Ultrasonics

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Ultrasonics

The word **ultrasonic** combines the Latin root word "ultra", meaning **beyond** and "sonic" or **sound**.

Ultrasonic refers to any study or application of sound waves that are higher frequency than the human audible range.

Classification of sound:

(i)	Infrasonic	<20 Hz	(Inaudible)
ii)	Audible	~20 to 20,000Hz	
(iii)	**Ultrasonic**	**>20,000Hz**	**(Inaudible)**

Ultrasonics

Bats use ultrasonic frequencies up to 100 kHz for locating their food sources and navigating.

Infrasonic

Rhinoceroses use infrasonic frequencies as low as 5 Hz to communicate

Ultrasonics

Table 2-2 Range of Hearing for a Variety of Species

Humans	20–20,000 Hz
Cats	100–32,000 Hz
Dogs	40–46,000 Hz
Horses	31–40,000 Hz
Elephants	16–12,000 Hz
Cattle	16–40,000 Hz
Bats	1000–150,000 Hz
Grasshoppers	100–50,000 Hz
Rodents	1000–100,000 Hz
Whales, Dolphins	70–150,000 Hz

Properties of ultrasonic waves

- Ordinary wave properties such as reflection, refraction, absorption.

- High energy content because energy of a mechanical wave increases with frequency. (Note: $E \propto \omega^2$)

- Negligible diffraction due to their small wavelength, therefore they can be transmitted over large distances without any appreciable loss of energy. (Diffraction angle θ is related to wavelength λ by $a\sin(\theta)=n\lambda$, *a smaller wavelength λ means smaller diffraction θ.*)

- Intense ultrasonic wave has a disruptive effect in liquids by causing bubbles to be formed. (A rapid variation of pressure over a very small distance leads to the formation bubbles.)

- If an arrangement is made to form stationary waves of ultrasonic in a liquid, it serves as a diffraction grating (called acoustic grating)**.** Again rapid variation of pressure over distance leads to rapid variation in density. Region with smaller density will allow light easily thus acting effectively as slits.

Applications of ultrasonic waves

- The broad sectors of society that regularly apply ultrasonic technology are the medical community, industry, the military.

- The field of ultrasonic have applications for
  - Imaging
  - Detection
  - Navigation

Ultrasonics Production

Ultrasonic waves are produced by the following methods.

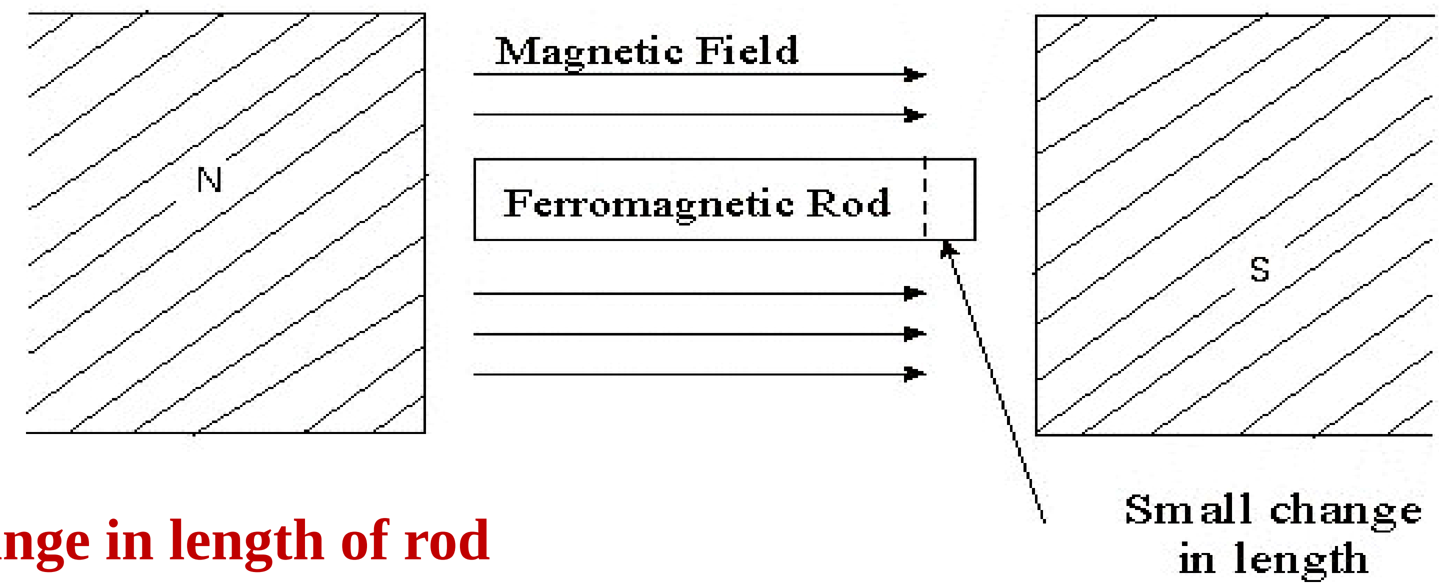
1) Magnetostriction method (low frequency ultrasonics)

(2) Piezoelectric method

Magnetostriction method

Principle: Magnetostriction effect

When a magnetic field is applied parallel to the length of a rod made of ferromagnetic materials such as iron or nickel, a **small change** occurs in its length.



