H30877 **Sound Wave Demonstration Set** **NFU 705M**

This apparatus is used to demonstrate the wave properties of sound. It can then be used to further explore wave behaviour and demonstrate phenomena in other forms of wave radiation that are less easy to study. Interference patters show up particularly well, and owing to the convenient wavelength of the sound, path differences can be measured easily.

Apparatus Detail
The set consists of a junction box and three sound units which may be used as microphones or loudspeakers. The junction box makes connections convenient and easily visible. It includes a switch which allows the phase of one of the inputs (or outputs) to be altered by 180°. The transmitter and receiver units are stable and compact, and their small size means they can be considered as point sources of sound. They operate best at a frequency of 3.0 kHz, which gives a wavelength of 0.11m in air, as shown by:

$$\lambda = c\,f$$

Where: λ = wavelength
c = speed
f = frequency

The speed of sound in air is approximately $340ms^{-1}$.

Requirements

- A signal generator (e.g. B8H10579)
- Cathode Ray Oscilloscope (e.g. B8H28226)
- Dual Amplifier (possibly; B8H29140)

Any sine wave signal generator with an output of about 0 to 6V is suitable. The frequency can be adjusted in the region of 3kHz until the loudest sound is obtained. The units work best connected to the low impedance output of the signal generator. The ideal CRO to display the microphone output would be a double beam scope with sensitivity on both the X and Y of up to 5mV per division. If a less sensitive CRO is used, a pre-amplifier may be required, particularly if the volume of the sound is to be kept to a tolerable level during experimentation. The double beam facility is used in some of the experiments to follow to emphasize the idea of phase difference, but the experiments can be done with a single beam CRO.

The plugs and sockets on the units are 4mm stackable.

All the other equipment needed for the experiments is very simple and is to be found in most teaching laboratories. A pair of sheets of hardboard between 0.5m and 1.0m square is most useful.

Precautions – Unwanted Reflections
The sound intensity from the loudspeaker unit will need to be balanced against the Y- sensitivity setting of the CRO to give convincing traces at sound levels which are tolerable in the laboratory. To obtain the best results the units should be placed as far as possible from any hard surfaces that will reflect the sound. Standing them on stools on benches in the middle of the laboratory is often effective. The equipment

should be tried in various configurations in different places in the laboratory until the best and most easily demonstrated results are achieved. The screening of the sound units (the black 4mm plug) should be connected to the ground (chassis) terminal of oscilloscopes and signal generators.

Laboratories do not usually have soft, sound absorbing furnishings, so it may be worthwhile putting old carpet or corrugated cardboard on surfaces near the equipments. A more elaborate anechoic chamber could be produced by sticking cardboard egg boxes to hardboard sheets. It is useful to have available some pieces of material to drape over any troublesome reflectors.

The main problem caused by unwanted reflections is that of unwanted interference effects between incident and reflected sound. This effect is demonstrated intentionally in experiment 4a (Lloyd's mirror).

The experimenter too can produce unwanted reflections and care should be taken not to stand in the path of the sound. Careful planning of demonstrations to a class should avoid any problems.

Finally, control experiments should be carried out to check the effect observed is caused by the component in question. For example, remove a reflector to check the observed behaviour changes.

List of experiments

1. Reflection
    a. Reflection at plane mirrors
    b. Reflection at curved mirrors

2. Refraction
    a. Action of a single sound lens
    b. Action of two lenses transferring sound energy in a parallel beam

3. Diffraction of sound waves at a single slit

4. Experiments on interference patterns in the air
    a. Lloyd's mirror experiment
    b. First standing wave experiment (nodes and antinodes)
    c. Second standing wave experiment (resonant cavity)
    d. Interference patterns between waves from two sources (Young's fringes)
    e. Sound equivalent of thin film interference

5. Experiments on the phase differences between the signal received by two microphone units.
    a. Determination of the wavelength of sound
    b. Analogue of radio telescope interferometry

6. Experiment to measure the phase difference between loudspeaker and microphone and thereby measure the wavelength of sound

