Optical Fibre Communication Systems

Lecture 8 - Systems

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- System Design
- Digital Systems
  - Link power budget
  - Link rise time (bandwidth) budget
  - Transmission distance
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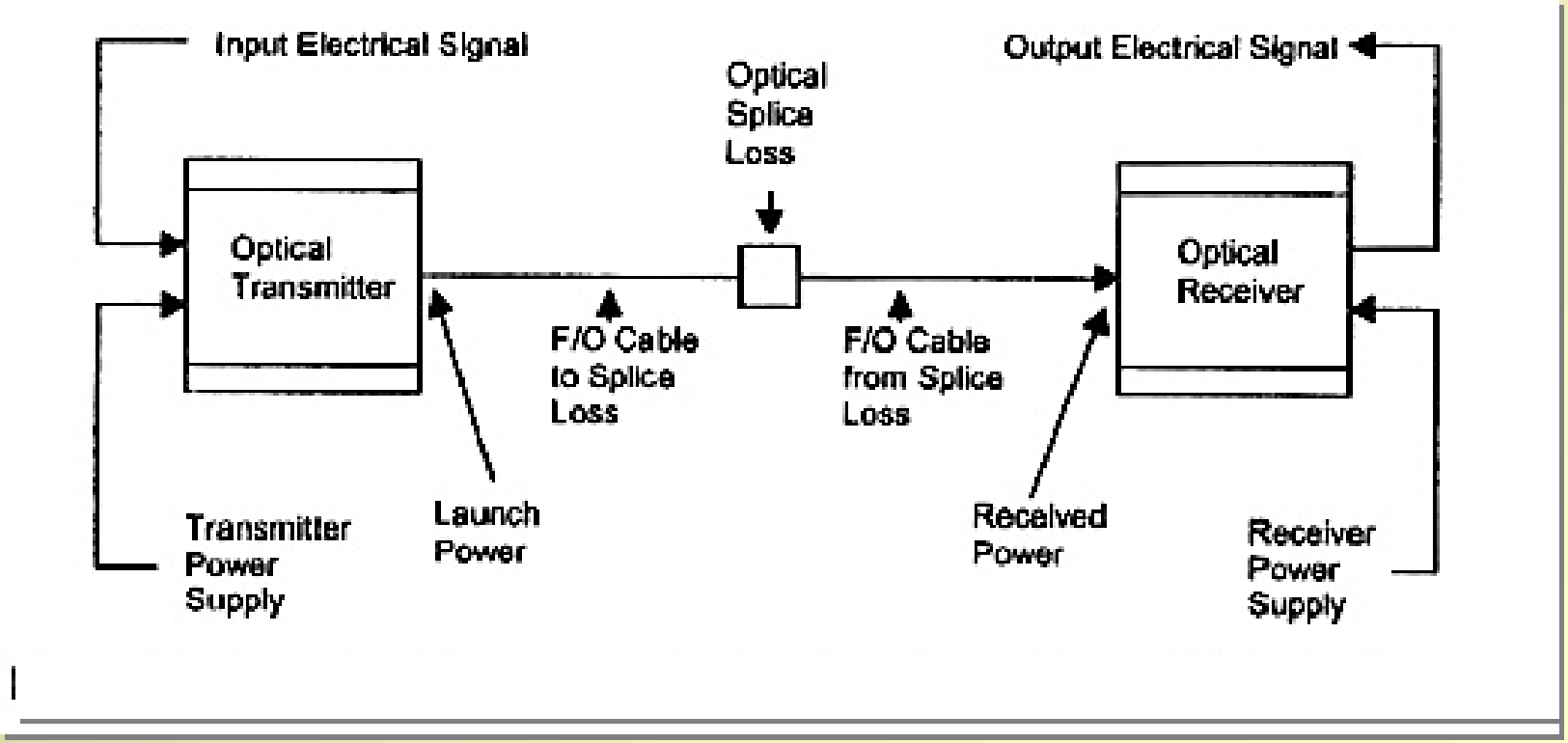
Fiber Optic System Design

- There are many factors that must be considered to ensure that enough light reaches the receiver. Without the right amount of light, the entire system will not operate properly.



