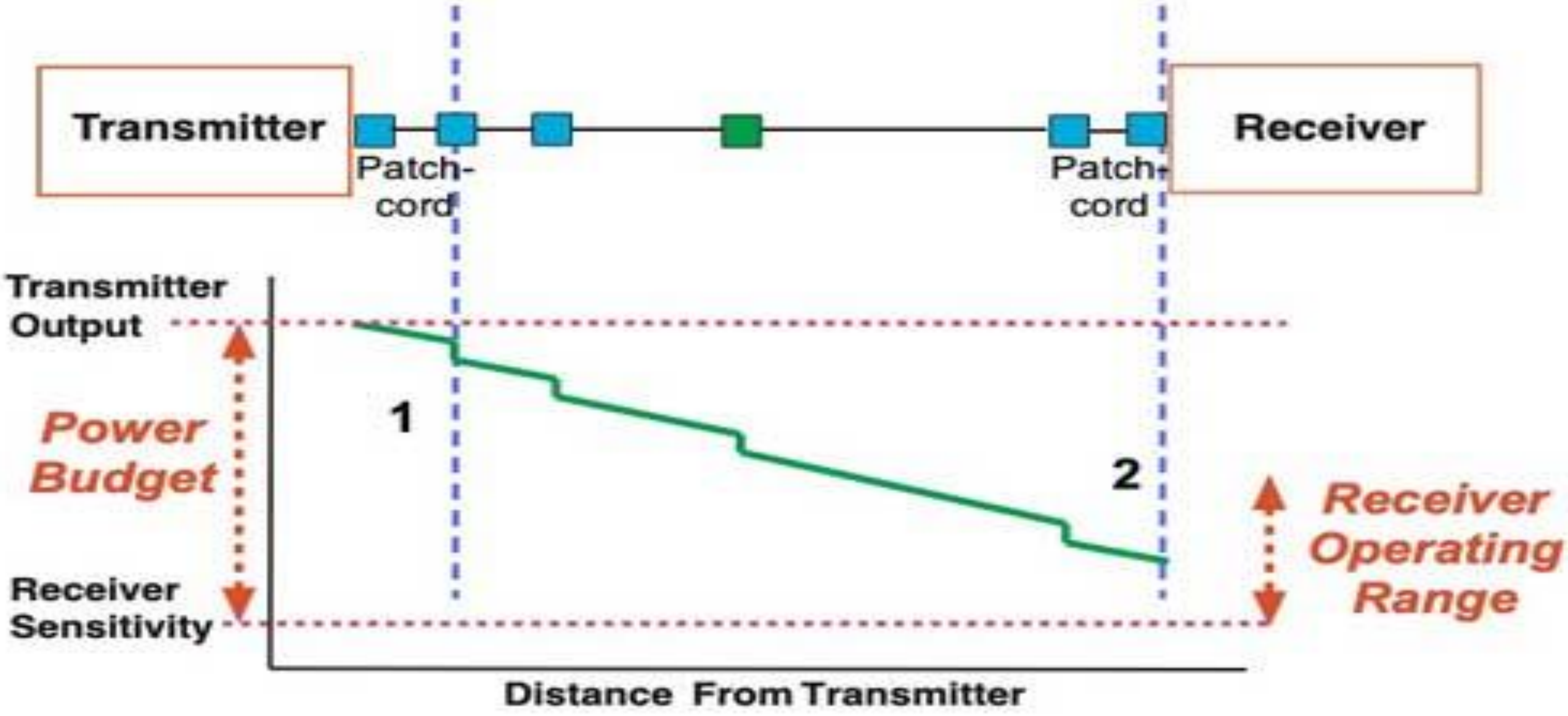


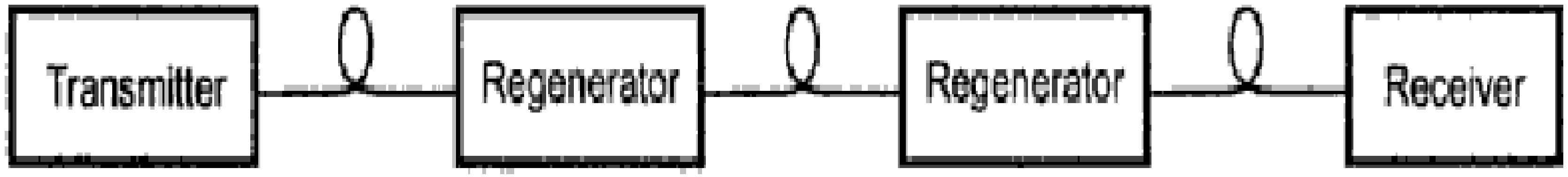
Module – 5
Digital links and Measurements

