FIBER BACKBONE: A PROPOSAL FOR AN EVOLUTIONARY CATV NETWORK ARCHITECTURE

James A. Chiddix, David M. Pangrac

American Television and Communications Corporation
Englewood, Colorado

Abstract **- A hybrid optical fiber/coaxial cable CATV system architecture is described. The architecture is intended to be an evolutionary one, building on existing coaxial CATV networks. A variety of approaches to the electro-optical equipment needed to realize such a system are described. Both short term operating benefits and longer term strategic advantages to the approach are explored and the conclusion is drawn that the approach meets both technical and economic needs of the CATV industry.**

INTRODUCTION

The transmission of information on optical fibers has become commonplace in many areas of telecommunications. The medium's great bandwidth, ruggedness, exceedingly low loss, and light weight make it a worthy candidate for use in any high capacity physical transmission system. The CATV industry has been relatively slow to adopt optical fiber as a major element of its networks. This arises in part because coaxial cable has suited CATV's needs relatively well, and because CATV's basic task of delivering scores of video signals has posed some difficult economic and technical challenges for fiber technology. Nevertheless, fiber optic transmission offers the promise of significant benefit to the CATV industry, and it is important that we explore this potential.

FIBER OPTIC SUPER-TRUNKS

Super-trunks are used in the CATV industry for point-to-point delivery of video signals. This is often necessary in large CATV systems to provide high quality signals to major processing points feeding broadband signals to traditional CATV networks. In the past, super-trunks were often constructed using coaxial cable. A common practice was to frequency modulate (FM) video signals at a variety of RF frequencies for carriage on such a trunk in order to minimize the effects of noise and intermodulation distortion on those signals from the broadband amplifiers necessary to compensate for coaxial cable losses. An alternative was often microwave distribution. Other applications for super-trunks are the delivery of video signals from remote earth station locations or between CATV systems sharing common signal sources for local advertising insertion.

In recent years, a number of optical fiber super-trunks have been built by the CATV industry [1,2]. These super-trunks generally use frequency modulated video and frequency division multiplexing (FM/FDM) of a number of signals onto a laser feeding a single fiber and have proven cost competitive with other techniques. They are also highly reliable, provide very little signal degradation, and have been shown to be capable of providing transmission for more than twenty miles without the need for repeaters. Figure 1 shows data on a number of typical fiber optic super-trunk installations in use today.

The use of optical fiber video transmission technology in super-trunks has opened the door to the possibility of further uses. It has demystified the technology for CATV engineers and has provided practical experience with the design, construction, and operation of fiber systems. It is natural that the CATV industry should look for additional applications where fiber optics may be of use.

LIMITATIONS OF CURRENT CATV SYSTEMS

In order to understand ways in which fiber may be useful in CATV, it is important to focus on the limitations of present system architecture. Figure 2 illustrates the kind of "tree and branch" architecture used in current coaxial CATV systems. All of the signals which are to be delivered to subscribers are gathered at a central "headend". Typical sources are satellite earth stations, off-air antennae, videotape playback facilities, and super-trunks providing delivery of signals from remote locations. At the headend the various video sources are vestigial sideband amplitude modulated (AM-VSB) at various frequencies, are combined into a single broadband signal, and are transmitted over a single coaxial cable. This coaxial cable undergoes repeated branching until it passes down each street in the community. Broadband amplifiers are required every one to two thousand feet in order to overcome cable and branching losses.

This architecture is quite straightforward and practical and is the historical basis of the CATV industry. Nevertheless, it has a number of inherent problems and limitations. Fundamental to many of those problems is the fact that a number of brandband

Date	Location	Company	# channel	Max. Path Miles
4/85	Indianapolis, IN	ATC	8	7.5
9/85	Rockville, MD	Hauser	33	12
12/85	Louisville, KY	Storer	24	11.9
1/86	Honolulu, HI	ATC	32	14
7/86	Toledo, OH	Buckeye	30	8.5
7/86	Flushing, NY	Warner	60	4.5
10/86	Van Nuys, CA	United	60	9.7
6/87	Woodside, NY	ATC	12	8
9/87	Manhattan, NY	Paragon	10	6
12/87	St. Petersburg, FL	Paragon	54	12
1988	Cleveland, OH	Ohio Bell	60	9.5