Fiber Optic System Design- Step-by-Step

- Select the most appropriate optical transmitter and receiver combination based upon the signal to be transmitted (Analog, Digital, Audio, Video, RS-232, RS-422, RS-485, etc.).
- Determine the operating power available (AC, DC, etc.).
- Determine the special modifications (if any) necessary (Impedances, bandwidths, connectors, fiber size, etc.).
- Carry out system link power budget.
- Carry out system rise time budget (I.e. bandwidth budget).
- If it is discovered that the fiber bandwidth is inadequate for transmitting the required signal over the necessary distance, then either select a different transmitter/receiver (wavelength) combination, or consider the use of a lower loss premium fiber

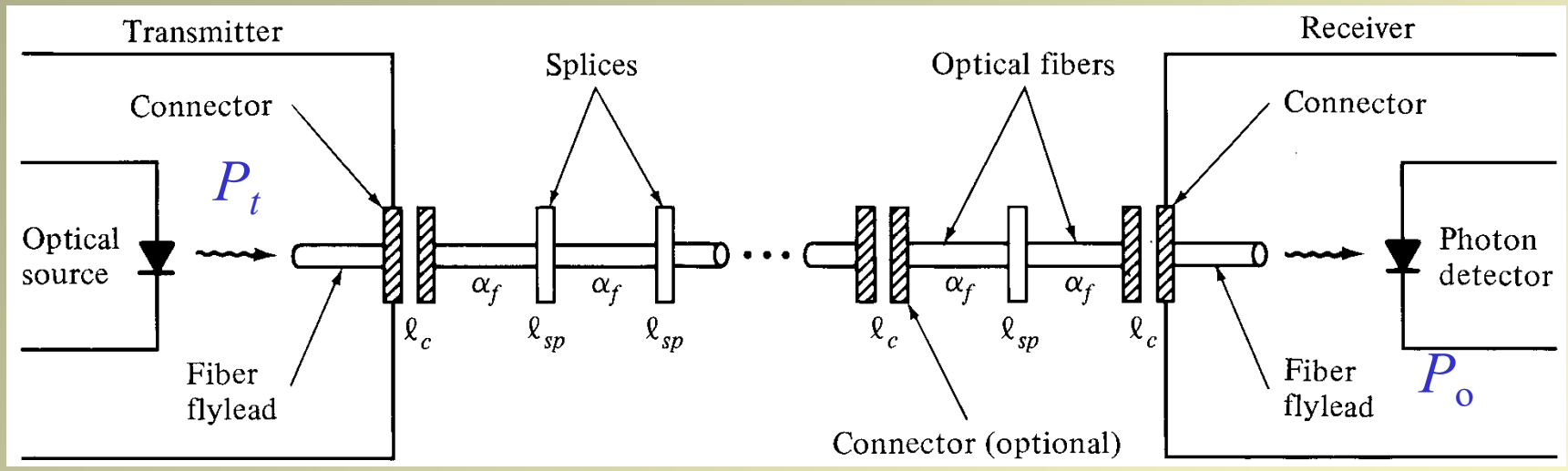
Digital Systems

- Compared with analogue systems:
  - It Gives superior performance
  - It reduces problems associated with the optical source non-linearities and temperature dependency (in baseband transmission)
- Provide ideal channel for data transmission
- Information is carried in the baseband using Intensity Modulation (IM).

System Design – Evaluation Factors

System Factor	Considerations
Type of Fiber	Single-mode or Multimode
Operating Wavelength	780, 850, 1310 and 1550 nm typical
Transmitter Power	Typically expressed in dBm
Source Type	Laser, LED
Receiver Sensitivity and Overload Characteristics	Typically expressed in dBm
Detector Type	PIN Diode, APD or IDP
Modulation Code	**AM, FM, PCM or Digital**
Bit Error Rate (BER) (Digital Systems Only)	**10^{-9} ,10^{-12} Typical**
Signal to Noise Ratio	**Specified in decibels (dB)**
Number of Connectors	**Loss increases with the number of connectors**
Number of Splices	**Loss increases with the number of splices**
Environmental Requirements	**Humidity, Temperature, Exposure to sunlight**
Mechanical Requirements	**Flammability, Indoor/Outdoor Application**

Link Power Budget



$$\text{Total loss } L_T = \alpha_f L + l_c + l_{sp}$$

$$P_t - P_o = L_T + SM$$

P_o = Receiver sensitivity (i.e., minimum power requirement)

SM = System margin (to ensure that small variation the system operating parameters do not result in an unacceptable decrease in system performance)

Link Power Budget - Example 1

Parameters	Value	dB
▪ *Transmitter*		
▪ Average transmitted power	3 mW	4.8 dBm
▪ Fibre coupling losses		-3.7 dB
▪ *Channel*		
▪ Fibre loss		-15.7 dB
▪ Splitting losses		-10 dB
▪ Splice & Connector losses		-0.79 dB
▪ Fibre dispersion & nonlinearity		0 dB
▪ All losses		30.19
▪ *Receiver*		
▪ Signal power at the receiver		-25.39 dBm
▪ Receiver sensitivity		-31 dBm
System Margin = (Ps – Pr) - Losses= 4.8-(-31) – 30.19 =		+5.6 dB

