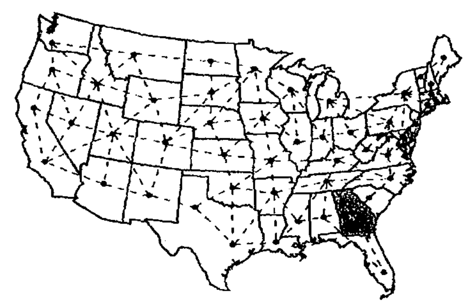
THE DIGITAL INFORMATION HIGHWAY

The next generation cable television broadband networks are taking over where traditional data communications solutions leave off. They are operating with the widely available installed base of broadband cable television coaxial and fiber optic cable plants.

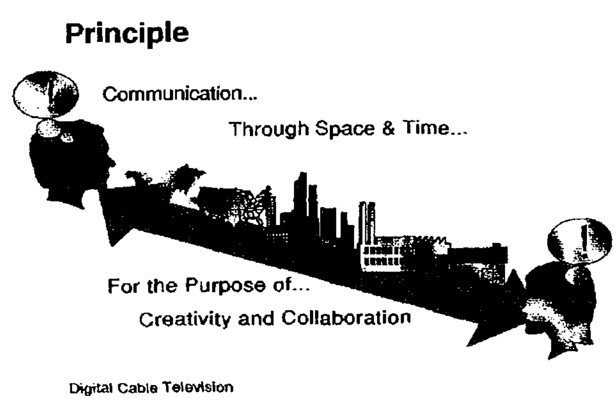
Subscriber systems are using any available standard cable television channel pair for 2-way communications networking, with intelligent modems interfacing to standard computers and networks.

In most cable franchises the number of capable return channels is limited within entertainment networks, thus 2-way capacity must be managed effectively until fiber is justified and deployed deeper into the plant. This paper looks at providing a complete mix of interactive digital data, voice and video information referred to as multimedia services into the same 6 MHz channel, thus enabling the maximum utilization of the installed base of

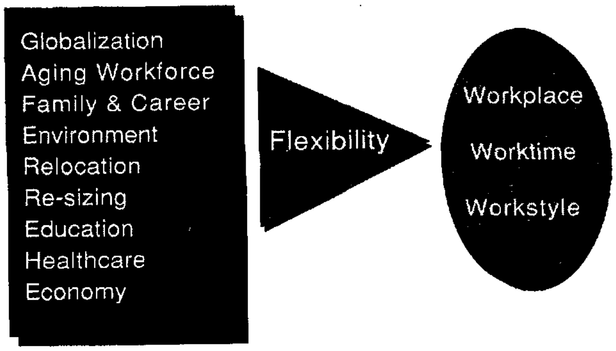
INFORMATION HIGHWAY



(⊙ MAN BY CATV — WAN BY TELCO = CABLCO INDUSTRY) UP TO 1000 TIMES BETTER



Societal Trends

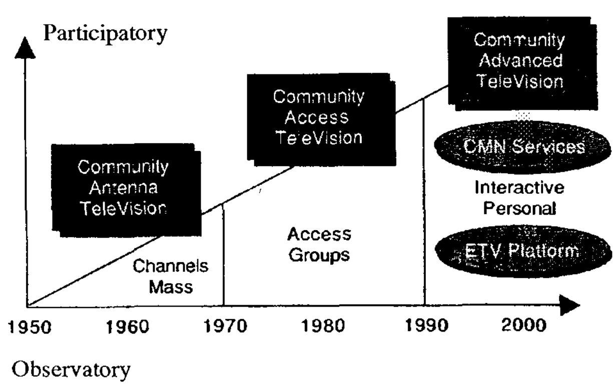


Digital Cable Television

return bandwidth with a wide range of new and diverse revenue streams.

The Community Multimedia Networking Architecture enables Personal Telecomputers to be added to the distributed 2-way cable network, with the ease of traditional televisions and videotape machines, while being registered and configured like personal computers as members of the networked community with digital capabilities.

CATV Migration



ETV - Ethernet via Cable Television

FULL TELECOMMUNICATIONS PROVIDER

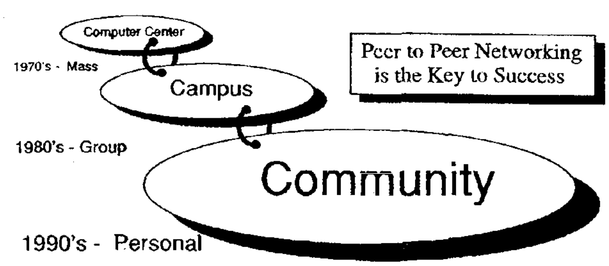
The cable television industry is capable of being a full telecommunications provider as it evolves it's infrastructure into an all digital networking platform. This new advanced infrastructure has become the platform for all previous cable, telephone and computer network information applications and services which currently exist.

Flexibility

This network platform is exhibiting the needed flexibility to support many unknown future service possibilities while meeting these important, responsible and necessary goals today.

Vision Migration

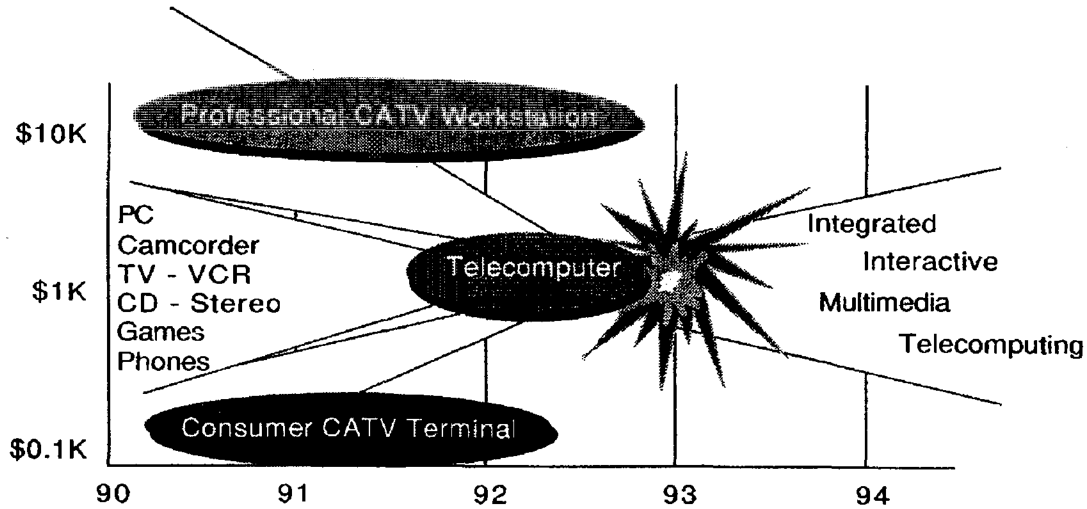
We have arrived at a convergence of technologies which has created an opportunity to extend the computing infrastructure all the way to the ultimate beneficiary.



Integrated Model

Both the telephone and computer industries are suggesting their networking models of traditional point to-point and extended distributed local area network technology can be enhanced as part of the cable industry broadband transport solution to a full multimedia networking information highway. An integrated network model that enables current and future solutions with standard interfaces for seamless connectivity will be needed to network technology of the past with technology of the future.

Community Multimedia Convergence



Digital Cable Television

COMMUNITY SETTING

This paper looks specifically at a computer network model interconnecting integrated personal cable modems with personal computers and television systems in a community setting.

Information Islands

Today, there are islands of information in the form of corporate, educational, and healthcare campuses which have extensive information processing, storage and networking capabilities. The opportunity exists to extend, expand and connect these islands into a more contiguous and ubiquitous infrastructure providing services to more people "off-campus" by utilizing CATV system as an information highway. The integration of computer, telecommunications and cable television technology models enables new personalized community based networking.

OPTIMIZING RESOURCES

The utilization of any cable plant bandwidth must be managed with optimization of technical resources with program streams and revenue flow in a timely fashion.

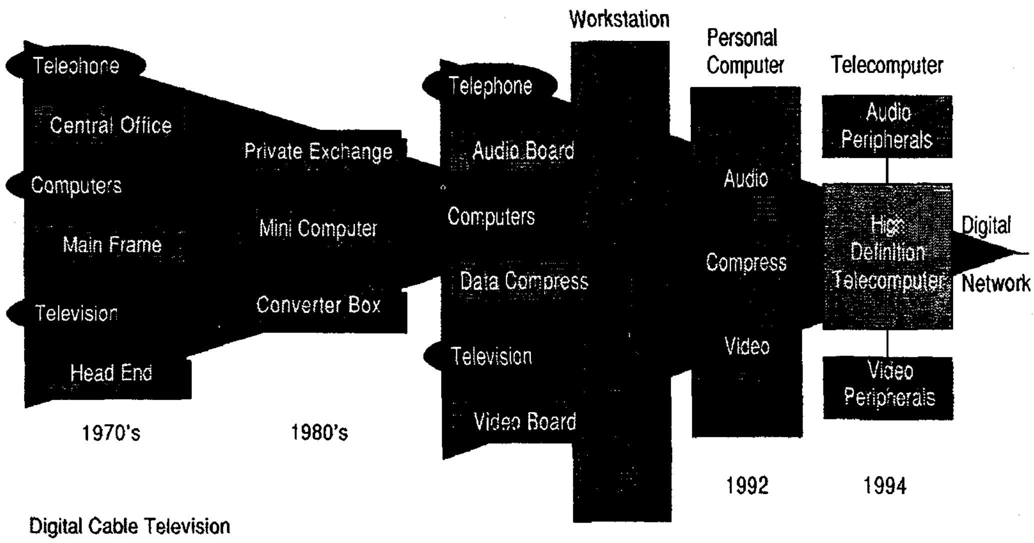
Telecomputing

Both network and systems hardware and software are optimized to enable highly integrated intelligent interactive personal telecomputers to operate throughout the community across the coaxial and fiber optic cable, under full management of the cable operator. Management systems monitor and maintain the digital traffic flow among the systems across the network, while having fully secured visibility of tiered and transactional services selected by the subscriber.

Diverse Revenue Streams

Increasingly more highly intelligent system and network hardware and software components at consistently decreasing costs through the use of very large scale integrated circuits is enabling broader configuration flexibilities with concurrent decreasing operational complexities, while at the same time generating more revenue.

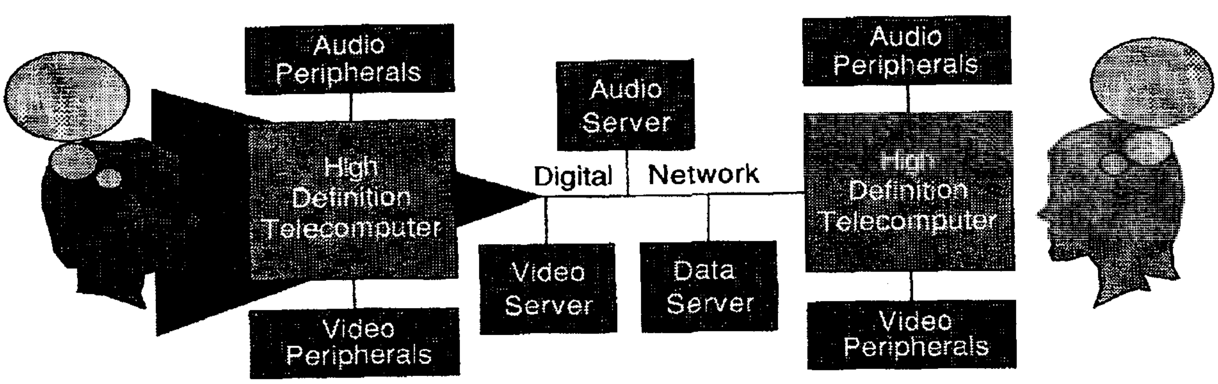
Community Multimedia Migration



Individually Driven

Both network and systems hardware and software are optimized to enable highly integrated intelligent interactive personal telecomputers to operate throughout the community across the coaxial and fiber optic cable, under macroscopic management of the cable operator. While the cable operator has full management oversight of all of the necessary network entities, the individual subscriber has personal management oversight of his/her choice of network services on a continual rolling basis.

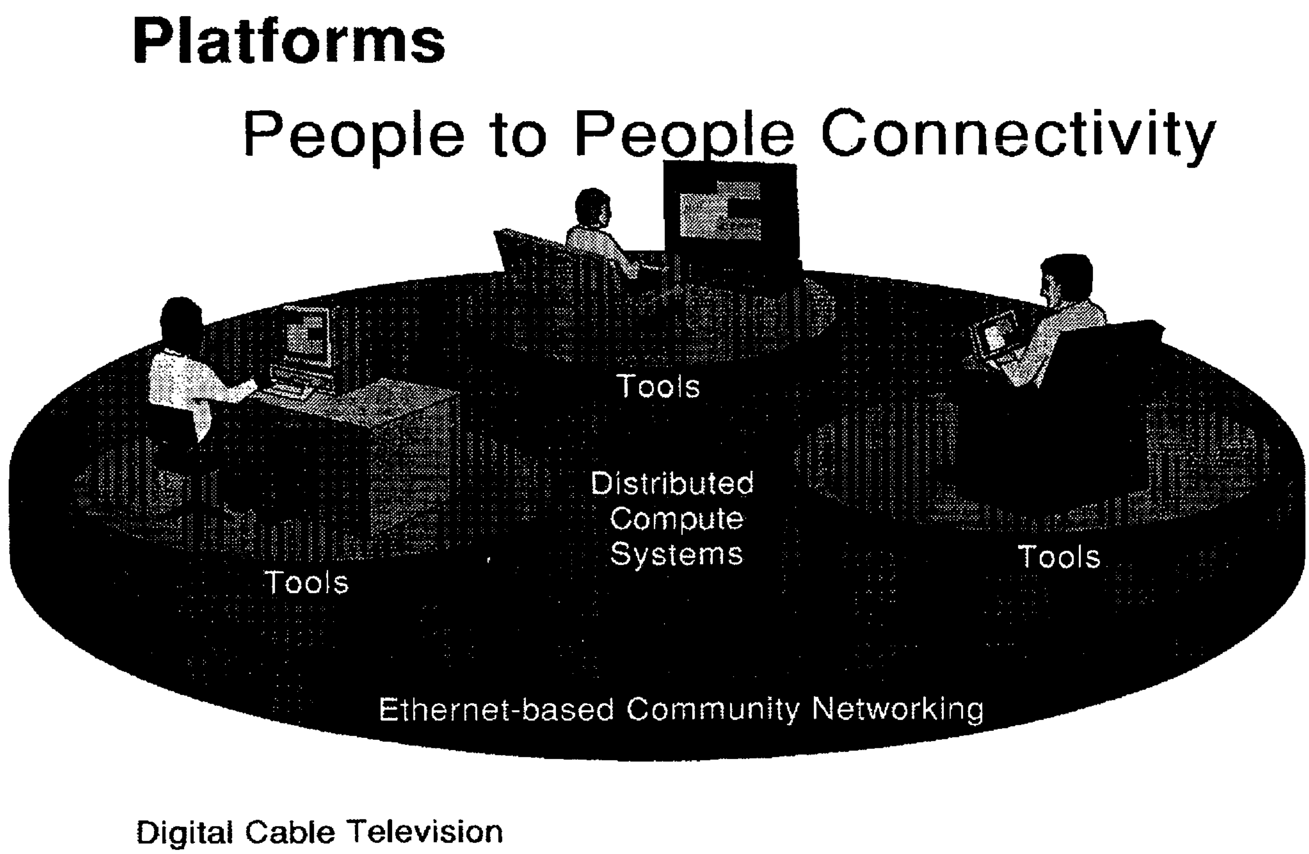
Community Multimedia Migration: Peripherals & Applications



Total Visibility

Management systems monitor and maintain the digital network traffic flow among the systems across the network, while having fully secured visibility of tiered and transactional migration of full revenue services. This is different from the traditional use of channels, where different analog/digital applications are programmed in different 6 MHz channels.

