Repeaterless 16 Km Fiber Optic CATV Supertrunk Using FDM/WDM

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A key advantage of optical fibers over coax for CATV supertrunk is the elimination of trunk amplifiers or repeaters. By substantially reducing the amount of active electronics associated with supertrunk plant, overall reliability is increased and maintenance costs greatly reduced. Warner Amex is evaluating fiber optics for such an application by way of a field trial in its Dallas network. A 16 Km repeaterless link, is overlashed along an existing cable trunk route, to provide supertrunk quality video signals from the East Master Head End to a hub in the downtown Dallas area. A minimum of four video channels per fiber is transmitted by using two wavelengths per fiber with two frequency multiplexed video channels on each wavelength. A description and results to date of this field trial are presented in this paper.

The Warner Amex Cable Communications network under construction for the Dallas Cable Television Franchise is of a "hub-spoke-rim" design as illustrated in figure 1.0. In this design broadcast signals are distributed over conventional coaxial cable from seven hubs located geographically around the city in a pattern similar to the rim of a wheel. Supertrunks, containing the program channels, radiate, for the most part, from the hub in the center. Trunks vary from 8.9 Km to over 20 Km in length. A secondary diversity interconnect around the rim is accomplished using Microwave Amplitude Modulated Links (AML) to be used in the event service is interrupted in the "spoke" supertrunk. The design is for a full 100 channel capacity distributed from each hub. Channels originate from a Master Head End to the east of town. A 16 Km supertrunk carries these channels to the center hub, for distribution to the hubs on the spoke supertrunk cables. Presently the network is made operational using the AML microwave "rim" interconnect. The "spoke" interconnect, which will become the primary trunk network, will begin construction in 1984. At completion, full redundant signal paths will exist for the interconnect of programs to each distribution hub, making the Dallas CATV system design the highest reliability large scale CATV system in the world.

The planned technology for the "spoke" interconnect is fiber optics. In contrast to the other technologies, optical fibers have the potential for very long repeater spacings, vastly greater reliability due to the reduction or elimination of amplifiers, reduced cable size, and superior signal quality with no susceptability to external radio frequency interference.

In an effort to evaluate the practical use of fiber optics technology for this network, a 16 km repeaterless supertrunk evaluation link will be installed in Dallas. The evaluation will test a four channel per fiber configuration, with end to end performance per channel of a 55 dB weighted peak signal to RMS noise. The potential of 6 channels per fiber will also be evaluated.

The fiber optics supertrunk system design is illustated in Figure 2. The system multiplexes four frequency modulated video channels on a single fiber using frequency division and wavelength division multiplexing (WDM). The system accepts four baseband color video inputs with their companion audio. The companion audio, on a 5.8 MHz carrier, together with the video baseband forms the composit signal which is FM modulated. Wide deviation modulation, 8 MHz peak-to-peak, is used to achieve the maximum improvement factor while maintaining a reasonable channel bandwidth for multiple carrier transmission.

Carriers of 30 MHz and 70 MHz were chosen to allow for the 36 MHz RF bandwidth of the FM modulators. The FM modulated carriers are combined in pairs onto two fiber optic laser transmitters operating at different wavelengths. Wavelengths of 1.2 um and 1.3 um +/- .02 um were chosen for the reasons that laser sources are available at these wavelengths, high signal isolations can be achieved with practical wavelength multiplexers, and moderately priced fibers can be obtained with very low loss and high bandwidths at these wavelengths. The two laser optical outputs are combined in a passive optical wavelength division multiplexer and transmited on a single graded index multimode fiber. The WDM couplers were specified to achieve 30 dB of optical isolation (60 dB electrical) and optical insertion loss values of 1.75 dB max. The WDM couplers are spliced to "pigtail" fibers which are coupled to the lasers and detector diodes. The coupler is them mated with the transmission fiber thru an optical connector.

At the receive end the signals are optically separated by wavelength and converted to electrical signals with a photodetector followed by an amplifier. The resultant RF signal consists of 30 MHz and 70 MHz FM modulated carriers. These carriers are separated and demodulated to produce baseband video and audio signals.

With fiber optic cable over 30 fibers can be contained in a cable which is less than the diameter of a single conventional 0.750 inch trunk cable. At four channels per fiber a 100 channel cable can be achieved with 25 fibers.

