A Digital Solution for Cable Television Systems

David Jordan * *
Product Manager
C-COR Electronics

Abstract

Digital fiber optic systems have become a strong alternative to analog technology for high performance delivery of CATV signals throughout a cable plant. This paper reviews the performance and characteristics of a currently available digital system that does not use bandwidth compression.

Digital transmission has become the foundation of modern communications networks, and digital signal processing is now the dominant technology in television studio equipment. However, the strong advantages of digital transmission have been offset by a perception that the equipment occupies extensive rack space and expensive in typical multi-channel CATV applications.

Today there are digital systems that are competitive in price, size, and features with current FM analog fiber optic systems, and they are designed around an architecture for a long term "systems approach" to CATV signal distribution. Rather than being limited to an individual, point-to-point optical link that replaces a portion of a coax plant, today's digital system will evolve, in a compatible way, to extend fiber optics deeper and deeper into the plant without fear of signal degradation or equipment obsolescence.

Advances in high speed digital processing will offer the possibility of digital transmission to practically interface with other signal formats. Advances in high speed digital optical components will allow significant increases in signal carrying capacity, without disrupting installed digital plants.

Research indicates the consensus among cable operators favors a long-term evolution toward a digital based architecture. Adopting a digital strategy today will further strengthen the future competitive position of cable operators who look beyond interim fiber optic solutions.

In this presentation I will briefly examine the basic building blocks of a typical digital transmission system and then present a case study. I will describe the Mountain View Cable System and outline the digital fiber optic equipment that could be installed in this system. Finally, I will summarize the presentation with a review of the advantages of digital fiber optics in a CATV application.

I. Introduction of Digital Fiber Optic Systems

Digital transmission of video, with audio subcarrier through optical fiber is achieved by converting the analog video and audio inputs to digital data. The digital data is then "line encoded" (such as scrambled NRZ) for ease of time synchronizing, error monitoring and bandwidth economy. The line-encoded signal then modulates a light source.

Converting analog video and audio to digital is done by precision A/D circuits that are also used in broadcast studio equipment. As in all digital systems, sample rate and accuracy affect the end-to-end signal performance of the system.

High sampling rates with sampling precision of 7 bits or more for video and 12 bits or more for audio ensures high quality signal performance. The resulting data rates of these systems exceed 70 megabits/second for video and 700 kilobits/second for audio, which gives rise to two types of digital systems:

1. Full bandwidth or linear pulse code modulation (PCM) systems that transmit all of the digitized signal information.

2. Bandwidth compressed systems that transmit only a portion of the original digitized signal according to a predetermined processing algorithm.

Uncompressed, linear PCM systems are directed toward high signal quality applications in dedicated links or private networks. PCM coding is ideal for transmission systems where bandwidth is virtually unlimited as in fiber optic systems. Compressed systems are most useful in digital telecommunication networks where standard, fixed bandwidth channels are available (as with twisted pair telephone wiring.)

Digital transmission systems do not require a linear light source, are highly noise immune, and operate with both multi-mode and single mode optical fiber. Thus, light sources for digital systems can have a wide range of non-critical operating parameters.

Because digital PCM is very noise immune, system performance does not degrade with increased transmission distances, and very long ranges are possible without repeaters. If required, digital systems can be regenerated many times without signal degradation.

Digital systems are very tolerant of losses and reflections from connectors, splices and optical devices such as splitters and optical multiplexers (WDM). This provides flexibility in designing point-to-multipoint optical systems and networks.

II. Digital Building Blocks

All commercially available digital fiber optic systems have many similarities in terms of the building blocks (or the boxes) that are used to create a video delivery system. A list of those building blocks is outlined below.

Digital Fiber Optic System Building Blocks

Optical Transmitter / Receiver terminals
Channel multiplexers
Video encoders and decoders
Subchannel multiplexers
Audio encoders and decoders
Data interfaces

A block diagram of a typical digital system configuration is pictured in Figure 1.