The **change in length of rod**

i) depends on the strength of the magnetic field,

ii) depends on the nature of the ferromagnetic materials

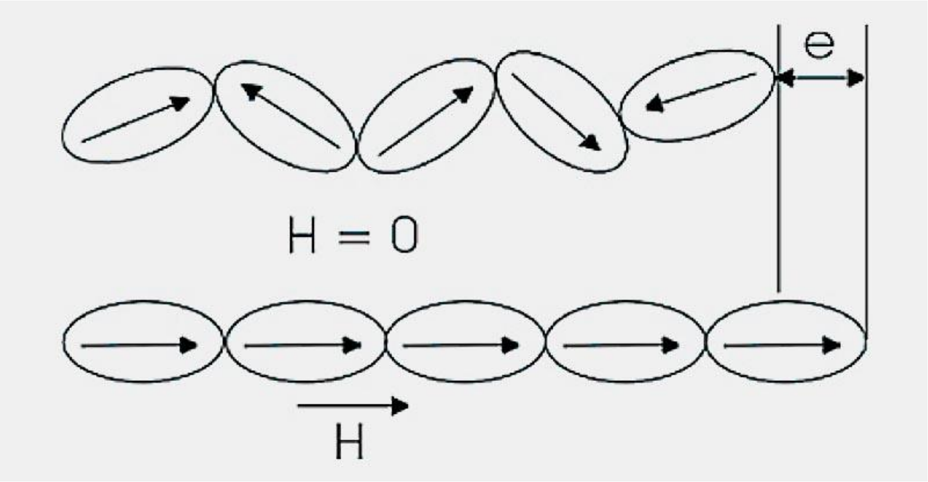
More on the principle of magnetostriction effect

❑ Ferromagnetic materials consists of what is called magnetic domains. The magnetic domains have a net non zero magnetic moment. They result from magnetic anisotropy in the material.

❑ All the magnetic moments in a magnetic moment point in the same direction.

❑ In the absence of magnetic field, the magnetic domains are oriented in random directions.

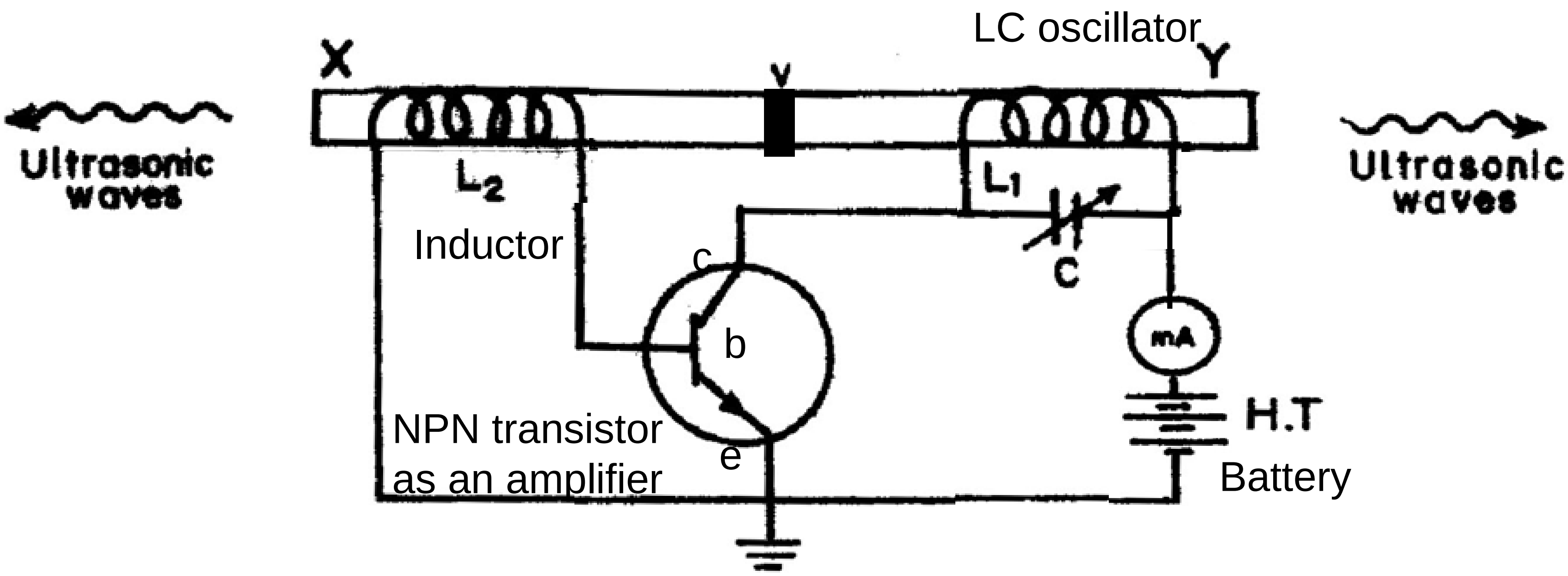
❑ On applying magnetic field the domain boundaries shift so that magnetic domains gets oriented in such a manner that all of them have same magnetic moment direction. But this causes strain in the ferromagnetic material leading to change in it’s size.



