

Determining speed of sound through Doppler's Effect

Abhishek Dasgupta 06MS07

April 30, 2007

Abstract

My aim in this experiment is to determine the speed of sound using Doppler's Effect. I see the frequency shift as a buzzer moves on a circumferential path. From this frequency shift I can easily calculate the speed of sound using a formula, as long as we know the speed of the buzzer, which I calculated using a stopwatch.

1 Introduction

The Doppler effect, named after Christian Doppler, is the change in frequency of a wave that is perceived by an observer moving relative to the source of the waves. For waves that propagate in a wave medium, such as sound waves, the velocity of the observer and of the source are reckoned relative to the medium in which the waves are transmitted. Here we will be considering the simple case of doppler effect in sound.

The Doppler shift is given by

$$f' = \left(\frac{v - v_o}{v - v_s} \right) f$$

where f is the original frequency, v the velocity of sound, v_o the velocity of observer and v_s is the velocity of the source of sound.

Our **objective** is to determine the speed of sound.

2 Procedure

First we mounted the buzzer on a wheel, as shown below:



and the observer is my laptop with integrated microphones. The sound is recorded, first in the static condition to find out the original frequency, f and a Fast Fourier Transform is done on the recorded sound which shows me the intensity/frequency distribution. From this graph it is easy to pick out the sound frequency.

Another sound is recorded, this time while rotating the wheel at a speed of around 5 m/s using a DC Motor. The frequencies are again seen by doing an FFT.

Now, as by the earlier formula, we can get the velocity of sound as shown below: (observer at rest)

$$f' = \left(\frac{v}{v - v_s \cos \theta} \right) f$$

$$\Rightarrow \frac{f}{f'} = 1 - \frac{v_s \cos \theta}{v}$$

As we will be taking the two cases when the frequency is at extremes, i.e. when the object is moving away ($\theta = \pi$) or it is approaching directly ($\theta = 0$); so then we get the two cases as:

$$\frac{f}{f_1} = 1 - \frac{v_s}{v}$$

$$\frac{f}{f_2} = 1 + \frac{v_s}{v}$$

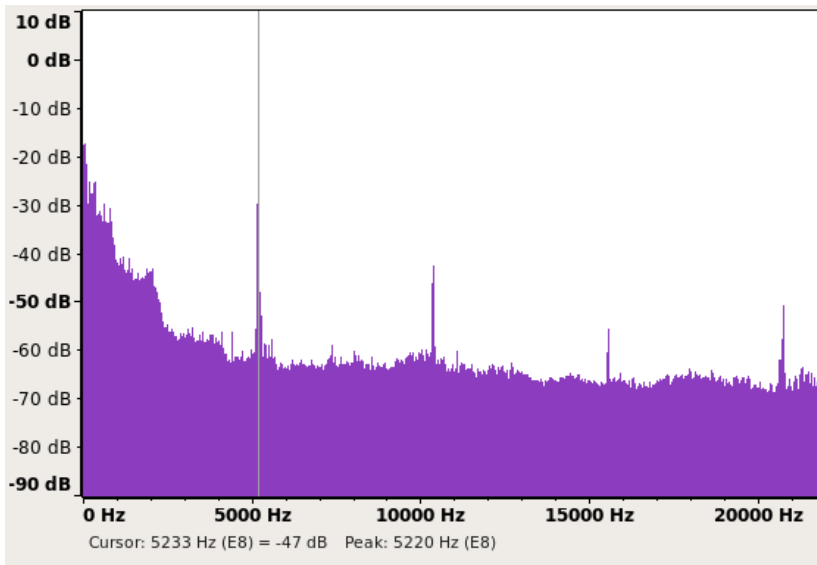
Subtracting, we get:

$$f \left(\frac{1}{f_2} - \frac{1}{f_1} \right) = \frac{2v_s}{v}$$

This is the formula I will use for the calculation of speed of sound.