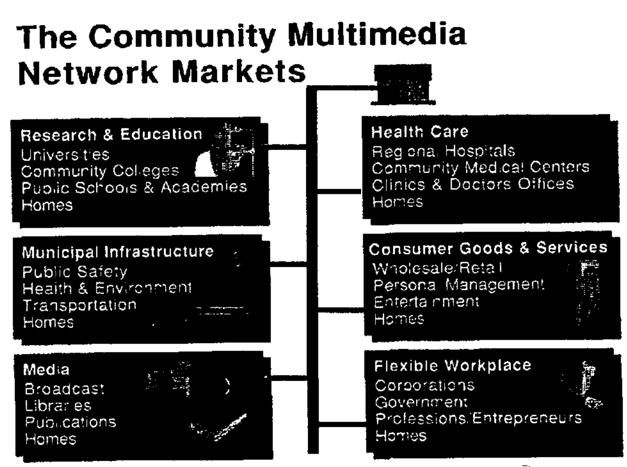
Through more and more computing power, a finer and finer granularity of channel usage

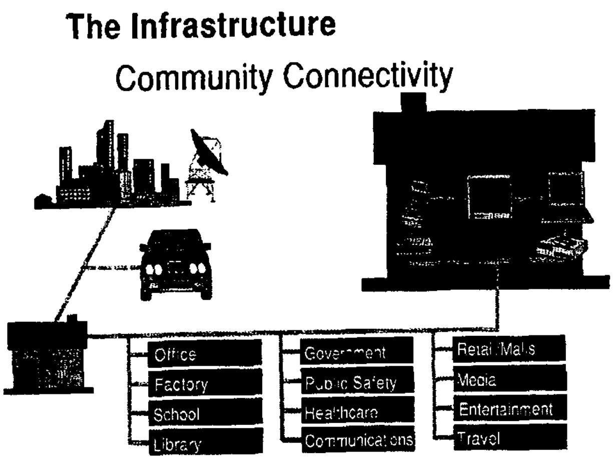


services selected by the subscriber. The networked services and applications selected by the subscriber are driven by the individual subscriber, who needs to know the type and how much of network resources are being utilized at all times and over a period of time. Network resource choices could be changed at anytime by the subscriber and with notification by the overall network manager.

Finer Granularity

As channels become fully utilized, then additional channels with the same mix of voice, video and data are activated with a continual can be managed, such that traffic flow can be optimized over various time-lines.





Digital Cable Television

CABLE-READY TELECOMPUTING

The Digital Community Multimedia Networking Architecture enables Personal Cable Telecomputers to be added to the distributed 2-way digital network with ease and operational friendliness.

Personal Networking

The focus on personal systems architecture is about simple user interface regardless of connectivity and not on the physical aspects of the connectivity components, where aspects are portrayed by software on Personal Computer (PC) screens.

Applications are based around networked pictures and sound with traditional data treated as secondary information, indicating multimedia networking.

The function of personalized system/networking itself is displayed on the configuration of the PC and emphasized through ease of operation and friendly windows.

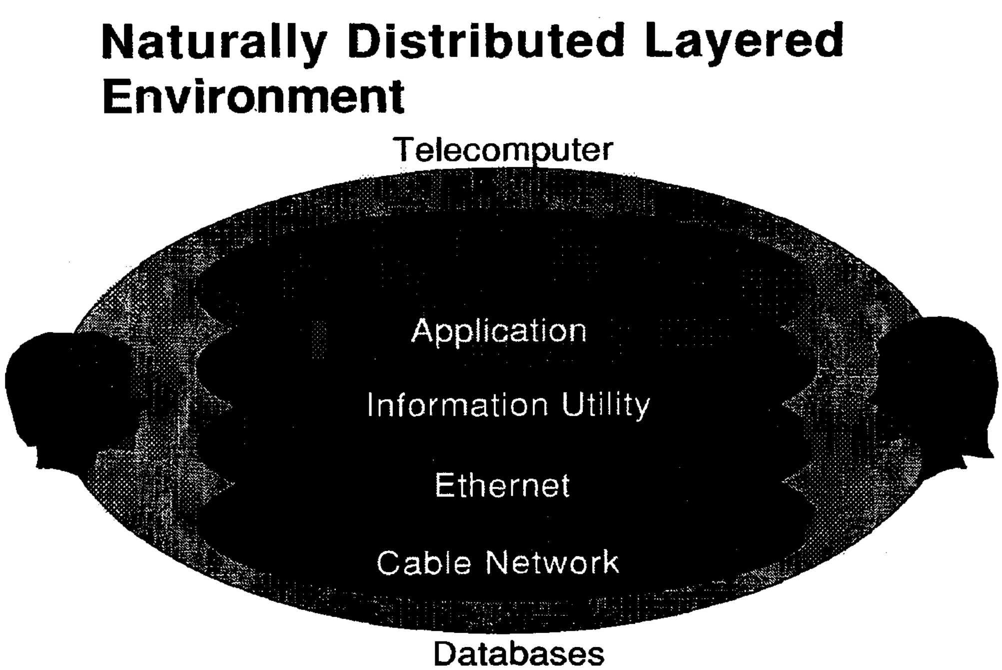
WHAT IS MY STATUS?

Future capabilities can include all aspects of management capabilities; specific functions would include what is going on across the network, from the network managers perspective and, what is going on with the individual's session from the node/subnetwork perspective.

How Am I Operating?

Examples include:

- What is my mode of network operation?



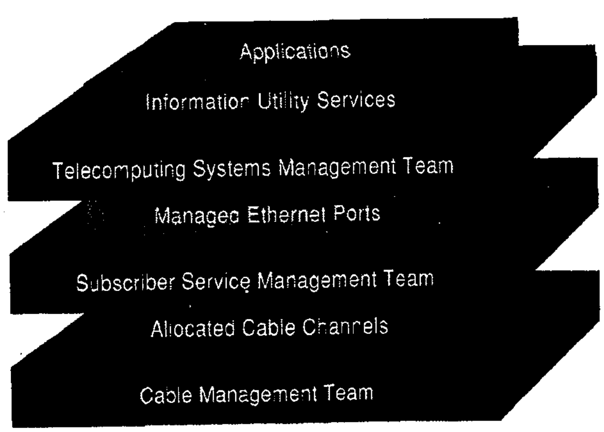
Digital Cable Television

• What kind of session do I have between me and my peer(s)?
• What is my bandwidth availability currently between me and my peer(s)?
• Am I operating on a dedicated link, or switched link, and will my link be torn down after my current session?
• How much data am I currently transferring, and how much data have I transferred during this session, this day, and this month?
• Can I afford to continue operating in this mode, or should I change to something different?

What Are My Costs?

Based on a set of arbitrary price tables:
• How much is this current session costing?
• How much is my bill so far for this month?
• How much will my bill be at the end of the month if I continue in this mode?
• What are my more cost effective alternatives?
• How much does contention, reserved and isochronous service cost, based on the bandwidth I need for my upcoming session that I have scheduled?
• What is the distance between me and my peers for this (planned) session?

Layered Management Teams

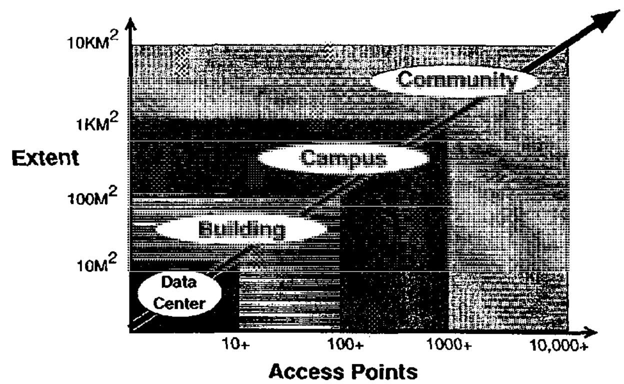


Digital Cable Television

• What is the best time for me to use the network based on my needs based on traffic and costs?

The above information could be gathered from each system and kept in the network management station(s), with read rights from the network manager and the individual subscriber.

10 Mbps LAN Expansion



INFORMATION ON DEMAND

Reading your applications needs, the cable network provides you with the economical bandwidth for your needs. Each node doesn't use more bandwidth/network resources than it needs from the network for a session. The primary icons from the system could be transferred to the applications of the PC(s) attached on the initial screens.

RETURN ON INVESTMENT

The cable industry needs to know which network services makes money. We not only want to optimize the cable plant in terms of 6 MHz bandwidth investment, but need to know which are the best configurations of traffic and times of usage.

Using the existing information highway created by CATV, it can deliver the entire data networking services of the '80s, plus video and audio networking services of the '90s as the key to multimedia networking.

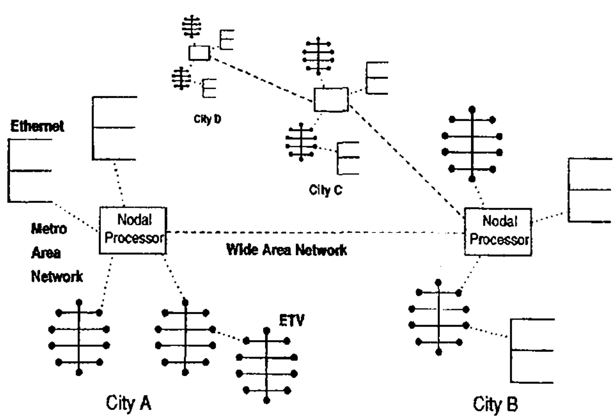
Parameters

Some of the primary parameters for cable optimization are: bandwidth use, time, distance, costs, traffic patterns, node addresses, etc., with statistics and probabilities, all things that computers are good at, while business people keep track of how to spend and make money.

Intelligent CATV Modems

New cable modem technology enable to take on the size and shape of traditional telecommunications modems. They can now: Fit in a briefcase, sit on top of a desk, hang from a wall, mount in standard racks, carry under your arm, and even become part of specialized outside environmental systems, as well as be part of PCs.

Community to Community Networking

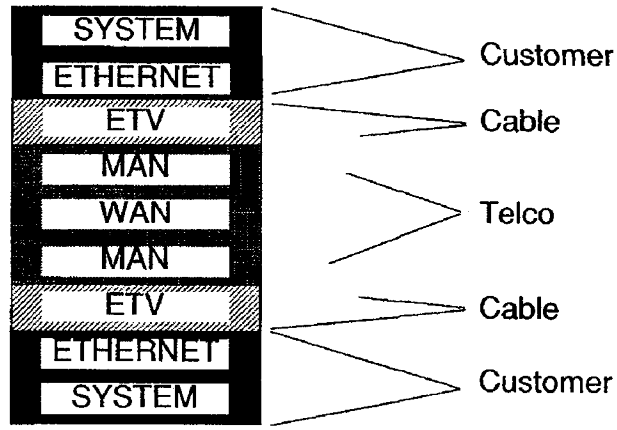


FULL SERVICE NETWORK

The Cable Television industry is capable of deploying interactive digital technology and is well positioned to be a "The Full Service Network".

- System built to enable full telecommunications cable services.
- System designed to provide a full range of multimedia services.

CMN Interfaces



- System designed for full concurrent integrated, a) digital data services, b) digital audio services, c) digital video services, around the current cable program streams.

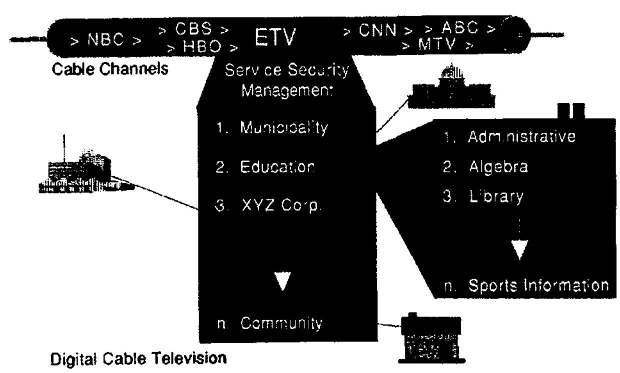
TRADITIONAL TELECOMMUNICATIONS SERVICES FOR CABLE

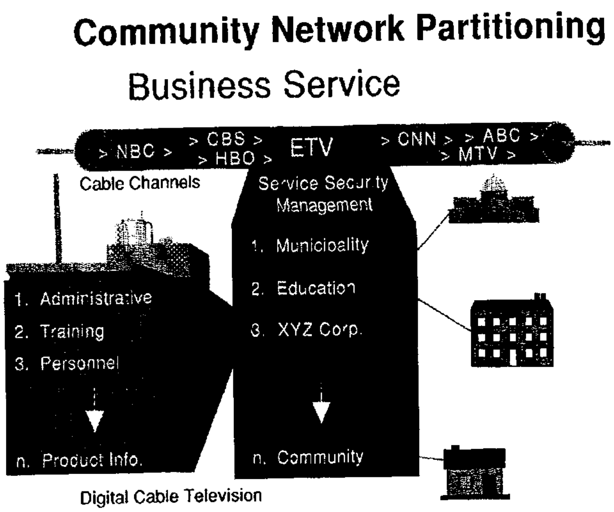
Cable television alternative solutions for telco data network solutions of 10 Mbps service up to 70 cable miles are available for public and virtual private circuit use provides;

- Point-to-multipoint dedicated polled circuits.
- Multipoint-to-multipoint dedicated/switched circuits.

Community Network Partitioning

Educational Management Service





TRADITIONAL COMPUTER NETWORK SERVICES FOR CABLE

Cable television alterative solutions for computer Local Area Network (LAN) solutions up to 10 Mbps service to 70 miles are available. Extended and seamlessly integrated existing institutional LANs across communities connect and extend institutional and community LANs to a Metropolitan Area Networks (MAN). These can:

- Create public and virtual private community networks.
- Create public and virtual private Metropolitan Area Networks (MAN).

BENEFITS TO THE CABLE TELEVISION INDUSTRY

Optimize the use of existing investment in coax and fiber cable bandwidth with a single 6 MHz channel in each direction enables full duplex 10 Mbps digital data highway.

10 Mbps 2-way highway provides integrated broadband transportation for:

- Traditional digital data..
- Digital sound, music, audio, voice.
- Digital pictures, images, video.

System designed for full multimedia networking for the cable industry for all community information needs, are available today, with the ability to form strategic partnerships between Telco and CATV industries. A Cableco relationship and these combined industries provides society with an affordable and full service worldwide solution.

Full functionality for cable

Concurrently on the same 10 Mbps 2-way digital highway a full range of traffic patterns are managed for optimized operations of switched/dedicated and public/private networking consisting of:

- Asynchronous traffic, for local large data loads, bursty, unpredictable access, guaranteed untimely delivery.
- Synchronous traffic, for long haul data loads with predictable, reserved access, regularly timed delivery.
- Isochronous traffic, for quality pictures and sound with guaranteed real-time precision delivery, with reserved access.

Bandwidth Scaling to Many Subscribers

Multiple 10 Mbps channels activated and interconnected via Ethernet subnetworks with full Spanning-Tree-Bridge (STB) capability enables parallel redundant data paths for self-healing configurations for traffic scaling/ management.

Full frequency channel agility under software control for receivers and transmitters in 250 kHz increments enables services for all channel allocation schemes.

Distance Scaling to Many Subscribers

Channel segment links extend to 70 cable miles, with additional 70 cable mile links concatenated through Ethernet 10 Mbps subnetworks. Links can be connected by modem at multiple points with cable topologies that will yield maximum reliability using the built-in STB technology.

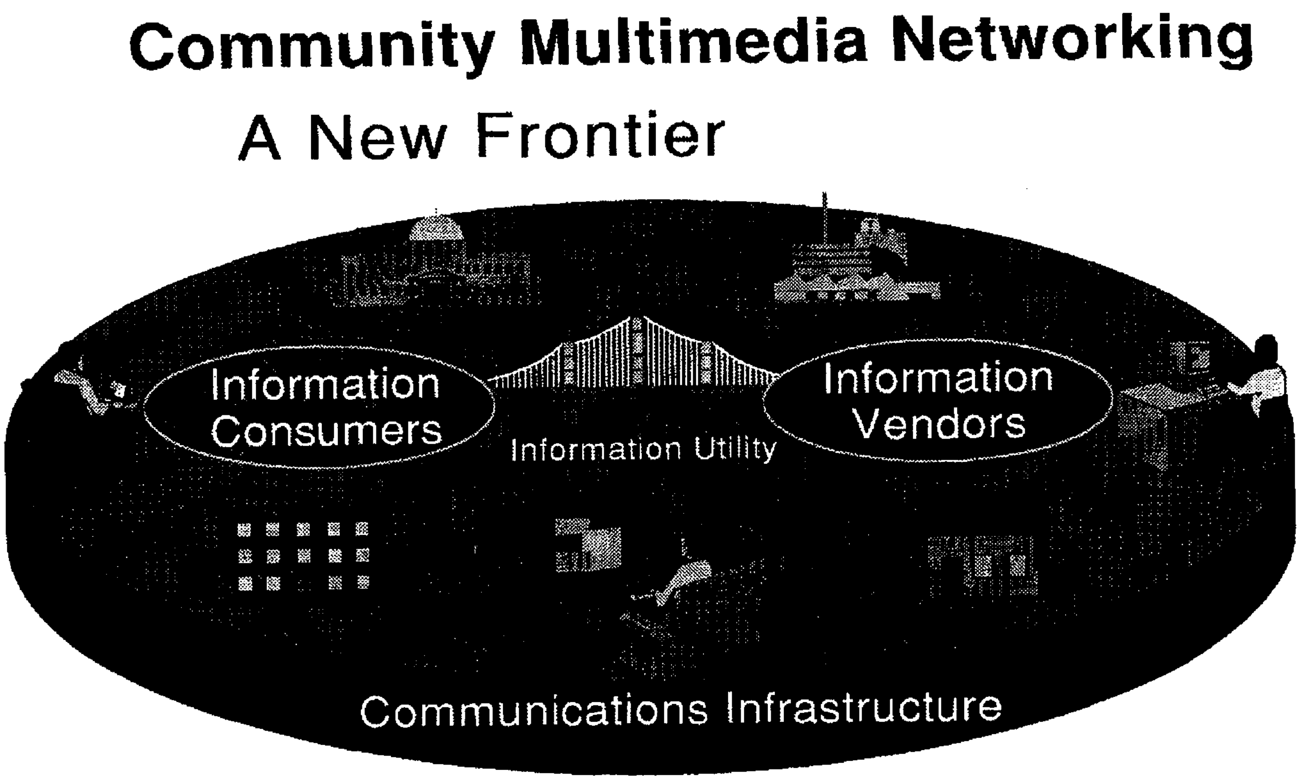
NETWORK/SYSTEMS MANAGEMENT

The cable network modem system is totally intelligent 10 Mips 20 MHz RISC computer processor based which:

- Knows all about itself.

eters easy to configure.