I will briefly describe the function of the major blocks in the the system diagram.

The **Encoder** accepts baseband video inputs. Sampling at greater than twice the highest frequency, the encoder digitizes the baseband signal into a linear, full bandwidth data stream. An audio encoder performs the same function by digitizing a baseband audio signal.

The **Time Division Multiplexer** accepts digitized audio, video, and data and converts it to a serial data stream. In addition, a clocking reference signal is generated by the TDM which ensures proper recovery of the digitized signal at the receiver.

The **Optical Transmitter** accepts a serial data stream and converts an electrical signal into an optical signal. Within the transmitter there are typically several alarm outputs which give the operator the ability to monitor the status of the transmitter. Transmitter alarms generally include power supply status, temperature, and laser drive current.

The **Optical Receiver** detects an optical signal and converts it back to an electrical signal. Much like the transmitter, there are several alarms present in the receiver which give the operator the ability to monitor receiver status. These alarms typically include, temperature, power supply status, clock, and optical signal.

The **Time Division Demultiplexer** separates video and audio from data and converts serial information into parallel information. The demultiplexer also sends the audio and video to the decoders and separates the clock from the data signal.

The **Decoder** accepts a digitized signal, converts it back to an analog format and recovers the original baseband signal.

The diagram in Figure 2 shows how a simple digital transmission system might appear. I have chosen to illustrate a system that operates at approximately 780 Mb/s and uses 8-bit coding. This particular system uses a multiplexing structure which gives the user the ability to combine 2 blocks of 4 channels in order to optically transmit 8 channels per fiber. This particular system accepts 8 baseband video inputs and delivers 8 baseband video outputs on one fiber. The typical link loss budget of this system is 29 dB.

As you can see, each of the building blocks is relatively basic in its design and function. Each of the "boxes" in a video transmission link can be built using "off-the-shelf" devices. However, one of the most significant advantages of digital transmission systems when compared against analog alternatives is that digital system performance is not affected by the linearity of the light source. Lasers in digital applications must simply have the ability to turn on and off, and therefore attempting to optimize the linear characteristics of the light is of little concern.

III. System Application

Much has been written about digital fiber optic technology and its usefulness in a CATV system. Most authors accept that digital is indeed the long term solution for cable operators, yet in the same breath they point out that current costs and physical size of the equipment suggest that digital technology is several years away from becoming a viable alternative. The conclusion drawn from these articles is that operators should delay investing in digital transmission systems to allow the technology to "catch up" with user requirements.

This assumption must be challenged. First, the costs for digital fiber optic systems are declining and technology is advancing so quickly that assumptions made even within the last 18 months can no longer be held true. Second, fiber optic transmission equipment available today which occupies no more physical space than comparable analog transmission equipment.

In addition to a digital system's significant advantage that was mentioned above (a much less restrictive operating requirement for the laser diodes) there are several other advantages inherent in digital technology that operators should be aware of when evaluating fiber optic transmission systems.

The high optical budgets available in digital systems, when combined with the fact that it is fundamentally easier to restore and regenerate a digital "word" as opposed to an analog signal, gives many more options to cable operators. For example, in some long distance applications where high quality signal transmission is required, digital has proven to be the most viable and cost effective solution.

Digital fiber optics requires operators to look beyond the "link" or "box" solution offered by analog fiber optic products and examine the use of fiber from a "system" perspective. Figure 3 illustrates one of the system advantages for considering digital technology. The concept introduced here is called digital "fan out" (or drop and repeat). With this concept it is possible for operators to generate two identical blocks of signals with the same transmit and encoding equipment, thus minimizing per channel cost for transmission to multiple hub sites. At the location of the second transmitter the link loss budget would be restored to its original performance specification (in the previous example that is 29 dB).

Many MSO's have concluded that digital technology must be given serious consideration in a cable operation when there is a requirement to interconnect headends or a need to connect multiple receive sites to a single headend.

