FIBER OPTIC VIDEO SUPERTRUNKING
FM VS. DIGITAL TRANSMISSION

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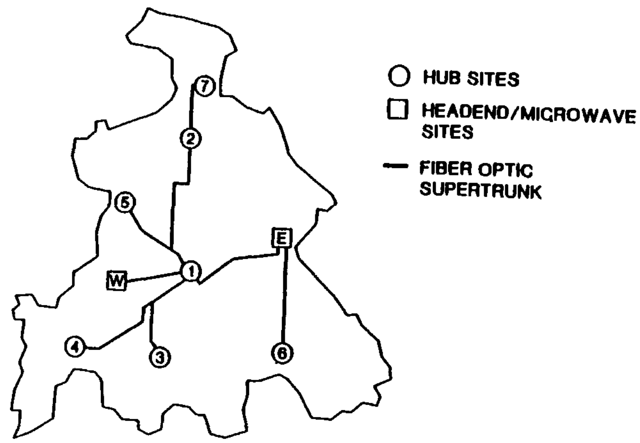
ABSTRACT

The rapidly evolving technology of fiber optics is providing many new options to the CATV systems integrator. For many years within the broadcast and CATV industry, fiber optics has provided short, single channel per fiber links for interference-free broadcast quality transmission. Not until recently has fiber optics become economical for video supertrunking. The ability to frequency and wavelength multiplex large groups of channels on a single fiber for repeaterless transmission beyond 10 miles has made fiber cost-competitive with coaxial supertrunk in certain systems. Advances in the fiber technology, with the introduction of low-cost single mode fiber, provide new cost and capacity advantages to the service provider. Although FM transmission on fiber is the lowest cost near-term approach, the projected introduction of low-cost digital encoders may make PCM transmission the future choice, particularly for long haul transmission.

The cost and performance of FM video transmission over multimode and single mode fibers is compared. Comparison with digital transmission is made. Test data will be presented to confirm analytical results.

THE PROBLEM

In today's larger metropolitan areas, a trunked hub architecture is generally employed for CATV video transmission. Such an architecture is shown in Figure 1 as conceived for the City of Dallas. Operationally, video programming originates from the headend(s) and is delivered to the hubs via microwave, coaxial, or fiber optic supertrunks. From the hubs, it is distributed to the subscriber over a conventional coaxial network. This supertrunk distance is generally on the order of 8 to 12 miles. As separate systems within a metropolitan area begin to merge through acquisition or business venture, a need for even longer, higher quality supertrunks arises for inter-systems interconnect. Interest in data interconnect along with video is rapidly emerging. Fiber optics is evaluated here as a supertrunking means.



Fiber Optic Supertrunk Routing
Figure 1

APPROACHES

Three approaches to video supertrunking are evaluated:

a) Frequency modulated, frequency multiplexed, wavelength multiplexed (FM/FDM/WDM) transmission on multimode fiber;

b) FM/FDM/WDM transmission over single mode fiber; and

c) Pulse code modulated, time division multiplexed, wavelength multiplexed transmission (PCM/TDM/WDM) over single mode fiber.

The three approaches are illustrated in Figures 2 and 3.