Operations help information is provided in hardcopy and softcopy discs with friendly help menus for ease of use. System is fully field replaceable with no component changes or adjustments.



Digital Cable Television

- Knows all about it's network peers.
- Network manager knows all about all network members.
- Doesn't know about it's network peers that it doesn't need to know about.

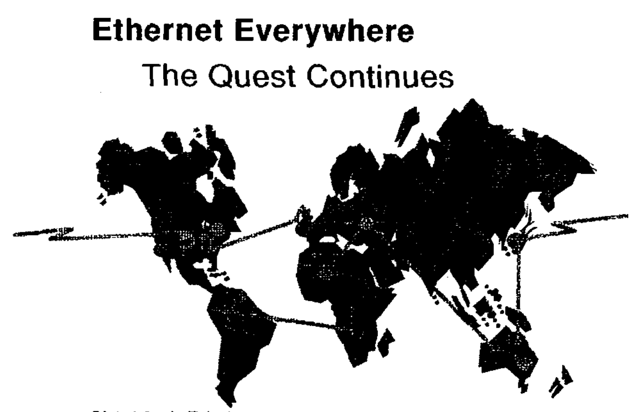
As all determined by the network manager.

System Configuration

Specific modem system personality provided is by personal computer serial port locally or via telecom modem from anywhere. System is activated via standard PC windows program utilizing check-list format with friendliness and simplicity. Channel frequencies, network addressing, security attributes and other param-

Network Configuration

Specific network personality is provided by a personal computer, either locally or via



Digital Cable Television

telecom modems from anywhere in a centralized or distributed operation. System incorporates standard SNMP (Simple Network Management Protocol). Network management is applied to the network via system modem-bridge through it's serial port or Ethernet port. All modem systems on the cable network are managed across the cable backbone in a nonintrusive virtual private circuit within the 10 Mbps stream.

The STB feature allows continuous management from multiple network directions. Global network operations center of choice can provide network management services as needed.

SUMMARY

The need for the Cable Television industry to become a full information network provider today, is a reality when utilizing the technology described in this paper. For over 10 years network technologists in the computer and cable industry have been working toward this end. The time has arrived with the convergence of technology development and societal trends to deploy broadband digital interactive cable television applications and services throughout communities everywhere. All elements are in place, and deployment is underway.

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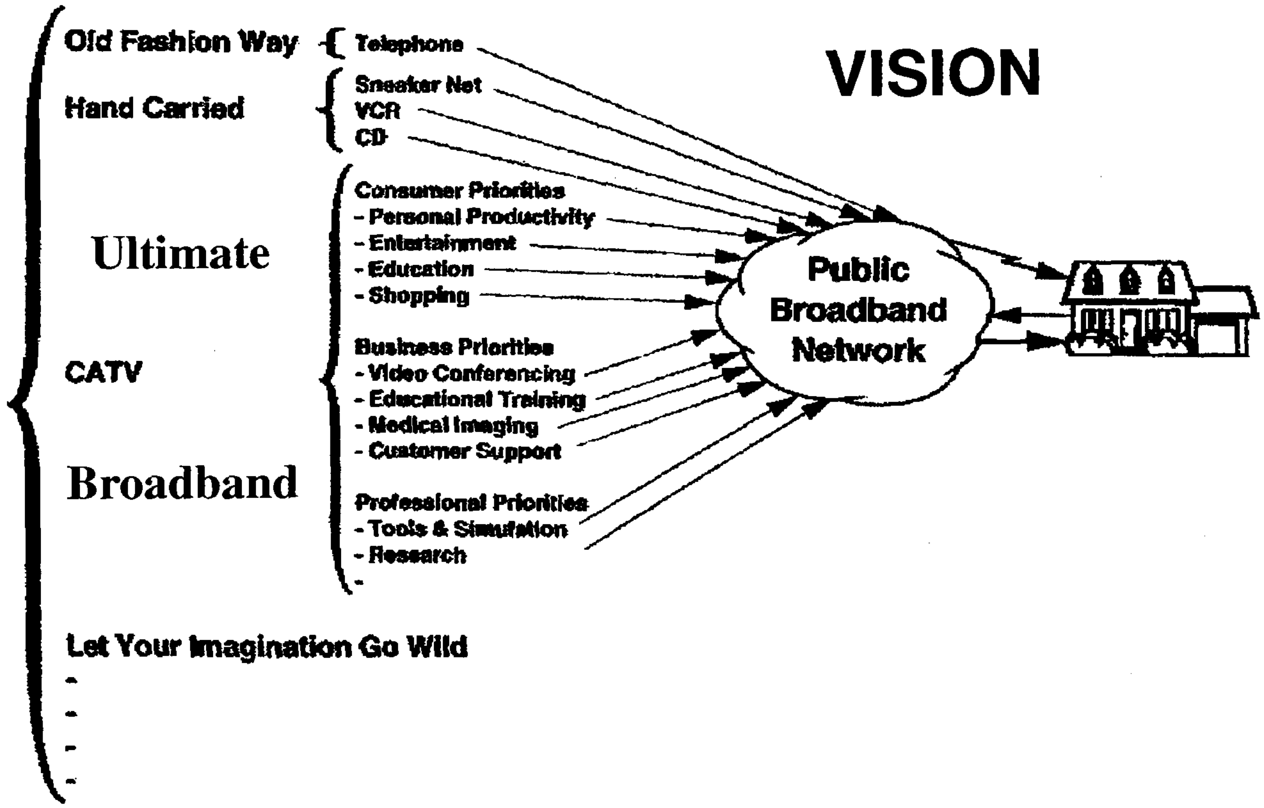
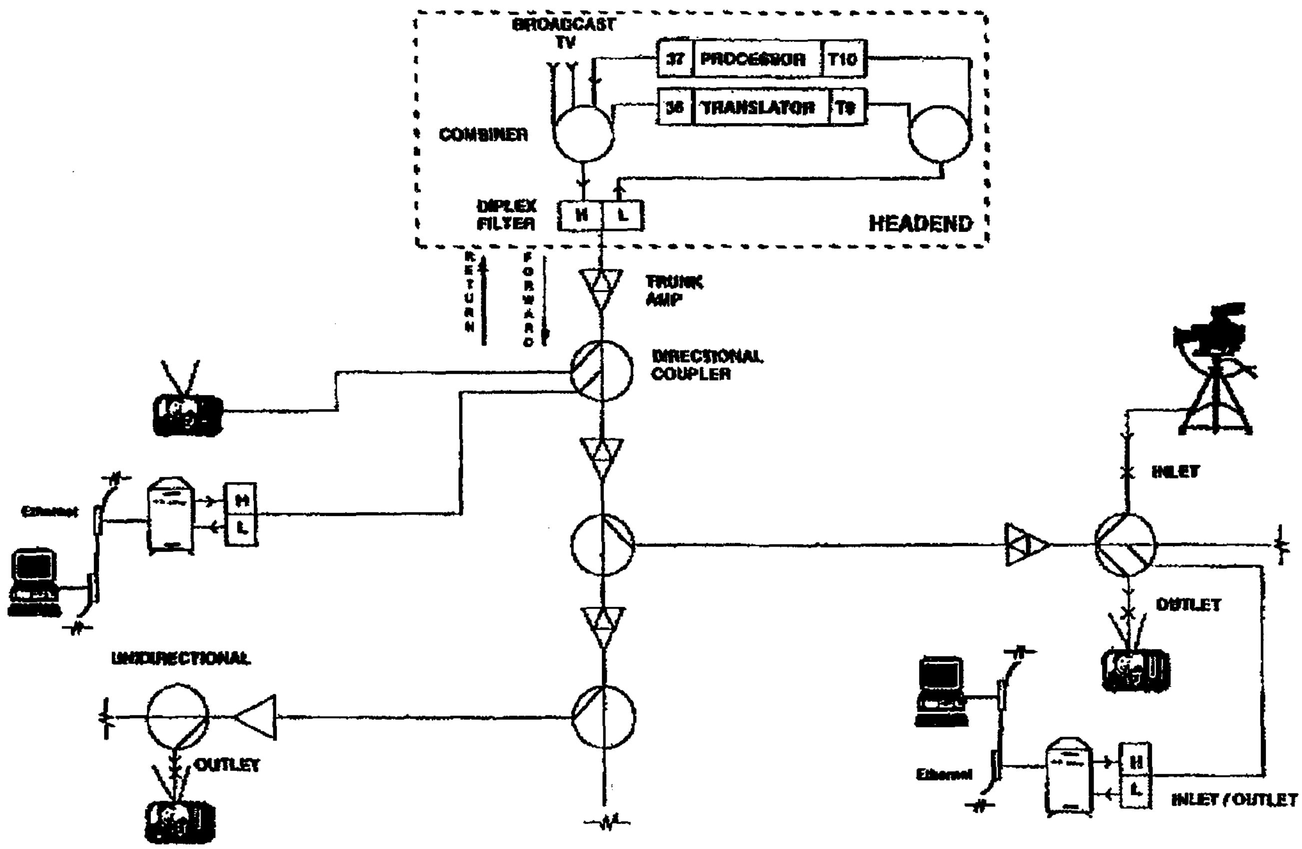
[4] "LANcity Profiles", Yassini, R., LANcity Corporation, Andover, Massachusettes 01810, (1993).





BIDIRECTIONAL CATV SINGLE CABLE PLANT

THE TECHNICAL PERFORMANCE REVIEW,

WHAT NEEDS TO BE DONE ?

Patrick K. McDonough

United Cable Television Corporation

DEFINITION OF SYSTEM AUDIT

ABSTRACT

This paper will consider the technical audit function in light of current system operational requirements. A checklist will be the result of a review of technical topics including CLI, frequency accuracy, picture quality, system response, plant physical condition, service call analysis and preventative maintenance.

AIM

The aim of a system audit is to provide management with a tool that accurately defines the operational status of a CATV system. In large MSO's corporate management is often out of touch with the day to day operations of each system. They need to have a source of information about each system that will enable them to make responsible decisions regarding the systems. This is especially true when considering major capital expenditure items such as rebuilds or upgrades. A good system audit will present an accurate overview of the physical condition and operating status of the plant.

The second aim of a system audit program is to maintain a set of records on each system so that periodic comparisons can be performed. The result of this analysis can help identify trends in operation that may need to be corrected or that may be applied to other systems to help them operate more efficiently. The system records can be kept in notebooks for easy reference or can be summarized, by system, in a computerized data base. Whatever filing system is used, the information should be easily accessible, regularly updated and be retained in a format that is applicable to the end user.

PROGRAM GOALS

The goals of an audit program are to provide the above noted information to management in a clear and concise format. In order to do this correctly, the system technical audit must be performed by a qualified outside party. The resulting audit report should present an unbiased view of the system, uncolored by any personal interest on the part of the auditor. Since the auditor has no interest in the system, he can be as critical or as laudatory as is required by the circumstances.

It is also important that an outside party examine the system because it is often true that someone who is very close to the system will not see problems that may be quite obvious to someone else. It is critical to the long term validity of the program that this view be maintained. Otherwise, the resulting reports will end up being useless in so far as real information is concerned.

REPORTING REQUIREMENTS

In general, the reporting requirements are fairly simple. The audit should result in a detailed formal report of the system operating environment. In addition, there may be an executive summary which provides an overview of the highlights of the detail report. These reports should be written in clear, concise English with a minimum amount of jargon.

For long term records, maintained in whichever department that is responsible for the audit program, the system test sheets, photographs and other acquired data should also be retained along with the final reports. This provides a handy reference if any questions arise regarding the results. The system book is also used to prepare for the next audit in that particular system. For instance, if the last audit turned up the information that a system was having difficulty maintaining system response, then that issue will become a focus area for the next audit.

It is our standard practice to hold an exit review of the audit results with system management before the auditor leaves the system. This practice minimizes the amount of disagreement which could arise later when the report is issued and gives the system a chance to correct any errors made by the auditor. It is also common practice to send the system a rough draft of the audit report and allow them the opportunity to respond to the findings. For instance, if the auditor states that the system needs to increase the amount of preventative maintenance being done, the system can indicate what steps are being contemplated to correct the problem. The system may also dispute a result entirely if they feel the auditor is mistaken. In either case, management has a complete picture of the system.

The technical audit may be incorporated into an operational audit report if both of these functions are performed concurrently. In this case, the operational auditor will normally be resposible for the final draft of the technical portion of the report. All of the acquired data should in any case be retained, as noted above, for future reference.

PHYSICAL PLANT TESTS

TESTPOINTS

Depending on the size and geography of the system, test points are selected so as to reflect the worst case amplifier cascades. The normal practice is to randomly select two or three locations at the extremities of each major trunk run. Separate headend or hub areas are treated independently with each area being fully tested.

The test point is usally the last tap in the feeder line. If at all possible, it is advantageous to perform the tests in a subscriber's home. Although this is becoming more difficult to do, it has the advantage of allowing the auditor to see the system as it is percieved by the subscriber. The auditor can also ask the customer about the service and any difficulties they may have encountered. The resulting information will paint a much truer picture of the system than many technical tests can.

In real life though, it is not always practical to try and gain access to the subscribers dwelling. In these cases, a long piece of drop cable should be used as the test lead to approximate conditions at the subscriber set. The test cable, approximately 150 feet in length, should be of the same type and size of cable being used in the system. The auditor should sweep the cable prior to using it to verify attenuation and response characteristics.

TEST EQUIPMENT

The auditor carries his own set of test equipment. This is done for a number of reasons. First, each system does not always have have all of the gear necessary to perform the full range of tests that are done. Second, the use of dedicated equipment assures repeatable results from system to system. For the sake of accurate long term comparative analysis, dedicated equipment is required to insure that results are valid. Third, there is the remote possibility that the system's equipment is out of calibration or otherwise faulty. If the system is unaware of this condition it could result in incorrect headend or amplifier levels being used, leading to increased problems throughout the plant. Independent equipment can identify this problem and the auditor may be able to use his test gear to do a rough calibration of the system equipment.

The actual test equipment used will vary depending on budget limitations, personal preferences and the physical requirement that the gear needs to be transported to each test location. A balance must be achieved between having too much equipment to move and having too little to get the job done correctly.

Because test gear is expensive and because it is necessary to maintain calibration, the use of very good shipping cases is called for. There are a number of commercially available cases which will serve this purpose quite well. For the best balance between protection and flexibility, the use of custom designed and built cases should be considered. Custom cases can maximize the amount of equipment available and help keep shipping costs down to a manageable level. Whichever route is taken, shipping cases should be of the highest quality to provide the maximum amount of protection and long term service.

Test equipment should also be of the best quality to insure the type of results that are required of a solid audit program. A list of the test equipment used in the author's systems is shown below.

1. A good quality portable spectrum analyzer, such as the HP 8590A. This is an automated, menu driven analyzer designed specifically for CATV usage.

2. A good quality field strength meter such as the Wavetek SAM IIIE.

3. A portable frequency counter, preferably one with an oven controlled crystal and accuracy rated to one part per million over a ten MegaHertz range.