Link Power Budget - Example 2

- **Transmitter**
  - Date rate = 500 Mb/s
  - Source Laser @ 1300 nm
  - Coupling power = 2 mW (3 dBm) into a 10 um fibre.
- **Channel**
  - Mono mode fibre of length 60 km and a loss of 0.3 dB/km
  - Connector loss = 1 dB/connector
  - Splicing every 5 km with a loss = 0.5 dB /splice
- **Receiver:**
  - PIN @ 1300 nm
  - BER = 10^{-9}
- **System margin = ?**

Link Power Budget - Example 2 *contd.*

Receiver sensitivity -29 dBm

$$P_t - P_o = L_T + SM$$

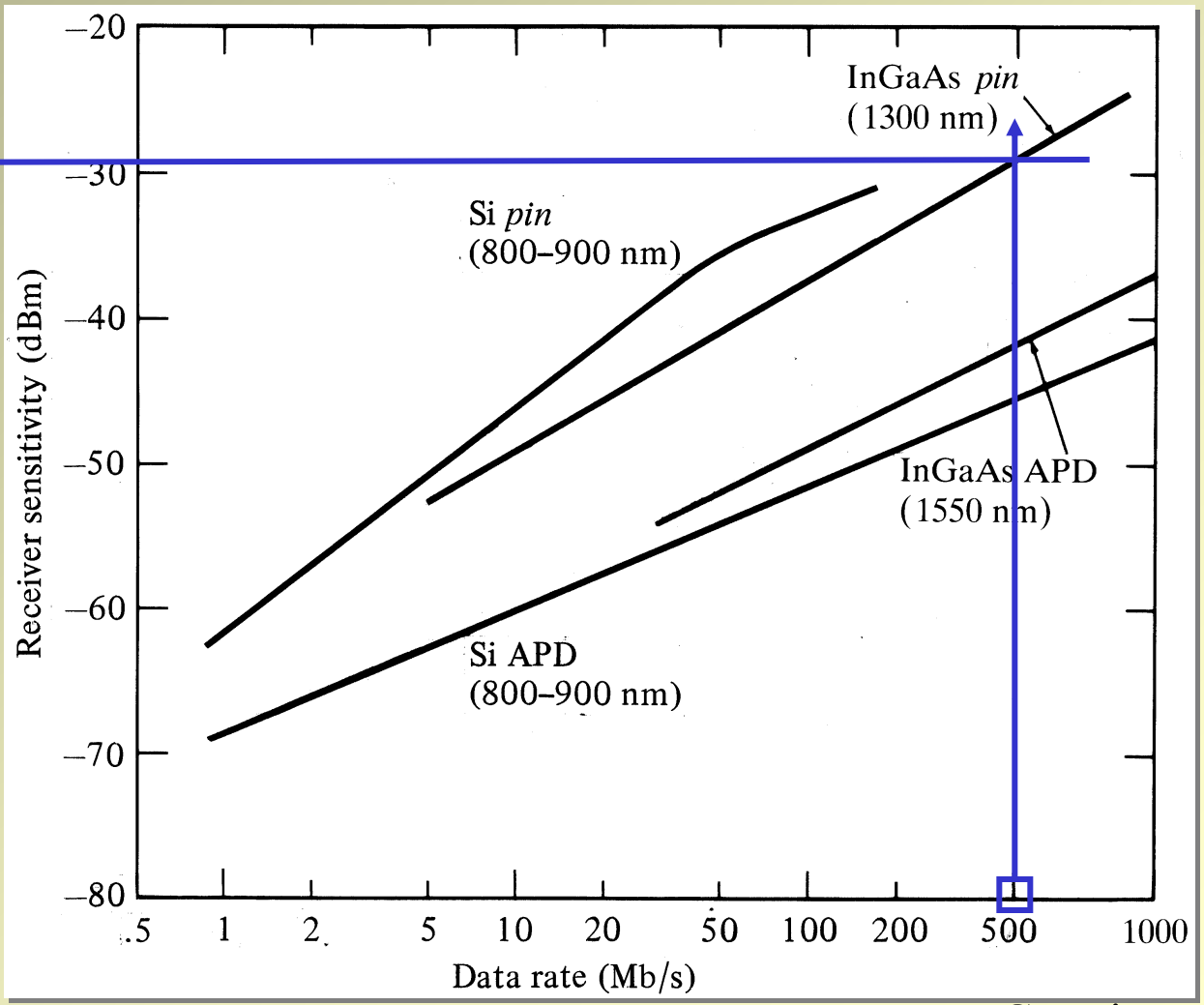
$L_T = 2(1\text{ dB}) + 0.3(60) + 0.5\,(11)$
$= 25.5$ dB

