

# Wave experiments using low-cost 40 kHz ultrasonic transducers

Mak Se-yuen

Department of Curriculum and Instruction, Faculty of Education, The Chinese University of Hong Kong, Shatin, NT, Hong Kong SAR

E-mail: symak@cuhk.edu.hk

## Abstract

In this article, we describe how 40 kHz piezoelectric ultrasound transducers can be used to study wave phenomena. Hints for general usage and tips for individual experiments are suggested. Easily reproducible sample results for quantitative measurements are quoted for readers' reference.

## Introduction

Ultrasonic devices have found many applications in the home, industry, medicine and oceanography. One such device is the 40 kHz piezoelectric ultrasound transducer invented some decades ago. They were used once as remote control and anti-theft devices, and recently as parking sensors in cars. Despite its convenient wavelength of 8.6 mm at 25 °C, its potential as a tool for studying wave motion has not been fully explored by physics teachers [1]. The opportunities for investigation proposed by the pioneering designers were limited by the size of the modules [2], which is far too large compared with the wavelength of the ultrasound. Here we describe how bare transducers can be set up in a simple way such that group experiments covering most wave phenomena can be carried out smoothly in most secondary schools.

## General properties of transducers

### *Frequency matching*

According to the specification supplied by a manufacturer, transducers sold in matched pairs operate at a frequency of  $40.0 \pm 1.0$  kHz. A typical transmitter can withstand a maximum input voltage of 20 V<sub>rms</sub> and deliver a sound pressure level around  $110 \pm 5$  dB at 10 V and 30 cm. Our tests show further that (a) most transducers of the

same model, being structurally identical, can be used either as the transmitter or the receiver, and (b) transducers of different power/models can also be matched easily to form a transmitter–receiver pair.

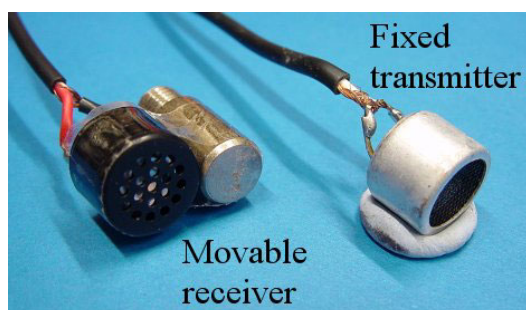
### *Size limitation*

Since the wavelength of 40 kHz ultrasound is only 8.6 mm, a receiver with dimension larger than the wavelength is not recommended for wavelength measurements. In general, the cost of the transducer is proportional to its power and dimension. So the smallest/cheapest transducer, in our case HTC40-10, with a mesh diameter of 7.5 mm and an effective sensing area less than 20 mm<sup>2</sup> is used as the receiver. The same model will be used in all the following experiments.

### *Power requirement, range and output voltage*

By measuring the voltage across a series resistor of low resistance, we found that when the input voltage is  $V_p = 10$  V, the input current,  $I_p$ , through the transmitter is about 20 mA at resonance. Hence, the power requirement for the signal generator is only  $\frac{1}{2}V_p I_p \approx 100$  mW and a school model will provide sufficient power for two or more groups.

To obtain the highest output for direct transmission, both the transmitter and the receiver



**Figure 1.** A simple set-up using a pair of bare 40 kHz transducers.

are placed on the bench facing one another. In this way, the bench acts as a Lloyd's mirror [3], generating a pressure antinode all the way along the line of transmission on the bench surface. The output signal of the receiver at resonance, 1 m away from the transmitter, gives a CRO display of  $V_{pp} \approx 80$  mV.

