# DOPPLER EFFECT

## OBJECT

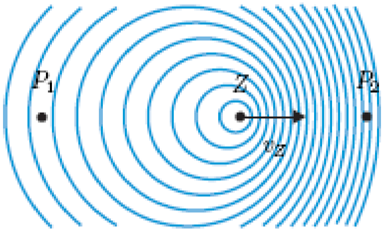
Measure frequency shift of an ultrasound wave if the observer and the source are in mutual motion.

## THEORY

### Doppler effect

If the source (transmitter) and the observer (receiver) of a sound wave are in mutual motion then the receiver detects another frequency than the source transmits. This phenomenon is called Doppler effect.

**Figure 1**




If the source moves, then the middle point of transmitted waves shifts in the direction of the vector of velocity $\mathbf{v}_Z$, so the wave surfaces in front of the source are thicken while wave surfaces behind the source dilute as shown on the Figure 1.
Source Z moves towards the observer $P_2$ with the velocity $v_Z$, which means, that it comes closer by the distance $v_Z T$ during each period T. Hence the wave crests in front of the source are not $\lambda = cT$ apart, where the $c$ is speed of sound, but they are λ' apart, where the $\lambda' = \lambda - v_Z T$, which is the wave length registered by the observer. The corresponding frequency i

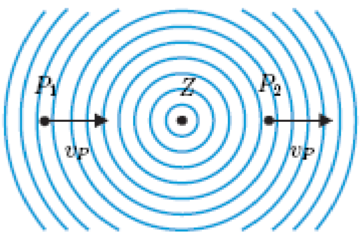
$$f' = \frac{c}{\lambda'} = \frac{c}{\lambda - v_Z T} = \frac{c}{cT - v_Z T} = \frac{c}{c - v_Z} f, \tag{1.1}$$

where f= 1/T is the frequency emitted by the source. If $v_Z < c$, then $f' > f$ and the observer registers higher frequency.
If the source moves away with the $v_Z$ from the observer ($P_1$ on the figure), then the distance between wave crests extends, so the wavelength registered by the observer is $\lambda' = \lambda - v_Z T$ and the corresponding frequency

$$f' = \frac{c}{c + v_Z} f. \tag{1.2}$$

Observer $P_1$ then registers lower frequency.

**Figure 2**




Another situation appears when the source is still and the observer moves, as shown on the Figure 2. The observer $P_1$ moves towards the source with velocity $v_P$, so he shortens periods between his encounters with neighboring wave crests. Relative wave speed form the point of view of the observer $P_1$ is $c' = c + v_P$, while the wavelength remains unchanged $\lambda = cT$. The frequency registered by the observer is

$$f' = \frac{c'}{\lambda} = \frac{c + v_P}{cT} = \frac{c + v_P}{c} f. \tag{1.3}$$

Relative wave speed form the point of view of the observer $P_2$ is $c' = c - v_P$ , so the frequency registered by the observer is

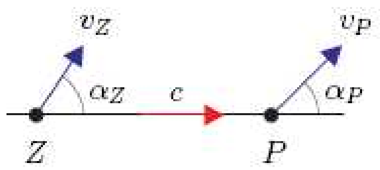
$$f' = \frac{c - v_P}{c} f.$$

(1.4)

If both source and observer move, then the frequency registered by the observer can be obtained as combination of formulae 1.1, 1.2, 1.3 and 1.4.

$$f' = \frac{c \pm v_P}{c \mp v_Z} f.$$

In case the observer and the source do not move on the same straight line, as shown on the figure, then the formula for the registered frequency changes into



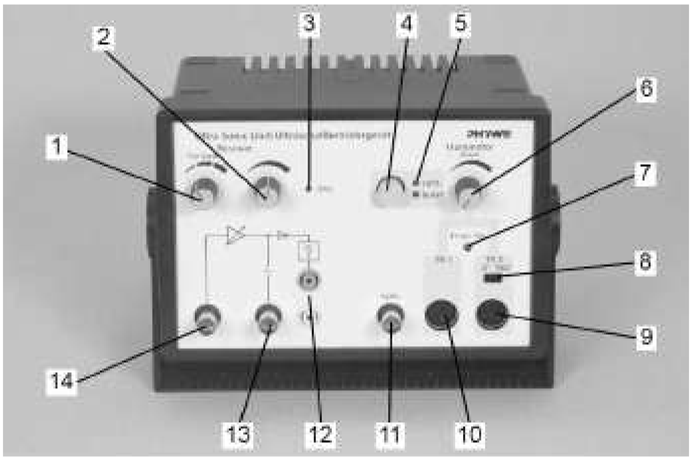

$$f' = \frac{c - v_P \cos \alpha_P}{c - v_Z \cos \alpha_Z} f.$$

# PROCEDURE

### Procedure of measurement

1. Check connection of all devices and get acquainted with the **Measure** program and with controls of the train.
2. Set the amplifier of the **ultrasound unit** (knob 1 and 2) and amplitude of the output signal (potentiometer 6) so that the frequency measurement would work also in extreme positions of the train. Place the optical gate in the middle of the railway, where the velocity is approximately constant.
3. Measure the frequency of received ultrasound wave for various velocities of the train and for both directions of motion. Repeat the measurement several times for each velocity and calculate the average value.
4. Check the room temperature and calculated the speed of sound according to the formula c= 331.06 + 0.61t [m/s, °C].
5. Compare measured values with theoretical calculations.

