COST AND PERFORMANCE COMPARISON OF FIBER OPTIC CATV SUPERTRUNKS UTILIZING FM AND DIGITAL TRANSMISSION TECHNIQUES

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ABSTRACT

This paper discusses practical implementation of cable TV supertrunks utilizing FM and digital transmission techniques carried on single mode fiber optic links. Architectures and link budgets are discussed, along with cost and performance comparisons.

Noise and distortions inherent in FM and in digital techniques are analyzed. Those factors necessary for good FM performance over a fiber link are considered. In the digital domain, the performance factors of the digital converters are presented. The problems encountered in utilizing video distortion test equipment to evaluate digital systems are reviewed. Finally, some projections for future developments are described.

I INTRODUCTION

A CATV trunk system made up from today's fiber optic components enjoys a number of important advantages over conventional coaxial or microwave links. Chief among these are long transmission paths without amplifiers, no leakage from or ingress into the cable, very wide bandwidth, increased security, and low maintenance costs (all active electronics indoors). Fiber optic cable is exceptionally reliable and impervious to environmental effects like rain fade. The available bandwidth is presently limited by the electronics at either end of the fiber, not the fiber itself. Future advances in transmission techniques will utilize this bandwidth to carry more channels. The cable is suitable for aerial or buried installation, and is not limited by licensing or line-of-site restrictions. CATV super-trunk systems utilizing both FM frequency division multiplexing (FM-FDM) and digital time division multiplexing (TDM) are now coming on the market.

II SUPERTRUNK OPTICAL COMPONENTS

In recent years, considerable progress has been made in theoretical and practical development of single mode (SM) glass fiber, semiconductor lasers, silicon photodiode (PIN) receivers, and avalanche photodiodes (APD) receivers. The characteristics of the components must be understood so that they may be used effectively. For example, when modulated, a laser chirps (changes wavelength slightly). The velocity of propagation through the fiber varies with wavelength (chromatic dispersion). It is desirable to operate a SM fiber at the point that has the most constant velocity vs. wavelength. This minimum dispersion generally occurs at about 1310nm. Proper selection of the laser-fiber-receiver combination will result in nearly zero chromatic dispersion, and in signal attenuation of 0.3 to 0.5 dB per kilometer. Operating at or near the zero dispersion wavelength of SM fiber results in pulse rise times on the order of 0.5ns, and bandwidths in excess of 1GHz. This combination of components and operating parameters yields adequate performance for both FM-FDM and digital TDM supertrunks.

Figures 1a and 1b, laser transfer characteristic, illustrate how the device is light intensity modulated by varying the drive current. This is the case for FM, digital, and for AM modulation. Optical output is proportional to drive current; for FM-FDM modulation, the laser diode must be operated in the linear portion of figure 1b. The DC current bias point, I_b, and the variation of drive current, ΔI, must be controlled to minimize intermodulation products.[1]

III FM SUPERTRUNKS

FM supertrunk equipment is on the market today that can transmit 16 or more channels of video and associated audio on one single mode fiber. With proper design, RS-250B video specifications can be achieved with cable lengths up to 40km. Proper design means selection of FM deviation and channel spacing to minimize second and third order intermodulation products, and to achieve acceptable signal

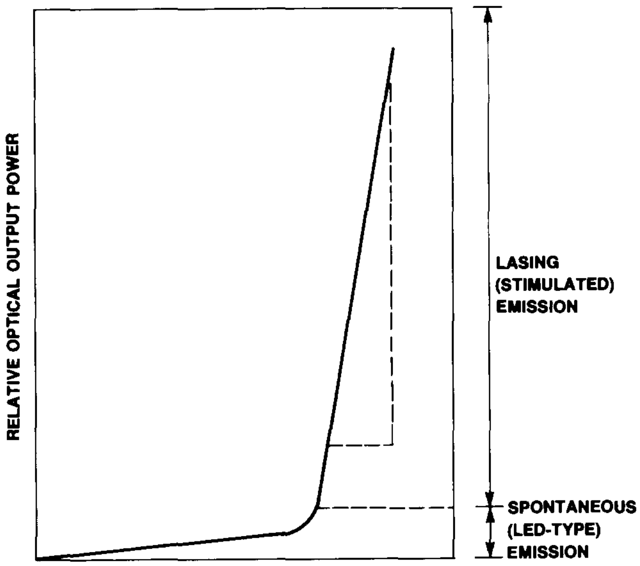


FIGURE 1A

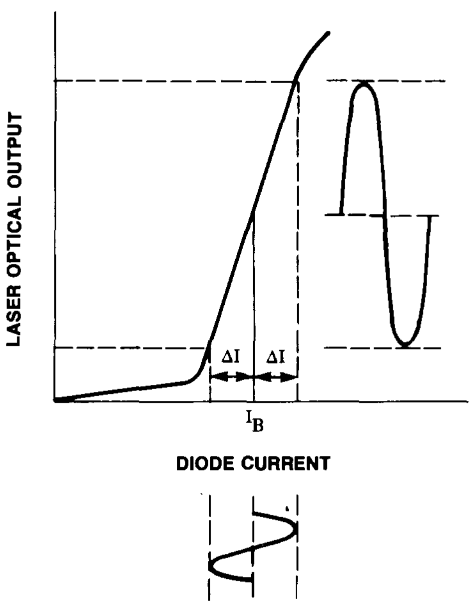


FIGURE 1B

FIGURE 1 LASER TRANSFER CHARACTERISTIC

to noise ratio.

IIIa Intermodulation Distortions

The second order distortions predominate in laser diodes. These may be minimized by a frequency plan proposed by Simons[2]; in this plan the channel frequencies are described by:

$$F_{ch} = f_s/2 + (n \times f_s)$$

where F_{ch} = channel frequency [MHz]

f_s = frequency spacing [MHz]

n = channel number (integer)

The second order products have the form

$$f_{im2} = m \times f_s$$

where m = integer

As a result, the second order products fall between channels; with proper selection and application of the laser diode and receiver, third order products are far enough below the desired signal to be acceptable.

It can now be seen that the wide bandwidth available in a properly designed fiber optic FM system can be used to advantage. This is illustrated in Figure 2, FM supertrunk frequency plan. This plan utilizes over 700MHz of bandwidth to carry 16 wide deviation FM video channels. The channel spacing in governed by the equations above so that second order products fall between channels. This frequency plan also affords adequate adjacent channel protection ratio as described by Gysel.[3]

IIIb Signal to Noise Ratio

Figure 3 illustrates the triangular spectrum of random noise present in an FM system. Due to this characteristic of FM , widening the transmission bandwidth improves the signal to noise ratio. Further improvement can be gained by utilizing CCIR pre- and deemphasis.[4]

By proper selection of the single mode fiber, laser diode source, and diode receiver, a CNR on unmodulated carriers of 34 to 36db is practical. This presumes a reasonable optical loss budget, which will be discussed later. CNR can be measured in the lab with a spectrum analyser. Video S/N can be calculated from C/N from:[3]

$$SNR = CNR + 12db + 20 \log D_{stpw}$$

where SNR = CCIR weighted video SNR, referenced to 100 IRE

D_{stpw} = sync tip to peak white deviation

note: 12Db is gained by pre- and deemphasis

With a measured CNR of 34DB and a deviation of 8MHZ, the calculated SNR is 64DB. This agrees with lab measurements of video SNR with a Rohde & Schwarz noise meter of 63 to 65DB.

