

PM8**ULTRASONICS**

*Puccini was Latin, and Wagner Teutonic,
 And birds are incurably philharmonic
 Suburban yards and rural vistas
 Are filled with avian Andrews Sisters.
 The skylark sings a roundelay,
 The crow sings The Road to Mandalay,
 The nightingale sings a lullaby
 And the seagull sings a gullaby.
 That's what shepherds listen to in Arcadia
 Before somebody invented the radia..*

OBJECTIVES**Aims**

In this chapter you will study ultrasonics. Much of the lecture is concerned with the applications of ultrasonics using techniques of echoscopy and the Doppler technique.

Minimum Learning Goals

When you have finished studying this chapter you should be able to do all of the following.

1. State the frequency range of ultrasound.
2. Do simple calculations relating the wavelength, frequency and speed of sound waves and ultrasonic waves.
3. Describe an ultrasonic transducer and explain how it is used to generate or detect ultrasound.
4.
 - (i) Explain how the short wavelength of ultrasound makes it possible to focus a lot of energy into a small space.
 - (ii) State two applications of this property.
 - (ii) State an illustration of the Doppler effect with electromagnetic waves.
 - (iii) State and describe two applications of the Doppler effect with ultrasonic waves.
5.
 - (i) Describe what is meant by the Doppler effect.
 - (ii) State one illustration of the Doppler effect with electromagnetic waves.
 - (iii) State and describe two applications of the Doppler effect with ultrasonic waves.
6. Describe and distinguish the techniques of radar, sonar and echoscopy.
7. Describe and explain one example of the use of echoscopy.

PRE-LECTURE

Refer back to lecture PM7 to remind yourself of the concept of **specific acoustic impedance** and of its importance in the transmission of sound from one medium to another.

LECTURE

8-1 INTRODUCTION

Sound experienced by human falls in the frequency range 0 - 20 kHz. Sound above this frequency is known as **ultrasound**. It can be detected by some animals.

Demonstration

A dog can hear low frequency ultrasound such as that produced by a Galton whistle (the principle of this whistle is discussed in the T.V. lecture).

Ultrasound has many important applications some of which will be discussed in this lecture. These arise partly because sound at these high frequencies has short wavelengths and partly, just because it is sound, it is a pressure wave and hence will travel in materials.

Though the use of ultrasound by man is of relatively recent origin, BATS have always used it. For a long time it was thought bats made no noise but by recording them on magnetic tape and playing the tapes back at a slower speed (this reduces the frequency of the recorded sound) it was found that they make sounds in the 40 - 55 kHz regime. They use this ultrasound for navigational purposes and also for locating their prey. The ultrasound is produced in short duration screeches of about 10 - 15 milliseconds and that part of it which has bounced off something back into the direction of the bat is heard by it. The elapsed time gives the bat information on how far the object reflecting the pulse of ultrasound is from it.

8-2 GENERATION AND DETECTION OF ULTRASOUND

Demonstration

Sound is produced when an object vibrates

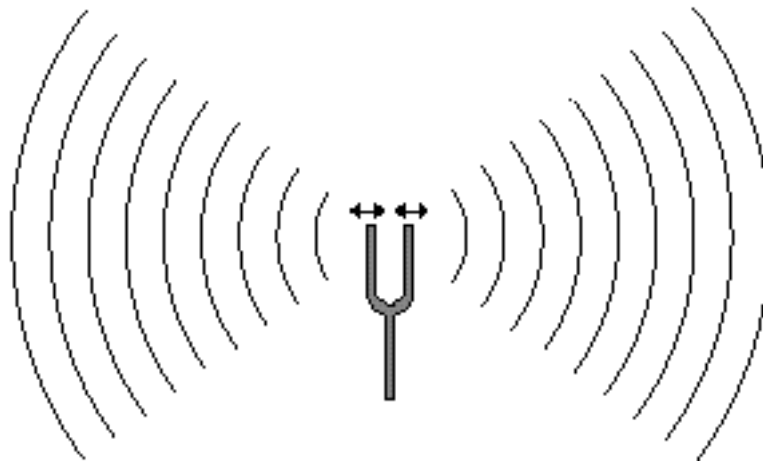
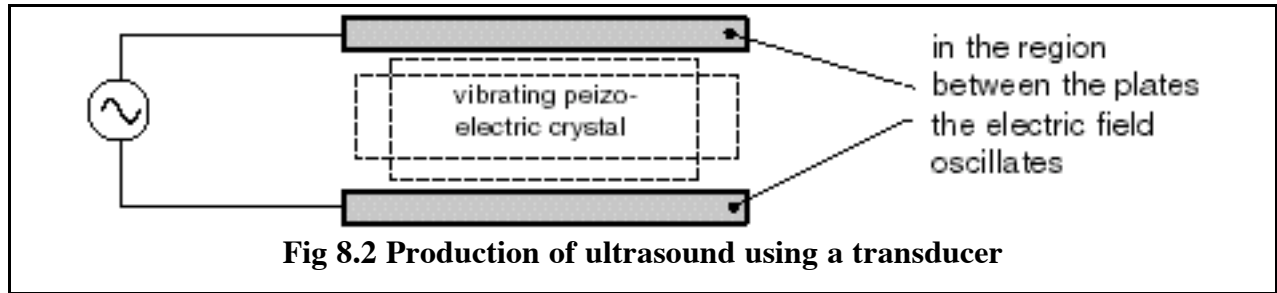


