Ultrasonic Doppler effect

LEP 1.5.24 -15

Related topics
Propagation of sound waves, Doppler shift of frequency.

Principle
If a source of sound is in motion relative to the medium of sound propagation, the observed sound frequency is shifted for a resting observer or if an observer is in motion relative to the medium in which the sound propagates, the observed frequency is shifted both due to the Doppler effect.

Task
The frequency changes are measured and analysed for different relative velocities of source and observer.

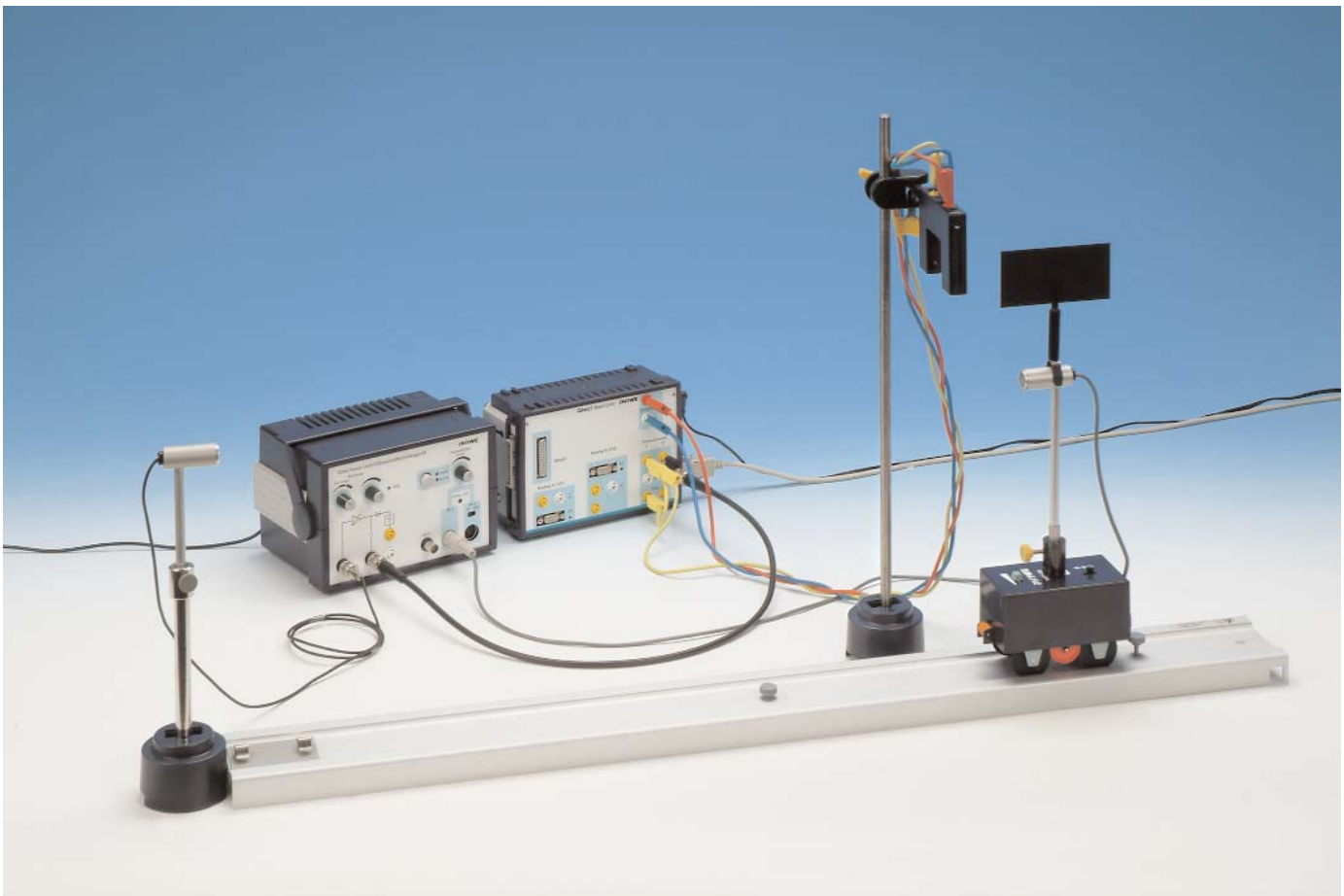
Equipment

Ultrasonic unit	13900.00	1
Power supply f. ultrasonic unit, 5 VDC, 12 W	13900.99	1
Ultrasonic transmitter on stem	13901.00	1
Ultrasonic receiver on stem	13902.00	1
Car, motor driven	11061.00	1
Attachment for car	11061.02	1
Round cell, 1.5 V, R 14 DIN 40865 (for car)	07922.01	2
Barrel base -PASS-	02006.55	2
Stand tube	02060.00	1
Connecting cord, l = 100 cm, red	07363.01	1
Connecting cord, l = 100 cm, yellow	07363.02	1
Connecting cord, l = 100 cm, blue	07363.04	1
Connecting cord, l = 10 cm, yellow	07359.02	1
Screened cable, BNC, l = 750 mm	07542.11	1
Adapter, BNC-socket/4 mm plug pair	07542.27	1
Track, l = 900 mm	11606.00	1
Cobra3 Basic Unit	12150.00	1
Power supply, 12 V-	12151.99	1
RS232 data cable	14602.00	1
Cobra3 Timer / Counter Software	14511.61	1
Double sockets,1 pair,red a.black	07264.00	1
Source holder, swivel-type	18461.88	1
Screen with plug, l = 100 mm	11202.03	1
Support rod, stainless steel, l = 600 mm	02037.00	1
Light barrier, compact	11207.20	1
Boss head	02043.00	1
PC, Windows® 95 or higher		

Set-up and procedure
In accordance with Fig. 1 and the circuit diagram Fig. 2.

a) Frequency measurement:
Connect the Cobra3 Basic Unit to the computer port COM1, COM2 or to USB port (for USB computer port use USB to RS232 Converter 14602.10). Start the program “measure” and then the “Timer/Counter” program in the menue “Gauge” and set the parameters for the frequency measurement according to Fig. 3. The “space”-key starts the measurement. The Transmitter Amplitude, the Reciever’s Pre Amplifier switch and gain control on the Ultra Sonic Unit may be set to medium values. Check whether the signal strength is sufficient for the counter to count at greatest distance between emitter and reciever. If not, increase the Amplitude setting and/or the gain setting.

Fig. 1. Experimental set-up for the case of a moving observer and sound source at rest