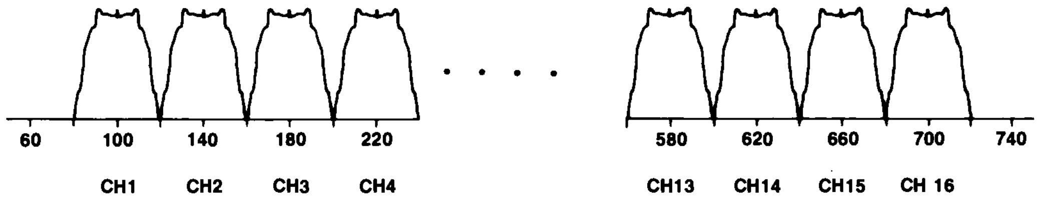


FIGURE 2

FM SUPERTRUNK FREQUENCY PLAN

Schwartz discusses modulation index, FM noise spectrum, and noise improvement in wideband FM in chapter 6.[4]

IIIC Audio Carriage

The stereo (BTSC format) audio program is carried along with the video by wideband FM subcarrier techniques in today's FM supertrunk. The required bandwidth is about 300khz for each BTSC encoded stereo pair. The audio subcarriers may be carried with the associated video carriers, or grouped together in their own portion of the available spectrum. Audio dynamic range better than 60Db is practical, with channel separation of approximately 30db. The audio frequency response is 50hz to 15khz.

IIID Architectures and Link Budget

Figure 4 illustrates one FM supertrunk architecture that carries 16 TV channels with stereo audio from point-to-point. The transmission equipment consists of 16 FM video/audio modulators, an RF combiner, and a laser transmitter. The modulators are driven by baseband audio and video signals, which could come

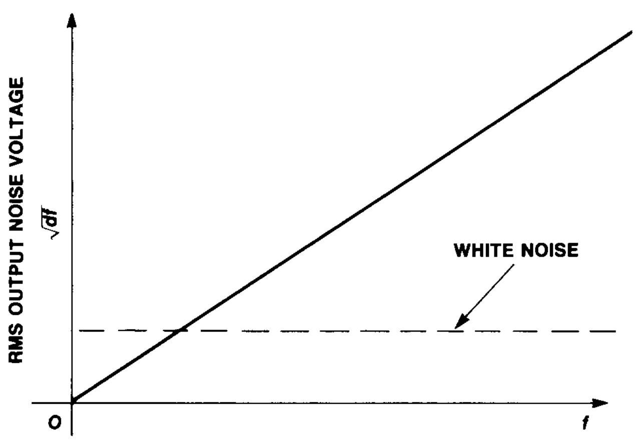


FIGURE 3

SPECTRUM OF NOISE IN FM SYSTEM

from satellite receivers in a typical head end. The SM fiber is likely one of several carried using a loose-tube buffer surrounded by a protective cover.(Figure 5)[10] The receiving equipment consists of the PIN diode or APD receiver with transimpedance amplifier, an RF splitter, and 16 video/audio demodulators. The outputs are at baseband suitable for driving standard AM modulators and BTSC encoders. Thus an 80 channel system could be carried on 5 fibers, with spare fibers, in one cable.

A supertrunk architecture designed to feed two receive sites is illustrated in Figure 6. The optical splitter is a small passive device that typically exhibits a 3DB power split and less than 1db additional insertion loss. At 0.35Db/km, a 4Db loss represents 10km less reach in each leg. An 80 channel system could be carried with additional electronics and one splitter per fiber.

A link budget is based on the following assumptions:

1. The optical power launched by the laser transmitter is -3Dbm, at 1310nm.
2. The semiconductor receiver sensitivity is -25db.
3. The fiber loss is 0.35db/Km at 1310nm.
4. A system margin of 3DB is assumed to allow for component aging and temperature effects.
5. Fusion splice losses are less than 0.1DB and can be ignored for the purpose of a comparative analysis.
6. Connector losses are assumed to be 0.5DB per connector

Figure 7 is an optical power loss model that illustrates the cumulative losses between the laser and the receiver. If P_t is the transmit power in DBm and P_r is the receive power in dbm, then P_l is the total loss budget for the link:[1]

$$P_l = P_t - P_r$$
$$= -3 -(-25) = 22\text{dbm}$$
and
$$P_l = 3xl_c + a_f \times L + \text{system margin}$$

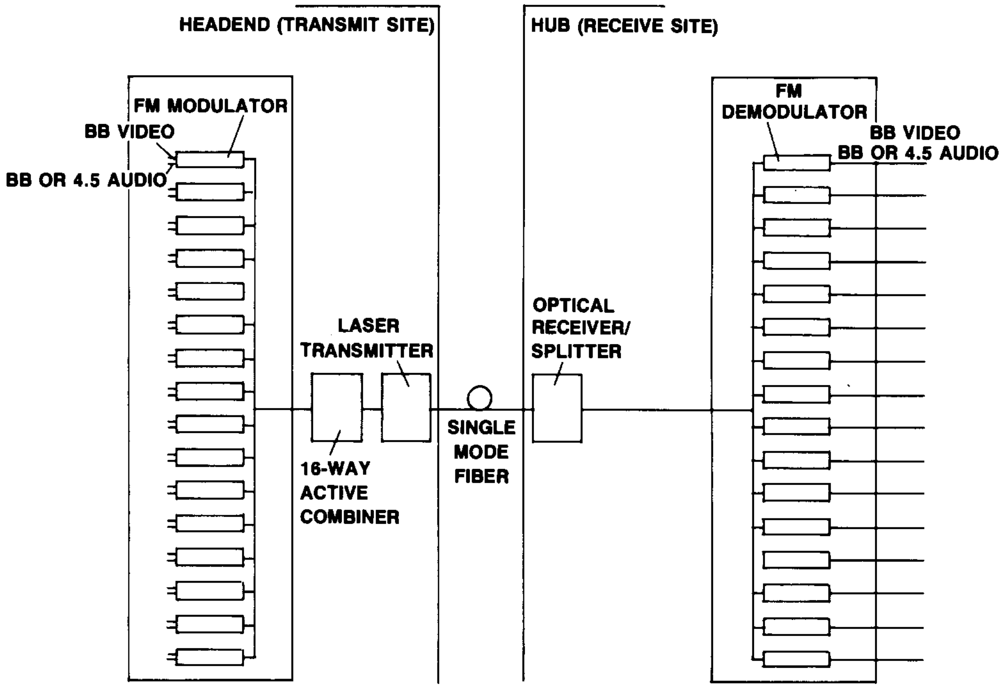


FIGURE 4

16 CHANNEL FM-FDM SUPERTRUNK

where: L = transmission distance (km)
l_c = connector loss
a_f = fiber attenuation in db/km

then:

$$22db = 3x0.5db + 0.35db/km \times L + 3db$$

and

$$L = (22 - 3x0.5 - 3)/0.35db/km$$

we find $L = 50km$

Therefore, the link may be more than 40km long with adequate margin.