H is the magnetic field

Magnetostriction method

Construction



Note: NPN transistor in common emitter (CE) mode is known to Work as an amplifier, i.e, voltage gain V_{ce} / V_{be} is significantly large. Similarly there is current gain.

Magnetostriction method

Construction

- XY is a rod of ferromagnetic materials Fe or Ni clamped at the middle.
- The alternating magnetic field inside the rod is generated by electronic oscillator or LC oscillator.
- The LC oscillator has a variable capacitor so that the frequency of the oscillator can be changed as desired.
- The coil L_1 , LC oscillator is wound on the right hand portion of the rod.
- The coil L_2 on the left hand portion of the rod connected to base circuit in order to generate a feedback to amplifier.
- There is alternate current in the coil L_2 with same frequency which is fed back to the NPN transistor (amplifier). The amplifier amplifies the input voltage or current.
- A battery is used to support the sustained electronic oscillation in the circuit.

Magnetostriction method

Working

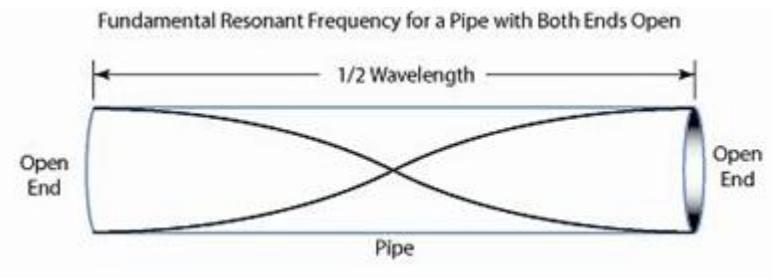
- When High Tension (H.T) battery is switched on, the collector circuit oscillates with a frequency,

$$f = \frac{1}{2\pi\sqrt{L_1 C}}$$

- This alternating current flowing through the coil L_1 produces an alternating magnetic field along the length of the rod. The result is alternating contraction and elongation of the rod due to magnetostrictive effect.

Magnetostriction method

Natural frequency or fundamental of mechanical oscillation of the rod is given by (n = v/(λ)=v/2l)



$$n = \frac{1}{2l}\sqrt{\frac{Y}{\rho}}$$

where l = length of the rod

Y = Young's modulus of the rod material and

ρ =density of rod material

- The capacitor C is adjusted so that the frequency of the oscillatory circuit (n) is equal to natural frequency (f) of the rod and thus resonance takes place.
- Now the rod vibrates longitudinally with maximum amplitude and generates ultrasonic waves of high frequency from its ends.

Magnetostriction method

Advantages

1. The design of this oscillator is very simple and its production cost is low as the magnetostrictive materials are easily available
2. At low ultrasonic frequencies, the large power output can be produced without the risk of damage of the oscillatory circuit.

Disadvantages

1. It has low upper frequency limit and cannot generate ultrasonic frequency above 3000 kHz (i.e. 3MHz).
2. The frequency of oscillations depends on temperature as the magnetization and length of rod also depends on temperature.
3. There will be losses of energy due to hysteresis and eddy current.

