Explaining the principles of Photonics and optical communications

Teacher's notes

Photonics Education Systems
www.PhotonicsEducationSystems.com

Safety notice

This product includes a low power (<1mW) visible red laser, which has the same characteristics as a laser pointer. Improper use of the laser, including pointing the beam at other people or staring into the beam, may damage the eye. You must read and then conform to safety guidelines set out by your state educational department when using this product. Tell students about the possible dangers of lasers.

- **Never point the laser at a person.**
- **Never stare into the laser beam.**
- **Make sure that the user informs others that the laser is on and where the beam is directed.**

The light emitting diodes on the second transmitter board are safe. They are not lasers.

Introduction

Photonic technologies are widely used and have had an enormous impact on our lives. The *Photonics and Optical Communications Experiment* has been designed to help you teach the optics, Photonics and communications components of the science syllabi. The package contains a working optical communications system, with coloured lights and audible radio sound designed to capture the student's attention. After a hands-on class with the *Optical Communications Experiment* the student will understand the physical principles of photonics that allows modern optical communication.

You may wish to adapt the experiments to your particular curriculum or educational goal. That is why we have made these notes available to you in electronic form. We give you permission to extract parts of these notes and write your own lesson plans around them on your word processor and then hand out hard copies to your class. We request that you email or send us your notes so that we can improve our notes for future users.

Photonics and Optical Communications

Photonics is the science and technology of light. Some aspects of photonics include:

- Generation of light, for example using lasers or light emitting diodes
- Detection of light, for example with silicon photodiodes that supply an electrical current proportional to the intensity of the light that falls upon them
- Information storage and retrieval using light, for example compact disks
- Measuring with light, for example interferometric length measurement or gas detection
- Communicating with light, by encoding information on a beam of light or a guided light wave

Photonics has made a particularly large impact on everyday communications. Therefore, the experiments presented here concentrate on *communicating with light*. Because of Photonics we are now able to send vast amounts of information around the world. This has enabled technologies such as the Internet and allowed cheap international phone calls, connecting people around the globe.

Communicating with light started many centuries ago with smoke signals, for example. Puffs of smoke could carry information because the clouds reflected light rays that could be observed from a distance. This principle is similar to the dots-and-dashes system used in Morse code. Although smoke signals are slow and can only travel short distances, they were an interesting early form of optical communication.

Can you think of other ways of sending information using light? Hint: sailors, scuba divers and aircraft pilots all send signals using light.

Modern optical communications allow much faster communication over greater distances than can be achieved using smoke signals. As with smoke signals, we can send a message using light by turning it on and off, or changing the light intensity. Using smoke signals, we could imagine a skilled person letting rise a smoke signal approximately once per second, or one bit of information per second. However, an optical fibre connecting two continents is now capable of sending more than 1 Terrabit or 1,000,000,000,000 bits of information per second. This is the equivalent of more than 100,000,000 simultaneous telephone calls or 40,000,000 pages of text every second.

How many years would it take you to speak every word that is transmitted down an optical fibre every second? (Hint: Assume 2 words per second for each telephone call, and up to 100,000,000 simultaneous telephone calls)

Optical fibre is now used extensively to send information between continents and cities. Figure 1 shows current optical fibre links around the globe. These links have mostly replaced satellite communications because they can carry much more information cheaply.

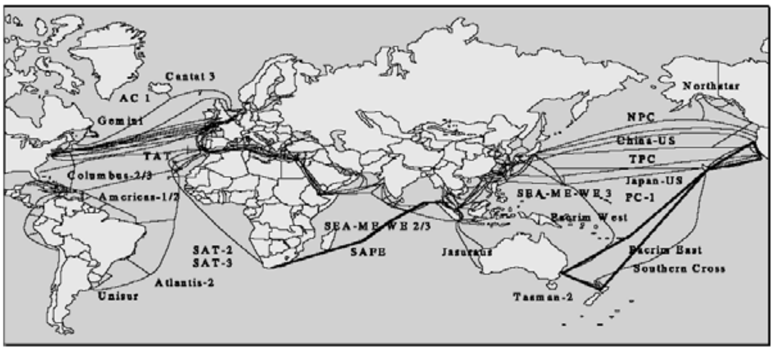


Figure 1. Optical fibre connections across the world around in year 2000.
(Beaufils, *Opt. Fiber Tech*. **6** 15 (2000))

