Ultrasonic

- ✓ Ultrasonic machining and drilling
- ✓ Ultrasonic cleaning
- ✓ Ultrasonic soldering and welding
- ✓ Emulsification: dispersal of pigments in paint, medicine, cosmetic products, dyes, shoe polish, etc.
- ✓ Medical applications: Sonograms
- ✓ Non destructive testing

Contents in this topic

- Introduction of Ultrasonics
- Production of Ultrasonic waves
  i) Magnetostriction Method
  ii) Piezo Electric Method
- Detection of Ultrasonic waves
- Applications –
  i. green energy
  ii. sound signalling
  iii. dispersion of fog
  iv. Car’s airbag sensor

Ultrasonic

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.

Classification of sound:

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

Generally ultrasonic waves are called **high frequency waves**.

Ultrasonic:

Hearing range for different 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 :

- They are mechanical/elastic waves i.e. need a medium to travel.
- They have high frequency and hence, high energy content.
- Just like ordinary sound waves, ultrasonic waves get reflected, refracted and absorbed.
- They can be transmitted over large distances with no appreciable loss of energy. Because of small wavelength, diffractions is negligible.
- They produce intense heating effect when passed through a substance. Hence, these can be used for drilling and cutting of materials.
- When ultrasonic waves are propagated is to a liquid media, they include alternate regions of rarefaction and compression.

Properties of ultrasonic waves :

- When ultrasonic waves are propagated in to a liquid bath, stationary wave pattern is formed due to the reflection of wave from the other end. The density of the liquid thus varies from layer to layer along the direction of propagation. In this way the plane diffraction grating is formed which can diffract light.

- Velocity is, $v(velocity) = \nu\lambda$.

  $v(velocity) = \sqrt{\frac{E}{\rho}}$ where E is modulus of elasticity and ρ is density of medium.

Production of ultrasonic waves :

Methods by which ultrasonic waves can be produced :

1. **Piezoelectric Oscillator**

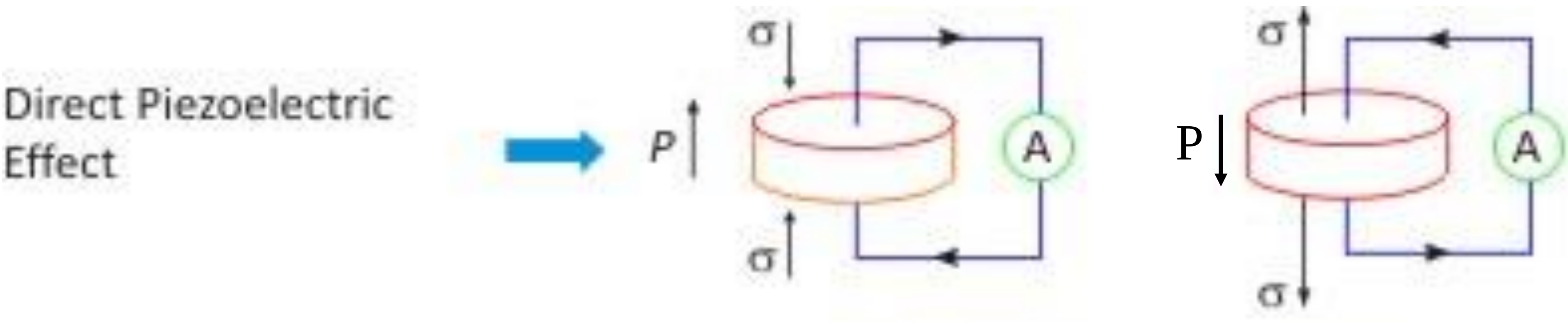
2. **Magnetostriction oscillator**

Piezoelectric Effect:

If mechanical pressure is applied to the opposite faces of certain crystal slices cut suitably, then equal and opposite electric charges are developed on opposite faces. But when crystal slice is under tension, sign of charges is reversed. This is called as **Piezoelectric effect**.

Naturally occuring Quartz, tourmaline, Rochelle salt exhibit this effect.

Artificial crystals such as lead zirconate ($PbZrO_3$), lead zirconate–titanate (PZT) [$Pb(Zr,Ti)O_3$] and potassium niobate ($KNbO_3$).

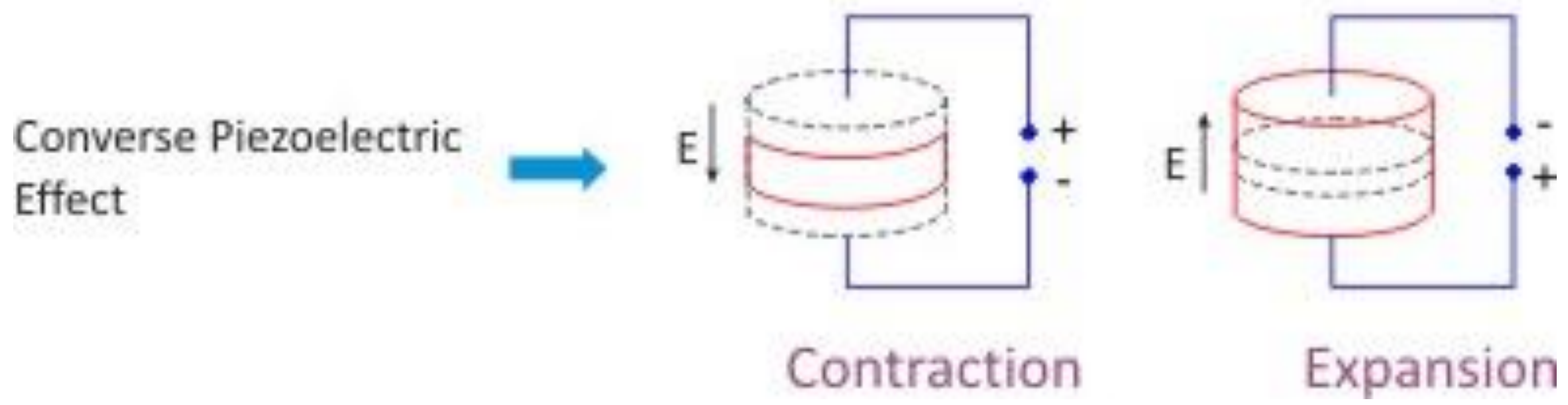


$P \propto \sigma$ (P is polarization, σ is applied stress)

Inverse Piezoelectric Effect:

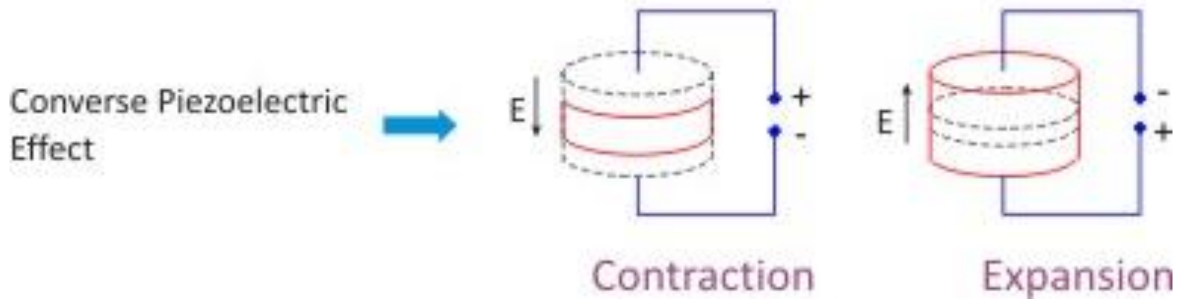
The inverse of piezoelectric effect is also true. If an electric field is applied to one pair of faces, the corresponding changes in the dimensions of the crystal are produced. This is known as ***inverse piezoelectric*** effect.

All materials exhibiting piezoelectric effect also exhibit inverse piezo electric effect.



Inverse piezoelectric effect is used for production of ultrasonic waves.

Inverse Piezoelectric Effect:



If an alternating electric field/potential is applied then crystal will start vibrating at frequencies equal to frequency of alternating field. Amplitude of vibrations will be maximum when frequency of alternating field is equal to natural frequency of the crystal.

The natural frequency of crystal is given by $\nu = \frac{n}{2l}\sqrt{\frac{E}{\rho}}$

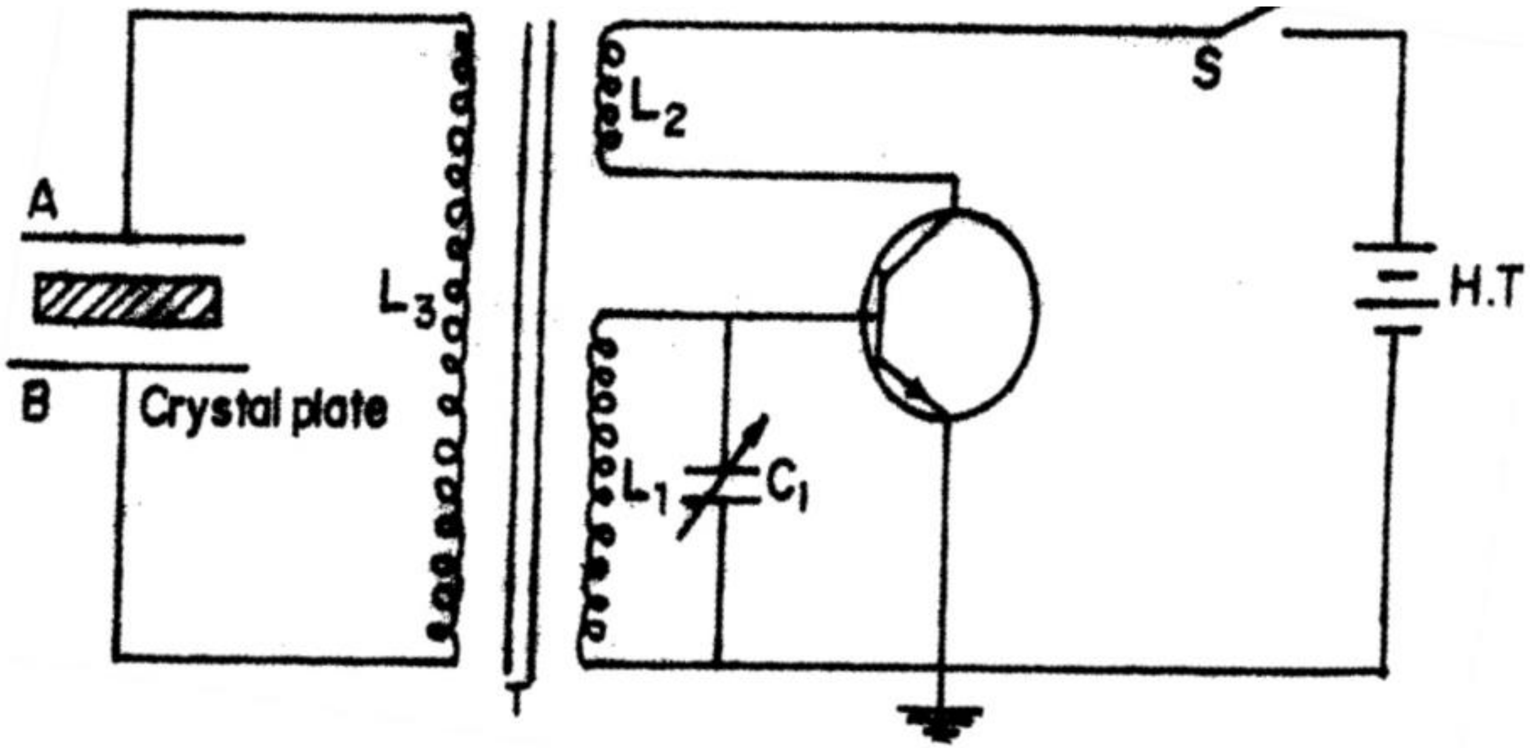
where n = 1, 2, 3… for fundamental, first overtone, second overtone, etc.

l = length of the crystal

E = Young's modulus of the crystal

ρ = density of the crystal.

Production of ultrasonic waves by Piezoelectric method :



Construction :

The circuit consists of a primary and a secondary circuit. In the primary circuit L_1 and L_2 are two inductances connected with transistor through a battery.

C_1 is a variable capacitor connected parallel to L_1. This combination of L_1 and C_1 is known as *tank circuit*.

L_1 and L_2 are connected inductively with the secondary circuit. The secondary circuit consists of an inductance L_3 and a parallel plate condenser. The quartz crystal is kept between the plates of the parallel plate capacitor.

Production of ultrasonic waves by Piezoelectric method :

Working :

On passing alternating current through coil L_1, changing magnetic field is set up which gets linked with coil L_2 and induces emf. This acts as feedback circuit to keep the amplitude of oscillations constant.

Changing magnetic field of coil L_1 also gets inductively coupled to coil L_3 producing alternating emf. This results in alternating current in secondary circuit. The charge on plates between which quartz crystal is placed oscillates with frequency of current. This sets Quartz crystal into vibrations resulting in ultrasonic waves.

Tank circuit lead to alternating current through coil L_1.