In general a possible overload on the reciever at small distances does not disturb the counter since it counts on the rise or fall of the signal and distortion of the signal does not necessarily affect this. Nevertheless the overload may be avoided by increasing the distance between Emitter and Reciever, i.e. put the transmitter or reciever (whichever is not on the car) some decimeters away from the end of the track, and thus decreasing the dynamic range of the signal level at smallest and biggest distance. If the overload-LED "gets stuck" (which does not affect the unit's function and may happen only with the Pre Ampl. switch at highest set) a short disconnection from the mains of the unit will reset it.
Select a speed setting on the car and measure the frequencies several times with the car resting, approaching and going away for both the source resting and the observer on the car and the observer resting and the source on the car – all for the same speed setting. Before starting the frequency measurement by hitting the "space"-key, be sure that the car moves with constant speed.

b) Speed measurement:
Now set the "Timer/Counter" program according to the parameters seen in Fig. 4. Measure the car's speed for both directions several times. Be sure that the screen passes through the light barrier after the car's velocity has become constant! The speed may differ between forward and backward direction due to the car's construction.

If the cars' speed does not remain constant but decreases with number of experiments with same velocity control setting, the batterys in the car may be low and you may need to replace them.

Repeat the experiment with different settings of the velocity control of the car.

Theory and evaluation
a) The medium has a speed of sound c. A source moves relatively to the medium with speed $v < c$ and oscillates with constant frequency f, the observer is at rest relatively to the medium.
The source moves during one period of the sources' oscillation

$$T = \frac{1}{f} \quad \text{the distance} \quad s = T \cdot v = \frac{v}{f} \ .$$

Thus the wavelength

$$\lambda = \frac{c}{f}$$

is shortened in direction of the movement to

$$\lambda' = \lambda - s = \lambda - \frac{v}{f} = \frac{c}{f} - \frac{v}{f} = \frac{c - v}{f}$$

and extended in the other directon to

$$\lambda'' = \lambda + s = \lambda + \frac{v}{f} = \frac{c}{f} + \frac{v}{f} = \frac{c + v}{f} \ .$$