Link Budget

The optical link power budget used to specify and design the four channel per fiber configuration is shown in table 1.0. The power output of the laser, coupled into a "pigtail" fiber, is 1 milliwatt or 0 dBm, a practical value for available long wavelength semiconductor lasers. The next component in the link is the WDM coupler. This coupler maintains an optical insertion loss to less than 1.75 dB per end. The optical connector which mates the coupler to the transmission fiber is specified at 1.5 dB per connector, a value achievable with butt contact connector types.

An optical fiber rated at 1 db/Km attenuation was specified. Allowing for a worst case added cable induced attenuation of 0.4 db/Km this would yield a net loss of 22.4 dB over the 16 Km length. Since the cable comes in reels from 1 to 2 Km long, the cable will be spliced at various points along the route. Eight splices at an average splice loss of 0.25 dB were used for the design.

As shown in Table 1, the summation of optical power and link losses results in a -32.9 dBm optical power at the receiver. Receiver sensitivity is referenced to a 30% source modulation index and a CNR of 21 db delivered to the FM demodulator. This is the minimum required to achieve a 55 db weighted SNR for the demodulated baseband video. Receiver sensitivity was calculated to be -36.6 dB. As shown in Table 1, the summation of power and loss leave an excess power margin of 3.7 dB.

Table 1

Optical Link Power Budget

Design Objective

Transmitter Average Coupled Power	0 dBm
Wavelength Division Mux Insertion Loss (Pair)	-3.5 dB
Fiber Attenuation (16 Km)	-16.0 dB
Excess Cable Loss	-6.4 dB
Splice Loss (8 splices)	-4.0 dB
Connector loss (2 connectors)	-3.0 dB
	-32.9 dB
Receiver Sensitivity for 21 dB CNR	-36.6 dB
Excess Optical Power Margin	3.7 dB

Although it appeared that the optical power budget was adequate for the desired systems performance, another factor which may limit the system carrier to noise was evaluated. Noise associated with the laser source, and optical mode interactions within the fiber, pose an upper limit on transmitted carrier to noise. Stable multimode sources were used in order to minimize these effects.

Bandwidth of the various components were specified in order to achieve an overall electrical bandwidth of 90 MHz minimum for the 16 Km link. The laser transmitter has a bandwidth of approximately 500 MHz, and as such can be ignored. The receiver bandwidth is set at approximately 1.3 x 90 MHz=117 MHz for optimal detection. The fiber optical bandwidth must be sufficient to support this. It is known that some bandwidth improvement is gained thru concatenation, i.e., the splicing together of long lenghts of fiber. The relationship is as follows:

$$BW_F\ (\text{MHz-Km}) = BW_T\ (\text{MHz})\ (1 + (L-1)^{\gamma})$$

where L = length of span in Km
BW_F = optical bandwidth of 1 Km fiber
BW_T = total end-to-end bandwidth required
Optical BW = electrical BW/0.7
therefore:

$$BW_T = \frac{90}{0.7} = 128.7\ \text{MHz}$$

γ = concatenation factor, 0.5 assumed.

$$BW_F = 128.7\ \text{MHz}\ (1 + (16-1)\ 0.5) = 626.5\ \text{MHz.Km}$$

Allowing for uncertainties in true concatenation improvement and a desire to achieve span lengths beyond 16 Km, an 800 MHz-Km fiber was specified for initial tests.

Test Results

At the date of this writing, tests have been performed on first production hardware over a 16 Km uncabled optical fiber. The validity of using the uncabled fiber for these initial tests has been confirmed with measurements made on over 18 Km of cabled fiber produced to date. Excess cable loss was shown to be negligible on the average, and at worst 0.2 db/Km.

For initial tests seven reels of fiber averaging 2.25 Km in length were spliced together with six fusion splices to form a 15.8 Km link. Fiber tension on the spools was relaxed to simulate the cabled state. Attenuation measurements taken on the sections prior to splicing gave an average attenuation of 0.78 dB/Km at 1.30 um and 0.91 dB/Km at 1.20 um. Average optical bandwidth was 1099 MH-km. After splicing, the full 15.8 Km was measured. The total end-to-end optical bandwidth was 80 MHz or a bandwidth distance product of 1280 MHz-Km. The total attenuation was 12.8 dB at 1.3 um (0.81 dB/Km) and 14.9 dB at 1.2 um (0.94 dB/Km).

