LECTURE-5

Link Power Budget:

- For optimum link power budget an optical power loss model is to be studied as shown in Fig. 6.2.3. Let $l_c$ denotes the losses occur at connector.
  $L_{sp}$ denotes the losses occur at splices.
  $\alpha_f$ denotes the losses occur in fiber.

  ![Fig. 6.2.3 Optical power loss model]

- All the losses from source to detector comprise the total loss ($P_T$) in the system.
- Link power margin considers the losses due to component aging and temperature fluctuations. Usually a link margin of 6-8 dB is considered while estimating link power budget.
- Total optical loss = Connector loss + (Splicing loss + Fiber attenuation) + System margin ($P_m$)

  \[ P_T = 2l_c + \alpha_f L + \text{System margin} (P_m) \]

Where, $L$ is transmission distance.

Example 6.2.1: Design as optical fiber link for transmitting 15 Mb/sec of data for a distance of 4 km with BER of $10^{-9}$.

**Solution:**

Bandwidth x Length = 15 Mb/sec x 4 km = (60 Mb/sec) km

**Selecting optical source:** LED at 820 nm is suitable for short distances. The LED generates – 10 dBm optical power.

**Selecting optical detector:** PIN-FER optical detector is reliable and has – 50 dBm sensitivity.

**Selection optical fiber:** Step-index multimode fiber is selected. The fiber has bandwidth length product of 100 (Mb/s) km.
Links power budget:

Assuming:

Splicing loss $l_s = 0.5$ dB/slice

Connector loss $l_c = 1.5$ dB

System link power margin $P_m = 8$ dB

Fiber attenuation $\alpha_f = 6$ dB/km

Actual total loss = $(2 \times l_c) + \alpha_f L + P_m$

$$P_T = (2 \times 1.5) + (6 \times 4) + 8$$

$$P_T = 35 \text{ dB}$$

Maximum allowable system loss:

$$P_{\text{max}} = \text{Optical source output power - optical receiver sensitivity}$$

$$P_{\text{max}} = -10 \text{ dBm} - (-50 \text{ dBm})$$

$$P_{\text{max}} = 40 \text{ dBm}$$

Since actual losses in the system are less than the allowable loss, hence the system is functional.

Example 6.2.2: A transmitter has an output power of 0.1 mW. It is used with a fiber having $\text{NA} = 0.25$, attenuation of 6 dB/km and length 0.5 km. The link contains two connectors of 2 dB average loss. The receiver has a minimum acceptable power (sensitivity) of $-35$ dBm. The designer has allowed a 4 dB margin. Calculate the link power budget.

Solution:

Source power $P_s = 0.1$ mW

$$P_s = -10 \text{dBm}$$

Since $\text{NA} = 0.25$

$\therefore \text{ Coupling loss } = -10\log (\text{NA}^2)$
\[-10\log (0.25^2)\]
\[= 12 \text{ dB}\]

Fiber loss = \(\alpha_f \times L\)
\[l_f = (6\text{dB/km}) \times (0.5\text{km})\]
\[l_f = 3 \text{ dB}\]

Connector loss = 2 (2 dB)
\[l_c = 4 \text{ dB}\]

Design margin \(P_m = 4 \text{ dB}\)

\[\therefore \text{ Actual output power } P_{out} = \text{ Source power} - (\Sigma \text{ Losses})\]
\[P_{out} = 10\text{dBm} - [12 \text{ dB} + 3 + 4 + 4]\]
\[P_{out} = -33 \text{ dBm}\]

Since receiver sensitivity given is – 35 dBm.

i.e. \(P_{\min} = -35 \text{ dBm}\)

As \(P_{out} > P_{\min}\), the system will perform adequately over the system operating life.

Example 6.2.3: In a fiber link the laser diode output power is 5 dBm, source-fiber coupling loss = 3 dB, connector loss of 2 dB and has 50 splices of 0.1 dB loss. Fiber attenuation loss for 100 km is 25 dB, compute the loss margin for i) APD receiver with sensitivity – 40 dBm ii) Hybrid PINFET high impedance receiver with sensitivity -32 dBm.