Point-to-Point Links

- Simplest optical communication link

- It consist of one transmitter and one receiver

- Important aspects of link analysis
  - Distance of transmission
  - Channel bit rate/bandwidth
  - Bit error rate



Link calculations

Specifications: transmission distance, data rate (BW), BER

- Objectives is then to select

- FIBER:
  - Multimode or Single mode fiber: core size, refractive index profile, bandwidth or dispersion, attenuation, numerical aperture or mode-field diameter

- SOURCE:
  - LED or Laser diode optical source: emission wavelength, spectral line width, output power, effective radiating area, emission pattern, number of emitting modes

- DETECTOR/RECEIVER:
  - PIN or Avalanche photodiode: responsivity, operating wavelength, speed, sensitivity

Design of Point-to-Point Links

- To determine repeater spacing one should calculate
  - Power budget/Link power budget
    - Ensure that enough power will reach the receiver
    - One should be able to estimate required margins with respect of temperature, aging and stability
    - Minimum sensitivity required
    - Optical power loss due to junctions, connectors and fiber
  - Rise-time budget/ Bandwidth budget
    - Ensure that the system is able to operate properly at the intended bit rate
    - For rise-time budget one should take into account all the rise times in the link (tx, fiber, rx)
- If the link does not fit into specifications
  - more repeaters
  - change components
  - change specifications

Link Power Budget

- Power arriving at the detector must be sufficient to allow clean detection

- Signal at the receiver must be larger than the noise

$$P_r \geq P_s$$

- P_r - Power at the detector
- P_s - Receiver sensitivity

Numerical problem

- A receiver has sensitivity P_S of –45 dBm and a BER of 10^{-9}. What is the minimum power that must be incident on the detector?

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$$-45dBm = 10\log\left(\frac{p}{1mW}\right)$$

$$P = (1mW)\times 10^{-4.5} = 3.16\times 10^{-5}\, mW = 31.6nW$$

Link Power Budget

- The received power at the detector is a function of:
  - Power emanating from the light source (laser diode or LED)—(P_L)
  - Source to fiber loss (L_{sf})
  - Fiber loss per km (FL) for a length of fiber (L)
  - Connector or splice losses (L_{conn})
  - Fiber to detector loss (L_{fd})

Link Power Budget

- The allocation of power loss among system components is the power budget

- The loss margin is the difference between the received power and the receiver sensitivity

$$L_m = P_r - P_s$$

- If all of the loss mechanisms in the system are taken into consideration, the loss margin can be

$$L_m = P_L - L_{sf} - (F_L \times L) - L_{conn} - L_{fd} - P_s$$

Link Power Budget

$$P_S - L_C - \alpha_f L - nL_s - mL_m - A \geq S_R / \eta$$

where:

P_S = Power Emitted from source

L = Distance (total fiber length)

