Terminals & Systems

The advantages to the EMC engineer of data transfer using fiber optic technology have been well documented (Ref. 1). The replacement of metal conductors by the non-inductive glass fiber in the interface routing components eliminates a major source of RF interference and emanation. However, as pointed out in Reference 1, the transmitter and receiver terminals still require appropriate shielding. In particular, the photodiode/amplifier interface is especially vulnerable to RF interference since the output current of the photodiode is quite low (on the order of nanoamps or microamps) and the transimpedance amplifier is, of necessity, a high gain device converting such currents to useful voltage levels.

In Section 2 we review the fundamental principles of the design, integration and construction of devices combining photodiode and amplifier in a single enclosure such as a TO-5 transistor header.

Characteristics of these integrated optical receivers dominate the total system performance in both digital and analog data transmission links. (Section 3)

2.0 Optical Receivers

An optical receiver consists of a photosensor (such an avalanche or pin photodiode) coupled directly to appropriate processing electronics. The photosensors are generally operated in the photoconductive current mode.

The simplest way to achieve current-to-voltage conversion is shown in Fig. 1 where load resistor R_L is directly driven by the photocurrent I_p from the diode. The output voltage and risetime is given by $V_o = I_p R_L$ (1) and $\tau = R_L C_p$ (2), where we assume that the photodiode capacitance C_p is the dominant factor, ignoring parasitic and stray capacitance. The Johnson (thermal) noise voltage associated with the resistor is $Vn = (4kTR_L B)^{1/2}$(3), where B is the electrical bandwidth, T the temperature and k Boltzmann's constant. By comparing equations (1) and (3), it is seen that the signal-to-noise ratio can be improved by increasing R_L, but at the expense of speed.

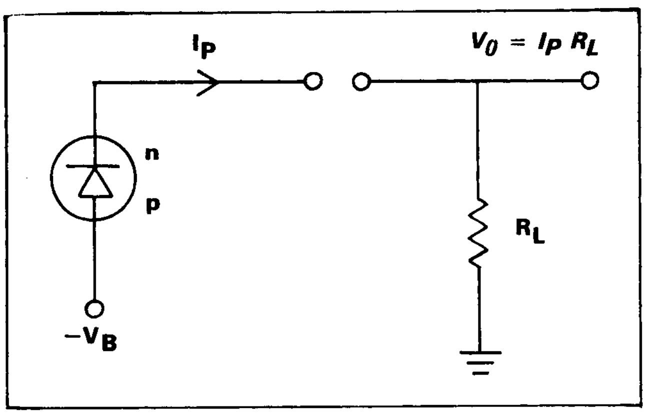

Fig. 1. Converting photocurrent to voltage with external load resistor

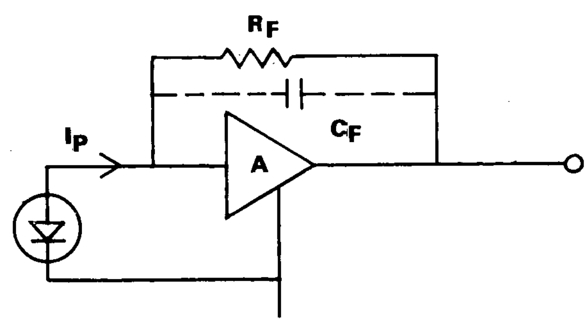

Fig. 2. Photodiode with transimpedance amplifier

With amplifiers operating in the current-to-voltage conversion mode, (Fig. 2), it is possible to achieve high signal output consistent with high speed. In the ideal case, the inverting input of the amplifier is at ground and the output voltage $V_o = I_p R_F$(4), is the result of the photocurrent being driven by the amplifier through the feedback resistor. However, the effective load seen by the photodiode current generator is the input impedance of the amplifier, $R_{in} = R_F/A$(5), which is much less than R_F. "A" is the open-loop gain.

The time constant at the amplifier input is consequently shorter, i.e. $\tau = C_p R_F/A$(6). The limiting time constant in this case is generally that associated with the stray capacitance C_F. The Johnson noise is $V_n = (4kTBR)$ (7).

Essentially, then, a well-designed transimpedance amplifier with a feed-back resistor provides a signal-to-noise ratio similar to that given by the same value of load resistor, but with much larger bandwidths.

Risetime and electrical-frequency bandwidth for typical pulses are generally related by $\tau B = 350$, where B is the bandwidth in megahertz, and τ is the risetime in nanoseconds.

