Optical Fibres

Introduction

Optical fibres are widely used for transmitting data at high speeds. In this experiment, you will take a critical look at the performance of optical fibre systems, and see how their performance is determined by the physics of the light sources and detectors used, as well as the properties of the fibres themselves.

Safety precautions

For your safety

Note that the laser diode source emits invisible infrared radiation (785 nm, 5 mW or less, class 1M) which may cause eye damage if viewed directly. Do not stare at the output port of the source, or the end of an optical fibre, when the dust covers are removed. Do not attempt to view the emission using any external optics.

For the safety of the apparatus

Keep the optical ports and fibre ends covered with their dust caps when they are not in use. Thus helps prevent dust and scratches, which would spoil your results. The active part of the fibres is a continuous strand of glass, of only 0.25 mm diameter. Treat them with care: do not pull, crush or bend sharply. Be careful not to pull on the fibre or knock the ends when removing the caps or inserting into the optical ports.

Make sure that the bias current controls for the light sources are turned down before switching the Optosci unit on or off.

1 Risk assessment

You should start this experiment by doing a simple risk assessment on the use of the laser. This will involving finding out what kind of laser is in the box and then looking up (probably on the web) the laser classifications. In assessing the risk you need to consider the power, wavelength and divergence of the beam together with the conditions under which it will be used.

2 Characteristics of the light sources

Connect a 1 m fibre patchcord between the light-emitting diode (LED) output and the photoreceiver. Gradually increase the LED bias[1] current and observe the increase in the detected photocurrent. Record the detected optical signal as a function of LED current, and plot your results. Take care not to disturb the fibre connections during the measurement, as the efficiency of their optical coupling can change. Take note of which end of which fibre is in use, as there can also be variation between different connectors.

Repeat the measurement using the laser diode instead of the LED source. Comment on how the graphs of light output vs. current input differ in the two cases. Why is this? Discuss with a demonstrator.

Decide on a standard bias current for each source. It should be the current necessary to produce about 50% of the maximum output power, and should be in the middle of the approximately linear region of the light output vs. current input characteristics. Use this current for future measurements. Why is this a good recipe for selecting the bias current?

3 Attenuation in optical fibre links

Perform these measurements using the bias currents you decided upon in the previous section. These are comparative measurements, so be consistent in which fibres you use, and in which end goes where.

---

[1] "bias" refers to the current in the absence of any time-varying signal. Since we are not sending any signal at the moment, it is the only current present.

Attenuation at a connector

Measure the signal loss at a single optical fibre connection as follows. First set up the connection

$$\text{LED} \rightarrow \text{fibre reel 1} \rightarrow \text{receiver}$$

and measure the detected power, P_1. Then set up

$$\text{LED} \rightarrow \text{fibre reel 1} \rightarrow \text{patchcord} \rightarrow \text{receiver}$$

using a bulkhead fibre connector to join the fibres. Measure the detected power again, P_2. Calculate the fractional power loss at the connector, which can be expressed in decibels[2] as

$$\text{Connector loss } = 10\log_{10}\left(\frac{P_2}{P_1}\right)\text{ dB}$$

The loss along the patchcord itself is negligible, as you will see later.

Repeat this measurement using the laser diode as the light source. Is any difference you see significant?

Attenuation in a long fibre

Compare the received power in the following circuits:

$$\text{LED} \rightarrow \text{patchcord} \rightarrow \text{receiver}$$

$$\text{LED} \rightarrow \text{fiber reel 1} \rightarrow \text{receiver}$$

$$\text{LED} \rightarrow \text{fibre reel 2} \rightarrow \text{receiver}$$

to determine the loss caused by transmission along each of the long fibres. Repeat these measurements using the laser source. Why might the results be different this time? The wavelength of the laser light is 785 nm; that of the LED is 850 nm.

---

[2] A negative number of dB signifies a loss. People often omit the sign.

4 Determining the fibre lengths

In this part, you will determine the length of the fibres on the reels by measuring the time taken by a light signal to travel along them. Connect the output of the waveform generator to the oscilloscope, and set it up to display about 10 cycles of a 1 MHz sine wave. Using a BNC T connector, connect that same signal to the RF input of the laser source, and connect its optical output to the photoreceiver using fibre reel 1. Finally, connect the signal output of the receiver to the second channel of the oscilloscope. Set the bias current of the laser diode to that which you previously decided.

As you vary the frequency of the transmitted signal, the phase relationship between input and output signals will, in general, vary. Locate the time at which the phase relationship is independent of frequency. You may find it easier to see what is going on if you switch the scope to digital mode, and set the trigger point in the center of the screen. Be sure you can explain why that time is the time taken for the signal to travel along the fibre, as outlined below.

The signal travelling along the fibre can be represented as $\Phi_1 = \sin(\omega t - kx)$, which for a constant speed of propagation $c = \omega/k$, we can write as

$$\Phi_1 = \sin\omega\left(t - \frac{x}{c}\right).$$

At a different position $x + \Delta x$ and a later time $t + \Delta t$, this becomes

$$\Phi_2 = \sin\omega\left(t + \Delta t - \frac{1}{c}\left(x + \Delta x\right)\right)$$

from which it is easy to determine the condition under which $\Phi_1 = \Phi_2$ for all ω.

