Example 12.1 Consider the design of a typical digital fiber-optic link which has to transmit at a data rate of 20 Mbits/s with a BER of 10^{-9} using the NRZ code. The transmitter uses a GaAlAs LED emitting at 850 nm, which can couple on an average 100 μw (–10 dBm) of optical power into a fiber of core size 50 μm. The fiber cable consists of a graded-index fiber with the manufacture's specification as follows: $\alpha_f = 2.5$ dB/km, $(\Delta T)_{\text{mat}} = 3$ ns/km, $(\Delta T)_{\text{modal}} = 1$ ns/km. A silicon *p-i-n* photodiode has been chosen, for detecting 850-nm optical signals, for the front end of the receiver. The detector has a sensitivity of –42 dBm in order to give the desired BER. The source along with its drive circuit has a rise time of 12 ns and the receiver has a rise time of 11 ns. The cable requires splicing every 1 km, with a loss of 0.5 dB/splice. Two connectors, one at the transmitter end and the other at the receiver end, are also required. The loss at each connector is 1 dB. It is predicted that a safety margin of 6 dB will be required. Estimate the maximum possible link length without repeaters and the total rise time of the system for assessing the feasibility of the desired system.

Solution

Using Eq. (12.2), the total channel loss C_L may be calculated as follows:

$$\begin{aligned} C_L &= \alpha_f L + (\text{splice loss per km}) \times L + (\text{loss per connector}) \times \text{no. of connectors} \\ &= (2.5\ \text{dB/km}) \times L\ (\text{km}) + (0.5\ \text{dB/splice}) \times (1\ \text{splice/km}) \times L\ (\text{km}) + (1\ \text{dB}) \times 2 \\ &= (3L + 2)\ \text{dB} \end{aligned}$$

Here, $P_{tx} = -10$ dBm, $P_{rx} = -42$ dBm, and $M_S = 6$ dB. Substituting the values of P_{tx}, P_{rx}, C_L, and M_S in Eq. (12.1), we get

$$-10 = -42 + (3L + 2) + 6$$

or

$$L = 8\ \text{km}$$

Therefore, a maximum transmission path of 8 km is possible without repeaters.

Let us now calculate the total rise time t_{sys} using Eqs (12.8) and (12.9). It is given that $t_{tx} = 12$ ns, $t_{rx} = 11$ ns. In the case of multimode fibers, intramodal dispersion, is primarily due to material dispersion, and hence $t_{\text{intramodal}} \approx t_{\text{mat}}$.

$$t_{\text{mat}} = (3\ \text{ns/km}) \times L = (3\ \text{ns/km}) \times (8\ \text{km}) = 24\ \text{ns}$$

$$t_{\text{intermodal}} = (1\ \text{ns/km}) \times L = (1\ \text{ns/km}) \times (8\ \text{km}) = 8\ \text{ns}$$

Therefore,

$$t_{\text{sys}} = [(12)^2 + (24)^2 + (8)^2 + (11)^2]^{1/2} = 30\ \text{ns}$$

The maximum allowable rise time t_{sys} for our 20-Mbits/s NRZ data stream [from Eq. (12.11)], is

$$t_{sys} \leq \frac{0.70}{B} = \frac{0.70}{20 \times 10^6} \text{ s} = 35 \text{ ns}$$

Since t_{sys} (= 30 ns) for the proposed link is less than the maximum allowable limit, the choice of components is adequate to meet the system design criteria.

Example 12.2 A type-I intensity-modulated analog fiber-optic link employs a laser transmitter which couples a mean optical power of 0 dBm into a multimode optical fiber cable. The cable exhibits an attenuation of 3.0 dB/km with splice losses estimated at 0.5 dB/km. A connector at the receiver end shows a loss of another 1.5 dB. The *p-i-n* photodiode receiver has a sensitivity of –25 dBm for a CNR of –50 dB with a modulation index of 0.5. A safety margin of 7 dB is required. The rise times of the ILD and *p-i-n* diode are 1 ns and 5 ns, respectively, and the intermodal and intramodal rise times of the fiber cable are 9 ns/km and 2 ns/km, respectively. (a) What is the maximum possible link length without repeaters? (b) What is the maximum permitted 3-dB bandwidth of the system?

Solution

(a) *Link power budget*

The mean optical power coupled into the fiber cable by the laser transmitter (P_{tx}) = 0 dBm, the mean optical power required at the *p-i-n* receiver (P_{rx}) = –25 dBm, and the total system margin ($P_{tx} - P_{rx}$) = 25 dB.

Assume that the repeaterless link length is L. Then, using Eq. (12.2), the total channel loss C_L may be calculated as follows:

$$\begin{aligned} C_L &= (\text{attenuation/km}) \times L + (\text{splice loss/km}) \times L + \text{connector loss} \\ &= (3 \text{ dB/km}) \times L + (0.5 \text{ dB/km}) \times L + 1.5 \text{ dB} \\ &= (3.5L + 1.5) \text{ dB} \end{aligned}$$

Therefore, from Eq. (12.1), we have

$$P_{tx} - P_{rx} = C_L + M_S$$

$$\Rightarrow \qquad 25 \text{ dB} = [(3.5L + 1.5) + 7] \text{ dB}$$

Thus $$L = \frac{16.5}{3.5} \approx 4.7 \text{ km}$$

(b) *Rise-time budget*

$$t_f^2 = [(9 \text{ ns/km} \times 4.7 \text{ km})^2 + (2 \text{ ns/km} \times 4.7 \text{ km})^2] = 1877.65 \text{ ns}^2$$

$$\begin{aligned} t_{\text{sys}} &= (t_{tx}^2 + t_f^2 + t_{rx}^2)^{1/2} \\ &= [(1 \text{ ns})^2 + 1877.65 \text{ ns}^2 + (5 \text{ ns})^2]^{1/2} \\ &= 43.63 \text{ ns} \end{aligned}$$

Therefore, the system bandwidth

$$\Delta f = \frac{0.35}{t_{\text{sys}}} = \frac{0.35}{43.6 \times 10^{-9}} \text{ Hz}$$

$$= 8 \times 10^6 \text{ Hz} = 8 \text{ MHz}$$

Thus the proposed link length without repeaters is 4.7 km with a 3-dB bandwidth of 8 MHz.