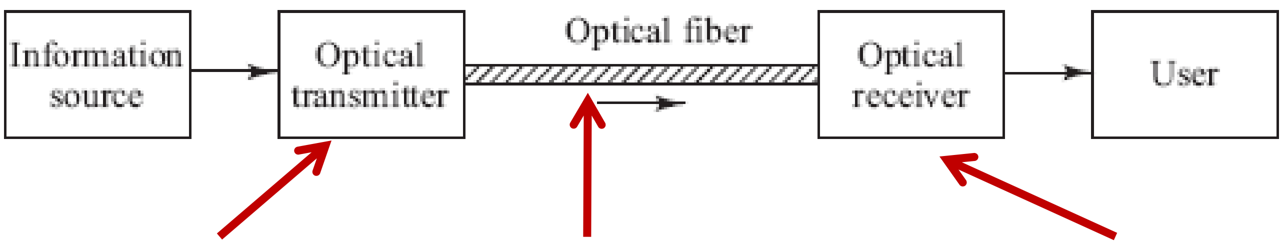
Design of Optical Digital Transmission Systems

Point-to-Point Links

Key system requirements needed to analyze optical fiber links:

1. The desired (or possible) transmission distance
2. The data rate or channel bandwidth
3. The bit-error rate (BER)

LED or laser **MMF or SMF** **pin or APD**



(a) Emission wavelength
(b) Spectral line width
(c) Output power
(d) Effective radiating area
(e) Emission pattern

(a) Core size
(b) Core index profile
(c) BW or dispersion
(d) Attenuation
(e) NA or MFD

(a) Responsivity
(b) Operating λ
(c) Speed
(d) Sensitivity

Selecting the Fiber

Bit rate and distance are the major factors

Other factors to consider: attenuation (depends on?) and distance-bandwidth product (depends on?) cost of the connectors, splicing etc.

Then decide

- Multimode or single mode
- Step or graded index fiber

Selecting the Optical Source

- Emission wavelength depends on acceptable attenuation and dispersion
- Spectral line width depends on acceptable ………… dispersion (LED → wide, LASER → narrow)
- Output power in to the fiber (LED → low, LASER → high)
- Stability, reliability and cost
- Driving circuit considerations

Selecting the detector

- Type of detector
  - **APD**: High sensitivity but complex, high bias voltage (40V or more) and expensive
  - **PIN:** Simpler, thermally stable, low bias voltage (5V or less) and less expensive
- Responsivity (that depends on the avalanche gain & quantum efficiency)
- Operating wavelength and spectral selectivity
- Speed (capacitance) and photosensitive area
- Sensitivity (depends on noise and gain)

Typical bit rates at different wavelengths

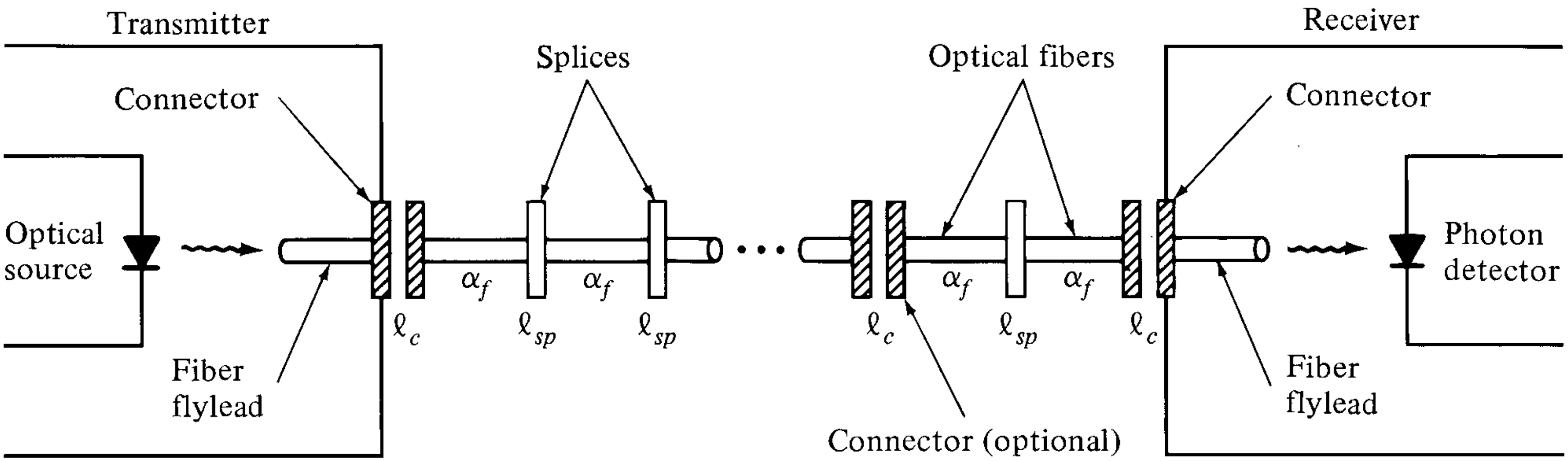
Wavelength	**LED** Systems	**LASER** Systems.
800-900 nm (Typically Multimode Fiber)	150 Mb/s.km	2500 Mb/s.km
1300 nm (Lowest dispersion)	1500 Mb/s.km	25 Gb/s.km (InGaAsP Laser)
1550 nm (Lowest Attenuation)	1200 Mb/s.km	Up to 500 Gb/s.km (Best demo)

