Ultrasonics

Department of Physics and Materials Science (DPMS)
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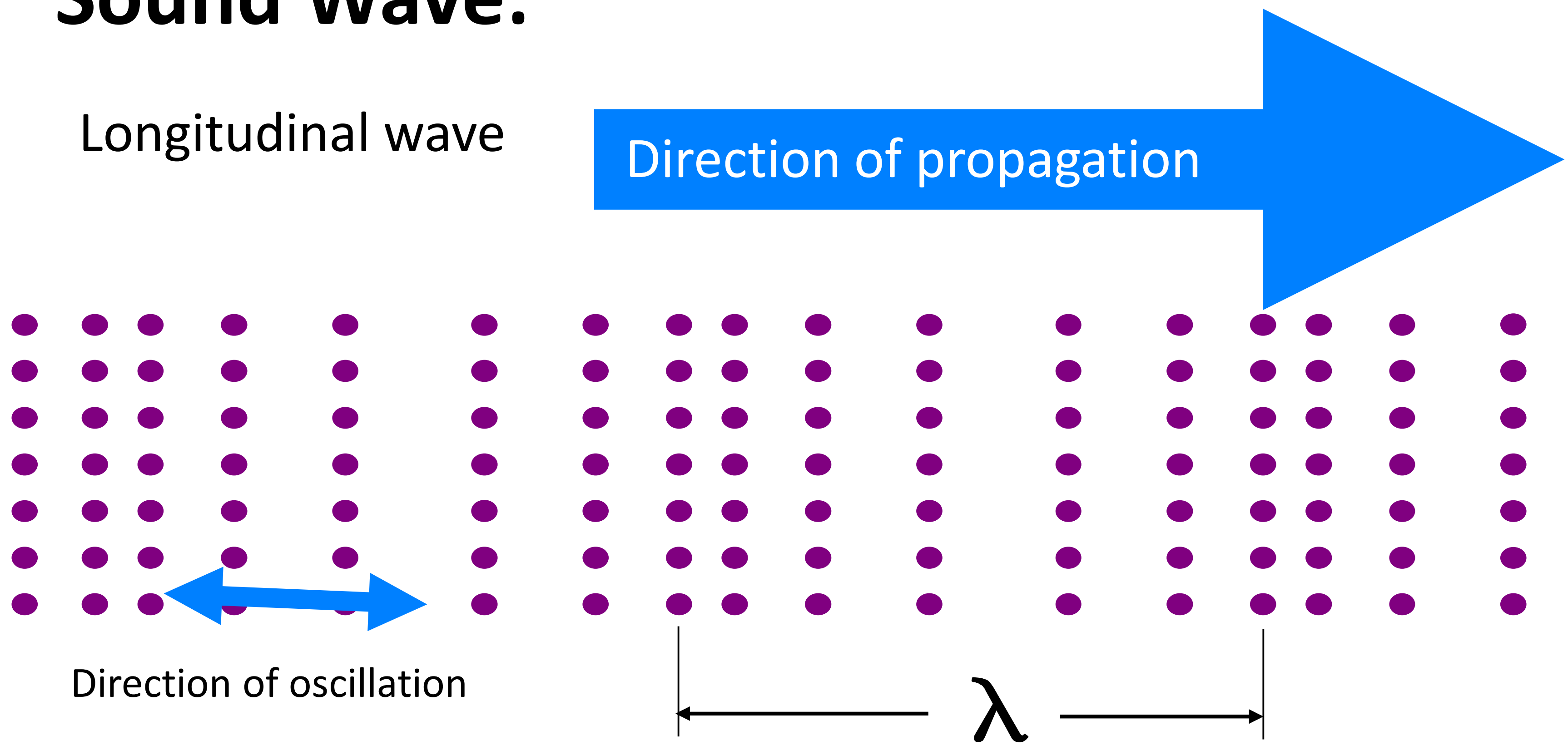
Sound Wave:



Travels : Longitudinal Wave Motion
Form of Energy : Emitted by a vibrating body
Propagation : In all directions

Classification of Sound Waves: Depends upon Frequency
Divided into 3 groups.

Description	Frequency range Hz	Example
Infrasound	0 - 20	Earth quake
Audible sound	20 – 20,000	Speech, music
Ultrasound	> 20,000 to 5M	Bat, Quartz crystal

The word **ultrasonic** combines the Latin roots 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.

Generally these waves are called as **high frequency waves**.

Ultrasonic waves

Rhinoceroses use infrasonic frequencies as low as 5 Hz to call one another.

Humans	*20-20K Hz*
Cats	*100-32K Hz*
Dogs	*40-46K Hz*
Horses	*31-40K Hz*
Elephants	*16-12K Hz*
Cattle	*16-40K Hz*
Bats	*1K-150K Hz*
Grasshoppers	*100-50K Hz*
Rodents	*1K-100K Hz*
Whales, Dolphins	*70-150K Hz*

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

Properties of ultrasonic waves

- They have a high energy content.
- Just like ordinary sound waves, ultrasonic waves get reflected, refracted and absorbed.
- They show negligible diffraction due to their small wavelength. Hence can be transmitted over large distances without any appreciable loss of energy.
- Intense ultrasonic radiation has a disruptive effect in liquids by causing bubbles to be formed.
- If an arrangement is made to form stationary waves of ultrasonic in a liquid, it serves as a diffraction grating (called acoustic grating).

Applications of ultrasonic waves

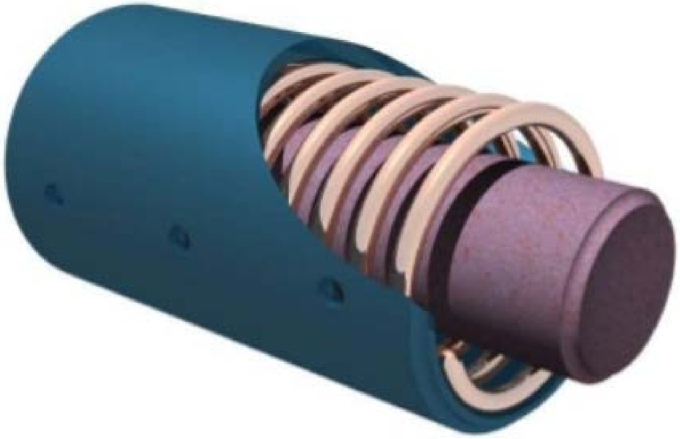
- The broad sectors of society that regularly apply ultrasonic technology are the medical community, industry, the military and private citizens.