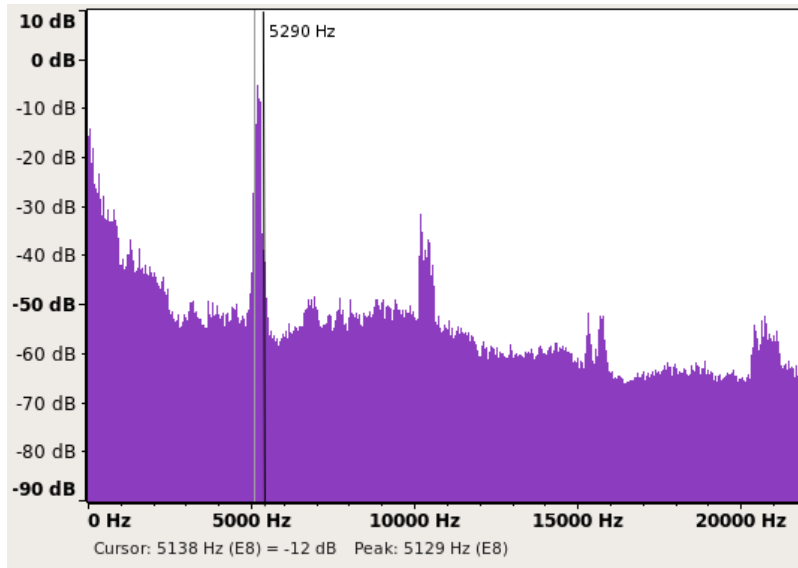
3 Observations

1. By using a stopwatch on my mobile, I estimated the speed of the buzzer to be about **5.17** m/s. This I did by measuring the time period, calculating the frequency and using the formula $v = 2\pi fr$. The radius was measured to be 0.32 m.
2. Graph I got under static condition:



So here the peak is at 5220 Hz. This is f .

3. Now we move on to the analysis of the sound which was taken while the buzzer was being rotated at 5 m/s. The graph is as shown:



As we see the peaks are at 5129 Hz and 5290 Hz, on either side of the central peak, as we expected. (For we should get two peaks corresponding to when the source is moving away, and the source is moving closer to the observer, respectively). So we get our f_1 and f_2 .

By substituting these values in the formula, we get:

$$5220 \left(\frac{1}{5129} - \frac{1}{5290} \right) = \frac{2 \times 5.17}{v}$$

From this we get $v = 333.8$ m/s.

4 Conclusion

In this experiment, a buzzer of frequency 5220 Hz was mounted on a rotating wheel. The frequency shift was detected by analysing the sound waveform; from this we got the two frequencies on either side of the mean, and using that we calculated the velocity of sound to be 333.8 m/s, which agrees with the expected value of $v \sim 300$ m/s.

5 Endnote

Precautions, Pitfalls, Improvements

While doing this experiment, there were many pitfalls and problems, which I cleared up with the help of the excellent guidance of my teachers. In the original version of the experiment, our plan was to use a condenser microphone to feed the sound input into the PHOENIX, where we would use the CRO program to see the waveform. Unfortunately, the condenser microphone wasn't sensitive enough to detect the slight frequency difference; as a result, when we analysed the waveform data in Scilab using FFT, there was no appreciable difference.

Then we fed the input of the condenser microphone to a digital storage oscilloscope; unfortunately here too, though we could detect the waveform change, the frequency it was reporting oscillated between three values 5556, 5714, 5882 Hz, for **both** the static and the moving condition of the buzzer.

Finally, it occurred to me that I could simply record the sound using a good sound recorder, and simply do an FFT on it. So that's what I did.

So some of the precautions ...

- Buzzer should be at constant frequency; our buzzer's frequency varied a bit.
- The receiver should be sensitive enough.
- Sufficient detail must be there in the waveform, for the FFT to successfully give the actual values.
- The sound input must within allowable range of the microphone used, or we'll get a cutoff.

Another thing that we could have done is verifying the speed of sound through another experiment such as resonance in air column. If we can accurately identify the speed of sound, then we can turn the experiment around to measure the speed of the buzzer. In real life, the Doppler Effect is used extensively to measure the velocity of objects which are emitting sound. A practical example is measuring the velocity of a train by observing the frequency shift of its whistle. It is extensively used in astronomy to determine the speed at which galactical objects move towards or away from us.

6 Acknowledgements

My heartfelt thanks to Dr. Swapan Kumar Datta, who helped me at every stage of the experiment, including giving ideas on how to setup the apparatus, and on the procedure itself. Without his help, this experiment would not have been possible.

I also thank my other physics teachers, Dr. Ananda Dasgupta (who explained to me the concept of FFT), Dr. Somdatta Bhattacharya and Dr. Ranjan Bhattacharya, all of whom guided me and gave me useful tips to improve the experiment. I also thank Mr. Subhas Malo, for helping me in every step of the experiment.

Lastly, I thank our Director, Dr. Sushanta Dattagupta, for giving us this opportunity to express ourselves.

7 References

1. H.C. Verma, Concepts of Physics, Bharati Bhawan, pp 342-344.
2. http://en.wikipedia.org/wiki/Doppler_effect