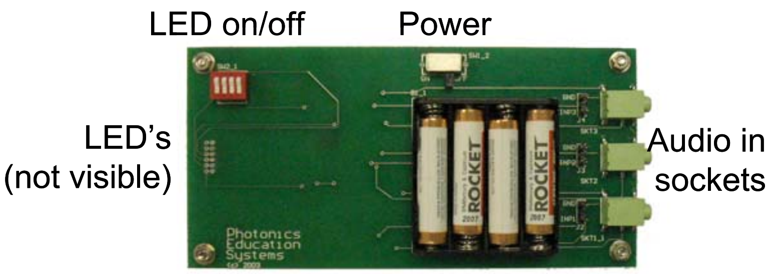
The kit: Becoming familiar with the components

Examine the experimental components. The function and controls of each component are described below.

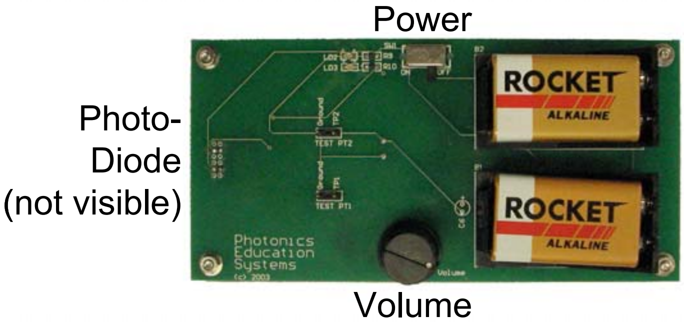
Three radios or CD players. These are not supplied in the kit. We use the stereo headphone socket on each radio as an audio signal source. It's best that the radios or CD players are each playing easily differentiable sounds (classical, popular and talk-balk radio, for example). Become familiar with the volume and tuning controls, and confirm that the internal speaker (if there is one) is disabled when you connect a cable to the headphone socket.

Three stereo cables. These are used to connect the headphone socket on the radios or CD players to the audio input socket on the laser or LED transmitter units.

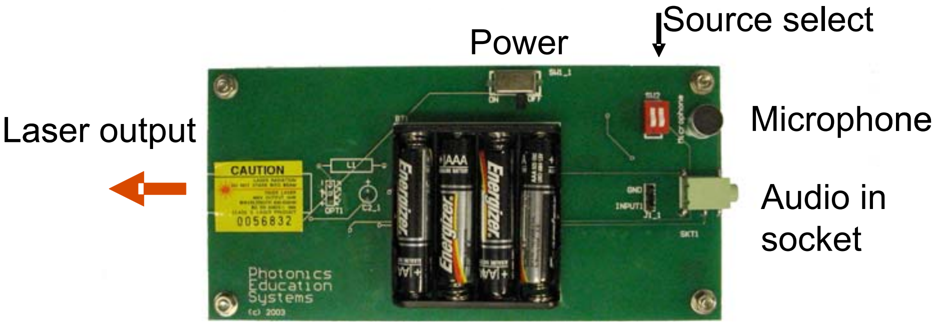
One LED transmitter unit. The headphone socket on each radio can be connected to an audio input socket on the LED transmitter unit. Each signal is encoded onto the light emitted by either a blue, green or red coloured LED. The information is represented by changes in the light intensity. There is a power switch. Each individual LED can also be tuned on or off. Find the switches for each LED.



One receiver unit. The silicon photodiode on this unit detects the light carrying the audio signal, producing a current that is proportional to the intensity of the light striking it. The circuity retrieves the audio signal and then plays it through the inbuilt speaker. There is a power switch and a volume knob.



One laser transmitter unit. The headphone socket from a single radio or CD player is connected to the audio socket on the laser transmitter with a stereo cable. It encodes the audio signal onto a laser beam. There is also a microphone on the laser transmitter unit that can supply an alternative audio signal. You can switch between the audio socket and microphone inputs with a switch. There is a power switch.



Three colour filters. The red, green and blue filter will only allow light from the red, green and blue LED's respectively to pass, absorbing the other two colours. This is used to separate the colours before they reach the receiver.