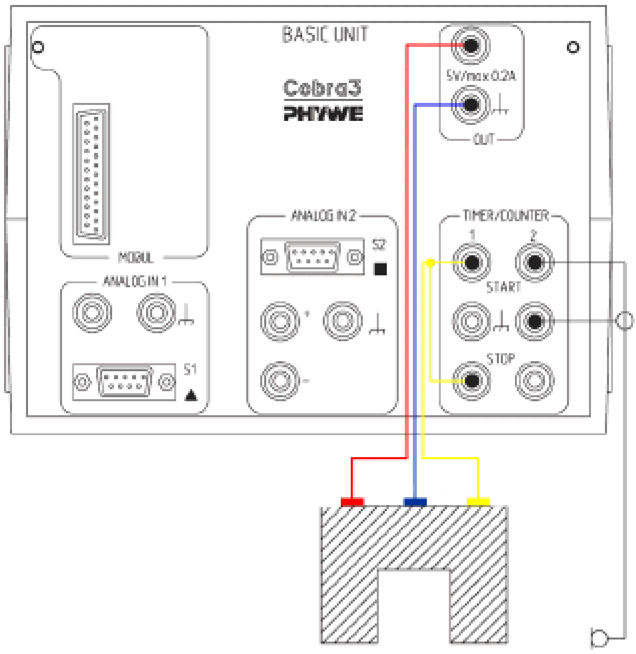
**Ultrasound unit controls:**
1 – three level switch of the input signal amplification; 2 – potentiometer for the continuous change of the input signal amplification; 3 – LED indication of amplifier overloading; 4,5 – operating mode setting and indication (continuous or burst); 6 – amplitude of the output signal; 7 – frequency correction of the ultrasound signal; 8 – phase switch of the output signal; 9,10 – connection of ultrasound converters (transmitters); 11 – analogous output of the signal; 12 – rectified output signal of the ultrasound converter; 13 – AC output of the amplified signal from the ultrasound converter; 14 – connection of ultrasound converters (receivers)




**Ultrasound unit**

**Wiring of devices**

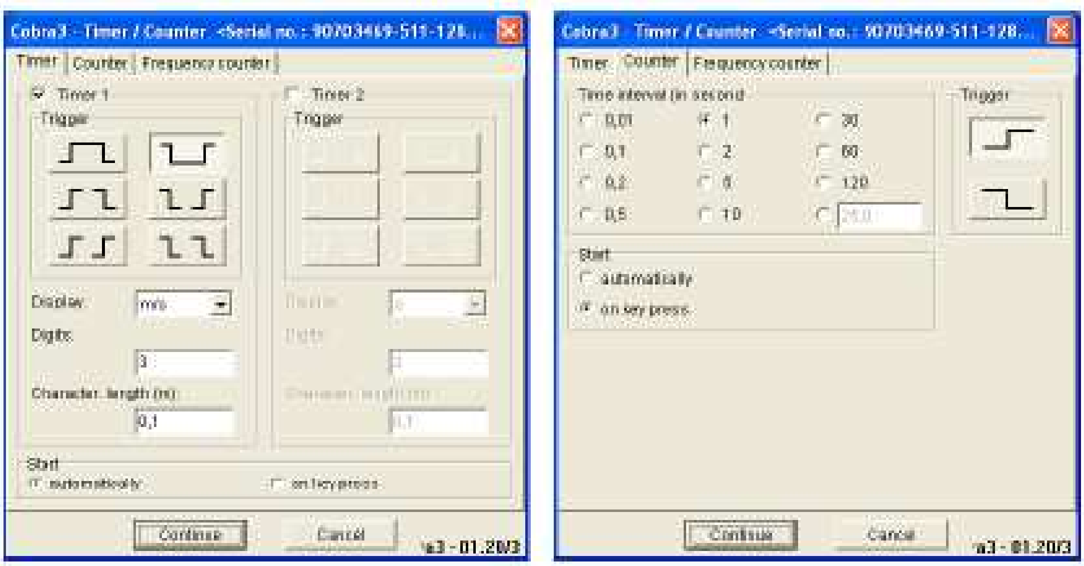
It is not necessary to disconnect devices after finishing the measurement, so do not do this. In case that your colleagues would do so, here is the procedure how to connect devices together. Connect the ultrasound receiver to the BNC connector of the ultrasound unit (No. 14). Connect AC output of the ultrasound unit (No. 13) with the **Timer/Counter** input of the Cobra3 unit. Take care of the polarity. Connect the ultrasound transmitter to the connector TR1 on the ultrasound unit (No. 10) and switch the ultrasound unit to the continuous mode (button 4, LED indication **Cont.**). Connect the optical gate with the Cobra3 unit according to the figure “Cobra 3 unit”. Connect the Cobra3 unit with the computer by the data cable.




**Cobra 3 control unit**

**MEASUREMENT SOFTWARE**

Run the program **Measure**. After it executes click the **New measurement** item from the **File** menu. One of two menus from the figure below should appear. If it doesn’t, check whether the item **Cobra 3 Timer/Counter** from the menu **Gauge** is checked.



### How to measure the train velocity

Click the Timer bookmark and make all settings the same like on the figure (left part). After clicking the Continue button a new window appears, where the train velocity is displayed. The measurement automatically repeats after every train passing through the optical gate. If you want to finish the measurement, press the **Stop** button.

### How to measure the ultrasound wave frequency

Click the counter bookmark and make all settings the same like on the figure (right part). After clicking the Continue button a new window appears. Measurement can be triggered either by clicking the **Start** button or by pressing the **Space**. If you want to finish the measurement, press the **Stop** button.

## SEMESTER PROJECT INSTRUCTIONS

Create a program, which depicts the variable density of acoustic wavefronts as a function of velocity, see Fig. 1 in the manual for the measurement. Take into account also supersonic velocities. The program should also be able to calculate the received frequency for the observer depending on the source frequency, the source velocity and direction represented by an angle and the observer velocity and direction represented by an angle.
Input parameters: observer velocity, observer angle, source velocity, source angle, speed of sound, sound frequency of the source