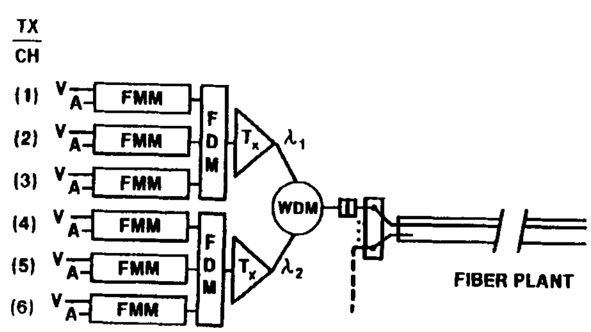


Figure 2

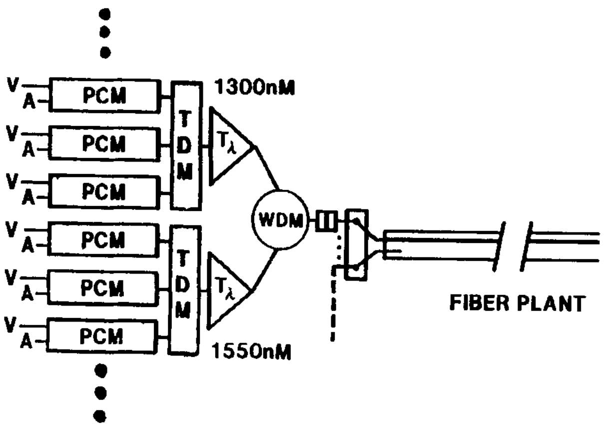


Figure 3

PERFORMANCE

Performance of a fiber optics link is a function of the received, detected carrier to noise (CNR_R) vs. the CNR required to achieve demodulated weighted video signal to noise (SNR_W). Received CNR_R is a function of received optical power (P_R) vs. noise introduced in the optical link by the source (modal noise) and the receiver. In general, therefore, SNR_W is affected by P_R. Since optical power margins are usually small (30 to 40 dB), encoding must be used to improve the CNR to SNR relationship.

FM/FDM

For FM modulation, wide deviation (8 to 10 MHz) is used to reduce the required CNR_R. FM improvement factors of 32 to 38 dB have been demonstrated. A CNR_R of 21 dB, for example, is shown to achieve a 55 dB CCIR weighted video SNR. Allowing for guardband, a 36 to 40 MHz passband is required. Optical receiver sensitivity (required P_R) at 21 dB CNR_R is the range of -36 to -32 dBm. FDM divides the available optical source power by the number of channels transmitted per wavelength and utilizes a transmission bandwidth which is, as a minimum, N x Bc, where N is the number of channels and Bc is the passband per channel. A 10-channel per wavelength system, therefore, requires 400 MHz BW.

Multimode vs. Single Mode Performance For FM/FDM

Multimode fiber has the following performance disadvantages over single mode:

Attenuation: .9 to 1.2 dB/km vs. 0.5 to 0.6 dB/km for single mode

Bandwidth: ∠ 1.6 GHz-km vs. multiple GHz for single mode

Noise: Multimode lasers and their interaction with multimode fibers creates a noise component which becomes a limiting factor; optical power penalties of typically 3 to 4 dB can be attributed to modal noise.

Intermod: Although single mode sources have linearity limitations, they are inherently more linear than multimode since stability of one mode is easier to control than that of multiple modes. Source screening may prove a low yield, high cost operation for multimode.

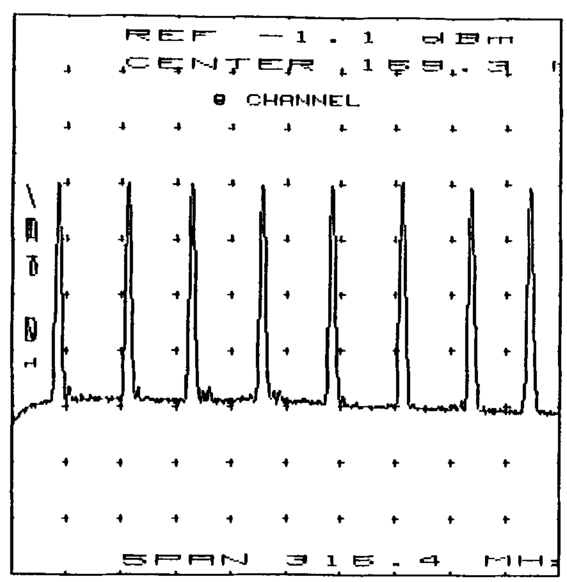
Table 1 gives the results of tests performed at Warner Amex which compares the performance of FM/FDM video trunking over multimode and single mode fibers. Multimode tests were performed over 16 and 22 km, and single mode over 20 km of cabled fiber.

Figure 4 shows the spectrum analyzer printout for 8 channels per wavelength FM/FDM over a 20-km distance.