By the same method, the two receive sites in figure 6 could be over 30 km from the transmit site.

IV DIGITAL SUPERTRUNKS

Figure 8a illustrates how one baseband channel of video can be quantized, delivered to a D/A converter, and converted back to the analog domain. The distortions and noise inherent in this

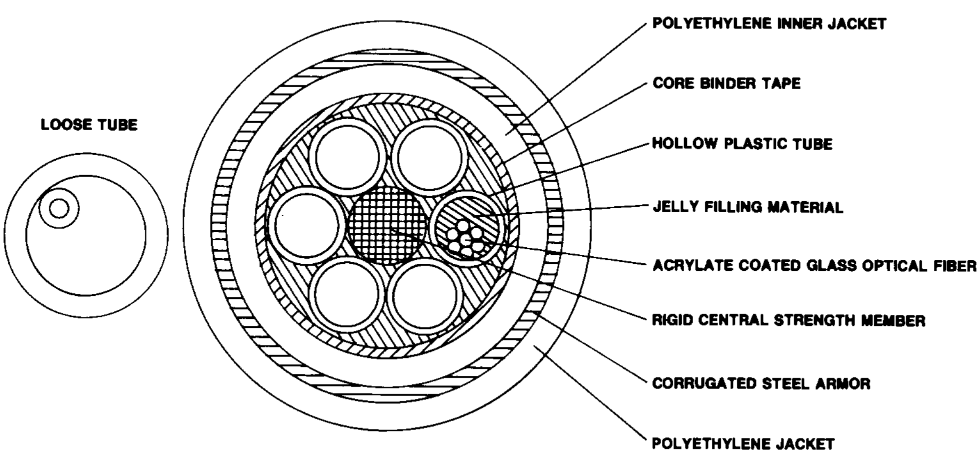


FIGURE 5 LOOSE-TUBE CABLE CONSTRUCTION

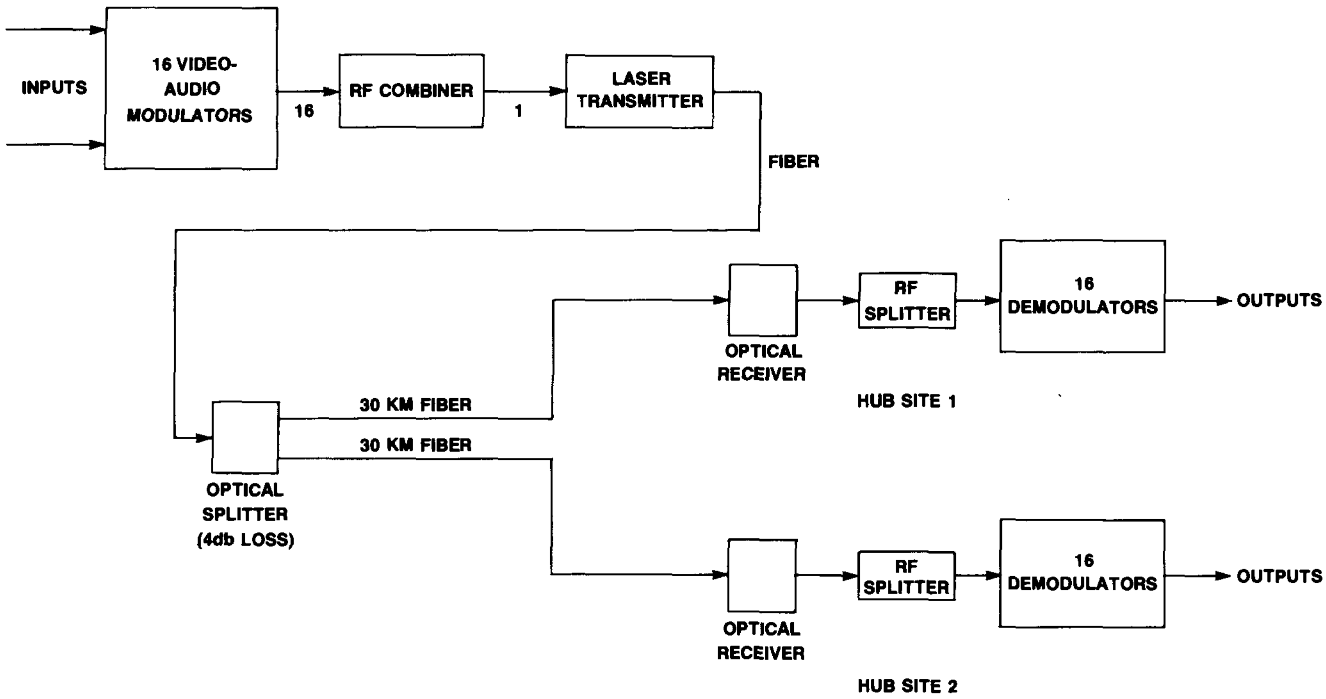


FIGURE 6

FM SUPERTRUNK TO TWO HUBS

process are far different than in FM transmission. Figure 8b shows how several digitized channels of video (or audio) can be time division multiplexed for carriage over a link. In this TDM technique, there are no intermodulation distortions as are present in FM. In a properly designed digital trunk system, all significant noise and distortions occur in the A/D and D/A converters. The presence of channel N in the system has no effect on channel 1.

Other advantages of the digital system are uniform performance over long fiber links (assuming acceptable bit error rates), and the ability to digitally regenerate signals using a receiver and laser while introducing no additional distortion. In a digital supertrunk, the audio is also digitized and time division multiplexed into its own subchannel. There is no interaction with the video, and the digitizing process may be optimally designed for audio.

