Some Experiments with Light and Sound.

Sambit Bikas Pal*

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Abstract

This work deals with the attempt to measure the speed of light in air. For the purpose of measurement of light a diode laser was used as a light source. An optical chopper was used for generation of light pulses. The time differences between the light pulses received by two photo-detectors, one placed right next to the optical chopper another kept in the path of the light after it gets reflected back from a mirror kept 30m away. Unfortunately the time difference could not be measured due to some problems mentioned later. The next attempt was made to measure the speed of sound(ultrasound) in air using a pair of resonant peizo-electric transceiver. I faced several difficulties here too as illustrated later on and unfortunately had to abandon the project due to lack of time.

1 Introduction

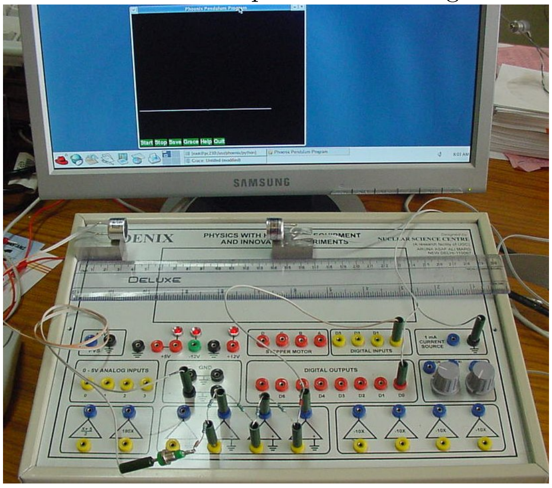
1.1 Background

This was not originally what I had intended to do. My initial idea was to measure velocities of the order of $1ms^{-1}$ using the *Doppler Effect* of light. The Doppler Effect in case of light in the non-relativistic limit is given by $\frac{\delta\nu}{\nu} = \frac{v}{c}$. But for velocities of the order of $1ms^{-1}$ and ν of the order of $10^{15}Hz$ (*visible light*) we get $\delta\nu$ of the order of 10^7Hz. So visible light is shifted by a frequency of the order of tens of megahertz. Such an immensely small shift is barely detectable even by Fabry- Perot interferometers of very high resolution. My idea was to utilise the formation of beats when two waves of almost same frequencies are superimposed. One part of a laser beam after splitting from a beam splitter would be allowed to fall on a mirror mounted on the moving body. By a arrangement of mirrors the reflected light would be superimposed with the other beam obtained from the beam splitter. Since the reflected beam is slightly shifted in frequency, it would form beats after superimposition with the original beam. The beat frequency will be same as the shift in frequency due to Doppler effect. A photo-detector of suitably fast response time would be able to see this as an amplitude modulated carrier wave, the amplitude oscillating with a frequency equal to the beat frequency. Though fast photo-diodes having response times of the order of nanoseconds are available in the market, they could not be procured at the time of this project, so it had to be abandoned.

*Indian Institute of Science Education & Research, Kolkata
Email : sambit@iiserk.edu.ms

1.2 Next Idea!

The previous idea having failed, at the suggestion of Prof. Swapan Kumar Datta[1] next I tried to measure the velocity of light in air. The idea was to measure the time taken for a light pulse to travel a total distance of 60m. This ended up in failure, due to the same reason - nonavailability of sufficiently fast photo-detector. Having failed to get any useful results with light, next work was to attempt to measure the speed of sound in air. The aim was to determine the time interval between creation of a ultrasonic pulse and its reception by a resonant peizo-electric crystal kept some distance away using the PHOENIX[2] Interface Kit. The experimental arrangement was like the following:



Not my actual setup, image taken from NSC's website.

2 Experimental.

2.1 Materials and methods.

2.1.1 Experiment with light.

Materials Required:

- Diode Laser
- Optical Chopper
- Photo-transistors- 2N5777
- Photo-transistors- L14G1
- Oscilloscope
- LM339 Quad Comparator
- Beam splitter & Mirror

[1]IISER, Kolkata
[2]Physics with HOmemade EquipmeNts and Innovative eXperiments, IUAC, New Delhi.