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

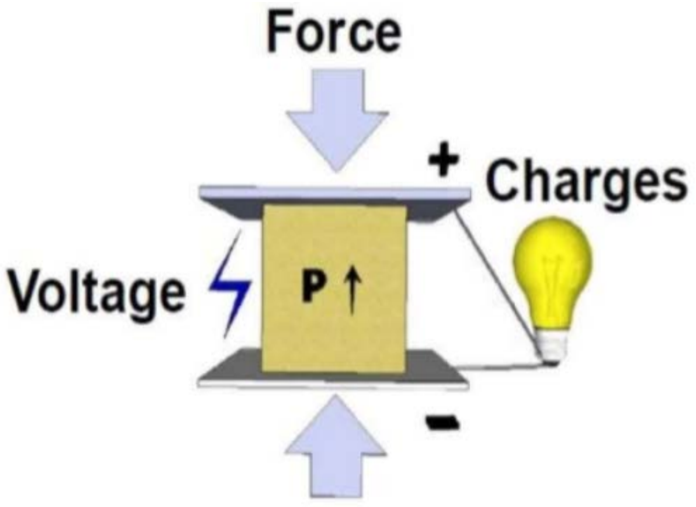
Ultrasonics Production

Ultrasonic waves are produced by the following methods.

(1) Magnetostriction method



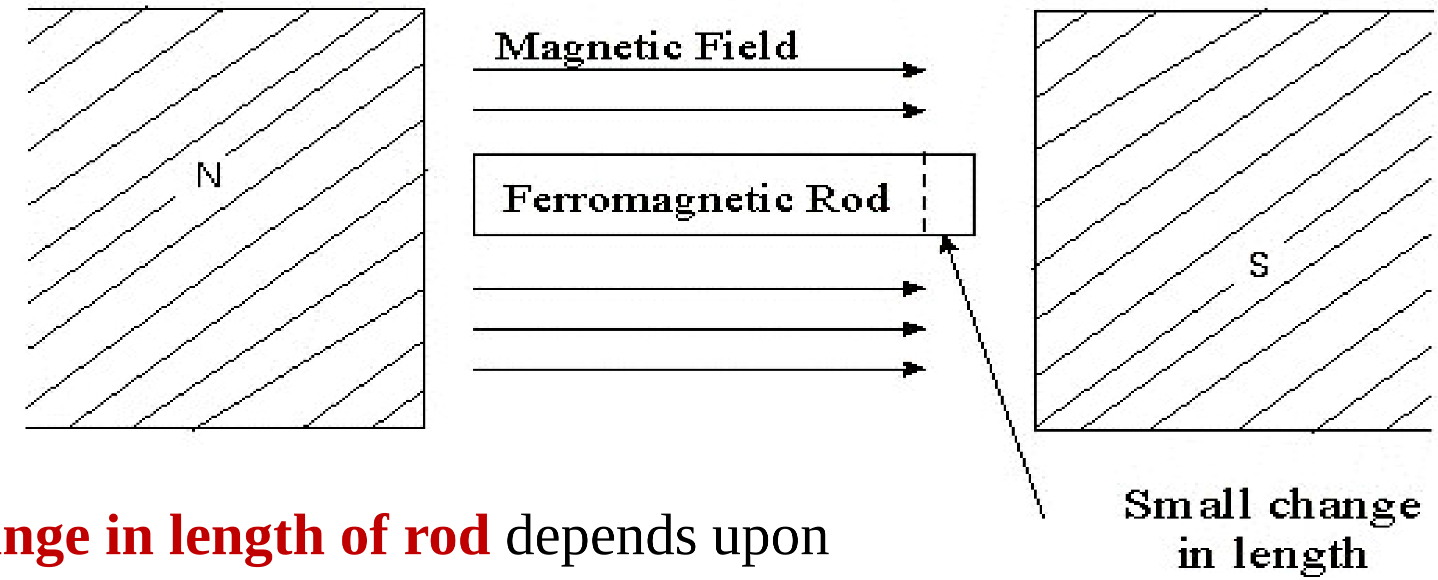
(2) Piezoelectric method



Magnetostriction method

Principle: Magnetostriction effect

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



The **change in length of rod** depends upon

i) the strength of the magnetic field,

ii) the nature of the ferromagnetic materials

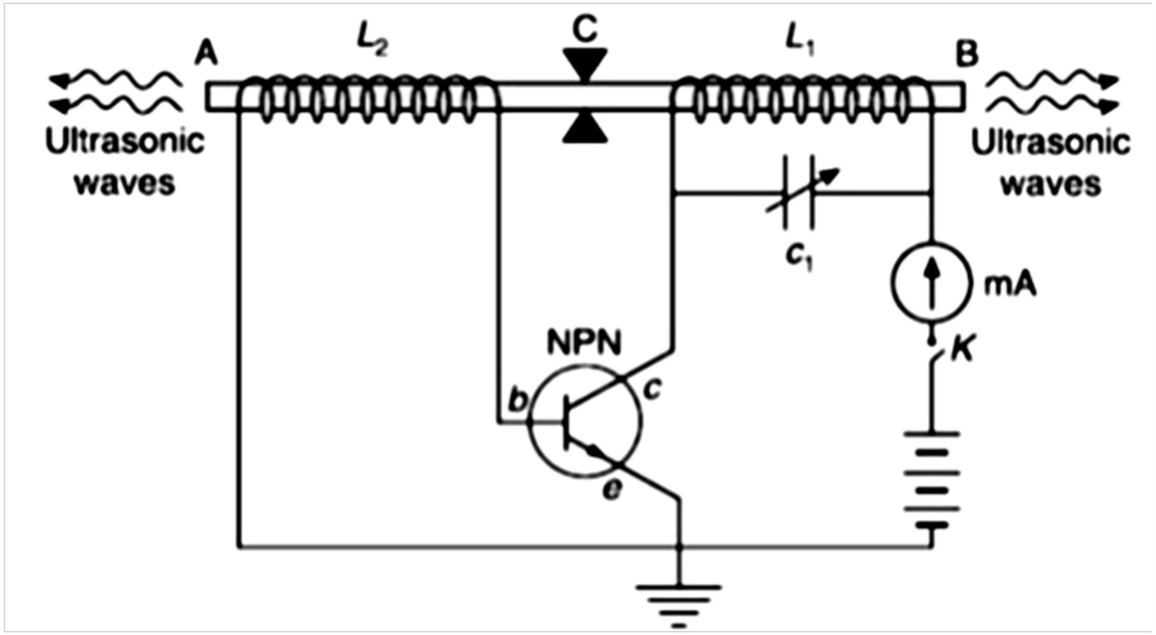
iii) does not depend of the direction of the field.

