Exercise 6A: Sound waves in air

In this experiment you use several different methods to measure the wavelength of high frequency waves travelling through air. The sound waves are produced in a small transmitter driven by electrical signals from a sine wave oscillator, and are detected by a receiver which is a small microphone, similar to the transmitter, whose electrical output is displayed on the oscilloscope. Transmitter and receiver are placed facing each other on a graduated slide. Their response is sharpest near a frequency of 40 kHz, so your measurements relate to this frequency.

Frequency response

- Set the transmitter and receiver facing each other about 30 cm apart (figure 1). Vary the oscillator frequency and observe the response on the oscilloscope; there is a narrow band of frequencies for efficient reception. Set the oscillator to maximise the amplitude, measure the frequency with a laboratory frequency meter, and check it during the course of the experiment.

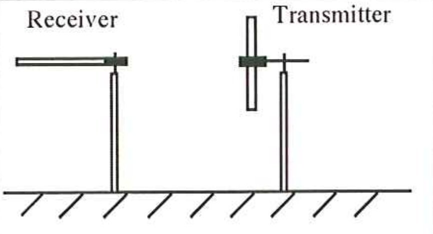

Figure 1 Basic set-up

Direct measurement of wavelength

- Move the transmitter slowly towards the receiver. As you do so the relative phase of the transmitted and received signals changes, the wave trains shifting by one whole wavelength when you have moved the transmitter exactly this amount. There are millimetre scales on the shoeplates; measure the distance d that corresponds to a large number, N, of wavelengths, deduce the wavelength λ at this frequency, and so calculate the sound velocity v_s.

- Now recall the expression $v_s = \sqrt{(K/\rho)}$. In a gas the appropriate modulus K is the pressure, and in an ideal gas pressure divided by density is proportional to the absolute temperature T. So (show this for yourself) $v_s(T\,^\circ\mathrm{C}) = v_s(0\,^\circ\mathrm{C})\sqrt{(1 + (T\,^\circ\mathrm{C})/273)}$. Find the temperature of the air in the lab, and so reduce your value for the speed of sound to the value at 0 °C. Compare this with tabulated information (e.g. Kaye and Laby). Estimate the errors in your measurement.

Standing waves

- Sound waves can bounce back and forth between the transmitter and receiver clamps. If the separation between transmitter and receiver is a whole number of half wavelengths, the there-and-back distance for one reflection is twice this, which is an exact whole number of wavelengths, and a **standing wave pattern** will be formed with **nodes** where the opposing waves cancel and **antinodes** where they reinforce. As you move the transmitter you can see the received signal increase in amplitude every half-wavelength as the standing wave pattern is formed. (In between there is a rather confusing variation of response because the travelling waves partially interfere). If this is difficult to observe try putting the aluminium discs on the receiver and transmitter, clamping them carefully so that the discs are flush with the fronts of the transmitter and receiver, and parallel to one another.

- Measure the change in distance corresponding to passing through a large number of nodes, deduce the wavelength, and compare with your earlier value.

- The change from one standing wave pattern to the next is accompanied by a change in the phase of the received and transmitted signals which you can see on the two-beam display of the 'scope. This phase change becomes more noticeable if you switch to *XY* display. In normal display mode the ***horizontal*** axis is controlled by a **timebase** circuit which drives the display in the horizontal (*X*) direction at a constant rate, adjustable by a front-panel knob at the right.

Selection of the *XY* display mode turns the timebase off and allows the display to be driven horizontally by one of the input voltage signals. Do this, and describe what you see.

Interferometry

- Place the perforated metal plates on the slide at right angles to the sound wave (figure 2). They let some of the wave through while reflecting part of it. Between these semi-reflecting plates the sound wave bounces back and forth, some of its energy escaping towards the receiver. There will therefore be a standing wave pattern between the plates when their separation is an integer number of half wavelengths, as we have seen. At these spacings the amplitude of the signal displayed on the 'scope will increase to a maximum, with weak minima at intermediate spacings.

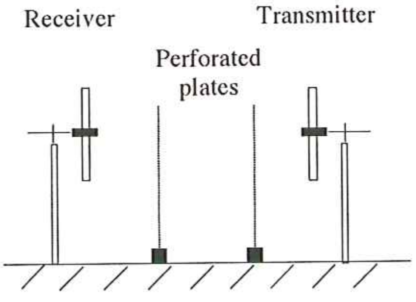

Figure 2 Interferometry

- Put the scope back into normal (not *XY*) two-beam operation, and move the perforated plates so as to measure the spacings of these maxima. This gives yet a third way of measuring the wavelength, so deduce it.

The technique of using semi-reflecting plates to form interference patterns of standing waves was developed by Fabry and Perot for use in optics, where it is widely used in spectrometers to measure, or select, different wavelengths. What you have here is a sonic analogue of the Fabry–Perot interferometer.

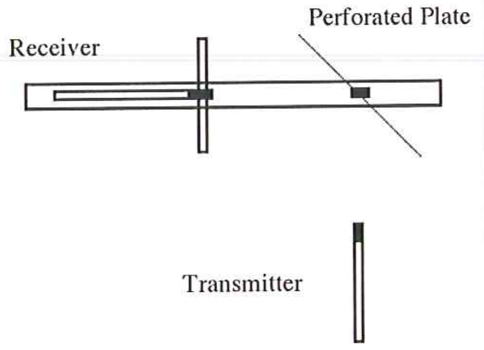

Figure 3 Phase-sensitive sonar

Phase-sensitive sonar

- Finally, take the transmitter off the slide and place it to one side with its ultrasonic waves directed at a perforated plate set at 45° (figure 3) so as to reflect the sound to the receiver. Viewing both traces on the 'scope, you will see that their relative phase changes as the plate is moved slightly towards or away from the receiver. A movement of one wavelength causes a complete phase shift of the same amount. The effect is seen more clearly if you switch to *XY* display, where the pattern is sensitive to quite small movements of the perforated plate.

- To increase the sensitivity still further, switch the oscillator from sine wave to square wave operation. You will see, on dual-trace display, that neither transmitter nor receiver can respond to the rapid changes of the 'square' wave so a sine wave is still displayed. Switch back to *XY* and observe the effect of *combining* the square wave with the sine wave in *X* vs. *Y*. You have an oblong display whose height (or width — it depends which way round your input channels are connected) is *extremely* sensitive to movement of the plate. Blow gently on it and you will agree!

- Set your pattern to fill most of the screen, estimate how large a change in the oblong shape you can detect (perhaps a millimetre or so?), and deduce what movement of the plate this corresponds to. You have built a sensitive device for remote measurement of small displacements — a phase-sensitive sonar.