Using the beam splitter, the laser light was split into two beams. One of the beam was made to fall directly on a photo-diode. The other beam was incident on a distant mirror, and the reflected ray, was incident on another photo-transistor. The optical chopper was creating short pulses of laser light. The time difference between arrival of pulse in the two photo-transistors gives the time taken by light to travel to and back from the mirror. The distance between the light source and the mirror was 30m. If the time difference is δt sec then speed of light c = $\frac{30}{\delta t} ms^{-1}$. The outputs from the two photo-transistors were connected to two channels of an oscilloscope. Since the photo-transistors had very large response time(around 200μs), it was not possible to observe the time difference between pulses directly from their outputs. A comparator chip (LM339) was used to get a sharp fall, once the signal reached a certain value. The time difference between the two sharp falls due to output from the two photo-detectors could be observed on a dual channel oscilloscope. I also tried with the photo-transistor L14G1, which comes with the PHOENIX Interface, having a rise time of 5μs. This time no comparator was used, and the signal was observed directly.

2.1.2 Experiment with sound.

Materials Required:

- Pair of resonant piezo-electric transceivers
- PHOENIX Interface along with a PC

The piezo-electric transceivers were connected to the PHOENIX Interface kit. A small piece of Python code was used to produce the pulses and measure the time between the transmitter producing one pulse and the receiver receiving the same. The code used was as follows:

```
import phoenix
import time
p=phoenix.phoenix()
i=0
while(i<100):
        i=i+1
        a=pulse2ftime(0,0,13,30,1)
        print a
        time.sleep(0.1)
print"Done"
```

The digital output D_0 is connected to the transmitter, while digital input D_0 is connected to the output of the receiver after amplifying the signal using op-amps. The library function

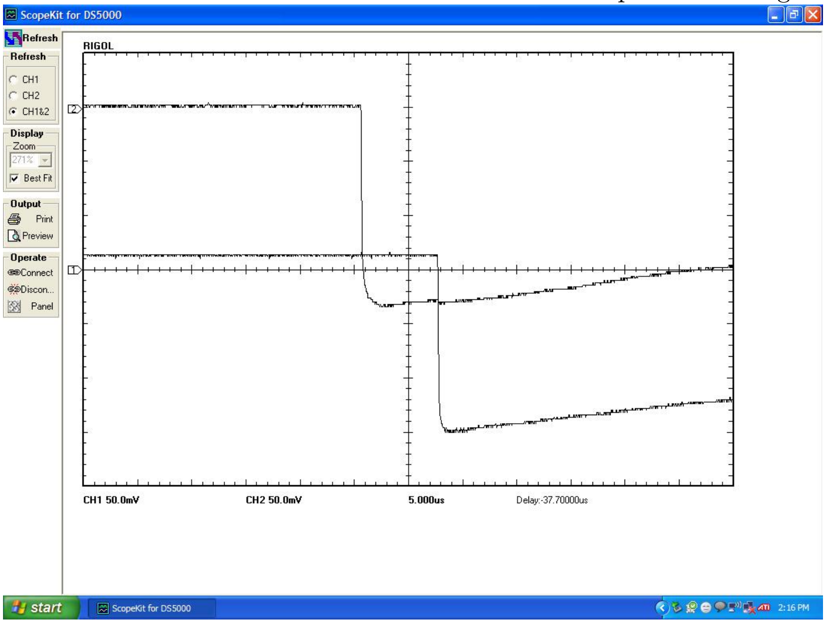
```
float=pulse2rtime(Int Pin1,Int Pin2,Int Width,Int Deadtime,Int Pol)
```

Generates a pulse on pin_1 and returns the time interval from that pulse to the rising edge on pin_2. The pair of transceivers were kept facing each other directly, as high frequency ultrasonic waves travel in almost straight lines.

