Digital Backbone Network Applications for Inter-City and Intra-City Regional CATV Networks

Robert W. Harris
C-COR Electronics, Inc.
State College, PA

Abstract

This paper describes five working examples of how high speed digital fiber optic transmission systems are currently being applied within CATV networks to deliver video, audio and data services for distribution into the cable network. These digital networks provide high signal performance (RS250C medium haul and short haul) and can process and transport the entire range of signals present within the CATV environment including: baseband video and audio, BTSC subcarrier audio, baseband and IF scrambled video, 64 QAM and 16-level VSB signals and low-speed asynchronous data. Also presented here is a review of the digital building blocks that comprise the network and the justifications for selecting digital transmission in each network.

INTRODUCTION

Over the past four years, a notable number of MSO's have been installing and activating synchronous high speed digital fiber optic networks in CATV systems. These networks supply high quality video, audio and data signals to hub sites for distribution into their CATV networks.

Dedicated digital networks provide a low-cost, video-optimized, alternative to SONET standard systems which can cost as much as four times that of proprietary systems. In fact, 9 of the top 15 and 18 of the top 30 MSO's currently use dedicated PCM (pulse code modulation) digital transmission systems in their networks and gain many of the key advantages of a SONET based network at a fraction of the cost

These digital systems offer similar network functions as SONET networks by providing automatic self-healing redundancy, Drop/Add multiplexing techniques (Drop and Insert), Drop and Repeat functions, and transparent optical regeneration.

This paper will review the advantages of digital transmission and the building blocks required for developing networks with a variety of capabilities. This paper will then describe the flexibility and reliability of digital transmission through five examples of functioning digital networks.

DIGITAL BACKBONE NETWORKING ADVANTAGES

Digital backbone networks utilize synchronous time division multiplexing, uncompressed full linear pulse code modulation (PCM) and high data rate optical transmission for use in a variety of CATV, educational and broadcast applications. Some of the more well known advantages of digital backbone networking are:

- Signal performance unaffected by optical distance, optical splits or optical repeats
- Very high signal performance unaffected by system expansions or additions
- Robust transmission format
- Transparent drop and addition of video, audio and data channels
- Cost effective with AM Supertrunking [1,2]

Another advantage of synchronous time division multiplexed digital systems is its ability to accept and process a wide variety of signal formats found within the CATV environment.

These advantages work to enhance practical and realizable digital networks in CATV systems. Digital system functions such as switching, routing, multiplexing, drop and insert, drop and repeat and regeneration (repeating) allow flexible and expandable networks which transparently manipulate video, audio and data signals without degradation.

DIGITAL NETWORK BUILDING BLOCKS

Synchronous Time Division Multiplexing

Synchronous time division multiplexing (TDM) is used as a cost effective and practical way to achieve multi-channel operation and digital Drop/Add/Repeat capability. By optimizing the maximum data transfer efficiency in the multiplexer, a minimum amount of data "overhead" is needed to operate the multiplex structure. This allows the maximum amount of transmission channel capacity to be available for signal "payload". Maximizing channel capacity is significant since the main purpose of these networks is to transport multiple channels of high data rate video signals rather than lower rate voice and data channels.

Synchronous TDM also allows every channel to be fully independent of one another. Therefore, video, audio and data channels can be added or removed from the optical transmission channel without affecting any other signal or other part of the network.

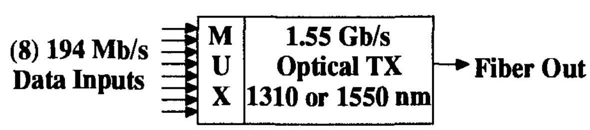
The synchronous TDM structure can also have a multi-level hierarchy (multiple TDM units operating within a system) each with a different but scalable rate. This is useful when the digital network is required to accept, process and transport a variety of signal formats.

Optical Transmission Terminals

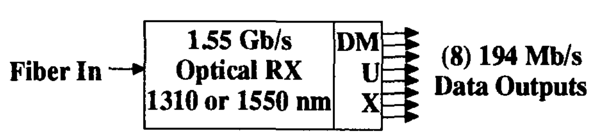
The optical transmission terminals are used to multiplex multiple data channels and launch the resulting high speed serial data stream onto the optical fiber (see figure 1a and 1b). As many as 16 video channels are transported on a single optical wavelength. Both 1310 and 1550 nm optical wavelengths are used and loss budgets are typically 30 dB. A typical range between the transmitter and receiver is <60 km, however, distances greater than 100 km can be achieved. Since both wavelengths are available, wavelength division multiplexing (WDM) can be used to operate optical carriers at both windows, thereby transporting as many as 32 uncompressed video channels per fiber.