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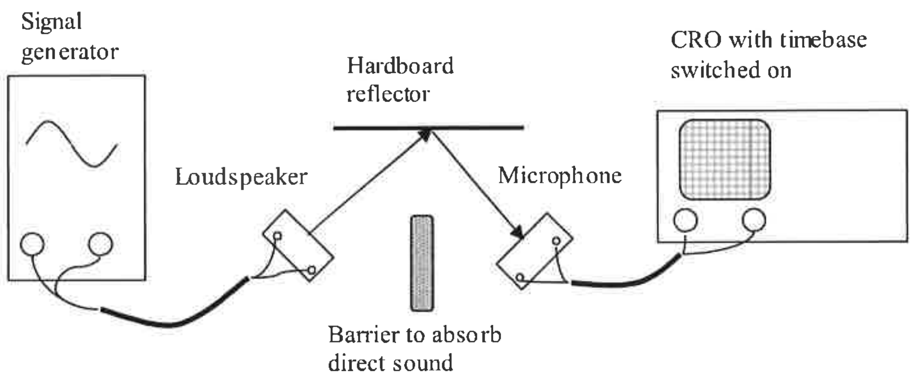
Experiments

1. Reflection of sound waves

a) Reflection at plane mirrors

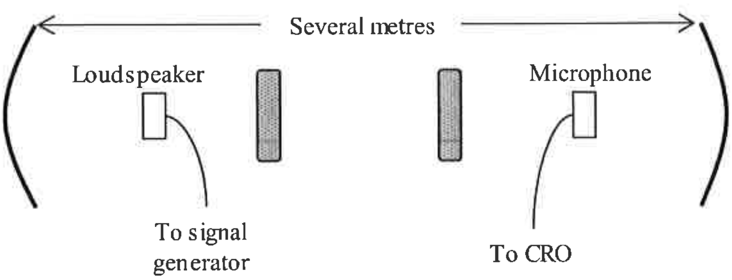


Sound will reach the microphone without the hardboard, but the amplitude will increase markedly with the hardboard in place. The units are sufficiently directional to give some evidence that the law of reflection is the same for sound as other waves.

Note that if too much sound reaches the microphone directly from the loudspeaker, noticeable interference effects will occur. The barrier's purpose is to reduce this direct sound.

b) Reflection at curved mirrors

The hardboard sheets can be gently curved and the focussing effects of a curved mirror demonstrated as shown below.



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The maximum amplitude of the CRO trace will be obtained when the microphone and loudspeaker units are at the focus of each hardboard mirror. The focal point of a curved mirror is half its radius of curvature.

A control experiment should also be performed with the microphone and loudspeaker units the same distance apart, facing each other.

2. Refraction

The speed of sound in a gas, c, is given by the following formula:

$$c = \sqrt{\gamma \cdot \frac{p}{\rho}}$$

Where: γ = adiabatic index
ρ = density

The adiabatic index is ratio of specific heat of a gas at constant pressure to that of a gas at constant volume. A sound wave is a compression wave through air, and the heat caused by the compression does not have time to escape from the compressed air, and thus contributes to the overall pressure.

The adiabatic index of carbon dioxide is lower than that of air, and also the density of carbon dioxide is higher that that of air under the same conditions of temperature and pressure. These factors combine to make the speed of sound in carbon dioxide lower than that in air. Consequently carbon dioxide filled balloons act as lenses for sound waves and converge the sound energy.

With large balloons, that is, balloons several wavelengths across, quantitative work is possible. With smaller balloons, experiment accuracy will be greatly reduced.

It is nevertheless possible to demonstrate convincingly the action of the lens in two experiments. For the benefit of sceptical pupils, it is worth having air filled balloons available too as controls, as these will not 'bend' the sound waves and thus no effect will be observed.

Note that carbon dioxide balloons deflate rather more quickly than air filled balloons, so they should be inflated only shortly before they're required.