**Solution: Power budget calculations**

Source output power
5 dBm

Source fiber coupling loss
3 dB

Connector loss
2 dB

Connector loss
5 dB

Fiber attenuation
25 dB

Total loss
35 dB

Available power to receiver : (5 dBm – 35 dBm) – 30 dBm
i) APD receiver sensitivity – 40 dBm
   Loss margin [- 40 – (-30)] 10 dBm
ii) H-PIN FET high0impedance receiver -32 dBm
   Loss margin [-32 – (-30)] 2 dBm

\[
t_{\text{sys}} = \sqrt{t_{\text{tx}}^2 + t_{\text{GVD}}^2 + t_{\text{mod}}^2 + \ldots}
\]

\[
t_{\text{sys}} = \left( \sum_{i=1}^{N} t_{ri}^2 \right)^{1/2}
\]

**Rise Time Budget:**

- Rise time gives important information for initial system design. Rise-time budget analysis determines the dispersion limitation of an optical fiber link.
- Total rise time of a fiber link is the root-sum-square of rise time of each contributor to the pulse rise time degradation.
- The link components must be switched fast enough and the fiber dispersion must be low enough to meet the bandwidth requirements of the application. Adequate bandwidth for a system can be assured by developing a rise time budget.
- As the light sources and detectors have a finite response time to inputs. The device does not turn-on or turn-off instantaneously. Rise time and fall time determine the overall response time and hence the resulting bandwidth.
- Connectors, couplers and splices do not affect system speed; they need not be accounted in rise time budget but they appear in the link power budget. Four basic elements that contribute to the rise-time are,
  - Transmitter rise-time (ttx)
  - Group Velocity Dispersion (GVD) rise time (tGVD)
  - Modal dispersion rise time of fiber (tmod)
  - Receiver rise time (trx)

\[
t_{\text{sys}} = \left[ t_{\text{tx}}^2 + t_{\text{mod}}^2 + t_{\text{GVD}}^2 + t_{\text{rx}}^2 \right]^{1/2}
\]

\[
\ldots \text{ (6.2.1)}
\]

- Rise time due to modal dispersion is given as

\[
t_{\text{mod}} = \frac{440}{B_M} = \frac{440 L_Q}{B_0}
\]

\[
\ldots \text{ (6.2.2)}
\]

where,
B_M is bandwidth (MHz)
L is length of fiber (km)
q is a parameter ranging between 0.5 and 1. B_0 is bandwidth of 1 km length fiber,

- Rise time due to group velocity dispersion is
  \[ t_{\text{GVD}} = D^2 \sigma^2 \lambda L^2 \]  \hspace{1cm} \text{(6.2.3)}

where,

D is dispersion [ns/(nm.km)]
Σ_λ is half-power spectral width of
source L is length of fiber

- Receiver front end rise-time in nanoseconds is
  \[ t_{\text{rx}} = \frac{350}{B_{\text{rx}}} \]  \hspace{1cm} \text{(6.2.4)}

where,

B_{\text{rx}} is 3 dB – bW of receiver (MHz).

- Equation (6.2.1) can be written as
  \[ t_{\text{sys}} = \left( t_{\text{tx}}^2 + t_{\text{mod}}^2 + t_{\text{GVD}}^2 + t_{\text{rx}}^2 \right)^{1/2} \]
  \[ t_{\text{sys}} = \left[ t_{\text{tx}}^2 + \left( \frac{440 L d}{B_0} \right)^2 + D^2 \sigma^2 \lambda L^2 + \left( \frac{350}{B_{\text{rx}}} \right) \right]^{1/2} \]  \hspace{1cm} \text{(6.2.5)}

All times are in nanoseconds.

- The system bandwidth is given by
  \[ BW = \frac{0.35}{t_{\text{sys}}} \]  \hspace{1cm} \text{(6.2.6)}
**Example 6.2.4:** For a multimode fiber following parameters are recorded.

i) LED with drive circuit has rise time of 15 ns.
ii) LED spectral width = 40 nm
iii) Material dispersion related rise time degradation = 21 ns over 6 km link.
iv) Receiver bandwidth = 235 MHz
v) Modal dispersion rise time = 3.9 nsec

Calculate system rise time.