With the help of variable capacitor in tank circuit, frequency of current and hence magnetic field oscillations can be made equal to the natural frequency of quartz crystal

i.e. $\frac{1}{2l}\sqrt{\frac{E}{\rho}} = \frac{1}{2\,\pi\sqrt{L_1 C_1}}$

E is Young's Modulus of crystal
ρ is density of the crystal
l is length of crystal

Production of ultrasonic waves by Piezoelectric method :

Advantages

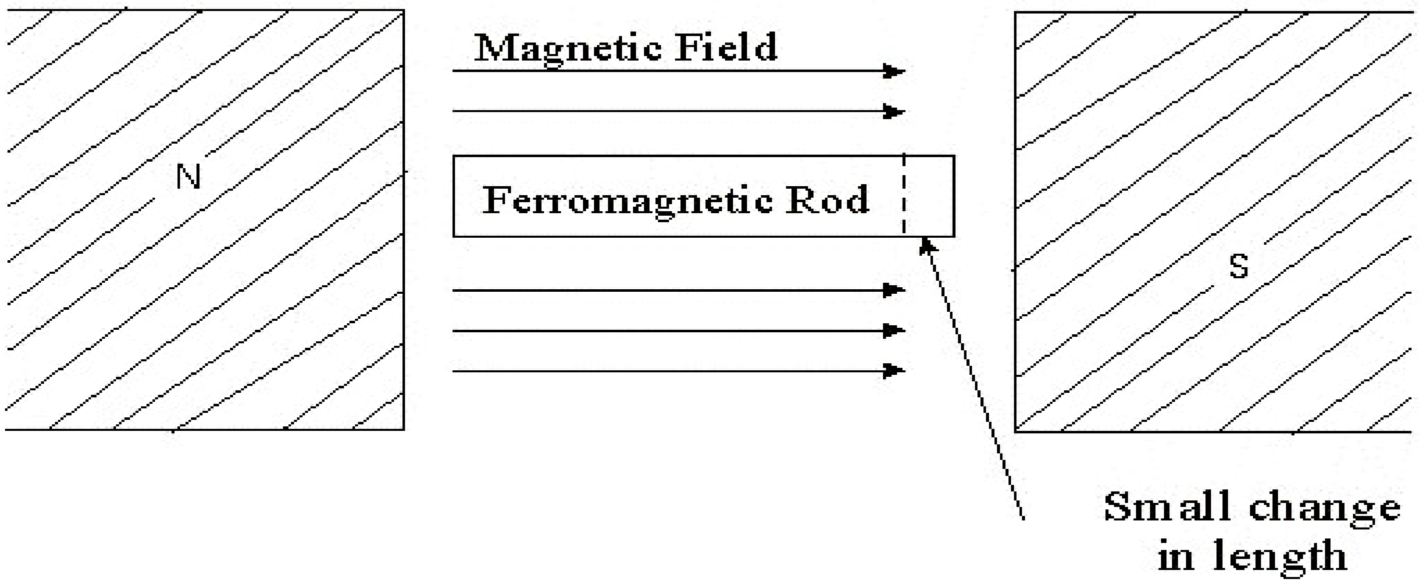
- Ultrasonic frequencies as high as 500 MHz can be obtained with this arrangement.
- It is not affected by temperature and humidity.

Disadvantages

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

Magnetostriction effect :

Magnetostriction is a property of ferromagnetic materials such as iron, cobalt, nickel that causes them to **change their shape (elongation or contraction)** when subjected to a magnetic field. The effect was first identified in 1842 by James Joule.



Magnetostriction is used for production of ultrasonic waves.

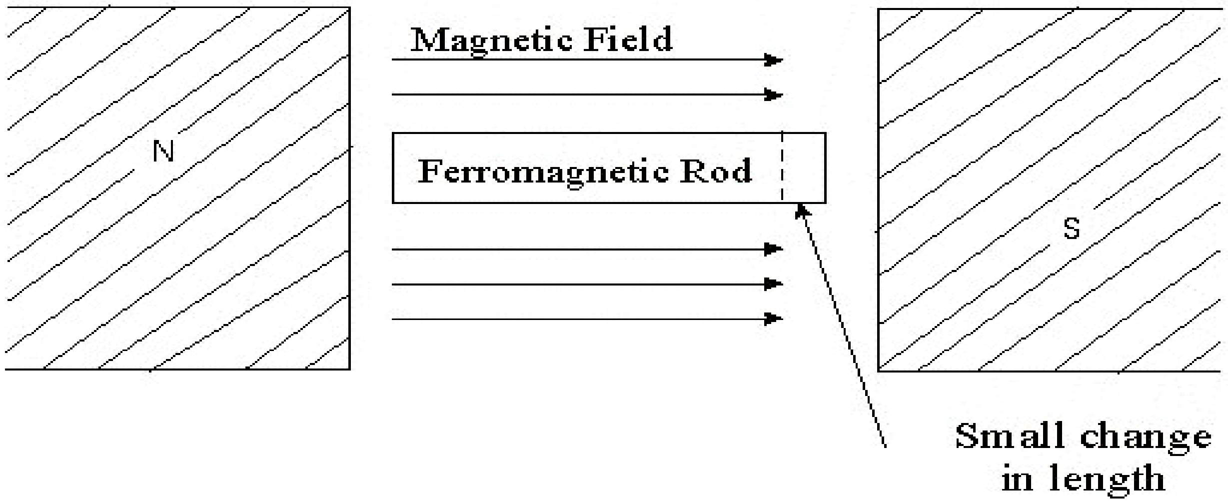
The **change in length of rod**

i) depends upon the strength of the magnetic field,

ii) depends upon the nature of the ferromagnetic materials

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

Magnetostriction effect :