thus

3 +29 = 25.5 dB+SM

therefore

$SM = 5.5$ dB



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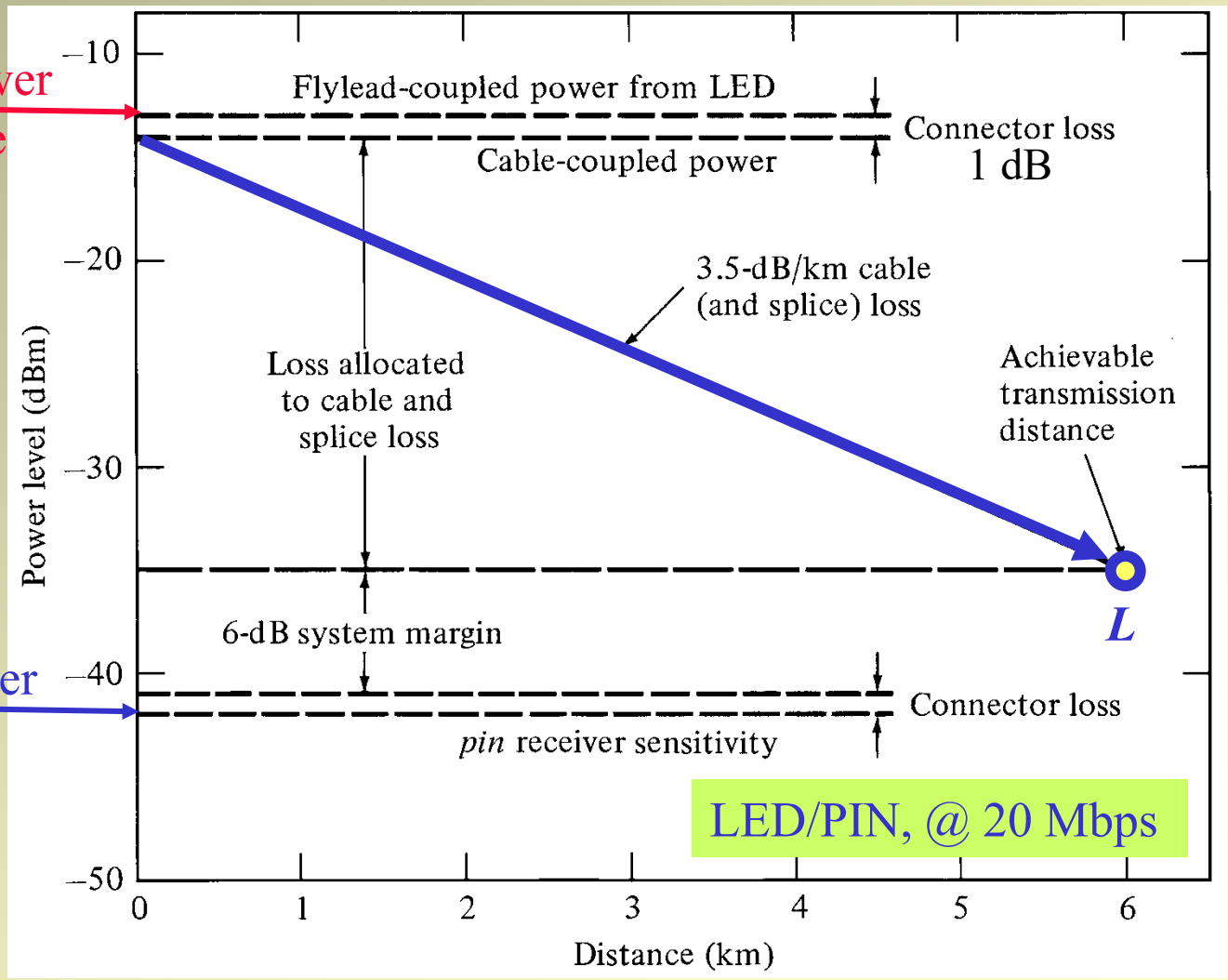
Link-Power Budget - Example 3

Launch power into fibre

Link power budget can be shown graphically in terms of receiver sensitivity Vs. the data rate



Launch power into fibre

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Link-Power Budget - *contd.*

- Dispersion -equalisation penalty is given as:

$$D_L = 2\left(2\sigma B_T \sqrt{2}\right)^4 \quad \textbf{(dB)}$$

Where B_T is the bit rate, σ is the rms pulse width.