N = no. of splices

M = no. of connectors

A = System margin

L_C = Coupling loss

α_f = attn. per unit length

L_s = splice loss

L_m = connector loss

η = Detector quantum efficiency

S_R = minimum Receiver sensitivity

Numerical Problem

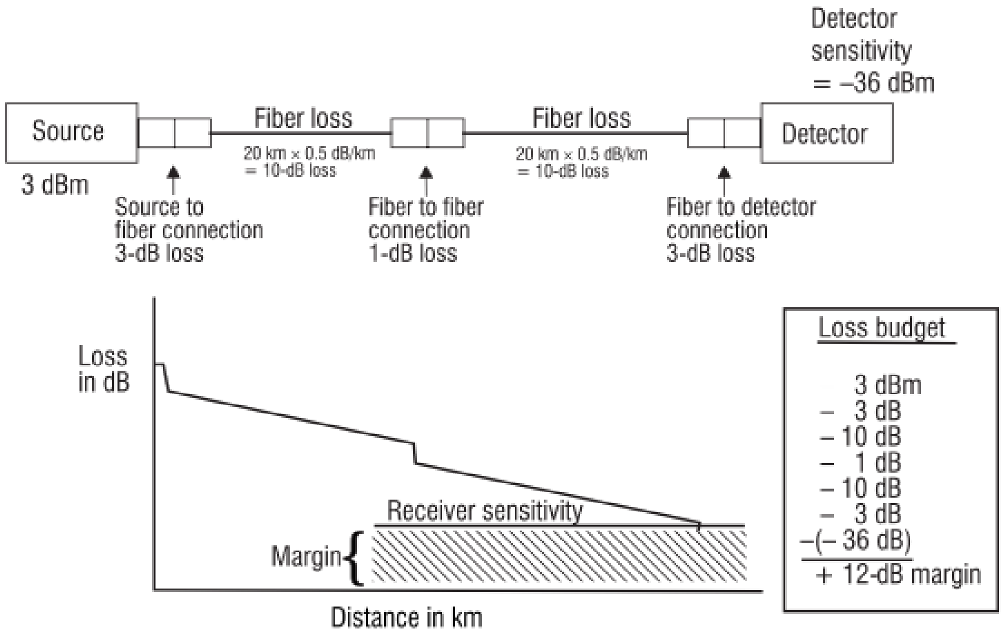
- A system has the following characteristics:
  - LED power (PL) = 2 mW (3 dBm)
  - LED to fiber loss (Lsf) = 3 dB
  - Fiber loss per km (FL) = 0.5 dB/km
  - Fiber length (L) = 40 km
  - Connector loss (Lconn) = 1 dB (one connector between two 20km fiber lengths)
  - Fiber to detector loss (Lfd) = 3 dB
  - Receiver sensitivity (Ps) = –36 dBm
- Find the loss margin.

Numerical Problem

$$L_m = P_L - L_{sf} - (F_L \times L) - L_{conn} - L_{fd} - P_s$$

$$= 3dBm - 3dB - (40km \times 0.5dB/km) - 1dB - 3dB - (-36dBm)$$

$$= 12dB$$



Numerical Problem

- An engineer has the following components available:
- GaAlAs laser diode operating at 850 nm and capable of coupling 1mW into a fiber.
- Ten sections of cable each of which is 500 m long, has a 4-dB/km attenuation, and has connectors on both ends.
- Connector loss of 2dB/connector.
- A pin photodiode receiver.
- An avalanche photodiode receiver.
- Using these components, the engineer wishes to construct a 5-km link operating at 20 Mb/s. If the sensitivities of the PIN and APD receivers are –45 and –56 dBm, respectively, which receiver should be used if a 6-dB system operating margin is required?

Numerical Problem

$$L_m = P_L - L_{sf} - (F_L \times L) - L_{conn} - L_{fd} - P_s$$

$$= 0dBm - (5km \times 4dB/km) - (11 \times 2)dB - (-45dBm)$$

$$= 3dB$$

$$L_m = P_L - L_{sf} - (F_L \times L) - L_{conn} - L_{fd} - P_s$$

$$= 0dBm - (5km \times 4dB/km) - (11 \times 2)dB - (-56dBm)$$

$$= 14dB$$

- APD receiver is suitable as the loss margin is more than 6 dB

Numerical Problem

- Determine the maximum attenuation-limited transmission distance of the following two systems operating at 100 Mb/s:
- System 1 operating at 850 nm
  - GaAlAs laser diode: 0-dBm (1-mW) fiber coupled power.
  - Silicon avalanche photodiode: –50-dBm sensitivity.
  - Graded-index fiber: 3.5-dB/km attenuation at 850 nm.
  - Connector loss: 1 dB/connector.
- System 2 operating at 1300 nm
  - InGaAsP LED: –13-dBm fiber-coupled power.
  - InGaAs pin photodiode: – 38-dBm sensitivity.
  - Graded-index fiber: 1.5-dB/km attenuation at 1300 nm.
  - Connector loss: 1 dB/connector.
- Allow a 6-dB system operating margin in each case