Design Considerations

- Link Power Budget
  - There is enough power margin in the system to meet the given BER
- Rise Time Budget
  - Each element of the link is fast enough to meet the given bit rate

These two budgets give necessary conditions for satisfactory operation

Optical power-loss model



$$P_T = P_s - P_R = ml_c + nl_{sp} + \alpha_f L + \text{System Margin}$$

P_T: Total loss; P_s : Source power; P_R: Rx sensitivity

m connectors; n splices

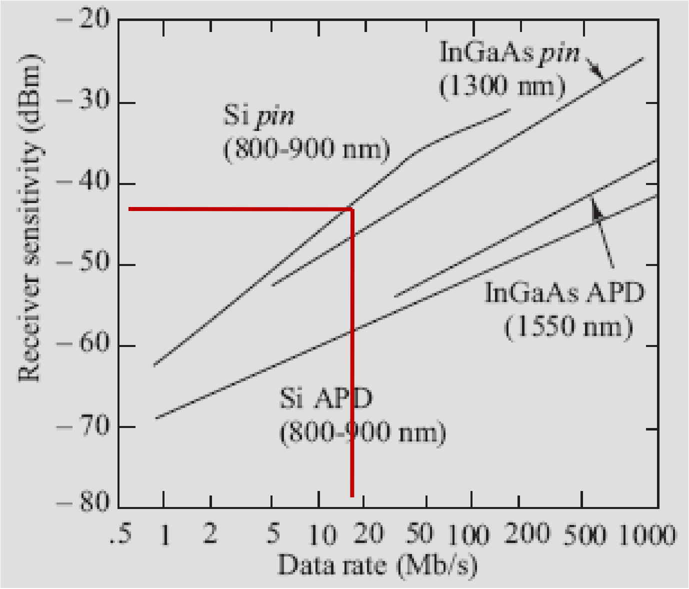
Try Ex: 8.1

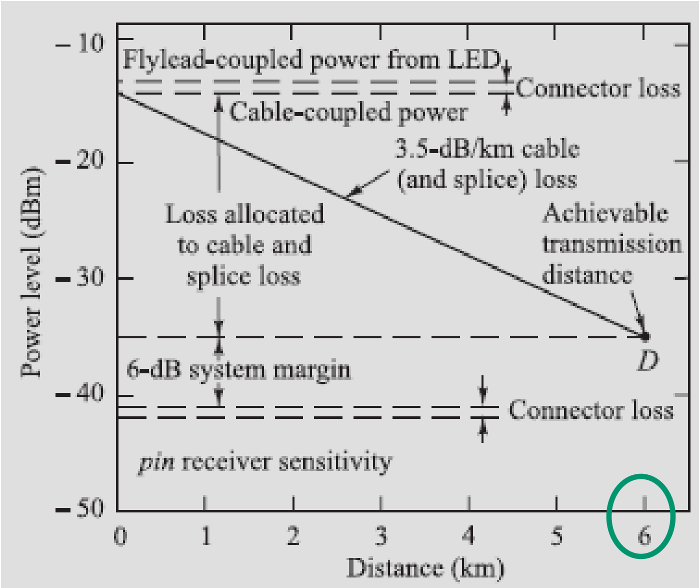
Power Budget Example

- Specify a 20-Mb/s data rate and a BER = 10^{-9}.
- With a Si *pin* photodiode at 850 nm, the required receiver input signal is –42 dBm.
- Select a GaAlAs LED that couples 50 mW into a 50-µm core diameter fiber flylead.
- Assume a 1-dB loss occurs at each cable interface and a 6-dB system margin.
- The possible transmission distance L = 6 km can be found from