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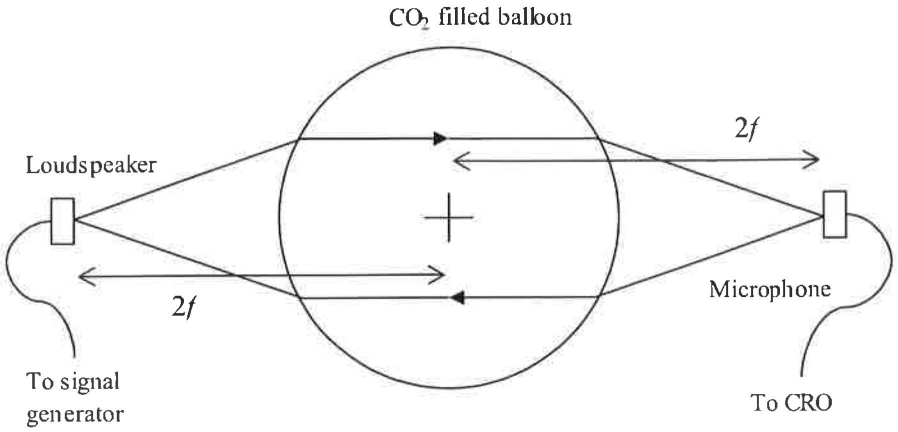
a) Action of a single sound lens



The distances of the units from the balloon are adjusted until the CRO trace is at its maximum. On removal of the balloon, the CRO trace should become much smaller. Similarly, replacing the CO_2 balloon with an air filled balloon will reduce the amplitude measured on the CRO.

If the units are the same distance from the balloon, this is the sound equivalent of an object being placed $2f$ from a lens and producing a real inverted image $2f$ away on the other side.

If quantitative work is being attempted the formula for the focal length, f of a spherical lens is:

$$f = \frac{rn}{2(n-1)}$$

Where: r = radius of lens
n = refractive index

The refractive index n is given by the ratio of the speed of sound c in air to the speed of sound in carbon dioxide:

$$n = \frac{c_{air}}{c_{CO_2}}$$

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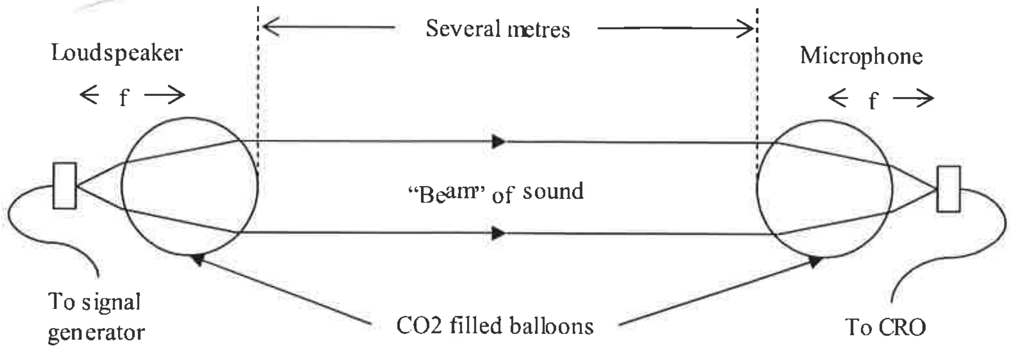
b) Action of two lenses transferring sound energy in a beam.



The microphone and loudspeaker units are placed a distance *f* away from the centre of each balloon. More energy is transferred because a parallel beam of sound is produced and then focussed. Without the balloons, or with air filled balloons, the CRO trace shows much lower amplitude.