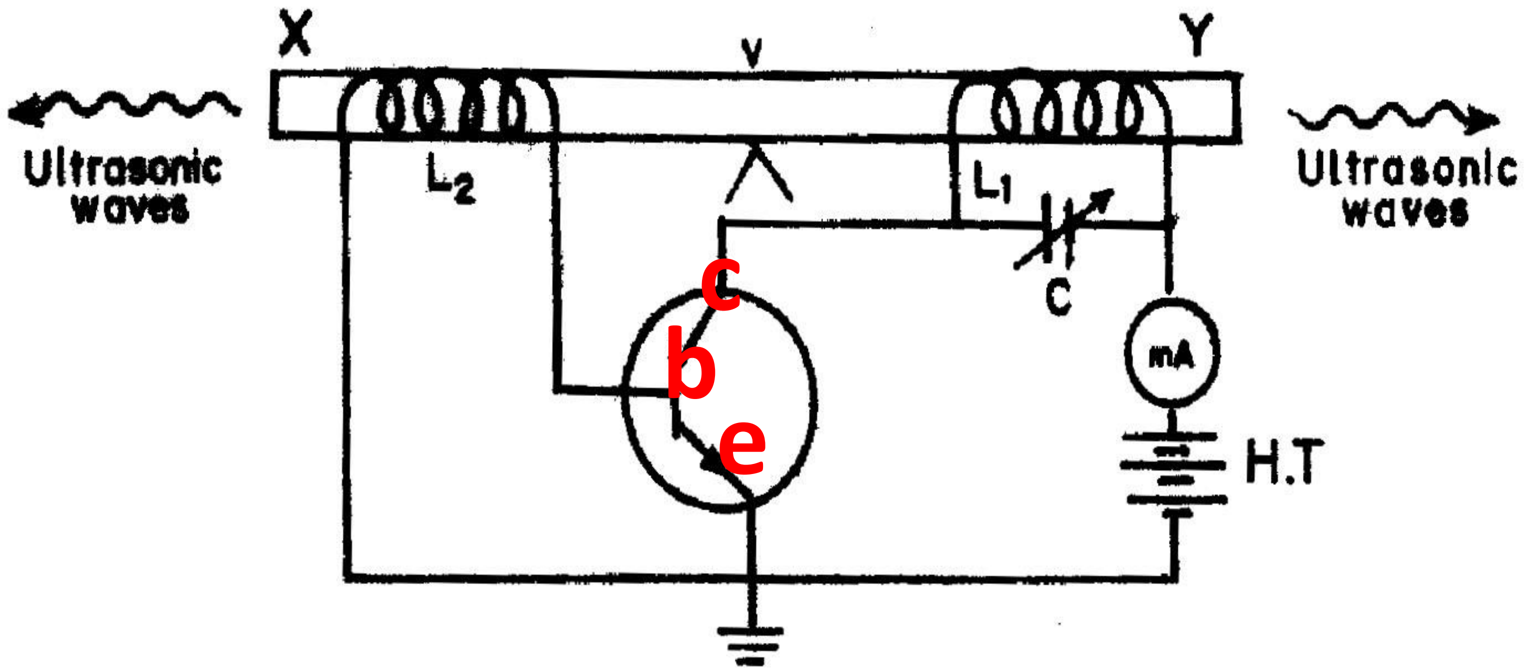
Suppose a ferromagnetic rod is placed inside a coil carrying an alternating current. This alternating current would give rise to a time-varying field and the rod will be put into vibration. The amplitude of this vibration is generally small.

If the frequency of the alternating signal can be the same as the natural frequency of the rod, a resonance will occur. This resonance will reinforce the vibrations that would result in the rod. The ends of the rod would then emit sound waves. By ensuring a sufficiently high applied frequency, ultrasonic waves can be generated.

Inverse Magnetostriction effect :

A ferromagnetic rod develops a varying field when subjected to alternate stresses.

Production of ultrasonic waves by Magnetostriction method :

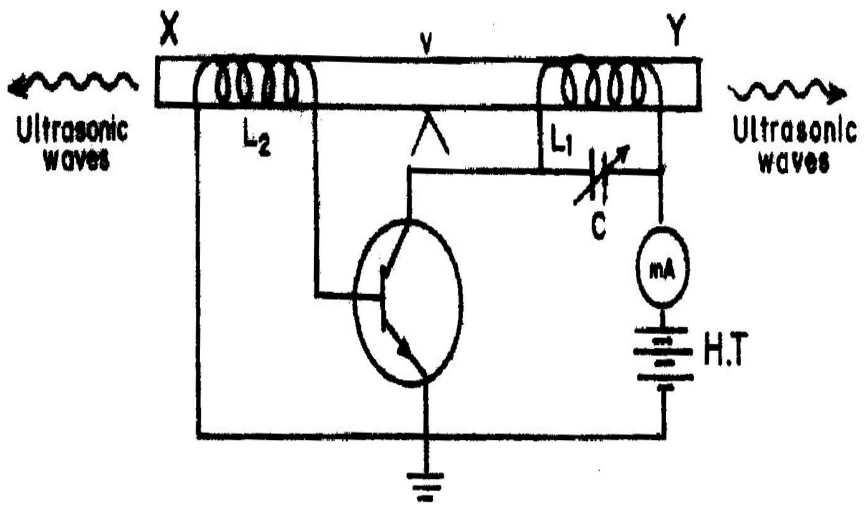


Construction:

The magnetostriction generator consists of a ferromagnetic rod clamped at the centre. The two ends of the rod are wound by coils L_1 and L_2.

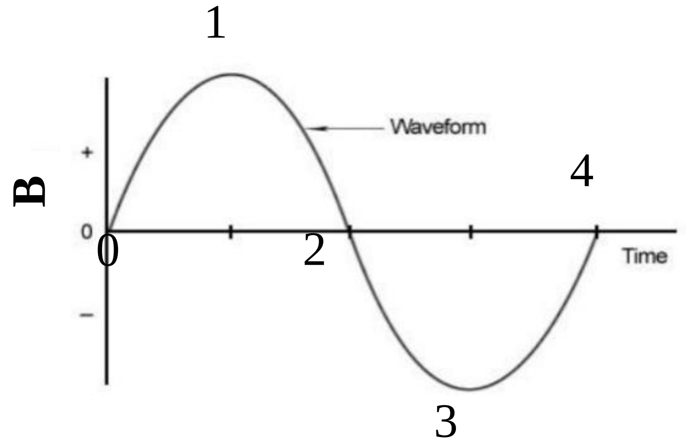
The coil L_2 is connected to the base of the transistor and the coil L_1 along with variable capacitor C forms a tank circuit.
The frequency of the oscillatory circuit can be adjusted by the variable capacitor C connected across the coil L_1. A battery is connected in the circuit that acts as a source.

Production of ultrasonic waves by Magnetostriction method :



On passing alternating current through coil L_1 (because of tank circuit), changing magnetic field is set up which gets linked with coil L_2 and induces emf. This acts as feedback circuit to keep the oscillations constant.

Alternating magnetic field sets the rod into vibrations resulting in ultrasonic waves.