FIG. 1 SOME CURRENT FIBER SUPER-TRUNK INSTALLATIONS

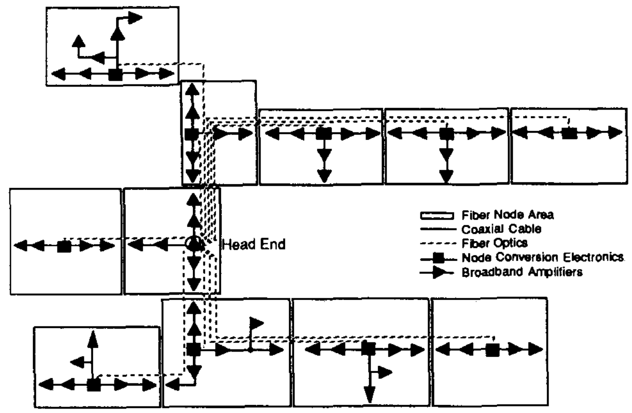

FIG. 3 HYBRID FIBER OPTIC BACKBONE/COAXIAL DISTRIBUTION SYSTEM

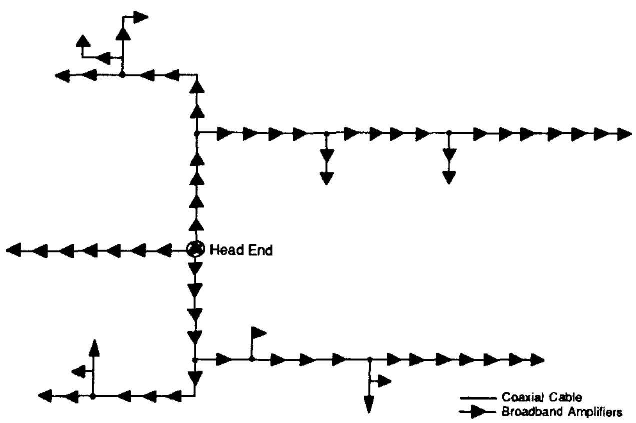

FIG. 2 TYPICAL CATV SYSTEM

amplifiers are required to operate in series, or cascade, in order to transport signals to system extremities. Each of these amplifiers contains active components and must be provided with power, both providing limits to the reliability which can be attained. In addition, each amplifier adds noise and intermodulation distortions to the signals passing through it. The addition of these phenomena over long cascades of amplifiers gives rise to systems which have real limitations in the achievable reliability and quality of the service delivered to subscribers.

Another effect of tree-and-branch systems with long amplifier cascades is on system operating tolerances. In order to realize design specifications, each amplifier in such a system must be adjusted to provide very flat gain over a wide range of frequencies, and must provide rather precise signal output levels. Such close operating tolerances require frequent alignment by highly trained technicians.

Another obstacle arising from this system architecture is a practical limitation on channel capacity. The types of coaxial cables used in CATV systems have a relatively wide potential bandwidth, perhaps approaching lGHz. Such cables have, in fact, been used for many years in small MATV systems to carry UHF channels, often at frequencies above 700 MHz. Typical cable systems operate with the highest frequency of only 300 to 400 MHz, however, with a few recent systems operating to 550 MHz. The difficulty in realizing the potential bandwidth of coaxial cable arises with the limitations of the broadband amplifiers themselves, particularly when those amplifiers are operated in cascade. It is expected that it will be difficult to push channel capacity dramatically further than today's numbers as long as CATV systems employ long cascades of amplifiers.

If there is a pressing problem with today's CATV systems which might be addressed through the application of fiber optics, it is that posed by long cascades of broadband amplifiers in coaxial tree-and-branch structures. One constraint which must be recognized, however, is that of embedded investment. Most communities have been wired for CATV, and the enormous investment this represents is not one which can be causally discarded with the arrival of new technology. Thus, it seems logical that we should search for ways to apply new technology to a hybrid fiber/coaxial system which makes use of at least some existing plant structures, but which focuses the use of fiber technology on relieving the most serious weaknesses of today's systems.

THE FIBER BACKBONE

In view of the shortcomings of today's CATV system architecture, and the practical constraints on outright network replacement, we have developed an evolutionary concept for the intergration of the fiber into our systems. We have termed this approach "fiber backbone". The approach is illustrated in Figure 3, and essentially consists of overlashing some percentage of the existing trunk system with optical fiber cables. Thus, a direct optical fiber path is established from the headend to "nodes", a number of feed-points in the CATV distribution system. From that point on, the existing coaxial plant is utilized, with some amplifiers being reversed in direction and some

Opitical Link Power Budget	10 dB
Channel Capacity	42 (50-330 MHz)
Carrier-to-Noise (C/N)	55 dB
Composite Triple Beat (CTB)	65 dB
Composite Second Order	65 dB
Cross Modulation	65 dB
Output Frequency Response	+/- 1 dB
Output Video Carrier Level	+40 dBmV
Max. Terminal Equipment Cost	$5000/node

FIG. 4 MINIMUM LINK SPECIFICATIONS

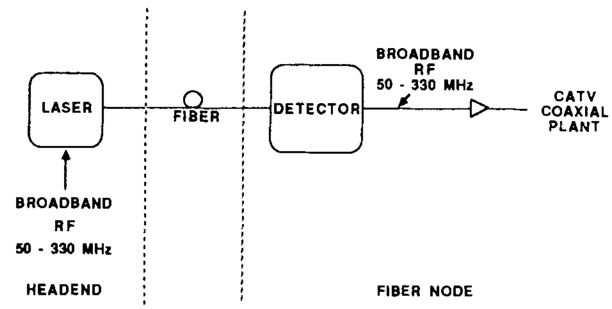

FIG. 5 DIRECT MODULATION OF BROADBAND SPECTRUM

spans of trunk cable between node areas being abandoned. The effect of this is to break up the CATV system into a number of very short systems. The length of those systems can be described by the maximum trunk amplifier cascade which will be allowed. At one extreme, fiber could be taken to each existing bridger amplifier location and the resulting coaxial system would consist only of distribution cable and line extenders. At the other extreme, a maximum trunk amplifier cascade of eight or ten might be defined, breaking a typical cable system into a few node areas. To illustrate, if present power supply locations were used as fiber node feed points, the maximum trunk amplifier cascade would be 2, with a maximum of 3 or 4, and the average node would serve several hundred subscribers.