Magnetostriction method

- AB is a rod of ferromagnetic materials Fe or Ni. The rod is clamped in the middle.
- The alternating magnetic field is generated by electronic oscillator.
- The coil L_1 wound on the right hand portion of the rod along with a variable capacitor C_1.
- This forms the ***resonant circuit*** of the collector tuned oscillator. The frequency of oscillator is controlled by the variable capacitor.
- The coil L_2 wound on the left hand portion of the rod is connected to the base circuit. The coil L_2 acts as ***feed –back loop.***

$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

Used to produce low frequency Ultrasonic waves



Magnetostriction method

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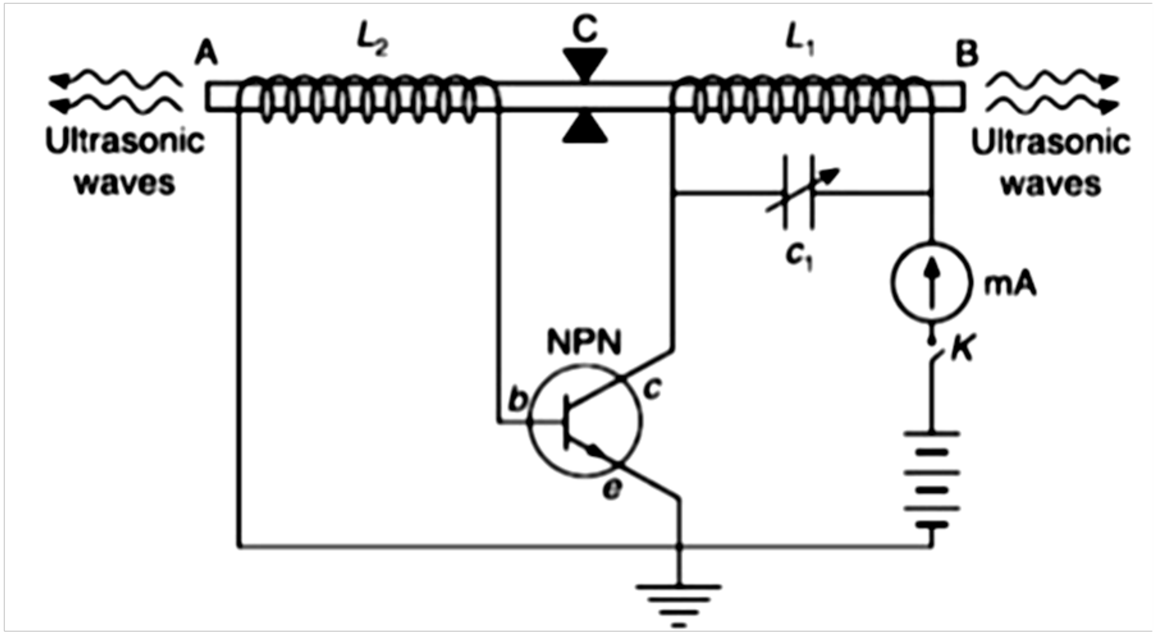


Magnetostriction method

The fundamental frequency of vibrating rod is given by

$$f_0 = \frac{1}{2l}\sqrt{\frac{Y}{\rho}}$$

where l = length of the rod

Y = Young's modulus of the rod material and

ρ = density of rod material

- The capacitor C_1 is so adjusted such that the frequency of the oscillatory circuit is equal to natural frequency of the rod and thus resonance takes place.
- Now the rod vibrates longitudinally with maximum amplitude and generates ultrasonic waves from its ends.

Magnetostriction method

Advantages

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

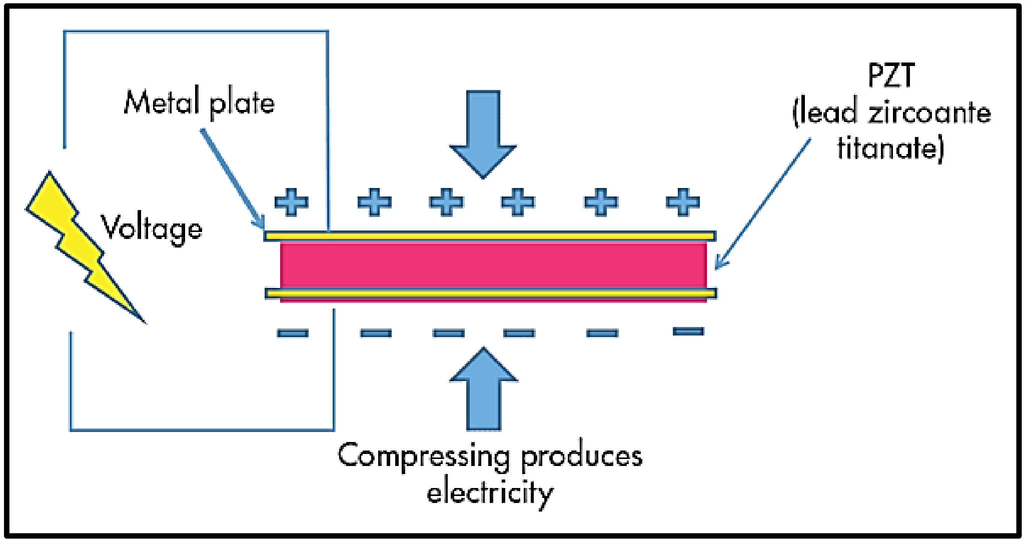
Disadvantages

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.
3. There will be losses of energy due to hysteresis and eddy current.

PIEZOELECTRIC EFFECT

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

The converse of piezo electric effect is also true. If an electric field 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***