Parameter	Multimode		Single Mode	
Mod/Mux	FM/FDM/WDM		FM/FDM	
FM Deviation	10 MHz		10 MHz	
Wavelength	1200, 1300 nm		1300 nm	
No. Ch/Fiber	4	6	6	8
Tx BW (MHz)	90	130	250	330
Tx Distance (km)	22	16	20	20
Tx Loss (dB)	25.6	21.1	11.5	11.5
Coupled Power (dBm)	-5	-5	-6.2	-6.2
Rcvd. CNR_e/Ch.	21	24	26	24
Typ. Intermod (dBc)	-30	-30	-42	-40
Video SNR_W (dB)	55	58	59*	59*

*Limited by FMM/FMD

Tests Comparing Single Mode To Multimode FM/FDM Transmission (Typical Values Shown)
Table 1



8 Channels Per Wavelength
Figure 4

PCM/TDM

The relationship between video SNR_W and number of PCM bits required is:

$$SNR_N = 6n + 10 \log \frac{fs}{b} + W$$

Where: n = Number of bits per sample
fs = Sampling rate
b = Video BW
W = Weighting factor

Note: $fs \approx 1.25 \times$ Nyquist Rate = 1.25(2b) to account for practical filtering

The data rate per channel is as a minimum:

$$Rc = Nfs$$

For a 4.2 MHz video bandwidth, therefore:

fs = 10.5 MHz (10.74 often used as multiple of color subcarrier)
N = 8
$Rc \approx 86$ Mb/s

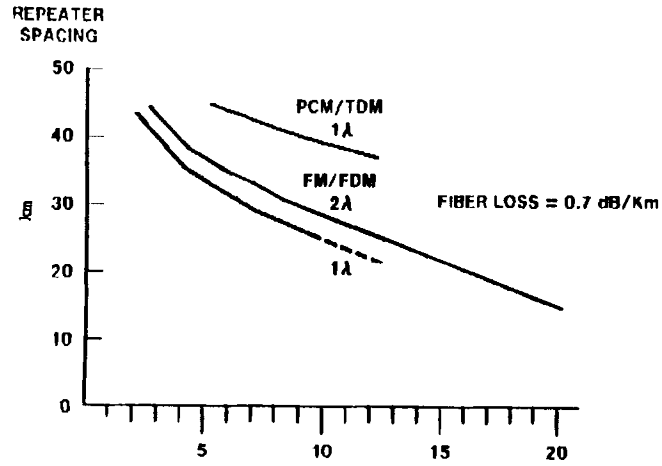
For TDM, the transmission rate is:

$$R_T = N(2nBb)(1 + \gamma)$$

Where: N = Number of channels
γ = An efficiency factor reflecting added frame bits for multiplexer and endcoder overhead and synchronization

If a 5% frame overhead factor (12/256) is assumed, the rate per channel is 90 Mb/s. If we assume scrambled NRZ encoding, then the minimum transmission bandwidth is $\approx R/2$. Bandwidth utilization per channel is, therefore, approximately 45 MHz or only slightly greater than that required for FM/FDM.

A key difference between FM and PCM is that for PCM, assuming few bit errors (10^{-7} to 10^{-9} BER), video SNR is a function of the encoding and not the transmission quality. The received peak signal to RMS noise to achieve a 10^{-9} BER is approximately 21 dB (or 15 dB average signal to RMS noise). This is a 3 dB optical power advantage over FM/FDM. PCM offers an additional advantage at repeaters where, with signal regeneration, degradation is negligible. With FM/FDM, approximately 3 dB optical power penalty per repeater can be assumed since video SNR is a direct function of received CNR above the FM threshold. Considering the above, intermod penalty, modulation depth, and noise bandwidth differences, the performance comparison is shown in Figure 5. Single mode fiber is assumed.