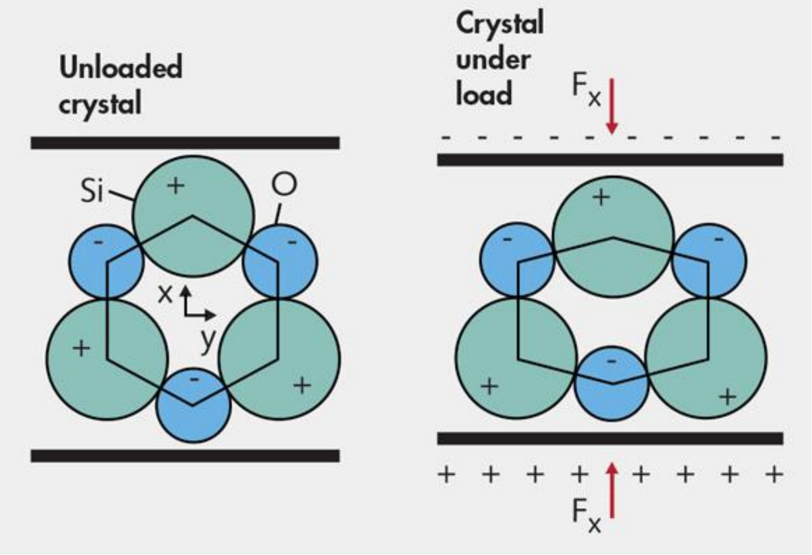
Piezo-electric method

This is based on the inverse piezo electric effect

PIEZOELECTRIC EFFECT

Principle

If mechanical pressure is applied to one pair of opposite faces of certain crystals like quartz, equal and opposite electrical charges appear across the faces. This is called as piezo-electric effect.



"Piezo" => "press" Greek word

Piezoelectric materials: titanates of barium and lead, lead zirconate ($PbZrO_3$), ammonium dihydrogen phosphate ($NH_4H_2PO_4$), and quartz (natural crystal).

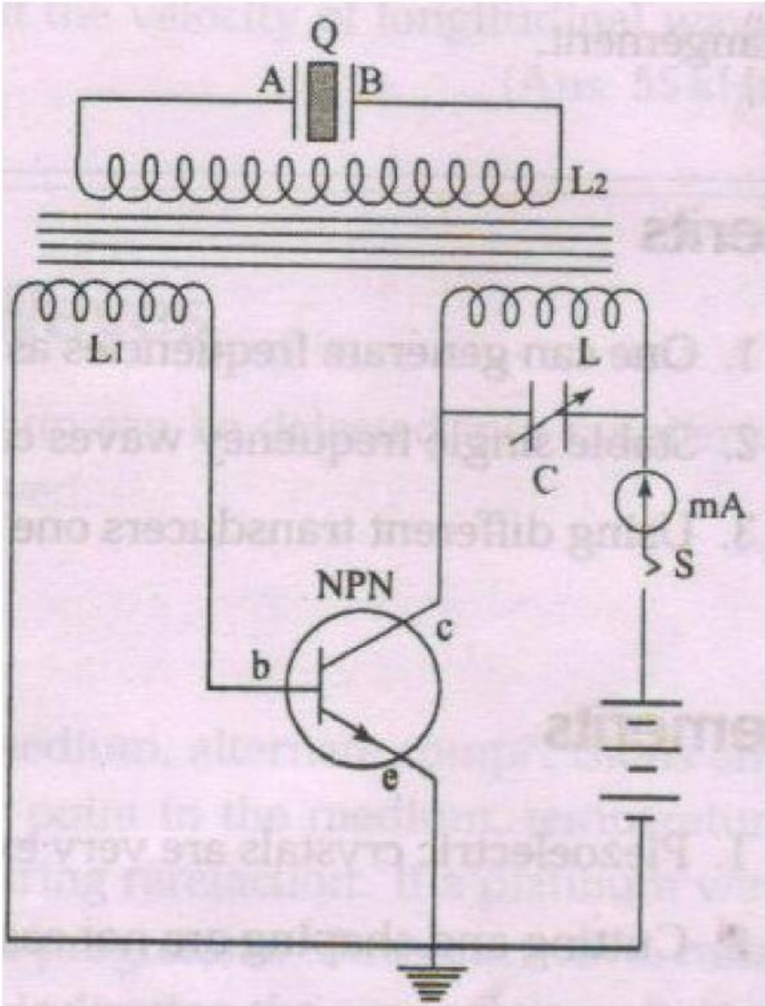
Converse Piezoelectric effect

Principle

The converse of piezoelectric effect is also true. If an electric field (or voltage difference) is applied to one pair of faces, the corresponding changes in the dimensions of the other pair of faces of the crystal are produced. This is known as ***inverse piezo electric*** effect or ***electrostriction.***

Piezo-Electric method

Construction



Piezo-electric oscillator

- The quartz crystal is placed between two metal plates A and B.
- The plates are connected to the coil L_2 which is inductively coupled to coil L of the electronics oscillator as well as to coil L_1 (using transformer).
- The coil L and variable capacitor C form the *tank circuit* of the oscillator.
- There is alternate current in the coil L_1 with same frequency which is fed back to the NPN transistor amplifier. The input voltage get amplified.
- The sustained oscillation is then supported by a battery.