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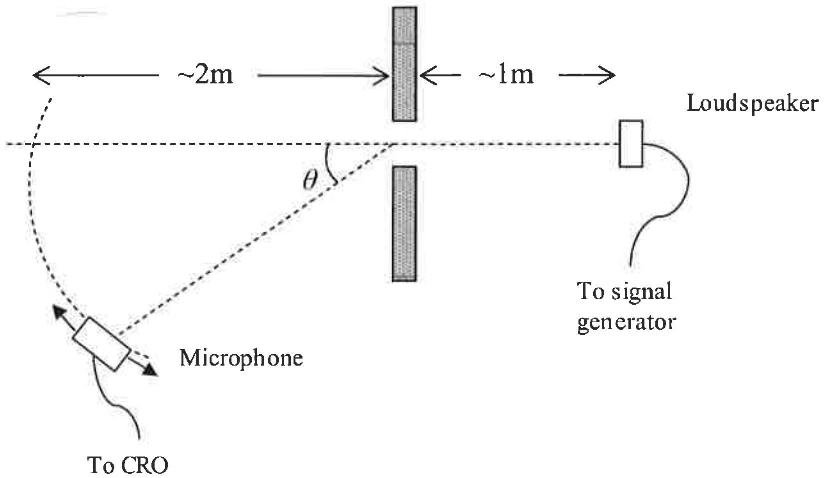
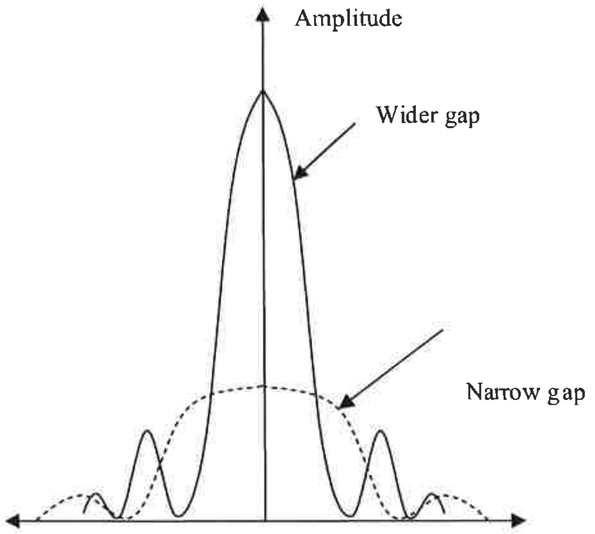
3. Diffraction of sound waves by a single slit



Initially there should be no gap between the hardboard sheets and the loudspeaker should be moved back until appreciable sound comes from round the edges of the sheets, and then moved forward a little. The purpose of this is to move the loudspeaker as many wavelengths away as possible from the hardboard, so the sound incident on the board is nearly a plane wave. The distance is limited by the size of the hardboard sheets.

When a gap is opened up it is possible to observe the maxima and minima of the diffraction pattern by moving the microphone along the radial line as show above. As the gap is widened, the pattern is compressed, that is, the first minimum is closer to the centre.



The angle θ is determined by the following:

$$sin\theta = \frac{\lambda}{d}$$

For example, for a gap of 2 wavelengths, or 0.22m:

$$sin\theta = \frac{\lambda}{2\lambda} = \frac{1}{2}$$

Therefore: $\theta = 30°$

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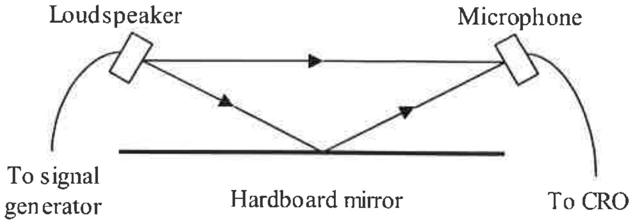
4. Interference patterns in air

