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FIBRE OPTICS

LA20-500

INSTRUCTIONS FOR USE

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INTRODUCTION

This apparatus allows students to explore many aspects of fibre-optics starting from the physical principles involved to applications such as data transmission. There is provision to use the apparatus to measure the speed of light through the fibre provided that adequate electronics facilities are available.

APPLICATIONS

- Optics
- Total internal reflection
- Data transmission and communication
- Speed of light

Features and general principles

The system uses a modern optical link system which incorporates easy to operate housings with precision transducers in an integrated format. The fibre can be used independently of the system to demonstrate its basic concept and then used to show how a signal can be changed from electrical impulses to light and back again for data transmission.

MEASURING THE SPEED OF LIGHT

This is essentially an A-Level or top GCSE experiment. The principles are simple but understanding the measurements requires complete familiarity with the working of a dual beam oscilloscope otherwise the process is meaningless.

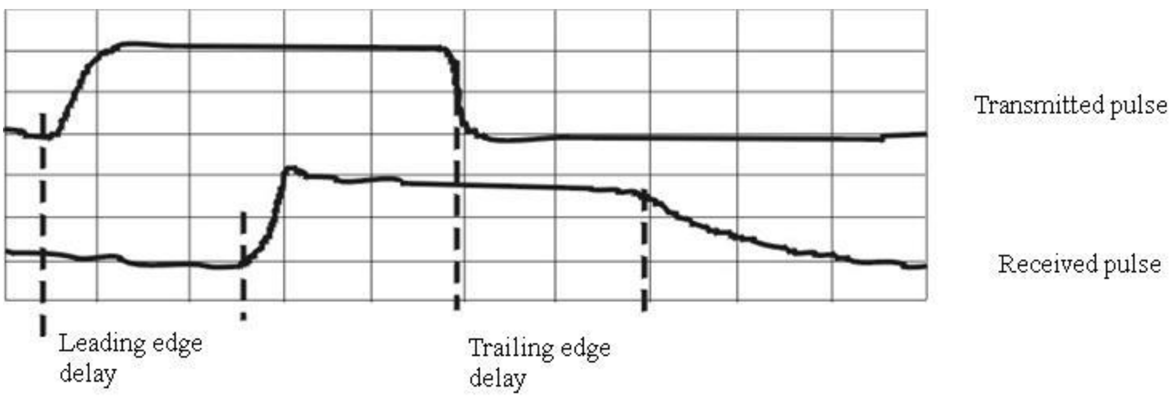
PROCEDURE

A 10 or 20 MHz dual beam oscilloscope is required.

Set up the system with the 5m cable attached. Connect the channel 1 probe of the oscilloscope to the output sockets on the transmitter unit which should be switched to 1MHz modulation. Adjust the CRO gain control to about 2V per division and the timebase to the highest frequency in the calibrated mode.

Adjust the triggering level until a stationary square wave trace is obtained. Measurements from the screen will enable the frequency to be calculated which is approximately 1 MHz.

Connect the probe for channel 2 to the sockets on the receiver. NOTE that the amplifier attached to the detector inverts the signal so that the oscilloscope must either use the channel inversion facility, if available, or the connections should be reversed at the receiver sockets i.e. connect the ground terminal of the CRO to +ve socket. Adjust the channel 2 gain control on the CRO to about 2V per div. With the two traces on the screen it should be noted that one is shifted along the x-axis relative to the other.



DATA TRANSMISSION

The system used in this apparatus is digital relying on switching electronics for its operation and as such is not suitable for sending analogue signals such as speech. Using other transducers it is possible to modulate the light beam using the amplified signal from a microphone and then reverse the process at the receiver end to hear the message. This would be the simplest use of fibre optics in communication.

In a digital system pulses of light are generated and the pulses are decoded at the receiver end. This is the basis of all computer data and modern telephone communications since the pulses are either on or off and there is no problem from the quality of the signal transmitted. It is, of course, possible to transmit the pulses as electrical signals along copper wires and the question immediately arises - why go to all the trouble of converting to light and then back again just to use a fibre optic system?

ADVANTAGES AND DISADVANTAGES

1. The light beams inside adjacent fibres cannot interfere with each other. Electrical signals radiate magnetic fields which cause electromagnetic interference (EMI) which can cause systems to malfunction. The data line using a light beam cannot disrupt other systems by causing EMI.

2. The data line using a light beam cannot itself be interfered with by other systems generating EMI.

3. Since there is no electricity involved in the fibre there can be no risk from faults which would generate sparks or heating effects.

4. The optical cable cannot transmit electricity and is immune to high voltage shock due to lightning strike etc.

5. Optical fibres are robust and less prone to breakage than copper wire equivalents.

6. The fibres are not susceptible to dampness or other climatic problems. This avoids the problems of electrical signals in underwater cables.

7. Optical fibres are very inexpensive compared to copper metal for wires.

8. More channels of information can be passed along a single fibre than can be used in a single equivalent pair of wires.

FEATURES AND OPERATION

OPTICAL

The fibre optic cable comprises a 1mm diameter polymer single step index fibre inside a black, optically opaque, protective sheath. The polymer is more robust than a glass fibre and in this application has no significantly greater transmission losses. The fibre can be repeatedly bent without risk provided that the minimum curve radius is not less than 3.5cm. The fibre is mechanically attached to the couplings and optically polished to ensure minimum losses. The housings contain miniature lenses in front of the transducers to ensure correct optical alignment. The transmitter uses a simple LED emitting light at 660nm while the receiver uses a wavelength matched photodiode coupled to a wide bandwidth d.c. amplifier.