No. Of Video Channels Per Fiber
Figure 5

COST ANALYSIS

The analysis compares equipment cost only, assuming labor and construction are equal. Cost projections incorporated the following assumptions:

a) Current costs were based on actual quantity quotations or recent experience;

b) Projections were based on today's pricing for similar components where volume or maturity has influenced cost;

c) Transmission assumes video only: one video with companion audio per channel;

d) Fiber optics cost projections assumed:

- Fiber @ 35¢/m
- Tx/Rx @ $4,500/pr. multimode, $5,000/pr. single mode

e) FM/FDM assumes actual costs for existing hardware;

f) PCM/TDM projected costs assume:

- Encoder costs (video vs. audio) will achieve same price levels as FM

- High speed TDM will reach the $4,000 to $6,000 per pair range (includes shelf and power supply)

The results are shown in Figures 6 through 9. Route lengths of 16 km (10 miles) and 32 km (20 miles) are compared as to total cost vs. channel capacity.

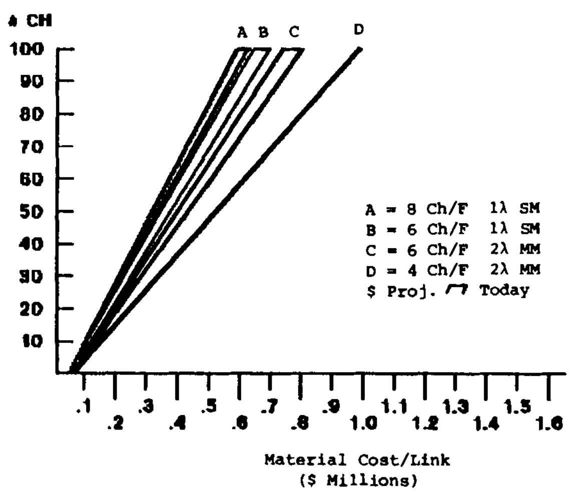
OBSERVATIONS

FM/FDM (FIGURES 6 AND 8)

For a 16 km route length, transmission on multimode is in practice limited to 3 channels per wavelength, i.e., 6 channels per fiber. Single mode transmission can achieve over 8 to 10 channels per wavelength at this distance. At only 8 channels per fiber, one wavelength, the single mode approach is 20% less than the best multimode approach (6 channels per fiber). In addition to the cost advantage, even at 8 channels per fiber, the single mode approach is not limited to 16 km repeater spacing. The excess optical power, the total absence of modal noise, and the low intermod of single mode results in much higher video performance, more capacity and longer repeaterless distance.

At 32 km spacing, the multimode system requires at least one repeater, while the single mode system does not. This results in a cost advantage for single mode of 40% at 8 channels per fiber (as compared with 6 channel per fiber, 2 wavelength, multimode).

Of interest to note is that multiple wavelength operation over single mode only has significant cost advantage for longer trunk distances. The logistic problems of maintaining two transmitter types may outweigh any small cost advantage for shorter distances.

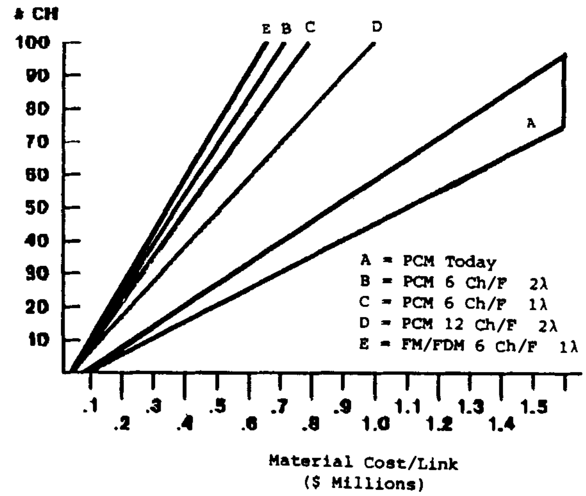


Single Mode vs. Multimode
FM/FDM 16 km Hub Spacing
Figure 6

PCM MODULATION (FIGURES 7, 8, AND 9)