I would like to outline in detail by describing an actual case where digital fiber optics is being proposed as an effective fiber optic solution. I will examine an actual cable television system and describe a quotation that was submitted to this system. At the request of the customer, I have changed the name of the system.

Mountain View Cable is a typical urban cable television system. They presently serve over 80,000 subscribers in a rather large geographical area. Franchising requirements are forcing Mountain View to rebuild its present system from 330 MHz to 550 MHz (77 channels). The digital system in this study expands in four channel blocks, so the quoted system will be capable of 80 channels. Mountain View Cable has two headends located 52 km apart. They are interested in connecting the East and West headend, dropping signals at the East headend for distribution, and distributing signals from the East headend to four receive sites. The distance from the East headend to the four receive sites are as follows:

Hubsite #1	13.9 km
Hubsite #2	28.0 km
Hubsite #3	18.5 km
Hubsite #4	18.0 km

Mountain View Cable has asked us to determine the cost per received channel, the loss budget margins present at each receive site, and system link performance.

A block diagram of the interconnect of the West and East Headend Site is shown in Figure 4.

The system described is operating at a rate of 780 Mb/s, which is capable of transmitting 8 channels of video per fiber. This particular diagram would be multiplied 10 times to arrive at the system requirement of 80 channels. The laser diodes transmit at -3 dBm and the APD receivers are -32 dBm devices resulting in a loss budget for this link is 29 dB. As an option, to achieve a greater system margin, a transmitter operating at 0 dBm output in conjunction with a receiver with -35 dBm sensitivity yields an optical loss budget of 35 dB.

Using a loss figure for fiber of .5 dB/km, the loss budget (safety margin) is calculated for each receive site. As stated previously, when you use digital technology to fan the optical receiver outputs to secondary decoders and transmitters, a second link can be established with the full 29 dB optical loss budget. The following chart specifies the loss budget remaining at each receive site even after transporting the signal through a series of splitters and connectors. As you can see a minimum of 6.2 dB margin remains in each link, including the East headend site which is 52 km from the West headend.

A block diagram of the regenerator and the distribution section of the proposal is shown in Figure 5.

As you can see we have recommended that Mountain View install both symmetrical and asymmetrical splitters. Obviously the losses are different for each leg of the asymmetrical splitters. Our attempt in proposing this configuration is to optimize the lower splitter losses over the longer fiber links. Once again this diagram portrays the equipment required to receive 8 channels at each of the four receive sites. To arrive at at full complement of 80 channels you must multiply this equipment by a factor of ten.

There are three important issues that are raised in this case study:

Loss budgets-even over 52 km (the distance separating the two head ends, a digital system will transport signals with over 6 dB of system safety margin.

Regenerators-using digital technology an operator is not required to "bring the signal back to baseband" in order to repeat the signal.

Multiple Receive Sites-because of the large loss budgets present in a digital system it is possible to regenerate a digital signal and restore it to an exact duplicate of the original signal and serve many receive sites with a single set of encoders by using optical splitting and digital fanout.

Without going into great detail I would like to discuss the cost analysis for the Mountain View Cable system which is outlined below.

Mountain View Cable Cost Analysis

1.	West HE - East HE Interconnect	$300,000
2.	East HE Regenerator	80,000
3.	East HE - Hubsite # 1	131,000
4.	East HE - Hubsite # 2	126,000
5.	East HE - Hubsite # 3	126,000
6.	East HE - Hubsite # 4	126,000
	Total	$889,000

Number 1 - East and West Interconnect The costs included the transmitters and encoders at the West headend site and the receivers and decoders at the East headend site.

Number 2 - East headend Regenerator The costs here include the transmitters, fan outs, and splitters required to send the digital signal to the receive sites.

Numbers 3 - 6 Hubsite Receivers all include the same equipment with the exception of Hubsite 1 which has additional splitters located there so that signals can be fed to Hubsite 2. With that exception each of the equipment is identical at each receive site. The costs for the receive sites include the receivers and the decoders necessary to detect the optical signal and convert it to a baseband signal.