4. A good quality handheld DVM with Amp. probe.

5. A set of tunable bandpass filters of adequate frequencies to cover the system being tested.

6. A tunable dipole antenna and preamp.

7. A data recording device, either a polaroid camera or a laptop computer and printer.

8. Quality shipping cases sufficient to encase all of the equipment.

9. An assortment of connectors, jumpers adaptors, etc.

The list above is not all-inclusive and can obviously be modified to meet the specific needs of the systems being tested.

A trend in the type of equipment which is currently available is the prominence of computer interfaceable gear. Both the spectrum analyzer and the field strength meter listed above can be connected to and driven by a computer. This can greatly speed up the acquisition of levels and can automate the performance of system test procedures. The use of a computer will allow the auditor to visit a higher number of test points in the same amount of time and thus get a much more comprehensive view of the system.

TESTS

Within the context of a modern CATV system, there are numerous concerns about picture quality and plant reliability that are more important every day. This is due to increased competition from alternate entertainment forms and the looming development of both fiber optic technology and the potential of enhanced NTSC delivery systems. There is also increased pressure from governmental bodies in response to a percieved increase in reception problems on the part of subscribers. This is mainly due, in reality, to unhappiness because of rate increases. Whatever the reason, there is a need for improvements in the overall operating efficiency of the systems to retain subscribers in a competitive environment.

To this end, the technical auditor must be aware of the latest requirements for quality operation within the system. Today, this means a full working knowlege of CLI and leakage specifications; headend frequency accuracy requirements and possible future demands on the system for additional channel carriage and the necessary technology to accomplish this.

The tests to be run on the plant should be comprehensive enough to allow management to make informed decisions based on accurate information on the system. The following tests will provide a solid overview of system operation and will provide the basis for future operational analysis.

1. LEVELS--A complete set of levels should be taken at every test point. This should include both video and audio carriers and a representative sampling of FM caariers. It is also a good idea to measure any data carriers present on the system. A field strength meter connected to a computer can read and record all of these levels in a matter of only several minutes. The data obtained can be stored on a disk for future retrieval or printed out immediately.

2. PICTURE QUALITY--A subjective evaluation of each channel on the system is made using a good quality TV and an appropriate converter where necessary. Picture quality is judged using a TASO rating system. The TASO system in use in the author's systems consists of the following ratings: 1=Excellent; 2=Good; 3=Fair; 4=Poor; 5=Barely Viewable; 6=Unviewable. Picture quality should rate at least a 2 or better on the TASO codes to be acceptable. Special attention should be given to the stability and overall quality of descrambled signals to assure the best possible reception.

3. CTB--The use of an automated test set, like the above noted spectrum analyzer, can make tests like composite triple beat practical in every day situations. All that is needed is an unused channel or a channel that can be turned off without any customer complaints.

4. CROSSMOD--Like CTB, this test can be routinely run in any system. Also like CTB, Crossmod is becoming a more important technical issue in the era of HDTV and other enhanced transmission systems.

5.CARRIER to NOISE--This test is probably the most informative of any that can be performed on an ongoing basis in any system. Noise is the base measurement that defines the overall quality of any operating plant. This parameter is also becoming more critical with the advent of enhanced picture standards.

6. HUM MODULATION--This test is not critical but is performed as a matter of course. It can provide the auditor with a key to how well and how often preventative maintenance is being done.

7. LEAKAGE--RF leakage should be monitored throughout the series of tests in the system via a truck mounted reciever, such as the Cuckoo or Sniffer units. When possible, a proof type test should be performed at the test point using a tunable dipole antenna. This test is currently among the most important than can be done in any system. Careful documentation of the results of

this test should be retained by the auditor and the system.

8. SWEPT FREQUENCY RESPONSE--The response of the system is an important consideration in overall picture quality. This test also reveals a good deal about the status of the maintenance program.

In addition to these objective tests, there are a number of physical inspections that should occur in the plant. These include visual inspections of the amplifier housings, cable, connectors, lashing wire, pole hardware and so on. In underground plant, the pedestals should be checked for integrity and vaults inpected for excessive water retention. The condition of shrink boots and other protective devices should be confirmed. System grounding, as well as drop grounds, should also be thoroughly inspected in all areas of the plant.

Power supplies require their own set of inspections, especially if they are standby types and use batteries. These tests should note whether the supply is properly installed and grounded, if the housing is correctly ventilated, if the batteries are connected correctly and if the charger and other parts are operative. If possible, a standby supply should be exercised to make sure it will operate in the event of a power outage.

HEADEND TESTS

The headend is assuming a role of major importance in the regulatory environment today. There is renewed emphasis on the accuracy of frequency assignments used in CATV, which must be maintained in the headend. As has always been the case, the ultimate quality of the system is determined by headend performance so particular importance should be given to the quality of the signals at this location.

The headend tests follow the same general pattern as the system tests. All video and audio carrier levels should be read and recorded, including all FM carriers and data carriers. A subjective picture quality test is done using the TASO codes noted previously. A set of CTB, X-MOD, C/N, Hum Modulation and a sweep response are done at the headend output for reference. All of these test results are recorded in the same format as the system tests for easy comparison.

In addition to the standard RF tests, the headend should also be tested at baseband video. Incoming signals should be subjected, at a minimum, to a video Signal to Noise test. If a video test set, such as the VM-700 from Tektronix, is available, a whole set of video tests can be performed quickly and with excellent accuracy. Incoming RF signals should be examined both before and after headend processing to ensure that no unacceptable distortion or noise is being introduced.

All video gear, such as VDA's, should be checked for 1 volt P/P output. Audio signals should be tested for depth of modulation along with the video waveform. A subjective test of audio quality should be performed on all audio signals including FM channels and especially on stereo encoded TV audio channels.

The headend facility should be checked for neatness and indications of regular maintenance activity. All wiring should be inspected to make sure each wire is in good condition, with connectors properly tightened and is installed so as to be reliable. AC outlets should be adequate for the facility and no doubling up on outlets should be allowed. The entire headend should be properly grounded, along with the tower, earth stations and antenna feed lines.

To insure reliability, the auditor needs to check the status of the standby power supply. This device should be exercised to prove emergency operation. Heating, air conditioning and fire alarm systems should also be checked to make sure they are operational.

Along with the headend, any addressable equipment should be inspected and tested. The important thing in looking at this gear is to treat it as a system rather than a bunch of discrete parts. The addressable computer should be exercised to communicate with each controllable headend piece, such as scramblers, and return communication verified. The computer's power conditioner should be checked to confirm proper connection. If the computer has a dial-in modem it should be disconnected unless it is in use. The area around the computer should be neat and clean and anti-static devices in place. Spare data tapes or disks should be available. The auditor should also make a note of access to the computer, which should be limited to authoized personnel. Passwords, if used, should be checked for the last time they were changed.

Along this same line, any return data carriers in the system must be tested as well. Each return trunk should be checked individually and the combined signal tested also. The minimum tests on return signals should be a Carrier to Noise and RF levels. It is also very helpful to confirm two-way converter operation and exercise the remote box functions.

Headend pieces should be tested for accurate output frequency and to confirm that the proper frequency off-set is being utilized. The output of the comb generator, if one is in use, should also be read with a frequency counter and levels verified.

While at the headend, a thorough check of the tower and antennas should be made. Overall tower condition should be noted as well as the status of the paint and beacons. Antenna downleads should be visually inspected for good condition, ice fall protection and proper installation. Tower grounding should be verified. If the tower is guyed, the tension on the guy wires should be noted.

Earth stations should be inspected for proper installation, that waveguide plumbing is neatly installed and that the LNA/LNB's are secure. Grounding should be verified as well. Power leads should be checked and all connectors inspected for corrosion. If a pressurization system is in place for the waveguides, this should be checked as being operational and the dessicant in good condition.

The headend facility should be checked for overall cleanliness and safety. Wiring should be neat and all inputs/outputs labled to indicate source or destination. Test equipment should be calibrated and in good operating condition. Spares should be properly stored and there should be no defective equipment laying around.

DOCUMENATION

A major part of the audit will be concerned not only with the physical tests but also with the record keeping used in the system. How the system documents its own activities and problems will tell the auditor a good deal about the depth of commitment to the maintenance program, CLI program and so forth. A system that is sloppy in record keeping habits can be assumed to be sloppy in doing the actual work as well.

A full inspection of the system's records is called for. This should include a check of all required operating licenses for two-way radios (FCC form 574-L), fixed earth stations (FCC form 488), microwave radio station license (FCC form 469), CATV relay service (CARS Band-FCC form 371-A), Common Carrier microwave radio station authorization (FCC form 462-C) and the tower aeronautical study (FAA form 7460-1). The system must also have a copy of their most current FCC form 325 and a current copy of the FCC rules.

Other documentation which ought to be on hand includes the system maintenance log, headend maintenance log, leakage logs (this is very important), up to date system design maps, headend rack and electronics diagrams, the latest proof of performance test results, power supply maintenance log and equipment manuals for all the equipment used in the system.

The auditor should compare the results listed in the system and headend maintenance logs with the results of the on-site audit tests. Obvious discrepancies should be noted and questioned. The main point in this area is that the auditor needs to evaluate the effectiveness of whatever maintenance or repair plans the system is utilizing. A system may have a great preventative maintenance plan on paper, scheduled out correctly and designed to cover every system amplifier twice a year, but if the plan is not implemented correctly or the system doesn't allocate enough personnel and equipment to the effort it will never work. This is especially true for CLI. The auditor must be aware of not only the presence of a viable plan but should confirm the effectiveness of the plan and the commitment of the system's management to seeing it through the long run.

RESULTS

The end result of the audit review, besides the formal report to management, is a concise, accurate technical summary of the system. The hard copies of the test results provide a yearly record of system performance, which is useful in a number of ways as decisions regarding the future of the system arise. The auditor must be unbiased in the approach to testing and completely honest in reporting the results. Otherwise the results would not be valid and would be of little practical value.

Shown below are samples of the level recording/TASO rating sheets which are used in the author's systems. Also shown are samples of automated test results done in an operating system. Lastly, an audit checklist is shown which provides a listing of the salient points to cover during the technical system audit.

ACKNOWLEGEMENTS

The author wishes to extend his thanks to Rey Johnson and David Glasgow, both Corporate Field Engineers at United Cable TV Corp. for their assistance in devising the the test procedures, automated testing methods and forms which have been developed over the past several years. Ralph Gillespie of United of Colorado has been responsible for writing the computer programs that make the automated testing work as intended.

CABLE TELEVISION CORPORATE TECHNICAL REVIEW

Test Site #________ System:________ Area:________
Review Date:________ Address:________ AMPS Deep:________
Time:________am/pm Billed Service:________
Const. Type:________ Sub Name:________ Tap Value:________
Test Point Type:________ Drop Length:________ FSM Used:________
Spect. Analyzer:________ TV Used:________
Converter:________

CHNL.	LEVELS Picture	Audio	S/N	C/N	TASO	PICTURE COMMENTS	OTHER COMMENTS
2							
3							
4							
5							
6							
106.5							
A-1							
A14							
B15							
C16							
D17							
E18							
F19							
G20							
H21							
I22							
7							
8							
9							
10							
11							
12							
13							
J23							
K24							
L25							
M26							
N27							
O28							
P29							
Q30							
R31							
S32							
T33							
U34							
V35							
W36							
AA37							
BB38							
CC39							
DD40							
EE41							
FF42							
				OVERALL:		LAST MAINTENANCE DATE:	

Service Call Prepared? Yes/No Results:________
General Comments:________

Signatures: General Manager:________ Corp. Eng. ________
Chief Technician:________
TASO Quality 1=Excellent 2=Good 3=Fair 4=Poor 5=Barely Viewable 6=Unviewable

CABLE TELEVISION CORPORATE TECHNICAL REVIEW

Test Site #________ System:________ Area:________
Review Date:________ Address:________ AMPS Deep:________
Time:________am/pm Billed Service:________
Const. Type:________ Sub Name:________ Tap Value:________
Test Point Type:________ Drop Length:________ FSM Used:________
Spect. Analyzer:________ TV Used:________

CHNL.	LEVELS Picture	Audio	S/N	C/N	TASO	PICTURE COMMENTS	OTHER COMMENTS
GG43							
HH44							
II45							
JJ46							
KK47							
LL48							
MM49							
NN50							
OO51							
PP52							
QQ53							
RR62							
SS63							
TT64							
UU65							
VV66							
WW67							
XX68							
YY69							
ZZ70							
71							
72							
73							
74							
75							
76							
77							
78							
79							
80							
81							
82							
83							
84							
85							
86							
				OVERALL:		LAST MAINTENANCE DATE:	

Service Call Prepared? Yes/No Results:________
General Comments:________

Signatures: General Manager:________ Corp. Eng. ________
Chief Technician:________
TASO Quality 1=Excellent 2=Good 3=Fair 4=Poor 5=Barely Viewable 6=Unviewable

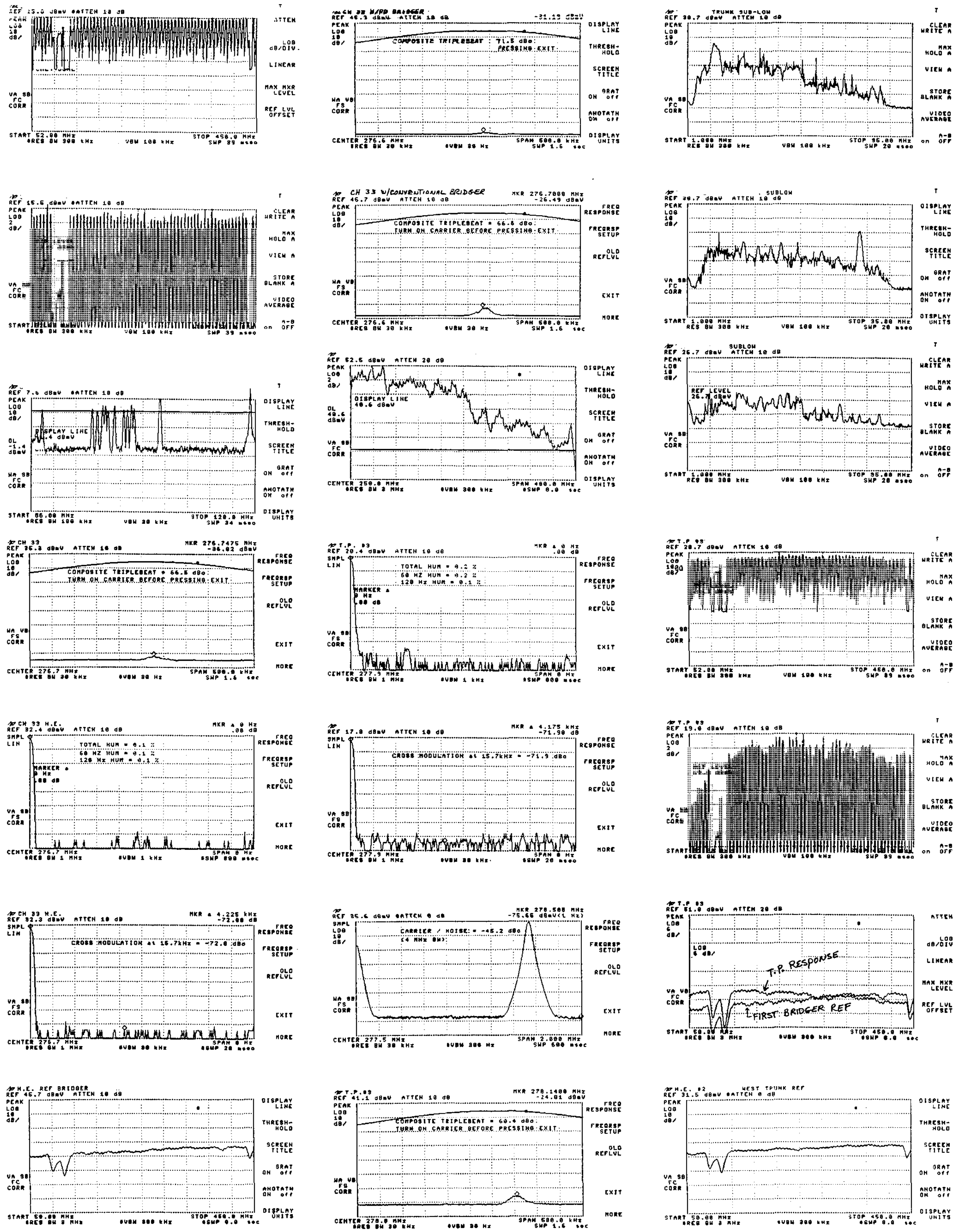
TESTPOINT NUMBER 01 READINGS

DATE: 01-10-1989 TIME: 12:08 P.M.

