



Course Name: Optoelectronics
Course Code: ECE491
Spring Semester Midterm Exam.
BME Program
Level 300



Exam Date: 4-4-2018
Allowed Time: 60 Minutes = one hour

Attempt all questions. Assume any missed data. Full mark is 15.

- a) A multimode step index fiber gives a total pulse broadening of 95 ns over a 5 km length. Estimate the bandwidth-length product for the fiber when a nonreturn to zero digital code is used. [2 Marks]
- b) A single-mode step index fiber has a bandwidth-length product of 10 GHz km. Estimate the rms pulse broadening over a 40 km digital optical link without repeaters consisting of the fiber, and using a return to zero code. [2 Marks]
- c) A K_2O-SiO_2 glass core optical fiber has an attenuation resulting from Rayleigh scattering of 0.46 dB km^{-1} at a wavelength of $1 \mu\text{m}$. The glass has an estimated fictive temperature of 758 K, isothermal compressibility of $8.4 \times 10^{-11} \text{ m}^2 \text{ N}^{-1}$, and a photoelastic coefficient of 0.245. Determine from theoretical considerations the refractive index of the glass. If Boltzmann's constant is $1.381 \times 10^{-23} \text{ J/K}$ [2 Marks]
- d) Design a single-mode step index fiber with a core refractive index of 1.49 and a critical bending radius of 10.4 mm when illuminated with light wavelength of $1.30 \mu\text{m}$. If the cutoff wavelength for the fiber is $1.15 \mu\text{m}$ calculate its relative refractive index difference. [3 Marks]
- e) Define optical fiber dispersion and drive an expression for the total root mean square pulse broadening in optical fiber? [3 Marks]
- f) How to reduce various types of losses in optical fiber? [3 Marks]

Hints: solve using the following formulas

| | |
|--|---|
| The Rayleigh scattering coefficient: $\gamma_R = \frac{8\pi^3}{3\lambda^4} n^8 p^2 \beta_c K T_F$ | Critical radius of curvature R_c in MMF $R_c \cong \frac{3n_1^2 \lambda}{4\pi(n_1^2 - n_2^2)^{3/2}}$ |
| Relative refractive index difference $\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$ | Critical radius of curvature R_{cs} in SMF $R_{cs} \cong \frac{20\lambda}{(n_1 - n_2)^{3/2}} (2.748 - 0.996 \frac{\lambda}{\lambda_c})^{-3}$ |

My best wishes to all of you!

Dr. Bedir Yousif

Model Answer

a- A multimode step index fiber gives a total pulse broadening of 95 ns over a 5 km length. Estimate the bandwidth-length product for the fiber when a nonreturn to zero digital code is used

Ans.

i- Bit rate on the link

$$B_T(\max) = \frac{1}{2\tau} = \frac{1}{2 \times 95 \times 10^{-9}} = 5.26 \text{ Mbps}$$

For NRZ, the bandwidth (B)

$$B = \frac{BT(\max)}{2} = \frac{5.26 \text{ Mbps}}{2} = 2.63 \text{ MHz}$$

bandwidth-length product = $B \cdot L = 2.63 \text{ MHz} \times 5 \text{ km} = 13.15 \text{ MHz km}$

b) A single-mode step index fiber has a bandwidth-length product of 10 GHz km. Estimate the rms pulse broadening over a 40 km digital optical link without repeaters consisting of the fiber, and using a return to zero code.

bandwidth-length product of 10 GHz km.

Ans.

$$B = \frac{B \cdot L}{L} = \frac{10 \text{ GHz km}}{40 \text{ km}} = 250 \text{ MHz}$$

For RZ, the bandwidth (B) = $BT(\max) = 250 \text{ Mbps}$

$$\sigma = \frac{0.2}{BT(\max)} = \frac{0.2}{250 \text{ Mbps}} = 0.8 \text{ nS} = 800 \text{ pS}$$

c) A $\text{K}_2\text{O-SiO}_2$ glass core optical fiber has an attenuation resulting from Rayleigh scattering of 0.46 dB km^{-1} at a wavelength of $1 \mu\text{m}$. The glass has an estimated fictive temperature of 758 K, isothermal compressibility of $8.4 \times 10^{-11} \text{ m}^2 \text{ N}^{-1}$, and a photoelastic coefficient of 0.245. Determine from theoretical considerations the refractive index of the glass. If Boltzmann's constant is $1.381 \times 10^{-23} \text{ J/K}$

Ans.