$$P_T = P_S - P_R = 29\ dB = 2l_c + \alpha L + \text{system margin} = 2(1\text{ dB}) + \alpha\text{L} + 6\text{ dB}$$

- The link power budget can be represented graphically (see the right-hand figure).





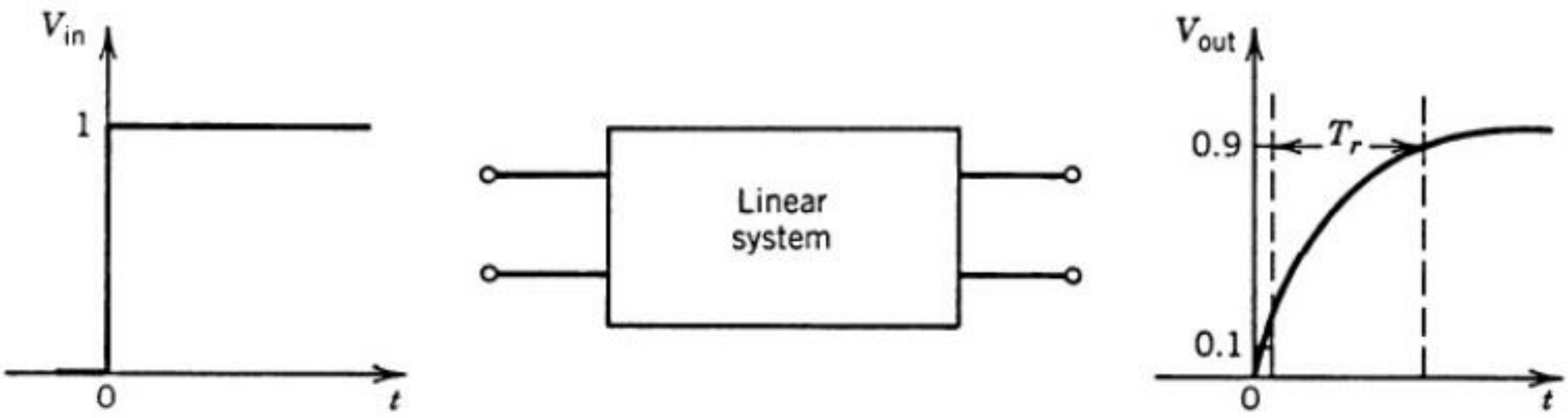
ple 8.2 Consider a 1550-nm laser diode that s a +3-dBm (2-mW) optical power level into a fiber an InGaAs APD with a –32-dBm sensitivity at , and a 60-km long optical cable with a 0.3-dB/km ion. Assume that here, because of the way the nt is arranged, a 5-m optical jumper cable is needed nd between the end of the transmission cable and ET equipment rack as shown in Fig. 8.5. Assume jumper cable introduces a loss of 3 dB. In addition, assume a 1-dB connector loss occurs at each fiber join at each end because of the jumper cables).

Table 8.1 lists the components in column the associated optical output, sensitivity, or lo column 2. Column 3 gives the power margin ava after subtracting the component loss from the total o power loss that is allowed between the light source a photodetector, which, in this case, is 35 dB. Adding losses results in a final power margin of 7 dB.

ble 8.1 *Example of a spreadsheet for calculating an optical-link power budg*

ent/loss parameter	*Output/sensitivity/loss*	*Power margin (*
tput	3 dBm	
sitivity at 2.5 Gb/s	–32 dBm	
l loss [3 – (–32)]		35
onnector loss	1 dB	34
+ connector loss	3 + 1 dB	30
tenuation (60 km)	18 dB	12
+ connector loss	3 + 1 dB	8
r connector loss	1 dB	7 (final margi

Rise Time Budget



Rise time T_r associated with a bandwidth-limited linear system.