#### Set-up precautions

With the exception of focusing experiments using spherical lenses and mirrors, all experiments will be carried out with the transmitter fixed to the bench with Blu-Tack and the receiver attached to a small weight (figure 1) sufficiently heavy to prevent turning and sliding caused by the twisting of connecting cables. To prevent unwanted

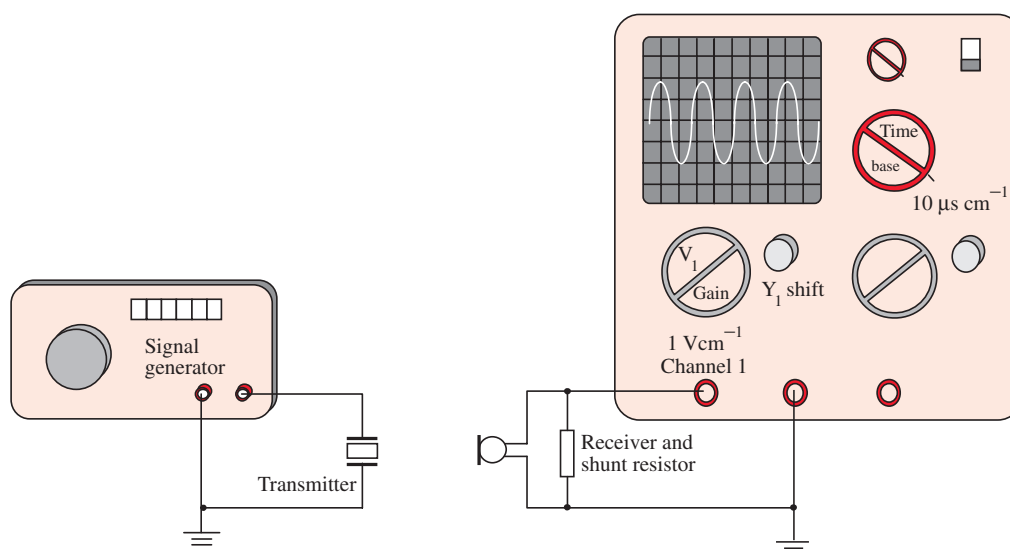
reflections from the signal generator and the CRO, both bits of apparatus should be kept at least 50 cm away from the path of propagation. A shunt resistor, of the order of 10 k $\Omega$ , connected across the receiver will filter out unwanted 50 Hz noise from the mains.

## Experiments

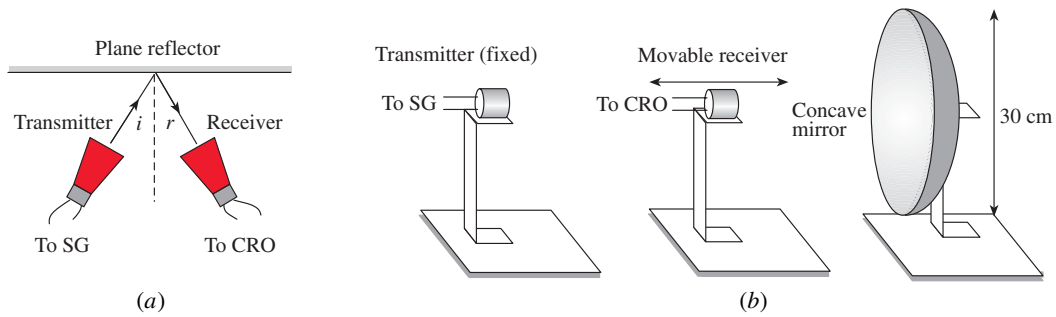
### Finding the resonance frequency of the transducer

Connect the circuit as shown in figure 2. The transmitter is driven by a signal generator with an output voltage set at 6.0 V<sub>rms</sub> and frequency in the range 10 kHz to 100 kHz. The receiver is held facing the transmitter about 50 cm away. It is connected to a CRO at some convenient settings, say, e.g., 0.5 V cm<sup>-1</sup> and 10  $\mu$ s cm<sup>-1</sup>.

To find the resonance frequency, the fine frequency control dial of the signal generator is adjusted until a maximum voltage trace is displayed on the CRO screen. In the absence of mechanical defects in the transducers, resonance normally happens at 40 kHz with a tolerance no bigger than that specified. The period can be read directly from the on-screen trace, which is sinusoidal irrespective of the triggering waveform.



