FIBER BACKBONE - MULTI-CHANNEL AM VIDEO TRUNKING

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Abstract - This presentation updates a scenario for the evolutionary integration of optical fiber transmission technology into existing cable television networks first presented at the NCTA transactions in 1988. The resulting "fiber backbone" yields a hybrid fiber/coaxial network with significantly better reliability and transmission quality than present systems. System and electro-optical component advances in the last year are reviewed, and the merits of various modulation techniques are examined. The fiber backbone approach emphasizes continuing the broadband delivery of a large number of video signals to the consumer.

INTRODUCTION

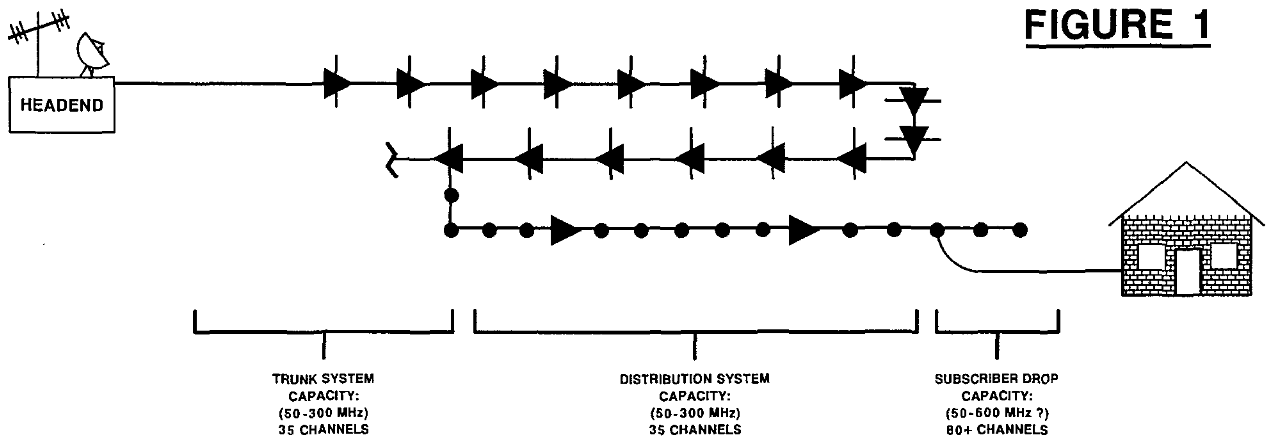
Optical Fiber Transmission Technology has achieved rapidly increasing acceptance by the cable television industry. While 87% of the homes in the United States are already passed by a broadband coaxial CATV network, coaxial technology, as it is presently being used, is beginning to approach its performance limits. Optical fiber offers a high bandwidth, low loss transmission medium which holds out the potential to allow significant performance improvement in today's cable television networks.

For some years, there has been increasing use of fiber for "supertrunking": high quality point-to-point video interconnections between major system hubs, connections earth station/headend connections, and links between headends to allow simultaneous insertion of local commercials. These fiber supertrunks have proven themselves to be highly reliable and cost effective, offering, in many situations, a viable alternative to microwave interconnection.[1,2]

It is, therefore, natural that the CATV industry has sought additional ways to use this new technology to improve its networks. The authors previously described an approach to such a use which they termed "fiber backbone".[3] In examining current CATV system architecture, it was noted that most of the performance limitations, including those reliability, transmission quality, and useable bandwidth, stemmed from the long amplifier cascades required by typical CATV tree-and-branch architecture when used in medium to large communities. This, in turn, is a product of the relatively high loss of coaxial cables (on the order of 1 dB per 100 feet: a loss of half the signal voltage every 600 feet). This loss, and the large number of amplifiers required in series to counteract it, requires that CATV system bandwidth be limited far below the potential of the coaxial transmission medium in order to achieve acceptable signal transmission performance. Current system architecture is illustrated in figure 1.