The selection of the maximum trunk amplifier cascade is constrained by trade-offs between the cost of the fiber backbone with its associated electronics, and the benefits to be gained by the degree of shortening amplifier cascade and coaxial plant. Regardless of node area size, however, the effect of this approach is to break the existing tree-and-branch coaxial plant into many small tree-and-branch systems, with each fiber node feeding anywhere from a few homes to a few thousand homes.

ELECTRO-OPTICAL COMPONENTS OF A FIBER BACKBONE SYSTEM

In examining implementation of a fiber backbone system, the least problem is provided by the installation of the fiber cables. Single mode fiber has become relatively inexpensive in recent years, and is available in a variety of cabled packages, containing from 1 up to 144 fibers in a physically rugged cable 1/2" or less in diameter. "Field-enterable" cable packages have been developed which allow the extraction and splicing of one or a few fibers from a multi-fiber bundle within a cable without the need to splice the other fibers. This type of cable would be particularly helpful in routing a single fiber to each node location in the fiber backbone approach.

The more challenging part of fiber backbone system implementation lies with the electro-optical components. These consist first of a laser diode transmitter feeding each fiber (or split to feed several fibers) leaving the headend. At each node location, an environmentally rugged optical receiver must be installed, capable of converting optical signals back to a broadband RF spectrum suitable for coaxial distribution. The optical link must be relatively transparent to the CATV signals if the advantages of the fiber backbone approach are to be realized. For the sake of investigation, we have postulated minimum performance specifications for such a link. They are illustrated in Figure 4.

While better performance might be desirable, an optical transport system meeting such specifications would enable a CATV operator to construct a useful fiber backbone. While there exists today no economically feasible off-the-shelf equipment meeting these requirements, there are a variety of design approaches which have potential to provide the desired result.

Figure 5 illustrates the simplest possible approach to the problem. In such a system, the laser transmitter would be directly modulated with the entire CATV spectrum, complete with video channels, scrambling (if present), FM radio services, and pilot and data carriers. The output of the detector would be this same broadband spectrum, ready for amplification and delivery to the coaxial portion of the plant. While highly attractive because of its simplicity, this approach is also relatively challenging because of the linearity and noise requirements established by necessary system specifications. A laser capable of meeting these requirements might need a Relative Intensity Noise (RIN) specification approaching -160 dB/Hz and a 3rd order intercept of +38 dBm or better. These are ambitious performance levels in today's off-the-shelf devices. Nevertheless, laboratory measurements of systems using selected lasers approach the system requirements closely enough to be encouraging. Far greater emphasis to date has been placed on digital than on analog performance by the electro-optical

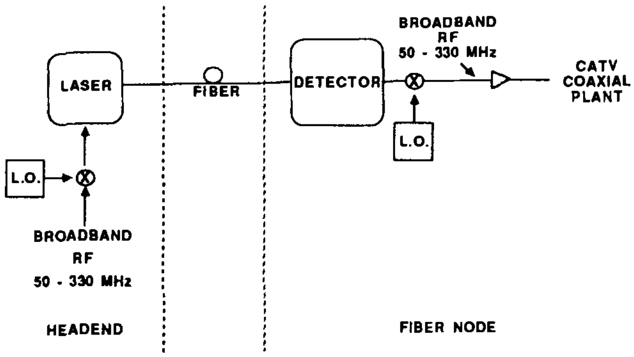

FIG. 6 DIRECT MODULATION OF BROADBAND SPECTRUM WITH BLOCK CONVERSION

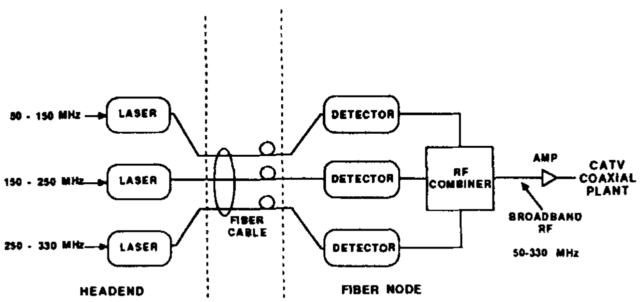

FIG. 7 DIRECT MODULATION USING MULTIPLE LASERS AND MULTIPLE FIBERS

component industry because of telecommunication industry needs. It appears that there is room to revisit device optimization with new applications in mind.

Figure 6 illustrates a variation of the direct modulation approach, with the input RF spectrum being mixed to a higher frequency to take advantage of potentially better laser performance in the 1 to 2 GHz range, as well as avoiding second order intermodulation products by keeping all carriers within a single octave. A corresponding down-conversion would be required at the receiving end.