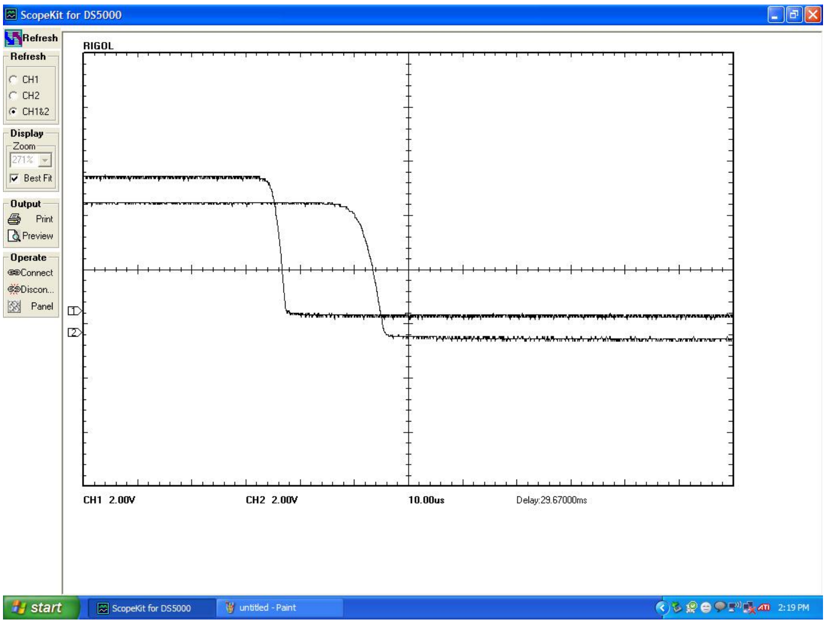
3 Results and Discussions

3.1 Light

The curves obtained from the dual channel oscilloscope have been given below:



It is evident from the curve that the difference between the two signals is 1.3μs



The time difference this time between the two pulses came to be around 2.4μs

Distance between the source and mirror = 30m
So net distance travelled by light = 2*30m = 60m
Hence time differences of 1.3μs and 2.4μs correspond to velocity of light being $4.61 * 10^7 ms^{-1}$ and $2.50 * 10^7 ms^{-1}$ which are an order of magnitude less than the accepted value. The most probable reason for this anomaly is that, the time lag between the two pulses that is being observed are originating from some other sources like the propagation delay of the electronic circuits used.

3.2 Sound

Due to lack of time, this experiment has been temporarily stalled, but will be completed soon. However the initial results are a bit anomalous. One of the problems I faced during this experiment was the electronic circuitry was picking up a RF signal of 30kHz from some unknown source. The signal was being amplified greatly, and it was interfering with the measurements. Another notable observation was that when any metallic block was kept in between the transmitter and receiver, the time taken by sound to travel the distance between the transmitter and receiver increased. If the ultrasonic waves were passing through the metal block, then the time should have decreased as sound travels faster through metal. The probability of the sound waves passing through the metal block was however very low, due to the huge impedance mismatch between air and metal. It may be possible that the sound waves were bending around, or somehow getting reflected from some nearby objects and reaching the receiver. However without further experimentation it would be difficult to ascertain the exact cause.

4 Conclusions.

None of the experiments yielded satisfactory results. In some cases the cause of the problem and possible solutions could be determined. Like in the case of light, the main trouble was being caused by the slow response times of the photo transistors. Use of faster photo detectors is expected to solve the problem. In the second case however further experimentation is necessary, for determining the sources of trouble. In fact I am interested to continue the experiments, during the winter break, if I am given the opportunity to do so.

5 Acknowledgments

I would like to convey my heart-felt gratitude to Dr. S.K. Datta[3], Dr. R. Bhattacharya[4], Dr. B. Pal[5], Dr. A. Dasgupta[6] and Dr. A. Poddar[7] for their invaluable guidance and help in every step of the work. I am also greatly indebted to Mr. S. Malo[8] for his kind help all throughout the project.

[3]Dept. of Phys, IISER Kolkata
[4]Dept. of Phys, IISER Kolkata
[5]Dept. of Phys, IISER Kolkata
[6]Dept. of Phys, IISER Kolkata
[7]Dept. of Phys, IISER Kolkata
[8]IISER Kolkata

6 References

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- Wikipedia, http://en.wikipedia.org