TESTPOINT LOCATON:
READINGS TAKEN BY:

METER BATTERY READING: 15 VOLTS
AMBIENT TEMPERATURE: 73 DEGREES FAHRENHEIT
ATTENUATOR SETTING: 5 TO 15 dBmV
SYSTEM HUM READING WAS: .3 % @ 73.96 Mhz
SYSTEM CARRIER/NOISE WAS: 44.5 dB @ 73.96 Mhz

CHANNEL	VIDEO FREQ (MHZ)	LEVEL (dBmV)	AUDIO FREQ (MHZ)	LEVEL (dBmV)
2	54	9.7	58.5	-6.4
3	60	9.7	64.5	-6.4
4	66	10.0	70.5	-6.1
X-PRESS	72.6	-8.9	0	0
5	78	10.3	82.5	-6.7
6	84	10	88.5	-6.4
FM	96.1	-5.3	0	0
FM	97.9	-6.0	0	0
FM	101.9	-5.0	0	0
FM	102.3	-5.2	0	0
FM	102.7	-8.5	0	0
FM	103.1	-6.8	0	0
FM	105.5	-5.0	0	0
FM	106.5	-7.6	0	0
FM	107.1	-6.0	0	0
FM	107.9	-5.7	0	0
DATA	108.5	2.0	0	0
SNIFFER	109.275	5.8	0	0
DATA	114	-9.2	0	0
TEST CARRIER	118.5	-12.0	0	0
14(A)	120	10.3	124.5	-5.8
15(B)	126	10.0	130.5	-6.1
16(C)	132	10.0	136.5	-7.3
17(D)	138	6.7	142.5	-11.2
18(E)	144	7.6	148.5	-6.1
19(F)	150	9.1	154.5	-3.9
20(G)	156	10.0	160.5	-7
21(H)	162	9.4	166.5	-7
22(I)	168	9.1	172.5	-6.7
7	174	9.1	178.5	-7.3
8	180	9.4	184.5	-7
9	186	9.7	190.5	-6.7
10	192	10.0	196.5	-6.4
11	198	10.0	202.5	-7
12	204	9.1	208.5	-7
13	210	9.7	214.5	-6.7
23(J)	216	9.7	220.5	-6.7
24(K)	222	9.7	226.5	-6.7
25(L)	228	9.4	232.5	-7.3
26(M)	234	9.1	238.5	-7
27(N)	240	9.4	244.5	-6.4
28(O)	246	15.7	250.5	-6.4
29(P)	252	9.7	256.5	-6.4
30(Q)	258	9.4	262.5	-6.4
31(R)	264	9.4	268.5	-7
32(S)	270	9.7	274.5	-7
33(T)	276	9.7	280.5	-7
34(U)	282	8.8	286.5	-7
35(V)	288	8.8	292.5	-7
36(W)	294	9.4	298.5	-6.7
37(AA)	300	7.6	304.5	-6.7
38(BB)	306	9.7	310.5	-7
39(CC)	312	10.3	316.5	-7.6
40(DD)	318	7.6	322.5	-8.2
41(EE)	324	8.8	328.5	-7.6
42(FF)	330	9.4	334.5	-7
43(GG)	336	9.7	340.5	-5.1
44(HH)	342	8.8	346.5	-7.6
45(II)	348	8.8	352.5	-7.6
46(JJ)	354	9.4	358.5	-7.3
47(KK)	360	8.8	364.5	-7.9
48(LL)	366	7.9	370.5	-7
49(MM)	372	8.2	376.5	-7.3
50(NN)	378	8.2	382.5	-8.5
51(OO)	384	8.8	388.5	-7.6
52(PP)	390	8.2	394.5	-7.6
53(QQ)	396	8.5	400.5	-7.6


CH 33 W/RD BRIDGER
COMPOSITE TRIPLEBEAT : 71.5 dBc
TRUNK SUB-LOW
CH 33 W/CONVENTIONAL BRIDGER
COMPOSITE TRIPLEBEAT = 66.6 dBc
SUBLOW
DISPLAY LINE
REF LEVEL
CH 33
COMPOSITE TRIPLEBEAT = 66.5 dBc
T.P. 93
TOTAL HUM = 0.1 %
60 HZ HUM = 0.2 %
120 Hz HUM = 0.1 %
CH 33 H.E.
CROSS MODULATION at 15.7kHz = -71.9 dBc
CROSS MODULATION at 15.7kHz = -72.0 dBc
CARRIER / NOISE: = -45.2 dBc
T.P. RESPONSE
FIRST BRIDGER REF
H.E. REF BRIDGER
COMPOSITE TRIPLEBEAT = 60.4 dBc
WEST TRUNK REF

AUDIT CHECK LIST

HEADEND

_______ Headend drawings current?

- _______ 1. Electronic Diagram
- _______ 2. Rack Diagram

_______ Headend Maint. Log (last date ________)

_______ Tower Condition:

- _______ Paint _______ Structural Analysis
- _______ Lights _______ Downguy Tension
- _______ Ground _______ Antenna Leads Protected from Falling Ice
- _______ Downleads neat
- _______ Date of Last Tower Inspection

_______ Earth station, LNA security, Waveguide plumbing, power leads, grounding.

_______ Defective equipment sent in for repair.

_______ Rack wiring neat and labeled.

_______ Standby power generator?

- _______ Check oil and water
- _______ Exercise generator
- _______ Check log book for exercise time

_______ Serial numbers and calib. dates of HE test equipment

_______ Check linearity of system sweep equipment, record response

_______ Record HE test point attenuation

- _______ 1. Video levels
- _______ 2. Audio levels
- _______ 3. Leakage XMTR and data carrier levels.
- _______ 4. FM carrier levels.
- _______ 5. Record HE response.
- _______ 6. Record CTB, XMD, HUM, C/N.
- _______ 7. Note beats on spectrum analyzer.

_______ Check off-air signal inputs (TV)

- _______ Check off-air FM inputs

_______ Confirm 1 Volt P/P levels on all modulator inputs from MW or Sat.

_______ Noise:

- _______ 1. S/N tests of Sat/MW signals.
- _______ 2. C/N tests of entire HE.

_______ Picture quality check (TASO) input ch's.

- _______ 1. Off-air input/output quality.
- _______ 2. MW/Sat. input/output quality.

_______ Frequency offset:

- _______ 1. Phaselock generator model.
- _______ 2. Frequency stability (± 1 Hz HRC/ ± 5 KHz Std.)

_______ Picture quality check (TASO) all ch's.

- _______ Check quality at HE output
- _______ Check quality at any intersystem cross connects (if applicable).
- _______ Note any visible impairment to pictures (ghosts, smearing, co-channel, Xmod, noise, beats).
- _______ Note effectiveness of scrambling (if used).
- _______ Note any impairment to descrambled channel.

SYSTEM TEST POINTS

_______ Check standby power supplies, batteries, connections, ventilation, excercise.

_______ Standby PS maintenance prog./log.

_______ Record system levels, all amplifiers.

_______ Record video levels.

_______ Record audio levels.

_______ Record pilot carrier levels.

_______ Record leakage, data carrier levels.

_______ Record/compare sweep response.

_______ Check picture quality (TASO)

_______ Record CTB, XMD, C/N. HUM.

_______ Check drop, correct cable ('D', 'X', etc.), grounding, proper installation, connectors correct, tagged.

_______ Visually inspect housings, cable, connectors, lashing wire, pedestal.

_______ Record all RF leaks detected by Rcvr. Note intensity of leak, whether legal.

The Universal Communications System of the Future, Telephone or TV Cable?

by Paul Baran
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Abstract

This paper addresses the question, "Can cable TV become the universal communications platform of the future, and even supplant the twisted pair telephone loop system?"

BACKGROUND

Pre-Cable

To begin, let's briefly review some of the history of cable television. Cable started life as an extension to a TV antenna forty years ago, delivering a couple of local TV broadcast stations to those unable to obtain a workable antenna site. TV was characterized then by Newton Minnow, chairman of the FCC, as being a vast wasteland -- three mass audience networks, each seeking the lowest common denominator of intelligence.

Impact of the Satellite

As recently as twenty years ago, cable's future didn't look bright. This outlook changed dramatically with the technological innovation of using satellites to deliver premium programming to each cable head end. For the first time, urban areas could justify cable to obtain access from satellites to new programming not available off the air from broadcast stations. This led to a period where the cable system operators fought for urban franchises, each promising to deliver more non-existing services relative to the competition in order to win the big city franchises. In parallel, the industry developed the political muscle to pull off the Cable Act of 1984 which absolved the industry from having to fulfill the more outrageous promises made during the franchising frenzy. Over time, in an era of minimum regulation of cable TV, the value of cable systems increased from about $600 to $2500 per subscriber.

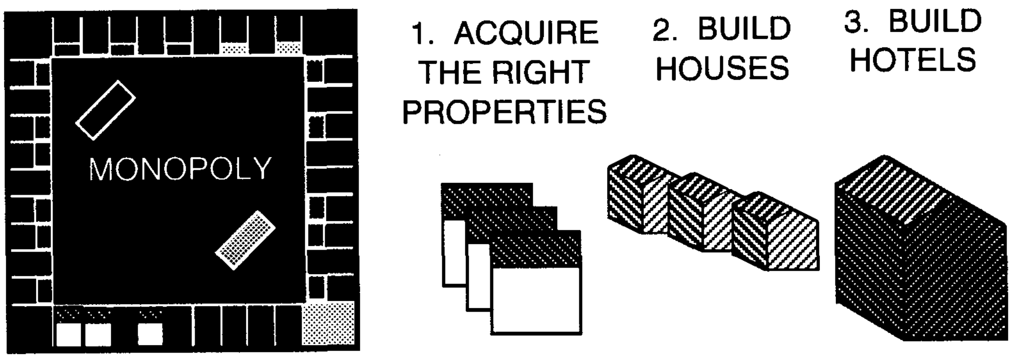
Today

The cable TV industry can be rightfully proud of the tremendously increased diversity of programming it has brought to the nation. I rarely watch the three over the air networks. Rather it is CSPAN, A&E, the Discovery Channel, the Learning Channel and a few PBS stations that get my attention. As the number of program channels has increased, so has the diversity of the audience and the wider the range of programming that became feasible. And, this trend is just beginning. The dramatic increase in the number of channels that can be delivered using the latest technology is but one dimension of the coming changes.

THE MONOPOLY GAME

The passage of the 1992 Cable Act represents a coming of age as Congress recognizes the importance of this new and growing industry and as an important monopoly subject to rate regulation. Of course, the cable industry tends to view it as our government's proclivity to punish success and reward failure. But, then there are many ways to look at the same situation. Since the industry is being considered as being a monopoly it is fun to think of it terms of the old board game "Monopoly"

Now, with the new digital technology now available, the cable TV industry is in position to build the Big Red Hotels -- with their huge potential revenue opportunities. Before we get into the specifics of the revenue implications for cable, let's review where the technology is going.



As you'll remember, when you played Monopoly, you acquired properties on the roll of the dice. Then after all the properties are divided, you'd swap properties with the other players. For example, when you hold all the yellow titles you create a monopoly position which allows you to double the rents the other players had to pay you if they were unlucky enough to land on your property As the game continued, you saved up enough money to build little green houses on the properties, increasing your rental income. After you accumulated even more money, you built big red hotels. And, when any of your rival players landed on them, you really cleaned up.

Since 92 % of the TV homes in the US are now passed by cable, the properties in the real game have already been divided up among the players. We are beyond that stage. Investment in new technology to increase revenue is underway -- more channels, pay per view, and even movies on demand. These investments are the little green houses. So far, so good.

TECHNOLOGY ADVANCES

About five years ago the architecture of using fiber as TV trunks to carry analog TV signals was developed by Jim Chiddix and his ATC colleagues. Given the increased use of fiber means that quality of the TV image, system reliability and the number of channels delivered by cable may all be expected to improve dramatically over time.

Digital

Also rapidly developing are new technologies in the areas of digital processing, transmission and switching. While analog TV sets will continue to be with us for many years, we are already seeing the benefits that digital brings. Images can be transmitted without additive distortion or picture quality loss. And, with digital processing, the removal of redundant information permits compression, allowing the signal to occupy far less channel bandwidth than before. Recording and resurrection no longer means irrevocably degraded picture quality. Once recorded, there need never be any reduction of image quality over time or over distance.

CableLabs Architecture

The cable system architecture of the future as envisioned by Steve Dukes and his colleagues at CableLabs is a universal two way general communications system, with the upper ends of the network interconnected by fiber loops. Separate fiber loops carry analog and digital signals, with some of the digital signals being ATM-based. ATM is a new transmission and switching scheme that uses small self-addressed packets of digital bits for very high speed transmission over fiber optic facilities. Longer distance fiber loops provide a redundantly connected transmission capability using fewer head ends in a regional area and offering significantly increased system reliability.

Time-Warner Orlando

While the CableLabs architecture is pointing the direction, others in the industry are also moving forward to develop their own systems of the future. One leading edge system is being developed by Jim Chiddix, Dave Pangrac and Jim Luddington and their Time-Warner colleagues for trial in Orlando, Florida. It is an ATM-based, digital transmission network that will support voice, data and TV.

On the Importance of ATM

With digital, all signals whether they be voice, or data or pictures are identical in transmission formats. This allows the transmission of a mixture of different signals together in a highly efficient form. Networks of the future will be based upon ATM, or asynchronous transfer mode, a fancy name for fast packet switching.

With ATM, all information is transmitted as short standardized 424 bit long cells or packets. ATM is a universal building block technology for future telephone and data networks and is particularly useful when video must be stored in digital memory and retrieved on demand. Some industry pundits even believe that all digital transmission and switching in the future will use ATM cells, because of its compatibility with very high speed digital switching networks.

If one were to design an entirely new telephone system to best meet today's and tomorrow's requirements, it would not be built the same way as our existing telephone system. It would be built using many of these new technologies instead. Of course, it would have to interconnect with the existing telco system. Functions that once required a large and complex installation like the telephone central office are today relatively simple to implement using new technology. New fiber optic, digital and radio technologies open new options to the designer. The designer of these future system sees three significant new factors to be considered:

- The availability of new technology such as ATM
- The availability of a cable TV network with up to one GHz transmission path to homes, either in place or anticipated
- The incremental deregulation of the telephone industry which is enabling efficient system interconnection

COM21, A NEW SYSTEM

A small group of colleagues and I have joined together to create a new company, Com21 Inc., which is working together with strategic partner companies to further define and study such a new telecommunications system. Com21 believes this new system can significantly enhance the Nation's telecommunications infrastructure by using several of these new technologies to deliver a wide range of new services over the cable television plant. Ultimately, Com21 intends to be a communications operating company which implements and supports this new system.

This new system is based upon the use of the existing cable TV plant as a transmission path. It uses short distance, unlicensed radio to eliminate any requirement for additional in-house wiring. It particularly matches the evolving future generation cable TV architecture as defined by CableLabs. By taking advantage of the dramatic progress in the technologies of fiber optics, advanced networking, and wireless communications, the new system will be able to deliver a new range of telecommunications services and do so at lower cost than current telephone systems. Voice telephone calls and computer to computer data calls will interconnect with the local telephone system and interexchange carrier long distance facilities. Importantly, while offering many more features and benefits to the subscriber, the new system also can utilize subscriber's existing telephone devices and in-building wiring.

Com21 System's costs are projected to be substantially less than the capital and operating costs of today's existing telephone system built on earlier technology. Based upon initial cost estimates, the capital required to install a Com21 System is about one-third of the cost for an equivalent local telephone system. And, most importantly, most of the cost occurs at the time that each subscriber is connected. Reduction in cost is achieved through the efficiency of shared use of existing facilities both within the local cable TV system as well as within the subscriber's home or business.

Com21 System Features

The Com21 System use small, personal cordless telephones sharing a 2+ Mb/s channel in a no-license-required radio band. Each cordless telephone has its own separate channel. Up to eight or ten different conversations can be simultaneously supported together with high speed data terminals and multimedia-based computers. An optional modular jack allows connection to the existing telephone system in the house for origination or reception of calls from either the present local telephone carrier or via the Com21 system. The modular jack arrangement allows full compatibility with existing consumer telephone equipment, fax machines, modems and existing in-building telephone system wiring. Flexibility to dynamically add devices to the network without installation delays is designed into the system, as each handset or data terminal interface has its own unique number. The entire system utilizes ATM cells for maximum efficiency and simplicity of system interconnection. Very high data rates of up to 155 Mb/s can be provided to meet the high bandwidth requirements of some business customers.

