EE 440 Photonic Systems & Technologies 2025

Graded 4 SOLUTIONS

Graded Exercise

You have an RZ-transmitter at a wavelength of 1550 nm operating at 10 Gbit/s and a 40 km standard SMF with a loss of 0.2 dB/km and a dispersion coefficient of 16 ps/(nm km). The receiver consists of a p-i-n photodiode with a quantum efficiency of 0.7 and a negligible dark current, as well as an electrical amplifier with a load resistance of 50 Ω, noise figure of 3 dB and a bandwidth of 8 GHz.

Due to GVD, the pulses have broadened into neighboring bit slot after transmission. By looking at the eye-diagram with an oscilloscope at the output, the average optical power in 1-bits and 0-bits is measured to be -8 dBm and -13.5 dBm, respectively (i.e. the extinction ratio is degraded). Assume that 1-bits and 0-bits are equally likely.

(a) Make assumption on the noise limiting regime (thermal or shot). Based on this assumption, determine the sensitivity of the receiver (defined at BER = 10^{-9}) with the dispersion-degraded extinction ratio as above.

We start by assuming thermal noise limit since this is the general case at the end of a link.

In this limiting regime, the receiver sensitivity is given by

$$P_{rec} = \frac{Q\sigma_T}{R}\left(\frac{1 + r_{ex}}{1 - r_{ex}}\right)$$

The receiver responsivity is $R = \frac{\eta q \lambda}{hc} = \frac{0.7\times1.6\times10^{-19}\times1550\times10^{-9}}{6.626\times10^{-34}\times3\times10^{8}} = 0.875$

The Q corresponding to BER = 10^{-9} is 6

The extinction ration is $r_{ex} = P_0 - P_1 = -5.5\ dB = 0.2818$

The thermal noise is

$$\sigma_T = \sqrt{\frac{4kT\Delta f}{R_L}F_n} = \sqrt{\frac{4(1.38\cdot10^{-23})300(8\cdot10^{9})}{50}2} = 2.302\cdot10^{-6}\ A$$

Therefore the receiver sensitivity is:

$$P_{rec} = \frac{6(2.302\cdot10^{-6})}{0.875}\left(\frac{1+0.2818}{1-0.2818}\right) = 2.8148\cdot10^{-5}\text{W=-15.5055 dBm}$$

(b) Verify that your assumption is correct.

We calculate the shot noise contribution:

$$\sigma_S = \sqrt{2qRP_{rec}\Delta f} = 2.511\cdot10^{-7}\ A$$

An order of magnitude lower than thermal noise. Assumption is correct.

(c) What is the actual average power received? By how much (in dB) should you change the average transmitter power (up or down) from its current setting to operate the system at a BER of 10^{-9}?

The actual average power received is

$$P_{rec} = \frac{P_1 + P_0}{2} = 10log\left(\frac{10^{-0.8} + 10^{-1.35}}{2}\right) = -9.932\ dBm$$

We have some margin since we only need to reach the detector with -15.5055 dBm. It means that we could lower the average transmitter power by 5.5735 dBm and still reach the correct BER.

(d) To avoid the problem of broadening due to GVD you are considering adding some DCF to the system. The DCF module compensates the dispersion perfectly, but has a loss of 3.5 dB. Find the power penalty due to the GVD, i.e. find how much the sensitivity has degraded compared to the case without GVD. Is adding the DCF a good idea?

The effect of GVD is the extinction ratio.
Without DCF, the power penalty with $r_{ex} = 0.2818$ is given by:

$$\left(\frac{1 + r_{ex}}{1 - r_{ex}}\right) = 1.786 = 2.52\ dB$$

Because the DCF has a loss that is higher than the gain from compensating the GVD, it would not help.