Once the loss budget and/or the distance limitation is reached, either an optical receiver or optical regenerator may be used. Unlike a transmitter or receiver, an optical regenerator (repeater) does not perform any multiplexing or demultiplexing functions on the data stream and is used when it is not necessary to drop the signals at that location.

Multiplexer and Optical Transmitter
Figure 1a.



Optical Receiver and De-Multiplexer
Figure 1b.

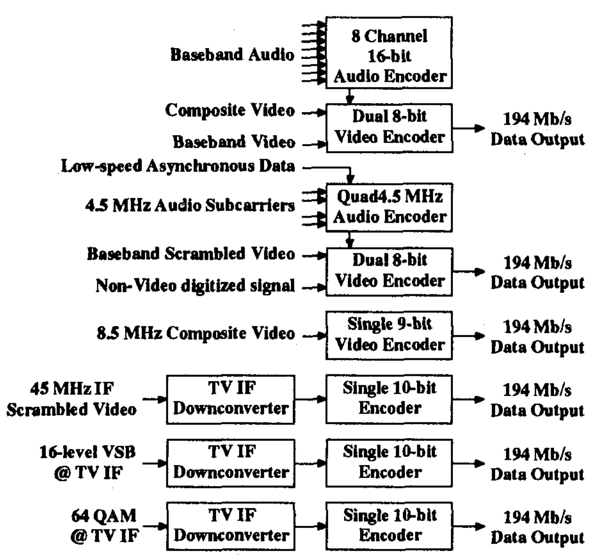


Signal Codecs

The signal codecs (acronym for COder/DECoder) provides the A to D (analog to digital) and D to A (digital to analog) conversion. These codecs have been designed to accept and process a variety of input signal formats found in the CATV environment. These include baseband video, composite video, baseband audio, 4.5 MHz audio subcarriers, baseband scrambled video, IF scrambled video and TV IF carriers. Because of the wide range of signal formats and performance requirements in the CATV network, the signal codecs require different input bandwidths, sampling frequencies, sampling accuracy, and coding formats.

Therefore, as part of a complete synchronous TDM system, the digital data ports are designed to accept any digital coding and/or framing pattern. This allows different types of signals to be multiplexed together and transported in the same optical channel. This could include video codecs with different sampling accuracy or coding formats (8-bit or 10-bit), digitized non-video signals and future signals such as digitized HDTV or digitally compressed signals.

Various Signal Codecs
Figure 2.

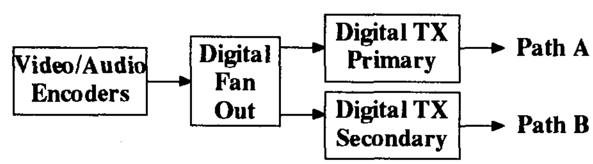


CONFIGURING DIGITAL BACKBONE NETWORKS

Redundant Transmitters

The configuration shown in figure 3 is for redundant transmitters. The output of the video encoders are routed to a "Digital Fan Out" device. The digital fan out simply duplicates the input data "n" times. In this example, the digital fan out is a 1x2 fan out and each output is routed to two separate transmitters. This configuration is usually done to provide redundancy on two paths (primary and secondary) to the receive site(s). Note also that both transmitters do not have to operate at the same optical wavelength.

Redundant Transmitters
Figure 3.

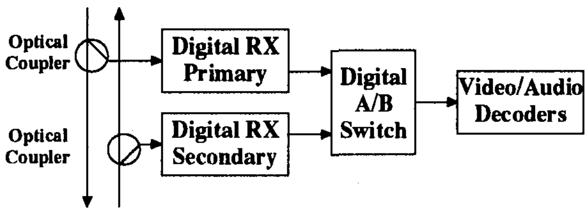


Redundant Optical Receivers

Figure 4 shows an application with redundant receivers. Each optical receiver accepts the optical signal from a separate path. The optical couplers shown are not necessary but do show how the signals can be dropped at the receive site and passively passed on the next receive site via the optical couplers.

