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Seat No. _______

King Mongkut's University of Technology Thonburi

Midterm Examination 1/2017

EIE 423 Optical Communications — **EIE juniors and seniors**

Tuesday 26 September 2017 — 1:00 p.m. – 4:00 p.m.

Instructions:

1. There are 5 problems and 6 pages (formula sheets included).
2. Each problem weighs 20 points.
3. Please calculate your results to 4 significant figures.
4. No textbooks or class notes are allowed into the examination room.
5. Students are allowed to bring a calculator to the examination.
6. Do all your work in the given booklet.

Students have to raise his or her hand when they finish working on their examinations.

Otherwise, they will not be allowed to come out of the examination room.

Bringing exam papers with students outside the exam room are not allowed.

Academic dishonesty during the exam may result in expulsion or permanent dismissal from the university.

Name...

Student ID...**Seat No**......................................

This exam is given by Apichai Bhatranand.

0-2470-9063

This examination has been approved by ENE department committees.

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(Assoc. Prof. Rardchawadee Silapunt)

Head of Electronics and Telecommunication Engineering Department

1. (a) A receiver requires an input power of 5 nW. If all the system losses add up to 40 dB, how many power (in watts) is required from the source?

   (b) Which photon between at 800 nm and 1300 nm has more energy? Show your work.

   (c) Assume a fiber system operates at a wavelength of 1.55 micron. The system can handle digital information at a data rate equal to one-hundredth of one percent of the optical frequency. How many HDTV compressed video channels, sent at 20Mbps per channel, can be multiplexed onto this fiber system?

2. (a) What would be the normalized intensity of a Gaussian beam at 0.6 mm away from the beam axis (center) if the spot size is 1 mm.

   (b) Draw and explain the two major orthogonal modes (s- and p-polarizations) of the light?

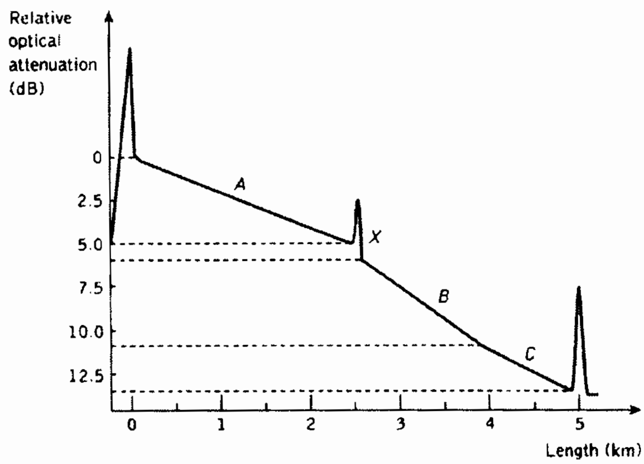

Fig. 1 A backscatter for an optical link provided by OTDR.

   (c) From Fig. 1, what would be the fiber attenuation for region A.

   (d) From Fig. 1, what would be the event X occurring at 2.5 km?

3. (a) What would be the length L of the coupler, shown in Fig. 2, if we want output 2 and output 3 to have the same amount of output power? Assume the coupling length L_c is 2 cm.

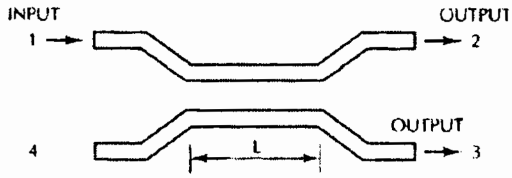

Fig. 2 A directional coupler.

(b) For a slab waveguide shown in Fig. 3 , find the film thickness such that at 1.55 micron, the only propagating TE mode is the TE_0, but at 0.82 micron both TE_0 and TE_1 modes are supported.

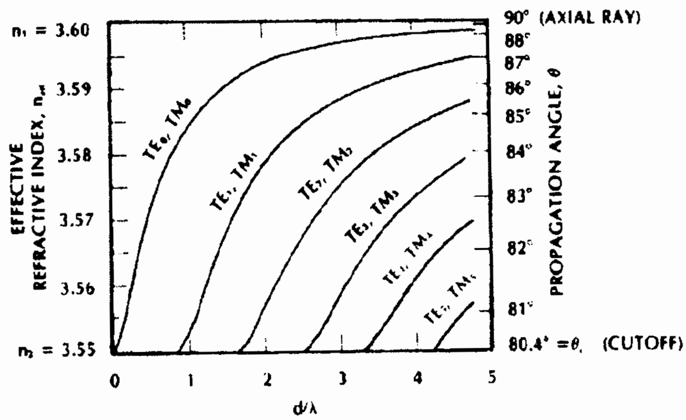

Fig. 3 A symmetric slab waveguide mode chart (n_1 = 3.60 and n_2 = 3.55).

