D104. Doppler effect

Aim: examination of Doppler effect

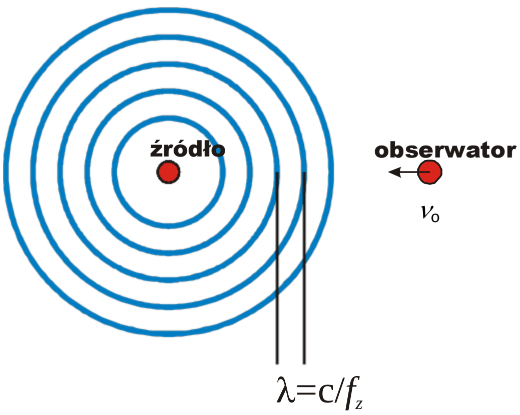
- *Measurement of velocity in uniform motion with the help of a photocell.*
- *Determination of changes in the frequency of sound caused by the movement of sound source.*
- *Measurement of velocity of a source of acoustic wave with the use of Doppler effect. .*

1. Introduction

The Doppler effect is phenomenon characteristic of waves. It occurs for all kinds of waves, in particular for water waves, acoustic waves and electromagnetic waves (light). It is observed when the source of waves and the observer move relative to each other, which leads to changes in the apparent frequency of waves.

In this experiment we will study the Doppler effect for a mechanical (acoustic wave) for two cases: a) when the observer moves and the source of waves is immovable and b) when the source of waves moves and the observer does not. Although it may seem that because of the relativity of motion there should be no difference, but the difference between these two cases is and it is the most pronounced if the velocity of the source of waves or the observer is close to that of the wave in the medium, it happens because the velocity of sound is constant with respect to the medium in which the sound waves move (air).

A) Moving observer



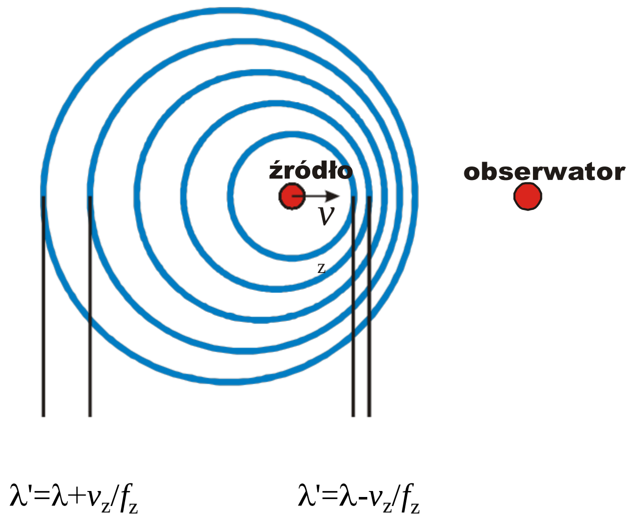
When the observer moves, the wavelength of the acoustic wave does not change, but its frequency measured by the observer, changes. The reason is that the observer meets the wave front more frequently if he/she moves towards the wave source and less frequently if he/she moves away from the wave source. For the observer moving at the velocity v_o towards the source, the wave apparently propagates at a greater velocity. The apparent wave velocity (in our experiment sound velocity) is a sum of the sound velocity in air, c, and the velocity of the observer, v_o. Thus, the frequency measured by the observer, f_o, is

$$f_o = \frac{c \pm v_o}{\lambda} \tag{A1}$$

Taking into account the expression for the wavelength in the medium, $\lambda = c/f_z$, this equation (A1) permits relating the frequency measured by the observer, f_o, with that generated by the source, f_z

$$f_o = f_z \frac{c \pm v_o}{\lambda} \tag{A2}$$

B) Moving source of waves



Let's consider the case when the source of waves moves at velocity v_z towards the observer. As the wave velocity with respect to the medium is constant, the distance between two subsequent wave crests (the length of the wave) is shortened by a certain value, s, in the direction of the wave motion. Therefore, the observed wavelength is

$$\lambda' = \lambda \mp s \tag{B1}$$

The value of s is the path covered by the source in the time equal to the period of the wave emitted, T, so $s = v_z T$. As the period of the wave is the reciprocal of its frequency, we get

$$\lambda' = \lambda \mp \frac{v_z}{f_z} = \frac{c}{f_z} \mp \frac{v_z}{f_z} = \frac{c \mp v_z}{f_z}. \tag{B2}$$

