DESIGN OF FIBER OPTIC BASEBAND VIDEO SYSTEMS

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ABSTRACT

Design of fiber optic single channel video systems is discussed. Attainable unrepeatered system length, and system performance are given. A discussion of source and detector selection, receiver sensitivity, fiber bandwidth, and the effect of nonlinear distortions are presented.

## INTRODUCTION

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.

## SYSTEM DESCRIPTION

A fiber optic video transmission system is functionally similar to other cable systems - 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 Fig. 1.

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:

$$L = \frac{P_T - 2A_C - P_R}{A} \qquad (1)$$

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 must 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 I.

Table I

| | 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 -60 dB |
| 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 Fig. 2. The light output power $P_T$ can be expressed as a sum of current harmonics, as shown below.

$$P_T = a_1 I + a_2 I^2 + a_3 I^2 + \dots \qquad (2)$$

The coefficients $a_1$, $a_2$, and $a_3$ are current dependent[3], and correspond to the fundamental, second and third harmonics respectively. It can be shown that for a standard staircase input, the color subcarrier compression or the differential gain can be approximated by the following expression:

$$\text{Diff Gain}(\%) = \left( \frac{1+3.6\ a_2 + 10a_3}{1-2.2a_2 + 3.7a_3} - 1 \right) \times 100\% \qquad (3)$$

Using the values for 2nd and 3rd harmonic listed in Table I, the differential gain is calculated to be 14% at 75% modulation. If the modulation index is decreased to 50%, the 2nd and 3rd harmonics drop to approximately -38 and -50 dB respectively[3] yielding a differential gain of 9% which is an acceptable level in a large number of applications.

The differential phase is more difficult to calculate. Experimental results show it to be less than 3° in most devices.

### 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 absorbtion 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.

$$F = 45\ \text{MHz}/L(\text{km}) \qquad (4)$$

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:

$$I_n^2 = \int_o^B \left(2qI_BM + \frac{4kT}{RiG^2} + \frac{4kT}{gG^2} C_i^2 \omega^2\right) df \tag{5}$$

Where B is the receiver bandwidth, q - electron charge, $I_B$ - average photocurrent, M - detector noise factor, k - Boltzman constant, T - temperature in °K, g - FET transconductance, G - photodetector internal gain, $C_i$ - input capacitance of the preamplifier, $\omega$ - 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 $I_n^2$.

Two types of photodetectors are used in fiber optic receivers - a PIN diode for which M=G=1 and an Avalanche Photodiode (APD) which exhibits internal gain G and whose noise factor M is gain dependent[7]. In systems employing APD's, the gain G is adjusted to minimize $I_n^2$. This effectively puts the receiver noise into the shot noise region, i.e., the first term in equation 5 is made dominant. In baseband video systems however, where the required signal to noise ratio is high, the average photocurrent level $I_B$ is such that even with G=1 and M=1, the first term is dominant. For example, in order to attain a signal to noise ratio of 50 dB in a typical receiver(Ck=10pF, $R_i$=300 kΩ, g=4 mhos, B=4.5 MHz), in a system where $I_s=0.5I_B$, the required average current is 1μA. Substituting these parameters into equation 5 one finds that the first noise term is three times the sum of the other two terms. Therefore, it is easy to see that for systems requiring the signal to noise ratio in the vicinity of 50 dB, both the PIN and APD diodes have similar performance since both keep the receiver noise in the shot noise limit. Since PIN is considerably easier to use, most designs employ PIN photodetectors. Using the typical receiver parameters listed above and the PIN light to current conversion constant of 0.5 Amp/Watt, the sensitivity of the receiver, that is, the light power required to produce a signal to noise ratio of 50 dB, can be determined. For a 50% carrier modulation, the average received power should be 2μW(-27 dBm).

## SUMMARY

Using Equation 1 and typical system parameters given in previous sections, i.e. $P_R$ = -27 dBm, a maximum unrepeatered system length can be calculated. This length for a system exhibiting an unweighted signal to noise ratio of 50 dB in 4.5 MHz bandwidth and differential gain less than 10% is 2.8 km. If the single mode laser is used in the transmitter circuit, the system length can be extended by an additional 3-4 km.

## 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. IEE, 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.

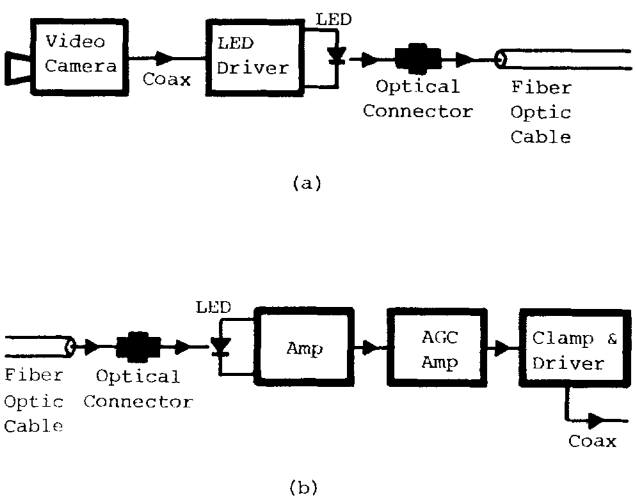


Fig. 1. Block diagram of a fiber optic video transmission system. (a) Transmitter end. (b) Receiver end.

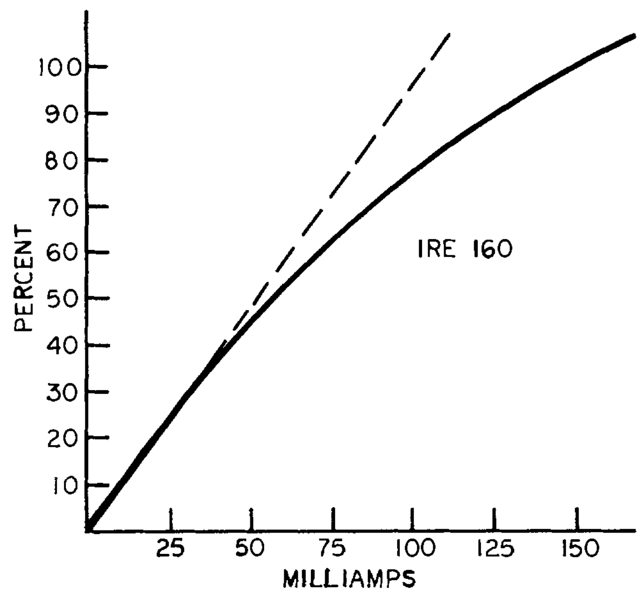


Fig. 2. Measured diode efficiency as a function of drive current.