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

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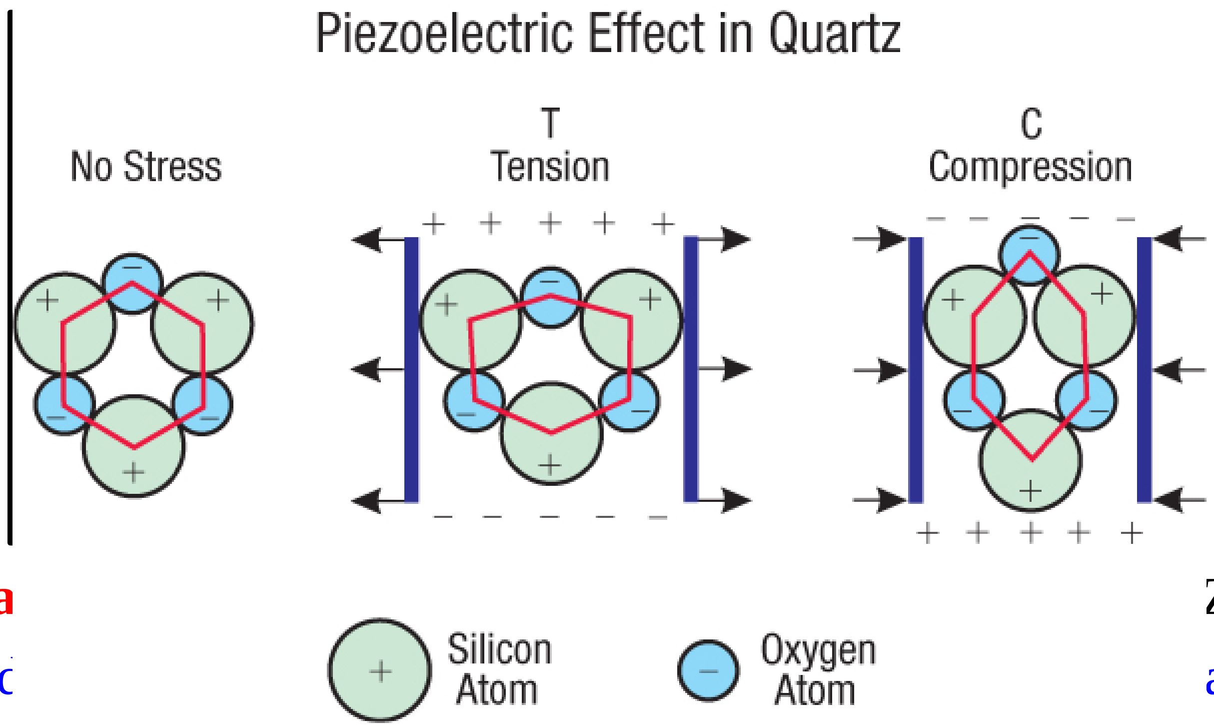
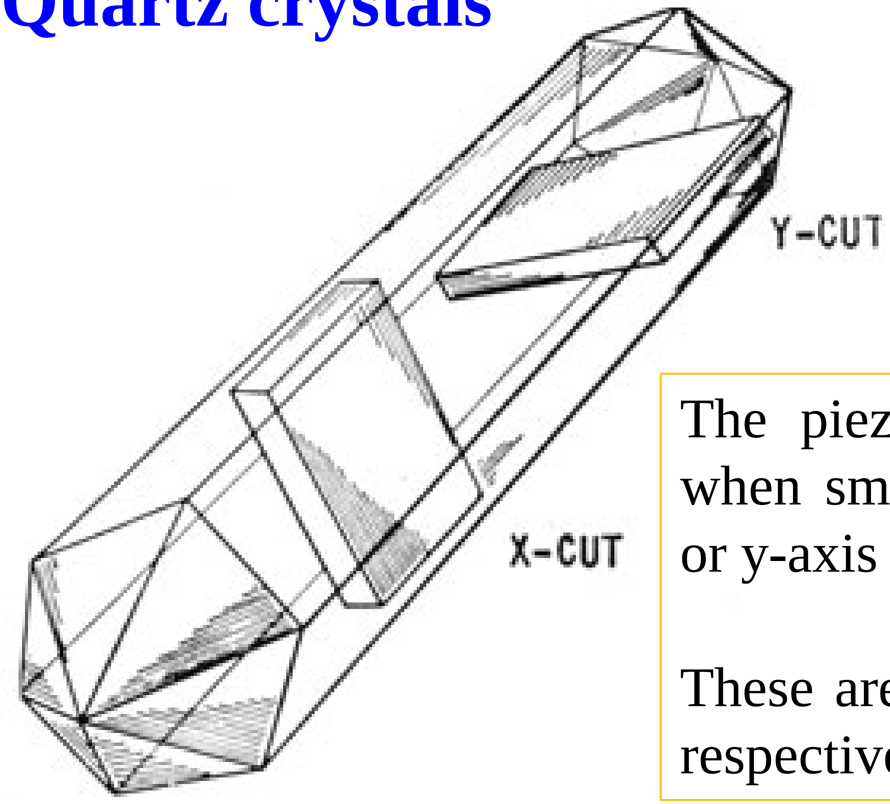


Piezoelectric ma ZrO$_3$),

ammonium dihyc al).

Quartz crystals



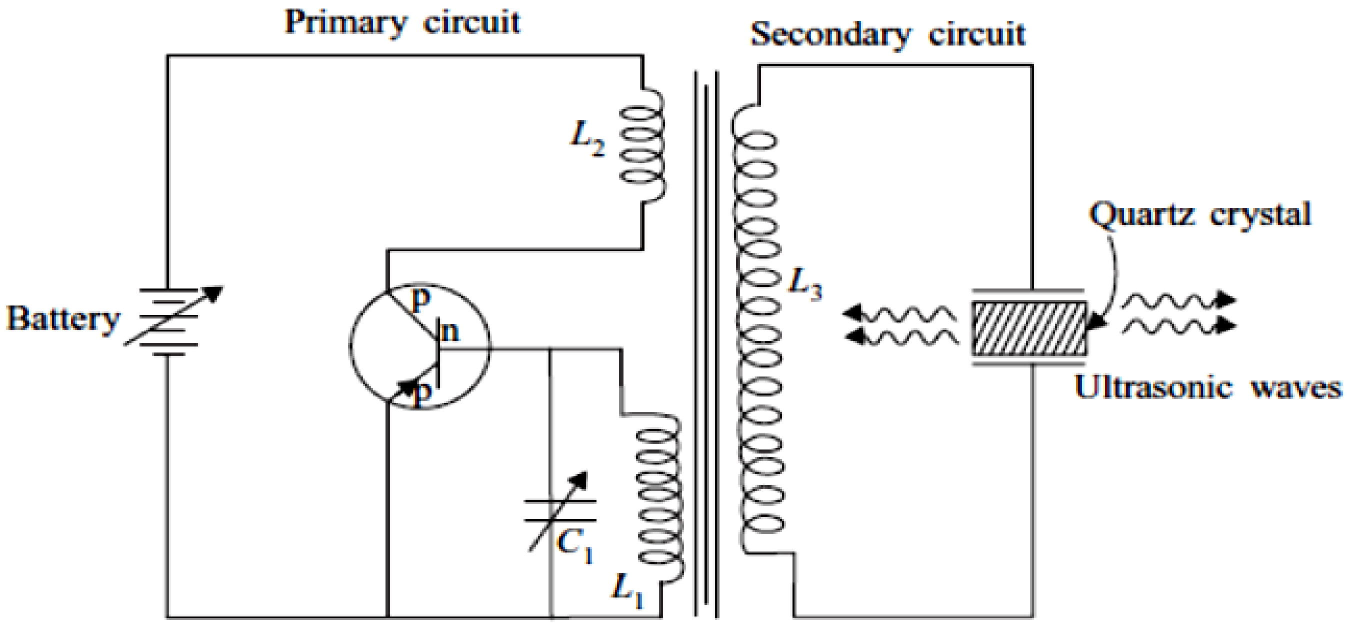
The piezoelectric effect can only be achieved when small plates perpendicular either to x-axis or y-axis are cut out of the crystal.

These are called *X-cut and Y-cut quartz crystals*, respectively.

- X-cut crystals are used for the production and detection of longitudinal ultrasonic waves.
- Y-cut crystals are used for the production and reception of transverse ultrasonic waves. These are seldom used in industry.

