80 Question bank in optical fiber communication

1. A single mode fiber is to be dimensioned. The normalized frequency is 80 % of the maximum allowed for single mode condition. The relative refractive index difference is 0.005 and the refractive index of the core is 1.5. The wavelength is 1.5 μm. Determine the radius of the core.

2. A standard single mode fiber is to be characterized. The refractive index of the core is 1.44 and the relative refractive index difference is 10-3. The fiber is to be used at 1.7 μm and has the normalized frequency of 2. How large is the diameter of the core? How much of the power is transported in the core? What is the material dispersion parameter? What is the minimal attenuation?

3. Calculate numerically the field intensity of the fundamental mode in a fiber, however normalized to the field intensity of the midpoint of the core. The radius of the core is a = 5 μm and its refractive index is 1.5. The relative refractive index difference is 0.005<<1. Normalized frequency is 2. Calculate the normalized values for 0a, 0.5a, a, 1.5a.

4. A step-index fiber with a pure silica core has a core refractive index of 1.5000, a cladding refractive index of 1.4967, and is used to transmit light at 1.55 μm. The core radius is 5 μm.

a) How many modes can propagate in the fiber?
b) Which are the two main causes of dispersion in this fiber?
c) Determine the dispersion due to these two mechanisms.
For waveguide dispersion, make the (realistic) assumption that the material dispersion can be neglected ($d_n/d_\omega=0$).

5. A standard single-mode optical fiber has minimum dispersion at λ≈1.3 μm and minimum attenuation at λ≈1.5 μm. To be able to make use of the low attenuation we would like to design a dispersion shifted optical fibre with zero dispersion at 1.5 μm. To facilitate coupling of light into the fiber, the core radius should be as large as possible. By minimizing the core-cladding index difference, the core radius will be sufficiently large. Determine the core radius and the core-cladding index difference. The fiber material is S_iO_2 and the refractive index is approximately 1.5. Neglect the material dispersion when calculating the contribution of waveguide dispersion.

6. Some features of the fundamental mode shall be determined of a waveguide from the wave equation and boundary conditions. The wave guide is an infinite slab in the x-axis and z-axis direction and has thickness d in the y-axis direction. The coordinate system is symmetrically oriented with respect to the slab. The slab has the refractive index n1 and is surrounded on both sides of a refractive index of n2<n1. The mode propagates in the z-axis direction. The angular frequency is ω. It can be assumed that the electrical field only has one field component apart from zero and that the field is directed in the x-axis direction. Further, the field component is an even function of y and is independent of x. Derive the dispersion relation, i.e. the relation between the propagation constant

β and the free-space wave number k0. How does the E-field vary in the y-axis and the z-axis directions?

7. A Gaussian pulse with the RMS-width, $\sigma 0$, of the intensity and with the chirp parameter C is transmitted through a standard fiber. It is found that the pulse can be compressed in the time-domain. Derive an expression for the position of the fiber where the compression is maximal and how large it is. What is the time derivative of the instantaneous frequency at this position? What is the RMS width σ_ω of the optical spectrum (i.e., the spectrum which is measured with an optical spectrum analyzer) at this position of the fiber compared to the optical spectrum of the input pulse?

8. Define a fiber optic system.

9. What are the uses of optical fibers?

10. Differentiate between glass and plastic fiber cables.

11. Mention the advantages of optical fiber communication.

12. Define reflection.

13. Define refraction.

14. What is Snell's law?

15. What is total internal reflection?

16. What are the conditions for total internal reflection?

17. What is waveguide dispersion and what is its cause?

18. An advantage with an optical fiber is its immunity against electromagnetic interference even without metallic shield. Explain why outer light disturbances, for example lightning, which penetrate the fiber at midpoint of the fiber link, are harmless.

19. What is multimode dispersion?

20. What is and how does polarization-mode dispersion behave?

21. What is the main mechanism for attenuation in a standard fiber at 1.55 μm? Describe this mechanism physically.

22. The dispersion limit in a link with a standard single mode fiber has different slopes in a log(length)-log(bitrate)-diagram for different light sources. What is the slope when the light source is a LED and a single mode laser with small spectral width and without chirp? The wavelength is 1.55 µm.