Figure 7 shows a variation of the direct modulation scheme with several lasers, each modulated with a segment of the total RF spectrum. This should improve performance and require less expensive, more readily available lasers. This approach has been demonstrated in the laboratory, but the investment in additional fibers provides significant system cost penalties.

Figure 8 shows the same approach, again using multiple lasers, but combining their optical outputs onto a single fiber. This approach has two constraints. The first is the additional link loss created by the passive combining device. The second is the necessity of insuring that the optical wavelengths of the lasers are sufficiently separated so that frequency beats are not present in the RF spectrum of interest. At

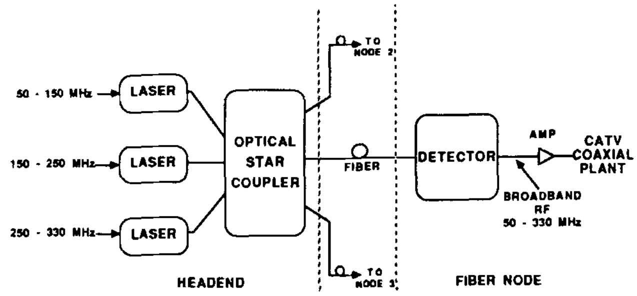

FIG. 8 DIRECT MODULATION USING MULTIPLE LASERS, SINGLE FIBER TO NODE

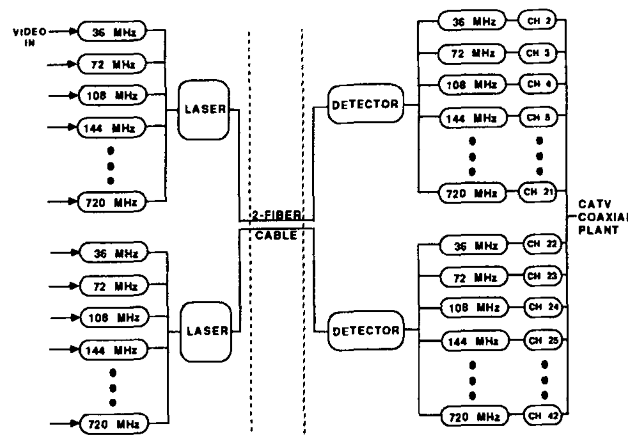

FIG. 9 FM/FDM VIDEO FIBER TRANSMISSION

the operating node receiver, a single detector responds to the sum of the intensity variations in the received light. It thus effectively recombines the various segments of spectrum back into a continuous one. One advantage of this approach is the possibility of using a star coupler for the combining of the laser outputs. This would provide multiple outputs which could feed fibers going to multiple nodes.

Figure 9 shows the FM/FDM system of the type used in today's fiber optic super-trunks. Such a system is capable of very high quality video transmission and, were the node equipment sufficiently compact, inexpensive, and environmentally rugged, could be applied to a fiber backbone application. To be economically interesting, however, such a system would have to cost no more than $100 to $200 per channel at the receive end (because of the large power budget available with FM, a single laser could feed a number of nodes through splitting at the headend, and a single bank of modulators could drive a unlimited number of laser transmitters). It is possible that this goal is achievable through large scale intergration (LSI) of demoduator and modulator circuitry. A high level of reliability and stability would also be operationally important for node link electronics using this approach. The system would also need to accomodate video signal scrambling.