Numerical Problem

$$L = \frac{L_m - P_L + L_{sf} + L_{fd} + L_{conn} + P_s}{-F_L} = 12km$$

$$L = \frac{L_m - P_L + L_{sf} + L_{fd} + L_{conn} + P_s}{-F_L} = 11.3km$$

Rise Time Budget

- Transmission data rate is limited by the rise time of the various components
- The concept of rise time budget is to allocate bandwidth among individual components
- Rise time budget analysis determines the dispersion limitation of an optical fiber link
- Four basic elements that contributes to the rise time are
  - Transmitter rise time (t_{tx})
  - Group Velocity Dispersion (GVD) rise time (t_{GVD})
  - Modal dispersion rise time of fiber (t_{mod})
  - Receiver rise time (t_{rx})

Rise Time Budget

- Total rise time of a fiber link is the root-sum-square of rise time of each contributor to the pulse rise time degradation

$$t_{sys} = \left(\sum_{i=1}^{N} t_i^2\right)^{1/2}$$

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

Rise Time Budget

- Transmitter rise time t_{tx} (ns)
- GVD rise time t_{GVD} (ns)→ $|D|\ L\ \sigma_\lambda$
- Modal dispersion rise time t_{mod} (ns) → $440L^q/B_o$(MHz)
  - q → mode mixing factor
  - q = 0.5 steady state modal mixing
  - q = 1 no modal mixing
  - q = 0.7 practical estimate
- B_o → 3 dB optical bandwidth of 1Km length of fiber
- Receiver rise time t_{rx} (ns) → 350 / B_{rx}(MHz)
  - B_{rx} → 3 dB electrical bandwidth of receiver
- For RZ scheme, the maximum system bandwidth/bitrate is given as $0.35/t_{sys}$
- For NRZ scheme, the maximum system bandwidth/bitrate is given as $0.7/t_{sys}$

Numerical Problem

- A 10-km fiber with a BW × length product of 1000 MHz × km (optical bandwidth) is used in a communication system which uses RZ coding scheme. The rise times of the other components are t_{tx} = 10 ns, t_{mod}= 3 ns, t_{GVD} = 3 ns and t_{rx} = 12 ns. Calculate the BW of the system.

Numerical Problem

- A 10-km fiber with a BW × length product of 1000 MHz × km (optical bandwidth) is used in a communication system which uses RZ coding scheme. The rise times of the other components are t_{tx} = 10 ns, t_{mod}= 3 ns, t_{GVD} = 3 ns and t_{rx} = 12 ns. Calculate the BW of the system.

$$t_{sys} = [t_{tx}^2 + t_{\mathrm{mod}}^2 + t_{GVD}^2 + t_{rx}^2]^{1/2} = 16.03ns$$

$$BW = 0.35/(16.03 \times 10^{-9}) = 21.8MHz$$

Numerical Problem

- Consider an LED with its drive circuit has a rise time of 15 ns. Taking a typical LED spectral width of 40 nm, the material dispersion related rise time degradation of 21 ns over the 6 km link. Assuming the receiver has a 25 MHz bandwidth and the fiber we select has a 400 MHz.km bandwidth distance product . The system is intended to operate at the bit rate of 20 Mbps with NRZ coding scheme. Calculate the system rise time and verify the chosen components are adequate to meet the system design criteria.

Numerical Problem

- Consider an LED with its drive circuit has a rise time of 15 ns. Taking a typical LED spectral width of 40 nm, the material dispersion related rise time degradation of 21 ns over the 6 km link. Assuming the receiver has a 25 MHz bandwidth and the fiber we select has a 400 MHz.km bandwidth distance product . The system is intended to operate at the bit rate of 20 Mbps with NRZ coding scheme. Calculate the system rise time and verify the chosen components are adequate to meet the system design criteria.

$$t_{\mathrm{mod}} = \frac{440L^q}{B_o} = \frac{440 \times 6^{0.7}}{400} = 3.9ns \qquad t_{rx} = \frac{350}{B_{rx}} = \frac{350}{25} = 14ns$$

$$t_{sys} = [t_{tx}^2 + t_{\mathrm{mod}}^2 + t_{GVD}^2 + t_{rx}^2]^{1/2} = 30ns$$