Clear plastic rods. These are used to guide light by total internal reflection from the LED transmitter unit to the receiver unit. This simulates an optical fibre.

Signal generator. This is not supplied in the kit. A software based signal generator that can run off a PC, and which is supplied, can be substituted for the signal generator. The signal generator can be connected to the LED transmitter unit using the pins on the board. This enables a pure tone to be transmitted.

Glass or beaker filled with water and a few drops of milk. This is not supplied in the kit. This is used to demonstrate total internal reflection.

Sample of optical fibre. For inspection.

Experiments

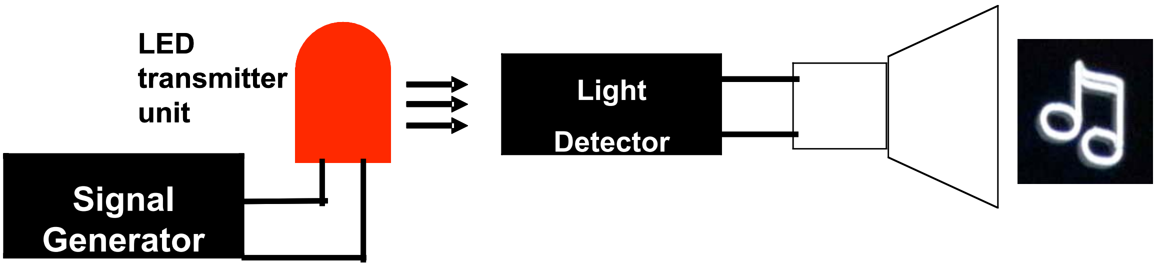
Experiment 1 - Modulated light carries information

Aim

To show simple audio information can be encoded onto light by modulating the light intensity.

Equipment

- Signal generator *or* PC with supplied signal generator software
- Cable with alligator clips to connect signal generator and LED transmitter unit, *or* stereo cable to connect PC headphone socket and LED transmitter unit
- LED transmitter unit, with only one LED turned on
- Receiver unit (check it is on and the volume is turned up)



Schematic of the arrangement for experiment 'Modulated light carries information'

Method

- Turn the frequency of the signal generator to around 1 Hz and turn the output voltage down to its minimum value.
- Connect the signal generator output to the LED transmitter unit, and ensure the LED transmitter is on. Check that you have connected the signal generator to the LED that is on.
- Slowly turn up the output voltage on the signal generator so the LED light starts to fade and grow strongly.
- Place the photodiode on the receiver unit 10 cm away from the LED. Turn the receiver unit on.
- Increase the frequency of the signal generator and listen to the change in the audio frequency
- Record what over what frequency range you can hear a tone (Note that audio frequencies below around 15 Hz are out of the range of human hearing).

What changing light property contains the information that represents sound?

What does this demonstrate?
The student observes the flashing light and simultaneously hears a tone. The flashing LED and the audio frequencies change together when the signal generator frequency is changed. The student understands that simple audio information can be encoded onto light by modulating the light intensity.

Extra activity

- Ask the student to point the receiver around the room.
- The student should generate an audio buzz from the fluorescent lights, which flash at 100 Hz.
- The student should then do the same with an incandescent light, which do not flash, and thus will give no audio buzz.
- Ask the students what can they deduce about these two light sources.
- The students should deduce that fluorescent lights flash and incandescent lights have continuous output.
- On comparison with audible tones from the frequency generator the student should be able to estimate the frequency of the flashing.

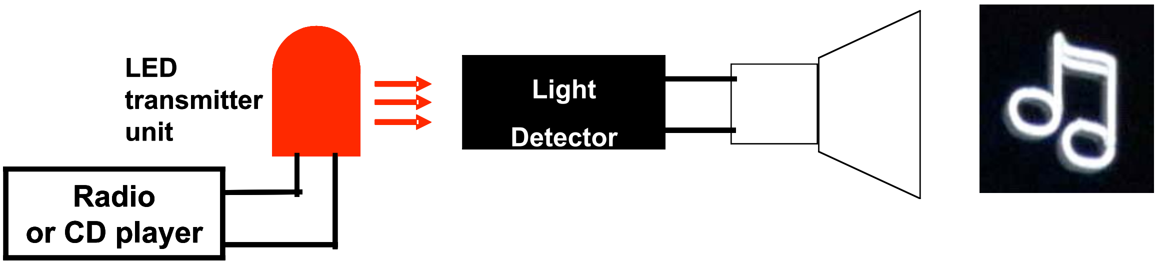
Experiment 2 - Light can carry complex information

Aim

To demonstrate that complicated information can be encoded onto light.