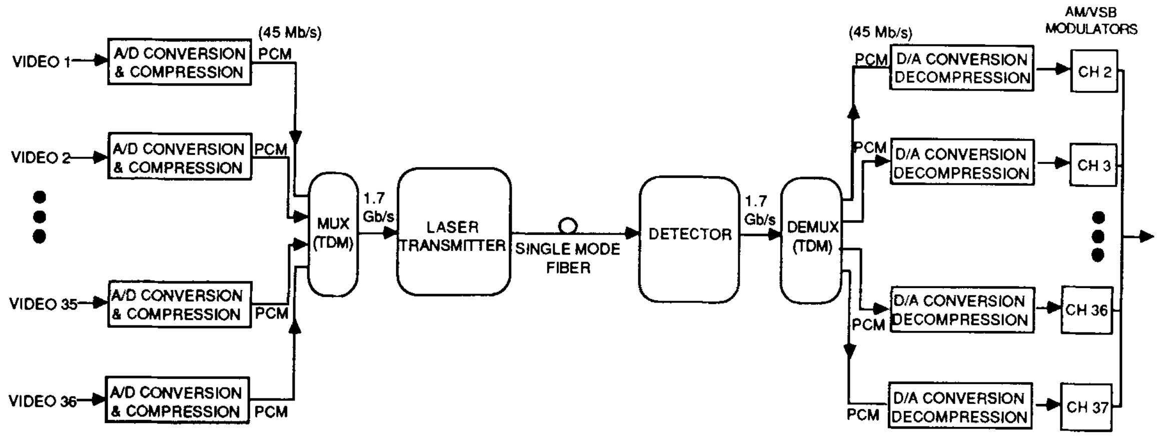

FIG. 10 DIGITAL (PCM/TDM) VIDEO FIBER TRANSMISSION

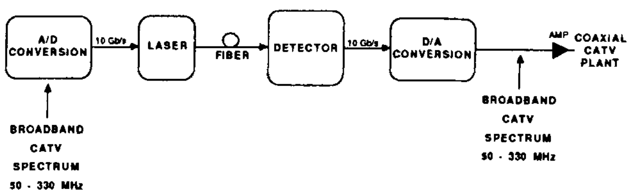

FIG. 11 DIRECTLY ENCODED DIGITAL TRANSMISSION OF CATV SPECTRUM

Figure 10 shows a digital pulse-code modulation, time division multiplexed (PCM/TDM) system for delivery of video to fiber backbone nodes. Several manufacturers have demonstrated the practicality of coding and compressing full motion video to a DS-3 (45 Mb/s) channel. It is conceivable that 36 such channels could be time division multiplexed onto a single 1.7 giga-bit/sec (Gb/s) data stream and transported using optical systems which are commercially available for telecommunications applications. This approach may become practical in the future, but would provide severe economic challenges today.

Figure 11 shows a highly speculative digital solution to this problem; one which is not workable today. In such a system, the entire CATV RF spectrum would be directly converted to digital form through sampling at a frequency some multiple of the highest RF frequency of interest. The sampling rate would certainly be in the 1 GHz-plus range. The resulting exceedingly high bit-rate data stream would then be applied to a single laser. A corresponding decoding process at the receive end would yield the broadband CATV spectrum as an output. While the electronics to do such high speed encoding and decoding are not available, it is possible that high speed gallium-arsenide chip technologies may offer this capability in the future. Laboratory work is under way at Bell Labs and in Japan on optical links in the 7-10 Gb/s range. Such links would be required to transport these signals. There may be variations on this approach which could make digital transmission a practical mode for transporting signals to fiber backbone nodes with relatively simple reconversion to broadband RF. Systems implemented today with other types of terminal electronics could easily take advantage of such developments without the need for costly replacement of the fiber itself.

OPERATING ADVANTAGES

There are a number of direct operating advantages to be derived from a hybrid fiber backbone/coaxial tree-and-branch delivery system architecture. They can all be viewed as direct outgrowths of two facts. First, the worst-case length of the coaxial portion of such a distribution system would be dramatically shortened, eliminating the majority of the amplifiers as well as power supplies, connectors, and directional couplers to be found in the signal path between the head end and any given subscriber. The second is the fact that each small area of the community served by a node would be delivered signals via a dedicated connection to the headend, with the capability of delivering a separate mix of signals to each node area, rather than having to broadcast all signals to the entire system, as in traditional CATV architecture.

Reliability

Under the fiber backbone scenario, there would be essentially the same number of active components in the distribution network as in a traditional CATV system. It is likely that some trunk transportation amplifiers (without distribution bridging circuitry) could be discarded from the system completely. On the other hand, while it is foreseen that most node locations would replace a trunk amplifier, there would be the addition of optical transmitters at the headend. Thus, the number of components which could fail is not likely to change dramatically. On the other hand, from the standpoint of each subscriber, the network would be substantially more reliable because there would be far fewer active and passive network components between the subscriber and the headend. Thus, the impact of any given equipment outage would be substantially reduced in terms of the number of subscribers affected. This should give rise to the perception on the part of cable subscribers that the network had become substantially more reliable. While this is a highly desirable end in itself, it also gives rise to the effect that massive system outages, with their tendency to overload the resources of a cable operation, should become less common.

Signal Quality

Most of the degradation of signals in current CATV systems is the effect of cumulative noise and intermodulation contributions from broadband amplifiers in cascade. Significant reduction of the number of active components in cascade would certainly yield quality benefits, assuming that the optical link portion of the hybrid system was relatively transparent by comparison with the broadband coaxial amplifiers. Since the majority of the intermodulation contribution to degradation occurs, however, in the feeder portion of the system, there would be limitations to the degree of improvement unless and until the coaxial portion of the system underwent some degree of redesign. Nevertheless, overlay of the backbone, by itself, would provide some immediate quality improvement stemming directly from the reduction in amplifier cascade. Full quality benefits would be harvested when system design was rethought, with reoptimization of the balance between noise, intermodulation, and channel loading.

Operating Tolerances

Current trunk amplifier cascades can be as high as 30, 40 or even 50 amplifiers. Such systems necessarily must be operated within very tight operating level and response flatness tolerances if design specifications are to be realized. Maintenance of these specifications is a significant operating challenge, requiring the attention of highly trained technicians. A dramatic reduction in maximum amplifier cascade through construction of a fiber backbone should result in the opportunity to operate the system within wider tolerances, offering some degree of cost savings and operational simplification. This is based on the assumption of very stable and reliable operation of the optical link portions of the system. It must be recognized that such a loosening of tolerances is only one way to "spend" the improvements arising from the construction of a fiber optic backbone and must be balanced with allocations resulting in improved signal quality or increased channel capacity.