Therefore, the total channel loss is given as:

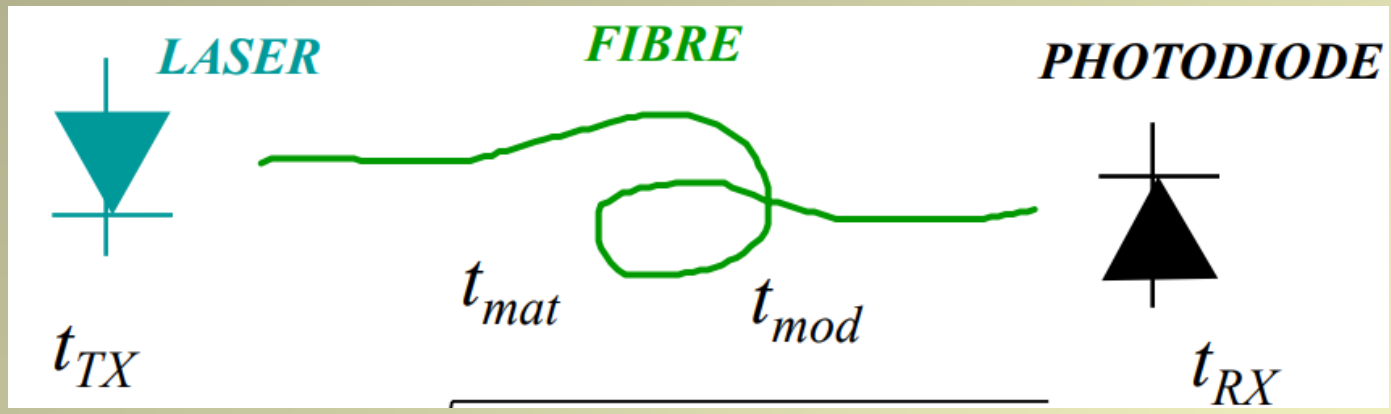
Total loss $L_T = \alpha_f L + l_c + l_{sp} + D_L$ (dB)

D_L is only significant in wideband multi-mode fibre systems

Rise Time Budget

- The system design must also consider the temporal response of the system components.
- The total loss L_T (given in the power budget section) is determined in the absence of the any pulse broadening due to dispersion.
- Finite bandwidth of the system (transmitter, channel, receiver) may result in pulse spreading (i.e., intersymbol interference), giving a **reduction in the receiver sensitivity**. I.e. worsening of BER or SNR
- The additional loss penalty is known as **dispersion-equalisation or ISI penalty.**

Rise Time Budget - *contd.*



The total system rise time $t_{sys} = \left(\sum_{i-1}^{N} t_i^2 \right)^{0.5}$

$$t_{sys} = \left(t^2{}_s + t^2{}_{inter} + t^2{}_{intra} + t^2{}_d \right)^{0.5}$$

Source | Fibre intermodal | Fibre intramodal | Detector

Rise Time Budget - *contd.*

Note - 3 dB bandwidth of a simple low pass RC filter is given as:

$$B = \frac{1}{2\pi RC}$$

With a step input voltage into the RC filter, the rise time of the output voltage is:

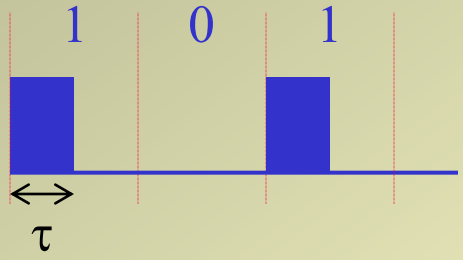
$$t_r = 2.2B = \frac{0.35}{B}$$

Rise Time Budget - *contd.*

For a fibre optic link:

$$t_{sys} = t_r = \frac{0.35}{B}$$

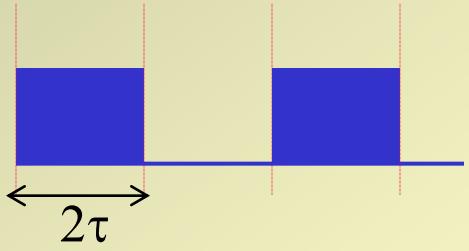
For RZ data format



$$Bit rate R = B = 1/\tau$$

$$B_{RZ} = \frac{0.35}{t_{sys}}$$

For NRZ data format



$$Bit rate R = B = 1/2\tau$$

$$B_{NRZ} = \frac{0.75}{t_{sys}}$$

Rise Time Budget - *contd.*

- Calculate the total rise time for a system using a light emitting diode (LED) and a LED driver with a rise time of 15 ns. Assume that the:
  - LED bandwidth is 40 nm
  - receiver has a 25 MHz bandwidth
  - MMIS fiber length of 6 km, with a core referactive index of 1.5 and a relative refractive index difference of 1%.

