

### Related topics

Longitudinal waves, sound pressure, Huygens' principle, Interference, Fraunhofer and Fresnel diffraction.

### Principle

Ultrasonic waves of the same frequency, amplitude and direction of propagation are generated by two sources positioned parallel to each other. The sources can vibrate both in-phase and out-of phase. The angular distribution of the intensity of the waves, which interfere with each other, is automatically recorded using a motor-driven ultrasonic detector and a PC.

### Equipment

Goniometer with reflecting mirror	13903.00	1
Power supply for goniometer	13903.99	1
Ultrasonic unit	13900.00	1
Power supply f. ultrasonic unit, 5 VDC, 12 W	13900.99	1
Ultrasonic transmitter on stem	13901.00	2
Ultrasonic receiver on stem	13902.00	1
Barrel base PASS	02006.55	2
RS 232 data cable	14602.00	1
Measuring tape, $l = 2\text{m}$	09936.00	1
Screened cable, BNC, $l = 75\text{cm}$	07542.11	1
Adapter, BNC-socket/4 mm plug pair	07542.27	1
Measure Software Goniometer	14523.61	1
PC, Windows <sup>®</sup> 95 or higher		

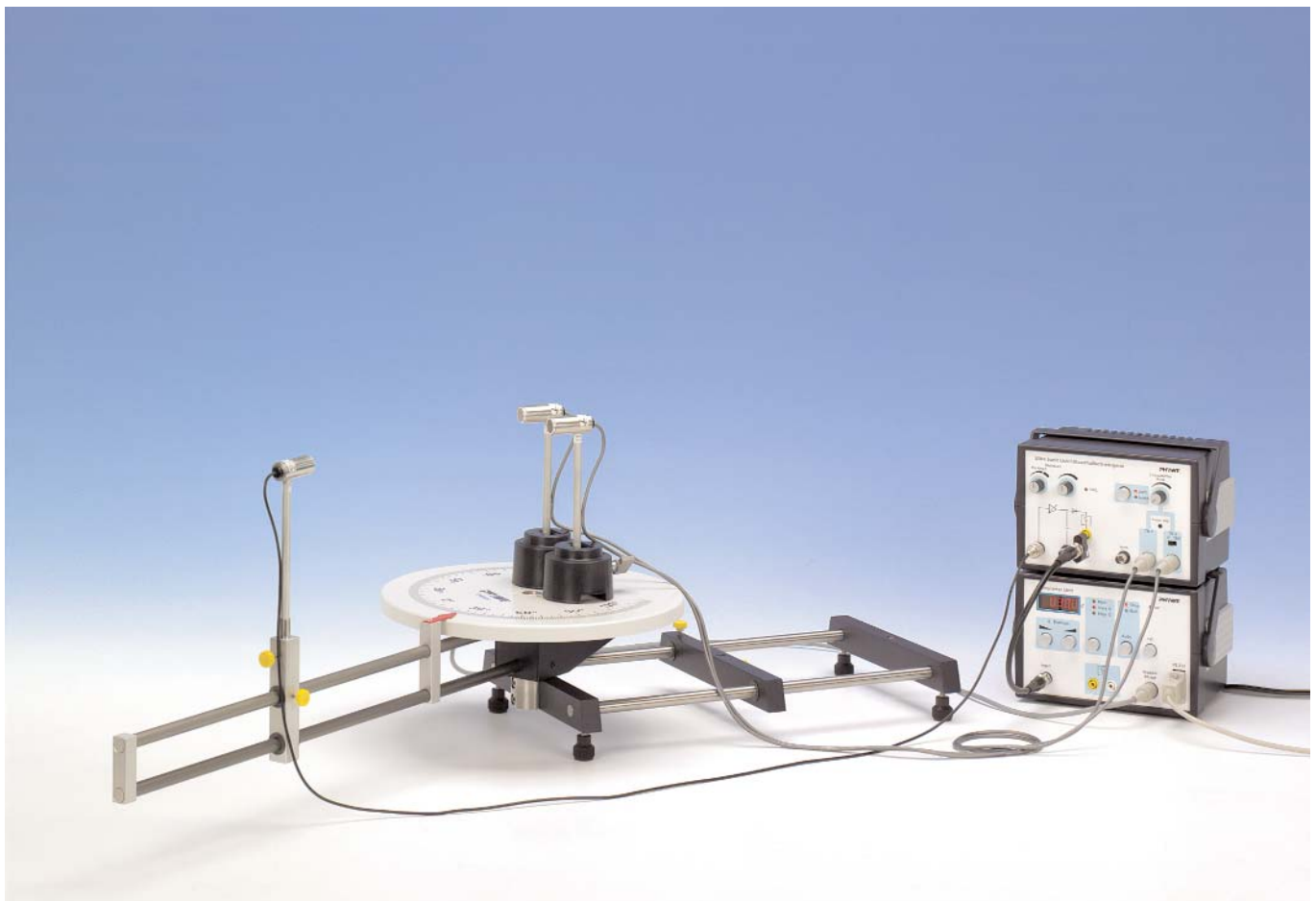
### Tasks

1. Determine the angular distribution of the sound pressure of two ultrasonic transmitters vibrating in  $-$ phase.
2. Determine the angular positions of the interference minima and compare the values found with those theoretically expected.
3. Repeat the measurements with the two ultrasonic transmitters vibrating out-of-phase.
4. Repeat the first measurement and additionally determine with the angular distribution of the sound pressure of each single transmitter.

### Set-up and Procedure

Set up the experiment as shown in Fig. 1. It is important that the two transmitters are each positioned parallel to the middle axis of the goniometer. They should be at a distance apart of 6.5 cm. This distance is given when the two barrel bases in which the transmitters are held touch each other. To achieve this, it is first necessary to remove the pin from the centre of the goniometer table. Ensure that the fronts of