IVa Noise and Distortion in The Digital Process

In the digitizing process, the baseband signal (video or audio) is converted into a series of quantum values which serve to represent the original

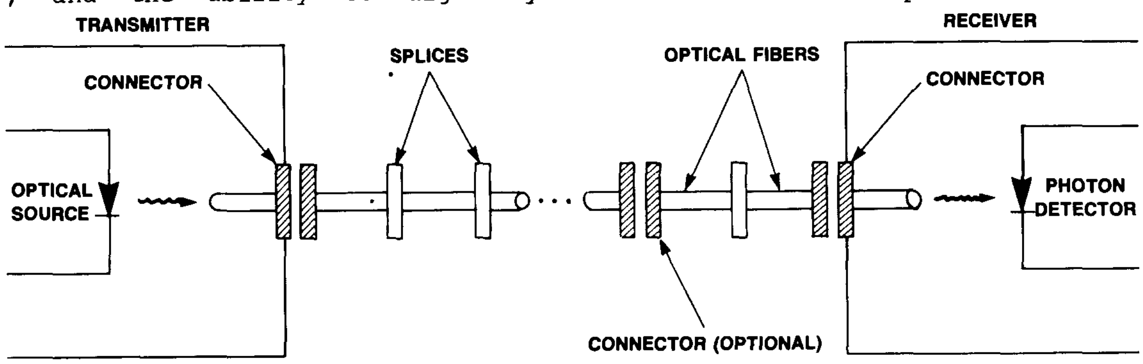


FIGURE 7

OPTICAL POWER LOSS MODEL

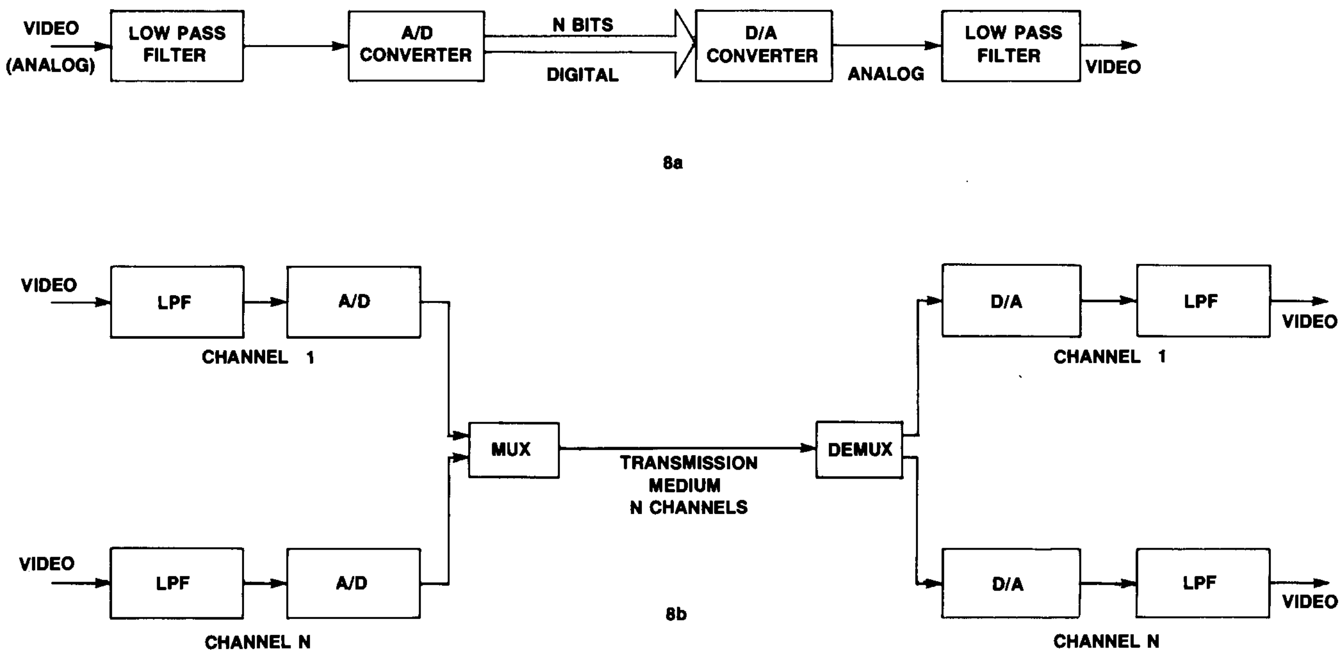


FIGURE 8

DIGITAL TRANSMISSION

signal. Consider that the digital signal contains no information describing the analog signal between samples. The most important factor in converter performance is the number of bits, or resolution. Another important parameter is the linearity when processing low frequency signals, as much important information is contained in these components. This error is best measured using an unmodulated ramp video signal. Test methods to measure this parameter are described in IEEE standard 746-1984.[6] Bellanger discusses sampling theory in chapter 1.[5]

The transfer characteristics of ideal A/D and D/A converters are shown in figure 9. The quantizing error of +/-1/2 LSB is also illustrated in this figure. The nonlinearities that occur in real converters will be discrete, as opposed to the continuous nonlinearities that can occur in analog circuits. If the sampling of the video ramp described above is coherent (synchronous) with the video, these errors can appear as vertical lines on a monitor. Proper choice of converters, resolution, selection of low pass filters, and good circuit design practice will reduce this type of distortion to acceptable levels (not visible on monitor). In today's monolithic converters,+/- 1/2 LSB linearity is practical; this represents +/-0.2% of full scale in an 8-bit system. It can be seen that linearity improves with resolution.

Sampling theory and the Nyquist criterion tell us that we must sample with a clock frequency at least two times the highest component in the transmitted signal to preclude aliasing. If we wish to carry 4.2MHz video, we must digitize at 8.4MHz or higher. It is much easier to design realizable low pass filters if we digitize at a higher rate. A common practice is to digitize at 4 times the NTSC color subcarrier rate of 3.58MHZ, or 14.318180 MHZ.

The signal to quantizing ratio may be calculated as follows:[6]

$$SNR(db) = 6.02N + 10.8db + 10 \log F_s/2F_{vmax}$$

where N = number of bits

F_s = sampling frequency

F_{vmax} = max freq content of video

For 4.2MHZ video sampled at 14.3MHz, the calculated SNR is 61.3db for an 8 bit system. Each additional bit of resolution represents 6.2db of SNR. Lab measurements using a Rohde and Swartz noise meter of an 8 bit system yield .62 to 63db. The care required in measuring SNR will be discussed below.