Piezo-Electric method

- The quartz crystal is placed between two metal plates A and B.
- The plates are connected to the primary (L_3) of a transformer which is inductively coupled to the electronics oscillator.
- The electronic oscillator circuit is a base tuned oscillator circuit.
- The coils L_1 and L_2 of oscillator circuit are taken from the secondary of a transformer T.
- The collector coil L_2 is inductively coupled to base coil L_1.
- The coil L_1 and variable capacitor C_1 form the *tank circuit* of the oscillator.



Piezo-Electric method

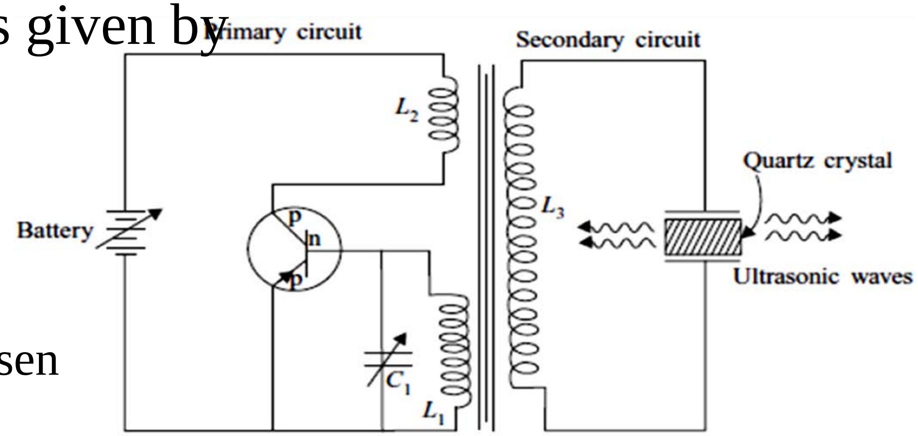
Working

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

$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

- Due to the transformer action, an oscillatory e.m.f. is induced in the coil L_3. 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

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



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.

Numerical

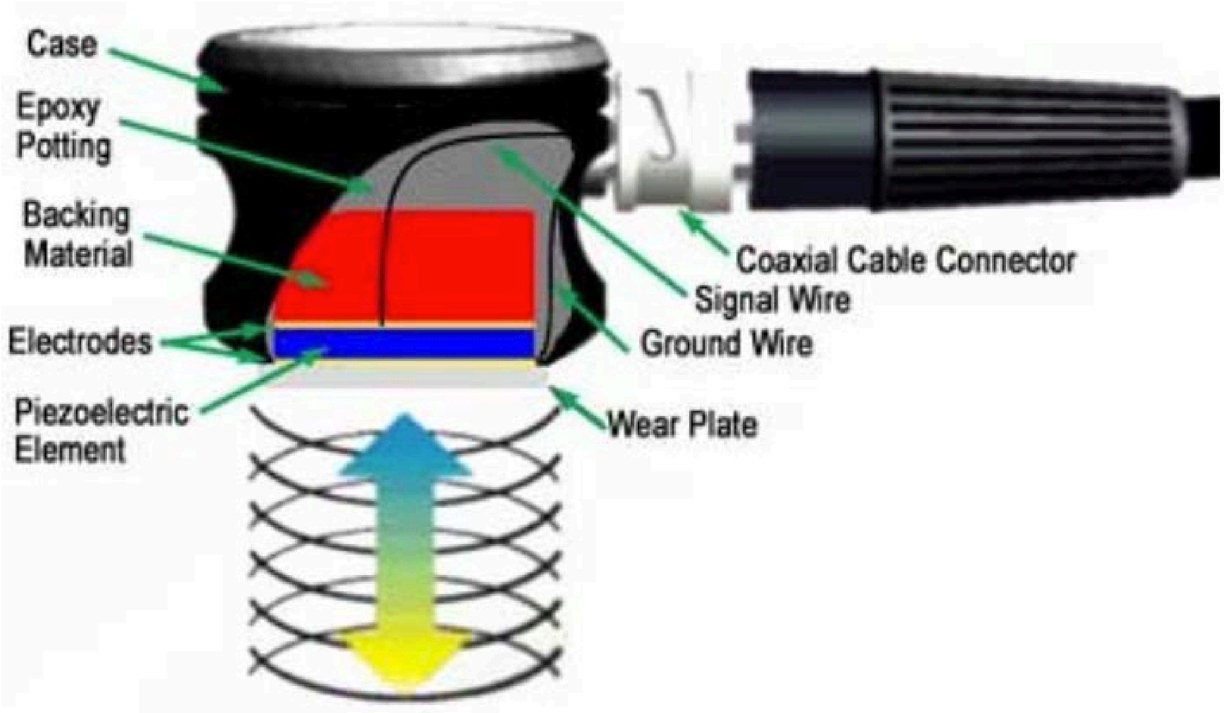
A quartz crystal of thickness 1 mm is vibrating at resonance. Calculate the fundamental frequency. Given Y for quartz = 7.9×10^{10} Nm^{-2} and ρ for quartz = 2650 kg m^{-3}.

What should be the minimum length of an iron rod to generate ultrasonic wave of frequency 0.03 MHz? Given Y for iron = 1.15×10^{11} Nm^{-2} and ρ of iron = 7.23×10^{3} kg m^{-3}.

Detection of Ultrasonic Waves

1. Piezoelectric Detector

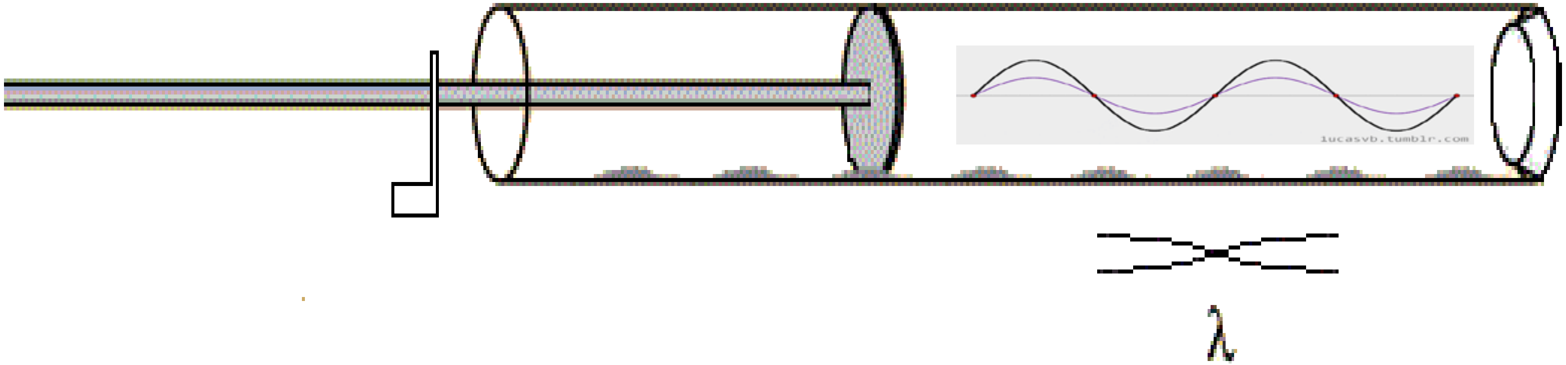
Piezoelectric effect can also be used to detect ultrasonic waves. If ultrasonic waves comprising of compressions and rarefactions are allowed to fall upon a quartz crystal a certain potential difference is developed across the faces which after amplification by a value amplifier can be used to detect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