23. A student makes a fiber optic experiment. He increases the transmitter power in steps of 1 dB from an ideal unmodulated laser with narrow spectral width. He observes that received power, after transmission through the fiber, also increases in steps of 1 dB initially, but thereafter less.
What has happened?

24. A normal single mode laser is placed in a module and is positioned so that the light is optimally coupled into a single mode fiber. After some time the light power is zero in the fiber and it is suspected that the laser became defect. However, an investigation shows that the laser has started to lase in another mode, which has two variations in the lateral direction instead of one, which is normal. Is this a possible explanation to the zero power? Motivate you answer.

25. The waveguide dispersion, DW, is one part of the chromatic dispersion, and is caused by a field redistribution between core and cladding when frequency changes and hence the group velocity changes with frequency.

26. In a multimode fiber the light propagates in several modes (hundreds) which have different group velocity, and hence a pulse will be smeared out when it propagates trough the fiber. The mode dispersion is much larger than the intramode dispersion and is dependent on the bandwidth of the pulse. The smallest mode dispersion is achieved with a parabolic attenuation profile.

27. Rayleigh scattering. Small "in-frozen" density fluctuations give rise to variations in index. When the light reaches these the light is scattered (similar to light in fog). Attenuation ~1/λ4.

28. A laser is biased at 40 mA and has the threshold current 20 mA. The reflectance of the mirrors is 0.3. The length of the cavity is 500 µm and the internal loss coefficient is 10 cm-1. The reflectance of the left hand side mirror is increased to 1 by depositing a coating. How many percent does the output power increase from the right hand side mirror compared to the first case? The bias current is still 40 mA. The spontaneous emission is neglected and the stimulated emission is proportional to the number of the charge carriers, i.e. the transparency value is 0.

29. Two FP-lasers differs only by having different lengths. One of them is 300 µm and the other one is 600 µm. The bias current is well above threshold current. For a small change of the bias current of 1 mA, a change of the output power throughout one of the mirrors is measured of 0.24 mW and 0.19 mW. What is the internal efficiency and internal loss coefficient for the optical mode? Assume the reflectivity is 0.32. The wavelength is 1.55 µm.

30. A Fabry-Perot laser diode shall be used as a pump laser for an optical fiber amplifier. The given bias current I shall optimally be used, so that the optical, outcoupled power through one of the mirrors is maximum. When manufacturing the laser diode it is possible to choose the mirror reflectance within the interval 0 to 1. Both mirrors should be equal. What is the maximal outcoupled power to the fibre amplifier? Use the linear gain model in equation (3.5.3), where GN and N0 are considered known. The charge carrier lifetime is τc. Internal losses/(unit length) is αint. Rsp is neglected. The group velocity is vg. The confinement factor, Γ, and the internal efficiency, η, are 1.

31. Calculate the so called turn on time for a semiconductor laser. If a laser is biased under threshold and the current is increased by a current step so that the total current exceeds the threshold current, then after certain time, the turn on time, the laser starts to lase. This is due to that it takes time to fill up with charge carriers so that the threshold is reached, whereafter the laser can be considered to immediately start to lase. Assume that the spontaneous recombination into the laser mode is negligible. Thus, calculate the turn on time for Ibias=5 mA, Ithreshold=10 mA and Istep=10 mA. Further, the life time of the charge carriers is 1 ns and 1 ps for the photons.

32. Why is not the more mature Si-technology used for semiconductor manufacturing?

33. Why is the modulation bandwidth of a LED much smaller than of a LD?

34. What are the similarities and differences in the construction between a DFBlaser and a DBR-laser?

35. Calculate some characteristics for a receiver with an APD. Determine the minimum detected power for a ONE signal in order to achieve a BER=10-9 by using an optimal APD-amplification. Also determine the ratio between the threshold level and the mean level for the sampled ONE signal. Calculate also the thermal noise percentage of the total noise in a ONE signal.

36. What are the corresponding three quantities for a receiver where the APD has been replaced with a PIN-diode and otherwise the same conditions.