IVb Video Distortion and Noise Measurements in Digital Systems

A standard measurement technique for weighted signal to noise measurement using a Rohde and Swartz noise meter is to select a blank line in the vertical

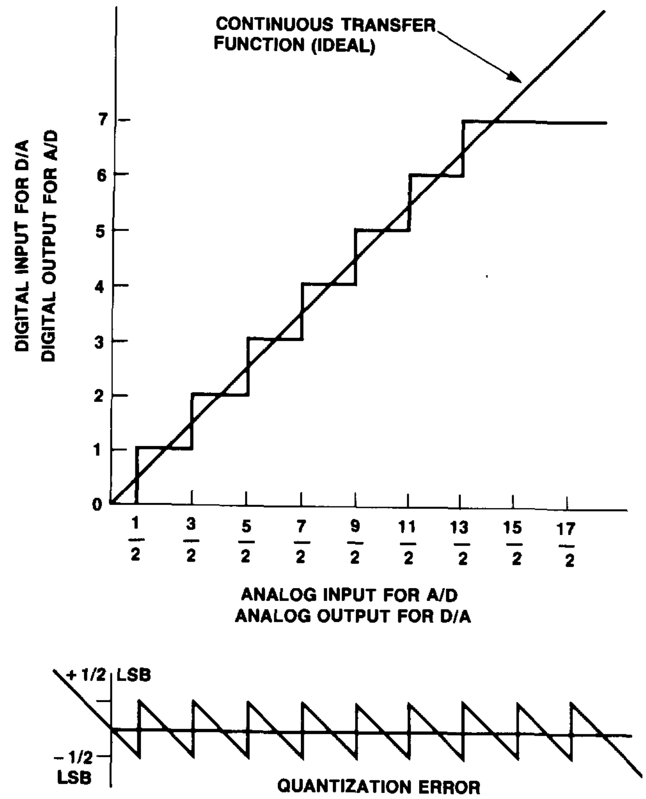


FIGURE 9

A/D AND D/A TRANSFER FUNCTIONS

interval. This line will contain a zero IRE flat field. This is a legitimate test in an analog system; in a digital system, it may yield a misleading result. If the flat field at 0 IRE happens to land halfway between A/D slicing levels, the A/D may output a fixed digital value; there will be no quantizing error and the resulting SNR will be artificially high.

A far more meaningful SNR measurement may be made as described in IEEE standard 746-1984. The test signal is a highly saturated chroma signal with constant luminance. It causes all the bits to change and quantizing errors to occur. Measurement using this technique confirms the calculation of video SNR given above.

Another phenomenon unique to digital processing is the occurrence of gliches in the output of the D/A converter. A glitch is an unwanted excursion that occurs at a D/A converter code change. It is due to unequal switching times within the DAC. In binary coded converters, the largest glitch is likely to occur at the half-scale transition when all the bits change simultaneously. Please refer to figure 10.

In an unmodulated ramp test signal, glitches at the same point in each line will cause a sharp vertical line on a monitor. In the modulated ramp signal used for differential gain and phase measurements, severe glitches will cause a crankcase effect on the differential gain and phase displays of a vectorscope. A severe case is shown in figure 11. This causes noticeable chroma saturation and hue changes in the picture.

In today's monolithic D/A converters, careful design has reduced glitch energy to 50 pV-sec or less. At this level, the peak differential gain can be approximately 2%, and differential phase as low as 1 deg. These levels are not discernible on a television monitor.

There is an in-depth discussion on these measurements in IEEE standard 746-1984.

IVc Audio Carriage

The digital supertrunk enjoys an advantage over the FM supertrunk for audio carriage because digital processing of audio is a mature technology. This technology offers the highest performance of any transmission technique. Low THD, well below 0.1%, 60db separation, and dynamic range approaching 90db are easily achievable. There are 12, 14, and 16 bit linear PCM converters designed for high-performance audio applications. Data used by these converters can easily be time division multiplexed with digitized video. Compact disk quality PCM audio requires approximately 1.4MHz serial data rate per stereo pair carried in the trunk TDM data stream. Dolby Laboratories has developed an adaptive delta modulation technique that requires 650KHz to achieve compact disk quality stereo audio. This technology is now field proven.[7] Either format will give audio performance

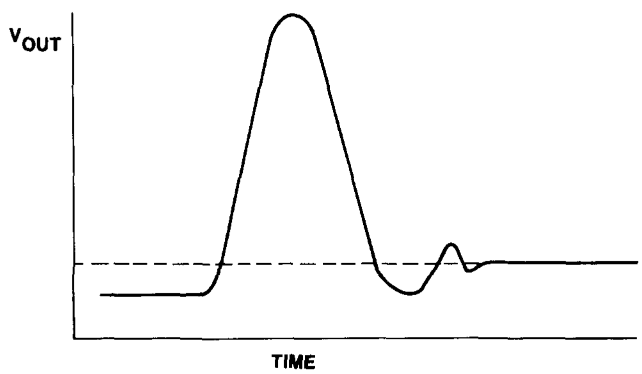
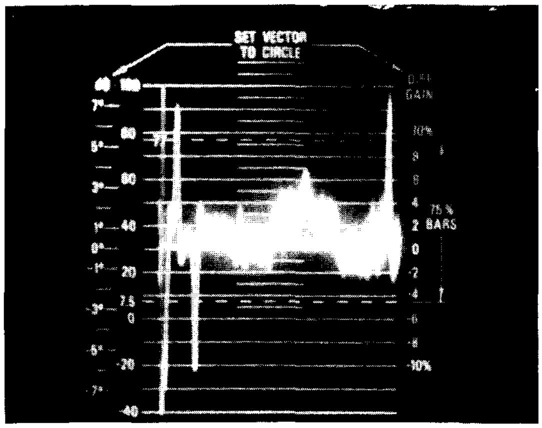
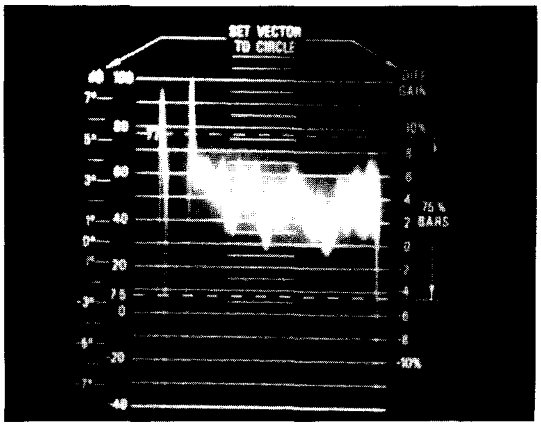


FIGURE 10

D/A OUTPUT GLITCH



DIFFERENTIAL PHASE



DIFFERENTIAL GAIN

FIGURE 11
SEVERE DISTORTION IN DIFFERENTIAL PHASE AND GAIN

superior to that delivered by FM.

IVd Architecture and Link Budget

The architecture of a digital supertrunk employing equipment on the market today is illustrated in figure 12. This equipment carries 8 channels of video and associated stereo audio over a SM fiber at 560Mbit. This equipment employs 7-bit codecs and achieves video SNR of 57 to 58db. Audio dynamic range is better than 65db with channel separation of 60db. The audio encoding is 12 bit PCM.