The demultiplexed data from the outputs of each receiver (primary and secondary) are routed to a "Digital A/B Switch" device. This intelligent switch will pass the primary path signals to the decoders. However, in the event of a fiber cut, or a failure in the primary transmitter or receiver, the digital A/B switch will switch automatically and instantaneously to pass the secondary receiver output to the decoders.

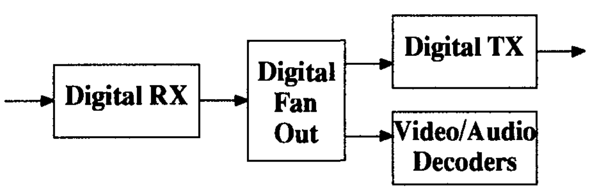
Redundant Optical Receivers
Figure 4.



Drop and Repeat

Figure 5 shows a network technique known as "Drop and Repeat". This allows for some or all of the transported channels to not only be dropped off at the receive site and decoded but also be repeated, *transparently*, to another receive site. The repeating process is transparent because the received data signals remain in a digital format as they are routed to the input of the repeating transmitter, hence, no signal performance degradation.

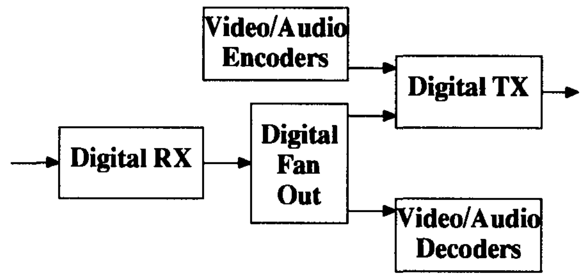
Drop and Repeat
Figure 5.



Drop/Add and Repeat

Figure 6 shows a network technique known as "Drop, Add and Repeat". Like drop and repeat, this too allows for some or all of the transported channels to be dropped off at the receive site, decoded and also be repeated, *transparently*, to another receive site. However, additional channels may also be added or inserted at this site for transmission on the network. Drop/Add multiplexing plays a significant role in digital systems where there are multiple signal origination points within the network.

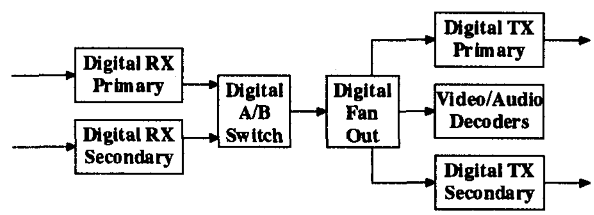
Drop/Add and Repeat
Figure 6.



Redundant Drop/Redundant Repeat

Figure 7 shows the maximum level of redundancy at a digital site using both redundant optical transmitters and receivers.

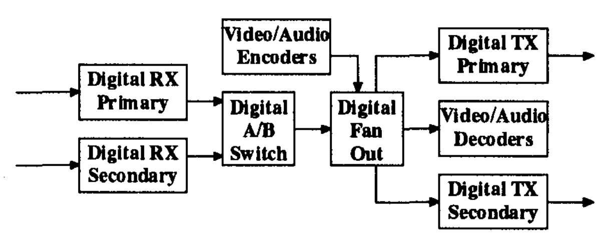
Redundant Drop/Redundant Repeat
Figure 7.



Redundant Drop and Add with Redundant Repeat

Figure 8 shows a site configuration similar to "Drop, Add and Repeat" except for the added redundancy in the optical terminals.

Redundant Drop, Add, Redundant Repeat
Figure 8.



DIGITAL FIBER OPTIC NETWORK EXAMPLES

The following five examples show the flexibility and reliability features of high speed synchronous digital fiber optic networks.

Network Example 1.

A fully redundant self-healing digital ring network transporting 64 channels to five hub sites around a metropolitan area and making extensive use of transparent Add/Drop Multiplexing and Drop/Repeat functions.

This network is shown in figure 9. The franchise area encompasses most of the suburbs around a medium-sized midwestern city. Originally, the sites were both standalone headends and AML microwave receive sites. The system engineers wanted a network with the following functions; a central headend for primary satellite signal reception, a single location for primary advertisement insertion and full, automatic redundancy via a backup headend which was already in place.

A digital backbone was chosen because of the relatively long distances between hub sites and for the ability to perform the "Drop/Add/Repeat" functions transparently.

The digital network uses a variety of configuration building blocks shown earlier. The network includes a primary and backup headend as well as two sites which serve as the primary insert for local off-air channels. The local off-air channels are inserted at these locations because the reception at these sites are much better than at the primary site.

