OPTICAL COMMUNICATION SYSTEMS

LECTURE # 06

Optical Link Design

Layout of Lecture # 06

- Introduction
- Power and Noise Budgets
- Rise-time Budget.

Introduction (1)

- Lectures 1-5 focused on the three main components of a fiber-optic communication system namely;
  1) ***Optical fibers***
  2) ***Optical transmitters***, and
  3) ***Optical receivers***.
- In this lecture we consider the issues related to **system design** when the three components are put together to form a practical fiber-optic communication system.

Introduction (2)

- Specifically, the following issues are discussed;
  1) ***The design guidelines for fiber-optic communication systems by considering the effects of fiber losses and group-velocity dispersion.***
  2) ***The power and the rise-time budgets.***

- The **power budget** is also called the **link budget**, and the **rise-time budget** is sometimes referred to as the **bandwidth budget**.

Design Guidelines (1)

- The design of fiber-optic communication systems requires a clear understanding of the limitations imposed by the ***loss, dispersion, and non-linearity of the fiber***.
- Since fiber properties are wavelength dependent, the choice of ***operating wavelength*** is a major design issue.
- The **bit rate** and the **transmission distance** of a single-channel system are limited by **fiber loss** and **dispersion**.

Loss-Limited Fiber-optic Systems (1)

- For long-haul fiber links, **fiber losses** play an important role in the system design.
- Consider an **optical transmitter** that is capable of ***launching*** an average power, $\acute{P}_{tr}$.
- If the signal is detected by a receiver that requires a ***minimum*** average power, $\acute{P}_{rec}$ at the **bit rate, B**, the maximum transmission distance is limited by;

$$\boxed{L = 10/\alpha_f \log_{10}(\acute{P}_{tr}/\ \acute{P}_{rec})}$$

- Where α_f is the **net loss** (in **dB/km**) of the fiber cable, including ***splice*** and ***connector losses***.

Dispersion-Limited Fiber-optic Systems (1)

- Fiber dispersion limits the ***bit rate-distance product, BL*** because of pulse broadening.
- When the ***dispersion-limited transmission distance is shorter than the loss-limited, the system is said to be dispersion-limited***.
- The mechanisms leading to dispersion limitation can be different for different operating wavelengths.
- A solution to the dispersion problem is offered by ***dispersion-shifted fibers*** for which dispersion and loss are minimum near 1.55μm.

Power Budget (1)

- The purpose of the ***power budget*** is to ensure that ***enough power will reach the receiver*** to maintain reliable performance during the entire system lifetime.
- The minimum average power required by the receiver is the **receiver sensitivity, $\acute{P}_{rec}$.**
- The average **launch power, $\acute{P}_{tr}$** is generally known for any transmitter.
- The power budget takes a simple form in decibels units with optical powers expressed in dBm units.

Power Budget (2)

- The power budget is expressed as follows:

$$\boxed{\acute{P}_{tr} = \acute{P}_{rec} + C_L + M_s}$$

- Where C_L is the ***total channel loss*** and M_s is the ***system margin***.
- The purpose of the system margin is to allocate a certain amount of power to additional sources of power penalty that may develop during system lifetime because of component degradation or other unforeseen events.
- A system margin of 4 – 6 dB is typically allocated during the design process.

Power Budget (3)

- The channel loss, C_L takes into account ***all possible sources of power loss***, including ***connector*** and ***splice losses.***
- If $\boldsymbol{\alpha_f}$ is the fiber loss in decibels per kilometer, C_L can be written as follows:

$$\boxed{C_L = \alpha_f L + \alpha_{con} + \alpha_{splice}}$$

- Where $\boldsymbol{\alpha_{con}}$ and $\boldsymbol{\alpha_{splice}}$ account for the **connector** and **splice** losses throughout the fiber.
- ***Sometimes splice loss is included within the specified loss of the fiber cable***.

Power Budget (4)

- The **connector loss, α_{con}** includes ***connectors at the transmitter*** and ***receiver ends*** but must include other connectors if used within the fiber link.
- The power budget can be used to estimate transmission distance for a given choice of the components.

Power Budget (5)

- Table 5.1 shows the power budget for the two transmitters by assuming that the splice loss is included within the cable loss.

Table 5.1 Power budget of a 0.85-μm lightwave system

Quantity	Symbol	Laser	LED
Transmitter power	$\bar{P}_{tr}$	0 dBm	−13 dBm
Receiver sensitivity	$\bar{P}_{rec}$	−42 dBm	−42 dBm
System margin	M_s	6 dB	6 dB
Available channel loss	C_L	36 dB	23 dB
Connector loss	α_{con}	2 dB	2 dB
Fiber cable loss	α_f	3.5 dB/km	3.5 dB/km
Maximum fiber length	L	9.7 km	6 km

Rise-Time Budget (1)

- The purpose of the ***rise-time budget*** is to ensure that the system is able to operate properly at the intended bit rate.
- Even if the ***bandwidth of the individual system components exceeds the bit rate***, it is still possible that the ***total system may not be able to operate at that bit rate***.
- The concept of rise time is used to allocate the bandwidth among various components.

Rise-Time Budget(2)

- The **rise time, T_r** of a linear system is defined as the time during which the response increases from 10 to 90% of its final output value when the input is changed abruptly.
- An inverse relationship exists between the **bandwidth, Δf** and the **rise time, T_r** associated with a linear system, as follows:

$$\boxed{T_r = 2.2/2\pi\Delta f = 0.35/\Delta f}$$

- This relationship is expected to hold for any linear system.
- However, the product **$T_r\Delta f$** would generally be different than 0.35.
- One can use **$T_r\Delta f$ = 0.35 in the design of optical communication systems as a conservative guideline.**

Rise-Time Budget(3)

- The relationship between the **bandwidth, Δf** and the **bit rate , B** depends on the **digital format (i.e. RZ and NRZ)**.
- In both these formats, the specified bit rate imposes an upper limit on the maximum rise time that can be tolerated.
- The communication system must be designed to ensure that the rise time, T_r is below this maximum value as follows:

Tr ≤ {0.35/B for RZ format,
0.70/B for NRZ format

Rise-Time Budget(3)

- The three components of fiber-optic communication systems (i.e. **transmitter, optical fiber**, and **receiver**) have individual rise times.
- The total rise time of the whole system is related to the individual component rise times approximately as follows:

$$\boxed{T_r^2 = T_{tr}^2 + T_{fiber}^2 + T_{rec}^2}$$

- Where T_{tr}, T_{fiber}, and T_{rec} are rise times associated with the transmitter, fiber, and receiver, respectively.

Rise-Time Budget(3)

- The rise times of the transmitter and the receiver are generally known to the system designer.
- The **fiber rise time, T_{fiber}** should in general include the contributions of both the ***intermodal dispersion*** and ***group-velocity dispersion (GVD)*** through the relation:

$$\boxed{T_{fiber}^2 = T_{modal}^2 + T_{GVD}^2}$$

- For single-mode fibers, $T_{modal} = 0$ and $T_{fiber} = T_{GVD}$

Rise-Time Budget(3)

Question

An engineer has the following components available: GaAlAs laser diode operating at 850nm and capable of coupling 1mW into a fiber, 10 sections of cable each of which is 500m long, has a 4-dB/km attenuation, and has connectors on both ends, connector loss of 2dB/connector, a p-i-n photodiode receiver and 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 p-i-n and APD receivers are -45dBm and -56dBm, respectively, which receiver should be used if a 6-dB system operating margin is required?