Piezo-Electric method

Working

- When H.T. battery is switched on, the oscillator produces high frequency alternating voltages with a frequency.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

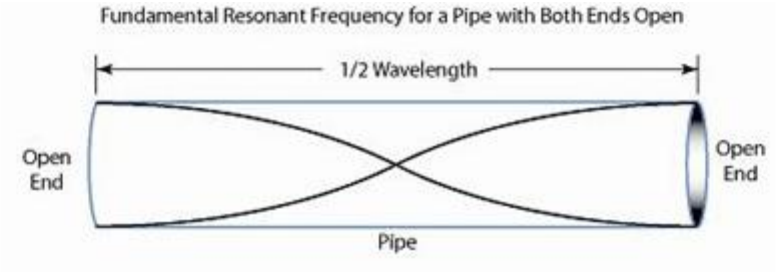
- Due to the transformer action, an oscillatory e.m.f. is induced in the coil L_2. This high frequency alternating voltages are fed on the plates A and B.
- Inverse piezo-electric effect takes place and the crystal contracts and expands alternatively. The crystal is set into mechanical vibrations..
- The frequency of the vibration is given by ($n = v/(\lambda) = v/2l$)

$$n = \frac{1}{2l}\sqrt{\frac{Y}{\rho}}$$

Where l = thickness of the crystal

Y = Young's modulus of the crystal axis chosen

ρ = density of the crystal.



Piezo-Electric method

Advantages

- Ultrasonic frequencies as high as 500 MHz can be obtained with this arrangement.
- The output of this oscillator is very high.
- It is not affected by temperature and humidity.

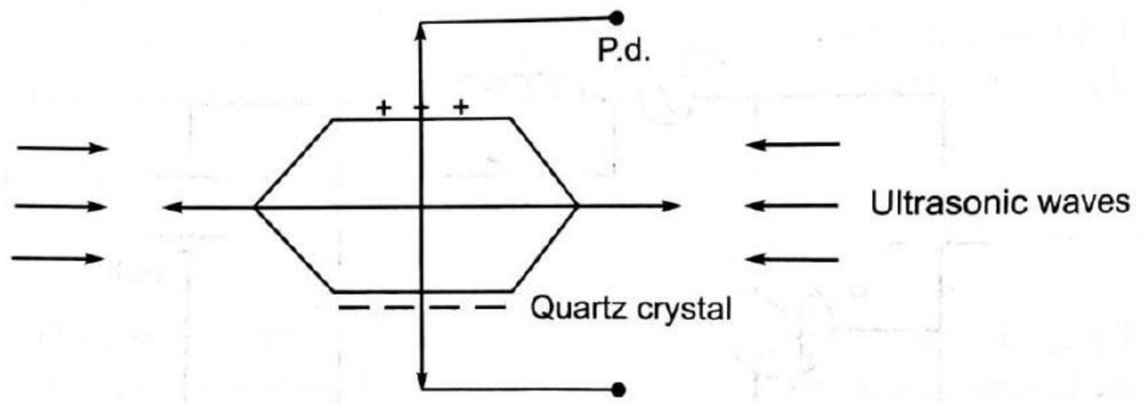
Disadvantages

- The cost of piezo electric quartz is very high
- The cutting and shaping of quartz crystal are very complex.

Detection of Ultrasonic Waves

1. Piezoelectric Detector

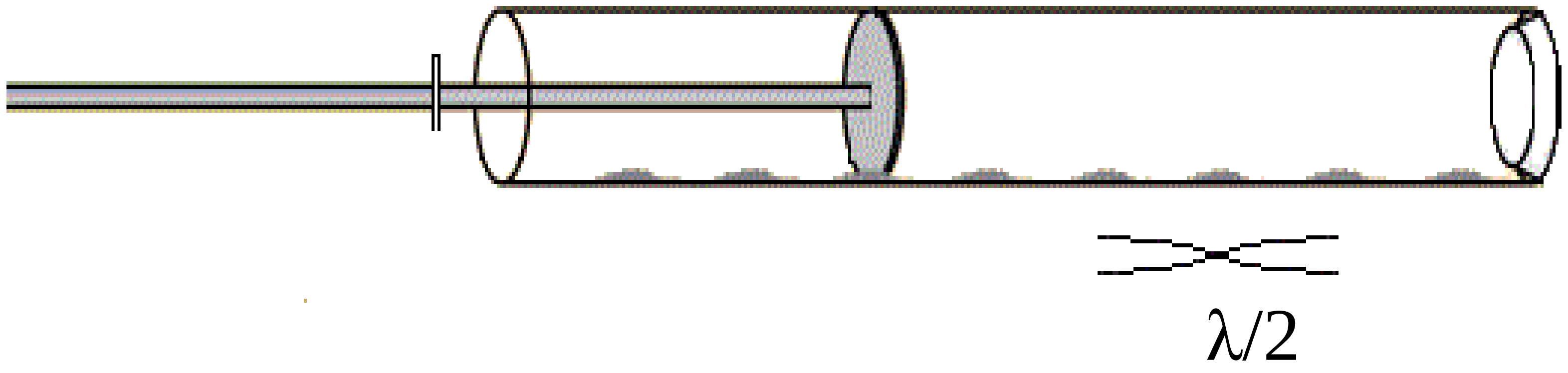
Piezoelectric effect can also be used to detect ultrasonics. If ultrasonics comprising of pressure compressions and rarefactions are allowed to fall upon a quartz crystal a certain potential difference is developed across the faces which after amplification by a value amplifier can be used to detect ultrasonics.