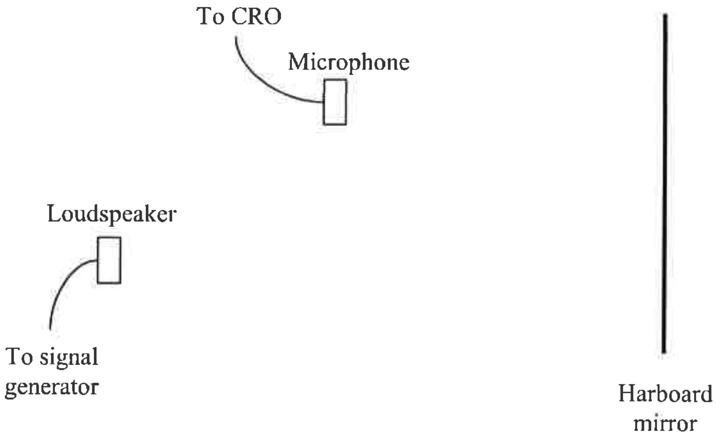
a) Lloyd's mirror



The sound travelling directly from the loudspeaker meets the sound reflected from the mirror, and they interfere depending on the path difference. The path difference can be altered by moving the mirror back and forth, and thus maxima and minima observed.

Using a ruler, it is easy to measure the movement of the hardboard mirror. Between two maxima or two minima, the distance moved by the hardboard mirror is one half of a wavelength.

b) Standing wave



A series of maxima and minima will be obtained with just one mirror in place caused by interference between sound waves incident on the mirror, and those reflected by it.

The points where the incident and reflected wave cancel out are called "nodes", and by moving the microphone around, it can be shown that nodes are half a wavelength apart.

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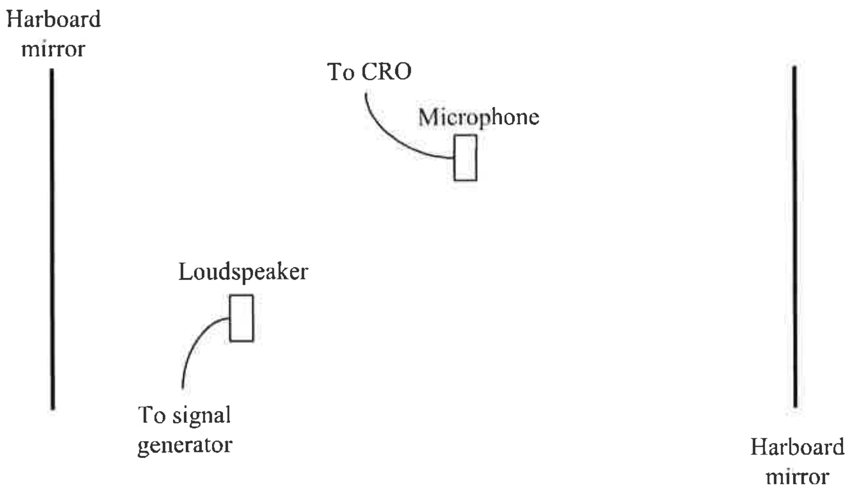
c) Standing wave in a resonant cavity

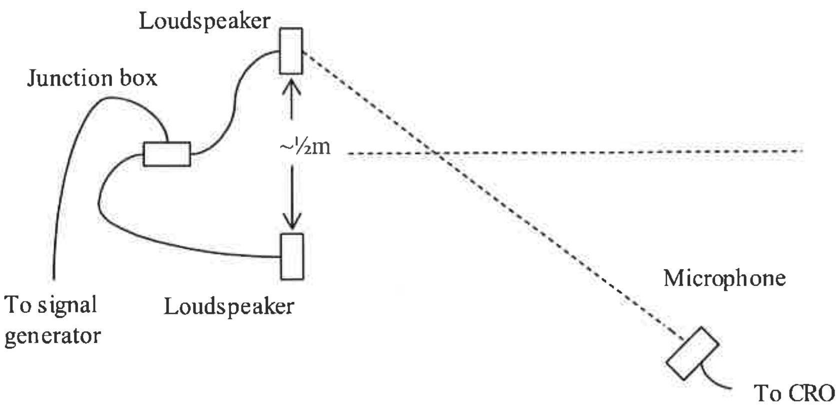


With a second reflector, the waves can be reflected more than once. If the incident waves are in phase with the waves that have been reflected twice, all the waves travelling in the same direction will be in phase. Consequently the amplitude of the antinodes is much greater.