From your time measurement, determine the length of the fibre on reel 1. Note that the speed c will be reduced from the speed of light in vacuum by the refractive index of the glass, 1.497. Repeat your measurement for the fibre on reel 2. You are now in a position to calculate the attenuation of the laser and LED light in these fibres, in decibels per kilometer.

5 Maximum possible fibre length

As fibres are made longer, there comes a point when the attenuation is so large that it is not possible to discern the signal above the noise produced by the receiver. In this part you will measure this noise and thus calculate the maximum useful fibre length in this system.

Connect the laser diode to the receiver using a patchcord, apply a square wave signal from the waveform generator, and set your chosen bias current. Measure the amplitude of the receiver output signal. Now disconnect the optical signal, and measure the noise output of the receiver. It should be a random signal of a few millivolts amplitude. Estimate its root-mean-square value by estimating the peak-to-peak size of the majority of the signal[3] and dividing by 6.

A rule of thumb[4] for digital signal transmission is that the signal power needs to exceed the r.m.s. noise by a factor of 12. Calculate the maximum possible fibre length using this criterion.

6 Frequency response

In this section you will investigate the maximum rate at which data can be transmitted via a fibre. Connect the LED transmitter to the receiver using both fibre reels in series. Using the oscilloscope to monitor the input signal from the waveform generator and the output from the receiver, apply a full range of frequencies of modulation, and plot the ratio of received to transmitted signal as a function of frequency. You should find that the ratio falls off quite markedly at high frequencies. To separate out the effect of the long fibres from that of the electronics, repeat the measurement with a fibre patchcord in place of the reels. From these data you should calculate and plot the attenuation versus frequency of the fibre reels alone.

The bandwidth of the system is defined as the frequency at which the received signal strength is reduced by a factor of 2, i.e. 3 dB, compared to its value at low freqencies. Clearly, it varies inversely with the fibre length, so the bandwidth×length product is used to characterise a particular kind of fibre. What is the value of this quantity for your fibre?

---

[3] A method Horowitz and Hill (in *The Art of Electronics*) describe as “not exactly world-famous for its accuracy”

[4] This results in one bit in every 10^9 being wrong.

7 Time domain response

Looking at the time response of the system to fast pulses provides another view of its behaviour at high data rates. Use the same experimental arrangement as in the previous section, but this time set the waveform generator to produce a square wave signal. Use the oscilloscope to study the risetimes of the signals, as shown in figure1. For a perfect square wave, the rise time is zero; in practice it will be a few nanoseconds. It is conventional to measure the time the signal takes to rise from 10% to 90% of the total step height.

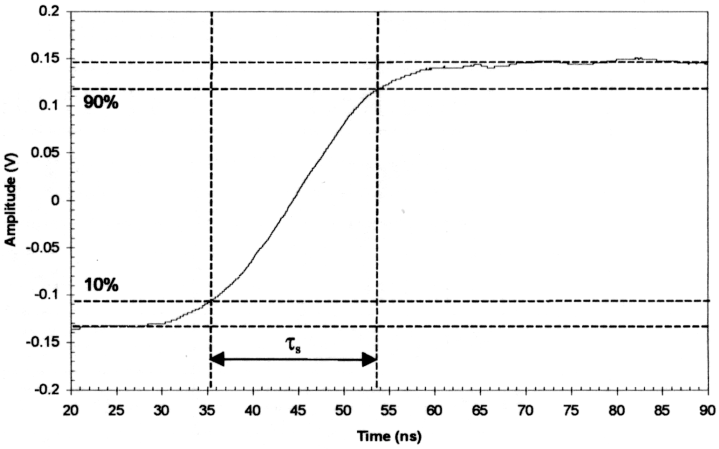

Figure 1: Measuring a risetime

As before, you should eliminate the response of the electronics by measuring the risetime τ_0 of the system with just a short patchcord. Then measure τ_S of the full system, and calculate the rise time contributed by the long fibre, $\tau_F = \sqrt{\tau_S^2 - \tau_0^2}$. Why is a simple subtraction not appropriate?

Clearly, when a rapid sequence of bits are sent along the fibre, each bit needs to last a minimum of about $2\tau_F$. Estimate the maximum number of bits per second that could be sent along your fibre. As before, the result depends on the fibre length. What is the (bit rate·distance) product for fibres of this sort, with the LED source?

Repeat your measurements with the laser diode source. You should find it is significantly better.

8 Questions

You may find the appendix helpful in answering these questions.

- What is the relationship between the time domain response and the frequency response? Are your quantitative results consistent?
- It is fairly obvious why the attenuation depends on fibre length; but this does not have any time dependence. So why do the frequency response and risetime depend on fibre length? What is it about the laser light that lets it give better time and frequency responses?

MSC 2011-10-05