Fig 8.1 Production of sound using a tuning fork

Ultrasound is produced in the same way but to get ultrasound we have to make a vibration at ultrasound frequencies. One device for doing this is the Galton whistle but ultrasound can be produced much more conveniently and efficiently by making use of piezo-electric materials such as barium titanate.

These have the property that when a voltage is applied in a certain direction, the dimension of the material in that direction increases, and if the sense of the voltage is reversed then the dimension decreases. By applying a high frequency alternating voltage, the material is caused to vibrate at a high frequency and so ultrasound is produced.



A device to produce ultrasound based on this principle is known as a **transducer**.

These transducers can detect ultrasound by using them in reverse.

Demonstration

Ultrasound falling on one of them causes it to vibrate and hence a voltage is produced across it, a voltage which can be detected using, for example, an oscilloscope.

Since ultrasound is at high frequency, its wavelength is short and so it can be focussed into small regions. When used at high power, this fact gives ultrasound a variety of important uses. Strongly focussed high power ultrasound can be used for example to kill microorganisms, to study cells by splitting them open, to produce small lesions in the brain, to treat a disease of the inner ear known as Meniere's disease, to remove hard deposits on the valves of the heart and so on. It can also be used for more prosaic applications such as drilling and cutting.

Demonstration

Ultrasound at high power is also used extensively for cleaning. The ultrasound is produced in a bath of liquid in which the object to be cleaned is placed. The high intensity ultrasound causes negative pressures in the liquid and as a result bubbles called "cavitation" bubbles are produced. Agitation produced by these cleans the object. If the object is kept too long in the cleaner, particularly if it is thin, it can be extensively damaged.

8-3 DOPPLER TECHNIQUES

The frequency of a wave emitted by a moving source is different to a stationary observer from that when the source is stationary. This is known as the DOPPLER EFFECT. When the source is moving towards the observer, the frequency is increased and when the source is moving away the frequency is decreased. The effect also applies to a wave reflected from a moving object.

Demonstration

The police make use of the Doppler effect in their radar speed traps. (NOTE: It is difficult to upset a speeding conviction based on a radar trap, because you can demonstrate the device is working properly just by using a tuning fork).

A common example of the Doppler effect is the sound of an ambulance siren as the ambulance approaches and passes. The "red shift" i.e. the shift to lower frequencies, of light from other galaxies is interpreted to mean that the galaxies are moving away from each other and hence the concept of the expanding universe.

Demonstration

The effect can be demonstrated by having an ultrasound generator mounted on a car which can run on rails either towards or away from a stationary ultrasonic detector. The frequency of the detected sound can be measured with a digital frequency meter..

Detailed measurements with such apparatus show that the change in frequency is proportional to the velocity of the source. Since the change in frequency is proportional to the velocity, a measurement of this change can be used to determine the velocity of the source. Or, alternatively, if the wave is reflected from a moving surface the change in frequency of the reflected wave relative to the incident one gives the velocity of the moving surface. In this latter form there are many uses of Doppler techniques with ultrasound in medicine. For example it is possible to detect the foetal heartbeat as early as the 10th week, and by measuring the motion of blood vessel walls it is possible to learn about their elasticity.