Equipment

- Radio or CD player
- Stereo cable
- LED transmitter unit, with only one LED on
- Receiver unit (check the volume is turned up)



Schematic of the arrangement for 'Light can carry complex information'.

Method

- Use the stereo cable to connect the headphone socket on the radio or CD player to the audio input socket of the to the LED transmitter unit
- Check that you have connected the radio or CD player to the LED that is on.
- Place the photodiode on the receiver unit 10 cm away from the LED. Turn the receiver unit on.
- The radio station or CD should be audible from the speaker on the receiver unit. If not check everything is on, the volume knob is turned up and you have connected the correct LED.
- Block the light from the LED. The sound should stop.

What does this demonstrate?

This demonstrates that complicated information, in this case music, can be encoded onto light. The student should be able to understand that other types of information, such as internet data, could also be encoded onto light.

How far can you move the receiver away from the transmitter before you can no longer hear the sound? What determines this distance?

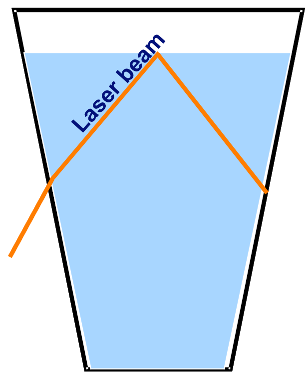
Experiment 3 - Total internal reflection

Aim

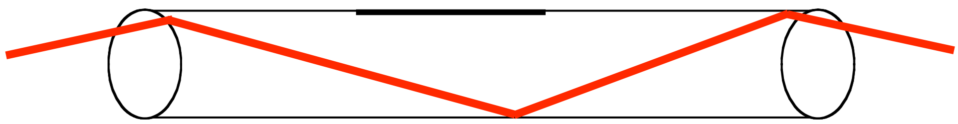
To demonstrate total internal reflection. This allows light to be guided along the core of an optical fibre.

Equipment

- Glass or beaker of water with a few drops of milk in it (you may have to experiment to optimise the amount of milk)
- Laser transmitter unit



Schematic of the arrangement for 'Total internal reflection'.



A ray confined in a glass rod by total internal reflection.

Method

- Turn on the laser transmitter board, to produce a laser beam.
- Direct the laser beam through the side of the glass, pointed up towards the surface.
- Observe that the beam is reflected at the interface between the water and the air because of total internal reflection. To see this properly you may have to change you viewpoint and turn the room lights off.
- Change the angle to observe the critical angle.

What does this demonstrate?

Total internal reflection is very important in optical communications because it is the fundamental principle enabling optical fibres. This experiment shows that a beam of light can be reflected by total internal reflection at the interface between a high refractive index material (such as water or glass) and a lower refractive index material. The guidance of a ray of light down a light guide, such as a rod of clear plastic, is easily grasped after this demonstration with the addition of a simple picture tracing a ray through a rod. A real optical fibre is composed of a glass core and a glass cladding. Because the core has a higher refractive index than the cladding, light is confined to the core by total internal reflection.

Experiment 4 - Signals in optical fibre go further!

Aim

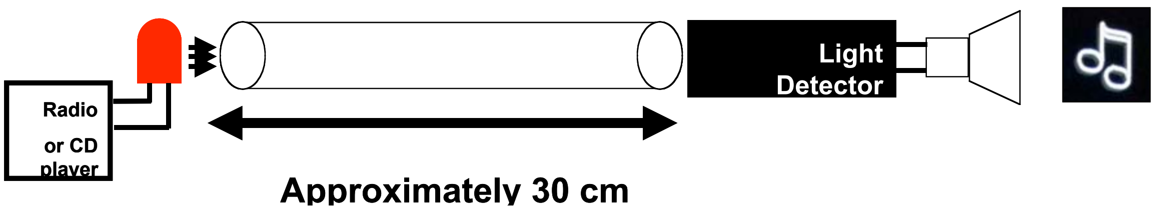
To demonstrate that light can be guided.

