Unit-5

Lecture -4

Power Penalties,

Power Penalties

- When any signal impairments are present, a lower optical power level arrives at the receiver compared to the ideal reception case.
- This lower power results in a reduced SNR, which leads to a higher BER.
- The ratio of the reduced received signal power to the ideal received power is the *power penalty* for that effect and is expressed in decibels.
- If P_{ideal} and P_{impair} are the received optical powers for the ideal and impaired cases, respectively, then the power penalty PP_x in decibels for impairment x is

$$PP_x = -10 \log \frac{P_{\mathrm{impair}}}{P_{\mathrm{ideal}}}$$

- In some cases, increasing the received optical power can reduce the power penalty. For other cases (some nonlinear effects) increasing the received power level will have no effect on the power penalty.
- Power penalties may be due to chromatic and polarization-mode dispersions, modal (speckle) noise, mode-partition noise, the extinction ratio, chirp, timing jitter, reflection noise, and nonlinear effects arising from high optical power level in a fiber link.

Chromatic Dispersion Penalty

- Chromatic dispersion arises since each wavelength has a slightly different velocity, and thus they arrive at different times at the fiber end.
- Therefore, the range of arrival times at the fiber end of the spectrum of wavelengths will lead to pulse spreading.
- The accumulated chromatic dispersion increases with distance.
- A basic estimate of what limitation chromatic dispersion imposes on link performance can be made by specifying that the accumulated dispersion should be less than a fraction ε of the bit period $T_b = 1/B$, where B is the bit rate:

$$|D_{CD}|\, L\, B\, \sigma_\lambda < \varepsilon$$

The *ITU-T Rec. G.957 for SDH* and the *Telcordia Generic Requirement GR-253* for SONET:

- For a 1-dB power penalty the accumulated dispersion should be less than 0.306 of a bit period ($\varepsilon \leq 0.306$).
- For a 2-dB power penalty the requirement is $\varepsilon \leq 0.491$.

Polarization-Mode Dispersion Penalty

- *Polarization-mode dispersion* (PMD) arises since light-signal energy at a given wavelength in a single-mode fiber occupies two orthogonal polarization states or modes.
- PMD arises because the two fundamental orthogonal polarization modes travel at slightly different speeds owing to fiber birefringence.
- This PMD effect cannot be mitigated easily and can be for links operating at 10 Gb/s and higher.
- To have a power penalty < 1.0 dB, pulse spreading from PMD must on the average be less than 10% of a bit period T_b:

$$\Delta\tau_{\mathrm{PMD}} = D_{\mathrm{PMD}}\sqrt{L} < 0.1\,T_b$$

Extinction Ratio Power Penalty

- The extinction ratio r_e in a laser is the ratio of the optical power level P_1 for a logic 1 to the power level P_0 for a logic 0, that is, $r_e = P_1 / P_0$.
- Letting $P_{1\text{-}ER}$ and $P_{0\text{-}ER}$ be the 1 and 0 power levels, respectively, with a nonzero extinction ratio, the average power is

$$P_{\text{ave}} = \frac{P_{1-ER} + P_{0-ER}}{2} = P_{0-ER}\frac{r_e + 1}{2} = P_{1-ER}\frac{r_e + 1}{2r_e}$$

- When receiver thermal noise dominates, the 1 and 0 noise powers are equal and independent of the signal level. In this case, letting P0 = 0 and P1 = 2Pave, the extinction ratio power penalty becomes

$$PP_{ER} = -10\log\frac{P_{1-ER} - P_{0-ER}}{P_1} = -10\log\frac{r_e - 1}{r_e + 1}$$

- Optical transmitters usually have minimum r_e of 7 to 10 (8.5 to 10 dB).
- The power penalties range from 1.25 to 0.87 dB.
- A minimum $r_e = 18$ is needed for an ER power penalty < 0.5 dB.

Chirping Power Penalty

- A single-mode laser may experience dynamic line broadening when the injection current is directly modulated.
- This line broadening is a frequency "chirp" associated with modulation-induced changes in the carrier density.
- Chirping can produce significant dispersion when the laser wavelength is displaced from the zero-dispersion wavelength of the fiber.
- When the effect of laser chirp is small, the eye closure Δ can be approximated by

$$\Delta = \left(\frac{4}{3}\pi^2 - 8\right) t_{\text{chirp}} D L B^2 \delta\lambda \left[1 + \frac{2}{3}\left(D L \delta\lambda - t_{\text{chirp}}\right)\right]$$

- The power penalty for an APD can be estimated from the SNR degradation (in dB) due to the signal amplitude decrease as

$$PP_{\text{chirp}} = -10 \frac{x+2}{x+1} \log\left(1 - \Delta\right)$$

ER and Chirping Power Penalties

Extinction-ratio, chirping, and total-system power penalties at 1550 nm for a 4-Gb/s 100-km single-mode G.652 link having a dispersion D = 17 ps/(nm-km) and a DFB laser with an active layer width of 1.75 mm. (From Corvini and Koch, Ref. 53.)