The channels from the backup headend, which contain the entire channel line-up, are also carried on the digital network. Any channel that fails in the primary headend or fails anywhere on the primary path is automatically switched to the backed-up feed until the problem is repaired.

The majority of channels are processed as composite baseband video and 16 channels each are transported at 1.55 Gb/s per wavelength. A long distance path (>66 km) uses 1550 nm optical terminals. The rack space required for the digital equipment at each site is approximately one and half six foot racks. In two of the sites, all equipment (digital, modulators, processors, etc.) is housed in underground closed environmental vaults. The remaining sites use existing buildings.

Network Example 2.

A fully redundant self-healing Inter-City digital ring network transporting 80 composite IF channels to six hub sites at the 1550 nm optical wavelength within a large metropolitan area and providing direct RF outputs at the hub.

This CATV system serves over 4,000 miles of cable plant in one of the largest cities in the U.S. Originally, there were several standalone headends throughout the area but were eventually replaced with high power AML to seven hub sites.

As improvements in end-of-performance and network reliability became increasingly important, alternate methods of delivering high quality signals to these sites were analyzed. AM Supertrunking, based on lightly loaded AM transmission (LLAM), and digital transmission were both considered.

Digital transmission was chosen because of its consistent performance, its ability to transparently repeat the signals throughout the network and its ability to be configured in a fully redundant, automatically self-healing ring network. The network is shown in figure 10.

The network makes extensive use of redundant transmitters, redundant drop techniques and optical splitting. Should a failure occur at any point in the network (fiber break or optical terminal loss), the network automatically by-passes the fault so that each hub site remains "on-line".

All 80 channels are processed at TV IF. In other words, the IF output from all modulators and IF scramblers in the main headend are routed to the input of the digital equipment. Therefore, no scramblers are required at any of the receive hub sites and only IF to RF upconverters are required for on-channel frequencies. Planned future signal formats to be transported over this digital network will include digitally compressed video using either 64 QAM or 16-level VSB.

The entire network is operating at the 1550 nm wavelength at a data rate of 1.55 Gb/s. The network was designed as such to exploit the lower loss at 1550 nm which results in only requiring two signal regeneration points. If 1310 nm optical terminals were used, at least four regeneration points would have been required. Therefore, the use of 1550 nm terminals within the network reduced the overall network cost.

The required rack space is equivalent to about three full six foot racks. All receive site equipment is housed in existing environmentally controlled buildings.

Network Example 3.

A 60 channel point-to-multipoint network processing and transporting a variety of signal formats throughout an Intra-City Regional Network within a state to six separate hub sites. Employs Drop and Repeat & Add/Drop multiplexing techniques.

Figure 11 shows the layout of this network. The primary reason to install this network was to eliminate seven standalone headends. Each headend served a different CATV system in different cities, each with about 5,000 to 15,000 passings and all systems are owned and operated by the same MSO.

Each system in this region is to be upgraded from 300 MHz to 550 MHz and will, therefore, require the addition of about 40 channels per city. But the cost to add 40 channels at each standalone headend, including satellite receivers, satellite antennae, modulators, scramblers, etc., was difficult to justify.

A Regional Headend concept was determined as the most cost effective way to centralize the capital-intensive investments and spread these investments across a wide base. Digital transmission technology was chosen as the best method to deliver headend quality signals to these sites. Further, unlike an AM system, the digital network is "channelized" and therefore each digital receive site can provide its own channel line-up independent of the other hubs.

The digital network is a point-to-multipoint configuration operating at 1310 nm at a transmission rate of 1.55 Gb/s. Multiple signal formats are transported including; baseband video, composite video, IF scrambled video, 4.5 MHz audio subcarriers and RS232 data. Future signal formats to be transported over this digital network will include digitally compressed video using either 64 QAM or 16-level VSB.

The total cost per received channel for this network is about $2,000.

Network Example 4.

An Intra-City Regional Digital Network transporting 64 CATV channels from Toronto to Ottawa through a distance of 425 km using 1550 nm optical terminals and five optical regeneration points.

This network is shown in figure 12. A redundant ring network is in place around the city of Toronto. The ring network is extended to Ottawa via digital transmission and five regeneration points through a total fiber distance of 425 km. There is no signal performance degradation at the end of the link since the signal has remained in a digital format.