Equipment

- Radio or CD player
- Stereo cable
- LED transmitter unit, with only one LED on
- Receiver unit (check the volume is tuned up)
- Straight and bent clear plastic rod (to simulate optical fibre)
- Sample of optical fibre

Method

- Separate the LED transmitter and receiver just far enough apart so that the clear plastic rod can fit between the LED and the photodiode.
- Make sure the LED is connected to an audio signal from the radio or CD player
- Turn the transmitter and receiver on. You should hear the music playing softly on the receiver unit's speaker.
- Insert the straight plastic rod between the LED and the receiver unit, butting the ends of the rods against the LED and photodiode. The sound volume should increase considerably.
- Look at the end of the clear plastic rod with the LED on. It should be clear that a considerable amount of light is guided by the rod.
- Try substituting the straight piece of clear plastic rod for the bent piece
- Try joining several pieces of clear plastic rod.
- Show a sample of optical fibre. Explain the connection with the clear plastic rod.



Schematic of the arrangement for 'Signals in optical fibre go further'

What does this demonstrate?

Light can be guided, thus increasing the distance optical signals can be sent, and that light can be guided around bends.

Can you think of two reasons optical fibre might be used in optical communications?

Experiment 5 - Scattering Loss in optical fibre

Aim

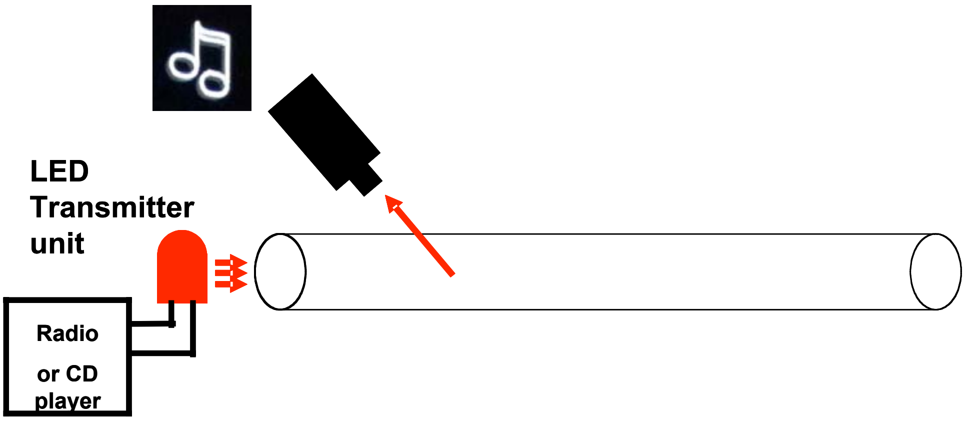
To demonstrate that waveguides have loss.

Equipment

- Radio or CD player
- Stereo cable
- LED transmitter unit, with only one LED on
- Receiver unit (check the volume is turned up)
- Long and straight clear plastic rod

Method

- Ensure radio or CD player is tuned and on.
- Connect radio or CD player to LED transmitter unit with cable and turn transmitter on.
- Butt the LED against one end of the rod so the light is guided within the rod.
- Put the photodiode very close to the side of the rod, angled away from the transmitter.
- You should be able to hear the radio signal from the receiver speaker.
- Run the receiver along the length of the rod. The sound should fade the further the receiver is moved away from the transmitter.



Schematic of the arrangement for 'Scattering Loss in optical fibre'

What does this demonstrate?

Firstly, it shows that some of the light is scattered out of the rod. This is because imperfections in the rod scatter the light at large angles. Some of the scattered rays do not satisfy the condition for total internal reflection and are lost. Also, dust and dirt on the surface can allow the light to escape. Secondly, this demonstrates that the guided wave becomes weaker along the length of the waveguide because of scattering and absorption loses. To compensate for loss in real optical fibre systems devices that amplify light ("optical amplifiers") are placed after every 80 km of fibre.

