

Exercises week 5: Fiber communication

Problem 1 (FoP 9.3-3): Scattering loss. At $\lambda_0=820$ nm the absorption loss of a fiber is 0.25 dB/km and the scattering loss is 2.25 dB/km. If the fiber is used instead at $\lambda_0=600$ nm, and calorimetric measurements of the heat generated by light absorption give a loss of 2 dB/km, estimate the total attenuation at $\lambda_0=600$ nm.

Problem 2 (FoP 23.2-1): Cascaded MZI MUX/DEMUX. Three Mach-Zehnder interferometers (MZIs) are cascaded as shown in Fig. 23.2-6 to multiplex or demultiplex four wavelength channels with wavelength separation $\Delta\lambda=0.2$ nm and central wavelength 1550 nm. Determine the necessary path length differences Δd in each interferometer if the refractive index is $n=2.3$.

Problem 3 (FoP 23.3-1): Power loss and crosstalk. A 4x4 switch may be implemented by use of five 2x2 switches. If each of these switches introduces a power loss of 0.5 dB and a crosstalk of -30 dB, determine the worst case power loss and crosstalk for a 4x4 switch.

Problem 4: Interconnects, routers, and switches.

An integrated Mach-Zehnder interferometer is used to separate two wavelengths, λ_1 and λ_2 , incident at one input port to either of the output ports (see fig. 1). $\lambda_1=1550$ nm, the path length difference is $\Delta d=500$ μm , and the refractive index is $n=1.5$. What must the wavelength λ_2 be in order to go to the other port? Are there several choices for λ_2 ? What must a third wavelength λ_3 be in order to go to the same port like λ_1 ? Is the total length d_0 of the device important for its function?

A nonlinear Mach-Zehnder interferometer is used for intensity-based routing (see fig. 2). Pulses with intensity I_1 go to output port 1 and pulses with intensity $I_2=I_1/2$ go to output 2. The nonlinear element, placed in one of the interferometer arms, has a nonlinear refractive index of $n_2=10^{-11}$ cm^2/W and is 1 mm long. At low intensity both interferometer arms have identical length. Find the intensities I_1 and I_2 . Assume $\lambda=1550$ nm. (Remember that the refractive index changes as $n=n_0+n_2I$.)

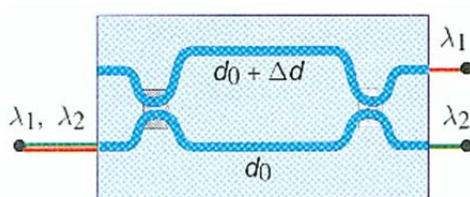


Fig 1: 2x2 optical coupler used as multiplexer.

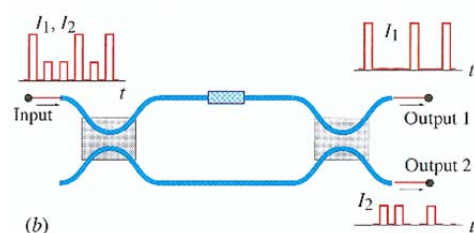


Fig. 2: Intensity-based routing

Problem 5: Fibre optical communication systems.

Power budget and time budget: We look at a fiber communication link operating at $\lambda=1550$ nm with a data rate of $B_0=5$ Gb/s. The link is spliced together from 10 km long pieces of fiber with losses of 0.2 dB/km and a dispersion coefficient $D_\lambda=17$ ps/km-nm. The coupling losses between the fiber pieces are 0.2 dB per connection, the in/out-coupling losses are 0.5 dB and we consider a power margin of 6 dB. The source is a distributed feedback laser with spectral width $\sigma_\lambda=0.1$ nm, a response time of 20 ps, and

a power of 1 mW. The detector requires 1.3 μ W of optical power at the output of the link and it has a response time of 100 ps.

Calculate the power and time budget and find out, if the system is attenuation or dispersion limited. Use the criterion that the response time of the overall system does not exceed 70% of the bit time. (Use $\sigma_s\sigma_v=0.375$ to find the Fourier limited pulse duration σ_s of the source.)

For the above link, if we replace the fiber by a dispersion shifted fiber with $D_\lambda=1$ ps/km-nm, what is the maximum dispersion limited length of the link? The link now obviously is attenuation limited. How many 20 dB gain Erbium amplifier segments would one need to splice into the link in order to remove the attenuation limitation (Let's forget about splicing losses and noise from the amplifier here!)?

Short answers:

Problem 1 (FoP 9.3-3): 9.85 dB/km at 600 nm.

Problem 2 (FoP 23.2-1): $\Delta d = 2.6$ mm for the first interferometer and $\Delta d = 1.3$ mm for the second interferometer.

Problem 3 (FoP 23.3-1): maximum loss of 1.5 dB. Maximum crosstalk 25.2 dB.

Problem 4: $\Delta\lambda = 1.6$ nm (at vacuum). $\lambda_2 = \lambda_1 \pm m\Delta\lambda$ with $m = 1, 3, \dots$, e.g. $\lambda_2=1551.6, 1548.4, 1554.8, 1545.2$ nm. $\lambda_3 = \lambda_1 \pm 2m\Delta\lambda$ with $m = 1, 2, \dots$, e.g. 1553.2, 1546.8 nm. The total length d_0 of the device is not important for its functioning (as long as it is shorter than the coherence length of the source).

$$I_1 = \frac{\lambda}{n_2 d} \approx 1.55 \times 10^8 \text{ Wcm}^{-2}.$$

Problem 5: Power budget: $L \approx 100.3$ km, time budget: $L \approx 53.6$ km. The system is dispersion limited.

With the dispersion-shifted fiber: $L=911$ km, 9 EDFA amplifiers are needed along the way.