PHYSICS 359

THE SPEED OF LIGHT

INTRODUCTION:

The first evidence that light propagates with a finite speed was given by R mer in 1675, when he reported observations that the eclipses of the moons of Jupiter had durations which were either longer or shorter, depending on whether the earth was receding from or approaching Jupiter. The first accurate measurements of the speed of light were made in the nineteenth century, starting with Fizeau in 1849, who obtained a result within 5% of the presently accepted value, using a rapidly rotating toothed wheel to measure the propagation time to and from a mirror at a distance of about 9 km. Modern measurements of the speed of light are made by quite different methods, such as making very accurate measurements of both the wavelength and frequency of a particular emission, e.g. a helium-neon laser. Very recently, it was decided to define the speed of light in vacuum as exactly 299,792,458 m/s. This effectively changes the definition of the metre from the length of a metal bar kept in Paris to the distance travelled by em waves in vacuum in 1/299,792,458 sec. See a first year text book for further details (Halliday and Resnick has a section devoted to the topic).

In this experiment you will determine the speed of light by modulating a light source, and observing the phase shift in the modulation as the distance between source and receiver is varied.

APPARATUS:

The speed of light will be measured in this experiment using a high speed light emitting diode (LED) modulated at 40 MHz as the source, and a PIN photodiode as the detector. The value of the speed of light is determined from the change in phase of the received signal as the detector is moved farther from the source.

To improve the accuracy of the phase shift measurement, both a reference signal from the transmitter and the detected signal are heterodyned with an oscillator (conventionally called a local oscillator) having a frequency about 100 kHz away from that of the transmitter. These two heterodyned 100 kHz signals will have the same phase difference as the original 40 MHz signals, but since a given phase difference at 100 kHz covers a much longer time, the phase measurement (which is really a time measurement) is much easier to make with the oscilloscope provided.

PRE-LAB PREPARATION:

Using fundamental trigonometric identities for sums and products, show that

(a) When two signals A and B of frequencies $\omega 1$ and $\omega 2$ are multiplied together (in the heterodyning process), the resulting signal contains the frequencies ($\omega 1+\omega 2$) and ($\omega 1-\omega 2$).

(b) If a third signal C of frequency $\omega 2$, but out of phase with B by φ is also multiplied by A, show that the phase difference between B and C is maintained in the resulting heterodyned signals.

Include these calculations in your lab report.

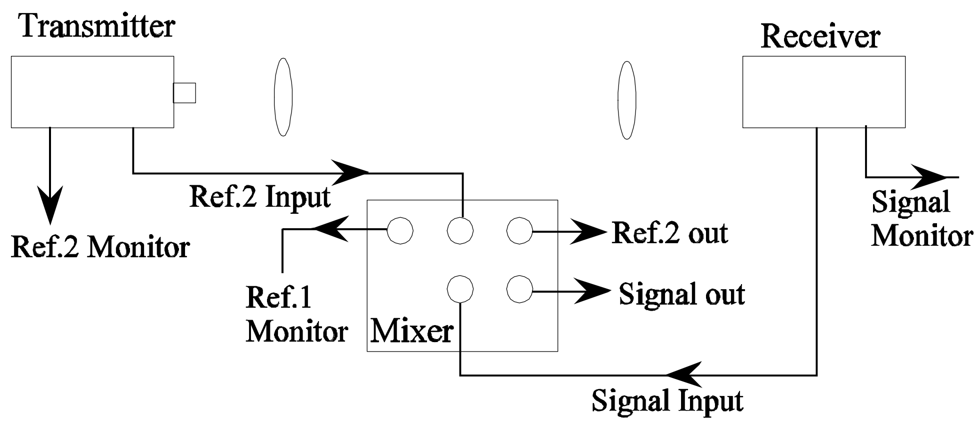

Fig 1. Experimental setup.