The condition for this resonance is that the waves that have been reflected twice have travelled a whole number of wavelengths more than those that have not been reflected at all. So, the distance between the mirrors must be a whole number of wavelengths.

This can be tested by moving the mirrors very carefully and observing the signal strength on the CRO.

d) Interference patterns between sounds from two sources



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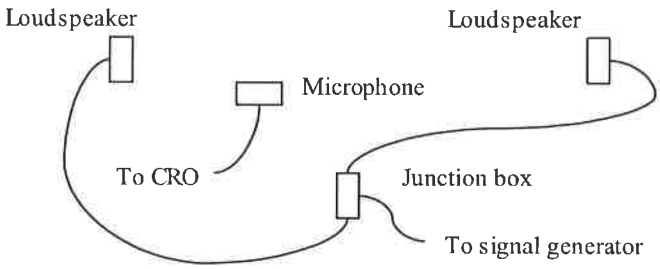
With the exception of the central position, the distance of the microphone from each loudspeaker will be different. These distances can be measured with metre rulers. If the path difference is a whole number of wavelengths, and the loudspeaker units are transmitting *in phase*, the two signals reaching the microphone unit will arrive in phase and interfere constructively. This will give rise to a CRO trace with a large amplitude.

If the path difference is a whole number of wavelengths *plus one half*, then the sounds will arrive at the microphone in *antiphase* and therefore cancel out. This will cause a CRO trace of low amplitude, but not zero due to unwanted reflections.

If the signals are changed into antiphase by changing the switch on the junction box, the situation will be reversed, that is, maxima will occur where minima occurred previously, and vice-versa.

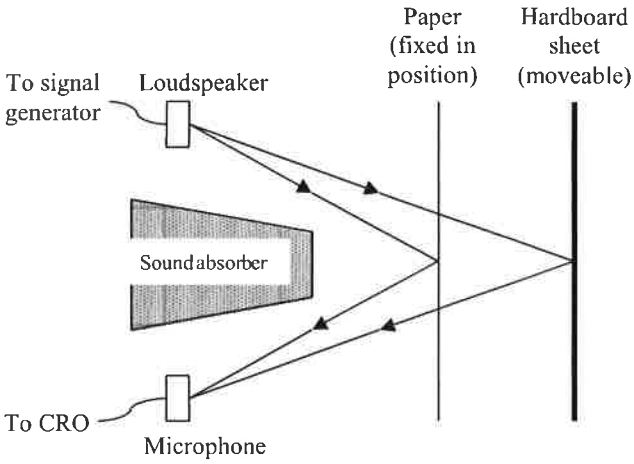


A similar experiment can be done by pointing two microphones at each other, and moving the microphone between them. Again, by measuring the distance of the microphone from each loudspeaker and determining the path difference, the wavelength can be measured.

The distance between each maximum is half a wavelength because one path has increased by half a wavelength and the other fallen by half a wavelength, thus giving a path difference of one whole wavelength.

The interference pattern makes a good analogue for teaching the principle of the DECCA navigation system. The ship is situated in two or three systems of fringes from pairs of radio transmitters transmitting in phase. The DECCA receiver on the ship counts the fringes as the ship sails through them, and because the ship knows its starting position, it can fix its position thereafter.

e) Sound equivalent of thin film interference effects



The sheet of paper is like a semi-silvered mirror in that it reflects around half of sound incident on it, and transmits the other half. The sound transmitted by the paper is instead reflected by the hardboard sheet, back towards the paper.

The sound reflected by the paper interferes with that reflected by the hardboard. If the distance from the paper to the hardboard and back is a whole number of wavelengths, the signals will arrive at the microphone unit in phase. By moving the hardboard mirror back and forth, the path difference will change and the amplitude observed on the CRO will oscillate.

For the experiment to work, as little sound as possible must reach the microphone directly from the loudspeaker, so an absorber should be placed between them.
Otherwise, one would simply be repeating the Lloyd's mirror experiment.