Channel Capacity

As previously discussed, the potential bandwidth of the coaxial cable in use in today's CATV systems (including many of the cables installed over the last 10 to 15 years) is significantly greater than we are currently able to use, given our present architecture. The move to a hybrid fiber backbone/coaxial distribution system would ease some of the current constraints on channel capacity. A small number of amplifiers in cascade and broader system tolerances should make it possible to significantly push channel capacity with relative economy. In addition to the construction of the backbone itself, it is assumed that most or all of the active and passive elements of the coaxial portion of the system would be replaced, except for the coaxial cable itself. A new system design would take advantage of the short cascade, and would seek the optimum balance between channel capacity and signal quality. Indeed, preliminary design studies (to be presented in a companion paper) indicate that a current 270 MHz system (30 channels) could be upgraded to 550 MHz (80 channels) through the construction of a fiber backbone allowing no more than 4 trunk amplifiers in cascade, and by fully replacing all active components with high performance wide-bandwidth amplifiers. All passive components (couplers, taps, etc.) would also be replaced, but the enormous investment in coaxial cable and its construction would be reused. While this undertaking would still represent substantial capital investment, that cost would be some fraction of the cost of building a new 550 MHz plant. It is possible that with wider bandwidth CATV distribution amplifiers, the fiber backbone/coaxial hybrid approach may make it possible to upgrade existing systems even more aggressively, or to build new plant with truly spectacular channel capacity.

The history of the CATV industry is a never-ending quest for more channels driven by new types and varieties of programming sources. There are indications that fiber backbone technology may provide a way to deal with the next phase of this challenge.

Network Flexibility

Because a hybrid fiber backbone/coaxial system would no longer automatically broadcast the same signals to every point in the community, there is an opportunity to rethink signal strategy. Different combinations of channels could be delivered to different areas to meet local community needs, or to target advertising. Clusters of hotels could be fed with entirely different channel line-ups than residential sections. Scrambling could be used in ohe neighborhood with plant security problems, a high rate of turnover, or a good market for pay-per-view, while unscrambled signals could be delivered and controlled using traps in other types of areas. Different types of scrambling could be used in different areas as new kinds of addressable set-top converters were phased in. System upgrade and maintenance work would be far less disruptive than today, and could be approached on a node-by-node basis. Ultimately, a hybrid system could provide a certain number of channels in each node area would be reserved for pay-on-demand signal delivery to an individual subscriber. This would require a degree of switching at the headend and addressable delivery at each home, but begins to be practical if the pay-on-demand business opportunity is real. This flexibility begins to shift our focus to the longer term advantages of a hybrid fiber/coaxial network.

STRATEGIC BENEFITS

In addition to the relatively immediate operating benefits cited above, there are a number of longer term strategic benefits which would accrue to a hybrid fiber backbone/coaxial distribution system architecture.

Two-Way Services

The CATV industry has yet to reach consensus on new businesses which make effective use of the two-way capabilities of CATV plant. Current systems are technically capable of providing some degree of return services, although because of noise-summing and the reliability constraints of today's architecture, there are significant challenges to maintaining such a system. In addition, there is a relatively small amount of return bandwidth available within most CATV system designs.

To the extent that two-way services begin to provide genuine business opportunities, hybrid fiber backbone/coaxial architecture could provide significant advantages. The short cascade of the return plant and the relatively small number of branches being summed at each node point should yield a substantially more reliable and tolerant return signal path. In addition, because of the relatively large number of discrete node areas in a given network and the ability to reuse the same upstream frequency spectrum to return signals to each node, the effective return bandwidth of the overall network would be greatly increased. This is all based on the assumption that the same fiber providing downstream services to a node area could also be used for return signals, using wavelength division multiplexing (WDM) or other techniques allowing for transmission of signals in both directions on the same fiber. In our thinking about long term strategy, this potential to provide significantly more effective two-way services is a significant consideration.

Commercial Services

The CATV industry has been experimenting with a variety of commercial services in recent years. Most of these consist of providing data links for businesses. Should this prove to be a significant opportunity for the cable industry, the existence of a fiber backbone network could facilitate its expansion. The availability of single mode fiber at neighborhood "node" points throughout the community could provide a significant amount of capacity beyond that required for a residental coaxial distribution system. That capacity could relatively easily be applied to commercial types of services, either by extending fiber from node points to commercial customers, or utilizing short links of two-way coaxial plant for that purpose. There is also an opportunity to build in a degree of route-redundancy and switching between key nodes to provide the levels of reliability which commercial customers expect.

Competition

The CATV industry faces a broad variety of potentially competitive video delivery systems in coming years. These include direct broadcast satellites, multichannel MDS microwave, overbuild by other CATV operators, and video delivery via the kinds of switched fiber-to-the-home voice and video networks now being experimented with by telephone operating companies, as well as video tape and video disk sales and rentals. The keys to meeting such competitive challenges lie in providing excellent service (including signal quality and reliability), reasonable pricing, and a large number and wide diversity of programming channels. These goals, while straightforward, pose significant challenges given today's CATV networks. The fiber backbone architecture described here provides an opportunity to significantly improve both quality of service and channel capacity in a gradual way, with reasonable economics. This gives it the potential of being a significant tool in the strategic planning of the CATV industry as it faces a competitive future.

