Exam *S-108.3110* 17.12.2009

No study materials are allowed. Answers can be given in English or Finnish. Questions have equal points.

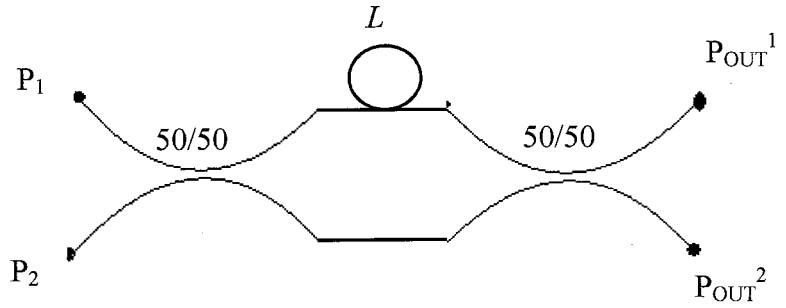
1. Tell if the following statements are true (T) or false (F). No minus points for wrong answers.

1. Standard fibers are single-mode for wavelengths above 1.32 μm.
2. The numerical aperture characterizes the acceptance angle for light to be guided within the fiber core.
3. Fiber losses are minimum at 1.3 μm.
4. Raman scattering amplifies signal shifted by 10 GHz from a strong pump field.
5. Brillouin scattering causes distortion in low power systems.
6. The Raman signal experience linear amplification.
7. Self-phase modulation affects only the optical spectrum of signals.
8. Four-wave mixing efficiency is independent of dispersion.
9. Fabry-Pérot filters are passband filters.
10. Increasing the reflectivity of the mirrors of a Fabry-Pérot cavity results in a higher Finesse.
11. The transmission of Mach-Zehnder filters is a periodic function of frequency.
12. The wavelength reflected by a Fiber Bragg grating is proportional to the grating period.
13. The signal transmitted across a 2×2 coupler experiences a π phase-shift.
14. The gain of EDFAs increases linearly with the signal input power.
15. EDFAs can amplify several signals at different wavelengths simultaneously.
16. Raman amplifiers provide gain over a narrow bandwidth.
17. The chirp of external modulators affects the optical spectrum of externally modulated lasers.
18. The responsivity of photodiodes is independent of the wavelength.
19. Avalanche photodiodes can detect signals with lower power compared to PIN photodiodes.
20. Optical Time Domain Reflectometry measures backscattering as a function of distance.

2. We want to design an optical fiber with a numerical aperture of 0.2, that supports 4 modes at the wavelength of 800 nm and whose inter-modal dispersion is 46 ns/km.
a) Calculate the core diameter of this fiber.
b) What is the cutoff wavelength of the fiber?
c) Calculate the refractive indices of the core n_1 and cladding n_2.

3. We consider an optical fiber links to transmit data at a rate of 20 Mb/s. The link uses a transmitter at a wavelength of 1.55 μm and a multi-mode fiber with attenuation is 0.25 dB/km, intermodal-dispersion of 0.03 ns/km, intra-modal dispersion of 17 ps/nm×km and a nonlinear coefficient of 2 /W/km. The transmitter has an output power P_{Out} =2 dBm and a spectral width $\Delta\lambda$=2 nm. The receiver has a sensitivity of -30 dBm.
Calculate the maximum length of the link:
a) due to attenuation
b) due to dispersion
c) What is therefore the maximum possible length of the link?
The length of the link is chosen to be equal to this maximum.
d) Calculate the maximum value of the nonlinear coefficient γ of the fiber that we can tolerate.
e) Assuming that γ is equal to this maximum value, calculate the Brillouin scattering threshold. The nonlinear refractive index of the fiber is $n_{NL}= 3\times10^{-20}$ m^2/W and the Brillouin gain is $g_B = 5\times10^{-11}$ m/W.

4. Consider the following component consisting of two 50/50 couplers connected together with a delay line inserted in-between as shown below. The delay line consists of a fiber of length L and effective refractive index $n_{eff} = 1.5$. The wavelength of the light propagating in the component is $\lambda = 1550$ nm.



a) Calculate P_{OUT}^1 and P_{OUT}^2 as a function of P_1 and P_2.
Calculate the length L of the fiber to obtain the following outputs:
b) $P_{OUT}^1 = P_1$ and $P_{OUT}^2 = P_2$
c) $P_{OUT}^1 = P_2$ and $P_{OUT}^2 = P_1$
d) $P_{OUT}^1 = P_{OUT}^2 = 1/2 \times (P_1 + P_2)$

5. An ideal semiconductor photodiode produces one electron-hole pair for each photon of wavelength λ absorbed by the photodiode.

a) Derive an equation for the spectral responsivity of the ideal photodiode in terms of wavelength and fundamental constants. Include the effect of reflectance ρ of the photodiode surface with the term $(1-\rho)$ to the equation.

b) Explain briefly what is meant by a *p-i-n* photodiode. Show the structure of a well known *p-i-n* photodiode.

c) Calculate the responsivity of a Germanium photodiode with an external quantum efficiency of 75% at the wavelength of 1480 nm.

6. Draw a block diagram of a measurement setup for measuring the nonlinear coefficient of optical fibers using two laser wavelengths. Explain briefly the working principle and the method.