The optical fiber transmission medium exhibits extremely low signal loss (on the order of 1dB of signal power per mile). The fiber backbone approach to CATV system architecture is designed to replace long runs of coaxial plant, which often contain twenty or thirty amplifiers in series, with completely passive low loss fiber trunks as illustrated in figure 2. With a fiber system within one or two miles of all subscribers, CATV signals can be handed off to an existing RF broadband coaxial network for delivery. By limiting the total number of amplifiers between the CATV system headend and any subscriber to a small number, significant improvements in reliability and signal quality can be achieved, and there is an opportunity to upgrade the remaining coaxial portion of the network to achieve substantially greater bandwidth then possible in traditional CATV systems.[4,5]

FIGURE 1



While conceptually simple, optical terminal technology capable of delivering broadband multi-channel signals to the coaxial portion of a system is technically very challenging. Nevertheless, substantial progress has been made on this front by a number of system developers, and implementation of both demonstration and operational fiber backbone systems has begun by a number of cable operating companies during the last year. There is growing acceptance of the idea that a hybrid fiber/coaxial CATV system has the potential to provide significant improvements in performance and channel capacity at relatively modest cost as the cable industry faces the challenges of the next decade.

DESIGNING A HYBRID SYSTEM

There are many different network topologies which could be adopted using a hybrid fiber/coaxial transmission medium. Questions naturally arise as to what forms of modulation should be used in which portions of the system, and how close to the home the fiber portion of the hybrid plant should extend.

AM MODULATION

There are several types of modulation available for the transmission of video information. The most obvious is amplitude modulation with a vestigial sideband (AM-VSB). This is perhaps the most bandwidth-efficient practical modulation system available for video transmission, and is used for over-the-air television broadcasting as well as in current CATV systems. With it, NTSC video can be transmitted within a 6 MHz channel. In addition to bandwidth efficiency, AM/VSB enjoys tremendous ubiquity. It is estimated that there are over one hundred and sixty million television sets in use in the U.S. today. All of these sets are designed to accept AM/VSB modulated video as their input. It follows that, regardless of the transmission modulation system adopted, AM/VSB modulation must be the final product of a CATV system at the point of hand-off to the customer's television set. Today's cable television systems use AM/VSB modulation throughout, with a simple broadband coaxial transmission medium carrying signals all the way to the television set. Some televisions require a channel converter, a hetrodyne frequency conversion device, if they cannot tune all channels provided bv the cable system directly. Our researcn indicates, however, that 52% of cable homes currently own at least one cable-ready television set capable of tuning non-standard cable channels directly. While converters with built-in descramblers are also sometimes used for signal security, particularly for premium services, the cable television industry's approach of delivering signal all the way to the home in directly tunable multi-channel AM/VSB form is clearly highly attractive.

FM MODULATION

Frequency modulation of video signals in the RF domain allows high quality multi-channel video transmission. FM video requires substantially more bandwidth than AM, unusally from 10 to 40 MHz per channel, depending upon the performance improvement sought. FM video is widely used for satellite transmission, as well as for cable supertrunking. At some point in any distribution system using FM, however, there must be demodulation of the FM signal and AM/VSB

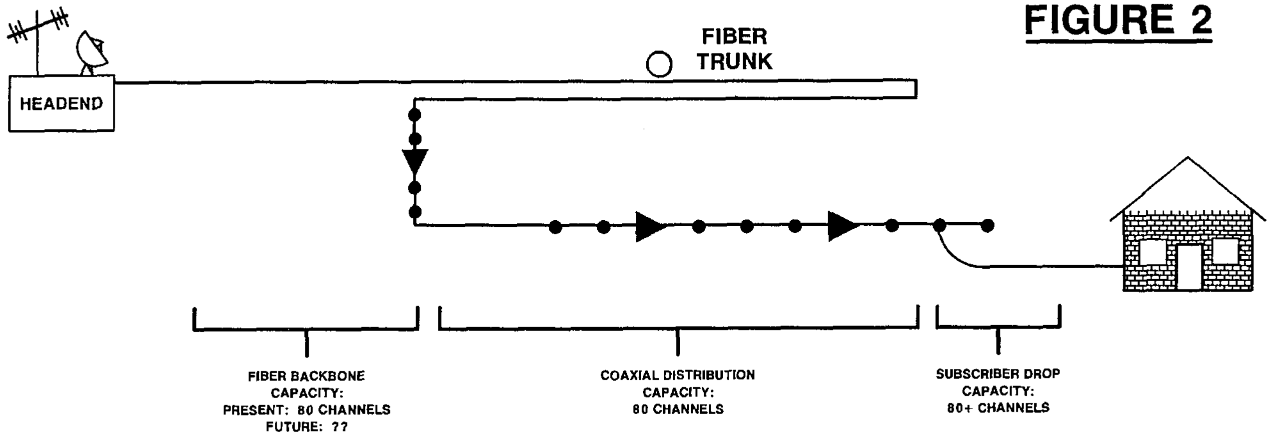


FIGURE 2

remodulation of the resulting baseband video in order that it may be received by today's television sets.