Detection of Ultrasonic Waves

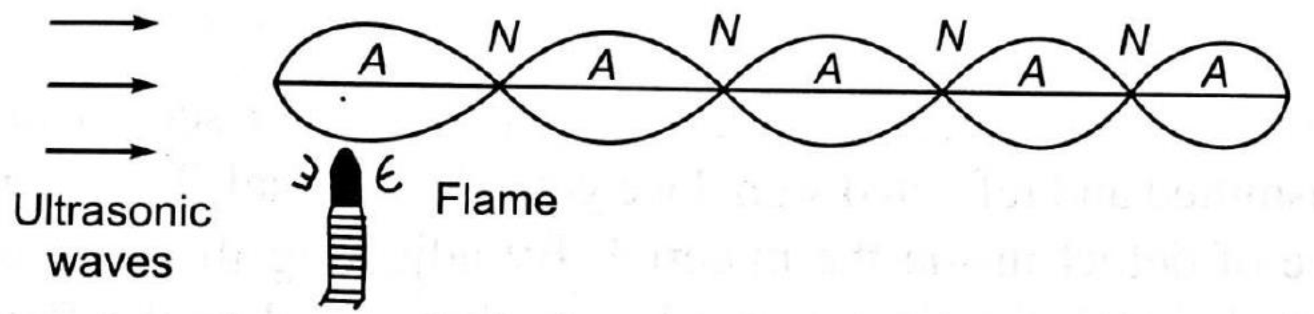
2. Kundt's Tube Method

Kundt's tube is a long glass tube supported horizontally with a air column in it. When the ultrasonic waves are passed through the Kundt's tube with talc or lycopodium powder sprinkled. The powder collects in the form of heaps at the displacement nodes p and is blown off from the displacement antinodes.



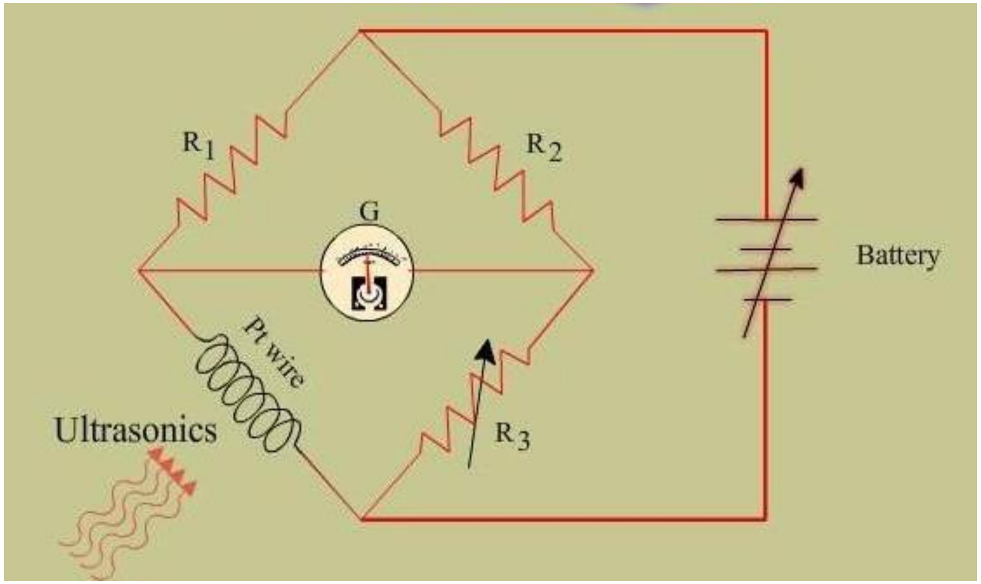
3. Sensitive flame Method

When a narrow sensitive flame is moved in a medium where ultrasonic waves are present, the flame remains stationary at displacement antinodes. At the positions of displacement nodes, the flame flickers because there is a change in pressure as a function of time. In this way, positions of nodes and antinodes can be found out in the medium. The average distance between the two adjacent nodes is equal to half the wavelength.