the transmitters are exactly above the  $90^\circ$  line on the goniometer table. The receiver is to be positioned at the end stop of the swing arm at the same height as the transmitters. Connect the transmitters to the diode sockets of the ultrasonic unit that are marked TR1 and TR2, and operate them in "Con" continuous mode. Connect the receiver to the left BNC socket (prior to the amplifier). Connect the analog output of the ultrasonic unit with the input of the control unit by means

Fig. 1: Experimental set-up.



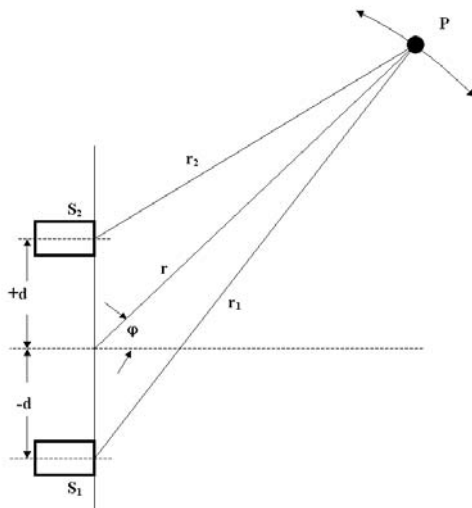


Fig. 2: Diagram for the determination of the path difference of two partial waves at measuring point  $P$ .

of the BNC cable, and the latter unit to the PC by means of the RS 232 data cable.

For control of the goniometer, connect the socket underneath the goniometer plate with the control unit.

To ensure proportionality between the input signals of the transmitters and their analog output signals, avoid operating the ultrasonic unit amplifier in the saturation range. Should such a case occur and the "OVL" diode light up, reduce either the transmitter amplitude or the input amplification. It is purposeful here to adjust the amplification at the zero position of the receiver so that the "OVL" diode just no longer lights up.

The reflecting mirror can remain but is then without any function.

5 Curves are to be recorded. With the "Cal" key of the control unit pressed, position the swing arm at  $0^\circ$ . Following this, deactivate the "Cal" function.

Use the software to set the range of swing of the receiver to  $\pm 60^\circ$ .

1<sup>st</sup> Measurement (see Fig. 3):

Operate the two transmitters in phase, with the TR 2 slide switch set at  $0^\circ$ .

2<sup>nd</sup> Measurement (see Fig. 4):

Operate the two transmitters in opposite phase, with the TR 2 slide switch brought to the  $180^\circ$  position.

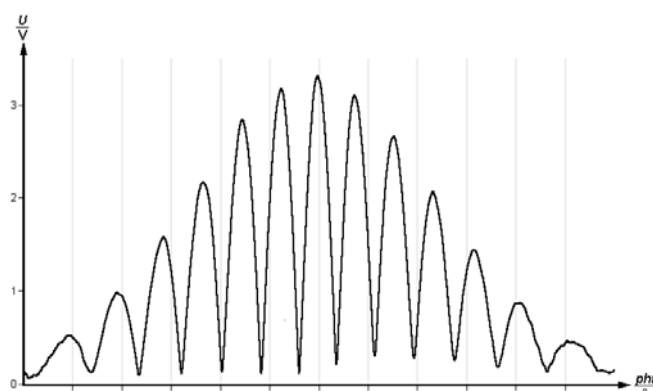


Fig. 3: Interference pattern of two ultrasonic emitters operating in phase.