Detailed Technical Description

A detailed technical description of the Com21 System can be found in "The Role for Cable and PCN" , *Conference Proceedings of the Society of Cable Television Engineers Annual Conference on Emerging Technologies*, New Orleans, LA, January 7, 1993). And, there is a second article describing the system, "Radical Telephone Grabs Huge Bandwidth Promise, "in the May 1993 issue of *Signal Magazine*, .

NEW REVENUES OPPORTUNITIES FOR CABLE

With that brief technology interlude complete, now let's go back to the Big Red Hotel opportunities that are just ahead for the cable industry. Probably the two largest markets representing the greatest opportunity are multimedia and telephony. While I personally believe that a large multimedia market will develop, there is the usual skepticism for any service that does not presently exist. I heard multimedia characterized by one skeptical industry observer who asked the question, "What happens when you cross a lemming and a sheep?" His answer: "A multimedia investor."

To avoid such cheap shots, let's set the multimedia opportunity aside for the moment and limit the discussion to a single service that presently exists today and can be quantified, telephony.

Entering Each Other's Business

My friend Dr. Michael Bowles of Hughes Aircraft Company asks the amusing question, "What will the costs and revenues likely to be if a) The cable TV companies entered the telephone business, and b) if the telephone industry enter the entertainment TV business?" Let's take a look at one analysis:

	Telco does CableTV	Cable TV does Telephone
Cost	\$150 to \$400 Billion	\$20 to \$40 Billion
Added Market Potential	\$15 to \$30 Billion /year	\$100 to \$200 Billion / year.

This chart suggests that this is a no brainer. The cost of cable entering into the telephone business is moderate, while the economic upside payoff can be very large. And, the opposite appears to be true for the telco industry's entry into cable TV. Thus, the cable TV industry has much more to gain from this coming competition, while the telephone industry, as we know it today, has more to lose -- unless it joins with the cable TV industry, or overbuilds using the same technology.

Similarities and Differences

Both the telco and the cable TV industries are moving towards a universal communications systems carrying voice, data and TV over fiber optic links, with voice and data in the form of ATM cells. At the top of the networks, both the telco and the cable industry's approaches appear to be converging. Each system in the future resembles the other. The only major critical difference is the last few miles -- the local loop as the telephone companies call it. Here, the advantage of cable TV's availability of a 1 GHz-capable coaxial cable to the home has a major cost/ performance advantage over the telephone company's twisted pair.

Of course, the local telephone carriers could change their tail circuits and overbuild with coax. They could acquire cable TV systems (something which is presently prohibited within their telephone service areas), or work together with cable TV companies. The technical options are open. Another constraint on the local telephone carriers is that their allowable rates of return are based on huge quantities of unamortized facilities on their balance sheets including the long depreciation lifetimes assigned to their twisted pair local loops.

To overcome the data rate choke point of the twisted pair local loop, the telephone industry has been pushing the development of improved digital twisted pair transmission technologies. These include ADSL and HDSL, and N- ISDN. ADSL, asymmetrical digital subscriber line, provides a 1.5 Mb/s data path in one direction and a lower data rate in the other direction for the delivery of data. HDSL, high speed digital subscriber line, uses two twisted pairs, one in each direction. For local loops in relatively close proximity to the central office with short transmission distances, the data rates can be increased using these technologies into the four megabit/second or higher range.

ISDN

Of the technologies that are being discussed, the one that has received most attention is ISDN, or Integrated Services Digital Network. ISDN was a wonderful idea many years ago when it was first created. However, it has become an increasingly obsolete technology as other options have been developed while its implementation was delayed. ISDN was intended to be the technology to deliver both data and voice telephony over a single twisted pair. There are several parts to the ISDN approach. One relates to switching in the network while the part of most interest is the digital channel to the home or business.

The major pressure for providing lower cost ISDN comes not from the telephone companies, but from information activists lobbying Congress and other governmental agencies. Data networks are being built to interconnect major universities and research centers. The government subsidized Internet is now operating in 30 countries and has been growing over 15% per month. Millions of computers are now intermittently connected. The Internet, an informal network of networks, was primarily intended to be used by the science and education communities. Instead it has grown into an international user-to-user network for non-commercial uses. The next generation of the backbones of this network are being planned to operate at gigabit per second rates, i.e. the National Research and Education Network. This network is viewed as the information superhighway with few off ramps. What is needed is a farm to market equivalent road system to connect users at home and schools at data rates beyond today's 9600 bits per second (or about 24,000 bits per second with next generation analog modems.)

ISDN offers a 2B+D connection on a twisted pair. This is two channels of 64,000 bits per second plus one of 16,000 bits per second. Unfortunately, ISDN's terminal devices are complex and expensive. In part, this is because the ISDN concept is based primarily on a circuit switched philosophy. Increasingly. data applications require a high burst rate, with long allowable dwell times. Instead, ISDN is optimized to support a low steady data rate.

In the US, ISDN has not gone well. The terminal devices for ISDN remain expensive. At each local telephone carrier, each separate switch to handle ISDN had to be retrofitted with new hardware and software at considerable expense. Then came the compatibility problems. Terminal devices made by Northern Telecom didn't work with the switches made by AT&T, and vice versa. After several years of this kind of impossible compatibility war going on in the marketplace, a new, lowest common denominator standard was defined, N-ISDN. Or, National ISDN. Terminal devices made to the N-ISDN standard were to be able to work with all switches with suitable software.

Last year, five RBOCs announced support N-ISDN. This new national standard was to overcome ISDN's past limitation of being able to serve only islands of users near ISDN equipment switches. No sooner than this announcement was made when US West and Southwest Bell spoke up and said in effect, 'Thank you, but we haven't been able to recover our early investment in ISDN, so we don't plan to change to N-ISDN.'

The momentum for National ISDN remains elusive. Indeed, it remains everyone's favorite example of how not to deploy new technology! Even if ISDN does eventually become widely available, it represents a high cost, low function service which will have to compete with the capabilities and inherent architectural advantages of cable-based alternatives. It shouldn't be much of a battle.

SUMMARY

While the regulatory issues are being resolved over time, cable is contemplating entry into the telephone business along at least two paths.

The first is joining with Competitive Access Providers to provide fiber optic dedicated trunks to businesses.

The second path is as a PCS provider, with the plum being a new monopoly to be given away by the FCC, a la cellular.

While these may be interesting businesses, they pale alongside the opportunities that cable faces as a potential new universal two-way network providing telephone, data, and multimedia telecommunications services taking advantage of its basic superior end-channel.

The key will be in understanding the opportunity , how to best utilize the new emerging advanced technologies and architecture, and the will to do so.

Trends in Output Power and Bandwidth of 1310 nm DFB Lasers for AM Video

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Abstract

DFB lasers have been used for AM video transmission for less than 5 years. In that time there have been spectacular improvements in the performance characteristics of 1310 nm DFB lasers. The output power of production lasers has increased from 3-4 mW to well beyond 10 mW. Output powers as high as 25 mW have been demonstrated. The channel capacity has increased from 40 channels for initial systems to 80 or more channels today. In this paper, the factors which limit the output power and bandwidth of DFB lasers will be examined. The performance capabilities that are expected in the near future and the potential impact on CATV architectures will be discussed.

I. Output Power Capabilities of 1310 nm DFB Lasers

The output power of a DFB laser module is determined by three factors; the efficiency of the laser chip, the efficiency of the coupling of the laser light to a single mode fiber, and the operating current of the laser above the threshold current.

Laser Chip Efficiency

The maximum possible efficiency for a semiconductor laser corresponds to an output of one photon for every electron injected into the laser. For 1310 nm DFB lasers, this maximum possible efficiency corresponds to 0.94 mW/mA. In practice, the laser efficiency is lower since not all injected carriers result in the generation of light and not all of the light generated is emitted from the front facet of the laser. Typical efficiencies have improved over the past several years from about 0.3 mW/mA to 0.40 mW/mA. The best results demonstrated to date for 1310 nm lasers are in the range of 0.6 mW/mA. Although there may still be unforeseen break-throughs in laser efficiency, it appears that the efficiency of production lasers will saturate at a level slightly higher than that which is achieved today, probably at around 0.5 mW/mA.

Fiber Coupling Efficiency

There are several factors which prevent coupling all of the light from a DFB laser into the fiber. The main losses are due to optical aberrations in focusing the highly divergent output beam from the laser onto the single mode fiber. Some losses also result from coupling the elliptical beam from the laser into a circular fiber. Finally, there is some loss from the internal optical isolator. Typical coupling efficiencies which can be obtained from production devices have improve from about 40% to 55% over the past several years. This has primarily been due to improvements in coupling optics. This trend towards improved optical design is continuing. Recent R&D results indicate coupling efficiencies of 75-80% are possible for improved optical designs. The expectation is that production efficiencies will continue to move up over the next few years with a probable saturation at about 70%.

Operating Current

Most of the improvements in output power from DFB lasers has been obtained by increasing the module efficiency. The impact of effiency improvements is to essentially increase system loss budgets with no other changes in operating characteristics such as linearity or RF drive levels. Output power can also be increased by simply operating the lasers at higher DC currents. However, this does have an effect on other operating characteristics.

One of the most challenging aspects of AM laser design is minimizing second order distortion in DFB lasers. The three dominant mechanisms responsible for CSO in DFB lasers are nonlinear leakage currents, axial hole burning effects[1], and laser resonance effects[2]. The last two effects decrease in importance at higher bias currents, but nonlinear leakage currents tend to increase at high bias currents. Leakage currents generally limit the maximum linear operating current of DFB lasers. Over the past several years, the typical maximum operating current above threshold for which AM CSO performance are maintained has increased from 40 mA to 50-60 mA. It is possible to significantly increase the maximum operating current, for example with longer laser chip lengths. Operating currents as high as 100 mA above threshold have been demonstrated, even for standard chip lengths, while maintaining levels of CSO required for AM systems. However, high operating currents can have some negative impact on system performance which must be considered.

One negative consequence of higher DC operating currents is that higher RF modulation currents are also required. Laser modules are commonly designed for 25 Ω and matched to 75 Ω with a 3:1 transformer. In this case, a module biased 60 mA above threshold and operating with 80 channels at 4% modulation depth per channel requires an RF power of 37.3 dBmV/ch for a lossless transformer. This can easily be supplied by either feed forward or power doubled amplifiers. If the bias current is increased to 100 mA above threshold the RF power requirement increases by 4.4 dB. At this power level, the distortion due to a power doubled amplifier is no longer negligible.

A second consideration for high operating current lasers is chirp and dispersion. 1310 nm DFB lasers biased 40-50 mA above threshold have chirp values which provide a nearly optimum trade off of dispersion induced distortion and interferometric noise[3]. To minimize CSO due to chirp and dispersion, low chirp is desired. To minimize interferometric noise from double Rayleigh scattering, high chirp is desired. The dispersion induced CSO depends on the amount of chirp per channel of RF modulation. This in turn is linearly proportional to the modulation current. Increasing the bias current and modulating current therefore increases the chirp level per channel and reduces the maximum amount of fiber dispersion that can be tolerated. For this reason, increasing operating currents is best suited to applications where higher power is required due to optical splitting losses. It is possible to increase transmission distances, but only if precautions are taken to minimize potential CSO problems from chirp and dispersion. This might include selection of lasers with operating wavelengths close to the fiber zero dispersion wavelength or selection of low chirp lasers.

High Power Potential of 1310 nm DFB Lasers

The trend in output power of DFB modules produced by Ortel is shown in Figure 1. Since the beginning of 1991 the power for both "champion" laboratory results and production devices has been increasing by 2 dB per year. Output powers as high as 25 mW have been demonstrated. This allows for AM links with very high optical loss budgets. The C/N versus optical loss for the 25 mW laser is shown in Figure 2. This was for 62 channel loading at 5.25%/ch. This is the near the clipping limit for modulation depth. If the modulation depth is restricted to 4%/ch to allow margin for adding digital channels, then the C/N is 2.4 dB lower.

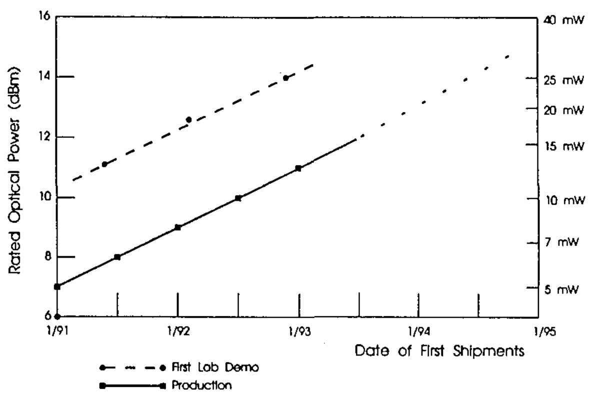

Figure 1. Trends in output power of 1310 nm DFB lasers.

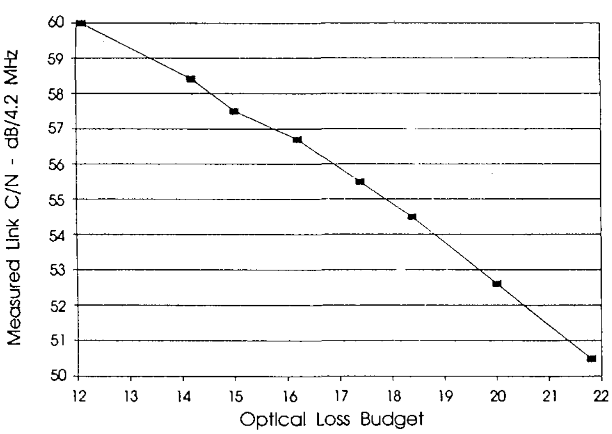

Figure 2. C/N vs. optical loss for a 25 mW 1310 nm DFB laser.

If laser operating currents are limited to 60 mA above threshold, for which there are minimal problems with RF drive levels and chirp, then the output power of production modules will most likely saturate in 1994 near 20 mW. If this constraint on operating current is not imposed, then output power can continue to increase up to the 30-50 mW range. For high current devices, it is desirable to reduce the chirp value from that which is typically obtained today.

II. Bandwidth Potential of DFB Lasers

The operating bandwidth of any electronic or optoelectronic device can either be limited by the frequency response of the device or by the dynamic range of the device. The frequency response of a high speed DFB laser is shown in Figure 3[4]. The operating bandwidth as measured by the -3 dB point is in excess of 16 GHz. For low dynamic range optical links, such as either baseband or subcarrier multiplexed digital links, the maximum transmission bit rate is primarily determined by the frequency response of the laser. The C/N and distortion levels are generally easy to achieve, particularly for the relatively low loss links used in CATV networks.

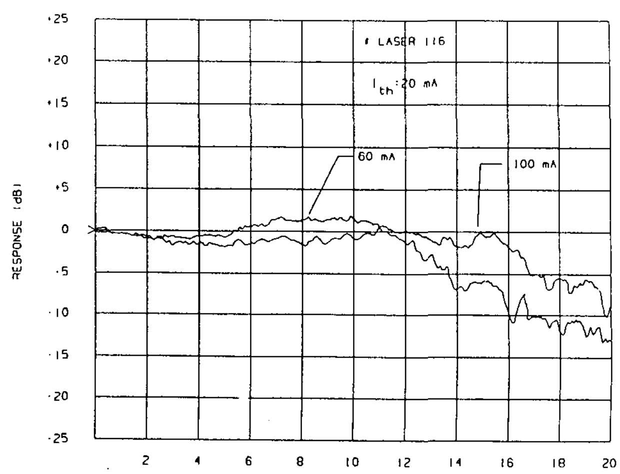

Figure 3. Frequency response of a high speed 1310 nm DFB laser.

For AM video, or other high dynamic range applications, the bandwidth is determined by the dynamic range of the laser and not the frequency response. To meet C/N requirements requires relatively high modulation depths per channel. The number of channels is in turn restricted by the requirement that the total RF modulation is below the laser clipping threshold. This clipping limit has been discussed in many technical articles[5,6]. Although there is still some controversy over the clipping limit, the limit to the parameter μ is in the range of 0.25-0.3, where μ is given by:

$$\mu^2 = m^2 N/2$$

where m is the modulation depth per channel and N is the number of channels.

Our own tests based on observable degradation to actual video signals corresponds to a limit of $\mu = 0.25$. For typical laser and receiver noise levels and 1 mW of received power, the AM channel capacity is about 150 at 52 dB C/N. At higher received power levels the channel capacity can be increased somewhat, but in all cases the bandwidth of an AM laser is far less than the inherent frequency response of the DFB laser.