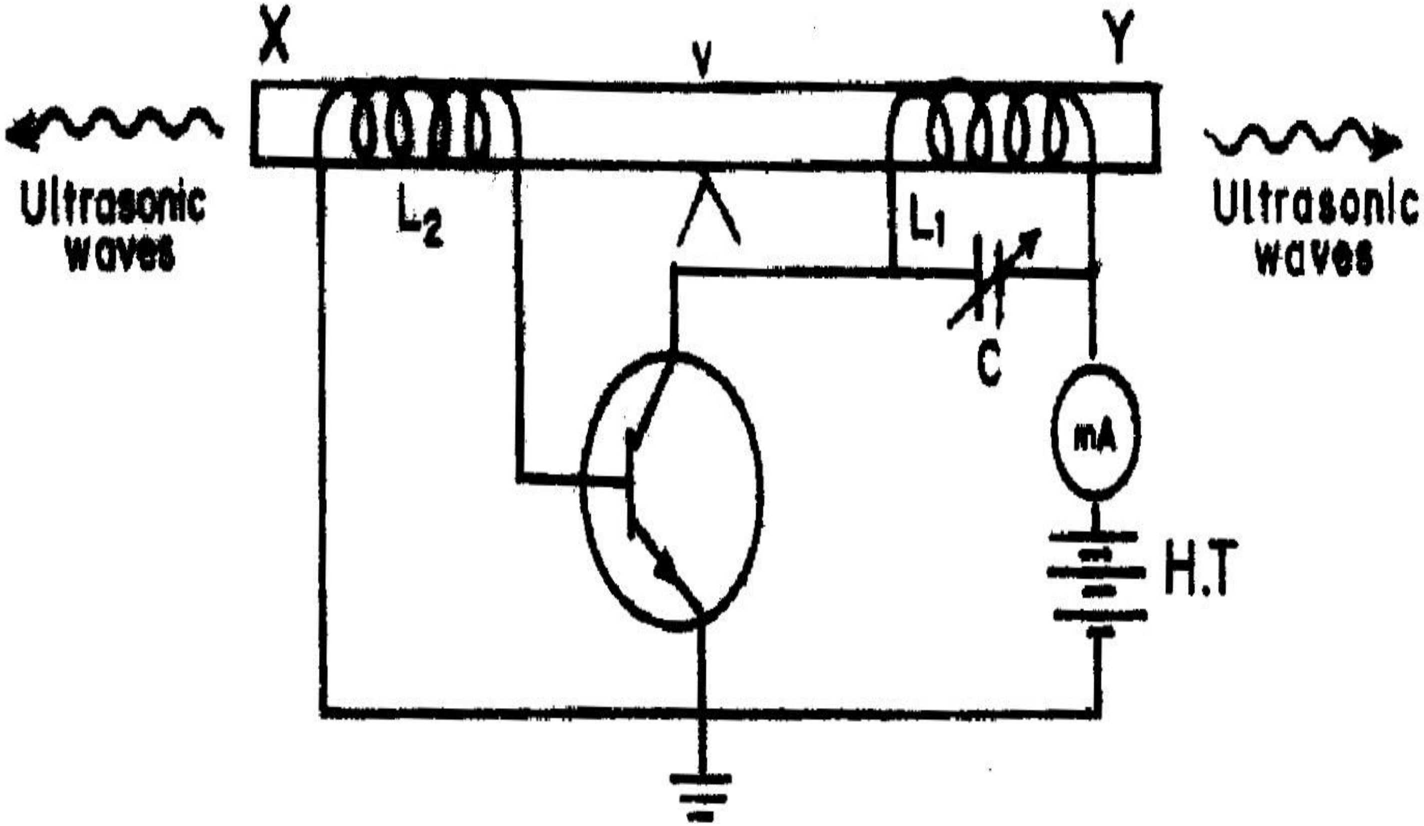


0 to 1, rod AB $\longrightarrow$ AC
1 to 2, rod AC $\longrightarrow$ AB
2 to 3, rod AB $\longrightarrow$ AC
3 to 4, rod AC $\longrightarrow$ AB

Hence, during 1 cycle of B, rod completes 2 vibrations.

Production of ultrasonic waves by Magnetostriction method :

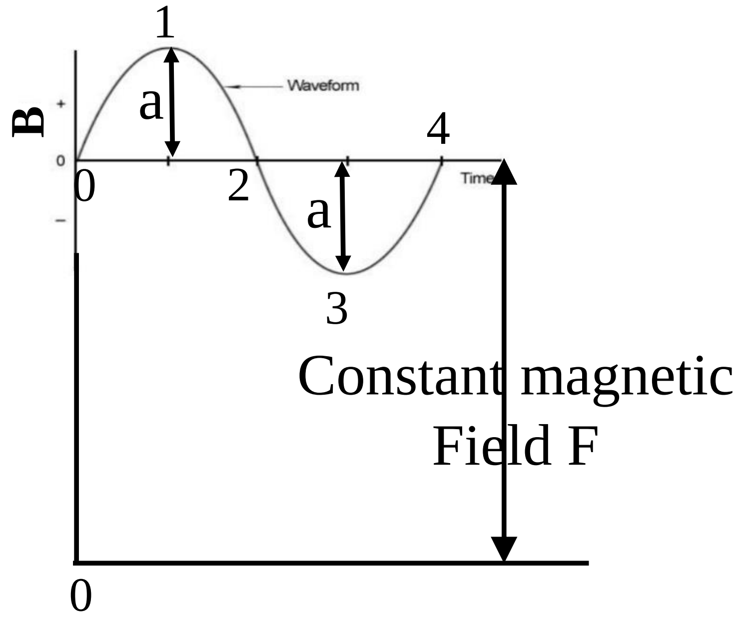
How to have 1 vibration of rod during 1 cycle of B?



When coil L connected to DC supply and wound around rod leading to a constant magnetic field on rod due to coil L and alternating magnetic field due to tank circuit.

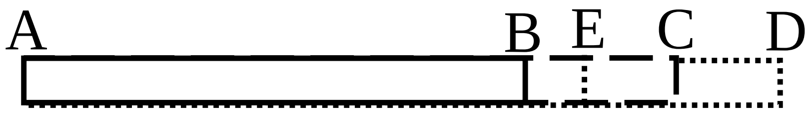
Production of ultrasonic waves by Magnetostriction method :

When coil L connected to DC supply and wound around rod is present, there is constant magnetic field on rod due to coil L and alternating magnetic field due to tank circuit :c



Max magnetic field = F+a
Min Magnetic field = F-a

Let us say that constant magnetic filed increases length of rod from B to C



0 to 1, Field F $\longrightarrow$ F+a, rod AC $\longrightarrow$ AD
1 to 2, Field F+a $\longrightarrow$ F, rod AD $\longrightarrow$ AC
2 to 3, Field F $\longrightarrow$ F-a rod AC $\longrightarrow$ AE
3 to 4, Field F-a $\longrightarrow$ F, rod AE $\longrightarrow$ AC

Hence, during 1 cycle of B, rod completes 1 vibration.