The regeneration points could be easily upgraded at a later date to a drop and repeat site if any of the sites were required to distribute the signals from that location.

All channels are processed at composite baseband video. Sixteen channels are TDM at 1.55 Gb/s and optically transported at the 1550 nm wavelength. Each digital regenerator is located within an environmentally controlled building.

Network Example 5.

A bi-directional, fully redundant, self-healing Inter-City digital ring network transporting 80 channels to nine hub sites within a large metropolitan area and providing direct RF outputs at each hub.

This CATV system serves over 4,500 miles of cable plant in one of the largest cities in the U.S. Originally, there was single headend and high power AML transmission to eight hub sites.

As improvements in end-of-performance and network reliability became increasingly important, alternate methods of delivering high quality signals to these sites were analyzed. AM Supertrunking and digital transmission were both considered.

Digital transmission was chosen because of its consistent performance, its ability to transparently repeat the signals throughout the network and its ability to be configured in a fully redundant, automatically self-healing ring network. The network is shown in figure 13.

The network makes extensive use of redundant transmitters, redundant drop techniques and optical splitting. Should a failure occur at any point in the network (fiber break or optical terminal loss), the network automatically by-passes the fault so that each hub site remains "on-line".

All channels are processed in the headend as baseband video (including baseband scrambled video) and separate 4.5 MHz audio subcarriers. Sixteen channels are transmitted per optical wavelength at a data rate of 1.55 Gb/s. The receive site video decoders use a patented technique for directly converting digital video to TV IF (45.75 MHz). The IF outputs are then routed to frequency agile IF to RF upconverters. All codecs, optical terminals, and IF/RF upconverters are driven by the same master clock frequency which yields highly accurate RF frequency outputs.

The cost for the entire digital network, including RF outputs, full optical redundancy and a single digital video return channel from each hub site is about $4,000 per channel.

CONCLUSIONS

Digital fiber optic transmission using synchronous TDM has been shown to be a cost effective and practical way to achieve multi-channel operation, Drop/Add capability and fully automatic self-healing redundant ring networks. Synchronous TDM not only facilitates multi-channel capability, but also allows every channel to be fully independent of one another. As a result, video channels can be added or removed from an optical transmission channel without affecting any other signal or other part of the system. The same advantages apply when TDM is applied to auxiliary services such as audio and data signals.

Another key characteristic of the digital systems described here is their ability to interface with a variety of input signal formats found in CATV systems. The synchronous TDM used allows any digital coding and/or framing patterns as long as its frequency synchronous with the system clock. This allows different types of signals to be multiplexed together and transported in the same optical transmission channel.

High speed synchronous TDM digital systems have been used to build video fiber optic networks from a set of basic building blocks consisting of optical terminals, signal codecs and simple processing elements such as digital switches and fan outs. These systems provide uniform signal performance independent of the number of channels transported as well as the types of video, audio and data services carried on the network. Additionally, the robust characteristics of digital transmission ensure system performance that is unaffected by link distances or repeats.

These characteristics have shown that flexible and reliable digital networks are realizable today and meet changing system needs such as system expansions, system additions or new signal formats.

