Photonics

ELEC-E3240

Assignment (Total 10 points)
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Problem 1: Fiber loss (2 points)

Solution:
There are 5 types of attenuation when working with optical fibers, such as material absorption, scattering loss, nonlinear loss, bending loss and mode coupling loss.
Material absorption and waveguide scattering can be the main reason for the huge loss during fabrication of the fiber. Due to impurities, e.g. transition-metal impurities (Fe, Cu, Ni, Mn and Cr) cause light in the range of $600\,\mathrm{nm}$ to $1.6\,\mu\mathrm{m}$ (including the $633\,\mathrm{nm}$ laser) to be strongly absorbed.
To solve this, the raw materials of the fiber need to be purified.
Furthermore, non-uniformity in the size and shape of the core, perturbations in the core-cladding boundary and defects in the core or cladding result in scattering loss.
The manufacturing process should be optimized to lower the imperfections in the waveguide structure of the fiber.

Problem 2: Fiber refractive index (2.5 points)

Solution:
Attenuation (dB/km) is lowest for light with a wavelength of approximately $1550\,\text{nm}$ (slide 63).
The V-number for single-mode fibers has to be smaller than 2.405. Using the lecture slides 34 and 35, the V-number can be calculated. The equation for the V-number is:

$$V = \frac{2\pi a}{\lambda}\sqrt{n_{core}^2 - n_{clad}^2}$$

It is not possible to make an optical fibre that has cladding refractive index higher than the core refractive index, and it is obvious from the equation. This is why the only way to make the optical fibre out of silica glass is to change the core material to a material with a refractive index higher than 1.47.
One solution is to make the core also out of the silica glass, but without making it so pure. This way it has higher refraction coefficient due to higher amount of impurities. The refractive index of the core can be in the range of 1.47 to 1.479 to still have the the fibre single-mode:

$$2.405 > \frac{2\pi 3.5\,\mu\text{m}}{1550\,\text{nm}}\sqrt{n_{core}^2 - (1.47)^2} \Rightarrow 1.47 \leq n < 1.4797$$

Problem 3: Telescope connection (3 points)

Solution:
Being an engineer presenting preliminary design of a project to customer and other stake holders has to be well presented including required data. It has to be illustrative, well emphasizing key points shortly to the point. In this assignment there can be multiple solutions, thus here is one example:

”Project McMurdo”

Example distance may be seen in the picture below. We may roughly estimate it to be 3450 km.