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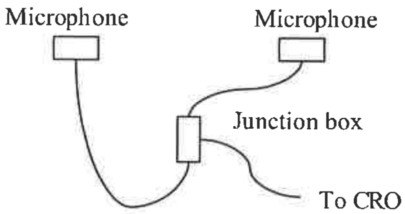
5. Phase differences between two received signals

There are three ways of showing the phase differences between the signals from two microphones:

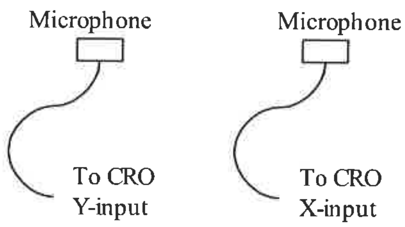
i. Mixing the signals and displaying their sum
ii. Using the X and Y inputs of the CRO to show Lissajous' figures
iii. Using a double beam CRO to show the signals separately

i. Mixing the signals



If the sounds arriving at the microphone units are in phase then a large CRO trace will be seen when the phase reverse switch is off, and a small trace seen when the switch is on. When the signals arrive out of phase, the reverse is true.

ii. Lissajous' Figures



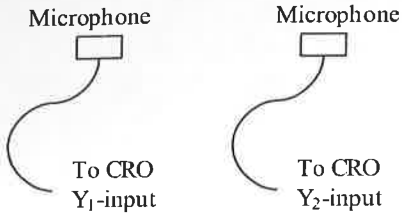
The CRO is used with its time base switched off and the microphone units connected as shown.

Unless a CRO with X and Y inputs of equal sensitivity is available, a pre-amplifier must be used to amplify the signal to the X inputs of the CRO. When the two signals are in phase a diagonal line of positive gradient is seen on the CRO. When they are 90° (or ¼ of a cycle) out of phase, a circle will be seen. As the phase differences of the signals changes, the following will be seen on the screen:

0° 45° 90° 135° 180° 225° 270° 315° 360°

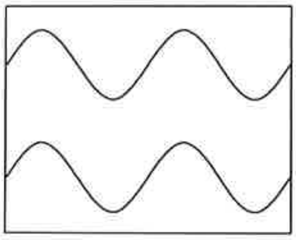
(in phase) (antiphase) (in phase)

iii.Using a double beam CRO

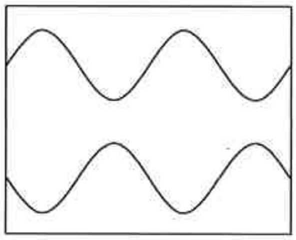


The CRO is used with the time base switched on.

Regardless of which signal triggers the CRO, the phase difference between the two signals shows up as indicated by the diagrams below.

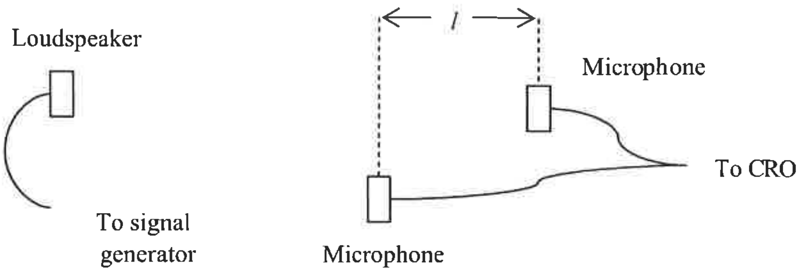


Signals in phase



Signals out of phase

a) Determination of the wavelength of sound by the phase difference between two microphone units



When the microphone units receive sound waves in phase, the distance between them must be a whole number of wavelengths. By changing the distance between microphone units one can observe a series of in phase positions and thereby calculate the wavelength of the sound reasonably accurately.