Demonstration

In clinical medicine, the technique is used to detect blood flow in arteries and veins by means of an external probe. This is placed against the skin and more or less angled along the blood vessel. A paste is applied between the skin and probe to improve impedance matching and so lessen power loss by reflection. The ultrasound produced by the probe is reflected from the flowing blood and then detected by the probe. A probe such as this shows quite different sounds for arteries and veins. For arteries, the sound is characteristic of the pulsatile blood flow in arteries. In veins, it is more like a wind-storm which cycles with the respiration. The probe can detect blockages in arteries and veins. (N.B. The medical term "patent" which is used in describing this technique means "unblocked".)

Doppler techniques have been used in a different way to measure the blood flow in research projects on animals.

Demonstration

Small probes are placed around arteries during an operation. They heal in place with the leads coming out of the skin. In an experiment, the leads are connected to a telemetering device carried in a package on the animal. In this way it is possible to look at patho-physiological conditions in conscious animals in realistic situations. This technique has been used for example on dogs which have been made hypertensive. It has also been used on small monkeys to study the effect of severe oxygen lack on the circulation. In a proposed experiment it is to be used on baboons to study the effect of diet on coronary disease.

8-4 ECHOSCOPY

If a pulse of waves of known velocity is set out from a transmitter and the time taken for the pulse to return after being reflected from a distant object is measured then this time is a measure of the distance of the object. This technique is called the "pulse-echo" technique and with electromagnetic waves is of course **radar**. This technique can also be used with ultrasound. It is of course the technique used by bats for navigation. It is used it as **sonar** for depth sounding, detection of submarines and shoals of fish.

In medicine, the technique is used and is then known as **echoscopy**. If ultrasound travelling in one medium encounters another, in general some will be transmitted into the other medium as well as being reflected.

How much energy is reflected depends on the sound power reflection coefficient, which in turn depends on the specific acoustic impedances of the two media. If these are almost the same, little energy is reflected; if they are widely different, much energy is reflected.

There are not large differences between the specific acoustic impedances of the various soft tissues in the body (see post lecture material). Thus the pulse-echo technique can be used to obtain two-dimensional cross-sectional views through various organs in the body. As the ultrasound penetrates into the organ, some is reflected at a soft-tissue boundary but most is transmitted to suffer further reflections from successive boundaries. The time delays and amplitudes of the signals from the different boundaries make up the two dimensional picture called an echogram.

In looking at an echogram it is important that it be not thought of in the same way as an x-ray picture. The latter is a three dimensional view compressed into the two dimensions of the x-ray plate. The echogram is, however, a true two dimensional cross-section through an object.

Demonstration

One use of this technique is in a machine designed to scan the eye. It can pick up retinal detachment and is extremely valuable in detecting tumours behind the eye. It should be noted that the acoustic impedances of the transducer and the eye are matched in this machine by having the transducer in water contained in a plastic membrane to which the eye, rubbed with a paste, is pressed. If the ultrasonic waves were sent through the air to the eye, most would be reflected at the outer surface of the eye.

Demonstration

This technique is also used in obstetrics to scan the pregnant uterus. The matching of acoustic impedances should again be noticed. The technique is of major importance in this field for unlike x rays, ultrasound appears to be completely safe. The technique gives information on the size of the foetus, how many there are, if it is growing at a reasonable rate, whether it has miscarried, whether there are any gross abnormalities etc. The technique can also be used for examining the non-pregnant abdomen for picking up tumours.

POST-LECTURE

8-4 ACOUSTIC PROPERTIES OF VARIOUS MATERIALS

The following table gives the acoustic properties of various materials.

Material	Velocity/m.s	Density/ 10^3 kg.m^{-3}	Specific acoustic impedance/ $10^6 \text{ kg.s}^{-1}.\text{m}^{-2}$
water	1530	1.00	1.53
blood	1534	1.04	1.59
fat	1440	0.97	1.40
brain	1510	1.03	1.55
liver	1590	1.03	1.64
muscle	1590	1.03	1.64
bone	3360	2.00	6.62
air	340	0.00012	10^{-4}

Q8.1 Why is the frequency of ultrasound which bats use so high? [Ans 6]

Q8.2 Show the importance of acoustic impedance matching in echoscopy by comparing the fractional power reflected for a water-flesh interface with that for an air-flesh interface. [Ans. 13]