Detection of Ultrasonic Waves

2. Kundt's Tube Method

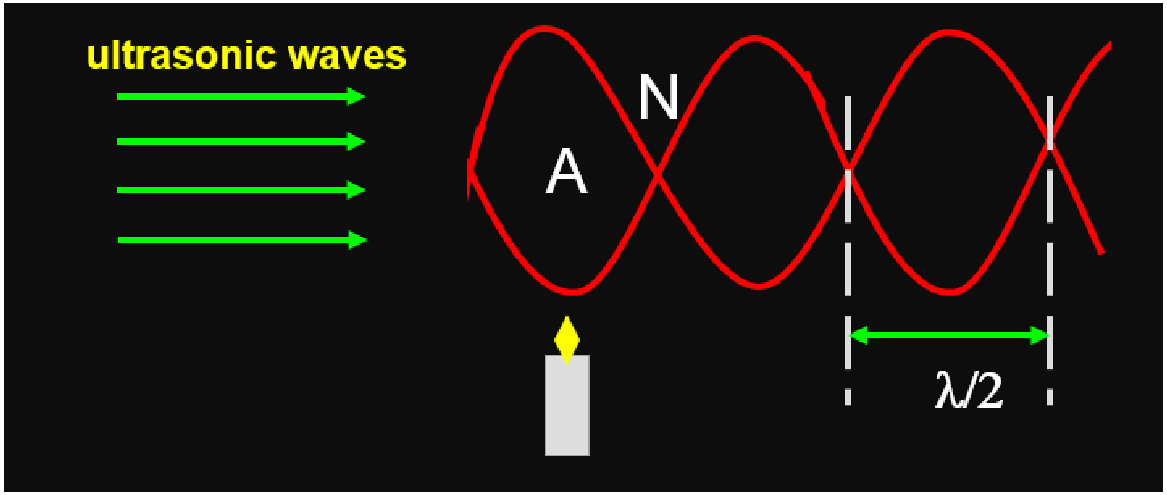
Kundt's tube is a long glass tube supported horizontally with a air column in it when the ultrasonic waves are passed the Kundt's tube, the lycopodium powder (flash powder) sprinkled in the tube collects in the form of heaps at the nodal points and is blown off at the antinodal points.



Detection of Ultrasonic Waves

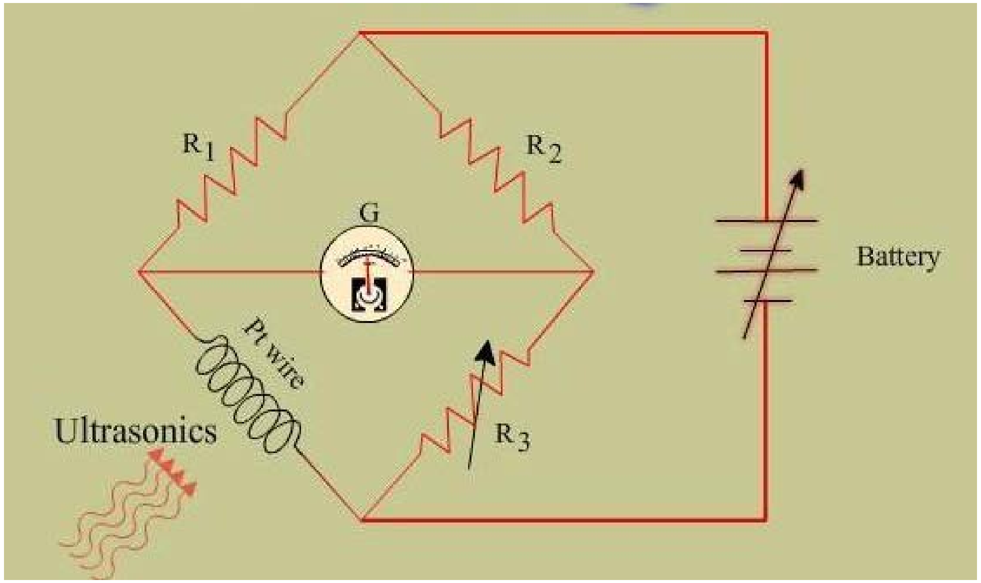
3. Sensitive flame Method

When a narrow sensitive flame is moved in a medium where ultrasonic waves are present, the flame remains stationary at nodes. At the positions of antinodes, the flame flickers because there is a change in pressure. 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 antinodes, due to alternate 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 metre bridge.

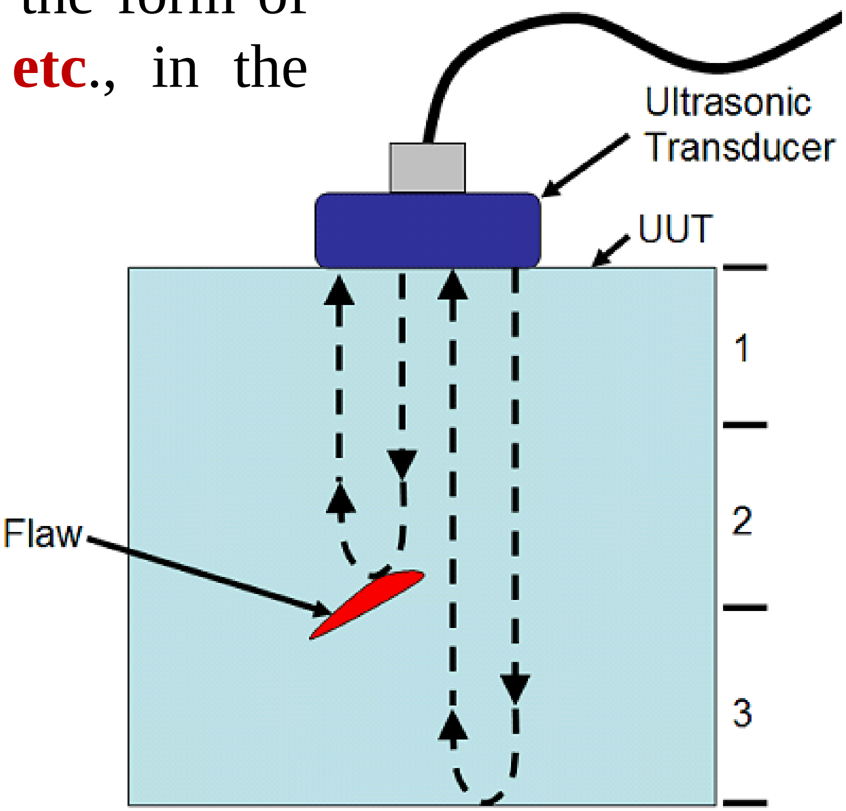


Applications of Ultrasonic Waves

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, blowholes porosity etc**., in the internal structure of a material.