Rise-Time Budget (1)

- A *rise-time budget analysis* determines the dispersion limitation of an optical fiber link.
- The total rise time t_{sys} is the root sum square of the rise times from each contributor t_i to the pulse rise-time degradation:
  - The transmitter rise time t_{tx}
  - The group-velocity dispersion (GVD) rise time t_{GVD} of the fiber
  - The modal dispersion rise time t_{mod} of the fiber
  - The receiver rise time t_{rx}

$$t_{sys} = \left[t_{tx}^2 + t_{mod}^2 + t_{GVD}^2 + t_{rx}^2\right]^{1/2}$$
$$= \left[t_{tx}^2 + \left(\frac{440L^q}{B_0}\right)^2 + D^2\sigma_\lambda^2 L^2 + \left(\frac{350}{B_e}\right)^2\right]^{1/2}$$

Here B_e and B_0 are given in MHz, so all times are in ns.

- Total rise time depends on:
  - Transmitter rise time (t_{tx})
  - Material Dispersion $\Delta t = M.\ \Delta\lambda.L$ (t_{mat})
  - Modal dispersion rise time (t_{mod})

– Receiver rise time (t_{rx})

$$t_{sys} = \left[\sum_{i=1}^{n} t_i^2 \right]^{1/2}$$

$$t_{rx} = 350/B_{rx} \text{ ns; where}$$

B_{rx} is receiver bandwidth in MHz

Similarly

$$t_{tx} = 350 / B_{tx} \text{ ns}$$

$$t_{\text{mod}} = \frac{440}{B_M} = \frac{440 L^q}{B_0}$$

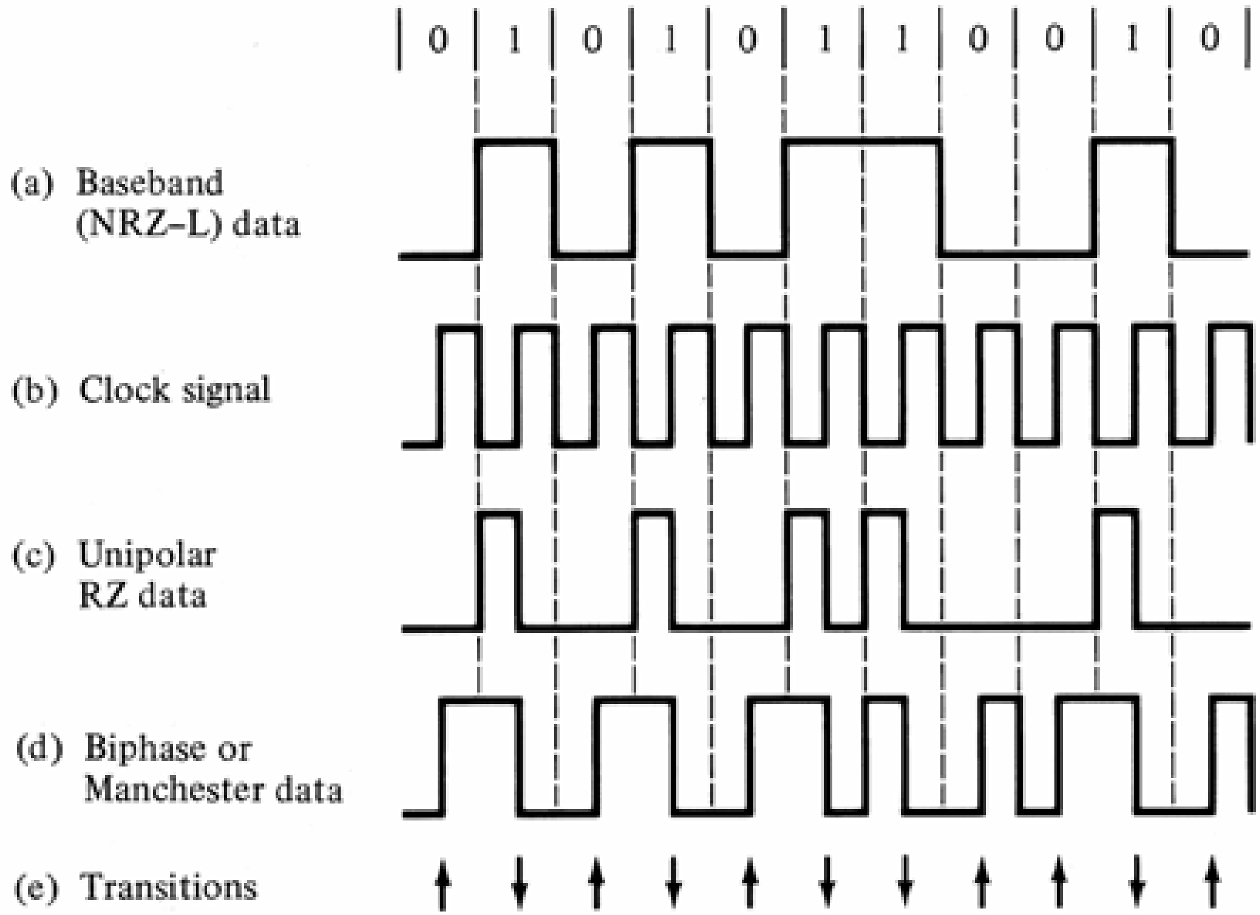
$$t_{\text{sys}} = \left[t_{tx}^2 + D_{\text{mat}}^2 \sigma_\lambda^2 L^2 + \left(\frac{440 L^q}{B_0} \right)^2 + \left(\frac{350}{B_{rx}} \right)^2 \right]^{1/2}$$