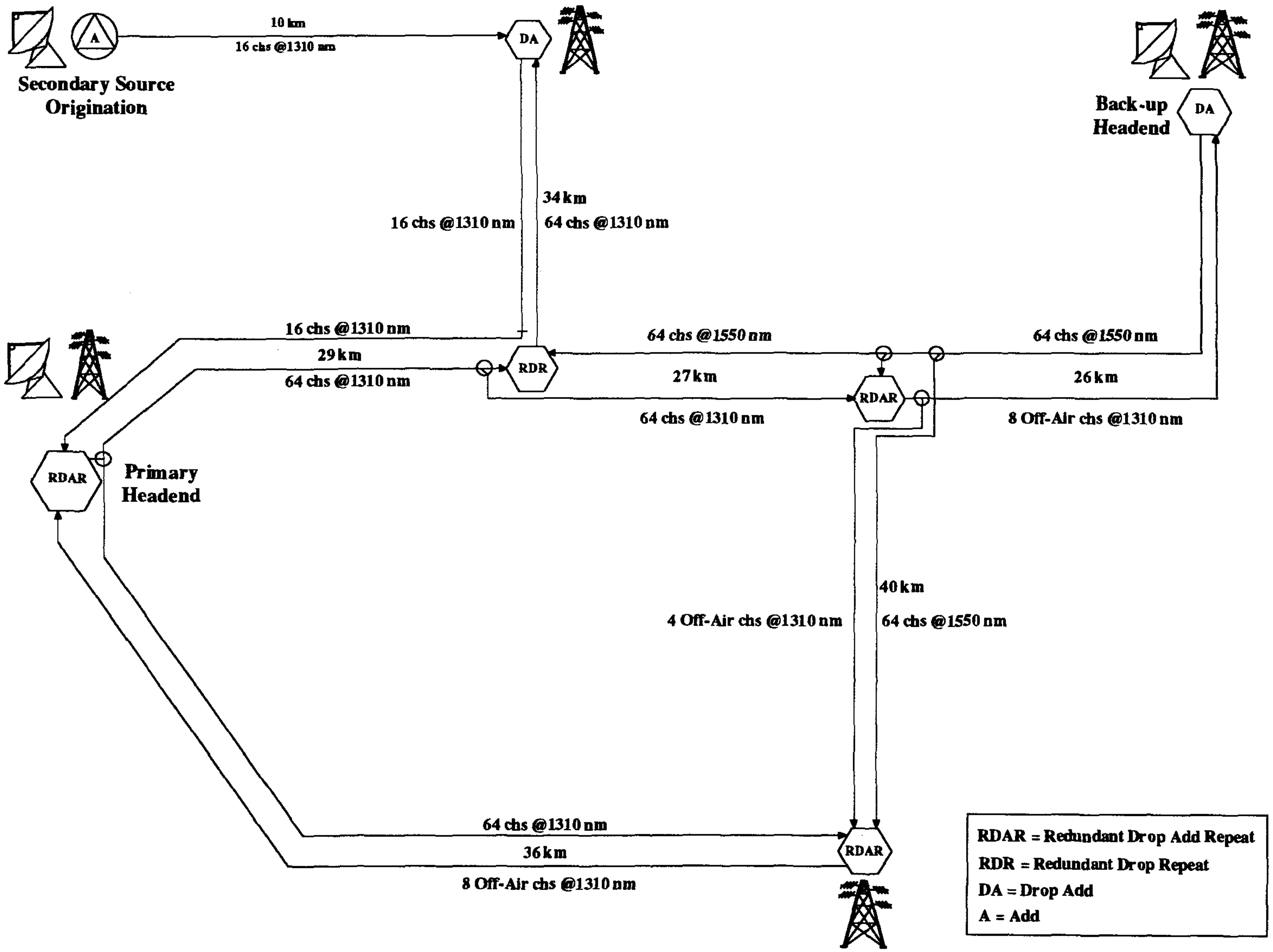
REFERENCES

[1] R.W. Harris, "Digital Video versus AM Supertrunking: A Cost and Performance Analysis", CED, July and Aug. 1993.