4. Thermal Detector

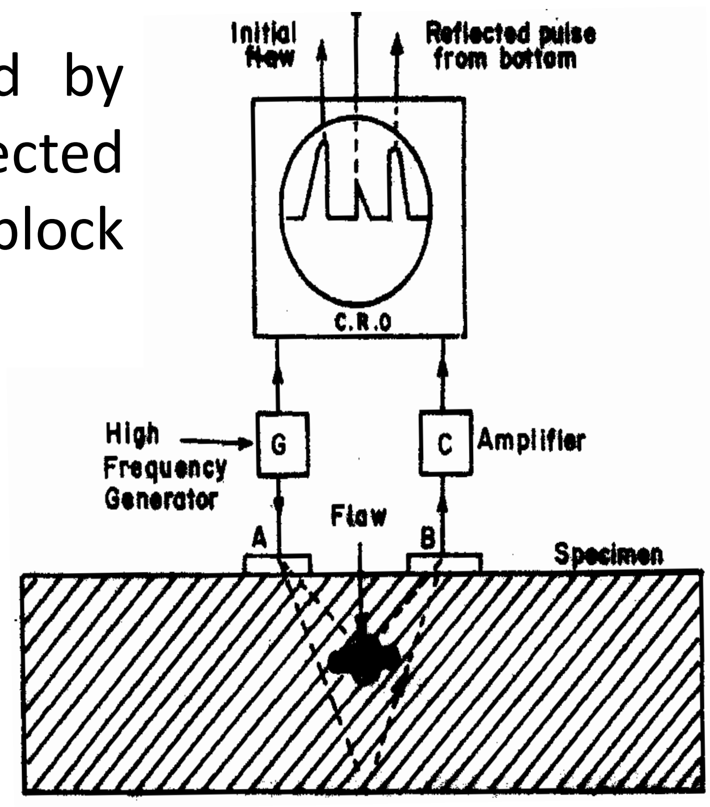
This is the most commonly used method of detection of ultrasonic waves. In this method, a fine platinum wire is used. This wire is moved through the medium. At the position of displacement nodes, due to alternate pressure compressions and rarefactions, adiabatic changes in temperature takes place. The resistance of the platinum wire changes with respect to time. This can be detected with the help of Callendar and Garrifith's metre bridge arrangement. At the position of the nodes, the temperature remains constant. This will be indicated by the undisturbed balanced position of the meter bridge.



Applications of Ultrasonic Waves

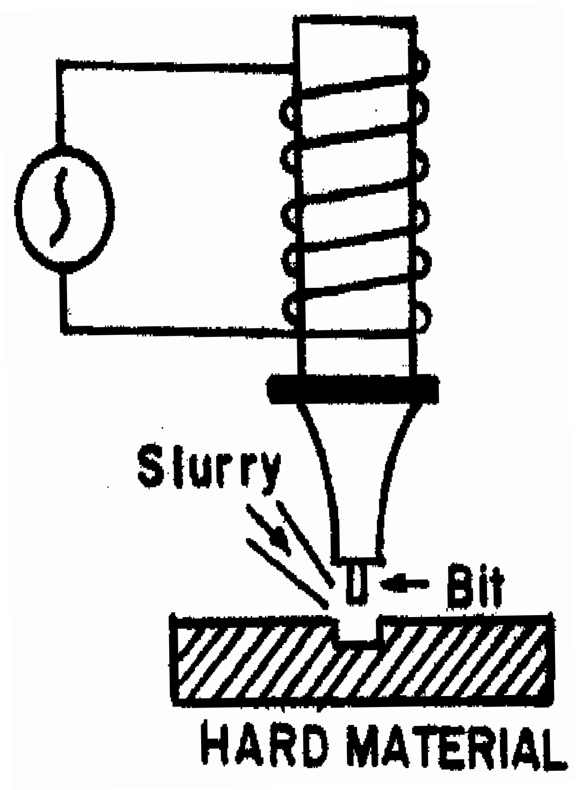
1. Detection of flaws in metals (Non Destructive Testing –NDT)

- Ultrasonic waves are used to detect the presence of flaws or defects in the form of **cracks, holes, porosity etc**., in the internal structure of a material.
- By sending out ultrasonic beam and by measuring the time interval of the reflected beam, location of flaws in the metal block can be determined.



(2) Ultrasonic Drilling

- Ultrasonics drillers are used for making holes in very hard materials like glass, diamond etc.
- A suitable drilling tool bit is fixed at the end of a powerful ultrasonic generator.
- Slurry (a thin paste of carborundum powder (SiC) and water) is introduced between the bit and the plate in which the hole is to be made.
- Ultrasonic generator causes the tool bit to move up and down with high frequency. The tool bit with the help of slurry particles is able to dig holes in the hard material.