For mixed formats where both AM video as well as lower dynamic range signals are sent, then the bandwidth is again limited by clipping assuming most of the capacity is allocated to transmitting AM channels. For example, in the case of AM video plus compressed digital video, the AM channels may require 52 dB C/N and the digital channels may require 35 dB C/N. The overall limit to capacity can be expressed as:

$$\mu^2_{TOT} = \mu^2_{AM} + \mu^2_{DIG} = 0.0625$$

where

$$\mu^2_{AM} = m^2_{AM} N_{AM}/2$$

and

$$\mu^2_{DIG} = m^2_{DIG} N_{DIG}/2$$

For the case of 80 channels at 3.5% modulation depth per channel, $\mu^2_{AM} = 0.049$. The remaining allocation for the digital channels is $\mu^2_{DIG} = 0.0135$. Because of the lower C/N requirement, the digital channels only require a modulation depth of 0.5% per channel. The total capacity for such digital channels is then $N_{DIG} = 1080$. Each of these 6 MHz wide digital channels could transmit up to 10 video channels. This would occupy the bandwidth of the DFB laser out to 7 GHz. In practice, the noise performance of the laser and of such a wideband receiver would result in a requirement for somewhat higher modulation depths for the digital channels. This will reduce the digital capacity, but the DFB lasers have the capacity to transmit many more digital channels than are being projected for any near term network architectures in addition to AM channels. The same general design rules can be used for other types of signals that might conceivably be transported on the network.

III. Impact of Laser Technology Improvements on System Architectures

The history of AM video has been that system architecture needs have determined the direction of technology development. To a large extent this continues to be the case. Recently, there has been significant interest in combining AM signals with digital signals. This application does not require any significant improvements in basic DFB device characteristics. It is desirable to operate at somewhat lower total modulation levels to avoid bit errors due to laser clipping. The only other requirement is that the electronics, such as RF amplifiers, can handle the mixed AM plus digital signal load. For systems up to 1 GHz, there are no new technical advancements required to implement such transmitters.

The role of high power DFB lasers in future CATV networks is highly dependent on the penetration of fiber into the CATV network. Most future architectures include a dedicated transmitter for blocks of 500-2000 homes. If this block of homes is served by a single optical receiver followed by a coaxial tree and branch network, then current DFB power levels are sufficient and what is desired are lower cost versions of current transmitters. However, if deeper fiber penetration is desired, for example fiber to the last amp (FTLA), a single laser would ideally serve many optical receivers. This requires higher loss budgets and correspondingly higher optical output levels. The application of high power DFB lasers to FTLA is shown in Figure 4.

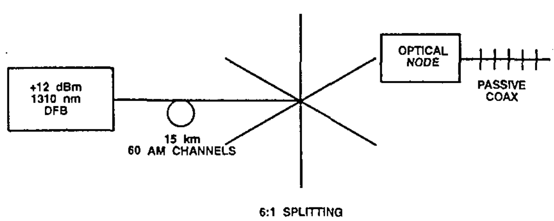

Figure 4. Fiber to the last amp architecture using high power 1310 nm DFB lasers.

The amount of optical splitting possible depends on several factors including laser power, the number of AM channels, the AM C/N, and the fiber link lengths. One feature of FTLA is that the C/N is completely determined by the fiber link and therefore lower values for fiber C/N are generally acceptable. Table I lists the launch power per optical node that is required for various combinations of parameters. In all cases a C/N of 50 dB, fiber losses of 0.4 dB/km and 1 dB loss margins are assumed. A receiver noise of 7 pA/Hz$^{1/2}$ and typical values of laser interferometric noise are assumed. 80 channel links are assumed to operate at 3.5%/ch and 60 channel links are assumed to operate at 4.0%/ch. This allows for margin from the clipping limit to add digital channels. If a laser output power of +12 dBm is assumed, then a 20 km link with 60 channels can have a 4:1 split assuming a 7 dB loss for the splitter. A 15 km 60 channel linkcan have 6:1 splitting and a 10 km 80 channel link can have 8:1 splitting.

Table I
Launch Power Per Link
Required to Achieve 50 dB C/N

	60 Ch	80 Ch
10 km	0.2 dBm	1.1 dBm
15 km	2.4	3.5
20 km	4.7	6.1

In FTLA architectures, more of the system distortion budget would also typically be allocated to the fiber link compared to more conventional fiber to the feeder (FTF) networks. This improves the yield and therefore the cost of high power DFB lasers for FTLA.

Another application of high power DFB lasers is as an intermediate step towards a network with dedicated lasers for groups of about 500 homes. Such an architecture is shown in Figure 5, with all of the splitting done at the head end. In this case, higher performance levels of FTF networks are generally required of the fiber links. This reduces the amount of optical splitting compared to FTLA, but still allows the transmitter to initially be shared by several optical nodes. At the time of a future upgrade, additional lasers can be added at the head end until there is a dedicated laser for each receiver. No changes are required to the network beyond the head end.

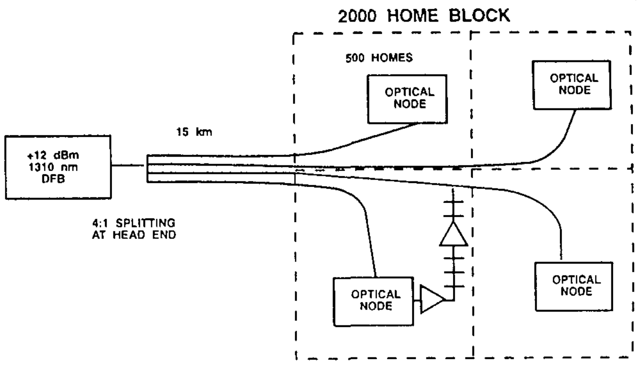

Figure 5. Using high power 1310 nm DFB lasers as an interim step to fiber rich narrowcast architectures.

IV. Summary

DFB laser technology is rapidly evolving to meet the needs of future CATV networks. Two of the main areas of advancement are in the area of bandwidth expansion and optical power improvement. Because of the high inherent dynamic range and 3 dB bandwidths of DFB lasers, no device improvements are required to add digital or other lower dynamic range channels to an AM laser. The only requirements are improvements in the bandwidths of the RF electronics associated with a laser transmitter. High power DFB lasers allow for cost effective solutions for network architectures with fiber penetration to optical nodes serving smaller blocks of homes than current architectures. This can be used to build networks that are better able to provide for anticipated future services as well as for services not yet contemplated.

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WIDE DYNAMIC RANGE CARRIER-TO-NOISE TESTING

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Abstract

An increasing demand for better system carrier-to-noise performance is, in turn, creating demand for better carrier-to-noise measurements. To help take the mystery out of this measurement, five correction factors are introduced to help describe a practical measurement method using a spectrum analyzer.

INTRODUCTION

The increasing use of fiber, new FCC technical standards, and higher quality expectations of operators and subscribers have all focused more attention on the carrier-to-noise measurement. Getting repeatable results when measuring noise at low levels requires a detailed knowledge of how the instrument being used measures noise, its limitations, and corrections necessary.

The carrier-to-noise test requires two measurements, carrier level and its related noise level. Much has already been written on measuring carrier levels. This paper will concentrate on the more difficult noise measurement.

THE NOISE MEASUREMENT

Measuring noise is more difficult than measuring carrier levels mainly due to two reasons:

1) the levels at which noise is measured are very much lower than carrier levels (see Figure 1), and,

2) noise is not really a "signal"; it is a continuously and randomly changing voltage, while a carrier's level is relatively constant.

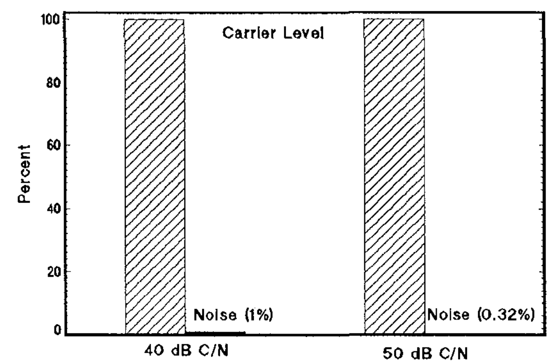

Fig 1 – Carrier vs Noise Levels

In Figure 1, note that for a 40 dB C/N, the voltage level of the noise is 1/100th of the carrier level and for 50 dB C/N it is 1/316th! In this case it doesn't even show up on the chart. One consequence of this is difficulty in getting the same kind of repeatable measurement results we are used to seeing when measuring higher level signals such as carrier levels.

CORRECTION FACTORS

When measuring noise, a number of corrections to the initial instrument readout are usually necessary. To understand what they are and why they are used, let's look at five of the most important of these.

Noise-Equivalent Bandwidth

To measure C/N in an ideal world we would use a perfectly rectangular, 4 MHz wide filter centered at the desired frequency with its output connected to a power meter.

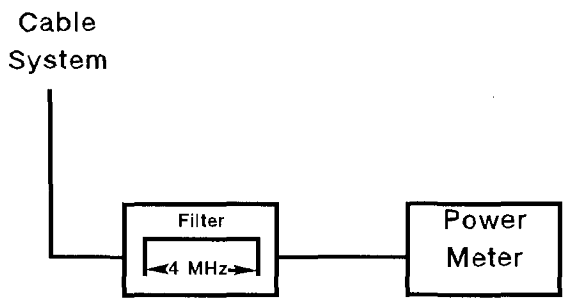

Fig 2 - Ideal World Setup

Unfortunately, our ideal world scenario is not possible for a number of reasons. These reasons give rise to the correction factors that are necessary in practice.

The first problem we encounter is that perfectly rectangular filters do not exist. So we must introduce the concept of "noise-equivalent bandwidth". This is simply the bandwidth that the filter would have if it were perfectly rectangular and letting through the same amount of noise as the imperfect filter. Since filter bandwidths are often specified as their bandwidth 3 dB down on either side of center frequency, our first correction factor is to change the specified bandwidth to a noise-equivalent bandwidth. A typical value is 0.52 dB. This means that, in this case, the noise-equivalent bandwidth is slightly wider than the specified bandwidth.

Correction to 4 MHz Bandwidth

We now know that specifying a filter by its noise-equivalent bandwidth gives us an effectively perfect rectangular filter. However, it still isn't likely to be what we want, i.e. exactly 4 MHz wide. So our second correction factor changes our real world filter bandwidth (whatever it is) to 4 MHz.

Loss

Real world filters have loss. Fortunately, since the carrier-to-noise test is a relative test where both measurements, carrier level and noise, are done through the same loss, we can usually neglect this factor.

Noise Figure

Now that we have dealt with the filter in Figure 2, let's consider the power meter. Again, the ideal world setup doesn't work. This is because power meters cannot directly measure the low levels of noise we need to measure. So we have to add an amplifier to bring the noise level up to what the meter can measure. But the amplifier adds its own noise. How much? What other effects could it have on the measurement?

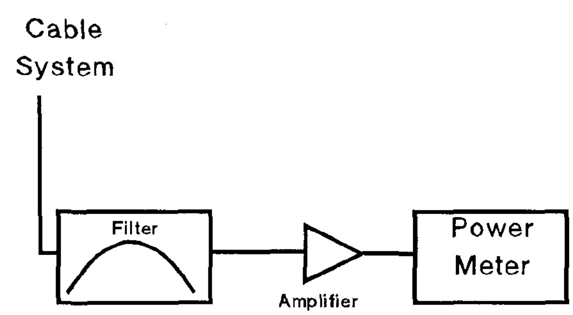

Fig 3 - Real World Setup

In practice, we usually only consider the effect of the amplifier's noise contribution (defined by its noise figure) and assume the other effects it could have on the measurement to be negligible. Thus, noise figure is our third correction factor.

So far, we have introduced three noise measurement correction factors:

1. Filter noise-equivalent bandwidth

2. Filter bandwidth corrected to 4 MHz

3. Amplifier noise figure

Real World Practices

Why don't we normally measure C/N with the Figure 3 setup? There are several reasons:

1. The setup in Figure 3 does not provide for a way to adjust a tunable bandpass filter.

2. Knowing the filter's noise-equivalent bandwidth is critical to the measurement, but the bandwidth of tunable filters varies as a percent of center frequency, so their noise-equivalent bandwidth will also change with tuning. Using calibrated filters is possible, but not very convenient.

3. Measuring in an exactly 4 MHz wide bandwidth has an advantage in that it incorporates any ripple or slope in the noise level over this range. However, it will also include any distortion products, extraneous signals, or the unmodulated carrier, if present. This might lead to an erroneously high result. In practice, noise measurements are done in narrower bandwidths, typically from 30 to 300 kHz, and then corrected to 4 MHz.†

4. Power meters are not commonly available at cable TV shops.

Using a Spectrum Analyzer

Spectrum analyzers are commonly available at cable TV shops and are very convenient to use for this purpose.

When it is not sweeping (zero span), a spectrum analyzer is a fixed tuned, frequency selective voltmeter. When it is sweeping, it is simply displaying the results of a series of measurements made over a range of frequencies. When an analyzer displays power, it is calculated from that measured voltage.

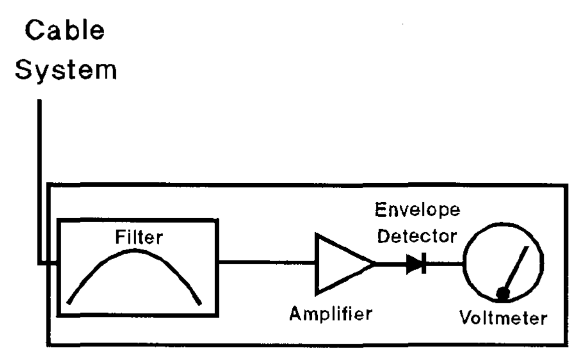

Fig 4 – Spectrum Analyzer

In Figure 4 we have transformed the ideal, but impractical setup of Figure 2 into a real world, practical measurement setup through the use of these three correction factors:

1. Filter noise-equivalent-bandwidth

2. Filter bandwidth corrected to 4 MHz

3. Amplifier noise figure

Logarithmic Detection of Noise

But, we're not done. The fourth correction factor to be introduced is a result of using the measurement unit "dB".

A spectrum analyzer is a voltmeter which, when displaying results in units of dB(m, mV, etc.), is actually measuring a voltage that has been converted into a logarithmic value. This allows very widely differing levels, such as carrier and noise, to be easily viewed on the same display. Otherwise noise, for example, when on screen with a carrier, would be too small to see. For an example of what this would look like, see Figure 1.

However, measuring noise in dB reports a value 2.5 dB too low. This is made up of 1.05 dB from envelope detecting the Gaussian noise distribution and 1.45 dB from logging that result. So our fourth correction factor is to add 2.5 dB to our measured noise level.

Our correction factor list now looks like:

1. Filter noise-equivalent bandwidth

2. Filter bandwidth corrected to 4 MHz

3. Amplifier (spectrum analyzer) noise figure

4. Log detect noise

Preamp Noise Contribution

The setup in Figure 4 performs well when measuring C/N in high level parts of the distribution system, such as at line extender outputs. However, for measuring C/N at lower levels (e.g. +15 to +25 dBmV or less) the amplifier noise figure correction, #3 above, is not adequate.

This is because spectrum analyzer designs put a high priority on amplitude accuracy. This is done at the expense of sensitivity. Thus, noise figure is traded off for best amplitude accuracy. To boost the noise to be measured into the measuring range of the spectrum analyzer, a preamplifier is used. See Figure 5.

