FIBER OPTIC BASEBAND VIDEO SYSTEMS

Considerable effort has gone into the design of various fiber optic digital systems; consequently, the technology as it applies to that field is well understood[1]. The application of optical fiber to the transmission of analog signals has been less intensive, mainly because of technical limitations and lower demand. Nevertheless, fiber optics is beginning to make inroads into the analog market[2] although on a lower scale.

The following is a discussion of the basic system design considerations for an application requiring the transmission of baseband video signal over a fiber optic cable. Attainable unrepeatered system length, and system performance are given, along with a discussion of source and detector selection, receiver sensitivity, fiber bandwidth, and the effect of nonlinear distortions.

SYSTEM DESCRIPTION

A fiber optic video transmission system is functionally similar to other cable sytems — it consists of a line driver (transmitter), cable, and a line receiver. However, the way in which these components are implemented in fiber optic systems differs drastically from conventional cable systems.

The transmission medium is completely dielectric, and therefore, does not conduct electric currents. The information is carried through the cable via the intensity modulated light beam. Consequently, the function of the line driver and that of a line receiver is to interface between the electrical medium and the optical fiber. A block diagram of a fiberoptic transmission system is shown in Figure 1.

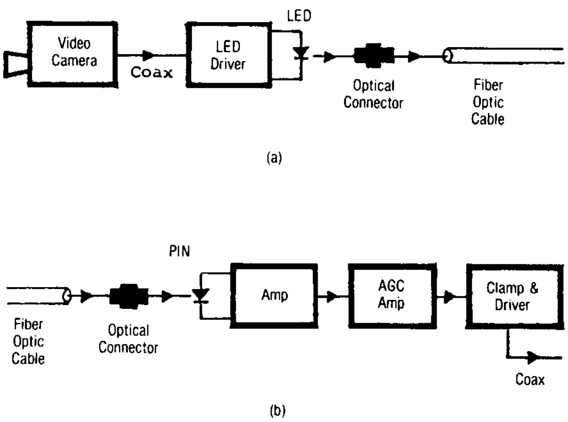

Fig. 1. Block diagram of a fiber optic video transmission system. (a) Transmitter end. (b) Receiver end.

At the transmitter end, a composite video signal from a camera or a VTR is fed through a 75Ω coaxial patch cable to a voltage to current converter. The resulting current drives either a Light Emitting Diode (LED) or an Injection Laser Diode (ILD) which generates a light signal with intensity proportional to the voltage of the composite video signal. This intensity modulated light is coupled into a fiber pigtail which guides the light into the optical cable. The transmitter is connected to the cable via a demountable fiber optic connector. The light, once in the cable, travels within the glass fiber where it undergoes attenuation and band limiting.

At the receiver end of the system, a photodetector converts the light signal into electrical current which in turn is amplified and processed to give a composite video signal identical to the signal at the output of the video camera. As a result of the processing performed at the receiver, the fiber optic system appears transparent to the electrical signal, and in a properly designed system, minimally degrades the video quality.

The maximum distance over which a video signal can be transmitted depends on the available transmitter power, receiver sensitivity, and the cable loss per unit length. The distance (in km) is given by equation 1:

$$L = \frac{P_T - 2A_c - P_R}{A}$$

Where P_T is the optical power coupled into the fiber by the transmitter (in dBm), A_c is the attenuation (in dB) of a single optical connector, P_R is the minimum light power (in dBm) required to obtain a specified signal to noise ratio, and finally, A is the attenuation of the fiber optic cable per unit length (in dB/km). The individual system parameters are determined by the choice of components and the design of electronic circuitry.

SYSTEM COMPONENTS

Transmitter

The critical design consideration for a transmitter is the selection of a light source. Ideally, in order to assure maximum transmission length, a source that yields maximum undistorted light signal is selected. In practice, however, the system cost and its reliability msut also be considered. Three types of light emitting devices are currently used in fiber optic communications, a Light Emitting Diode (LED), a multimode Injection Laser Diode (ILD), and a single mode ILD. Typical parameters characterizing these devices are listed in Table 1.

Table 1

	LED	ILD multi-mode	ILD single mode
Light power coupled into a 5 mil fiber	-16 to -10 dBm	0 to +10 dBm	0 to +10 dBm
2nd harmonic at 75% modulation	-35 dB	-15 to -30 dB	-50 to -60dB
3rd harmonic at 75% modulation	-45 dB	----	< -60 dB
Wavelength	840 nm	840 nm	840 nm
Spectral width	40 nm	2 nm	< 2 nm
Projected useful life	10 years	1-2 months	1-10 years
Transmitter Complexity	Low	High	High
Price, small quantities	\$100.- \$350.	\$500.- \$1000.	\$2,500.- \$3,500.

It can be seen that the multimode laser diode is not a good choice for application in an analog intensity modulated system primarily because of its short life time and very high distortion levels. The single mode laser diode is a better choice from the performance point of view, however, its high price and lack of adequate data on its reliability make this device an unattractive choice at the present time. The LED, on the other hand, is inexpensive, reliable, and has adequate performance for most applications of a baseband system.

A typical light vs. current curve for an LED is shown in Figure 2. The light output power P_T can be expressed as a sum of current harmonics, as shown below.

$$P_T = a_1 I + a_2 I^2 + a_3 I^2 + \ldots$$

The coefficients a_1, a_2, and a_3 are current dependent[3], and correspond to the fundamental, second and third harmonics respectively.

