EECE 598, Homework 02

Try to solve the problems by yourselves. Compare with your solutions after you are done.
Exams will be similar formats as these.

1. **Problem 3-2.**
2. **Problem 3-3.**
3. **Problem 3-4.**
4. **Problem 3-13.**
5. **Problem 3-17.**
6. **Problem 3-18.**

No submission is required. The solutions to select problems will be uploaded a week later.

PROBLEMS

3.1 Verify the expression given in Eq. (3.1*c*) that relates α, which is in units of dB/km, to α_p, which is in units of km^{-1}.

3.2 A certain optical fiber has an attenuation of 0.6 dB/km at 1310 nm and 0.3 dB/km at 1550 nm. Suppose the following two optical signals are launched simultaneously into the fiber: an optical power of 150 μW at 1310 nm and an optical power of 100 μW at 1550 nm. What are the power levels in μW of these two signals at (*a*) 8 km and (*b*) 20 km?

3.3 An optical signal at a specific wavelength has lost 55 percent of its power after traversing 7.0 km of fiber. What is the attenuation in dB/km of this fiber?

3.4 A continuous 40-km-long optical fiber link has a loss of 0.4 dB/km.

(*a*) What is the minimum optical power level that must be launched into the fiber to maintain an optical power level of 2.0 μW at the receiving end?

(*b*) What is the required input power if the fiber has a loss of 0.6 dB/km?

3.5 Consider a step-index fiber with a SiO_2–GeO_2

radii less than 10 cm at $\lambda = 1$ μm for fibers having core radii of 4, 25, and 100 μm.

3.9 Two common fiber jacket materials are Elvax® 265 (E_j = 21 MPa) and Hytrel® 4056 (E_j = 58 MPa), both made by DuPont. If the Young's modulus of a glass fiber is 64 GPa, plot the reduction in microbending loss as a function of the index difference Δ when fibers are coated with these materials. Make these plots for Δ values ranging from 0.1 to 1.0 percent and for a fiber cladding-to-core ratio of $b/a = 2$.

3.10 Assume that a step-index fiber has a V number of 6.0.

(*a*) Using Fig. 2.27, estimate the fractional power P_{clad}/P traveling in the cladding for the six lowest-order LP modes.

(*b*) If the fiber in (*a*) is a glass-core glass-clad fiber having core and cladding attenuations of 3.0 and 4.0 dB/km, respectively, find the attenuations for each of the six lowest-order modes.

3.11 Assume a given mode in a graded-index fiber has a power density $p(r) = P_0 \exp(-Kr^2)$, where the factor K depends on the modal where $E = hc/\lambda$ is the photon energy and E_0 and E_d are, respectively, material oscillator energy and dispersion energy parameters. In SiO_2 glass, E_0 = 13.4 eV and E_d = 14.7 eV. Show that, for wavelengths between 0.20 and 1.0 μm, the values of n found from the Sellmeier relation are in good agreement with those shown in Fig. 3.12. To make the comparison, select three representative points, for example, at 0.2, 0.6, and 1.0 μm.

3.13 (*a*) An LED operating at 850 nm has a spectral width of 45 nm. What is the pulse spreading in ns/km due to material dispersion? What is the pulse spreading when a laser diode having a 2-nm spectral width is used?

(*b*) Find the material-dispersion-induced pulse spreading at 1550 nm for an LED with a 75-nm spectral width. Use Fig. 3.13 to estimate $d\tau/d\lambda$.

3.14 Verify the plots for b, $d(Vb)/dV$, and $V\,d^2(Vb)/dV^2$ shown in Fig. 3.15. Use the expression for b given by Eq. (3.38).

3.15 Derive Eq. (3.13) by using a ray-tracing method.

3.16 Consider a step-index fiber with core and cladding diameters of 62.5 and 125 μm, respectively. Let the core index n_1 = 1.48 and let the index difference Δ = 1.5 percent. Compare the modal dispersion in units of ns/km at 1310 nm of this fiber as given by Eq. (3.13) with the more exact expression

$$\frac{\sigma_{\mathrm{mod}}}{L} = \frac{n_1 - n_2}{c}\left(1 - \frac{\pi}{V}\right)$$

where L is the length of the fiber and n_2 is the cladding index.

3.17 Consider a standard G.652 non-dispersion-shifted single-mode optical fiber that has a zero-dispersion wavelength at 1310 nm with a dispersion slope of $S_0 = 0.0970$ ps/(nm$^2 \cdot$ km). Plot the dispersion in the wavelength range 1270 nm $\le \lambda \le$ 1340 nm. Use Eq. (3.47).

3.18 A typical G.653 dispersion-shifted single-mode optical fiber has a zero-dispersion wavelength at 1550 nm with a dispersion slope of $S_0 = 0.070$ ps/(nm$^2 \cdot$ km).

(*a*) Plot the dispersion in the wavelength range 1500 nm $\le \lambda \le$ 1600 nm using Eq. 3.49.

(*b*) Compare the dispersion at 1500 nm with the dispersion value for the non-dispersion-shifted fiber described in Prob. 3.17.

3.19 Starting with Eq. (3.45), derive the dispersion expression given in Eq. (3.47).

3.20 Renner[19] derived a simplified approximation to describe the bend losses of single-mode optical fibers. This expression for the bending loss is

$$\alpha_{\mathrm{simp}} = \alpha_{\mathrm{conv}} \frac{2(Z_3 Z_2)^{1/2}}{(Z_3 + Z_2) - (Z_3 - Z_2)\cos(2\Theta)}$$

where the conventional bending loss is

$$\alpha_{\mathrm{conv}} = \frac{1}{2}\left(\frac{\pi}{\gamma^3 R}\right)^{1/2} \frac{\kappa^2}{V^2 K_1^2(\gamma a)} \exp\left(-\frac{2\gamma^3 R}{3\beta_0^3}\right)$$

where V is given by Eq. (2.57), β_0 is the propagation constant in a straight fiber with an infinite cladding given by Eq. (2.46), K_1 is the modified Bessel function (see App. C), and

$$Z_q \approx k^2 n_q^2 (1 + 2b/R) - \beta_0^2$$

$$\approx k^2 n_q^2 (1 + 2b/R) - k^2 n_2^2 \qquad \text{for } q = 2, 3$$

$$\Theta = \frac{\gamma^3 R}{3k^2 n_2^2}\left(\frac{R_c}{R} - 1\right)^{3/2}$$

$$\gamma = \left(\beta_0^2 - k^2 n_2^2\right)^{1/2} \approx k\left(n_1^2 - n_2^2\right)^{1/2}$$

$$\kappa^2 = k^2 n_1^2 - \beta_0^2 \approx k^2 (n_1^2 - n_2^2)$$

$$R_c = 2k^2 n_2^2\, b/\gamma^2 = \text{the critical bend radius}$$

Using a computer, (*a*) verify the plot given in Fig. 3.27 at 1300 nm, and (*b*) calculate and plot the bend loss as a function of wavelength for 800 nm $\le \lambda \le$ 1600 nm at several different bend radii (e.g., 15 and 20 mm). Let n_1 = 1.480, n_2 = 1.475, n_3 = $1.07 n_2$ = 1.578, and b = 60 μm.