**Figure 2.** Determination of the resonance frequency of the transducer. (The transmitter and the receiver are represented by different symbols but they are identical in structure.)



**Figure 3.** (a) Reflection by a flat surface. (b) Reflection by a concave mirror.

#### Reflection by plane/concave mirror

To show the law of reflection (figure 3(a)), a partially collimated 'beam' can be obtained by attaching a small paper cone to the opening of each transducer. Any flat vertical surface can be used as the reflector. Maximum reception is observed when  $i \approx r$ .

Like the 2.8 cm microwave, ultrasound can be focused by a giant concave mirror. When in use, both transducers should be placed on the mirror axis and facing the mirror. The receiver is moved along the axis until a maximum is detected (figure 3(b)). Lloyd's reflection from the bench surface has little effect in this experiment because the converging signal comes mainly from the mirror.

#### Refraction by a 'lens'

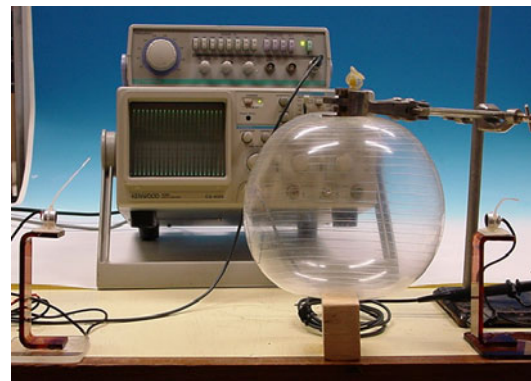
A 'skinless' condom-balloon<sup>1</sup> about 20 cm in diameter filled with liquid petroleum gas<sup>2</sup> (LPG) can be used as a converging lens. The arrangement and procedure are similar to that in the mirror set-up. Figure 4 shows the CRO trace with and without the lens.

#### Diffraction through a single slit

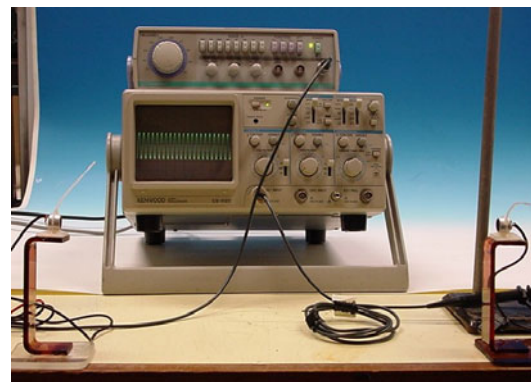
Figure 5 shows an arrangement to show qualitatively the diffraction of ultrasound through a 5 cm slit. The source is placed about 50 cm behind the slit and the detector 25 cm in front. The central maximum can be found near the axis of

<sup>1</sup> A condom-balloon is used instead of a rubber balloon because the ultrasound generated by a SG-transmitter combination available in most schools is not powerful enough to penetrate the skin of an inflated rubber balloon.

<sup>2</sup> LPG is used instead of CO<sub>2</sub> because the latter leaks rapidly in a condom. Moreover, LPG is acoustically denser and produces a better converging effect than CO<sub>2</sub>.



(a)



(b)

**Figure 4.** (a) Refraction and focusing by a LPG lens. (b) Same arrangement without the lens.

symmetry with secondary maxima and minima in two 'shaded' regions. Attaching the receiver to a straight rule, which can slide against a fixed rule on the bench, will minimize disturbances by hand.