Carrying FM video all the way to the home would require an FM receiver to demodulate the selected channel, and an AM modulator to remodulate it for viewing or recording. One of these receivers would be required for each TV or VCR in the home and many of the built-in features of televisions and VCRs, such as remote control tuning, would be rendered useless. FM is used today for high quality supertrunks. Upon delivery of FM signals to a system hub, each is demodulated and remodulated using AM/VSB modulation onto the correct RF channel for coaxial transmission to the home. FM has transmission quality advantages over AM, but the costs of modulation conversion limit how deep into a CATV system it is economically practical to use it.

DIGITAL TRANSMISSION

Digital modulation is an obvious approach to video distribution in systems which use optical fiber transmission. Although digital modulation is highly bandwidth inefficient, this will matter less in the future as fiber systems realize greater bandwidth. Digital modulation has the advantages of offering high transmission quality and almost infinite repeatability as its binary codes can be recovered and regenerated as needed.

Digital modulation is likely to become wide-spread in CATV supertrunking as large urban systems interconnect hubs with redundant routing to improve reliability. Costs for the electronic components required for digital video transmission will continue to drop. Nevertheless, the cost of converting to AM/VSB modulation will limit the depth into the CATV network to which digital modulation will be economically practical.

TRADE-OFFS

It is apparent that each modulation scheme has its advantages and potential points of application in a CATV system. In a hybrid fiber/coaxial system, it can be assumed that there will be a significant cost for the conversion interface between the optical and RF portions of the system. It can also be assumed that there will be a significant cost for conversions in the type of modulation used. It is assumed that there is a potential role for different modulation schemes and for both optical and coaxial RF transmission. The cost/benefit trade-offs will determine how far into the network both non-AM/VSB modulation and optical transmission should extend, since there is a strong economic motivation to limit the number of conversion points for both the transmission medium and the modulation, and since AM/VSB signals within a broadband RF spectrum is assumed to be the required final product.

Figure 3 shows a plot of relative system improvements as the coaxial portion of a CATV system is shortened and the number of amplifiers in cascade is reduced. These relative benefits include an improvement in both system reliability and transmission quality arising from the use of fewer active components in series, as well as the ability to deliver more channels. There is a direct relationship between amplifier cascade reduction and relative performance improvement.

Also in figure 3 is an estimation of the cost per home involved in the reduction of amplifier cascade through the extension of passive fiber plant closer to the home. This curve rises exponentially, as tree-and-branch architecture dramatically increases the number of conversion points required as the system approaches the home. The point of cavity. This structure acts as a reflector, where light is partially reflected from each corrugation. If the wavelength of the light matches the structure wavelength, all of the reflections from the structure are summed coherently and the light continues to travel in the cavity and to be amplified. If the wavelength does not match the grating, the reflections cancel out. Single mode operation is achievable in DFB lasers.

The best noise and intermodulation performance observed to date in ATC's testing have been in DFB lasers. An important element in maintaining low-noise operation of DFB lasers appears to be limiting the amount of reflected light re-entering the laser from the transmission medium. External reflections which have less than -40dB of attenuation appeared to cause a rapid increase in the laser's Relative Intensity Noise (RIN). In order to achieve useful performance in a multi-channel CATV system, where carrier-to-noise ratios of 53 to 55 dB or better are desirable, RIN's approaching -160 dB/Hz appear to be required. It is, therefore, critical that external reflections be controlled. Success has been observed with both external Faraday rotation isolators, and with systems which utilize careful splicing of geometrically matched fibers and incline-ground connectors and inclined detector faces to minimize reflections.

DFB lasers are relatively expensive, as there are two diffusion steps in their fabrication, and yields are relatively low in each step. Nevertheless, DFB structures hold out great promise for AM fiber backbone systems for the CATV industry.

QUANTUM WELL LASERS

This is a new technology, and quantum well lasers are not commercially available now. In quantum well lasers, the area where electrons combine with holes is made very thin. There are several ways to build a laser having quantum wells, and usually a single mode of operation is achieved, with a line width narrower than that of current DFB lasers. Another benefit of quantum well structure is in having very low threshhold current, enabling operation of the laser with less external electronics.