Experiment 6 - Bend loss in optical fibre

Aim

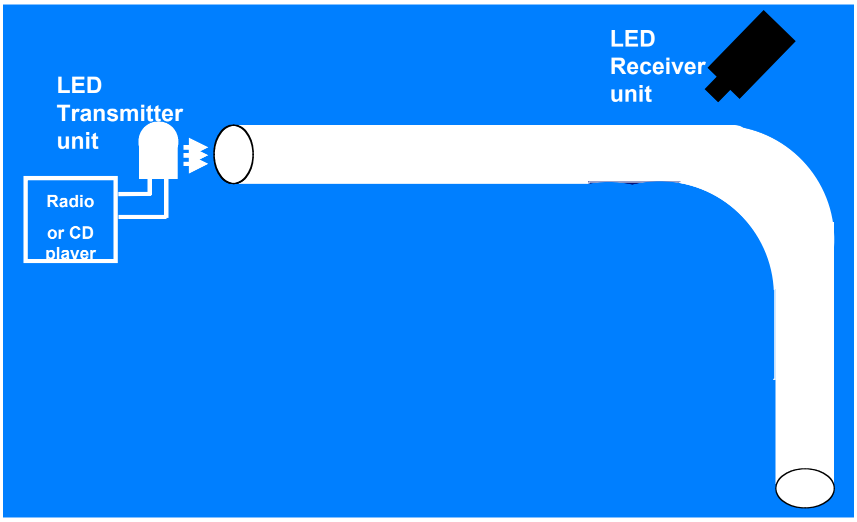
To demonstrate that light can escape at sharp bends

Equipment

- Radio or CD player
- Stereo cable
- LED transmitter unit, with only one LED on
- Receiver unit (check the volume is turned up)
- Clear plastic rod with sharp bend

Method

- Ensure radio or CD player is tuned and on.
- Connect radio or CD player to LED transmitter unit with cable and turn transmitter on.
- Butt the LED against one end of the rod so the light is guided within the rod.
- Put the photodiode very close to the side of the rod, angled away from the transmitter.
- You should be able to hear the radio signal from the receiver speaker.
- Run the receiver along the length of the rod. The sound should become much louder at the bend.



Schematic of the arrangement for 'Bend loss in fibre'

What does this demonstrate?

When the rays get to the bend some of them hit the rod sidewall at an angle that does not satisfy the condition for total internal reflection and are thus pass through the side wall. Bend loss is a significant problem in optical fibres.

Can you trace rays that travel around a bend? Can you trace rays that leave a rod at a bend? Assume *n*=1.5

Experiment 7 - Wavelength Division Multiplexing

Aim

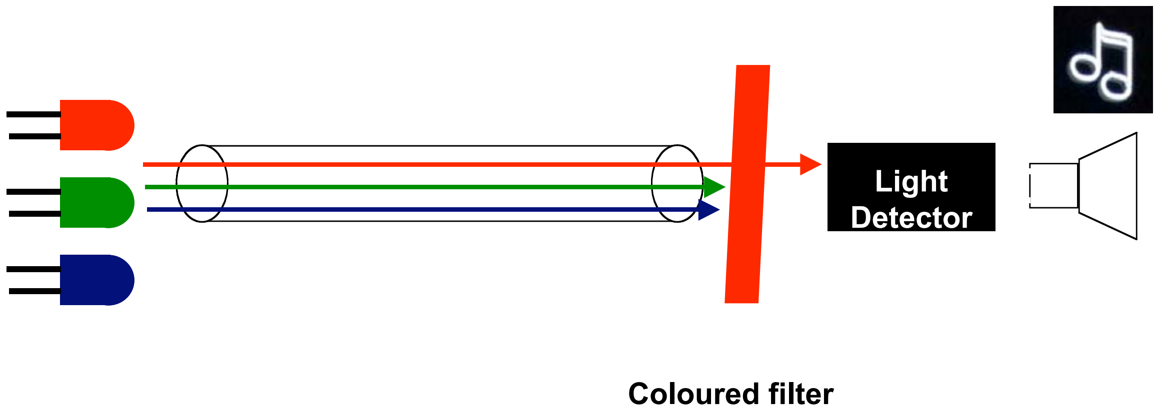
To demonstrate that more than one colour can be sent down an optical fibre, increasing the information that can be sent.