**Solution:**

\[ t_{\text{tx}} = 15 \text{ nsec} \]
\[ t_{\text{Tmat}} = 21 \text{ nsec} \]
\[ t_{\text{mod}} = 3.9 \text{ nsec} \]

\[ t_{\text{rx}} = \frac{350}{B_{\text{rx}}} \]

\[ t_{\text{rx}} = \frac{350}{25} \]

\[ \therefore t_{\text{rx}} = 14 \text{ nsec} \]

\[ \therefore t_{\text{rx}} = 14 \text{ nsec} \]

Since

\[ t_{\text{sys}} = \left( \sum_{i=1}^{N} t_{ri}^2 \right)^{1/2} \]

\[ t_{\text{sys}} = [15^2 + 21^2 + 3.9^2 + 14^2]^{1/2} \]

\[ t_{\text{sys}} = 29.61 \text{ nsec} \]

**Example 6.2.5:** A fiber link has following data

<table>
<thead>
<tr>
<th>Component</th>
<th>BW</th>
<th>Rise time (tr)</th>
</tr>
</thead>
</table>
Compute the system rise time and bandwidth.

Solution: System rise time is given by

\[ t_{sys} = \left( \sum_{i=1}^{N} t_{ri}^2 \right)^{1/2} \]

\[ ct_{sys} = \sqrt{(1.75^2 + 3.5^2 + 3.89^2 + 1.00^2 + 1.94^2)} \]

\[ t_{sys} = 5.93 \text{ nsec} \]

System BW is given by

\[ BW = \frac{0.35}{t_{sys}} \]

\[ BW = \frac{0.35}{5.93 \text{ nsec}} \]

\[ BW = 59 \text{ MHz} \]

Line coding in optical links:

- Line coding or channel coding is a process of arranging the signal symbols in a specific pattern. Line coding introduces redundancy into the data stream for minimizing errors.
- In optical fiber communication, three types of line codes are used:
  - Non-return-to-zero (NRZ)
  - Return-to-zero (RZ)
  - Phase-encoded (PE)
Desirable Properties of Line Codes

The line code should contain timing information.
The line code must be immune to channel noise and interference.
The line code should allow error detection and correction.

NRZ Codes

- Different types of NRZ codes are introduced to suit the variety of transmission requirements. The simplest form of NRZ code is NRZ-level. It is a unpolar code i.e. the waveform is simple on-off type.
- When symbol ‘1’ is to be transmitted, the signal occupies high level for full bit period. When a symbol ‘0’ is to be transmitted, the signal has zero volts for full bit period. Fig. 6.2.4 shows example of NRZ-L data pattern.

Features of NRZ codes

- Simple to generate and decode.
- No timing (self-clocking) information.
- No error monitoring or correcting capabilities.
- NRZ coding needs minimum BW.

RZ Codes

In unipolar RZ data pattern a 1-bit is represented by a half-period in either first or second half of the bit-period. A 0 bit is represented by zero volts during the bit period. Fig. 6.2.5 shows RZ data pattern.

Features of RZ codes
The signal transition during high-bit period provides the timing information. Long strings of 0 bits can cause loss of timing synchronization.

**Error Correction**

The data transmission reliability of a communication system can be improved by incorporating any of the two schemes Automatic Repeat Request (ARQ) and Forward Error Correction (FEC).

In ARQ scheme, the information word is coded with adequate redundant bits so as to enable detection of errors at the receiving end. If an error is detected, the receiver asks the sender to retransmit the particular information word.

Each retransmission adds one round trip time of latency. Therefore ARQ techniques are not used where low latency is desirable. Fig. 6.2.6 shows the scheme of ARQ error correction scheme.

![Fig. 6.2.6 ARQ scheme](image)

Forward Error Correction (FEC) system adds redundant information with the original information to be transmitted. The error or lost data is used reconstructed by using redundant bit. Since the redundant bits to be added are small hence much additional BW is not required.

Most common error correcting codes are cyclic codes. Whenever highest level of data integrity and confidentiality is needed FEC is considered.

**Sources of Power Penalty**

Optical receiver sensitivity is affected due to several factors combine: e.g. fiber dispersion, SNR. Few major causes that degrade receiver sensitivity are – modal noise, dispersive pulse broadening, mode partition noise, frequency chirping, reflection feedback noise.