37. By decreasing the intrinsic region of a PIN-diode the bandwidth may increase. At the expense of what?

38. The receiver unit between the detector and the sampler acts as a filter. What are the purposes of the filter?

39. How should an APD be designed so that the excess noise factor is as small as possible, and how small is it for large M?

40. What is the maximum transmission distance in the fiber-optical communication system specified below? Is the system loss or dispersion limited? What is the real system margin?

41. Calculate the mean number of photons, which are needed in order to achieve a bit error rate of 10-9 for two different cases.

42. A single mode fiber is to be dimensioned. The normalized frequency is 80 % of the maximum allowed for single mode condition. The relative refractive index difference is 0.005 and the refractive index of the core is 1.5. The wavelength is 1.5 μm. Determine the radius of the core. Calculate numerically also the ratio between the intensity at the center of the core and the intensity at the surface of the cladding.

43. A standard single mode fiber is to be characterized. The refractive index of the core is 1.44 and the relative refractive index difference is 10-3. The fiber is to be used at 1.7 μm and has the normalized frequency of 2. How large is the diameter of the core? How much of the power is transported in the core? What is the material dispersion parameter? What is the minimal attenuation?

44. A step-index fiber with a pure silica core has a core refractive index of 1.5000, a cladding refractive index of 1.4967, and is used to transmit light at 1.55 μm. The core radius is 5 μm. a) How many modes can propagate in the fiber? b) Which are the two main causes of dispersion in this fiber? c) Determine the dispersion due to these two mechanisms. For waveguide dispersion, make the (realistic) assumption that the material dispersion can be neglected ($dn/d\omega=0$).

45. A standard single-mode optical fiber has minimum dispersion at $\lambda \approx 1.3$ μm and minimum attenuation at $\lambda \approx 1.5$ μm. To be able to make use of the low attenuation we would like to design a dispersion shifted optical fiber with zero dispersion at 1.5 μm. To facilitate coupling of light into the fiber, the core radius should be as large as possible. By minimizing the core-cladding index difference, the core radius will be sufficiently large. Determine the core radius and the core-cladding index difference. The fiber material is SiO2 and the refractive index is approximately 1.5. Neglect the material dispersion when calculating the contribution of waveguide dispersion.

46. A standard single mode fiber is excited with a pulse with carrier frequency 194 THz. The power of the pulse is Gaussian shaped and has an RMS-width of 0.2 ns. The optical field is without chirp at the exciting position. Where along the fiber has the time derivative of the instantaneous frequency a maximal absolute value and what is the maximal absolute value? Also find the RMSwidth of the pulse power for this position.

47. A single mode fiber has the length L and the power attenuation coefficient α per unit length (not dB/unit length). The propagation constant β can be written in a Taylor series β(ω0+Δω)= β0+ β1Δω + β2(Δω) 2 /2. The fiber is excited with a light pulse which is chirp free and its power varies as Gaussian function with peak power P and RMS-width σ0. The angular frequency of the carrier is ω0. What is the peak power, the RMS-width of the power, the time delay and the time derivative of the instantaneous frequency of the pulse at the output?

48. Estimate the limiting bit rate for a 60 km single-mode fiber link at 1.3 and 1.55 μm wavelength assuming transform-limited 50 ps (FWHM) Gaussian input pulses. Assume $\beta 2=0$ and -20 ps2 /km and $\beta 3=0.1$ ps3 /km and 0 at 1.3 and 1.55 μm wavelengths, respectively.

49. A laser diode is current modulated so that Gaussian shaped pulses with RMSwidth of T/8 are obtained, where T is the bit slot. The laser is assumed to have a Gaussian shaped spectrum when it is unmodulated, the linewidth of the spectrum is 5 MHz at the full width half max. The linewidth enhancement factor of the laser is +4 or -4. The pulses are launched into a standard single mode fiber at 1.55 μm. How long can the fiber be in the two cases if the dispersion criterion σ/T.

50. Consider a single mode fibre system from a dispersion point of view. The system works at minimum dispersion parameter D, and the transmitting laser is direct modulated and has a chirp parameter = 6. The unmodulated laser has the linewidth 50 MHz at full width at half height of the spectral density. The data rate is 1/T = 10 Gbit/s. The launched pulse is Gaussian with the width of the optical intensity 35 ps at full width at half height. Determine the maximal length of the fibre with the condition that the dispersion condition is fulfilled, i.e. the received RMS-width of the optical signal<T/4.