Quantum well structures may be constructed in a Fabry Perot cavity laser, with the promise of better performance and lower prices than existing DFB lasers. Quantum well structures may also be combined with a DFB cavity to create still better performance, but at a premium price.

Quantum well semiconductor laser technology is expected to develop over the next several years, and holds out the promise of dramatic improvements in noise performance for optical links used in AM fiber backbone systems.

EXTERNAL CAVITY LASERS

In external cavity lasers, the semiconductor laser cavity is optically coupled to a second, external, cavity. There are many different structures possible, but the main idea is to fabricate a device which enables the creation of an extremely narrow line width, and a corresponding decrease in modal noise. External cavities may be combined with DFB and quantum well laser structures, as well as basic Fabry Perot structures.

External cavity lasers exist today only in the laboratory. The main development problems to be overcome relate to physical stability with respect to vibration and temperature change. The possibility of an external cavity integrated on the same substrate with the laser is being explored and holds great promise. The commercialization of these lasers, with the potential for very high performance at low cost, may be 5 to 10 years away.

EXTERNAL MODULATORS

Another promising line of development work involves the generation of low noise, high power light using a constant-output Continuous Wave (CW) laser, feeding an external modulator. This is illustrated in figure 5. This allows the generation of substantially more optical power than is possible in practical, directly modulated lasers. The external modulators available today are of the Mach-Zehnder inferometer type. These devices split the optical input and allow it to follow two paths through the device. One leg is entirely passive, but the other allows variable delay through the application of an electrical field. If this field is varied, the delay will vary, and the output of the device, where the legs are

FIGURE 3

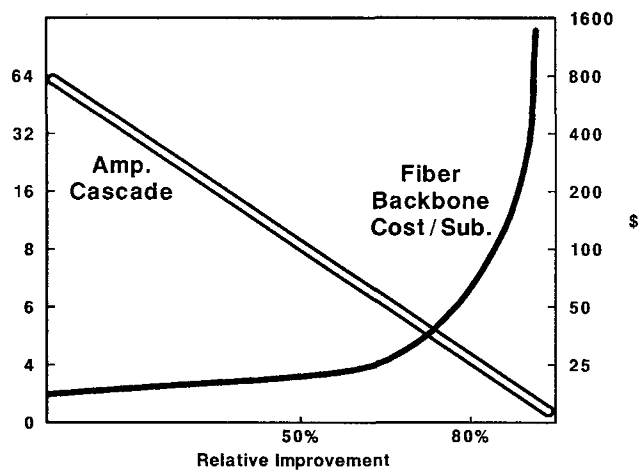
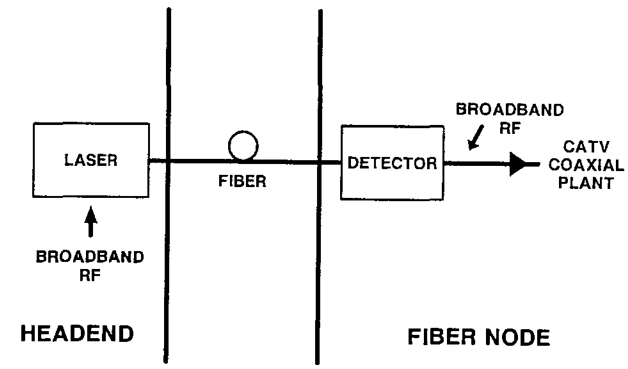


FIGURE 4



diminishing returns is difficult to pin-point precisely, but it appears that the optimum balance between fiber and coaxial plant in a hybrid system comes with a maximum amplifier cascade between two and five trunks amplifiers.

OPTICAL COMPONENTS FOR USE IN AM VIDEO FIBER SYSTEMS

It is apparent that in a hybrid fiber/coaxial CATV system, it would be highly desirable to maintain AM/VSB modulation throughout. If this could be accomplished, the only signal conversion required outside of the headend would be that from optical to RF at the end of each optical trunk. This approach greatly simplifies the electronics needed at each conversion point, since it should be possible to directly detect the intensity modulation of the light on the fiber, with the resulting detected output being the broadband RF spectrum, a complex waveform complete with all the original channel information, scrambling, data carriers, etc. Such a conversion point could be contained in a small weather-proof housing, directly powered off the coaxial portion of the CATV system. Because AM/VSB modulation is relatively fragile, however, this approach is technically quite challenging.