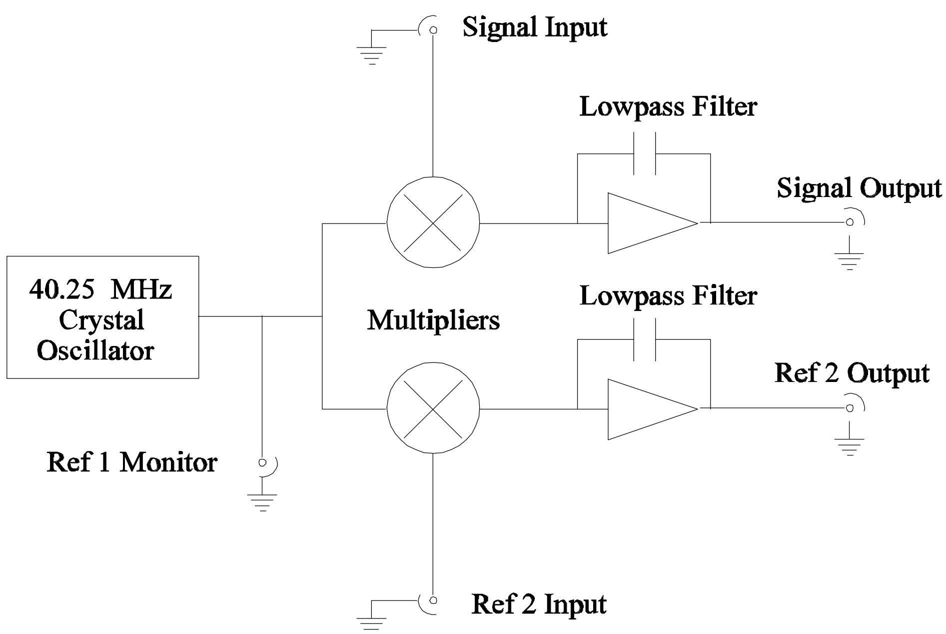

FIG.2 Schematic of mixer box.

PROCEDURE:

In the following,

REFERENCE 1 is the local oscillator (used for heterodyning)
REFERENCE 2 is the oscillator in the transmitter used to modulate the LED output.

WARNING: Make sure the horizontal sweep speed of the scope is not in uncalibrated position before making phase comparisons.

1. Preliminary measurements

(a) Use the Fluke timer/counter to measure the frequencies of the two oscillators (REF.1 MONITOR and REF.2 MONITOR.)

(b) Measure the frequency of the heterodyned reference 2 (REF.2 OUT).

(c) Place the detector near the transmitter and use a lens to focus the beam onto the detector. Observe the received signal (SIGNAL MONITOR) as you vary the light intensity on the detector by moving the lens. Observe the heterodyned signal (SIGNAL OUT) as you vary the light intensity. You should ensure that the sinusoidal nature of the modulation is not distorted by saturation in the detector.

(d) Connect REF.2 OUT and SIGNAL OUT to the two channels of the oscilloscope and measure the phase difference. This measurement will be more reliable if the two signals have the same amplitude. What part of the waveforms is most useful for accurate phase comparisons?

(e) What happens if you replace a cable from the mixer box to the transmitter or detector with a shorter or longer cable? What happens if you replace a cable from the mixer box to the oscilloscope with a shorter or longer cable? Explain.

2. Determination of the speed of light in air

Move the detector about one metre away from the transmitter, adjust the signal level and measure the phase difference again. Repeat for three or four more distances. From your measurements, determine the speed of light in air. You can improve the precision of your phase difference measurements by varying both the vertical gain and the horizontal sweep speed to enlarge the region of interest; however make sure you check the zero position of the trace, which may change as you go to high vertical gains.

3. Determination of the index of refraction of water

Since the index of refraction n for a medium is just $n = c/v$, where c and v are the speed of light in vacuum and in the medium respectively, one should be able to use the apparatus to measure n in a transparent material if the path length is long enough and if n is large enough to produce a significant time delay. Measure the added phase shift introduced when the tube of water is placed in the beam and calculate the index of refraction of water. With care in the selection of cable lengths and the distance between the transmitter and the detector, this measurement can be made on the highest sweep rate of the oscilloscope. It is important here to keep the signal and the reference at the same amplitude on the oscilloscope.

4. Speed of a signal in a coaxial cable

By using cables of various lengths, as in exercise 1(e) above, determine the speed with which electromagnetic signals propagate in the coaxial cables provided.