#### Young's interference experiments

Young's experiment can be carried out using a double source (figure 6(a)), a single source with

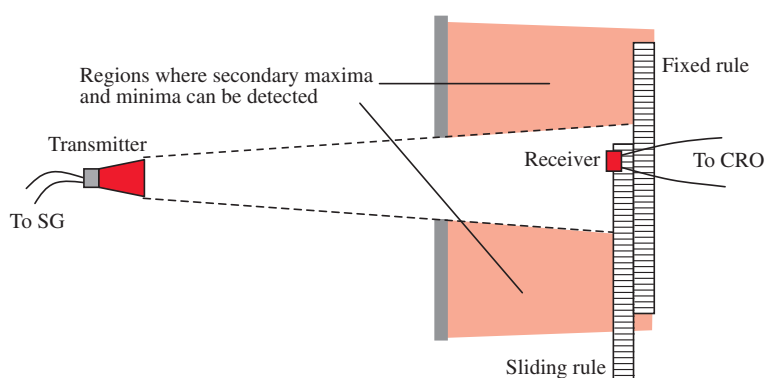


Figure 5. Qualitative demonstration of diffraction through a single slit.

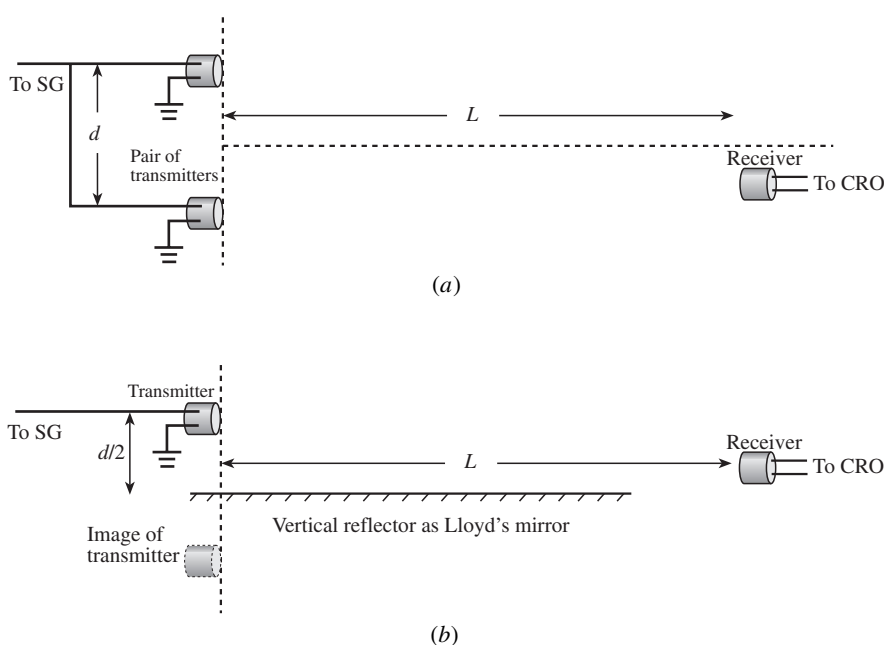


Figure 6. (a) Young's double source. (b) Young's experiment using one transmitter and a Lloyd's mirror.

a Lloyd's mirror (a flat vertical surface at least 30 cm long, figure 6(b)) or a double slit. The trace amplitude and fringe separations obtained from the first two methods are sufficiently distinct for quantitative measurement of the wavelength. A typical data set is as follows:

- Source separation,  $d = 10.0 \pm 0.5$  cm
- Distance between midpoint of sources and detector,  $L = 44 \pm 0.4$  cm
- Fringe separation,  $\Delta x = 3.8 \pm 0.2$  cm
- Angular fringe separation,  $\Delta\theta \approx \Delta x/L = 0.086 \pm 0.006$
- Wavelength,  $\lambda = d \sin \Delta\theta = 0.86 \pm 0.06$  cm

#### Amplitude modulation

Amplitude modulation can be done if the output transducer is driven by a signal generator equipped with such a function. The transmitted range is over a metre when a CRO is used to display a periodic modulated signal, but limited to only a few centimetres if a low-power amplifier–loudspeaker is used to play music.