Determine the system bandwidth.

The intramodal dispersion: $\tau_{mat} = -L\delta\lambda_0 \overbrace{\frac{\lambda_0}{c}\left|\frac{d^2 n}{d\lambda^2{}_0}\right|}^{D_{mat}} \quad ns/km$

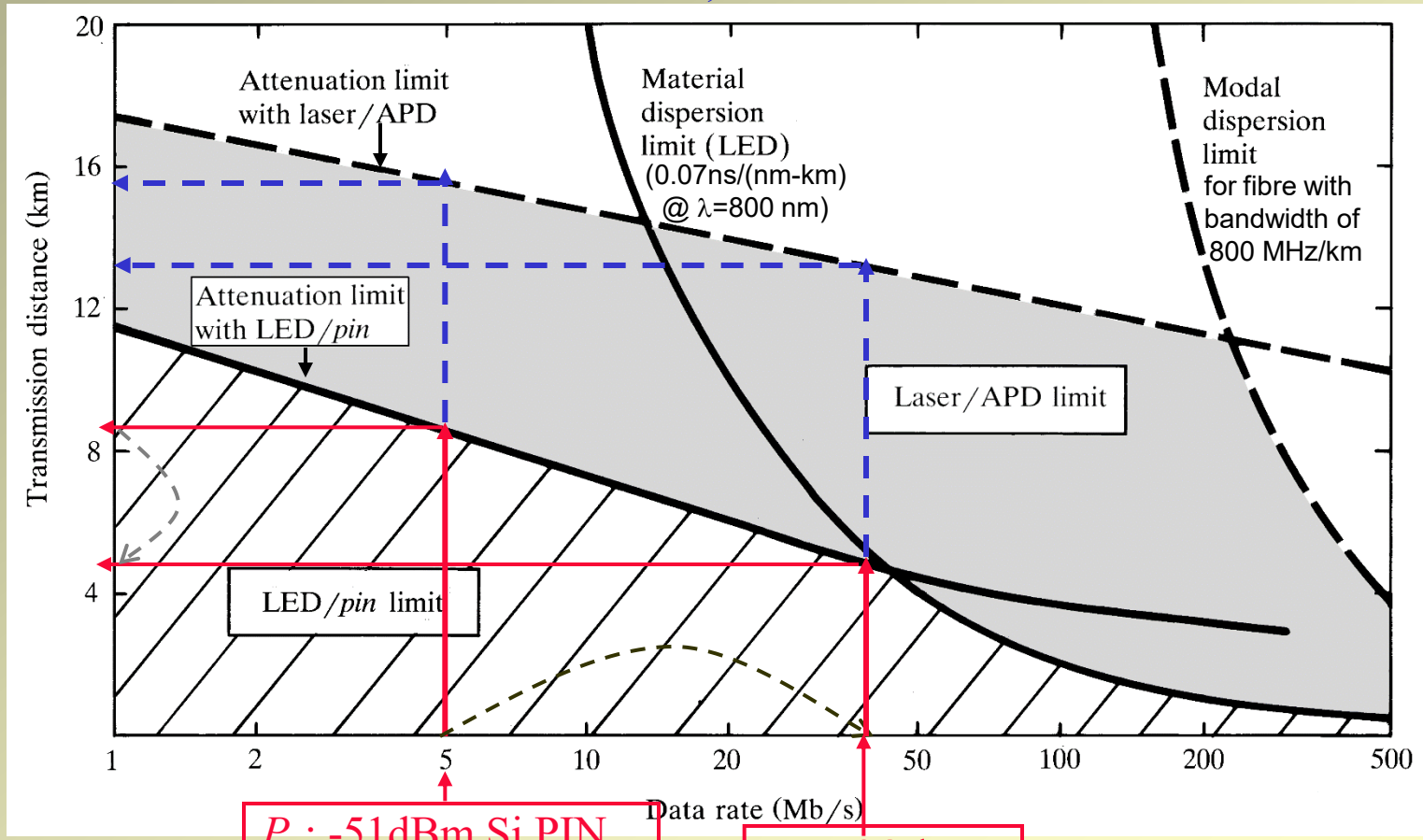
The intermodal dispersion: $\tau_{\text{mod al}} = \frac{Ln_1\Delta}{3.5c}$