From equation (4) the signal voltage is given by $V_o = I_p R_F = \varrho P_i R_F$, where $\varrho\lambda$ is the responsivity at wavelength λ in amps per watt, P_i is the incident power in watts, and R_F the value of the feedback resistor, generally limited by the frequency response required.

Fig. 3 shows the cross-section of a typical integrated photodiode/transimpedance amplifier which acts as a common denominator receiver front-end in both digital or analog data transmission systems. The device is built as a two-stack assembly where the hybrid microcircuit transimpedance amplifier is built as the lower substrate. The photodiode is placed on the upper wafer at a position close to the glass window for optimum field-of-view and coupling to the exit aperture of an optical fiber. The critical tie point between photodiode and amplifier is accomplished via one of the supporting posts within the shielded TO-5 enclosure. Since there is an optical window at the detector surface, RF-interference can penetrate the enclosure. There are, however, two solutions. First, the device is usually incorporated within an optical receptacle which in turn may

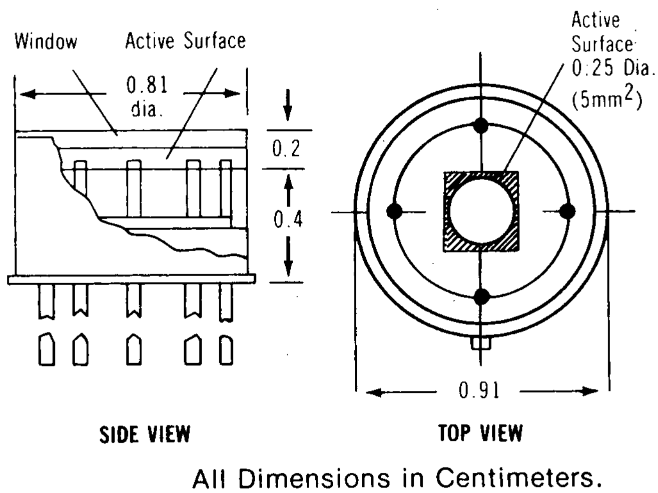

Fig. 3. Cross section of MDA Optical Receiver Series

The above article was prepared for ITEM by David B. Medved, Meret, Inc., Santa Monica, CA.

become part of a shielded minibox assembly. Also, it is possible to ensure self-contained shielding for the TO-5 itself by coating the glass window with a transparent conductive layer such as stannous oxide.

3.0 System Design and Performance

The common denominator elements of an optical data link are the same whether the signal to be transmitted is analog or digital. These elements are (Fig. 4):

(1) A light-emitted diode or injection laser emitting radiant power P_o

(2) A connector which couples the emitted light into an optical fiber with coupling loss $\alpha_c(E)$ power coupled into the fiber is given by:

$$P_o 10^{-[\alpha_c(E)/10]}$$

for $\alpha_c(E)$ in dB

(3) An optical transmission line of length χ (in meters), characterized by loss factor α in decibels per meter; optical power at the exit end of the fiber-optic transmission line is:

$$P_o 10^{[-\alpha_c(E) + \alpha(\chi)/10]}$$

(4) A connector, which couples the radiant power from the end of the optical fiber to the photodiode with coupling loss $\alpha_c(R)$. Generally $\alpha_c(R) << \alpha_c(E)$—the efficiency of coupling between fiber and photodiode—is much greater than that between source and fiber. When we define an over-all coupling loss α_c as $\alpha_c(E) + \alpha_c(R)$, the power P incident on the photodiode is:

$$P = P_o 10^{-(\alpha_c + \alpha\chi)/10}$$

An optical receiver consisting of a photodiode and a transimpedance amplifier of over-all responsivity ϱ_V

By combining these factors, a complete system can be defined in terms of output voltage as a function of the various parameters characterizing the fiber-optic link:

$$V_o = (\varrho_i Z_f P_o)^{-(\alpha_c + a\chi)/10}$$

Taking logarithims transforms this into a more useful

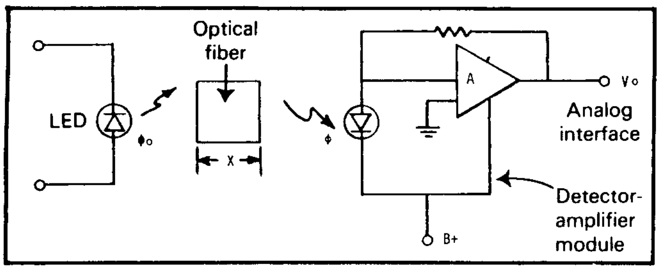

Fig. 4. Elements of a fiber-optic transmission system

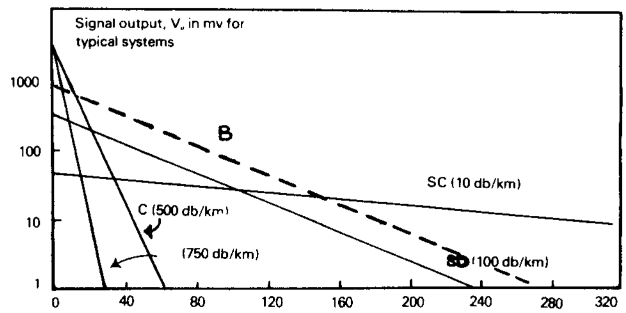

Fig. 5. Optical-signal output as a function of length in meters for various types of optical cables. Root-mean-square noise level for analog output is assumed to be less than 100 nanovolts; threshold voltage in digital systems typically is 5 to 50 mv

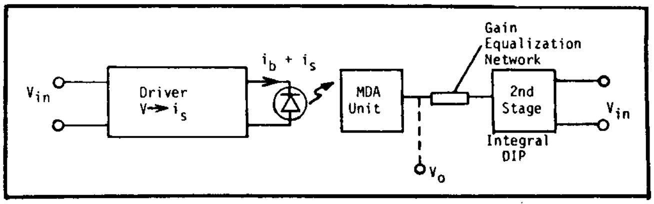

Fig. 6. Analog-transmission system

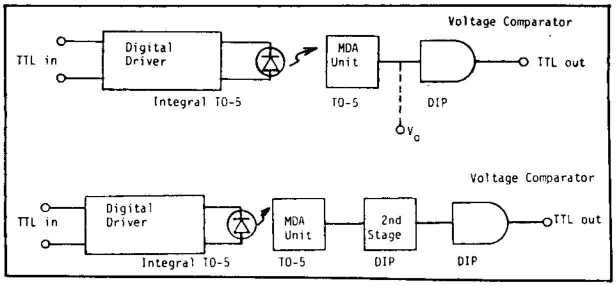

Fig. 7. Two types of digital-transmission systems

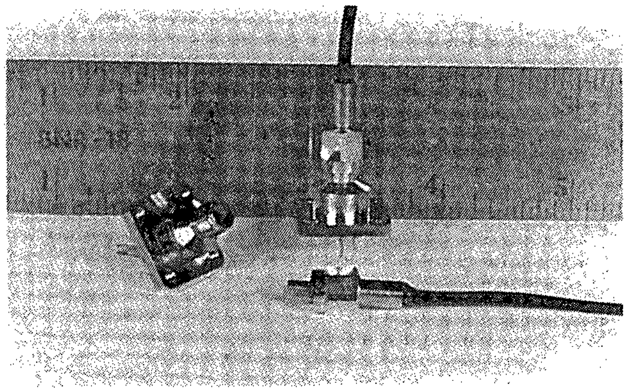

Fig. 7A

form:

$$\log V_o = [\log(\varrho_i Z_f P_o)_{\overline{10}}\, \alpha_c/10] - (\alpha/10)X \qquad (8)$$

For a given set of terminals, connectors and cable types, the variation of log V_o with cable length X is a linear function whose slope is determined by the cable-loss factor $(-\alpha)$; the y intercept varies with coupling loss and with the terminal parameters.

In Fig. 5 the cable Types A,B,C are multi-fiber bundles of cross-section from approximately 0.6 to 1.2 mm (23 to 45 mils), whereas Types SD and SC are single fibers with cross-sections ranging from 75 to 200 microns (3 to 8 mils). For short haul transmission over distances less than 50 meters and at data rates less than 10 MHz, the cost-performance trade-offs favor the use of multi-fiber bundles coupled to inexpensive surface-emitting IR-LED.

Typical analog and digital systems are shown in Figs. 6 and 7. It is difficult to design analog systems employing direct baseband modulation with a high degree of linearity and accuracy. In cases where output signals must differ from input by less than 1%, voltage-to-frequency conversion techniques have been used, with the frequency data then transmitted over a digital fiber-optic link. The package formats for all of the system terminals shown in Figs. 3,5,6 range from the simple format of all electronics within a receptacle (Fig. 7A) to dips designed for direct mounting on printed circuit boards, to mini-boxes with and without power supply conversion.

REFERENCES

1. Fiber Optic Technology, Item 1976, pp. 180-181