3<sup>rd</sup> to 5<sup>th</sup> Measurements:

First use the software to set to 2 repeat measurements. Now repeat the 1st measurement. Following this, carry out the measurement with only one transmitter. Finally carry out the measurement with the other transmitter.

Obtain the result by plotting the three measurement curves so that their maxima each have the same height. To obtain a correct scaling for a common presentation of the three measurement curves, activate the "scale curves" function and then the "fit collectively" function (see Fig. 5).

**Note:**

To keep such interference to the measurement field as small as possible, do not carry out experiments in too narrow rooms or in the direct vicinity of reflecting surfaces (walls, cupboards etc.). It is recommended that measuring and supply instruments be installed as far as possible behind the two transmitters. Further to this, the person carrying out the experiment should not stand too close to the measurement field.

**Theory and Evaluation**

Two identical sources of sound  $S_1$  and  $S_2$  are at a distance of  $2d$  from each other and emit waves of the same frequency and phase perpendicularly to their connecting line (see Fig. 2). When the path difference  $\Delta r$  of the two waves at a point  $P$  is an even multiple of the wavelength  $\lambda$ , then the waves are subject to constructive interference.

Should  $\Delta r$  be an uneven multiple of  $\lambda/2$ , however, then they will interfere destructively with each other.

The path difference is:

$$\Delta \vec{r} = \vec{r}_1 - \vec{r}_2 \tag{1}$$

For  $r_1$  we have (cosine theorem):

$$\begin{aligned} r_1 &= \sqrt{r^2 + d^2 - 2|r| \cdot |d| \cdot \cos(\vec{r}, \vec{d})} \\ &= r\sqrt{1 + \frac{d^2}{r^2} - 2\frac{d}{r} \cos(90 - \varphi)} \\ &= r\sqrt{1 + \frac{d^2}{r^2} - 2\frac{d}{r} \sin \varphi} \end{aligned} \tag{2}$$

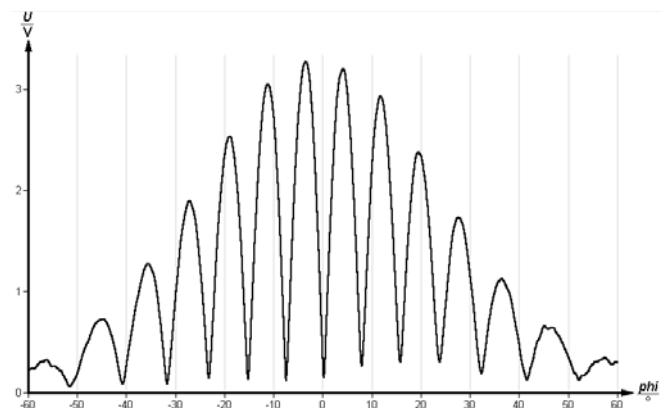


Fig. 4: Interference pattern of two ultrasonic emitters operating in opposite phase.

As  $r \gg d$ , the term  $d_2/r_2$  in the root can be neglected.

$$r_1 \approx r \sqrt{1 - 2 \frac{d}{r} \sin \varphi} \approx r - d \sin \varphi \quad (3)$$

The second approximation in equation (3) is also purposeful. On squaring the right side of equation (3), it is found that both terms are only then approximately equal when  $(r^2 - 2dr \sin \varphi) \gg d^2 \sin^2 \varphi$ . This is fulfilled under the given conditions ( $r = 55 \text{ cm}$ ,  $d < 10 \text{ cm}$  and  $\varphi < 60^\circ$ ), however. Analogously, for  $r_2$ :

$$r_2 = r + d \sin \varphi \quad (4)$$

We thus have for the path difference:

$$|\Delta r| = 2 d \sin \varphi \quad (5)$$

From which it follows for the angle of the maxima:

$$\varphi_{\max} = \arcsin n \frac{\lambda}{2d} ; \quad n = 0, 1, 2, 3, \dots \quad (6)$$

In the direction of the middle axis ( $\varphi = 0$ ), both partial waves always have the path difference null, so that an intensity maximum must always be given here.

The minima lie at the angles:

$$\varphi_{\min} = \arcsin \frac{2n + 1}{2} \cdot \frac{\lambda}{2d} ; \quad n = 0, 1, 2, 3, \dots \quad (7)$$

Fig. 3 shows the interference pattern of two ultrasonic sources which emit waves that are in phase and of the same frequency perpendicularly to their connecting line. The distance between the two sources is  $d = 6.5 \text{ cm}$ . As the central maximum does not usually lie exactly at  $0^\circ$ , it is preferable to determine the angular distance  $2\varphi$  between two extremes that lie symmetrically to the zero line from the measurement curve. Fig. 4 shows the interference pattern of the two ultrasonic sources when these are in opposite phase operation, i.e. with a phase difference of  $\pi$ . The geometric path difference  $\Delta r$  is now supplemented by the value of  $\lambda/2$ .