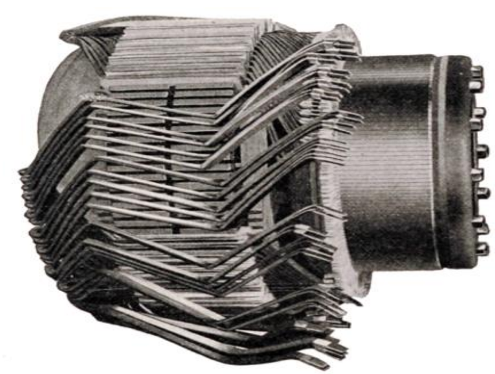


(3) Ultrasonic soldering

- For soldering glass, aluminium etc. Particularly, aluminium cannot be directly soldered. However, it is possible to solder such metals by ultrasonic solders.
- An ultrasonic soldering iron consists of an ultrasonic generator having a tip fixed at its end which can be heated by an electrical heating element.
- The tip of the soldering iron melts solder on the aluminium and the ultrasonic vibrator removes the aluminium oxide layer.
- The solder thus gets fastened to metal without any difficulty.

(4) Ultrasonic cleaning

It is the cheapest technique employed for cleaning various parts of the machine, electronic assembles, armatures, watches etc, which cannot be easily cleaned by other methods.



(5) SONAR

- SONAR is a technique which stands for ***Sound Navigation and Ranging***.
- It uses ultrasonic wave for the detection and identification of under water objects.
- The method consists of sending a powerful beam of ultrasonics in the suspected direction in water.
- By noting the time interval (*t*) between the emission and receipt of beam after reflection, the distance (d) of the object can be easily calculated.

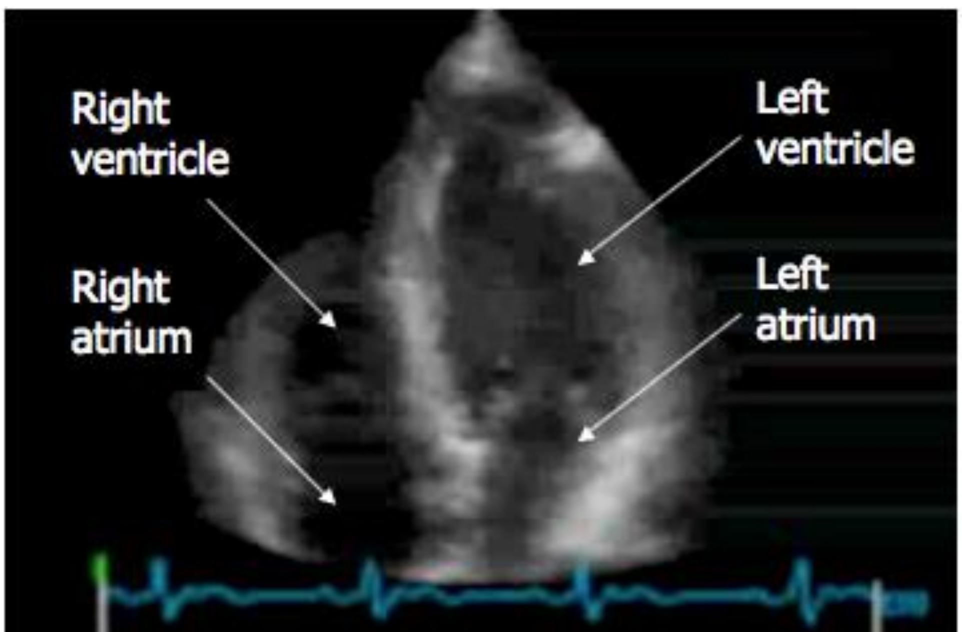
$$d = \frac{vt}{2}$$

Why not radar (radio detection and ranging)?

6. Ultrasonics in Medicine

Diagnostic sonography

Medical sonography (ultrasonography) is an ultrasound-based diagnostic medical imaging technique used to visualize muscles and many internal organs, their size, structure and any pathological lesions.



7. Car airbag sensor

Through piezoelectric effect shock and it’s intensity can be detected and an electrical signal is generated to trigger the airbag.

8. Dispersion of fog

Fog is defined as a mass of water vapour condensed into small water droplets or it can also be considered low lying clouds. When US waves is directed towards fog, they being longitudinal in nature, get reflected from its constituents and form stationary waves. The stationary waves, comprising of high and low density points, help coagulate the liquid and solid particles in the fog turning them into big particles. These particles fall on ground due to the gravity resulting in dispersal of fog

9. Green Energy

Piezoelectricity being non-polluting is called green energy. It can be an alternative green energy source in providing piezoelectric flooring at places such as floors, airports, shopping malls, train stations or places where heavy foot traffic is available.