High Definition Television

It appears probable that High Definition Television (HDTV) will develop as a significant home entertainment force over the next decade. While all the implications of this are not yet clear, it appears likely that HDTV will provide significant challenges in terms of signal transmission and channel capacity requirements for CATV systems. While NTSC compatible enhanced television systems are in the development stage, it appears likely that services which must be delivered to both standard NTSC receivers and to full quality high definition receivers will require the equivalent of at least 2 to 3 standard 6 MHz channels. If such services become widespread, the magnitude of pressure on channel capacity is apparent. A movement toward a fiber backbone type of architecture over this same period should put the CATV industry in good position to be a high quality provider of these new signals because it helps address both transmission quality and channel capacity issues.

Evolutionary Change

In thinking strategically about its future, it is critical that the CATV industry seek a series of evolutionary steps, moving its plant in directions which will satisfy the needs of coming decades. In order to maintain business health, it is important that these steps be of a relatively gradual, pay-as-you-go nature. The enormous investment in completely new plant necessitated by a radical change in system architecture would be highly imprudent unless off-set by huge new revenue streams.

Business caution, as well as our belief that the most expensive portions of the existing plant (the coaxial cable and its placement) have a significant amount of additional potential, encouraged us to look hard for the kind of hybrid architecture we have outlined. It is possible to envision a carefully orchestrated scenario whereby fiber backbone would first move into the neighborhood as described here, then move to bridger amplifier locations, and next to the tap, increasing channel capacity, improving system operation and customer satisfaction, and enabling new services each step along the way. Complete replacement of plant with fiber all the way to the home is an attractively dramatic concept. We believe, however, that there is a far more practical approach, with each step being taken when it makes business and economic sense, which can enable the CATV industry to improve its business and meet the array of challenges which the future holds.

IMPLEMENTATION

There are several steps required for effective implementation of a hybrid fiber backbone/coaxial distribution system. The first is the achievement of cost-effective optical link electronics which meet the technical demands of such an architecture. A variety of approaches are under investigation by ATC and a number of component and system vendors. These general approaches were outlined earlier. The second step to implementation is developing an understanding of economic and technical trade-offs leading to a decision on the maximum size of the coaxial subsystems which should be fed by a given fiber node. The technical benefits involved must be defined not only in terms of immediate system improvements with the addition of fiber backbone, but also the channel capacity upgrade-ability which is desired of the resulting system. The economic and technical issues involved are quite complex, and it is hoped that work on these issues will continue to emerge in coming years as the backbone concept itself is proven valid. An initial approach to both economic and technical issues is presented in two companion papers.[3,4] Broadly stated, these works indicate the cost of overlaying a fiber backbone on an existing CATV system should be somewhere in the $30 to $60 per subscriber range, depending upon depth of fiber penetration. Further, they indicate that a fiber backbone overlay may make relatively dramatic channel capacity upgrades feasible. In the typical network examined, a system upgrade from 270 MHz (30 channels) to 550 MHz (80 channels) was achievable, maintaining current system specifications, and using off-the-shelf coaxial cable equipment in addition to a fiber backbone performing to the specifications outlined in this paper.

IMPLICATIONS

The architecture of the fiber backbone system is such that many small, unique cable systems are created out of one large operation. As a result, several implications resulting from its implementation can be seen.

The short amplifier cascades created by this architecture provide us with an opportunity to enhance the performance of our plant. The additional operating overhead that results from the short cascades can be used to improve the quality of the signal delivered to the home, to increase bandwidth, or a combination of the above.

If we are trying to position the system to handle such new technology as HDTV without having to rebuild the plant to accommodate the first one or two HDTV channels, with a requirement for better system specs, then this might be provided by the fiber backbone.

Later, as HDTV and other needs for expanded bandwidth advance, a system upgrade becomes a good alternative to a complete rebuild. An upgrade assumes, of course, that the coax in the plant is capable of carrying additional spectrum.

A system could be expanded in bandwidth a number of times. This is a result of the relatively short distances between the fiber distribution point (node) and the end of the plant that the node feeds. To understand this point, we must consider that we have broken our large cable plant into many small plants with short cascades. When we upgrade, it may be necessary to not only change the electronics and passives, but to add additional amplifiers as well to make up the losses of the higher frequencies needed. While doing this while maintaining specifications in a system that may be thirty amplifiers or more in cascade could be impossible, it could be a relatively easy task within a fiber backbone system.

The small "neighborhood cable systems" created by the fiber backbone allow a CATV operator to consider new concepts in advertising. While cable can now "narrow cast" ads on selected stations such as MTV and CNN, one could, using a "neighborhood cable" approach facilitated by backbone architecture, produce neighborhood specific advertising. Neighborhood merchants rarley want, or can afford, city-wide advertising, but could be interested in ads reaching a few system nodes serving their potential customers. The fiber backbone makes this possible because of its unique feature of having a direct feed from the headend to each "neighborhood".

The "neighborhood cable system" lends itself to new approaches to programming as well. Since each system has a direct fiber feed from the head end, we may wish to consider providing different programming to selected areas. For example, in some cities there may be ethnic communities that would like specific programming. Once the primary boundaries were defined, additional ethnic channels could be delivered to the nodes serving that area.