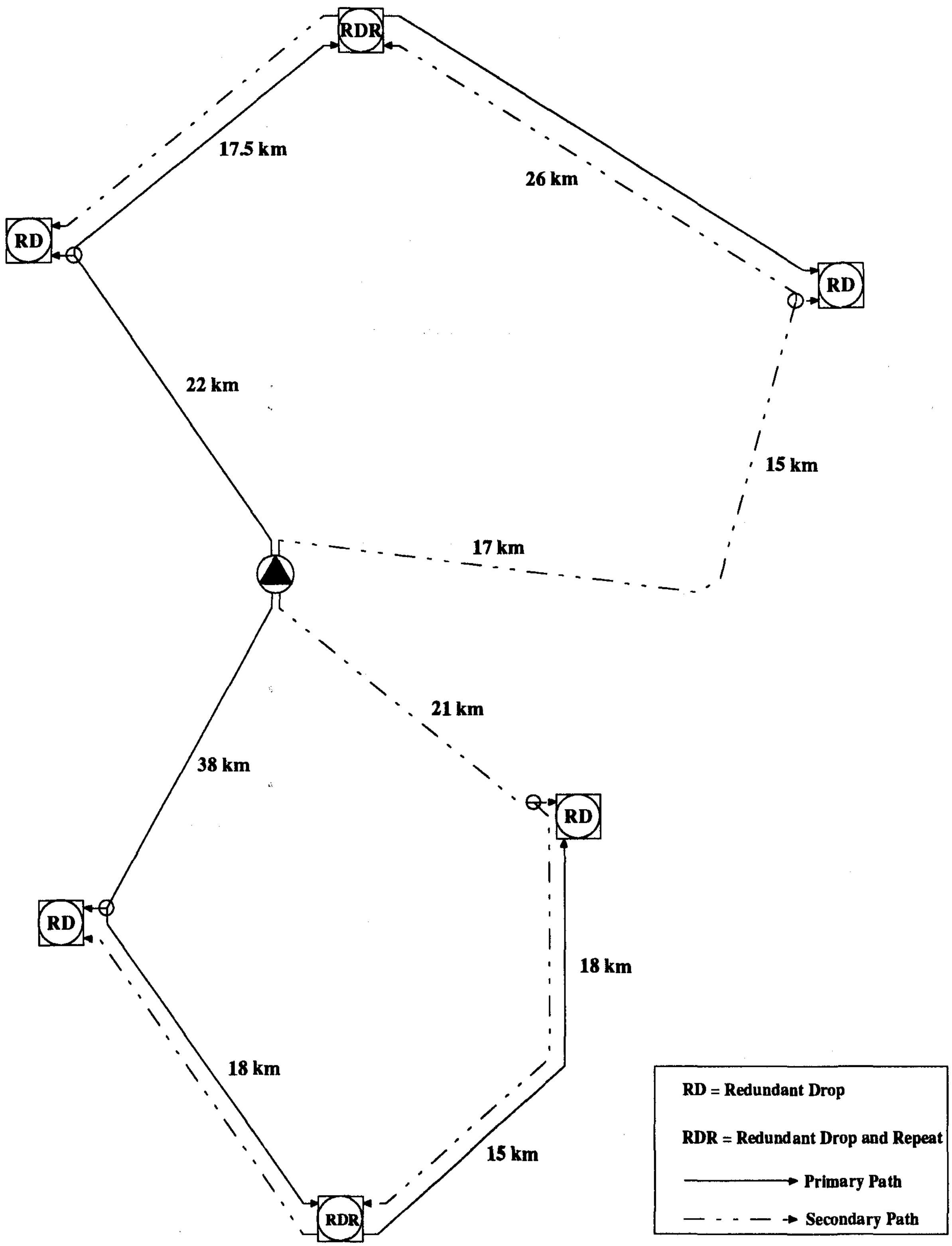
[2] R.W. Harris, "A Cost and Performance Comparison Between Uncompressed Digital Video and Lightly Loaded AM Supertrunking Methods within CATV Network Upgrades and Rebuilds", to be published in 1994 NCTA Proceedings, May 1994.

[3] S.D. Dukes, "Photonics for Cable Television System Design", Cable Television Laboratories, Inc.

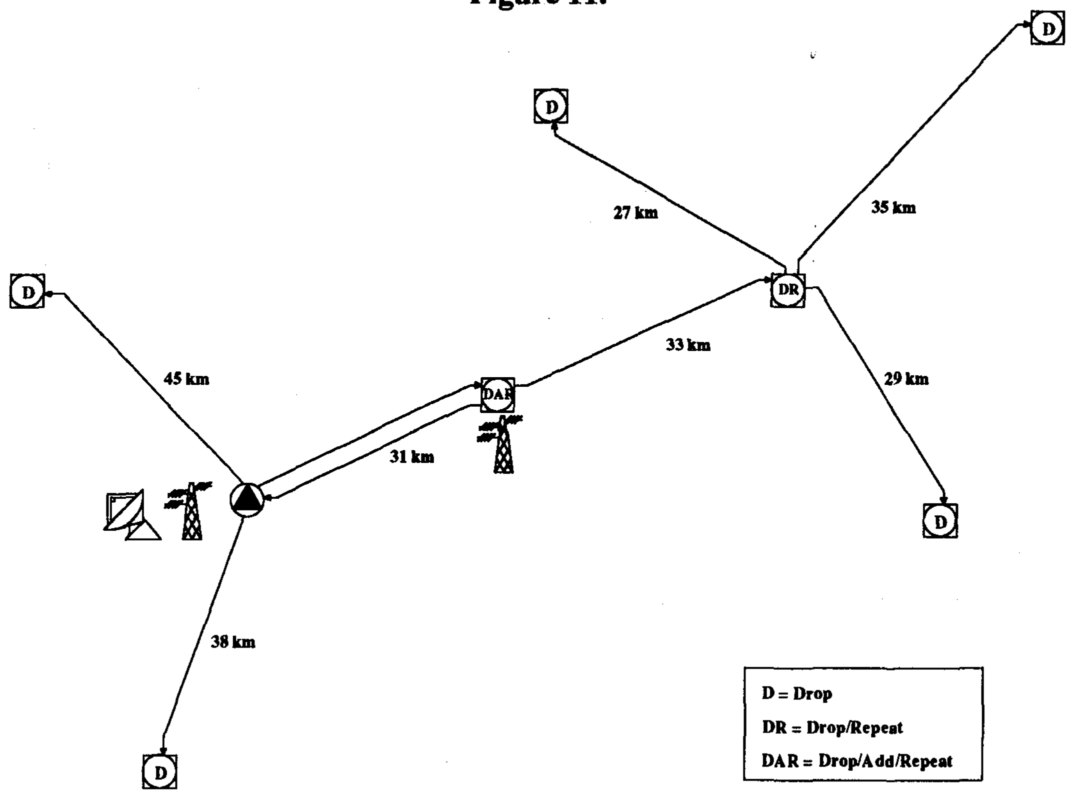
Inter-City Redundant Ring Network with Backup Headend, Drop/Add and Automatic-Self Healing Redundancy
Figure 9.