Because

$$f_o = \frac{c}{\lambda'}\,, \tag{B3}$$

we get

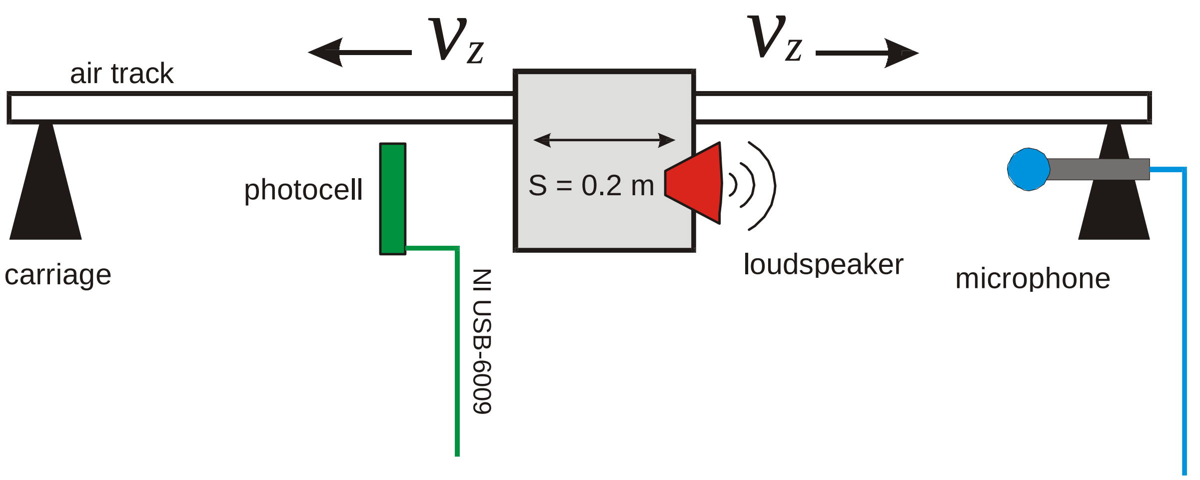
$$f_o = f_z \frac{c}{c \mp v_z}\,. \tag{B4}$$

After transformation of equations (A2) and (B4), we are able to use the Doppler effect for measurement of velocity of objects on the basis of the measured changes in the frequency of the wave they emit

$$v = c\frac{\Delta f}{f_z} \tag{C}$$

where $\Delta f = f_z - f_o$ is the difference in frequencies

2. Equipment



In the experiment you are asked to measure the velocity of a car of **S = 0.2m** in length, moving on the air track, making use of the Doppler effect. In our experiment, the source of acoustic waves is on the carriage, so it is the version with a moving source of acoustic waves. The signal generated from the source has a sinusoidal shape (ton) and its frequency and amplitude can be regulated. The signal is recorded by the fixed microphone and analysed in the program written in LabVIEW environment. With the use of advanced functions from this environment it is possible to accurately determine the frequency of the recorded sinusoidal wave. Measurement of the frequency of sound emitted from motionless source and that of the sound emitted from the source performing uniform motion at the velocity v_z, permits determination of Δf from equation (C), so also the velocity of the carriage. To verify the result, on the path of the carriage a photocell is mounted and when in uniform motion, the carriage blocks the sensor for some time dependent on the length of the carriage and its velocity. The signal from the photocell is recorded in the same program, so that it permits determination of the time of photocell blocking. Knowing the length of the carriage and the time of photocell blocking it is possible to determine the carriage velocity. Your task is to check the agreement between the results (the carriage velocity) determined by the two ways.

3. Experiment.

1) Start LabVIEW environment and download the program *Efekt Dopplera* which is on the computer desktop. If you have time look at the block diagram of the program.

2) Start the generator of sound attached to the carriage. This generator can emit sound signal of a few frequencies. At first set a high frequency, at the border of audibility. Set a minimum but sufficiently high amplitude (listening to a signal of a single tone for a long time is very unpleasant). Check if the program records correctly the generated signal.

3) Blow compressed air into the tube of the air track. Set the lowest possible pressure but high enough for the carriage to move with minimum friction.

4) Check if the fragment of the program responsible for measurements of the time of blocking the photocell works correctly; block the photocell and unblock it checking the effect in the program.

5) Start recording of the signal. Hold the carriage to be still, the signal recorded while it is still will be used for measurements of the frequency of sound for a motionless source of sound (f_z).

6) Without stopping the program, push delicately the carriage so that it moves with any velocity, when it reaches the end of the air track it reflects and changes the direction of motion. Because of the friction, the carriage will gradually slow down. Record the signal for

a long time in which the carriage has a wide range of velocities.

7) Stop recording of the signal and wait for data display. Switch off the sound generator (your colleagues will appreciate it). Set the cursors to mark out the period in which the carriage was motionless. Read off the frequencies corresponding to the zero velocity (f_z).

8) Find the fragments of the plot corresponding to the time ranges in which the photocell was blocked by the, *dt*. Change the scale of the plot, if necessary. Use the cursors to determine the time of photocell blocking by the carriage. Place the cursors at the sites at which the signal from the photocell rapidly decreases and rapidly increases. Record the frequency of the sound, f_o, when the photocell is blocked by the carriage (the signal on the plot selected by cursors is the only one which is analysed).

9) Making use of the measured times, *dt*, and frequencies, f_o, calculate the velocity of the carriage.

10) Assuming that in the time when the carriage blocked the photocell its velocity did not change (uniform motion), find the velocity of the carriage, $v_{z,1}$, knowing the time of photocell blocking, , *dt*, and the length of the carriage *S*.

11) Use equation (C) and substitute the values f_o and f_z to calculate $v_{z,2}$. Assume that the speed of sound in air is c=346m/s (at T=25^{o}C).

12) Compare the velocities $v_{z,1}$ and $v_{z,2}$. Estimate the errors of measurements. Estimate the uncertainty related to the finite width of the photocell.

13) Plot the dependence $v_{z,1}(v_{z,2})$. Discuss the correlation between these two quantities on the basis of the analysis of regression.

14) Switch on the generator, change the frequency and start again from point (5).