The bandwidth result indicated that the concatenation factor was actually 0.945 as shown below

$$(L-1)^{\gamma} = \frac{BWF-BWT}{BWT}$$

$$(15.8-1)^{\gamma} = \frac{1099 - 80}{80}$$

$$\gamma = .945$$

The attenuation results indicate a total spliced fiber related loss of approximately 0.5 dB or 0.083 db per splice on the average. It is suspected that this low attenuation differential is a length related improvement effect on both splice insertion loss as well as fiber attenuation. Individual splice losses, may be higher if measured over short fiber lengths.

Insertion loss results on the optical wavelength couplers as pairs gave: - 3.5 db @ 1.3 um and - 3.5 db @ 1.2 um.

The optical transmitters used in this series of tests used multimode lasers, one at 1.3 um and the other at 1.2 um. Performance of the 1.3 um laser indicated a source CNR of 37 dB at 60% modulation index. Performance of the 1.2 um laser indicated a source CNR of 35 db at 60% modulation index. For these link tests, source power was set at 1.2 mw @ 1.3 um and @ 1.2 um. The 60% modulation index represents two channel per laser transmission.

Optical receiver sensitivity varies as a function of carrier frequency.In the 30 MHz band, the received optical power necessary to achieve the required 21 db CNR was

-32.6 dBm. In the 70 MHz band the required received optical power was -30.5 dBm. With the above described transmitters and receivers integrated with the fiber link, end-to-end performance gave a CNR of 30 dB both at 1.3 um and 1.2 um at 30 MHz; 9 dB above the minimum required. Total path loss was measured to be 21.2 dB @ 1.2 um and 20.4 dB @ 1.3 um. Received optical power was therefore over 11 dB (optical) above required receivers sensitivity. If not for the CNR limitations at the source, this would result in a CNR improvement of 22 db over minimum. It is clear that CNR is dominated by source noise. True optical power margin is large and thus will allow for expansion in length or additional loss factors such as cabling loss or added splices while maintaining signal quality.

Conclusion:

Tests on the 15.8 Km link demonstrate the practicality of transmitting a minimum of 4 channels per fiber over distances of 16 Km or greater, with high quality video. The use of existing components and products to achieve these results shows fiber optics to be a practical solution to repeaterless, long haul video trunking, in the near term. Finally, with the continual development of new products that will increase receiver sensitivity, improve laser output power and stability, we are confident that 6-8 channels per fiber will be achievable in the near future. This coupled with continual component cost reductions will further drive this technology to be the logical CATV supertrunk approach for the 80's.