Since it is relatively easy to detect a logic one or zero with an optical receiver, digital supertrunks will have a somewhat longer reach than there FM counterparts. The parameter analoqous to CNR in FM is bit error rate (B.E.R.) in a digital link. A B.E.R. of 10^{-9} is the criterion for acceptable performance.

A link budget is based on the following assumptions:

1. The optical power launched by the laser transmitter is -3Dbm, at 1310nm.
2. The semiconductor receiver sensitivity is -35DB for a B.E.R. of 10^{-9} or better.
3. The fiber loss is 0.35db/Km at 1310nm.
4. A system margin of 3DB is assumed to allow for component aging and temperature effects.
5. Fusion splice losses are less than 0.1DB and can be ignored for the purpose of a comparative analysis.
6. Connector losses are assumed to be 0.5DB per connector

Figure 7 is an optical power loss model that illustrates the cumulative losses between the laser and the receiver. If P_t is the transmit power in DBm and P_r is the receive power in dbm, then P_l is the total loss budget for the link:[1]

$$P_l = P_t - P_r$$
$$= -3 - (-35) = 32\text{dbm}$$
and
$$P_l = 3xl_c + a_f \times L + \text{system margin}$$

where: L = transmission distance (km)
l_c = connector loss
a_f = fiber attenuation in db/km

then:
$$32\text{db} = 3x0.5\text{db} + 0.35\text{db/km} \times L + 3\text{db}$$
and
$$L = (32 - 3x0.5 - 3)/0.35\text{db/km}$$

we find L = 78km

Therefore, the link may be 60km long with adequate margin.

It can be seen that an optical splitter may be employed to deliver signals to more than one hub site.

Figure 13 illustrates a hypothetical trunk system to carry 12 channels of video and audio per fiber at 1.2Gbit/sec. This system employs 8 bit converters, as an 8 bit system most closely matches an FM-FDM supertrunk in video SNR (mid 60db range). The 100Mbit/sec data rate output of the transmitters assumes the the audio data is time division multiplexed into the data stream during the horizontal blanking interval of the video. This technique of carrying digitized audio embedded within the video is employed today in the Videocipher equipment used for satellite signal encryption. In this type of system, it is necessary to reconstruct the video composite sync at the receiving

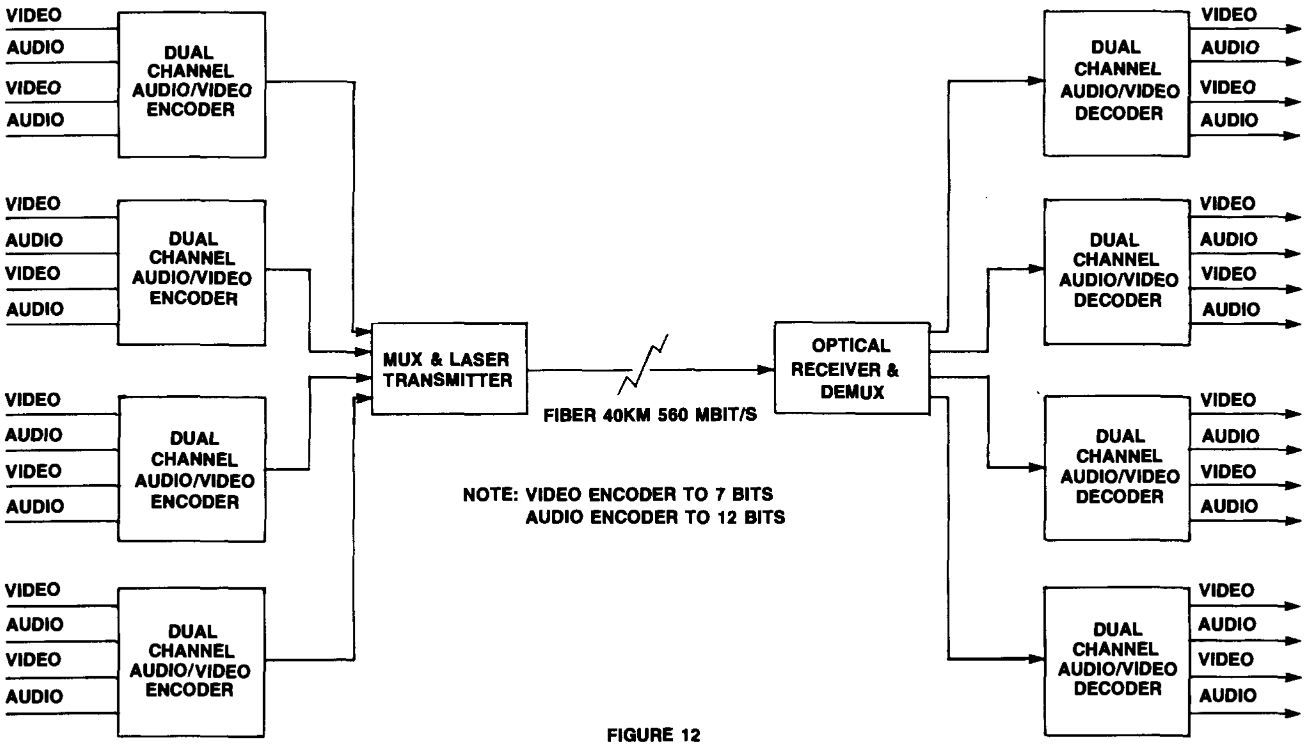


FIGURE 12
8-CHANNEL DIGITAL SUPERTRUNK

decoders, adding some complexity. The technique does make efficient use of the available bit stream.

The bandwidth required to carry 12 channels as described here is greater than on the 16 channel FM-FDM trunk. Figure 14 illustrates the spectrum of non-return to zero (NRZ) data modulated onto a carrier. F_b is the bit rate; the overall bandwidth is approximately equal to the NRZ bit rate, or 1.2Ghz.[8] This compares to 700Mhz for the 16 channel FM system.

A trunk system based on 9 bit converters would require a serial bit rate of approximately 109Mbit/sec per channel. The video SNR would improve to better than 67db, and the differential phase and gain could meet RS-250B short haul specifications. However, a 1.2Gbit link would only carry 10 channels per fiber. To exceed the video performance of the FM-FDM supertrunk (video SNR) requires 9 bit resolution, at higher cost.