Bit rate

For NRZ Coding $B_{max} = 0.7/t_{sys}$

For RZ Coding $B_{max} = 0.35/t_{sys}$

Two-level Binary Channel Codes



System rise-Time & Information Rate

- In digital transmission system, the system rise-time limits the bit rate of the system according to the following criteria:

$$t_{sys} < 70\% \text{ of NRZ bit period}$$

$$t_{sys} < 35\% \text{ of RZ bit period}$$

Example

Laser Tx has a rise-time of 25 ps at 1550 nm and spectral width of 0.1 nm. Length of fiber is 60 km with dispersion 2 ps/(nm.km). The InGaAs APD has a 2.5 GHz BW. Calculate the rise time budget. The system is designed for 2.5Gb/s.

<u>Soln</u>

$$t_{sys} = [t_{tx}{}^2 + t_{\mathrm{mod}}{}^2 + t_{GVD}{}^2 + t_{rx}{}^2]^{1/2}$$

$$= \left[t_{tx}{}^2 + \left(\frac{440 L^q}{B_0} \right)^2 + D^2 \sigma_\lambda{}^2 L^2 + \left(\frac{350}{B_{rx}} \right)^2 \right]^{1/2}$$

=14ns

The rise-time budget (required) of the system for NRZ signaling for 2.5 Gb/s is 0.28 ns whereas the total rise-time due to components is 0.14 ns only. Suitable for NRZsignalling.

Example

LED Tx has a rise-time of 15ns and spectral width of 40 nm. Length of fiber is 6 km with dispersion 2 ps/(nm.km). The InGaAs APD has a 25MHz bandwidth.q=0.7 and 400MHz/km bandwidth Calculate the rise-time budget (required) for this system.Check whether it is suitable for 20 Mb/s NRZ

Soln

$$
\begin{aligned}
t_{sys} &= \left(t_{tx}^2 + t_{mat}^2 + t_{mod}^2 + t_{rx}^2\right)^{1/2} \\
&= [(15\ \text{ns})^2 + (21\ \text{ns})^2 + (3.9\ \text{ns})^2 + (14\ \text{ns})^2]^{1/2} \\
&= 30\ \text{ns}
\end{aligned}
$$

- Maximum allowable rise time is 35ns for NRZ

Example

A single mode optical fiber link that uses a 1310 nm distributed feedback laser diode is designed to operate over 6 km distance in an optical network. Suppose the components of the operating link have the following parameters

- The laser transmitter rise time is =0.25ns
- The PIN photo diode receiver receiver rise time is 0.14ns
- Dispersion in the optical fiber is 2ps/(nm.km)
- Spectral width of the laser diode is 2.0nm

Calculate the system rise time

Determine the maximum bitrate for NRZ system

<u>Soln</u>

- $t_{sys} = \{(0.25)^2 + (0.002)^2(2)^2(6)^2 + (0.14)^2\}^{1/2}$
- $= 0.29$ns
- Thus $0.7/B_{NRZ} > 0.29$ns gives maximum bitrate 2.4Gb/s