Mountain View Cable System requested a proposal for a baseband transmission link. Therefore, the costs analysis includes only the equipment required to encode, transmit, receive, and decode a baseband video signal with BTSC stereo on a 4.5 MHz subcarrier.

The following list summarizes the proposal for the Mountain View Cable system.

Successfully connected two head ends over 50 km apart, and distributed signals to four receive sites (400 received channels-80 were dropped at the East headend/ regenerator.)

A minimum remaining loss budget of 6.2 dB was present at all the sites.

Mountain View Cable Loss Budget Analysis

Remaining loss budget at each site

West Headend - East Headend Site	52.3 km	6.2 dB
East Headend - Hubsite # 1	13.9 km	8.3 dB
East Headend - Hubsite # 2	28 km	9.2 dB
East Headend - Hubsite # 3	18.5 km	6.9 dB
East Headend - Hubsite # 4	18 km	7.1 dB

Performance of RS 250 B Medium Haul Specification was present at all receive sites. A minimum of 55 dB S/N was measured at the output of the decoders. Average S/N when measured over all receive sites was approximately 60 dB.

Physical rack space requirements for the digital transmission equipment was universal at 52.5 inches. The exception in the East headend site regenerator which required a total of 70 inches of rack space. The increased space requirement at the East headend is due to the additional optical transmitters and the digital fan outs.

The total system cost is calculated to be $889,000 which works out to be slightly over $2,000 per received channel.

IV. Summary / Conclusion

When considering fiber optics for cable television systems remember that digital technology's important characteristics make it the dominant choice in certain applications.

Those advantages are:

No adjustments.
Most digital fiber optic systems employ "set up and leave" equipment that is manufactured with off-the-shelf devices.

Drop and Insert.
Signals can be added or removed without degrading signal quality.

Repeaters and Range.
Unrepeated ranges of over 50 km are possible. Even when using regenerators, the repeat process is transparent to the transmission system.

Multiple channels and distribution networks.
Multiple video, audio and data channels are able to be transmitted on one fiber. In addition, the large loss budgets present in all digital systems allow the user to split the optical signal many ways.

These features combined provide the following advantages for cable operators:

- Simple installation and operation.
- Flexible system architectures.
- Better quality long distance transmission.
- Adaptable to future technology advances.

Digital technology encourages new ideas and discussions about its impact in the cable television business. There is a renewed emphasis on delivering a quality transmission to the customer. Digital fiber optic systems provide cable operators the vehicle to transmit very high quality signals very deeply into a cable television plant.

The cable operator who today decides to install digital fiber aggressively moves his system into the future. Cable operators installing digital fiber optics today position themselves to take full advantage of technology advancements and future cost reductions.