ELECTRICAL

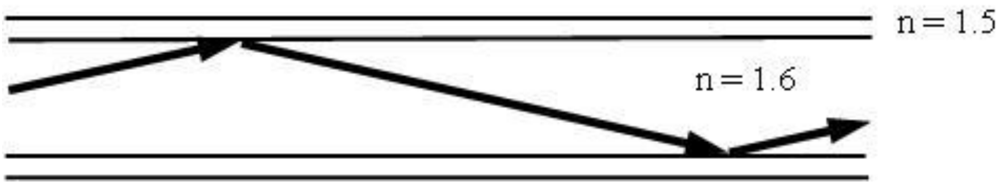
- **The transmitter** unit uses an integrated CMOS oscillator to provide a variable frequency audio signal in the range 1 to 400Hz. A second part of the oscillator produces a square wave pulse train of approximately 1MHz which can be used for speed of light investigations. Either oscillator can control the output LED which produces pulses of 660nm (deep red) light at the same frequency as the oscillator. A switch allows the operator to choose between the two frequencies. The unit is powered by a standard 9V PP3 battery.

- **The receiver** consists of a photodiode and integrated d.c. amplifier which drive a power output stage for a miniature loudspeaker. The gain of the power output stage is controllable from the front panel.

Both units have CRO monitor sockets coupled directly to the transducers so that quantitative data can be obtained.

DEMONSTRATING THE PRINCIPLES OF FIBRE OPTICS

Fibre optic cable relies on the principle of total internal reflection for its operation. A full treatment of this topic can be found in most physics text books but, in summary, if a light wave approaches the boundary between two transparent media of different refractive indices the wave will be reflected by the boundary provided that the incident refractive index is the greater and the angle of incidence at the boundary is greater than a certain minimum, or critical angle. If these conditions are met then no light energy crosses the boundary and there is no loss of energy from within the system. In a single step index fibre the core of the fibre is clad in a layer of material of lower refractive index and the light ray bounces down the fibre as shown in the diagram.



A large scale demonstration of this effect can be given using a bent acrylic rod or block and then the fibre coil from this apparatus used to demonstrate the real application.

- Hold one end of the fibre near to a light source (a ray-box lamp or desk lamp) and hold the other end about 2cm from the bench. The light passes along the fibre and is emitted in a miniature torch beam from the other end.

Applications of this effect involve any requirement where a cold light source is required, such as endoscopy in medical physics or where there would be a risk involved in having an electric lamp for illumination such as in inflammable environments.

- Multiple fibres from a single light source are used in aircraft control panels so that there is less heat generated than from hundreds of small lamps.

It should be noted that an *image* cannot be transmitted along a single fibre since the multiple reflections and path lengths prevent this. In an endoscope thousands of tiny fibres lie side by side inside an outer sheath and each fibre transmits the information about one part of the image. At the output end the fibres are in the same orientation and the image is then transmitted. Lenses are required to focus the image in a usable way.

USING THE TRANSMITTER AND RECEIVER UNITS

Each unit requires a a 9volt PP3 battery for operation. Remove the drawer from the battery enclosure on the side and insert the battery by pressing its base against the spring so that it fits in place. Observe the correct polarity as shown on the bottom of the drawer. Return the drawer to the enclosure. The ON-OFF switch can be operated and if all is well the green LED will light when ON is selected.

The optical cable may now be plugged into the housings once the grey protective stoppers have been removed. Keep these stoppers for use when the system is packed away so that dust is prevented from entering the optical systems. Even though the housings are colour coded (blue on the receiver and grey on the transmitter) the cable can be used either way round.

NOTE:

The cable and its terminations are very robust but care should be taken when plugging them into the system housings. A small force is required to overcome the snap-in facility and the housing should be held rather than the cable especially during removal. The large ring next to the ferrule is designed to provide a gripping surface.

Having demonstrated the light transmission properties of the cable the transmitter unit can be used to show that it produces pulses of deep red light. Use the AUDIO setting on the modulation switch with the control fully anticlockwise to get a really low frequency.

If the cable is now attached to the receiver unit with the power switch ON clicks will be heard from the loudspeaker behind the front panel grill. The volume of the sound is controllable over a small range with the GAIN control.

As the modulation frequency on the transmitter is increased the frequency of the received signal increases until an audio tone is heard rather than discreet clicks.

THEORY

Light takes a finite amount of time to travel the length of the fibre so the received pulse is delayed relative to the transmitted pulse. The wave “shape” changes due to electrical and optical coupling effects at this high frequency but the leading and trailing edges should be clearly identifiable on the pulse train. Using the oscilloscope calibrations measure the time delay from the start of a transmitted pulse and the start of the received pulse (leading edge) and also for the trailing edge. The pulse lengths are seldom equal due to losses so an average is taken of these two delays.

Repeat using the 20m cable coil and measure the average pulse time delay.

The measured delays are due to propogation delays in the electronics as well as due to the transmission delay of the light beam. The electronics delays should remain constant regardless of the optical path length so by subtracting the 5m delay from the 20m delay we should get the time delay due only to the increase in path length from 5m to 20m.

Typical results:

5m coil.	Leading edge delay 0.15μs	Trailing edge 0.12μs	Av. 0.135μs
20m coil	0.26μs	0.20μs	Av 0.23μs

Time delay due to 15m additional path length 0.23 - 0.135 = 0.095μs

Speed of light through the fibre = distance/time = $15/0.095 \times 10^{-6}$

$= 1.6 \times 10^{8}\ ms^{-1}$

Since the fibre has refractive index approx 1.6 and this is the inverse ratio of the speed of light in a vacuum to that in the fibre the expected result should be:

$3 \times 10^{8} / 1.6$ which is 1.87 ms^{-1}. Allowing for the various experimental errors this is an acceptable result.

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