This has the result that maxima are changed to minima and minima to maxima. In particular, a minimum is always given at  $0^\circ$ . For the evaluation of the extremes, equations (6) and (7) must now be used the other way round.

Table 1 lists both the  $2\varphi$  angles of the extremes determined from Figs. 3 and 4, and also the wavelength values  $\lambda$  calculated from Equations (6) and (7).

Table 1:  
 $S_1$  and  $S_2$  in phase; Fig. 3

Maxima			Minima	
$n$	$2\varphi / ^\circ$	$\lambda / \text{mm}$	$2\varphi / ^\circ$	$\lambda / \text{mm}$
0			7.6	8.61
1	14.9	8.43	23.0	8.64
2	30.7	8.60	39.0	8.68
3	46.6	8.57	55.4	8.63
4	63.1	8.50	73.0	8.59
5	81.7	8.50	92.7	8.55
6	102.3	8.44	118.3	8.58

$S_1$  and  $S_2$  opposite in phase; Fig. 4

Maxima			Minima	
$n$	$2\varphi / ^\circ$	$\lambda / \text{mm}$	$2\varphi / ^\circ$	$\lambda / \text{mm}$
0	7.6	8.61		
1	23.0	8.64	15.4	8.71
2	38.5	8.57	31.0	8.68
3	55.0	8.57	46.9	8.62
4	72.2	8.51	64.0	8.61
5	91.5	8.64	82.5	8.57
6	114.0	8.39	103.9	8.53

The mean value of the wavelength values listed in Table 1 is  $\lambda = (0.857 \pm 0.081) \text{ cm}$ .

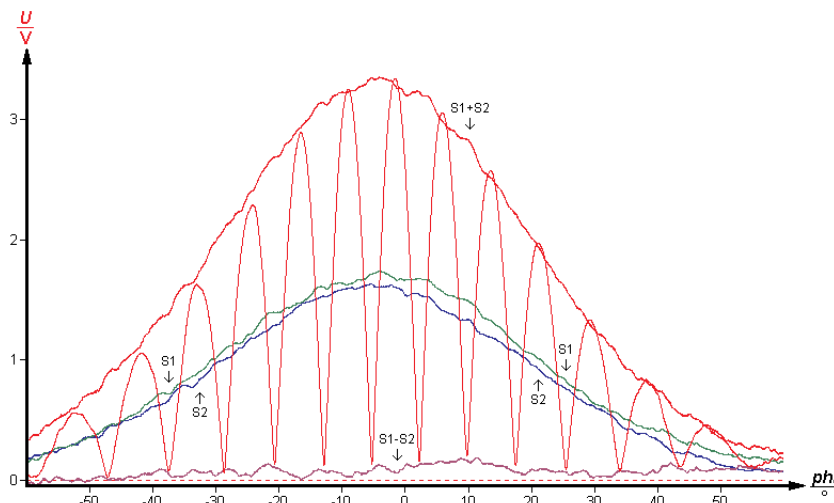


Fig. 5: Interference pattern of two ultrasonic emitters operating in phase with each separately measured angular distribution of the sound pressures of the sources  $S_1$  and  $S_2$  and presentation of their sums and differences.

The transmitter operates at a frequency of  $f = 40$  kHz. From  $c = f \cdot \lambda$  ( $c = 343.4 \text{ ms}^{-1}$  at  $T = 20^\circ\text{C}$ ) it follows that, in complete agreement with the experiment,  $\lambda = 0.858$  cm.

In Fig. 5, the interference curves of the sound pressure of the two transmitters emitting in phase is again shown. In addition, the sound pressure curves of each of the individual transmitters  $S_1$  and  $S_2$  were also measured, and their intensity curves are almost congruent. The sum of the sound pressures of  $S_1$  and  $S_2$  must be the envelope of the maxima of the interference curves, and their difference must be the envelope of the minima. This can be impressively confirmed by using the "Analysis" function and then "Channel modification" for the addition of curves calculated from  $(S_1+S_2) \propto (U_2+U_3)$  and  $(S_1-S_2) \propto (U_2-U_3)$ .

A true to scale presentation of the ordinate values is subsequently obtained, again with "scale curves" and "fit collectively".