- By sending out ultrasonic beam and by measuring the time interval of the reflected beam, flaws in the metal block can be determined.



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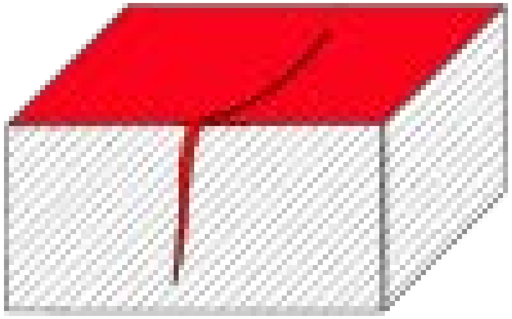

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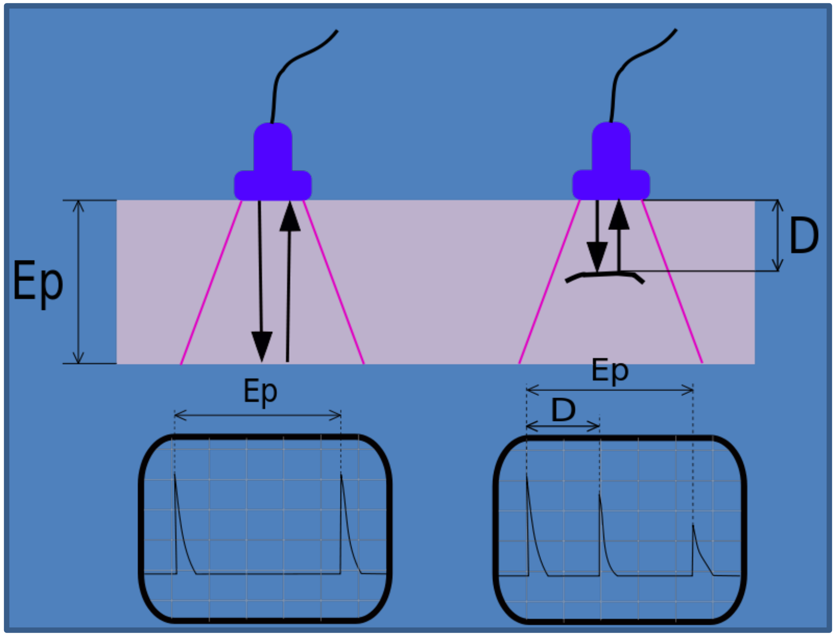
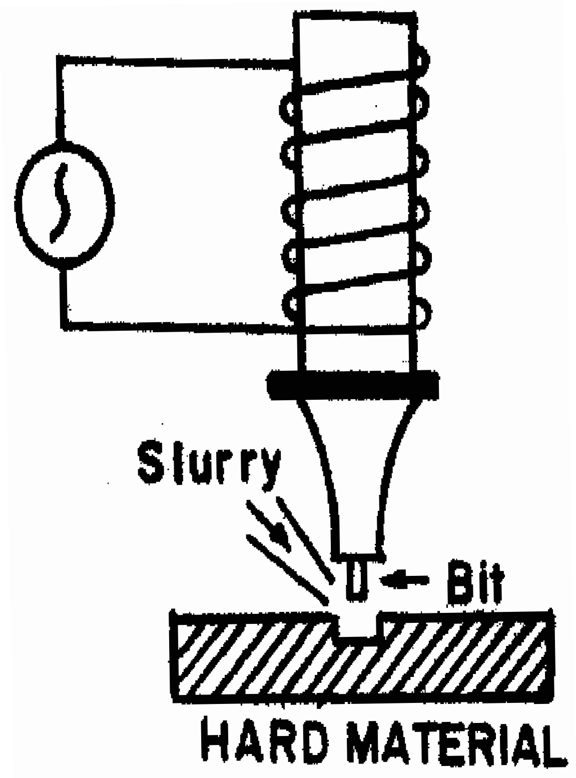


2. Ultrasonic Drilling

- Ultrasonics are used for making holes in very hard materials like glass, diamond etc.
- For this purpose, a suitable drilling tool bit is fixed at the end of a powerful ultrasonic generator.
- Some slurry (a thin paste of carborundum powder and water) is made to flow 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 very quickly and the slurry particles below the bit just remove some material from the plate.
- This process continues and a hole is drilled in the plate.



3. Ultrasonic soldering

- Metals like aluminium cannot be directly soldered. However, it is possible to solder such metals by ultrasonic waves.
- 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 clear metal without any difficulty.