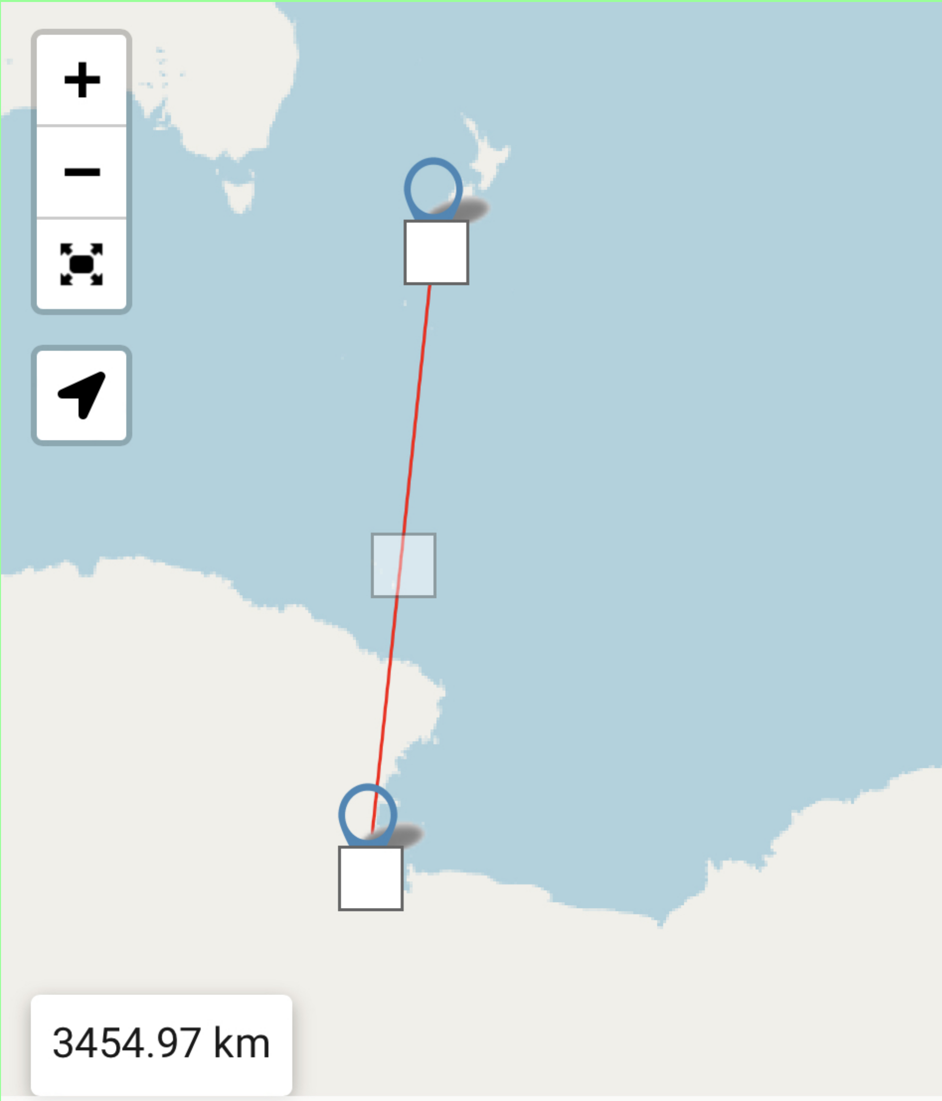

Figure 1: Example depiction for distance between Mt.Lister and HalfMoon Bay

Solution:
Choice of cable is single-mode polarization maintaining cable to provide quality signal throughout the cable section with cable design enabling dispersion compensation. Example depiction of such design is seen in the illustration below where refractive index varies periodically to allow different wave length pulses to maintain order.

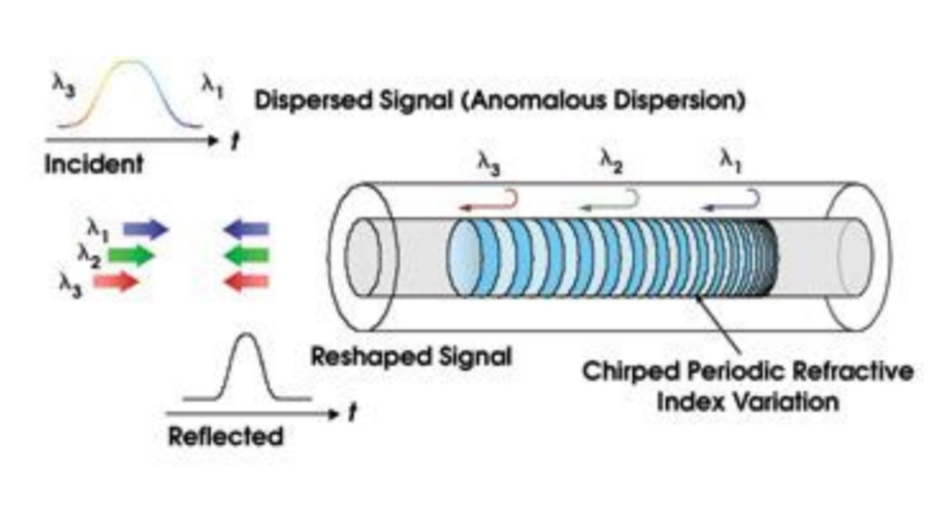

Figure 2: Illustration of design for dispersion compensation

Cross section depiction is visualized below. Our choice will differ a little as will be seen later.

Another detail to battle against signal disturbances will be to build connection in sections connecting each section with signal amplifiers including units on both ends of the connection to boost incoming and outgoing signals. (Details of the amplifier technology is not relevant in this preliminary design. Those will be covered within design and engineering phase of the project.)