With the frequency

$$f = \frac{c}{\lambda} \ ,$$

the frequency in direction of movement

$$f' = \frac{c}{\lambda'}$$

the frequency in the opposite direction

$$f'' = \frac{c}{\lambda''}$$

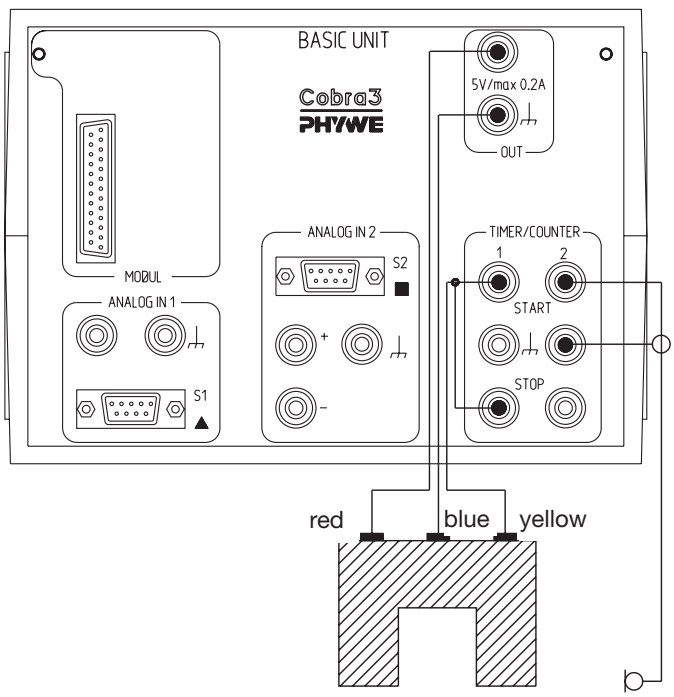


Fig. 2. Circuit diagram

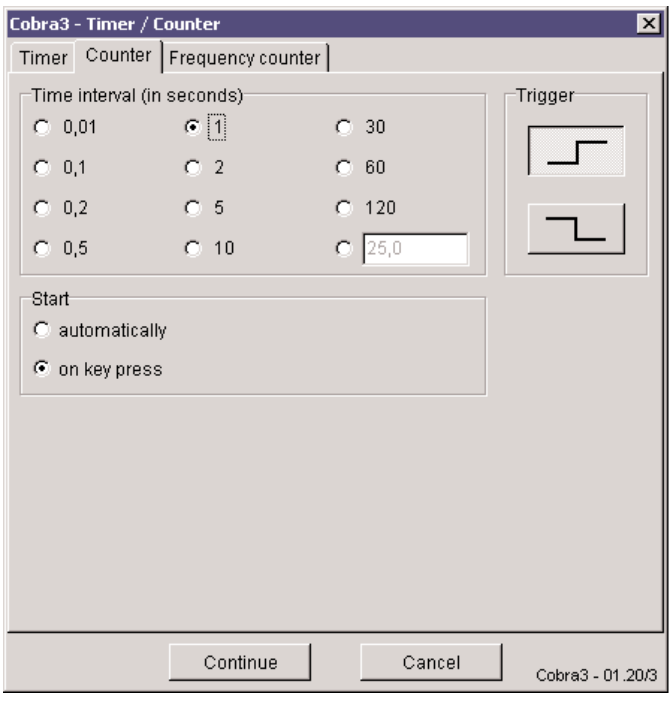


Fig. 3. Measuring parameters for frequency measurement

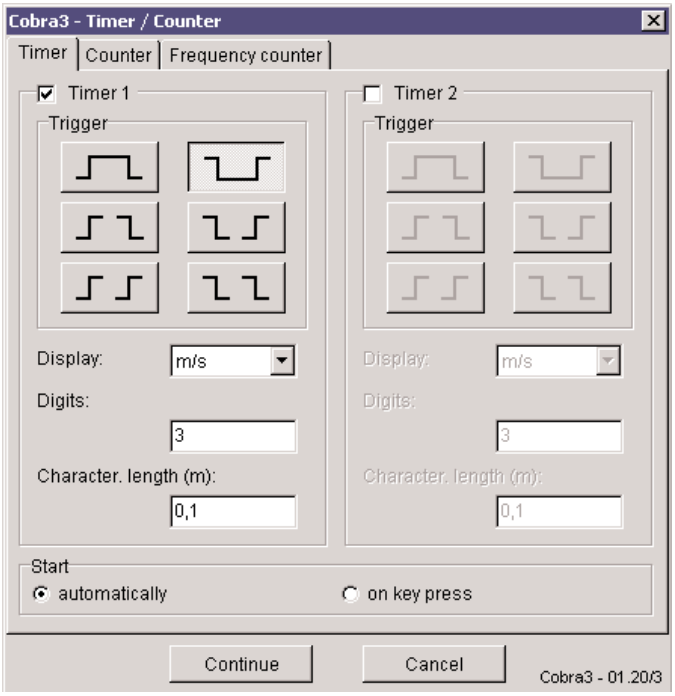


Fig. 4. Measuring parameters for velocity measurement

yields

$$f' = \frac{f}{1 - \frac{v}{c}} \qquad (1)$$

and

$$f'' = \frac{f}{1 + \frac{v}{c}} \qquad (2)$$

as the observable frequencies for a resting observer: the Doppler effect for the moving source.