Figure 4 shows a simple block diagram of an ideal system. At the headend, the broadband AM/VSB signal, containing all of the cable channels, is used to directly modulate a laser. This information is transmitted optically through the fiber to a conversion point deep in the cable system, where it is reconverted using a simple detector.

In the last year, substantial progress has been made on the necessary components to effect such a system. It is necessary that the laser used has a high degree of linearity, and adds very little noise to the signal. While there is room for improvement in detectors to insure the lowest possible noise contribution and highest sensitivity, it is the semiconductor lasers used in these systems which dominate system performance. Because this technology is critical to the implementation of practical AM fiber backbone systems, it is worth examining these components more closely.

FABRY PEROT LASERS

In semiconductor lasers, the distance between the laser mirrors defines the possible wavelengths of light amplified in the cavity. Only a integer number of half-waves can oscillate. We call this list of possible wavelengths the "Fabry Perot modes". There are an infinite number of Fabry Perot modes, but within the cavity, only a limited bandwidth is amplified. Normally, 10 to 15 Fabry Perot modes are within the amplification band, and they create the spectrum we see in Fabry Perot lasers.

Laser noise is directly related to the bandwidth of the emitted light. It is of interest, then, to create a laser with just one Fabry Perot mode, and to make this mode as narrow as possible. There are several ways to reduce the number of modes developed in the laser.

DISTRIBUTED FEEDBACK LASERS

Distributed feedback (DFB) is the most common means of achieving single mode operation. The laser is fabricated with a corrugated grating structure along the

FIGURE 5

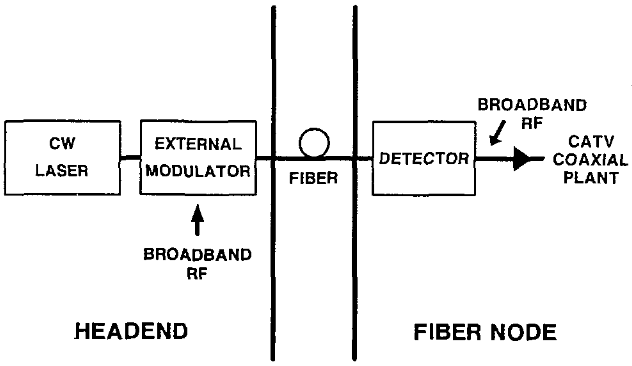


FIGURE 6

DESIRED PERFORMANCE

CHANNELS	60 - 80		
C/N	55	dB	
CTB	65	dB	
CSO	65	dB	
CROSS MOD.	65	dB	
POWER BUDGET	10	dB	(20 Km/12 Mi)

recombined, will vary through signal addition and subtraction caused by the relative phasing of the light through the two paths.

The primary drawback to Mach-Zehnder devices are that the modulation process is inherently non-linear. The change in intensity at the output of the device is related to the change in input voltage by a sine function. Non-linearity in a broadband, multi-channel device creates severe problems in the form of intermodulation products, but the fact that the Mach-Zehnder modulator has a precisely predictable characteristic opens the possibility that either preemphasis, feedback, or feedforward techniques can be used to produce overall system linearity.

It is possible that practical externally modulated optical transmitters will be realized with high enough output levels that they can be used in relatively long-haul applications, or that their outputs can be split to feed a number of conversion points in an AM backbone system, allowing the relatively high cost of the transmitter to be shared over several links.

OVERVIEW

While significant progress has been made in optical links for use in an AM backbone system, it is the authors' opinion that price/performance that the point which has been achieved is still somewhat short of that required for widespread proliferation of AM fiber backbone technology in CATV system rebuilds and upgrades. We continue to believe that the achievement of the goals illustrated in figure 6 will spark massive adoption of this technology by the CATV industry when combined with a cost between $5,000 and $10,000 per link. Nevertheless, developments by optical component manufacturers are the key element in achieving these goals, and it is clear that component technology has many promising avenues to explore.

CURRENT SYSTEMS

Figure 7 illustrates the results of ATC's most current system tests. These results are conservative but repeatable, and are made with CW carriers from a Matrix multi-channel signal generator. Multi-channel systems with asynchronous video modulating signals will yield somewhat better results. It can be seen that the goals set by ATC are being approached relatively closely by some of these systems. While the pricing of these systems ranges from $15,000 dollars to $30,000 per link, we expect that during 1989 there will be delivery to the CATV industry of a significant number of links, that the goals we have outlined will be met, and that prices will begin to drop toward the target we have set.