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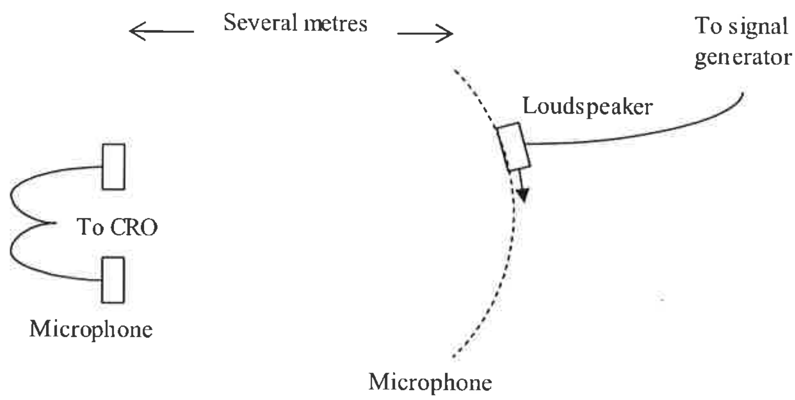
b) A sound analogue of the technique of radio telescope interferometry

As a radio source moves across the sky its signals are received by two aerials that are a known distance apart. Except when the radio source is directly overhead there will be a path difference between the signals arriving at the two aerials. As a result the signals received will sometimes be in phase, and sometimes not. From the timings of the in phase positions, it is possible to calculate the declination and right ascension of the radio source. The setup is rather like Young's interference in reverse.

The very simplest experiment is done with two dipole arrays about 100m apart and with this it is possible to observe the radio waves from the Sun and two other strong sources called Cassiopeia A and Cygnus A.



Ideally the loudspeaker should be as far away as the sensitivity of the CRO will allow. The microphone units should be one or two metres apart. As the loudspeaker unit is moved along the arc show in the diagram, as series of in-phase positions will be observed as the differences between the paths to the microphone units are a whole number of wavelengths.

To give some idea of the practical problems of radio telescopy, the room should be as noisy as possible during the demonstration: even for strong radio sources, the background noise is many times the intensity of the signal.

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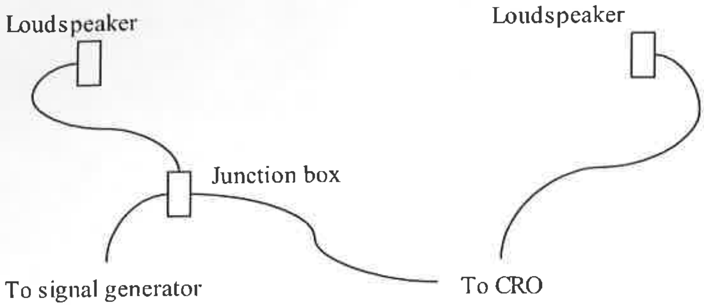
Experiment 6 – Phase difference between loudspeaker and microphone



If the difference between the loudspeaker unit and the microphone unit is a whole number of wavelengths, the signal being received will be in phase with that being transmitted. As the microphone unit is moved, the phase difference of the two signals will changes. Methods **ii** and **iii** in **experiment 5** can be used to show the phase difference.

The wavelength of the sound can be calculated by moving the microphone unit through a series of in phase positions, each of which is a wavelength from the next.

With a less versatile CRO, a pre-amplifier might be needed to amplify the signal from the microphone unit before studying its phase relationship with the signal to the loudspeaker unit.

Safety advice

For your safety, this product should be used in accordance with these instructions; otherwise, the protection provided may be impaired. Risk of shock if the unit is opened.

This unit is intended for use in DRY conditions. Avoid spillage of water and other liquids on to the unit. If spillage occurs, disconnect the mains supply.
There is no specific requirement for insulation of external circuits as they cannot become hazardous live, as a result of connection to this unit

Disclaimer

If the equipment is used in a way not specified by Philip Harris, then the protection provided may be impaired.

Warranty, repairs and spare parts

The Sound Wave Demonstation Set is guaranteed for a period of one year from the date of delivery to the customer. This warranty does not apply to defects resulting from the action of a user such as misuse, improper wiring, any operations outside of its specification, improper maintenance or repair, or unauthorized modification.

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