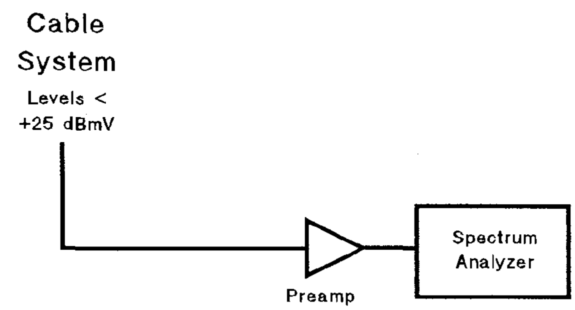

Fig 5 – Spectrum Analyzer w/ Preamp

We have now added yet another uncertainty to the measurement and have to add another noise figure correction factor. Our list of corrections with typical values for a spectrum analyzer now looks like:

1. Noise-eq-BW: 0.52 dB
2. 30 kHz to 4 MHz: 21.25 dB
3. Analyzer noise figure: (use Fig 6)
4. Log detect noise: 2.5 dB
5. Preamp noise figure: (use Fig 7)

An Example

Now that we know the correction factors involved, let's do an example measurement. Here are some typical measurement conditions:

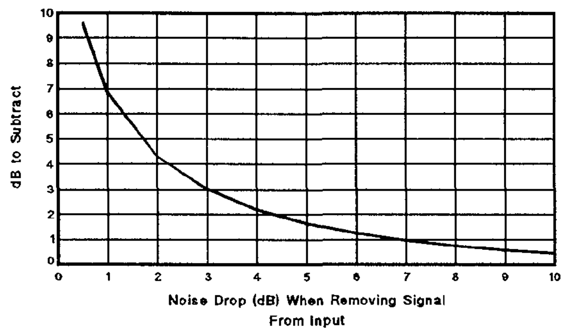

Fig 6 - Noise-near-Noise Correction

Carrier level at preamp output:	+13 dBmV
Uncorrected C/N:	73 dB
Noise drop when disconnecting cable from analyzer input: (use Fig. 6 to get 0.6 dB)	9 dB
Preamp Gain:	10 dB
Preamp Noise Figure:	7 dB

Using the above information we calculate C/N at the output of the preamp:

C/N at preamp output =

73 -	(Uncorrected C/N)
(-0.52	(Filter noise-equivalent bandwidth)
+21.25	(30 kHz to 4 MHz)
+2.5	(Log detect noise)
-0.6) =	(Analyzer noise fig)

50.37 dB C/N at preamp output

Now, to correct for the noise contribution of the preamp, we subtract the C/N just found above from the carrier level at the INPUT of the preamp, which is the output carrier level minus the gain:

+13 - 10 - 50.37 = -47.37

Find -47.37 on the x-axis of Figure 7 to find the noise correction value of 1.3 dB on the curve for a noise figure of 7 dB. This means the preamp is adding 1.3 dB of noise at its output so we should add thus:

50.37 + 1.3 = 51.67 dB C/N

51.67 dB C/N is now the value we would have measured with the ideal Figure 2 setup if it were possible.

Note that equation (1) at the end of this paper can also be used to directly calculate C/N at the preamp input.

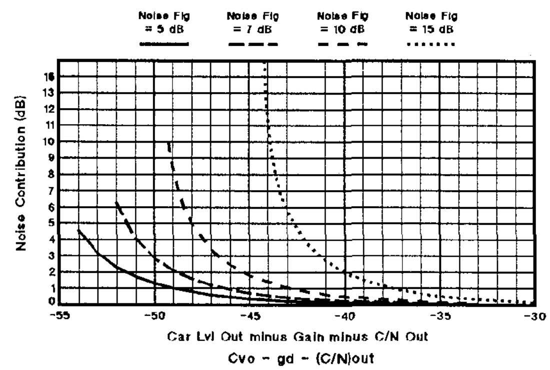

Fig 7 - Preamp Noise Contribution

SMART INSTRUMENTS

Newer spectrum analyzers, such as the HP8591E with cable TV measurement personalities, can automate many of the above tasks.

For example, Figure 8 shows the measurement information screen of the carrier-to-noise test in the HP85711B CATV measurements personality. It shows exactly how the instrument calculated C/N and what values it used for the correction factors.

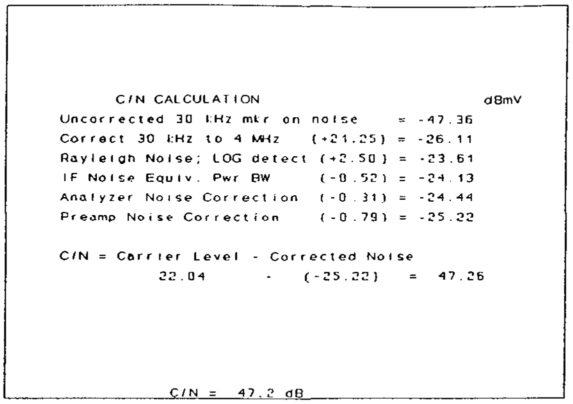

Figure 8

CONCLUSION

Getting repeatable results when measuring carrier-to-noise over a wide dynamic range requires attention to a number of details. Modern instrumentation can do a lot of the work while increasing measurement accuracy and reducing errors.

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†The noise measurement bandwidth used with a spectrum analyzer is often 30 kHz. Theoretically, any bandwidth can be used as long as the correction to 4 MHz is done properly from the chosen bandwidth. 30 kHz is a good compromise between keeping a reasonable measurement dynamic range and minimizing the effects of distortion products and of the carrier (if present) on the lower end of the noise measurement range.

PREAMP NOISE EQUATION

$$(C/N)_{sig} = C_{vo} - g_d - 10LOG\left[10^{\frac{C_{vo}-g_d-(C/N)_{out}}{10}} + 10^{\frac{-59.2}{10}} - 10^{\frac{-59.2+nf}{10}}\right] \quad (1)$$

Where:

$(C/N)_{out}$ = Carrier-to-noise at preamp output (dB)
$(C/N)_{sig}$ = Carrier-to-noise of applied signal at preamp input (dB)
C_{vo} = Visual carrier level at preamp output (dBmV)
nf = Preamp noise figure (dB)
g_d = Preamp gain (dB)
-59.2 = Thermal noise in a 4 MHz noise BW @ 17.5 °C (dBmV)

YOUR FUTURE IN EMERGENCY ALERTING

Kenneth Wright
Jones Intercable
Chair - SCTE EBS subcommittee

Abstract

Under the direction of the White House, the FCC has begun an overhaul of the Emergency Broadcasting System. They believe that they can greatly improve the effectiveness of the system by adding cable participation. Participation in the new system truly represents an opportunity for cable operators to help minimize the loss of lives in their communities. It also could represent a significant cost to the cable industry.

WHY THE CHANGE ?

After hurricane Hugo, and shortly before Operation Desert Shield was publicly announced, the white house directed the FCC to update the Emergency Broadcasting System (EBS) in order to provide an effective means of alerting the public to both national and local emergency situations. Following an initial investigation, FCC staff determined that cable operators needed to be involved in the system. In fact, former FCC Chairman Sikes stated a number of times that "Since over 60% of U.S. households now have cable television, no emergency alert system would be effective without cable participation".

For this reason, Chairman Sikes asked the cable industry to participate in designing the new system and in determining how cable would participate in the new system. In response to this, the SCTE established the EBS subcommittee. It has been the feeling of our committee that, since the FCC intends to include cable in the new system, it would be best to be involved in defining both the system and our participation.

THE CURRENT SYSTEM

Under the current EBS, when there is a reason to activate the system, the activating party notifies designated regional broadcast stations (called CPCS-1 stations). These broadcasters transmit a "two-tone" signal (that annoying sound which makes you change stations once a week during tests). The two-tone is received by secondary broadcasters, who are required to monitor the CPCS-1 station, and retransmitted. Broadcasters who are down stream from (and monitoring) these secondary stations then, in turn, retransmit the signal to still more distant broadcasters, and so on.

This "daisy chaining" method of delivering the activation is one the areas of weakness with the current system which the FCC has identified. If any broadcast station in the link does not retransmit the signal, all stations (and listeners) down stream do not get the message. In addition, it is felt that the two-tone is an antiquated and ineffective method of signaling, primarily because it can not deliver any information about the emergency situation.

Another area of weakness with the current system is the human factor. If a broadcast operator (announcer) does not hear the alert, or is not properly trained in what to do when an alert is received (which is often the case), the alert will not be passed on to other areas.

THE NEW SYSTEM

As currently proposed, the new system would improve upon the current system in a number of ways. The system could be activated by a number of authorities at the Federal, State, and local level. These could include the National Weather Service (since 85% of emergencies are weather related), local emergency management offices or police agencies, and private industries which pose a danger to their communities (such as nuclear power plants, chemical plants, etc.).

System participants (such as broadcasters and cable operators) could receive activations from a number of sources, thereby eliminating the daisy chaining limitations. Equipment for the new system would automatically override programming in the event of an emergency situation, to ensure that human error didn't preclude getting the alert out.

A new, addressable, digital signalling scheme would replace the current two-tone method. Not only would this speed up the activation of the network, but it would allow for the transmission of pertinent information. For example, information could be coded in data fields to indicate: whether the activation was a test or an actual emergency; the nature and severity of the emergency; and the affected area(s). The participants equipment could use this information so that the alert was only transmitted in affected areas (thereby eliminating the "cry wolf" situation experienced with the current system).

CABLE PARTICIPATION

In order to participate in the new system, a cable operator would need to have two pieces of equipment. The first is a new receiver/decoder device which the FCC proposed for all participants in both the Notice Of Inquiry (NOI) and the Notice of Proposed Rule Making (NPRM) regarding EBS. This device would monitor several sources, receive the activation signal, decode the information contained in the received signal, and, if appropriate, trigger the second piece of equipment. This second piece would be the equipment which delivers the emergency message to the subscriber.

There are a number of ways in which the cable operator could deliver the alert to subscribers. These include an override of audio programming, an override of video programming, a text crawl in the video, or a combination of these. In addition, equipment exists for the operator to deliver an alert independent of the television. With this equipment, a signal transmitted over the cable system activates an in home receiver (with broadband pass through). This receiver can then activate alarms, strobe lights, bed shakers, etc. This could address the concern of how to alert the hearing impaired or persons who are watching a signal from a VCR or have their television and radio turned off.

The FCC staff has been very interested in all of the above capabilities of cable systems. Our committee has put significant effort into stressing the costs associated with each of these capabilities.

INPUT TO FCC

Since its formation just over a year ago, our subcommittee has focused primarily on working with the FCC to provide them with a clearer understanding of cable's capabilities <u>and</u> limitations, as well as the cost implications to cable of participating in the new system. We have done this through frequent conversations with their EBS staff, serving on various work groups of theirs, and filing documents with them during their Notice Of Inquiry and Notice of Proposed Rule Making procedures. Along with these efforts, we have also researched the equipment which cable operators have already installed and the equipment alternatives which cable has available to it today.

Cable's Needs

One area which we have addressed with the FCC is the differences between cable and broadcasters (the traditional EBS participants). Since virtually all cable head ends are unattended sites (no round-the-clock staff to operate EBS equipment), it is essential that the new system operate in an automated mode (this is prohibited under current regulations). In addition, it will be necessary to have the emergency information (such as an audio and/or text message) fed to us so that our equipment can merely pass it through to subscribers (since we don't have announcers on duty). Cable operators will also need to receive an "end-of-message" signal so that our override equipment can be triggered to return to normal programming. We have also pointed out repeatedly that, unlike broadcasters, we will have the hardware cost of overriding not one, but dozens of channels.

Existing Equipment

We have also made the FCC aware that approximately four thousand cable head ends currently have programming override equipment in place. It is crucial that the new regulations not obsolete this alerting equipment investment which the industry has already made. Almost all of this equipment is activated with DTMF signals (via a phone line from a local authority) and provides a blanket override of the audio (only) signal of all channels.

Cost Of Participation

An area in which we have provided a significant amount of input to the FCC is the capital cost to cable operators of participating in the new system. In addition to addressing specific cost issues, we took the stance that equipment purchases should not be mandatory unless Federal or State funding is made available to offset those purchases. We felt that private businesses should not be required to fund this public program.

In the NPRM, the FCC estimated the cost of the new device at $3000. Assuming that this is accurate, and that there are 11,086 cable head ends in the U.S., this represents a cost to the industry of $33,258,000.

However, the larger cost by far will be the equipment for delivering the alert to the subscribers. Because there are approximately four thousand head ends with audio only override capabilities in place, we have strongly encouraged the FCC to only require cable operators to provide an audio override. As a result, when the NPRM was issued, it only proposed audio override capabilities for cable. However, in response to the NPRM, the FCC has received input (primarilly from the hearing impaired community and vendors) to require both audio and video override. At this point, they appear to be leaning toward requiring both in the Final Report and Order.

If the audio override equipment which is in place should prove to be acceptable, and we should need to outfit the 7,086 remaining head ends with audio override capability, this could be done for approximately $10,000 per head end. This represents a cost to the cable industry of $70,860,000. Added to the cost of the proposed new device, this represents a total cost to the industry of just over $100,000,000.

However, in the seemingly likely event that the FCC reverts to the position of requiring audio and video override, the cost will be significantly higher. Equipping a head end for audio and video override with equipment which is readily available today would cost approximately $42,000 for a

400MHz system. Since almost no head ends are currently equipped for video override, this would need to be done for almost all 11,086 head ends. This represents a cost to the cable industry of $465,612,000. Added to the cost of the proposed new device, this represents a total cost to the industry of just under $500,000,000.

It should be noted that we have spoken with a number of manufacturers regarding the development of lower cost equipment which would be either an alternative or an adjunct to the currently available equipment. At least one has responded with a design for such equipment. They feel that, once the FCC finalizes specifications for the new system, this equipment could be developed and produced within approximately six months.

Small And/Or Rural Systems

We have expressed particular concern over the impact on small and/or rural cable systems. It is important to note that, of the 11,086 cable systems in the United States, more than 5,800 serve fewer than 1000 subscribers. It is also crucial that it be realized that a typical cable system serving 500 subscribers likely has a net income (before taxes, depreciation, and interest) of approximately $70,000 annually. Mandatory participation in a new 'EBS' type system which would require equipment purchases in excess of $40,000 would be financially devastating to these operations. For these operations in particular, there needs to be some form of protection from the financial burden of participation - whether that protection comes in the form of federal or state funding of equipment, or a waiver of the participation requirements.

Digital Signals

In reply to the NPRM, we pointed out that the cable industry is moving very aggressively (and rapidly) toward transporting compressed, digitized video signals. We also stated that this is a major step toward a much larger and more important goal of establishing a broadband, high speed, telecommunications 'digital highway'.

Indeed, there has been much discussion and interest on the part of communications-dependant industries (such as computer industries), as well as legislators, the FCC, and the new administration, in the establishment of such a 'digital highway'. In addition to enhancing the competitive abilities of American businesses, this would allow the United States to maintain a status as the world leader in telecommunications infrastructure. We feel certain that the FCC will not want this rule making to impede such development.

We also pointed out that in the early stages of transporting compressed digitized video signals, many cable operators will merely pass through digital signals which they receive via a satellite link. In many cases, the local cable operator will not be able to alter the signal in order to insert information or override programming.

Including Other Technologies

The NPRM sought comment on the inclusion of other technologies as participants in the new system. We supported this idea on the understanding that the FCC desires to add cable television to 'EBS' in order to reach all viewers with emergency messages. We stated that, in order for the new system to approach ubiquitous coverage, it is essential that participation include Wireless Cable (MMDS), Satellite Master Antenna Television (SMATV), Multichannel Local Distribution Service (MLDS), video dial tone, and all other present and future providers (and technologies) of audio and video services.

Implementation Timetable

In the NPRM, the FCC proposed that all equipment be installed and operational by July 1, 1994. We replied that, before participants can implement equipment for the new system, a Rule Making will need to specify parameters for the new device and for the activation signal(s). Following that, manufacturers will need to develop and produce the necessary hardware. We suggested that the implementation timetable be tied to the commercial availability of the required equipment, rather than being fixed at this point. In addition, we stated that, after the equipment becomes available, participants will need sufficient time to plan, budget, install, test and activate the equipment. We therefore recommended that full implementation be set at 24 months after the equipment becomes available.

System Testing

Due to the "cry wolf syndrome" which results from the excessive testing of the current EBS system, we recommended that the weekly testing of the new system be done in a silent mode. this could be done by testing the system up to the point of programming override. Because there is a need to maintain some public awareness, and to test the final piece of the system (programming override), we proposed that the "on-air" testing be reduced to monthly, with all participants in an operational area testing simultaneously (to eliminate the "tune out" associated with the current one-at-a-time approach).

Other Areas Of Input

While most of the key points of concern have been discussed here, there are many other topics which were addressed in the subcommittees filing with the FCC. These include: voluntary versus mandatory participation; suggested features and configuration of the new device; the ability to automatically turn on televisions and radios during an alert; the shortening/elimination of the two-tone signal (to be used as an audible alert only); and the re-naming of EBS to eliminate the use of the word "Broadcast".

WHERE DO WE GO FROM HERE?

This summer, a work group established by the FCC will be conducting tests of some of the potential equipment, protocols, and operational aspects of the proposed new system. Members of our committee will be involved in those tests, as well as in the formulation of recommendations based upon the results.

We will also continue our discussions with potential manufacturers toward the development of low cost alternatives for the hardware requirements. It could be very beneficial for individual operators to also pursue this with their vendor contacts.

In addition to the new national system, each state and operational area has been charged with developing their own local plan to compliment the national system. In many cases, the committees which are formulating these plans are comprised entirely of broadcasters. In some cases, plans have been developed with requirements for cable operators which are difficult, if not impossible, to meet.

The FCC has committed to placing cable representatives as co-chairs on each of these committees (if candidates can be identified). We would strongly urge anyone who is interested to become involved (whether or not as co-chair) in these committees.

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