It should be noted that decreasing the channel loading of AM optical links has a relatively dramatic impact on performance. First, noise performance improves by 3 dB each time the number of channels is cut in half. Secondly, the available power budget also increases dramatically as the number of channels is decreased and the modulation index per channel increases correspondingly. This has lead to the commercial development of AM transmission systems of the type shown in figure 8. These multi-fiber/multi-laser systems are capable of carrier-to-noise ratio performance in the high 50's, with power budgets of 10 dB and more.

FIGURE 7

AM FIBER OPTIC LINK RESULTS

SYSTEM	CHANNELS	C/N	CTB	CSO	LOSS BUDGET
A	40	48	60	58	4
B	40	52	65	66	5.2
C	40	53	69	64	6
D	40	54	70	69	5.7

While their cost is high and they make relatively inefficient use of optical fiber, they are clearly useable in some applications. ATC has constructed and tested multi-fiber AM super trunks in several of its systems using this technology, and Jones Intercable has announced the construction of a fiber backbone hybrid system in an upgrade currently underway in Broward County, Florida.[6]

SUMMARY

1988 was the year when the true potential for integrating optical fiber into its systems began to dawn on the CATV industry. 1989 will be the year when the commercialization of practical systems begins to hit its stride, and field deployment will begin. By 1990, it is expected that the system architecture and economics originally predicted by ATC will be realized, that subsequent years will bring further improvements in both performance and price, and that applications will increase dramatically. We believe that the typical CATV system of the mid-'90s will be a hybrid fiber/coaxial network achieving levels of reliability, signal quality, and channel capacity once though unattainable.

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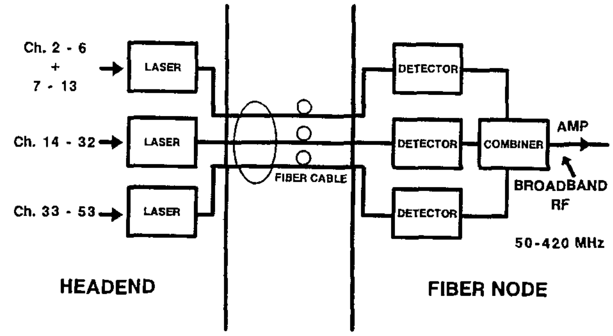
FIGURE 8



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Jim Chiddix - Senior Vice President, Engineering and Technology, for American Television and Communications Corporation, the country's second largest cable television operator, headquartered in Stamford, Connecticut. Mr. Chiddix is responsible for corporate engineering activities as well as research and development. ATC serves 3.9 million subscribers in 32 states and is 82% owned by Time, Inc. Upon completion of its pending merger with Warner Communications, which also owns cable TV operations, the combined companies will serve 5.6 million homes.

ATC leads the cable industry in exploring the use of optical fiber technology in cable television systems. Their "fiber backbone" concept for optical trunking has gained wide acceptance as an evolutionary approach, offering the prospect of improved performance and increased channel capacity from existing cable systems. In recognition of his pioneering role in exploring this use of fiber, Mr. Chiddix was named Man Of The Year by Communication Engineering and Design Magazine in January, 1989.

Mr. Chiddix, 43, has been in the cable television business for 17 years. He spent seven years as General Manager at Cablevision, Inc. in Waianae, Hawaii, and eight years as Engineering Vice President at Oceanic Cablevision in Honolulu, an ATC division. In September, 1986, he joined ATC's corporate office.

Mr. Chiddix is a Senior Member and former Director of the Society of Cable Television Engineers (SCTE). In 1983 he received the National Cable Television Association's Engineering Award for Outstanding Achievement in Operations, reflecting, in part, his role in introducing addressable converter technology.

Dave Pangrac is the director of engineering and technology for American Television and Communications Corporation (ATC), the country's second-largest cable television operator.

Pangrac has been in the cable television business for 22 years. He joined ATC in 1982 as Vice President and chief engineer for American Television of Kansas City and in 1987 joined the ATC corporate staff as director of engineering and technology.

Pangrac is a member of the Society of Cable Television Engineering and past president of the Hart of America Chapter.

Pangrac is currently involved in ATC's effort to develop the use of fiber optic technology in cable television plants.