#### Music transmitted by a waveguide

The range of audio-signal transmission can be increased to about 1.0 m by feeding the ultrasound wave into one end of a 1.5 cm bore air-pipe with

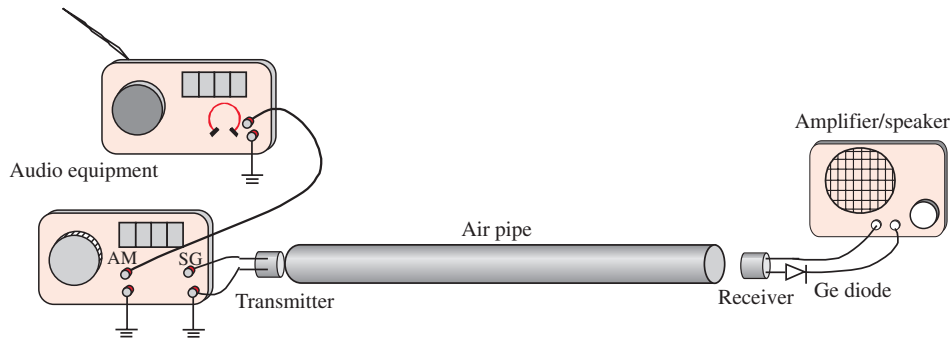


Figure 7. Transmission of an audio signal using a waveguide.

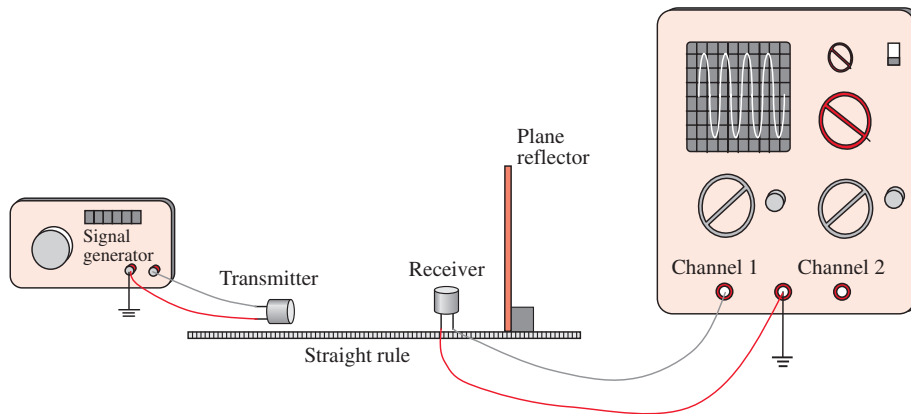


Figure 8. Determination of wavelength by a stationary wave method.

the receiver placed a few mm from the other end (figure 7). In this way, a standing wave is set up inside the pipe and a local pressure antinode is created at the diaphragm of the pick-up transducer. By slightly adjusting the position of the receiver, the speaker can respond to a rectified audio signal even when the pipe is bent. The method of transmitting audio information by an air-pipe is actually used in some monophonic earphones and public address systems.

#### Wavelength and speed measurement

*A standing wave in free space.* A standing wave can be set up by directing a beam of ultrasound towards a vertical plane reflector (figure 8).

If the receiver is moved slowly and smoothly towards or away from the reflector, the amplitude of the CRO trace will vary periodically and repeatedly every time the receiver traverses a distance of half a wavelength ( $\lambda/2 = \text{node-to-node separation} \approx 4.3 \text{ mm}$ ). The same result can

be obtained by moving the reflector while keeping the receiver stationary.

*Phase shift of a progressive wave.* The experiment is best carried out using a dual-trace CRO with the transmitter (T) connected to channel 1 and the receiver (R) to channel 2 (figure 9). The T signal should be the trigger source if the CRO can display only the R trace. In any case, the  $xy$  mode can also be used instead of the trigger sweep mode and Lissajous' figures would be observed.