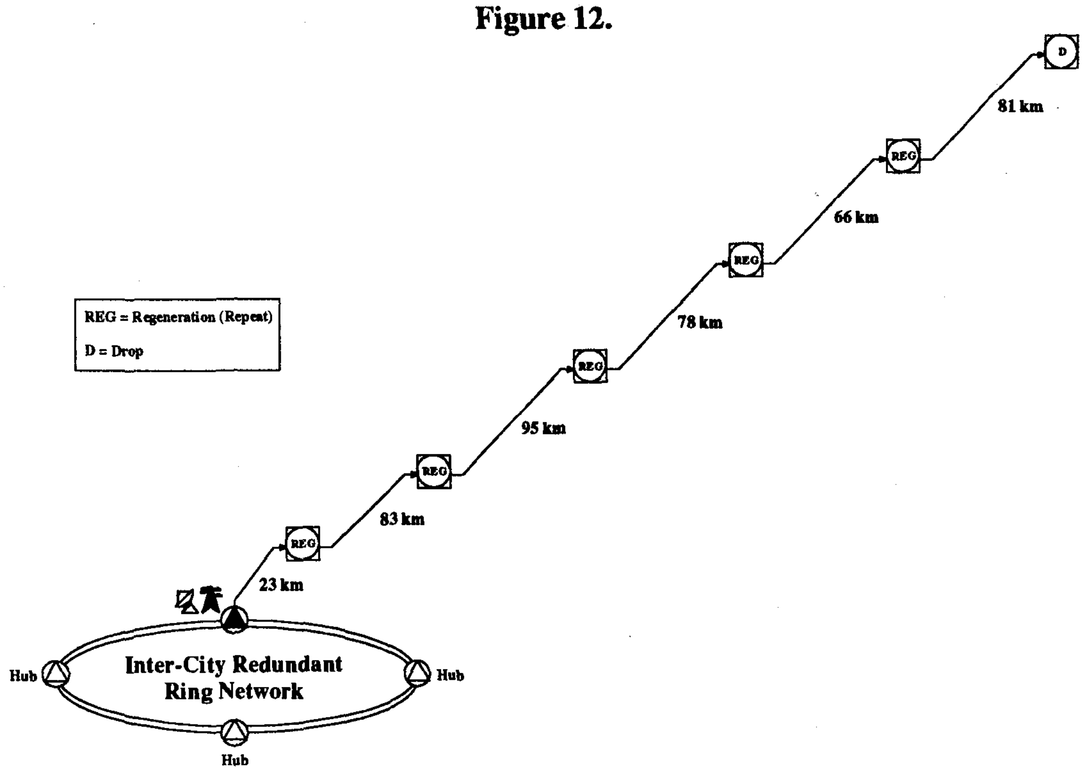
Inter-City Digital Network with Full Automatic Self-Healing Redundancy Transporting Composite IF Inputs and Providing Direct RF Outputs
Figure 10.



Intra-City Regional Network for Headend Replacement
Figure 11.



Intra-City Regional Network Through 425 km
Figure 12.



Inter-City Digital Backbone Network with Automatic Self-Healing Ring and Direct RF Outputs
Figure 13.