(c) An SI fiber with the mode chart shown in Fig. 4, find the number of propagating modes in an SI fiber having a radius of 5 μm and NA = 0.222 when the wavelength is 1.55 μm.

(d) The same fiber in the previous problem is used with the 533-nm light beam, how many propagating modes this fiber can support?

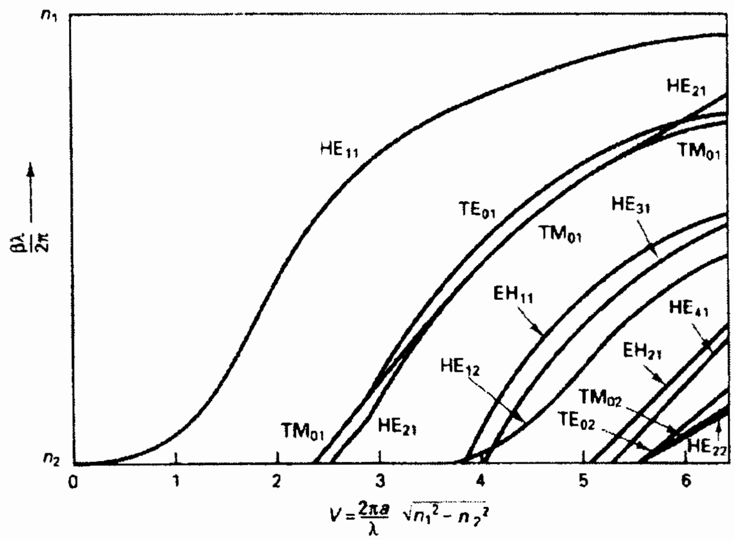

Fig. 4 A SI fiber mode chart.

4. The equilibrium length of a multimode fiber is 2 km. The modal spread (multimode dispersion) is 25 ns for 1-km length. The light source emits at 800 nm and has a spectral width of 50 nm. Compute the minimum electrical bandwidth $(f_{3\text{-dB}})_{elec}$ for a 10-km length of this fiber.

5. (a) The bandgap energy of GaAs is 2..204 x 10^{-19} J. What would be the wavelength of GaAs LED?

   (b) A GaAs (n = 3.35) laser diode has a 1.5 nm gain linewidth and a cavity length of 0.5 mm. Sketch the output spectrum as many details as you can including the central wavelength and number of modes.

Constants

c = speed of light in free space = 3 x 10^8 m/s   e = q = 1.6 x 10^{-19} C

h = Planck's constant = 6.63 x 10^{-34} J.s   k = Boltzmann's constant = 1.38 x 10^{-23} J/K

Useful Formulas (1/2)

$R = m.f_s$ $n_1 \sin\theta_1 = n_2 \sin\theta_2$ $\lambda f = c$ $v = \frac{c}{n}$

$$\Delta\left(\frac{\tau}{l}\right) = -\left(\frac{\lambda}{c}\frac{d^2n}{d\lambda^2}\right).\Delta\lambda = -M.\Delta\lambda \qquad M = \frac{\lambda}{c}\frac{d^2n}{d\lambda^2}$$

$$M = \frac{-0.095}{4}\left(\lambda - \frac{\lambda_0^4}{\lambda^3}\right) \qquad \frac{\Delta f}{f} = \frac{\Delta v}{v} = \frac{\Delta\lambda}{\lambda}$$

$$(f_{3\text{-}dB})_{opt} \le \frac{1}{2\Delta\tau}$$

$$(f_{3\text{-}dB})_{elec} \le \frac{0.35}{\Delta\tau}$$

$$R_{RZ} \times l = \frac{0.35}{\Delta(\tau/l)}$$

$$R_{NRZ} \times l = \frac{0.7}{\Delta(\tau/l)}$$

$$L_f(dB) = -10\log_{10}\left[e^{-0.693\left(\frac{f}{f_{3\text{-}dB}}\right)^2}\right]$$

$$\rho = \frac{n_1 - n_2}{n_1 + n_2} \qquad R = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2 \qquad E = hf$$

$$\rho_p = \frac{-n_2^2\cos\theta_i + n_1\sqrt{(n_2^2 - n_1^2\sin^2\theta_i)}}{n_2^2\cos\theta_i + n_1\sqrt{(n_2^2 - n_1^2\sin^2\theta_i)}}$$

$$\rho_s = \frac{n_1\cos\theta_i - \sqrt{(n_2^2 - n_1^2\sin^2\theta_i)}}{n_1\cos\theta_i + \sqrt{(n_2^2 - n_1^2\sin^2\theta_i)}}$$

$$R = \rho^2$$

$$T = 1 - R$$

$$\theta_B = \tan^{-1}\left(\frac{n_2}{n_1}\right) \qquad \theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) \qquad \alpha = k_0\sqrt{n_1^2\sin^2\theta_i - n_2^2}$$