When R is moved towards or away from T a distance of one wavelength  $\lambda$ , a change in phase of  $2\pi$  is observed in the R trace. So by counting the number ( $n$ ) of complete waves of trace 2 passing trace 1 and the distance ( $d$ ) moved by R, the wavelength of the wave can be determined. A typical result would be  $n = 10$  and  $d = 8.6 \pm 0.5 \text{ cm}$ , giving

$$\lambda = \frac{L}{n} = 0.86 \pm 0.05 \text{ cm.}$$

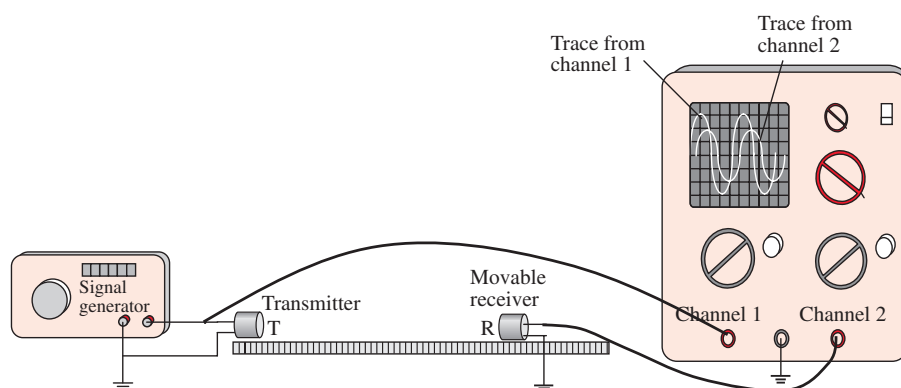


Figure 9. Determination of the wavelength of ultrasound by a progressive wave.

### A viable alternative to audible sound for group experiments

The 40 kHz ultrasound transducer is a desirable apparatus not only for demonstration but also for group quantitative experiments. Besides being cheap<sup>3</sup> and durable, it possesses the following indispensable features not found in its audible counterpart:

- It is tiny, easy to mount and easy to store.
- A worn-out transducer can often be replaced by one of a different model.
- The output signal is essentially sinusoidal irrespective of the input waveform.
- It requires little power. Either an audio-signal generator or a radio-signal generator can be used.
- If a school does not have enough signal generators, groups can obtain the same signal from bench terminals drawn from a single powered signal generator in the same way as with a central low-voltage pack.
- The space required for each experiment is limited to about 2.0 m<sup>2</sup>.
- It is silent. When in use, the transducer will neither produce audible sound (except in the modulation experiment), nor pick up noise from other sound sources.

Received 14 April 2003, in final form 12 May 2003  
 PII: S0031-9120(03)62132-5

<sup>3</sup> The cost for a pair of transducers varies from 50p to £2.00. If you are lucky, 40 kHz transducers can also be dismantled from outdated remote control kits or ultrasonic burglar alarms, available from time to time in second-hand markets at an attractive price.

### References

- [1] Greenslade T B 1994 Experiments with ultrasonic transducers *Phys. Teacher* **32** (October) 392–7
- [2] Philip Harris International 2001 *Catalogue* p 355. The cost for a kit with one transmitter, one receiver and one transducer (used as a double source) is £186.00 (about US\$280).
- [3] Nelkon M and Parker P 1978 *Advanced Level Physics* 4th edn (London: Heinemann) p 534

### Safety issues on exposure to ultrasound

The existing UK Health and Safety Executive directive refers to limiting exposure of ultrasound to 110 dB, but this is for ongoing work situations, not short duration classroom experiments.

The international literature confirms that 40 kHz ultrasound is considerably less hazardous than normal sound, for which the UK limit for occupational exposure is 85 dB.

It would be prudent therefore for teachers to limit pupil exposure to below 110 dB. This is achieved by enforcing

- a maximum of say 6 V<sub>rms</sub> input
- cautioning pupils against having their ears closer than 30 cm from the source
- limiting the likelihood of accidental exposure by turning off the ultrasound between measurements.

*Physics Education* would like to remind teachers that they should always consult their local rules and procedures on matters of health and safety.