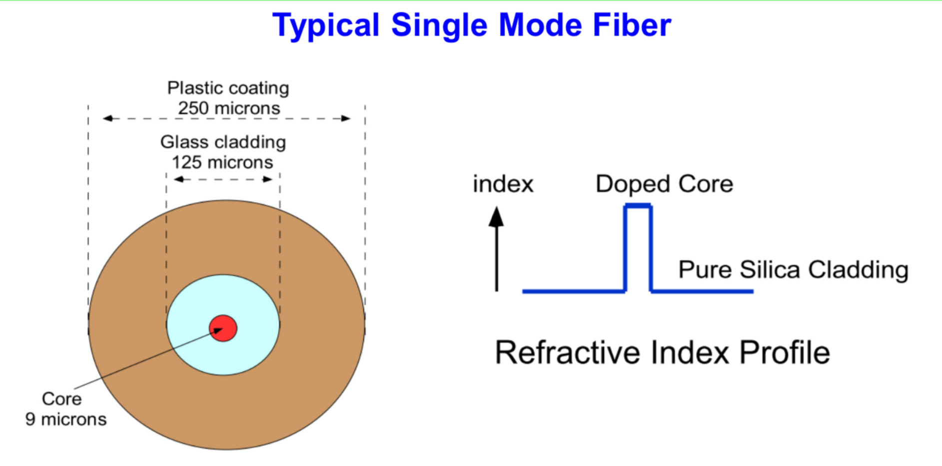

Figure 3: Example cross section of a typical fibre.

Solution:
As seen in table below, dispersion affects gravely on a bit-rate versus cable length. This is why preliminary design will have 4 sections of 765 km and one section of 390 km to provide minimum of full length of 3450 km distance.

Bit-rate	Dispersion-limited distance (L_d)
2.5 Gb/s	784 km
10 Gb/s	~50 km
40 Gb/s	~3 km

* D = 17 ps/(km•nm)

Figure 4: Illustration of design for dispersion compensation

Chosen values for the cable are core diameter $a = 8.99\mu m$, refractive index of the fibre core $n_{core} = 1.465$, refractive index of the fibre cladding $n_{clad} = 1.457$ and laser wave length to be zero-dispersion type $\lambda = 1276nm$. With these values we may analyze if our choices are infact below cutoff limit $V = 2.405$; which defines the limit between single mode and multimode type cables.

$$\Delta = \frac{n_{core} - n_{clad}}{n_{core}}$$

with having found relation Δ, we may get normalized frequency for the fibre:

$$V = \frac{2\pi}{\lambda} a n_{core} \sqrt{2\Delta}$$

Here we end up with $V = 1.57893 * 10^4$ that indeed is smaller that cutoff limit 2.405 With using that we can get number of guided modes:

$$M = \frac{V^2}{2} = 1.24651 * 10^8$$

Coating around cladding for the protection will be typical acrylate in diameter of $250\mu m$. All of these choices and values are based on available cable materials, particularly due to quality of fused cladding silica and fused doped core silica from local supplier in New Zealand and McMurdo regions for local usage of the materials as much as possible.

Problem 4: Readability of transmitted signals (2.5 points)

Solution:
The second window in the diagram is used in the choice of laser while designing for lowest dispersion during transmission and thus longest possible readability of the signal transmitted.
$\frac{d^2 n_{core}}{d\lambda^2}$ is 0 for $\lambda = 1300\,\mathrm{nm}$. For minimum dispersion one could match the waveguide dispersion to minimize total dispersion. Still with $D_{Material} = 0$ the maximum length is:

$$L_d = \frac{1}{D \cdot B \cdot \Delta\lambda} = \frac{1}{-3.5\,\frac{\mathrm{ps}}{\mathrm{km \cdot nm}} \cdot 0.001\,07\,\frac{\mathrm{bit}}{\mathrm{ps}} \cdot 0.3\,\mathrm{nm}} = 890.076\,\mathrm{km}$$

Reduce the dispersion further (see formula for options) or apply a dispersion compensation scheme (e.g. positive + negative dispersion elements)