Equipment

- Three radios or CD players.
- Three stereo cables
- LED transmitter unit, with all three LEDs on
- Receiver unit (check the volume is turned up)
- Red, green and blue optical filters

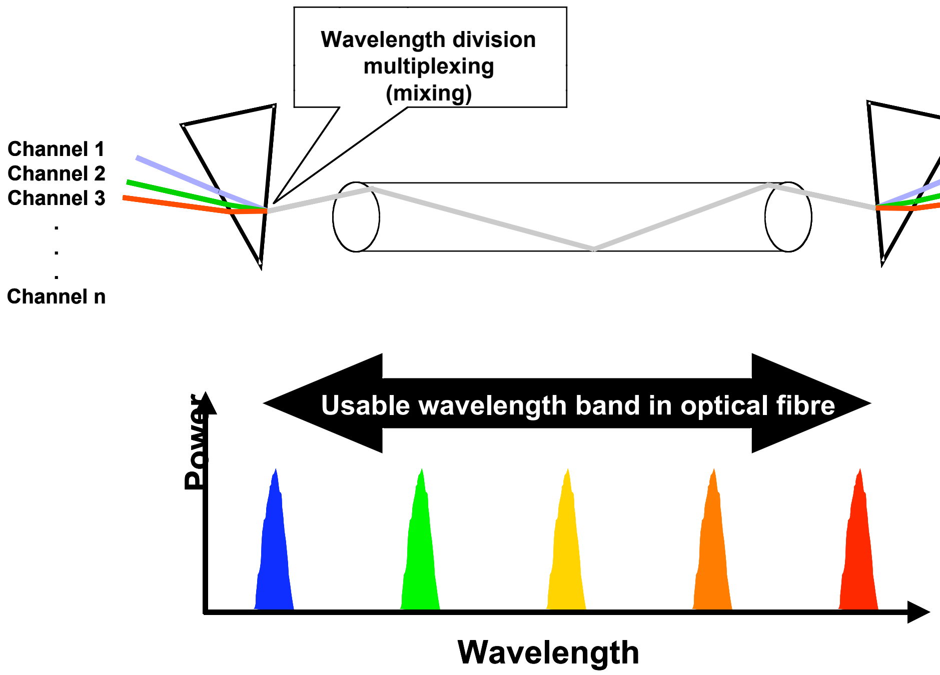
Method

- Turn the radios or CD players on one by one, ensuring they are playing different sounds.
- Connect each radio to a different audio socket on the LED transmitter.
- Place the photodiode on the receiver unit about 10 cm from the LEDs.
- You should hear the sound originating from all three sources at once.
- Insert one coloured filter between the LEDs and photodiodes at a time. Only one radio should be audible per filter.



Schematic of the arrangement for 'Wavelength Division Multiplexing'

What does this demonstrate?
Optical fibre is transparent over a very wide range of colours or wavelengths. We can increase the information carried by an optical fibre by launching several different colours of light, each wavelength carrying a separate signal. We call this *wavelength division multiplexing*. In real optical communication systems, prism-like devices are used to combine and separate the different colours.



Wavelength division multiplexing increases the information carrying capacity of optical fibre

Experiment 8 - Free space communication with laser

Aim

To demonstrate that lasers can be used to send optically encoded information a long way without using a waveguide.

Equipment

- One radio or CD player
- Stereo cable
- *Laser* transmitter unit
- Receiver unit (check the volume is tuned up)

Method

- Turn on the radios or CD player.
- Ensure laser transmitter is **off!**
- Connect the radio to the audio socket on the *laser* transmitter.
- Point the laser at a wall and turn it on.
- Place the photodiode on the receiver unit very close to the red spot on the wall to hear the radio or CD.
- You can try using the microphone instead of the radio.

What does this demonstrate?

Sometimes it is not easy or convenient to use optical fibre. Installing optical fibre is also expensive. In some cases it is easier and cheaper just to set up a laser between the sender and the receiver (for example, between two office towers).

Who are *Photonics Education Systems*?

We are a group of practicing scientists and engineers committed to helping people understand the science and technology of photonics and optics. We work at *The Optical Fibre Technology Centre* (www.oftc.usyd.edu.au) and the *ARC Centre of Excellence for Ultrahigh Bandwidth Devices for Optical Systems* (www.cudos.org.au), both of which are research centres within *The University of Sydney*. We developed the electronics, optics and these notes. *Photonic Education Systems* was formed by us as a way of making the experiments available to schools and other educational institutions. You can find out more about us on our website.

www.PhotonicsEducationSystems.com