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Digital Fiber Optic System

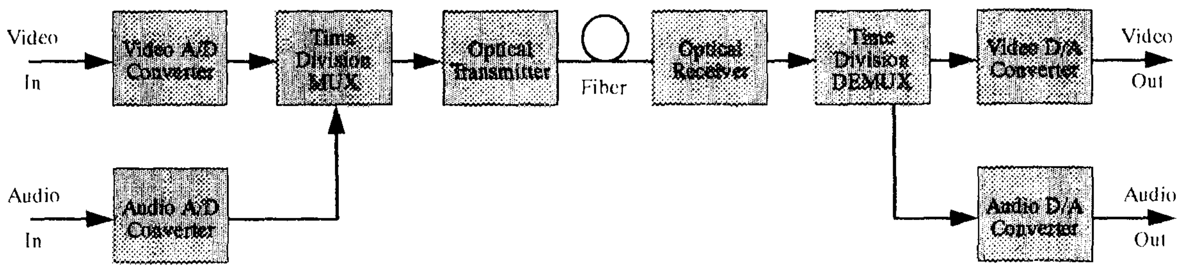
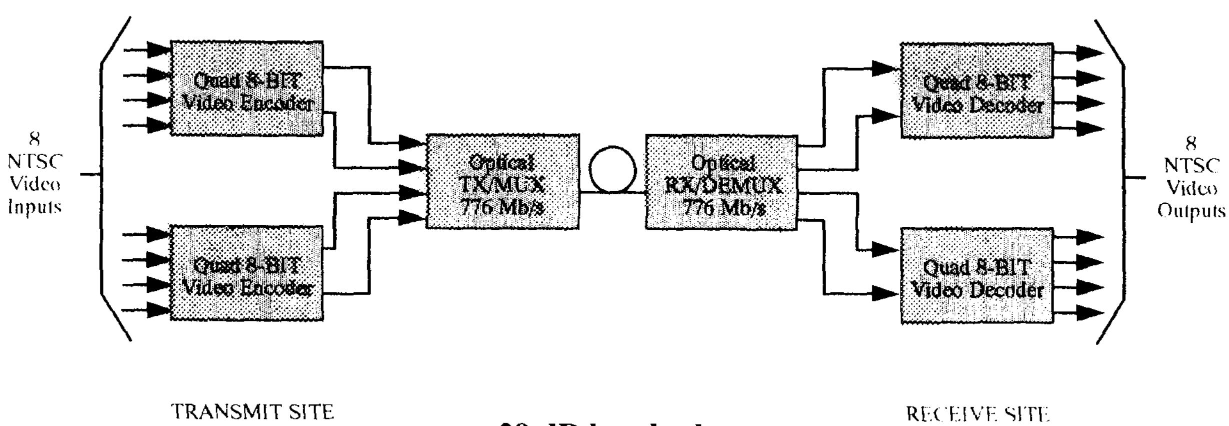


Figure 1

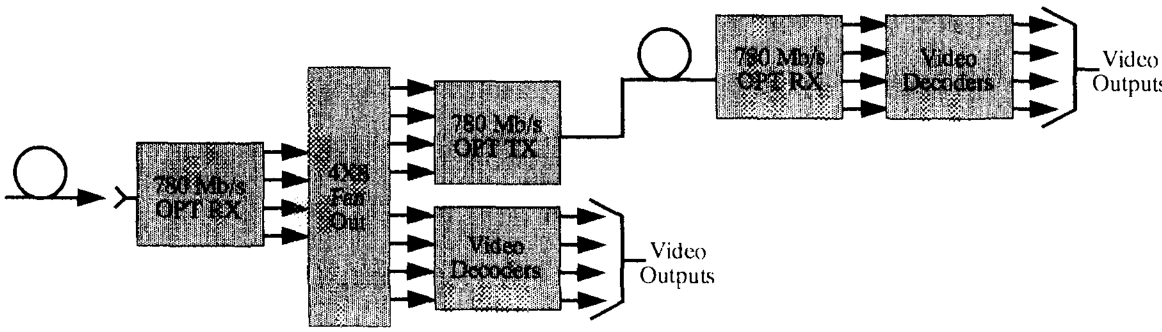
Digital Building Blocks
780 Mb/s TX/RX
8-bit encoding