Production of ultrasonic waves by Magnetostriction method :

With the help of variable capacitor in tank circuit, frequency of current and hence magnetic field oscillations can be made equal to the natural frequency of the rod material i.e. $\frac{1}{2l}\sqrt{\frac{E}{\rho}} = \frac{1}{2\,\pi\sqrt{L_1 C}}$

E is Young's Modulus of rod material
ρ is density of rod material
l is length of the rod

Production of ultrasonic waves by Magnetostriction method :

Advantages

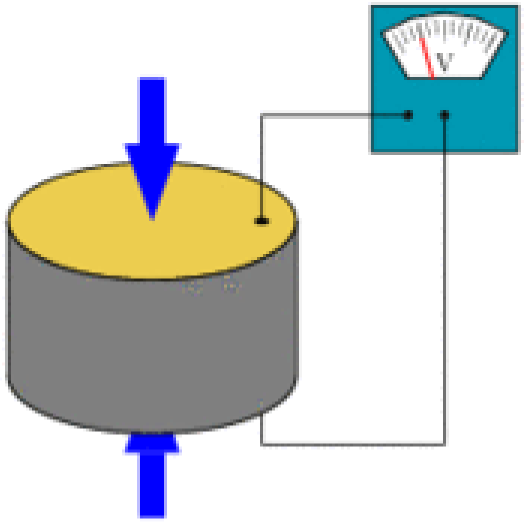
- The design of this oscillator is very simple and its production cost is low
- At low ultrasonic frequencies, the large power output can be produced without the risk of damage of the oscillatory circuit.

Disadvantages

- It has low upper frequency limit and cannot generate ultrasonic frequency above 3MHz.
- The frequency of oscillations depends on temperature.
- There will be losses of energy due to hysteresis and eddy current.

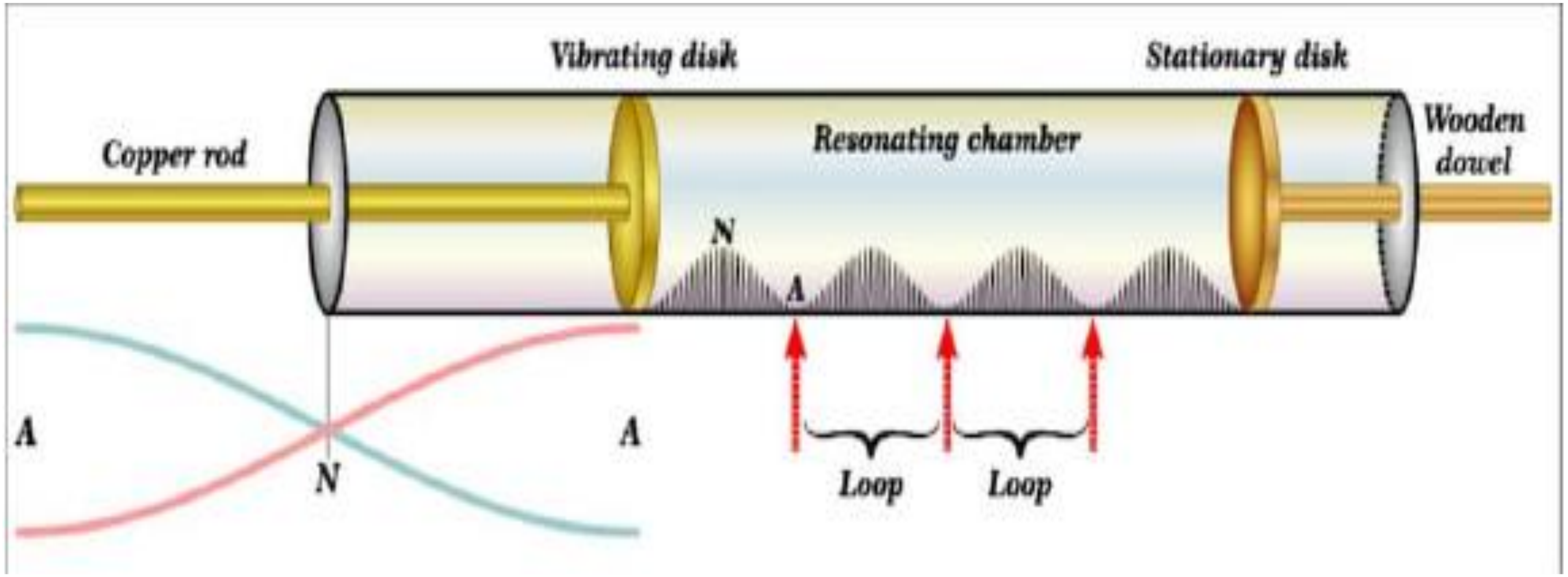
Detection of ultrasonic waves :

1. **Piezoelectric Detector :** Piezoelectric crystals have the ability to develop an electric potential when a stress is applied across certain faces of the crystal. This phenomenon can be used to detect ultrasonic waves. One pair of faces of a quartz crystal (piezoelectric material) is subjected to ultrasonic waves, An alternating potential then develops which can be amplified and measured to detect the presence of ultrasonic waves.



Detection of ultrasonic waves :

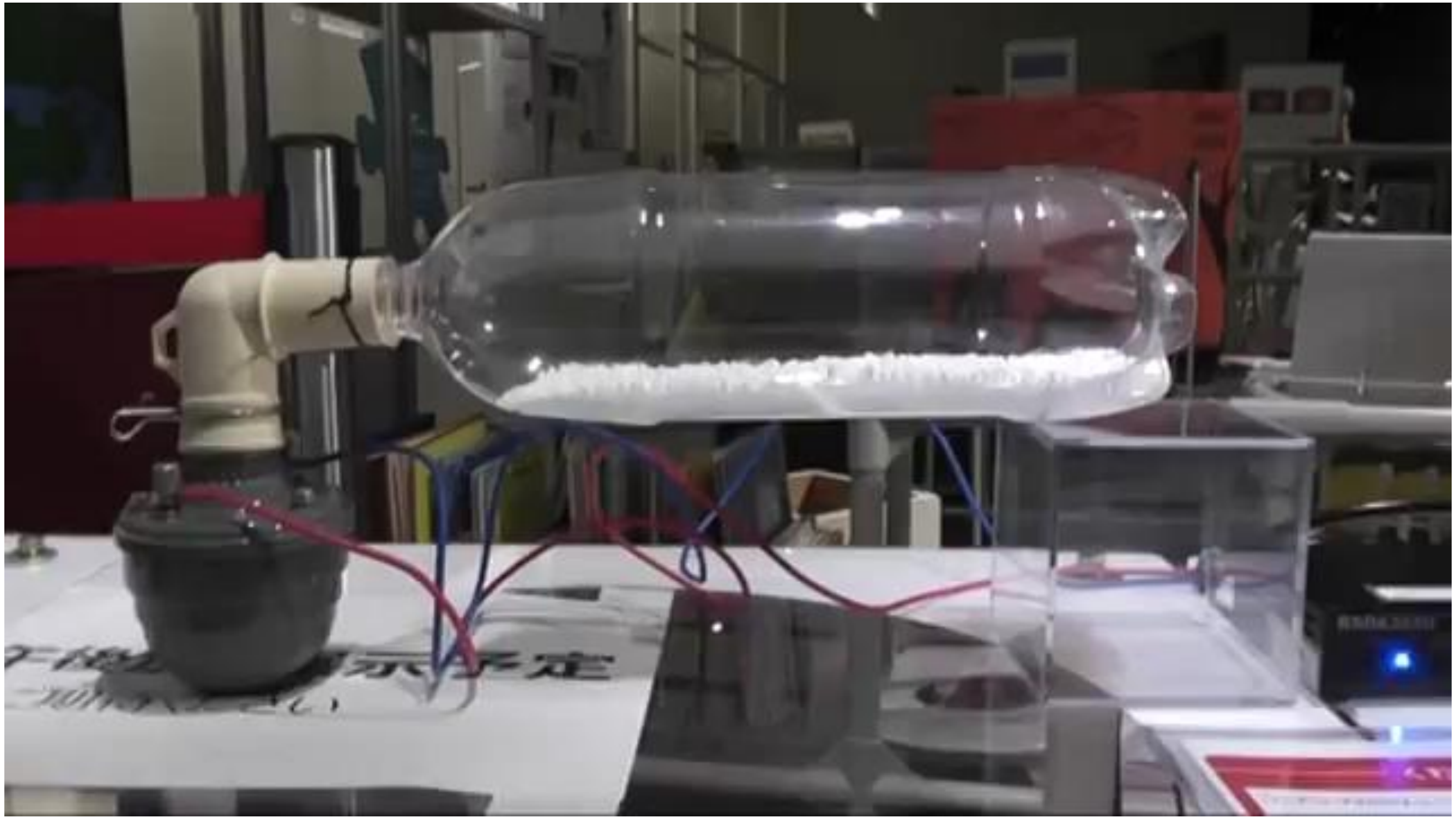
2. Kundt's tube method : Kundt's tube consists of a horizontal glass tube about 1 m long and 5 cm in diameter. A small amount of lycopodium powder is scattered in the tube. When ultrasonic waves are incident on the tube and pass through it, the lycopodium powder collects in the form of heaps at the nodal points and is blown off at the antinodal points. The distance between subsequent nodes is then equal to half the magnitude of the wavelength of ultrasonic waves. This information can then be used to determine the frequency of the waves.