The receiver rise time: $t_d = 0.35/B_d$

$$t_{sys} = \left(t^2{}_s + t^2{}_{inter} + t^2{}_{intra} + t^2{}_d\right)^{0.5}$$

Transmission Distance -1st window

Multi-mode, Input power P_t = -13 dB LED (0 dBm laser), fibre loss = 3.5 dB/km, SM = 6 dB, BER = 10^{-9}



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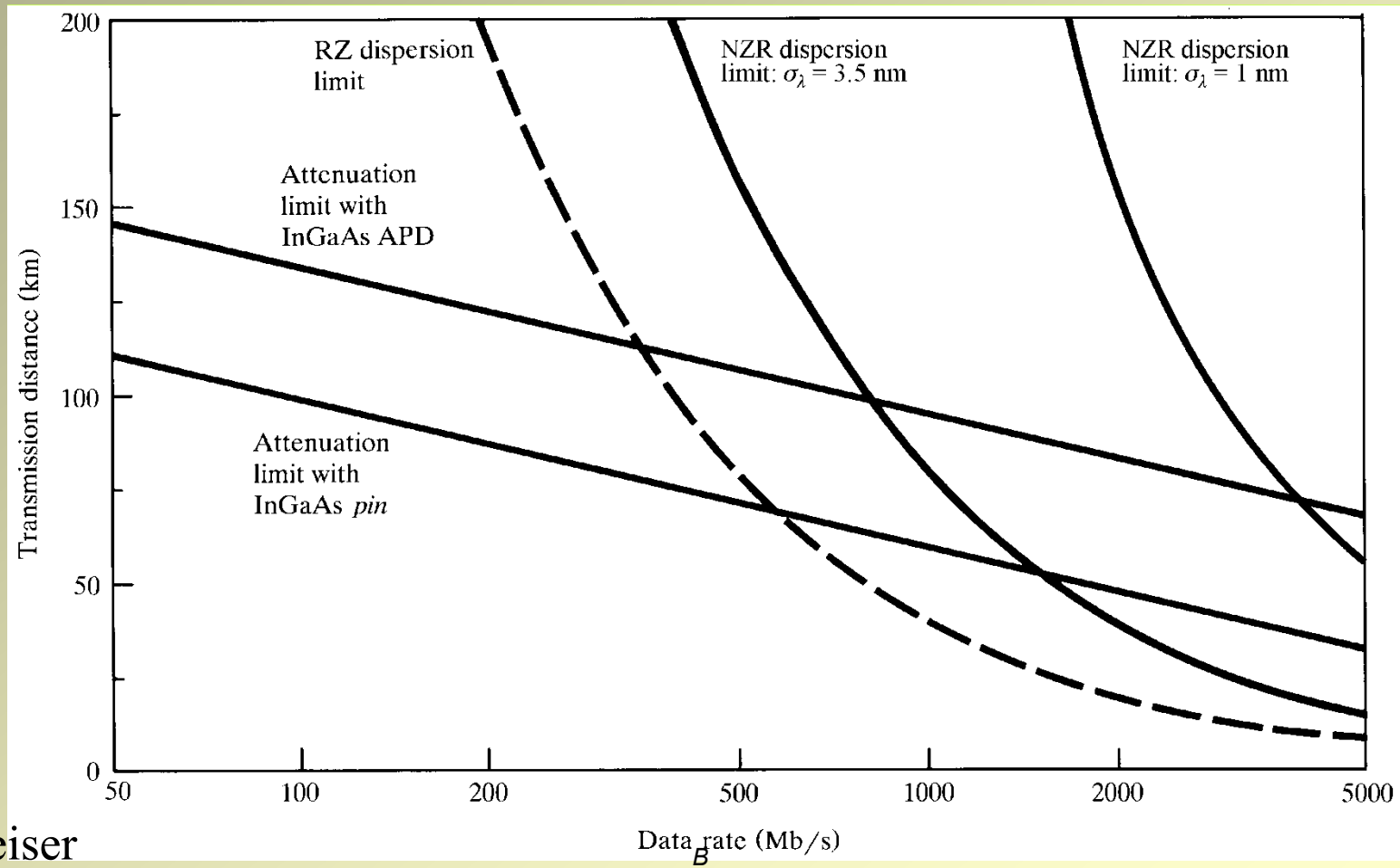
Transmission Distance -3rd window

D = 2.5 ps/(nm.km), fibre loss = 0.3 dB/km@ 1550nm, P_t = 0 dBm laser, P_o = 11.5 log B -71dBm forAPD, and = 11.5 log B- 60.5 dBm for *pin*