29 dB loss budget
Typical range up to 58 KM

Figure 2

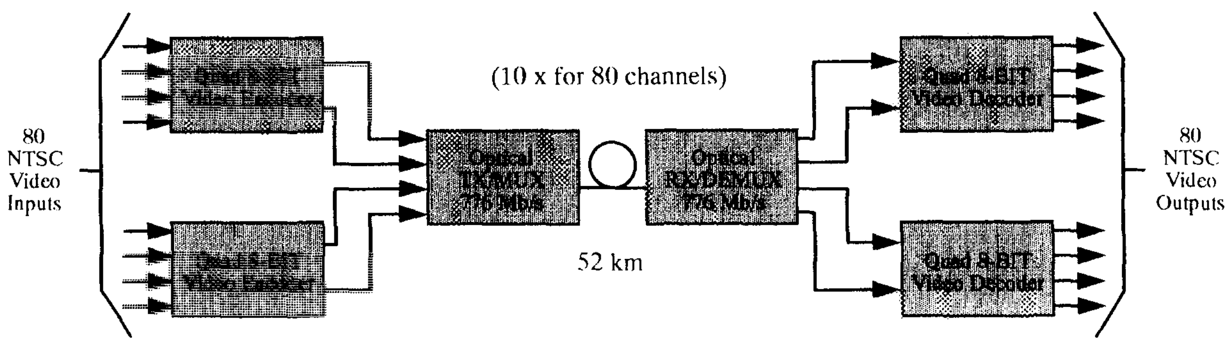
Digital Fiber Optic System



Receive Site with Drop and Repeat
Using 4X8 Fan Out

Figure 3

Digital Fiber Optic System
Mountain View Cable



WEST HEADEND SITE

EAST HEADEND SITE

35 dB loss budget
Typical range up to 70 km

Figure 4

Digital Fiber Optic System Mountain View Cable

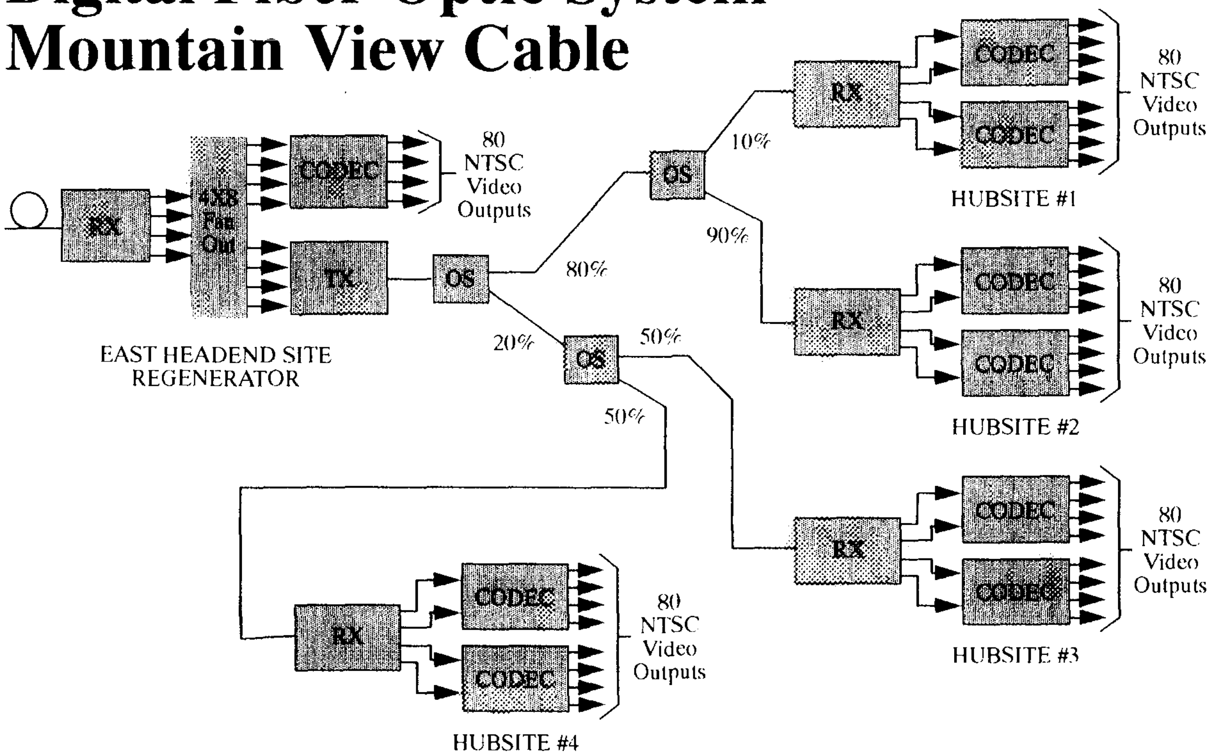


Figure 5