4. Ultrasonic cleaning

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

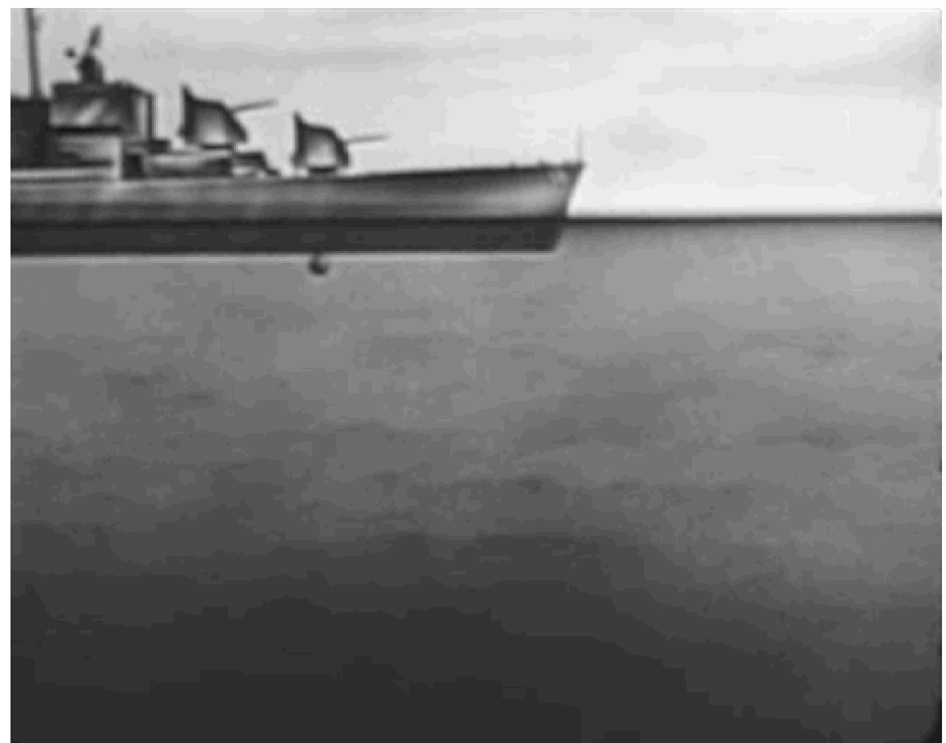
5. SONAR

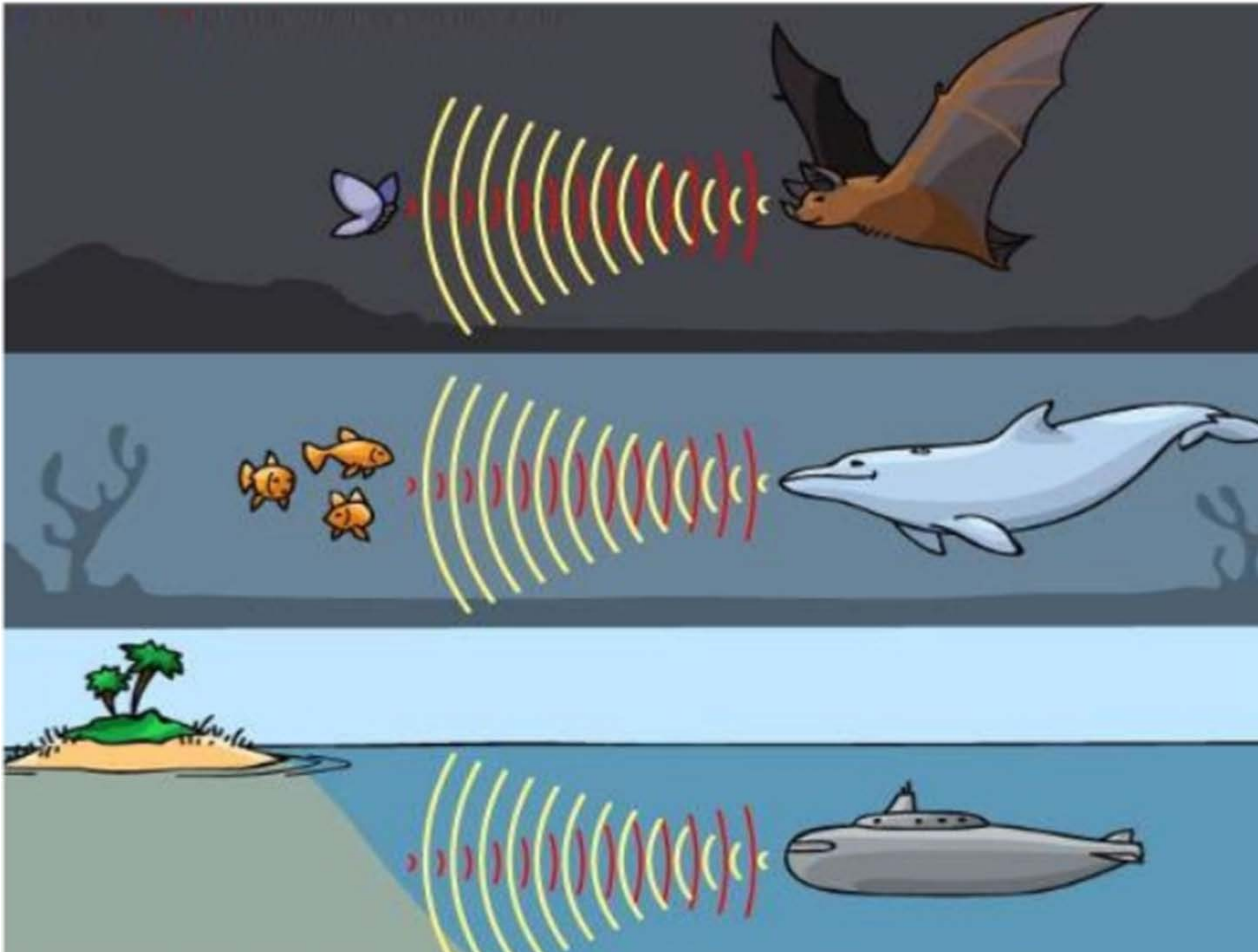
- SONAR is a technique which stands for ***SOund Navigation and Ranging***. It uses ultrasonic waves for the detection and identification of under water objects.
- The method consists of sending a powerful beam of ultrasonic waves in the suspected direction in water.
- By noting the time interval between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

Measuring the time interval (t) between the transmitted pulses and the received pulse, the distance between the transmitter and the remote object is determined using the formula.,

$$d = vt/2$$

where v is the velocity of sound in sea water.

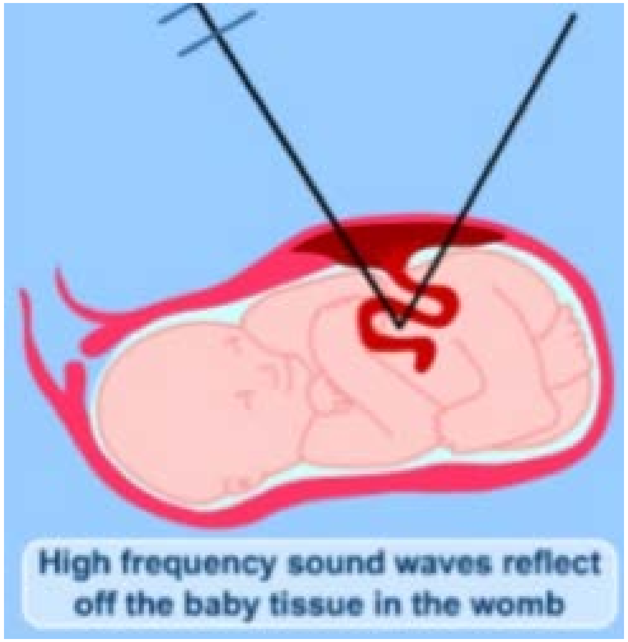




6. Ultrasonics in Medicine

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

Powerful US waves detect intensity of the shock and send an electrical signal to trigger the airbag.

8. Dispersion of fog

Fog is defined as a mass of water vapour condensed into small water droplets on powery materials made from smoke, tyres etc.

When Ultra Sonic waves travel through 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.

It adopts a method which accumulates the mechanical energy from people’s pressure on the piezoelectric board during the day in order to light up the street at night.

One can convert the pressure from cars passing by the streets into electric energy through the piezoelectric element under the street. This way all streetlights on highway and traffic lights can run on semi-permanent source of energy.

As piezoelectric technology uses vibrations to attain energy, even the slightest vibration can be stored as electricity.