332: 559 Optical Computer Communication Networks
Theoretical Questions for Exam 1

Exam 1: Wednesday, March 7, 2001, 6:10–7:30pm undergraduate students
Friday, March 23, 2001, 6:10–7:30pm, graduate students

CN = Class Notes; RS = Ramaswami and Sivarajan Textbook.

1. Define *TDM, FDM, and WDM*, signal multiplexing techniques. (CN, p. 2–3; RS, p. 5–7).
2. Present WDM architectures known as "*WDM broadcast and select*" and "*WDM routing*". (CN, p. 8–9; RS, p. 11–13).
3. Define the *refractive index* and state the *Snell law*. (CN, p.10; RS, p. 26–27).
4. Explain *light propagation through a multimode optical fiber*. (CN, p.10; RS, p. 26–27).
5. Discuss *differences between multimode step-index and multimode graded-index optical fibers*. (CN, p. 11; RS, p. 29–30).
6. Find the *time difference between the slowest and fastest modes* in a multimode step-index fiber. Express the result in terms of the fractional refractive index and define the upper bound on this time difference. Compare the time deference obtained with the corresponding time difference for graded-index multimode fiber. (CN, p. 12–14; RS, p. 28–30).
7. Define *capacity of the optical communication fiber*. Draw the corresponding curves for the step-index and graded-index fibers. Present the corresponding formula for the fiber capacity in terms of refractive indexes. (CN, p. 13; RS, p. 28–29).
8. State *simplifying assumptions used in solving the Maxwell wave equation* for light propagation in a single mode optical fiber (CN, p. 15–16; RS, p. 32–33).
9. Define the *propagation constant, wave number, effective refractive index, and effective wave speed* (CN, p.18; RS, p. 37).
10. State the *condition under which the fiber supports the single mode* (fundamental mode). CN p. 18–19; RS, p. 37).
11. Define *polarization mode dispersion*. Do not write any formula. (CN, p. 19–20; RS, p. 38–40).
12. Define *optical fiber power loss*, indicate loss sources, and present the corresponding loss [dB/km] vs wavelength diagram. Denote on the diagram the most important pair of numerical values. (CN, p. 21; RS, p. 41–43).
13. Define the *optical fiber bandwidth* and calculate it assuming that $\Delta\lambda = 100nm$. (CN, p. 22; RS, p. 42–43).
14. Define the *group velocity dispersion parameter* and show how it makes the group velocity frequency dependent (CN, p. 25–27; RS, p. 44–46).
15. Define the *chirp factor* and explain *chirping phenomenon*. (CN, p. 27–28; RS, p. 46–47).
16. Define the *dispersion length* and the *dispersion parameter*. (CN, p. 29, 31; RS, p. 49, 52).
17. What *limitations on the bit rate* B as a function of L (distance) imposes chromatic dispersion: (a) caused by pulse broadening, and (b) caused by large spectral source width. Answer: (a) limited by $1/\sqrt{L}$, (b) limited by $1/L$. Which one is worse? (CN, p 31–32, CN, p. 52–54).
18. Show how the propagation constant depends on the square of the electrical field intensity due to *fiber nonlinearities* and describe the nonlinear phenomenon known as *self-phase modulation*. (CN, p. 34–36; CN, p. 57–61).

19. Describe the nonlinear phenomenon known as *cross-phase modulation*. (CN, p. 37–38, RS, p. 62–63).
20. Describe the nonlinear phenomenon known as *fourway mixing (crosstalk)*. (CN, p. 40; RS, p. 71–72).
21. Define the *nonlinear propagation coefficient* and the *nonlinear fiber length*. (CN, p. 39; RS, p. 65).
22. Describe optical *couplers* (CN, p. 44–45; RS, p. 83–87).
23. Define optical *isolators and circulators* (CN, p. 45; RS, p. 87–89).
24. Indicate *features of good optical filters*, draw its wavelength characteristics (transfer function) and denote important quantities (CN, p. 47; RS, p. 91–93).
25. Present *Fabry-Perot filter* (CN, p. 48–49; RS, p. 102–106).
26. Present *multilayer dielectric thin-film filters* and demonstrate its use as a demultiplexer (CN, p. 50–51; RS, p. 106–108).
27. Present *Mach-Zehnder filters* (CN, p. 51–52; RS, p. 108–111).
28. Present *arrayed waveguide grating filters* (CN, p. 53; RS, p. 112–113).
29. Present principles of operation of *EDFA amplifiers* (CN, p. 57–60; RS, 120–124).
30. Draw the *gain characteristics and the normalized average inversion time change* curve for EDFA (CN only, p. 60–61)
31. Present the diagram of the *two-stage EDFA* and explain the role of its two EDFA amplifiers (CN, p. 61; RS, p. 125–126).
32. Explain principles of operation of *EDFA fiber lasers* (CN, p. 63–64; RS, p. 131–133).
33. Explain the construction of the *distributed feedback lasers* (DFB). Are they MLM or SLM lasers? (CN, p. 64–65; RS, p. 133–135).
34. Present principles of operation of *mode-locked lasers* (CN, p. 65–66; RS, p. 139–141).
35. Present principles of operation of *photodetectors* (optical receivers), (CN, p. 67–68; RS, p. 145–147).
36. State areas of applications of *optical switches*. Define optical switch parameters (CN, p. 69–70; RS, p. 152–153).
37. State criteria used in design of *large optical switches* (CN, p. 71, RS, p. 156–157).
38. Explain principles of operations of optical *wavelength converters* that use cross-gain modulation and wave mixing techniques (CN, p. 73–74; RS, p. 163, 165–166).
39. *** Show that the *optical fiber acceptance angle* is given by $\sin\theta_0^{max} = \sqrt{n_1 - n_2}$, where n_1 and n_2 are respectively the refractive indexes in the core and cladding. (CN, p. 23; RS, Problem 2.1).
40. *** Starting with the formula for the pulse time-width of a chirped Gaussian pulse

$$|T_z| = T_0\sqrt{\left(1 + \frac{k\beta_2 z}{T_0}\right)^2 + \left(\frac{\beta_2 z}{T_0^2}\right)^2}$$

derive the optimal initial pulse width T_0^{opt}. (Problem 2.11).
41. *** Show that the scattering matrix of the form

$$S = \begin{bmatrix} 0 & 0 & s_{13} \\ 0 & 0 & s_{23} \\ s_{31} & s_{32} & s_{33} \end{bmatrix}$$

can not satisfy the conservation of energy condition. (Problem 3.2).
42. *** Derive the power transfer function for Fabry-Perot filter. (Problem 3.6).
43. *** Derive the power transfer function of the Mach-Zehnder interferometer, assuming that only one of its inputs is active. (Problem 3.11).

*** not for undergraduate students