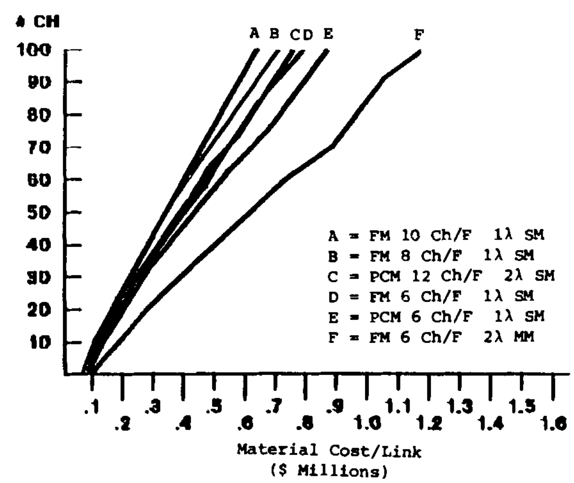
Figures 7, 8, and 9 illustrate the projected cost of PCM/TDM/WDM in comparison to FM/FDM. For PCM, today's cost is also reflected. Today's cost reflects linear encoding, single channel per wavelength operations as the lowest cost architecture available in product form.

What the figure shows is that for short trunks (10 miles), PCM at today's product costs is at best 2 1/2 times higher in cost than what can be achieved today with 8 channel FM/FDM. If we project PCM encoder cost to be equivalent to FM modem costs, 6 channels per fiber PCM/TDM becomes cost equivalent to only 4 channels per fiber FM/FDM. The difference is the TDM multiplexer cost.



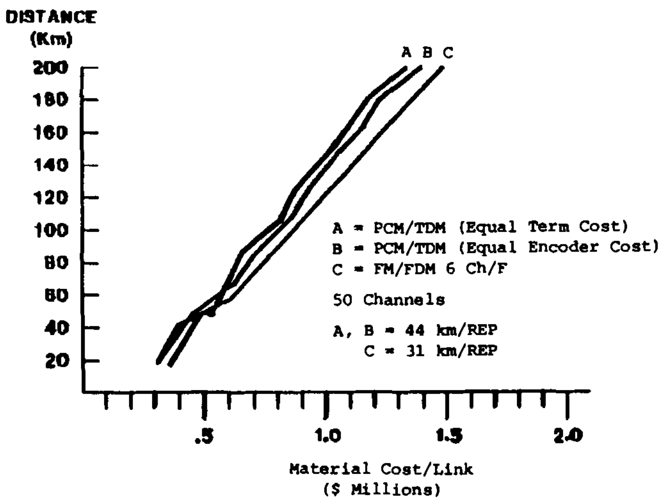
FM/FDM vs. PCM/TDM
16 km Hub Spacing
Figure 7

For PCM/TDM to compete with FM/FDM in metropolitan CATV networks, for example, the cost of a 6 channel video plus audio encoder/mux terminal end must be in the $10,000 to $14,000 range (excluding optics). This is true of the 16 and 32 km trunk distances. These costs are possible but not anticipated in the near term.



FM/FDM vs. PCM/TDM
32 km Hub Spacing
Figure 8

Addressing inter-LATA supertrunk distances beyond the 32 km range (Figure 9), PCM has a distinct performance advantage in its ability to be repeated with negligible degradation. The convenience of digital encoding and its ability to handle mixed service (video and data) makes it the preferred choice if and when costs come in line with FM. Figure 10 compares PCM to FM costs for long distance trunking at the 6 channel per fiber multiplexing density. Two PCM cost scenarios are presented: (a) equal encoder costs to FM modems, and (b) equal total terminal costs to FM/FDM. Using these assumptions, PCM is 5% to 10% lower in cost than FM/FDM, primarily due to longer repeater spacings assumed.



Long Haul Trunking
Figure 9

CONCLUSIONS

Where fiber optics is employed for supertrunking, FM/FDM incorporating single mode fiber, operating at 6 to 10 (or more) channels per fiber, appears the optimum solution for metropolitan area CATV video trunking. In order to be competitive, a PCM/TDM terminal pair with optics must achieve a cost below $4,000 per channel.

PCM is more advantageous for long haul trunking beyond 20 miles (32 km), although even here, today's costs render it non-competitive with FM.