51. The dispersion limit, i.e. the relation between the bit rate and the length of the link, for a system with a typical direct modulated light emitting diode and a typical direct modulated single mode laser diode should be compared numerically. In both cases the chirp parameter is assumed to be zero. The carrier wavelength is chosen so that the dispersion parameter is zero for the standard single mode waveguide used. The transmitted pulse width is assumed to be half of the permitted width at the receiver. Typical values can be found in the literature.

52. Consider a single mode fibre system from a dispersion point of view. The system works at 1.55 μm and uses a standard fibre. The linewidth of the laser is 100 MHz at full width half maximum of the spectrum, which is considered also to have a Gaussian shape. The laser is direct modulated and has a chirp parameter, $C = -4$. The bitrate is 1/T=2.5 Gb/s. Assume the transmitted pulse is a Gaussian pulse with the width equal to 140 ps at full width half maximum of the optical power at the transmitter. Calculate the maximum length of the fibre, providing normal dispersion limit criterion is fulfilled.

53. What is waveguide dispersion and what is its cause?

54. An advantage with an optical fiber is its immunity against electromagnetic interference even without metallic shield. Explain why outer light disturbances, for example lightning, which penetrate into the fiber at midpoint of the fiber link, are harmless.

55. What is multimode dispersion?

56. What is and how does polarization-mode dispersion behave?

57. Sketch the field distribution in core and cladding for the fundamental mode in a planar waveguide when the normalized frequency (1) goes to infinity (2) goes to zero (3) a typical intermediate frequency.

58. The dispersion limit in a link with a standard single mode fiber has different slopes in a log(length)-log(bitrate)-diagram for different light sources. What is the slope when the light source is a LED and a single mode laser with small spectral width and without chirp? The wavelength is 1.55 μm.

59. Explain Responsivity of detector.

60. Write a short note on in p-n photodiode.

61. Give the ac equivalent circuit of APD. Explain Avalanche photo diode in detail.

62. Write a short note on Evanescent field.

63. Name the basic principle of light propagation in optical fiber. Explain in detail.

64. Differentiate step index and graded index fibers. And derive the relationship between NA and Acceptance angle.

65. Express Snell's Law.

66. Draw the transverse field distributions of the lowest order transverse electric ($TE01$) and lowest order transverse magnetic($TM01$).

67. A single mode fiber operating at 1330mm has a modal birefringence of 1.5×10^{-5}. Measure the fiber beat length.

68. A manufacturing Engineer wants to make an optical fiber that has a core index of 1.480 and cladding index of 1.478. Identify the core size for single mode operation at 1550nm.

69. Mention the characteristics of graded index fiber.

70. Derive the wave equations for a step-index fiber and the normalized frequency or V-number for modes in cylindrical optical fibers.

71. Describe the mode analysis for optical propagation through fibers with significant illustration and expressions.

72. A fiber has an attenuation of 0.5 dB/Km at 1500nm. If 1500nm. If 0.5mW of optical power is initially launched into the fiber, estimate the power level after 25Km?

73. How does the scattering loss occur?

74. Light is launched from an injection laser diode operating at 1.55μm to an 8/(125μm) single mode fiber. The bandwidth of the laser source is 500MHz. The single mode fiber offers an average loss of 0.3 $dBkm$. Compute the values of threshold optical power for the cases of stimulated Brillouin scattering.

75. State the causes of dispersion.

76. Define polarization mode dispersion and write the expression for it.

77. Compare any two parameters of Si, Ge, InGaAs pin and avalanche photodiodes.

78. Explain briefly the fiber coupling losses.

79. What is Rayleigh scattering?

80. What is the mean optical power launched into an 8km length fiber is 120MW, the mean optical power at the fiber output is 3μW. Determine
(1) Overall signal attenuation in dB/km and
(2) The overall signal attenuation for a 10km optical link using the same fiber with splices at 1km intervals, each giving an attenuation of 1dB.