V COST ANALYSIS

Fiber optic cable, as illustrated in figure 5, is available with various fiber counts. For the purpose of cost analysis, the following price per foot, when purchasing 40 km of cable, will be assumed:

Number of fibers in cable	price/ft (armored)
4	$0.60
6	0.73
8	0.82
10	0.91
12	1.02
16	1.25

The cost of installing the cable has several constituents, which are assumed as follows:

Description	cost
Route make ready work	$0.45/ft
Hang cable	$0.70/ft
Cable Installation	$1.15/ft
Fusion splicing	$45/splice

(Assume a splice required every 4km and at each end of fiber)

Optical patch panel	$1000
Test & Document completed cable	$2000

The architecture in figure 4 will carry 16 channels per fiber. An 80 channel system would require 5 fibers. A cable with 6 fibers is selected to provide

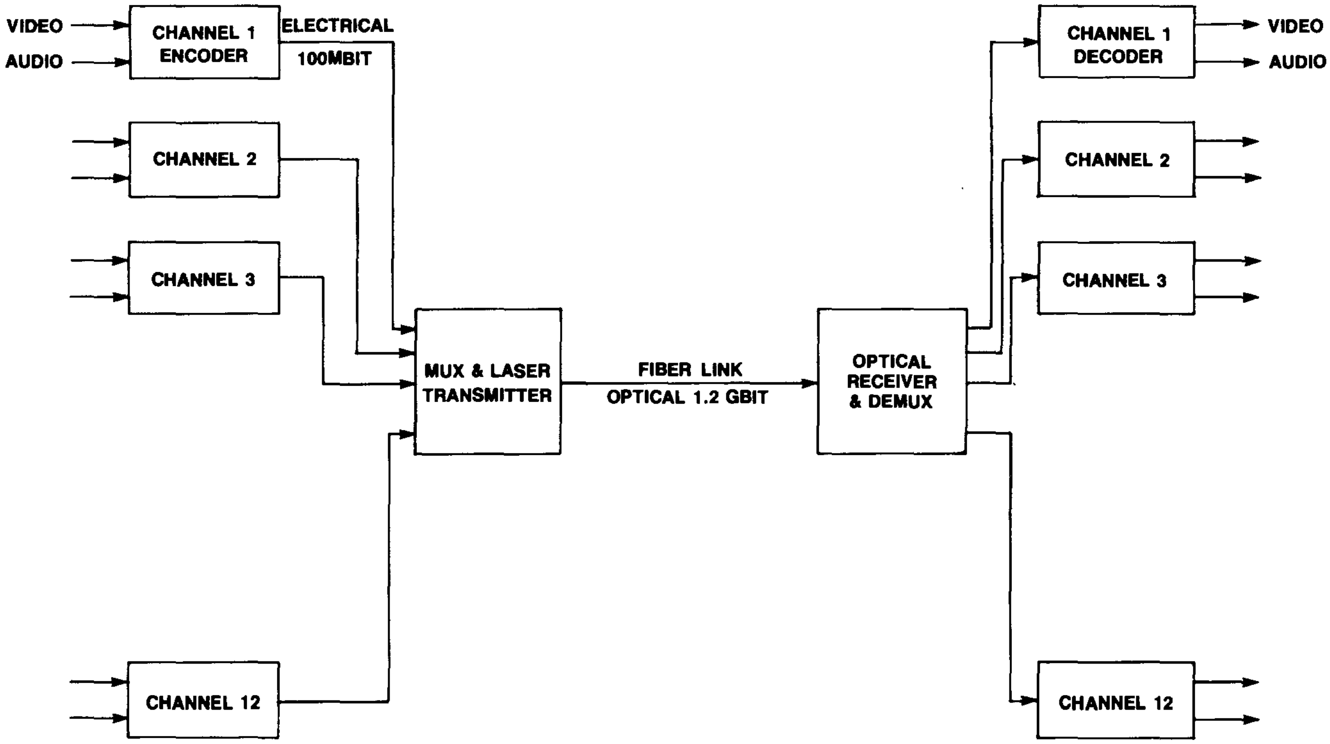


FIGURE 13

PROPOSED 12 CHANNEL 8-BIT SYSTEM

a spare fiber. The cost of pre-wired equipment racks is included in the unit cost of all rack mounted equipment. The cost of a complete 80 channel FM supertrunk is presented in table 1.

Therefore the average cost per channel of the 80 channel FM supertrunk is $7,843.

The digital supertrunk in figure 12 will carry 8 channels per fiber. Note that the encoders and decoders each carry two channels. An 80 channel system based on this architecture would require a cable with 10 fibers; a 12-fiber cable is selected to provide spares. Again the cost of pre-wired equipment racks is included in the unit cost of the equipment. The cost of a complete 80 channel digital supertrunk is presented in table 2.

The cost per channel of the 80 channel digital supertrunk is therefore $8,091. Consider that the video SNR of a 7 bit digital system is approximately 57db, as compared to 65db for the FM supertrunk.

The hypothetical system in figure 13 (8 bit) would carry 12 channels per fiber. An 80 channel trunk would require 7 fibers. A cable with 8 fibers is selected to provide 1 spare. An 8 bit system most closely matches the video performance of the FM-FDM trunk.

A conservative cost breakdown of this 80 channel supertrunk is given in table 3. The length of the trunk is assumed to be 40km.

In this case, the cost per channel is $13,823. It is expected that the cost of the encoders and decoders could be reduced

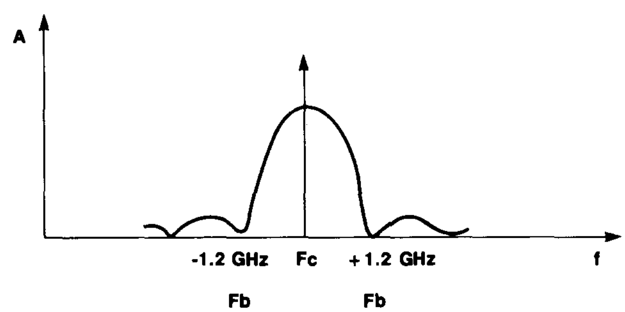


FIGURE 14

NRZ DATA SPECTRUM

TABLE 1
FM TRUNK IN FIGURE 4

ITEM	UNIT COST	QUAN	EXTENDED COST
FM Modulators	$2000	80	$160,000
16 Combiner	$1000	5	Chan $5000
Laser Transmitter	$6200	5	$31,000
Optical Receiver	$3200	5	$16,000
RF Splitter	$300	5	$1500
FM Demods.	$2000	80	$160,000
Cable (6 fibers)	$0.73/ft	40km	$95,805
Cable Installation	$1.15/ft	40km	$150,926
Optical Patch Panel	$1000	2	$2000
Splices (12 per fiber)	$45 ea	72	$3240
Test/Document Installation	$2000	1	$2000
			------
total cost			$627,471

by the application of large scale integration of the digital circuitry. This is important since these equipments are a major cost component of this proposed system.

VI SCRAMBLING

There is no practical need to secure signals while on a supertrunk, especially on a point-to-point fiber link that is difficult to tap. It is desirable, however, to carry signals that are already encoded to a hub site. This precludes the need for additional scramblers at the hub.