- The value falls below the maximum allowable 35 ns rise time degradation for our 20 Mbps NRZ data stream. The choice of components are adequate to meet our design criteria

Numerical Problem

- An optical fiber system is designed to operate at 8 km length without repeaters. The rise time of the chosen components are
    - LED = 8 ns
    - Fiber cable = 5 ns/km
    - Intermodal = 1 ns/km
    - Detector = 6 ns
- Estimate the maximum bit rate at NRZ and RZ format.

Numerical Problem

- An optical fiber system is designed to operate at 8 km length without repeaters. The rise time of the chosen components are
  - LED = 8 ns
  - Fiber cable = 5 ns/km
  - Intermodal = 1 ns/km
  - Detector = 6 ns
- Estimate the maximum bit rate at NRZ and RZ format.

$$t_{sys} = [t_{tx}^2 + t_{\mathrm{mod}}^2 + t_{GVD}^2 + t_{rx}^2]^{1/2} = 42ns$$

$$B_{NRZ} = \frac{0.7}{t_{sys}} = 16.67Mbps \qquad B_{RZ} = \frac{0.35}{t_{sys}} = 8.33Mbps$$

Numerical Problem

- A 90-Mb/s NRZ data transmission system that sends two DS3 (45-Mb/s) channels uses a GaAlAs laser diode that has a 1-nm spectral width. The rise time of the laser transmitter output is 2 ns. The transmission distance is 7 km over a graded-index fiber that has an 800-MHz·km bandwidth-distance product. Assume Dmat = 0.07 ns/(nm-km),
- If the receiver bandwidth is 90 MHz and the mode-mixing factor q = 0.7, what is the system rise time? Does this rise time meet the NRZ data requirement of being less than 70 percent of a pulse width?
- What is the system rise time if there is no mode mixing in the 7-km link?

Numerical Problem

$$t_{\text{mod}} = \frac{440L^q}{B_o} = \frac{440\times 7^{0.7}}{800} = 2.15ns \qquad t_{rx} = \frac{350}{B_{rx}} = \frac{350}{90} = 3.89ns$$

$$t_{GVD} = DL\sigma_{\lambda} = 0.07\times 7\times 1 = 0.49ns$$

$$t_{sys} = [t_{tx}^2 + t_{\text{mod}}^2 + t_{GVD}^2 + t_{rx}^2]^{1/2} = 4.89ns$$

$$0.7\times T_b = \frac{0.7}{90\times 10^6} = 7.78ns > T_{sys}$$

- The value falls below the maximum allowable 7.78 ns rise time degradation for our 90 Mbps NRZ data stream. So, that the rise time meets the NRZ data requirements

Numerical Problem

$$t_{\mathrm{mod}} = \frac{440L^q}{B_o} = \frac{440 \times 7^1}{800} = 3.85ns \qquad t_{rx} = \frac{350}{B_{rx}} = \frac{350}{90} = 3.89ns$$

$$t_{GVD} = DL\sigma_\lambda = 0.07 \times 7 \times 1 = 0.49ns$$

$$t_{sys} = [t_{tx}^2 + t_{\mathrm{mod}}^2 + t_{GVD}^2 + t_{rx}^2]^{1/2} = 5.84ns$$

Numerical Problem

- A single mode optical fiber link that uses a 1310 nm fabry perot laser diode is designed to operate over 6 km distance in a campus network. Suppose the components of the operating link have the following rise time values
- The laser transmitter rise time = 0.30ns
- The pin photo diode receiver rise time is 0.14ns
- Material 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

Numerical Problem

$$t_{GVD} = DL\sigma_{\lambda} = 0.002 \times 6 \times 2 = 0.024ns$$

$$t_{sys} = [t_{tx}^2 + t_{\mathrm{mod}}^2 + t_{GVD}^2 + t_{rx}^2]^{1/2} = 0.33ns$$

$$B_{NRZ} = \frac{0.7}{0.33ns} = 2.12Gbps$$