The Rayleigh scattering coefficient:

$$0.046 = 10 \log_{10} (1/l_{\text{km}})$$

$$l_{\text{km}} = 0.8995$$

$$\text{Ln}(0.8995) = -\gamma_R \times 10^3$$

$$\gamma_R = 0.106 \times 10^{-3} \text{ m}^{-1}$$

$$\gamma_R = \frac{8\pi^3}{3\lambda^4} n^8 p^2 \beta_c K T_F = 0.106 \times 10^{-3} \text{ m}^{-1}$$

$$n^8 = \frac{0.106 \times 10^{-3} \text{ m}^{-1} \times 3\lambda^4}{8\pi^3 p^2 \beta_c K T_F} = \frac{0.106 \times 10^{-3} \text{ m}^{-1} \times 3 \times 10^{-24}}{8\pi^3 \times 0.245^2 \times 8.4 \times 10^{-11} \times 1.38 \times 10^{-23} \times 758}$$

$$n = 1.49$$

d) Design a single-mode step index fiber with a core refractive index of 1.49 and a critical bending radius of 10.4 mm when illuminated with light wavelength of 1.30 μm . If the cutoff wavelength for the fiber is 1.15 μm calculate its relative refractive index difference.

Ans.

$$n_1=1.49, R_{CS}=10.4 \text{ mm} = R_{CS} \cong \frac{20\lambda}{(n_1-n_2)^{3/2}} (2.748 - 0.996 \frac{\lambda}{\lambda_c})^{-3}$$

$$\lambda = 1.3 \mu\text{m} \text{ and } \lambda_c = 1.15 \mu\text{m}$$

$$n_1-n_2 = 0.007 \quad \text{then } n_2 = 1.49-0.007 = 1.483$$

$$\text{then NA} = \sqrt{n_1^2 - n_2^2} = 0.1443$$

$$\Delta = 0.5 \left(\frac{\text{NA}}{n_1} \right)^2 = 0.0047$$

e) Define optical fiber dispersion and drive an expression for the total root mean square pulse broadening in optical fiber?

ans.

Dispersion is a data or pulse distortion due to the interference between the adjacent symbols, where the symbols are broadening as they travels a long distance and the delay time difference between the modes, where each mode has a different velocity inside the channel.

$$\sigma_T = (\sigma_c^2 + \sigma_n^2)^{1/2}$$

waveguide dispersion is generally negligible compared with material dispersion in multimode fibers, then $\sigma_c \cong \sigma_m$ and $\sigma_m = \sigma_\lambda L M$

$$\tau_g = \frac{d\beta}{d\omega} = \frac{1}{c} \left(n_1 - \lambda \frac{dn_1}{d\lambda} \right)$$

$$\tau_m = L\tau_g = \frac{L}{c} \left(n_1 - \lambda \frac{dn_1}{d\lambda} \right)$$

$$\frac{d\tau_m}{d\lambda} = \frac{L\lambda}{c} \left[\frac{dn_1}{d\lambda} - \frac{d^2n_1}{d\lambda^2} - \frac{dn_1}{d\lambda} \right] = \frac{-L\lambda}{c} \frac{d^2n_1}{d\lambda^2}$$

$$M = \frac{1}{L} \frac{d\tau_m}{d\lambda} = \frac{\lambda}{C} \left| \frac{d^2 n_1}{d\lambda^2} \right|$$

$$\sigma_m = \sigma_\lambda L M = \sigma_m \cong \frac{\sigma_\lambda L}{C} \left| \lambda \frac{d^2 n_1}{d\lambda^2} \right|$$

For modal disp.: delay difference δT_s between the extreme meridional ray and the axial ray

$$\delta T_s = \frac{Ln_1}{C} \left(\frac{n_1 - n_2}{n_2} \right) \cong \frac{Ln_1}{C} \Delta$$

rms pulse broadening at the fiber output due to intermodal dispersion for the multimode step index fiber $\sigma_s^2 = M_2 - M_1$

$$M_1 = \int_{-\infty}^{\infty} t p_i(t) dt = 0 \text{ and } M_2 = \int_{-\infty}^{\infty} t^2 p_i(t) dt$$

$$\sigma_s^2 = M_2 = \frac{1}{3} \left(\frac{\delta T_s}{2} \right)^2$$

$$\sigma_n = \sigma_s \cong \frac{Ln_1}{2\sqrt{3}C} \Delta = \frac{L(NA)^2}{4\sqrt{3}n_1 C}$$

multimode graded index fibers show substantial bandwidth improvement over multimode step index fibers

$$\sigma_g = \frac{Ln_1 \Delta^2}{20\sqrt{3}C} \text{ at } \alpha_{op} = 2 - \frac{12\Delta}{5}$$

f) How to reduce various types of losses in optical fiber?

Overcoming or reducing power losses

- 1- Reducing the absorption lossess due to atomic defects by making the material without crystalline defects
- 2- Reducing the absorption lossess due to intrinsic losses by using the optical fiber with light interaction in range from 800nm to 1550nm
- 3- Reducing the absorption lossess due to extrinsic losses by decreasing the impurities in fiber.
- 4- Avoid the scattering losses by making the fiber more homogeneous medium and the geometry perfect cylinder.
- 5- avoiding the fiber bending, particularly, must be above the critical radius.
- 6- cleaning, alignment, use matching fluid material during the fiber splicing.