We might find a large concentration of hotels and motels in another area, requiring a completely different channel mix. The flexibility of the backbone architecture opens up many options with regard to targeted program delivery.

The hotel/motel possibilities of a fiber backbone-fed system lead us into some enhanced commercial services possibilities. For example, the ability to use the reverse band on our cable plant starts to look more attractive. We can now look at the short cascades which equate to less noise addition on the reverse system and see that it becomes a much more reliable data path than before. This path could be used for pay-per-view signaling, interactive programming like home shopping, etc. Because we are dealing with "neighborhood systems" we might consider using our more reliable reverse path for local area networking in business areas.

Metropolitan area networks may become practical. In a metropolitan area network, we would be able to provide data communications between points located anywhere in the city. This is a result of having a node that is in every neighborhood connected directly to the headend with fiber which is passive and two-way. As a result, we would have established a very reliable communications path throughout the city.

Operating a cable system today can be a complex venture. Implementing a fiber backbone system might help reduce some of the day-to-day problems that exist. Because of the short cascades, we would probably see a reduction in the need to sweep the cable plant. That means a potential reduction in labor. In addition, we may see a reduction in phone traffic that would normally be caused by large system outages. Often, system failures overload the capability of our phone systems. For example, if the first amplifier in a thirty-two amp cascade fails, it can effect seven or eight thousand subscribers (based on studies of actual systems). If only one third of the affected customers were to call in, the phone system and customer service department would be unable to handle the load in an efficient manner. The result is that subscribers often feel that they are unable to contact the cable company when they need it the most. The phone system overload will often effect all lines going to the cable company office.

With backbone architecture, there will still be amplifier failures, but those failures will effect fewer people and create fewer calls. Thus, there is the potential for improved customer relations and a better image within the city.

Another use for the fiber backbone system could be in new construction. If we consider the rural and low density areas we would like to serve, but find conventional coaxial systems to be too costly, we might look at a fiber backbone-fed node feeding a "tapped trunk" system. We could benefit from the use of passive, low maintenance fiber to transport the signal and maintain reasonable quality to the start of such a system. It is probable that the cost of such a system would be less than traditional architecture.

Still another variation of the backbone could be a system that has no trunk at all, only a distribution system. That would say that the node would be at a bridger location and would feed line extenders rather than trunk amplifiers. It could be possible to cascade a few high quality distribution amplifiers with AGC circuits and still maintain the node performance quality without the need for trunk cable or amplifiers.

Overall, the implications of implementing a fiber backbone system are far-reaching, from marketing to operations to customer relations as well as improved image in the community. The system has the potential for assisting in solving, or at least reducing, a number of problems that exist in most cable systems today.

There is also the opportunity to increase revenues through the "neighborhood cable system" concept that lends itself to new advertising sales and marketing ideas.

CONCLUSION

In summary, the hybrid fiber backbone/coaxial distribution architecture outlined here is one which meets an array of needs within the CATV industry. It provides a means of significantly improving the operation of CATV plant, while laying the foundation for future evolution. It is foreseen that the introduction of optical fiber technology into CATV systems in this way opens the path for the industry to grow and survive in a competitive world well into the next century.

REFERENCES

[1] J. A.Chiddix, "Fiber Optic Technology for CATV Supertrunk Applications", in *NCTA '85 Technical Papers*, 1985.

[2] J. A. Chiddix, "Optical Fiber Super-Trunking, The Time Has Come; A Performance Report on a Real-World System", in *NCTA '86 Technical Papers*, 1986 and *IEEE Journal On Selected Areas In Communications, Vol. SAC-4, No. 5*, August 1986.

[3] Claude Baggett, "Cost Factors Relative to the Fiberoptic Backbone System", in *NCTA '88 Technical Papers*, 1988.

[4] Perry A. Rogan, Raleigh B. Stelle III, and Louis D.Williamson, "A Technical Analysis of a Hybrid Fiber/Coaxial Cable Television System", in *NCTA '88 Technical Papers*, 1988.

James A. Chiddix is senior vice president of engineering and technology for American Television and Communications Corporation, the country's second-largest cable television operator. ATC, a publicly owned corporation, serves 3.59 million subscribers in 32 states. Under Chiddix, the Engineering and Technology Department is responsible for corporate engineering activities as well as research and development.

Chiddix, 42, has been in the cable television business for 17 years. He spent seven years as general manager of Cablevision, Inc. in Waianae, Hawaii, and eight years as engineering vice president and senior vice president of Oceanic Cablevision in Honolulu. In November 1986 he joined ATC's corporate office in Englewood, Colorado.

Chiddix is a senior member and former director of the Society of Cable Television Engineers. 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.

Chiddix also has an extensive background in the development of a variety of tape automation systems. As a founder of CRC Electronics in Honolulu, he contributed to the development and manufacture of video playback systems for pay television, automated videotape delay systems, and systems for automated commercial insertion. CRC Electronics was sold to Texscan-Compuvid in 1982.

Chiddix was born in Easton, PA., taught courses in computer and radar electronics maintenance in the U.S. Army and studied electrical engineering at Cornell University.

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 Cablevision 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.