Can only be used if wavelength is at least few mm.

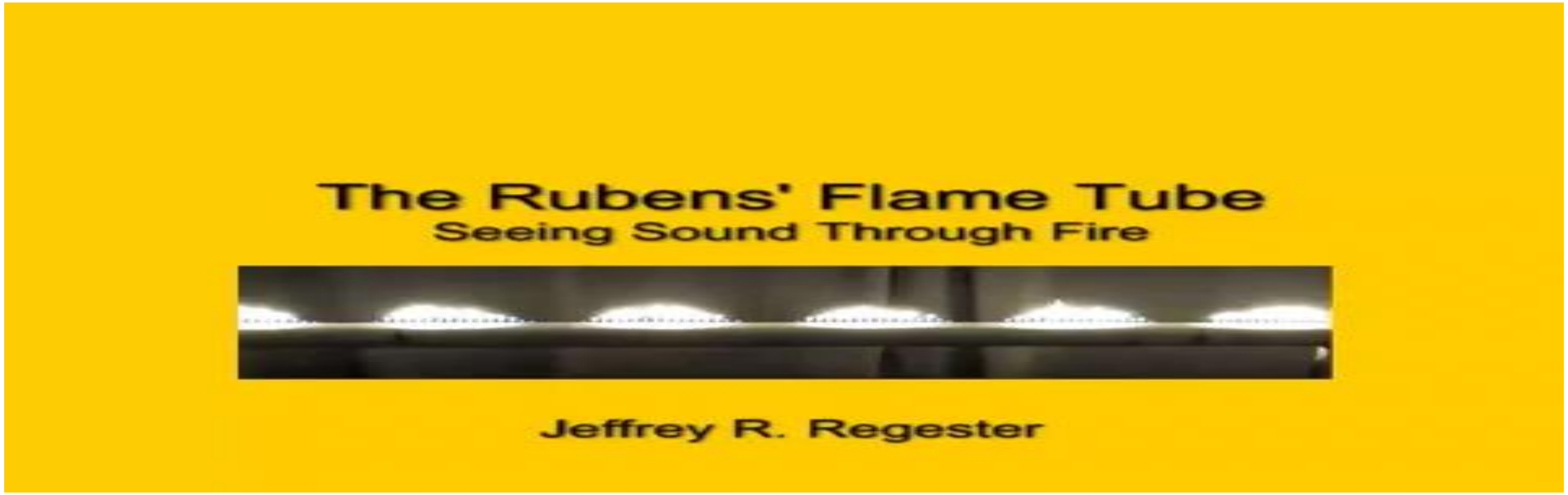
Detection of ultrasonic waves :

2. Kundt’s tube method :



Detection of ultrasonic waves :

3. Sensitive Flame Method : If a narrow sensitive flame is moved through the medium that carries the ultrasonic waves, the flame remains stationary at antinodes and tends to flicker at nodes because there is a change in pressure. The frequency of the ultrasonic wave can be found by equating the distance between subsequent nodes or antinodes to half the wavelength.