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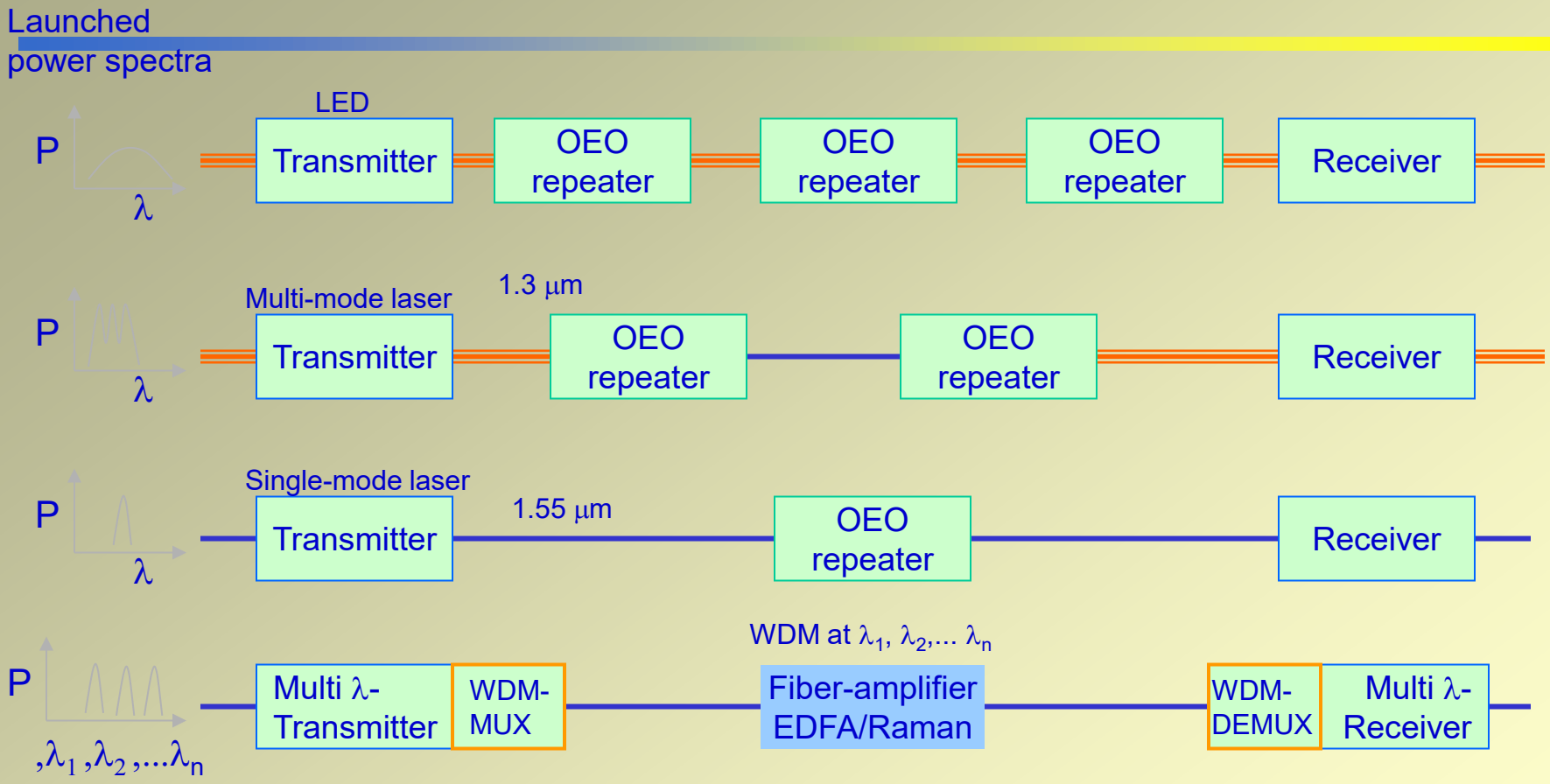
Analogue System

- The system must have sufficient bandwidth to pass the HIGEST FREQUENCIES.
- Link Power budget is the same as in digital systems
- Rise Time budget is also the same, except for the system bandwidth which is defined as:

$$B_{sys} = \frac{0.35}{t_{sys}}$$

Link Evolution



Cost Budget

Need to consider:

- Light source
  - Type
  - Wavelength
  - Drivers
- Modulator
- Fibre type
- Connectors type
- Photodetector Type
- Etc.

Final Comments

Covered link budget analysis for:

- Power
- Bandwidth (rise time)
- Cost