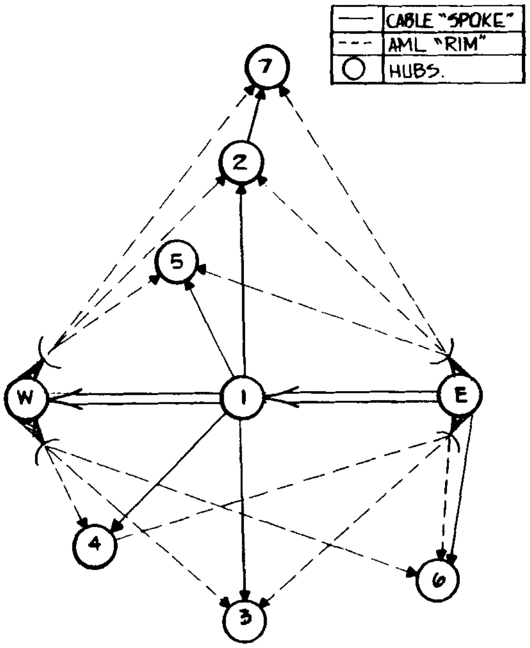

FIG. 1a HUB-SPOKE-RIM IMPLEMENTATION

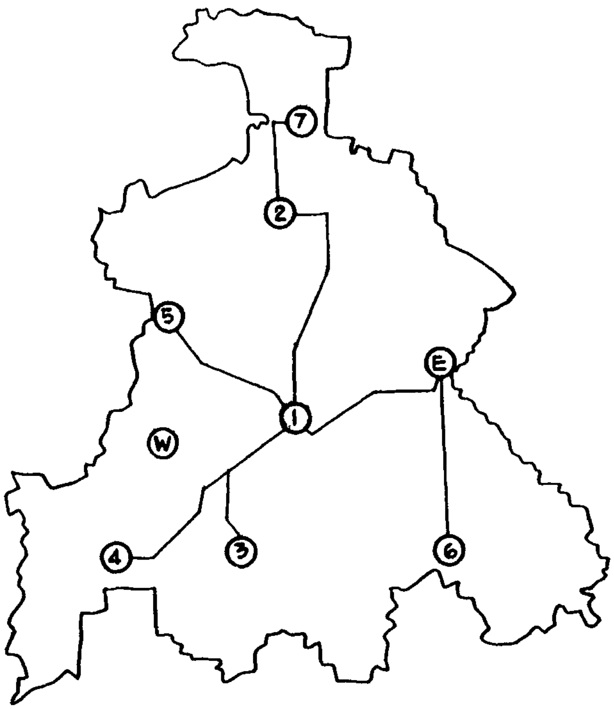

FIG. 1b SPOKE SUPERTRUNK CABLE INTERCONNECT

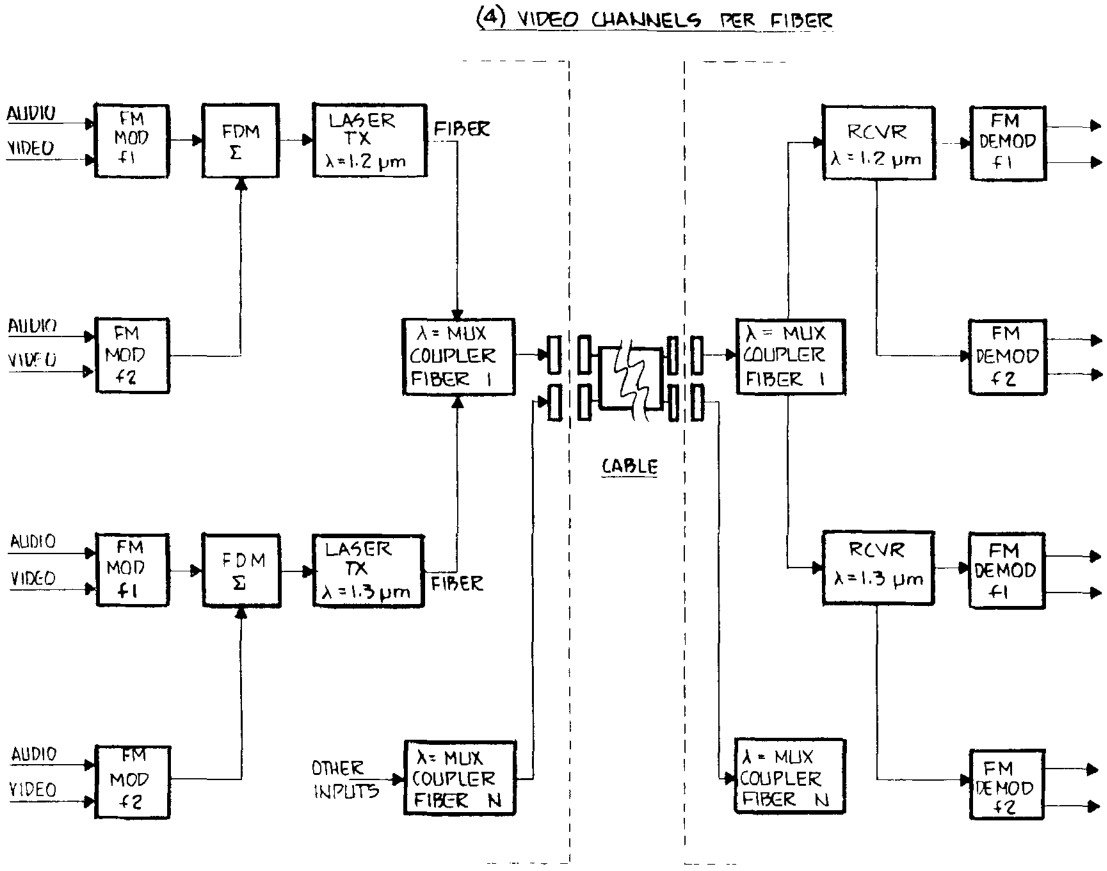

FIG. 2.0 LONG WAVELENGTH FM/FDM/WDM FIBER OPTIC SUPERTRUNK