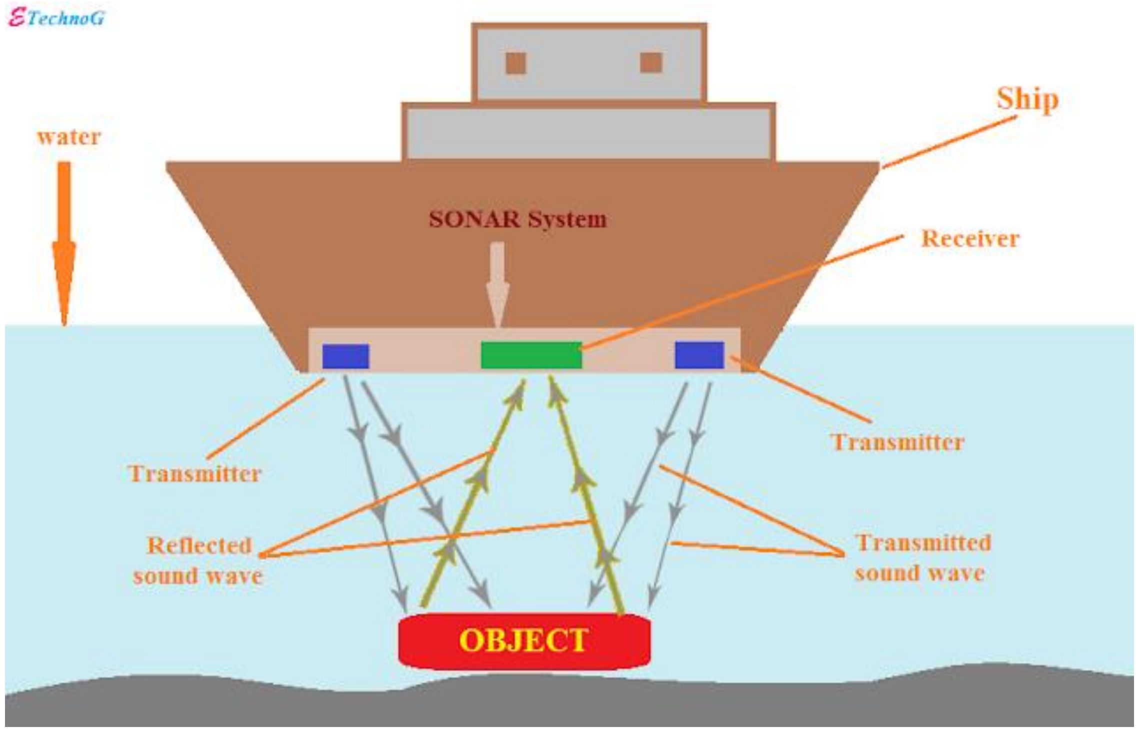


Detection of ultrasonic waves :

4. Thermal Detector Method : Whenever an ultrasonic wave propagates through a medium, it causes alternate compressions and rarefactions in the medium. Due to these compressions and rarefactions the temperature of the medium changes at the nodes while remaining almost constant at antinodes. A thermal detector comprises of a fine platinum wire whose resistance changes at the nodes due to these temperature variations.

Application of ultrasonic waves :

1. SONAR (Sound Navigation and Ranging) : Sharp beams of ultrasonic frequency are sent out in various directions in the sea. Objects like submarine, icebergs, shipwrecks, etc., result in reflections that are picked up, amplified, and displayed on suitable screens. The time lag between the incident pulse and the reflected pulse is used to estimate the location of the object that resulted in reflection.



$$2 \times distance = velocity \times time$$

Application of ultrasonic waves :

2. Fog dispersion : Fog is defined as a mass of water vapour condensed into small water droplets on powdery materials made from smoke, tyres etc. Ultrasonic waves can be used to bind or coagulate solid or liquid pollutants present in air such as dust, smoke, mist etc., into large clump. This process is called ultrasonic scrubbing. It is used at airports to increase visibility.

Application of ultrasonic waves :

3. Green Energy : Direct Piezoelectric effect can be used for generation of pollution free energy by installing these transduces in highly crowded areas such as roads, airport runways, pedestrian walkways and even discotheques.

A prototype for the piezoelectric technology designed and developed by Innowattech has been successfully tested over a ten meter stretch of road in Israel. Accordingly, several piezoelectric generators were installed underneath the asphalt to absorb the mechanical energy generated by cars driving by. This piezoelectric generators transform the stored mechanical energy to electricity which is then converted to power. A successful test implementation saw a total power output of 2000 Wh for the 10 meter strip of road.

Application of ultrasonic waves :

4. Car’s air bag sensor : Ultrasonic sensors of piezoelectric materials detect the intensity of shock and send an electric signal to trigger airbag.

Some other applications:

- Non destructive testing
- Ultrasonic imaging
- Ultrasonic cleaning
- For homogenization of two immiscible liquids in food, pharmaceutical and cosmetic industry. In frozen food industry, sauces produced by this method will withstand repeated freezing and thawing.

Additional:

Production of ultrasonic waves by Piezoelectric method :

Tank circuit connected to collector

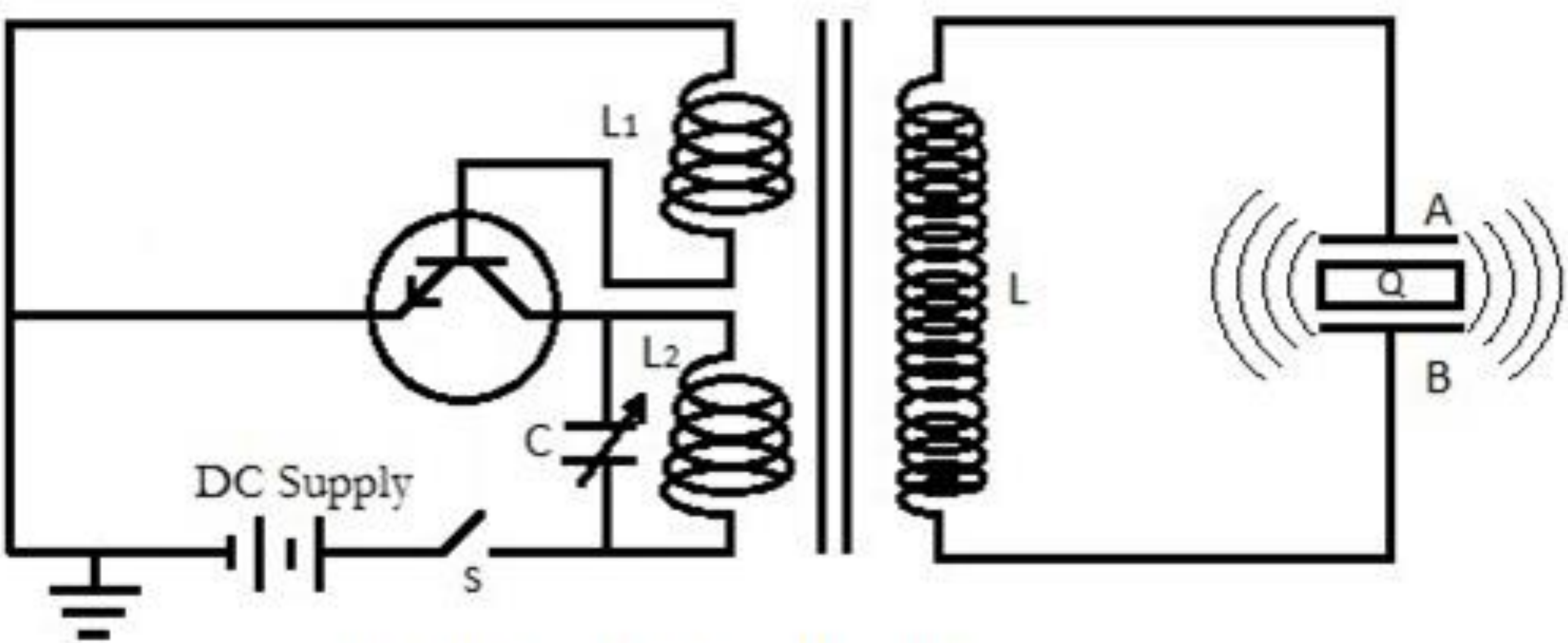


Fig. 7.1: Piezoelectric Oscillator