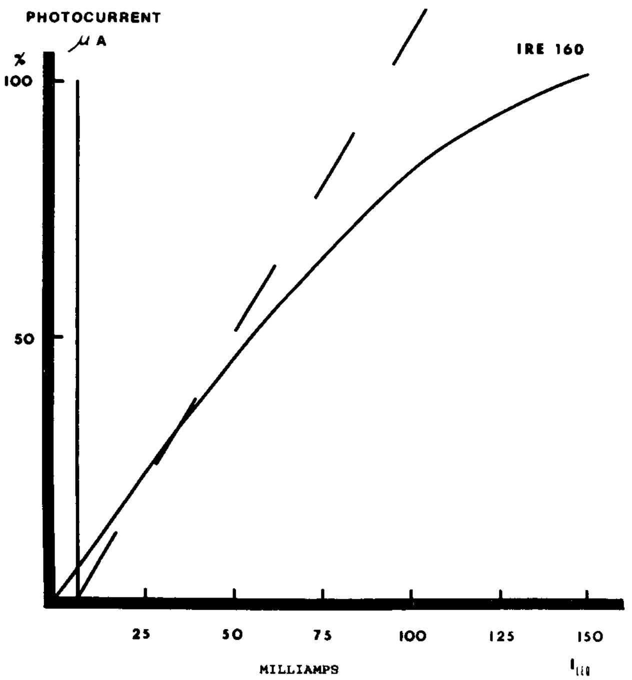

FIGURE 2. Measured diode efficiency as a function of drive current.

Cable and Connectors

Both the cable and connectors introduce loss into the system. The connector losses stem from fiber misalignments and variations in parameters between the two fibers being joined. Commercially available connectors exhibit losses that range anywhere between 0.5 dB and 2 dB.

The fiber exhibits two types of losses. One similar to the ohmic loss in the coaxial cable is caused by light scattering and absorption in the glass medium. This loss is uniform over the entire fiber bandwidth, and ranges between 4 and 5 dB/km for currently available fiber cables. The other type of fiber loss is frequency dependent and, as in coaxial cable, limits the useful bandwidth. The bandwidth depends on the light source used, and for ILD's a typical fiber will exhibit a 3 dB bandwidth of 300-400 MHz over the distance of 1 km. When an LED is used as a source, the available bandwidth is considerably lower. An approximate experimentally determined relationship between fiber bandwidth F and its length L is given below.

$$F = 45\ \text{MHz}/L\ (\text{km})$$

Therefore, a 2 mile long fiber cable will have a 3 dB bandwidth of 14 MHz, which is more than necessary to transmit a baseband video signal.

Receiver

The primary objective in designing a receiver circuit is to maximize the signal to noise ratio at the output of the transmission system. This objective is achieved by first maximizing the power transferred between the photodetector and the preamplifier and, second, by minimizing the noise power introduced by the preamplifier circuit.

The photodetector appears as a nearly ideal current source; therefore, maximum power transfer is achieved with a high impedance preamplifier circuit[4]. In order to maximize the power transfer over the entire frequency range of interest, a circuit with high input resistance and low input capacitance must be used. In order to minimize noise power introduced by the preamplifier, current noise sources must be minimized. This implies that transistors with low input bias currents and high internal gains must be employed.

A preamplifier design utilizing a Field Effect Transistor (FET) as a first gain stage satisfies all of the above requirements[5]. It is well known[6] that the equivalent noise current, that is the current that would have to be present at the input to the preamplifier to produce the measured noise voltage at the output, can be written as the following integral:

$$I_n^2 = \int_0^B \left(2q I_B M + \frac{4kT}{R_i G^2} + \frac{4kT}{g G^2} C_i^2 \omega^2 \right) df$$

Where B is the receiver bandwidth, q - electron charge, I_B - average photocurrent, M - detector noise factor, k - Boltzman constant, T - temperature in °K, q - FET transconductance, G - photodetector internal gain, Ci - input capacitance of the preamplifier, ω - frequency in radians. The first term represents the shot noise generated by the photodetector. The second term represents the effective thermal noise of the input resistors. Here, the effect of high input resistance is seen. The higher the resistance, the lower the effect of thermal noise. Finally, the last term represents the effective noise caused by the presence of input capacitance. The smaller the input capacitance, the lower the signal loss at higher frequencies, and therefore, the lower the effect of transistor noise. The signal to noise ratio is simply the ratio of peak signal photocurrent squared (I_s^2) to I_n^2.

REFERENCES

1. "Atlanta Fiber System Experiment Overview". B.S.T.J., Vol. 57, No. 6 — July-Aug., 1978.
2. P.J. Dobson, et.al. "Installation and Performance of a Fiber Optic Video System at Viacom", and other papers in these proceedings.
3. F.D. King, et.al. "High-radiance, Long-lived LED's for analog Signalling", Proc. IEEE, Vol. 123, pp. 619-622, June, 1976.
4. S.D. Personic, "Receiver Design for Digital Fiber Optic Communication Systems, I and II", B.S.T.J., Vol. 52, No. 6, 1973.
5. T. Witkowicz, "Design of Low-Noise Fiber-Optic Receiver Amplifiers Using J-FET's", IEEE, Vol. SC-13, No. 1, Feb. 1978, pp. 195-197.
6. T. Witkowicz, "Transistor Noise Model for Photodetector Amplifiers", IEEE, Vol. SC-13, No. 5, Oct. 1978, pp. 722-724.
7. P.P. Webb, et.al. "Properties of Avalanche Diodes", RCA Review, June 1974, pp. 234-278.

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