Seat No. ________

King Monkut's University of Technology Thonburi

Midterm Examination 1/2015

EIE 423 Optical Communications — EIE Juniors/Seniors

Wednesday 23 September 2015 — 1:00p.m. – 4:00 p.m.

Instructions:

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

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.

R. Silapunt

(Assoc. Prof. Rardchawadee Silapunt)

1. Write down your choice in the given working book.

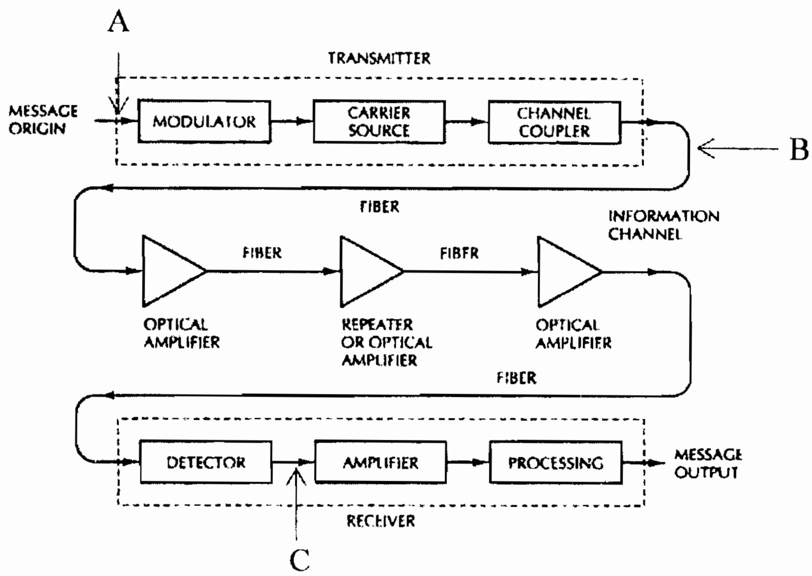

Fig. 1

a) From Fig. 1, the signal at point A is in .... form. a) optical b) electrical
b) From Fig. 1, the signal at point B is in .... form. a) optical b) electrical
c) From Fig. 1, the signal at point C is in .... form. a) optical b) electrical
d) In long-hual optical communication, what kind of light source is widely used?
   a) LED b) Laser c) Incandescent d) Fluorescent
e) What is the information channel in high-speed optical network?
   a) Air b) Optical Fiber c) Copper Wire d) Plastic Fiber
f) Which band is using in optical network at the moment?
   a) O-band b) S-band c) C-band d) L-band
g) Which one is <u>not</u> true?
   a) Optical fiber offers higher bandwidth than copper wire.
   b) Optical fiber offers higher attenuation than copper wire.
   c) Optical fiber is immune to electromagnetic interference.
   d) Optical fiber is easier to upgrade than copper wire.
h) For long-haul communication, which fiber should be used?
   a) single-mode fiber b) multimode fiber
i) What is the main cause of slow-data rate?
   a) Dispersion b) Attenuation c) Rain d) Animal
j) What does 0 dBm mean?
   a) 0 W b) 1 W c) 0.1 mW d) 1 mW

2. (a) A fiber telephone cable contains 144 fibers; each capable of operating the DS-3C signal rate. A copper telephone cable contains 900 twisted pairs; each pair can carry 24 voice messages. How many of the copper cables are required to equal the capacity of the fiber cable?

   (b) There are 10^{10} photons per second indicent on a photodetector at $\lambda = 0.63$ micron. Compute the power incident on the detector in W?

   (c) A beam of light is incident on a plane boundary between two dielectrics. The incident angle is at 20° to the boundary normal and the transmitted beam is at 15°. Which of the two media has the **higher** refractive index? Show your work.

3. For a symmetric slab waveguide of $n_1 = 1.50$ and $n_2 = 1.49$. The wavelength is 1,550 nm.

   (a) Find the thickness of the film if ray angle is 86° for the TE_0 mode.

   (b) Repeat (a) for the TE_3 mode.

4. A 20 km long fiber link contains a single amplifier in its path that provides a gain of 10 dB. The losses in the link include combined connectors and splice loss of 3 dB, and a fiber loss (fiber attenuation, α). When 2 mW of optical power is transmitted through this link, the optical power that reaches the receiver is 10 μW. Calculate the value of attenuation for the fiber in units of dB/km.

5. A mulitimode SI fiber (an equilibrium length L_e of 5 km) has a numerical aperture NA = 0.2062, a core refractive index = 1.46.