There are two basic type of video scrambling in common use today, baseband and RF scrambling. The common techniques are sync suppression and video inversion. Baseband scrambling may be carried over an FM link if a sync driven clamp is used at the receive site. The clamp is required to restore the DC offset of the video, which can not be carried over the FM link, before being AM modulated. RF scrambling has proven to be impractical due to the difficulty of carrying already modulated vestigial sideband (VSB) signals.[3,11]

TABLE 2
DIGITAL TRUNK IN FIGURE 12
(7 BIT)

ITEM	UNIT COST	QUAN	EXTENDED COST
2-Channel Encoder	$3900	40	$156,000
Laser Trans.	$4400	10	$44,000
Optical Receiver	$2400	10	$24,000
2-Channel Decoders	$3200	40	$128,000
Cable (12 fibers)	$1.02/ft	40km	$133,865
Cable Installation	$1.15/ft	40km	$150,926
Optical Patch Panel	$1000	2	$2000
Splices (12 per fiber)	$45 ea	144	$6480
Test/Document Installation	$2000	1	$2000

Total Cost			$647,271

Since a digital system can encode and decode the DC component of a video signal, no clamp is required at the receive hub site. Thus the digital supertrunk can carry baseband (sync suppression/video inversion) scrambling. However, the digital link would encounter the same problems with RF VSB scrambled signals as the FM trunk.

If at some time in the future digital signals are carried directly to the subscriber, the level of security achieved in a properly designed system could be orders of magnitude higher than that in an analog system. A good digital encryption system will introduce no distortion (residual effect) when the desired signal is decoded. The encryption may be time varying. Wechselberger has written an excellent paper on the subject of encryption as applied to CATV.[9]

VII FUTURE TRENDS

FM supertrunking is a relatively low volume, mature technology, with equipment having been in the field for several years. No dramatic breakthroughs in cost reduction can be expected in the modulators, demodulators, combiners, or splitters over that suggested in the

TABLE 3
DIGITAL TRUNK IN FIGURE 13
(8 BIT)

ITEM	UNIT COST	QUAN	EXTENDED COST
Video/audio encoders	$5000	80	$400,000
1.2Gbit Laser trans.	$10,000	7	Mux- $70,000
1.2Gbit Receiver	$7000	7	Optical $49,000
Video/audio decoders	$4000	80	$320,000
Cable (8 fibers)	$0.82/ft	40km	$107,617
Cable Installation	$1.15/ft	40km	$150,926
Optical Patch panel	$1000	2	$2000
Splices (12 per fiber)	$45	96	$4320
Test/Document Installation	$2000	1	$2000

Total Cost			$1,105,863

previous cost analysis. Additional channels per fiber will require improvements in the lasers and receivers to utilize more of the available bandwidth. This is likely to happen. As the optical components are improved in performance and built in volume, substantial cost reductions are expected. The telecommunications industry is driving the cost of the optical components down. The FM supertrunk will take advantage of this.

Digital technologies as applied to consumer electronics have repeatedly shown dramatic cost reductions with volume production. Digital watches and calculators are good examples. The designer may employ gate arrays, standard cells, or full custom technology to effect dramatic cost reductions. Although the digital supertrunk achitectures in figures 12 and 13 will not be built in the volumes of consumer products, judicious use of integration techniques can dramatically reduce size, power consumption, and cost.

The very high data rates required at the laser and optical diode interfaces can only be achieved using gallium arsenide logic. Today this logic is only available from a few vendors and exhibits relatively low yields; it is therefore expensive. However, only a small portion of the required logic need run at these very high speeds. Thus more cost effective logic families, such as ECL or 74HC, may be used to implement the lower data rate portions of the circuits.

In the last five years, dramatic cost reductions have occurred in monolithic A/D and D/A converters. Digital audio technology is coming into use in high volume consumer products. As lasers and high speed optical receivers come into high volume application, their cost will also come down. Use of these components by the telephone industry for digital transmission is pushing the technology forward. The digital supertrunk will take advantage of all these trends.

VIII CONCLUSION

Table 4 summarizes the factors to be considered when comparing FM and digital supertrunks:

TABLE 4

FACTOR	FM	DIGITAL 7 bit	DIGITAL 8 bit	DIGITAL 9 bit
channels per fiber	16	8	12	10
bandwidth	700Mhz	600Mhz	1.2Ghz	1.2Ghz
video SNR	65db	57db	63db	67db
diff phase	1deg	2deg	1deg	<1deg
Diff gain	1%	2%	1%	<1%
audio dynamic range	65db	65db	85db	85db
audio freq resp	50hz-15khz	- 20hz to 20khz-		
Audio Chan Separation	30db	>60db	>65db	>65db
System cost/channel	$7,843	$8,091	$13,823	?
ease of carrying scrambling	fair	--good--		
cost reduction potential	fair	high		

It can been seen from the table that a 7 bit digital system is cost competitive with an FM-FDM system, but does not provide the same level of video performance. An 8 bit digital system most closely matches the FM-FDM system in performance, at increased cost. This cost differential is likely to decrease with time. A properly designed 9 bit digital system can provide performance superior to the FM-FDM system at higher cost, with fewer channels per fiber.

REFERENCES

1. G. Keiser, "Optical Fiber Communications", McGraw-Hill Book Company, 1983

2. K. Simmons, "The decibel relationship between amplifier distortion products", pp. 1071-1086, Proceedings of the IEEE, Vol. 58, No. 7, July 1970

3. H. Gysel, "Properties and systems calculations of optical supertrunks for multichannel TV transmission, using analog intensity modulation, single mode fibers and high deviation FM.", Synchronous Communications Inc., San Jose, Ca.

4. M. Schwartz, "Information Transmission, Modulation, and Noise", McGraw-Hill Book Company, 1959

5. M. Bellanger, "Digital Processing of Signals", John Wiley & Sons, 1984

6. "IEEE Standard for Performance Measurements of A/D and D/A Converters for PCM Television Video Circuits", IEEE Std 746-1984, The Institute of Electrical and Electronics Engineers, Inc., 1984

7. J. Griffin, A. Radice, J. Waltrich, "A Digital Cable Audio System Using Adaptive Delta Modulation", General Instrument Corporation, Presented at the Western CATV show, Anaheim, Ca., Dec 1988

8. E. Fthenakis, "Manual of Satellite Communications", Chapter 11, McGraw-Hill Book Company, 1984

9. A. Wechselberger, "Encryption-Based Security Systems What makes the different and how well are they working?", Oak Communications Inc., 1987 NCTA Technical Papers

10. G. Benton, "Fiber Optics and Video: A Background", SMPTE Journal, July 1988. Presented at the 129th SMPTE Conference in Los Angeles, Novwember 1987

11. M. Davidov, "Topics in Broadband Modulator/Demodulator Design for Video Transmission", Paper presented at the RF-Expo 1987 in Anaheim, Ca.