$$k = k_0 n_1 = \frac{2\pi}{\lambda_0}n_1 \qquad \beta = \frac{\omega}{v_g} \qquad n_{eff} = \frac{c}{v_g} = n_1\sin\theta$$

$$\frac{P_2}{P_1} = \cos^2\left(\frac{\pi L}{2L_c}\right)$$

$$\frac{P_3}{P_1} = \sin^2\left(\frac{\pi L}{2L_c}\right)$$

Useful Formulas (2/2)

$$\tan\left(\frac{hd}{2}\right)=\frac{\sqrt{n_1^2\sin\theta-n_2^2}}{n_1\cos\theta}$$ *...for even solutions*

$$\tan\left(\frac{d\pi n_1\cos\theta}{\lambda}\right)=\frac{\sqrt{n_1^2\sin^2\theta-n_2^2}}{n_1\cos\theta} \qquad \left(\frac{d}{\lambda}\right)_m=\left(\frac{d}{\lambda}\right)_0+\frac{m}{2n_1\cos\theta}$$

$$\left(\frac{d}{\lambda}\right)_{m,c}=\frac{m}{2\sqrt{n_1^2-n_2^2}} \qquad n_0\sin(\alpha_0)_{\max}=NA=\sqrt{n_1^2-n_2^2}=n_1\sqrt{2\Delta} \qquad \Delta=\frac{n_1-n_2}{n_1}$$

$$M_g=\frac{\lambda}{c}\frac{d^2n_{eff}}{d\lambda^2} \qquad \Delta\left(\frac{\tau}{l}\right)=\frac{n_1(n_1-n_2)}{cn_2} \qquad n(r)=\begin{cases} n_1\sqrt{1-2\left(\frac{r}{a}\right)^{\alpha}\Delta} & ;r\le a \\ n_1\sqrt{1-2\Delta} & ;r>a \end{cases}$$

$$NA(r)=\begin{cases} n_1\sqrt{2\Delta(1-(r/a)^{\alpha}} & ;for\ r\le a \\ 0 & ;for\ r>a \end{cases} \qquad V=\frac{2\pi a}{\lambda}\sqrt{n_1^2-n_2^2} \qquad N=\frac{V^2}{2}$$

$$\frac{a}{\lambda}\le\frac{2.405}{2\pi\sqrt{n_1^2-n_2^2}} \qquad n_{eff}=\frac{\beta_{pq}}{k_0}=n_1-(p+q+1)\frac{\sqrt{2\Delta}}{k_0a} \qquad \frac{a}{\lambda}<\frac{1.2}{\pi\sqrt{n_1(n_1-n_2)}}$$

$$\Delta\tau=\sqrt{(\Delta\tau_m+\Delta\tau_g)^2+(\Delta\tau_{mm})^2} \qquad \Delta\tau_m=-M_m.\Delta\lambda.l$$

$$\left[\Delta\left(\frac{\tau}{l}\right)_{mm}\right]_{GRIN}=\frac{n_1\Delta^2}{2c} \qquad \Delta\tau_g=-M_g.\Delta\lambda.l \qquad P_0=\eta IE(eV)$$

$$\left[\Delta\left(\frac{\tau}{l}\right)_{mm}\right]_{SI}=\frac{n_1(n_1-n_2)}{cn_2}$$

$$\left(f_{3\text{-}dB}\right)_{opt}=\frac{0.5}{\Delta\tau} \qquad \left(f_{3\text{-}dB}\right)_{elec}=\frac{0.35}{\Delta\tau}=R_{RZ} \qquad \Delta\tau=\begin{cases} l.\Delta\left(\frac{\tau}{l}\right) & ;l\le l_e \\ \sqrt{ll_e}.\Delta\left(\frac{\tau}{l}\right) & ;l\ge l_e \end{cases}$$

$$m_j=\frac{I_{sp}}{I_{dc}} \qquad m_p=\frac{P_{sp}}{P_{dc}}$$

$$i(t)=I_{dc}+I_{sp}\sin\omega_m t$$
$$P_0(t)=P_{dc}+P_{sp}\sin\omega_m t$$

$$\Delta f=\Delta\nu=\frac{c}{2nL}$$

$$\Delta\lambda=\frac{\lambda_0^2}{c}\Delta\nu$$

$$P_{sp}=\frac{a_1I_{sp}}{\sqrt{1+\omega_m^2\tau^2}} \qquad (f_{3\text{-}dB})_{elec}=\frac{1}{2\pi\tau} \qquad \lambda_0=\frac{1.24}{E_g+kT} \qquad (E_{ph})_{\max}=E_g+kT$$

$$\phi=\tan^{-1}(\omega_m\tau) \qquad (f_{3\text{-}dB})_{elec}=\frac{0.35}{t_r} \qquad \frac{\Delta E}{(E_{ph})_{\max}}=\frac{3.3kT}{(E_{ph})_{\max}}=\frac{\Delta\lambda}{\lambda_0}$$