   (a) Calculate the amount of pulse spread in a 3 km length of this fiber due to multimode dispersion ONLY. The light source wavelength is 0.82 micron and has a spectral width $\Delta\lambda$ = 10nm.

   (b) What would the maximum 3-dB optical bandwidth for pulse spread occurred in (a)?

6. You are asked to design a laser diode emitting a red light ($\lambda = 0.64\ \mu m$) with a spectral width $\Delta\lambda = 1.5$ nm and a cavity length of 0.23 mm.
   (a) Which material should you use? Explain or show your work.
   (b) What would be a longitudinal mode spacing $\Delta\lambda_{lm}$ for this laser?
   (c) Sketch the output spectrum by including the emitted wavelength and the number of modes.

Digital transmission rates

Number of Voice channels	*Transmission Designation*	*Signaling Designation*	*Data Rate*
1	-	-	64 kb/s
24	T1	DS-1	1.544 Mb/s
48(2-T1 systems)	T1C	DS-1C	3.152 Mb/s
96(4-T1 systems)	T2	DS-2	6.312 Mb/s
672(7-T2 systems)	T3	DS-3	44.736 Mb/s
1344(2-T3 systems)	T3C	DS-3C	91.053 Mb/s
4032 (6-T3 systems)	T4	DS-4	274.175 Mb/s

Properties of some semiconductor materials

Material	Refractive Index (n)	Energy Bandgap (E_g) [eV]
InGaAsP	3.51	0.73 – 1.35
AlGaAs	3.6	1.4 – 1.55
GaAs	3.35	1.4
GaInP	3.72	1.82 – 1.94

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)

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

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

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

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

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

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

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

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

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

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

$$R = \rho^2$$

$$T = 1 - R$$

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

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

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

Useful Formulas (2/2)

$$E(y,z,t)=\begin{cases} E_2 e^{-\alpha\left(y-\frac{d}{2}\right)}\sin(\omega t-\beta z) & for\ y>d/2 \\ E_2 e^{\alpha\left(y+\frac{d}{2}\right)}\sin(\omega t-\beta z) & for\ y<-d/2 \end{cases}$$

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

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

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

$$M_g=\frac{\lambda}{c}\frac{d^2 n_{eff}}{d\lambda^2} \qquad V=\frac{2\pi a}{\lambda}\sqrt{n_1^2-n_2^2} \qquad N=\frac{V^2}{2}$$

$$\frac{a}{\lambda}<\frac{1.2}{\pi\sqrt{n_1(n_1-n_2)}}$$

$$\Delta\tau=\sqrt{(\Delta\tau_m+\Delta\tau_g)^2+(\Delta\tau_{mm})^2} \qquad \Delta\left(\frac{\tau}{l}\right)_{mm}=\frac{n_1\Delta^2}{2c}$$

$$\Delta\tau_m=-M_m.\Delta\lambda.l \qquad \Delta\tau_g=-M_g.\Delta\lambda.l \qquad \Delta\left(\frac{\tau}{l}\right)_{mm}=\frac{n_1(n_1-n_2)}{cn_2}$$

$$P_0=\eta IE(eV) \qquad (f_{3-dB})_{opt}=\frac{0.5}{\Delta\tau} \qquad (f_{3-dB})_{elec}=\frac{0.35}{\Delta\tau}=R_{RZ}$$

$$\Delta\tau=\begin{cases} l.\Delta\left(\frac{\tau}{l}\right) & ;l\le l_e \\ \sqrt{l.l_e}.\Delta\left(\frac{\tau}{l}\right) & ;l\ge l_e \end{cases}$$

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

$$m_j=\frac{I_{sp}}{I_{dc}} \qquad m_p=\frac{P_{sp}}{P_{dc}} \qquad \Delta f=\Delta\nu=\frac{c}{2nL} \qquad \Delta\lambda_{lm}=\frac{\lambda_0^2}{c}\Delta\nu$$

$$P_{sp}=\frac{a_1 I_{sp}}{\sqrt{1+\omega_m^2\tau^2}} \qquad \phi=\tan^{-1}(\omega_m\tau)$$

$$(f_{3-dB})_{elec}=\frac{1}{2\pi\tau} \qquad (f_{3-dB})_{elec}=\frac{0.35}{t_r}$$

$$\lambda_0=\frac{1.24}{E_g+kT} \qquad (E_{ph})_{\max}=E_g+kT$$

$$\frac{\Delta E}{(E_{ph})_{\max}}=\frac{3.3kT}{(E_{ph})_{\max}}=\frac{\Delta\lambda}{\lambda_0}$$