b) The observer moves relatively to medium with speed $v < c$, the source oscillates with frequency f and is at rest relatively to the medium with speed of sound c.

In this case the wavelength is not altered and is still $\lambda = c/f$, with the wavefronts moving with speed c. So the observer encounters the wavefronts with a frequency

$$f' = \frac{c + v}{\lambda} = f \cdot \left(1 + \frac{v}{c}\right) , \qquad (3)$$

if the movement is towards the source or

$$f'' = \frac{c - v}{\lambda} = f \cdot \left(1 - \frac{v}{c}\right) \qquad (4)$$

if the movement is away from the source: the Doppler effect for the moving observer.

For small speeds v formula (1)

$$f' = \frac{f}{1 - \frac{v}{c}}$$

can be approximated by

$$f' = f\left(1 + \frac{v}{c}\right)$$

and formula (2)

$$f'' = \frac{f}{1 + \frac{v}{c}}$$

by

$$f'' = f\left(1 - \frac{v}{c}\right) .$$

This means, that there is nearly no difference for the cases of moving source or moving observer if the movement is slow compared to the speed of sound. With the slow speed the car in this experiment can get, it is impossible to see the difference.

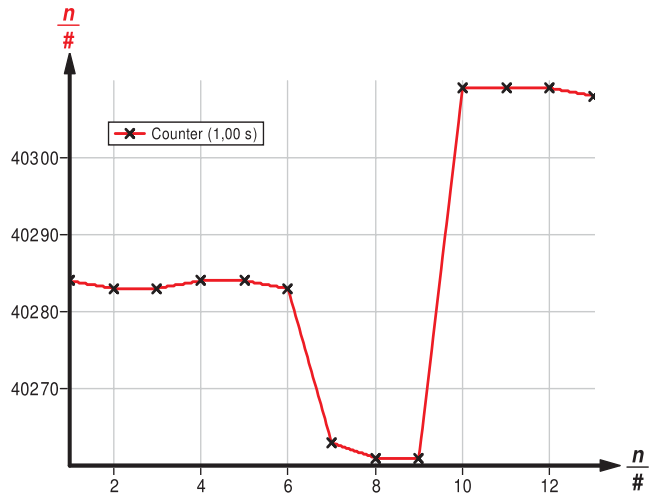


Fig. 5: Moving source

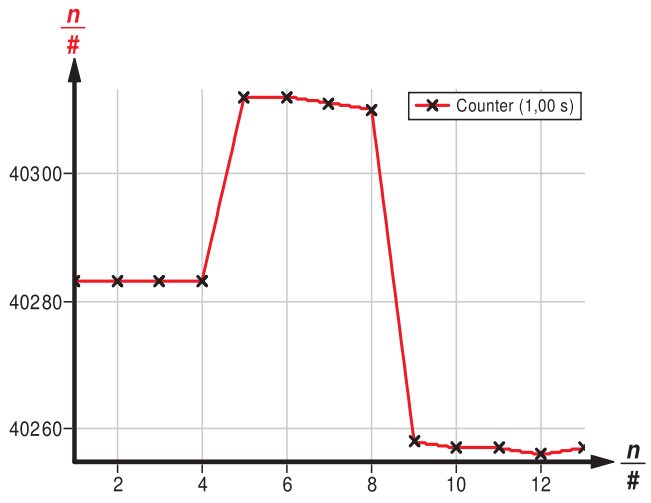


Fig. 6: Moving observer

The following table shows an example of values obtained in this experiment.

Table 1

frequency at rest: 40282 Hz	Movement toward		Movement away	
measured speed	0.22263 m/s		0.25812 m/s	
speed of sound: 340 m/s	moving source	moving observer	moving source	moving observer
frequency measured	40309 Hz	40311 Hz	40262 Hz	40257 Hz
frequency theoretical	40308.39 Hz	40308.38 Hz	40251.44 Hz	40251.42 Hz