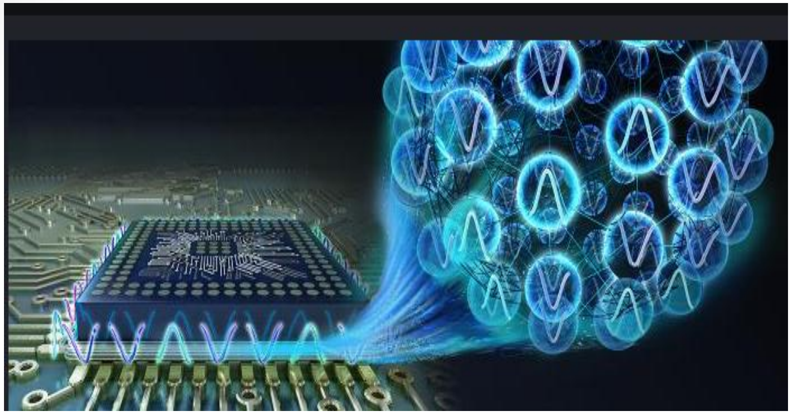
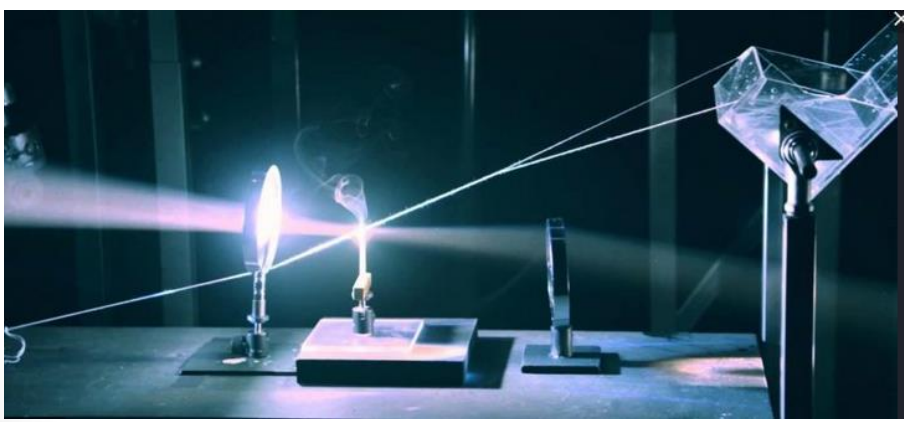
 

# Engineering Physics (PHY109)

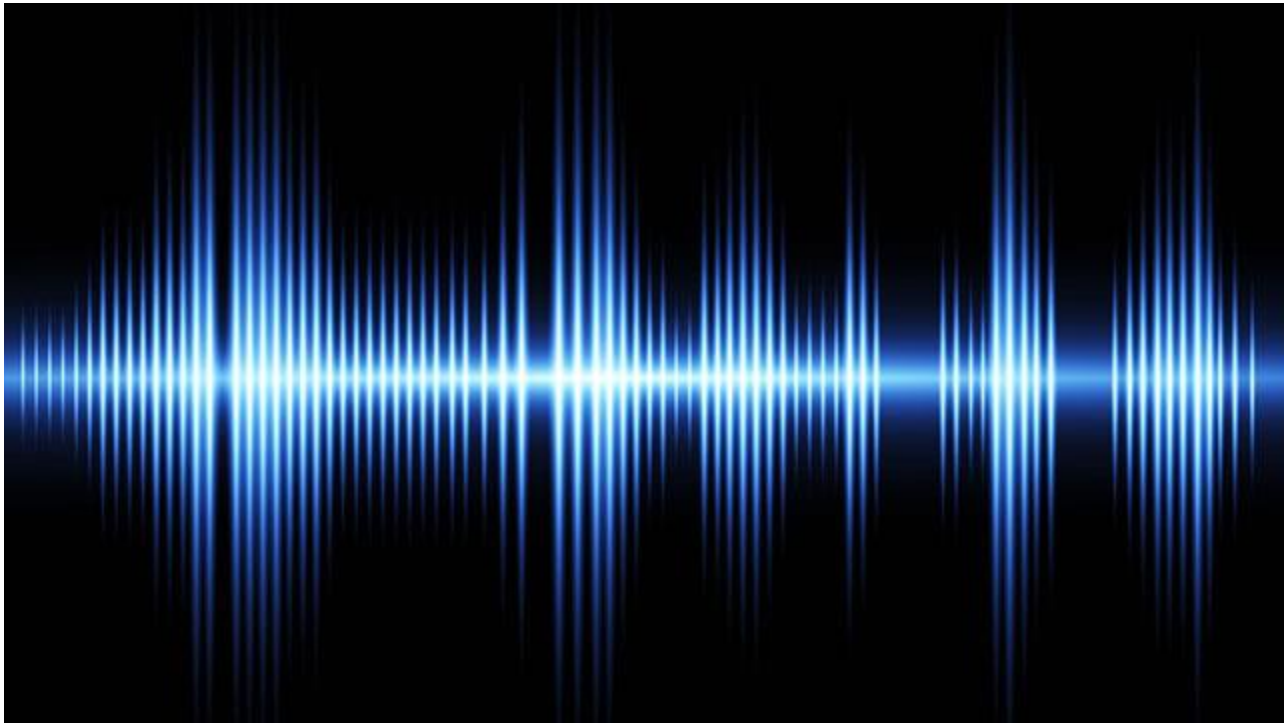
 

# Course overview

**L: 3 T:1 P:0 Credits:4**

- **Unit 1: Electromagnetic theory**
- **Unit 2: Lasers and applications**
- **Unit 3: Fiber optics**
- **Unit 4: Quantum mechanics**
- **Unit 5: Waves**
- **Unit 6: Solid state physics**

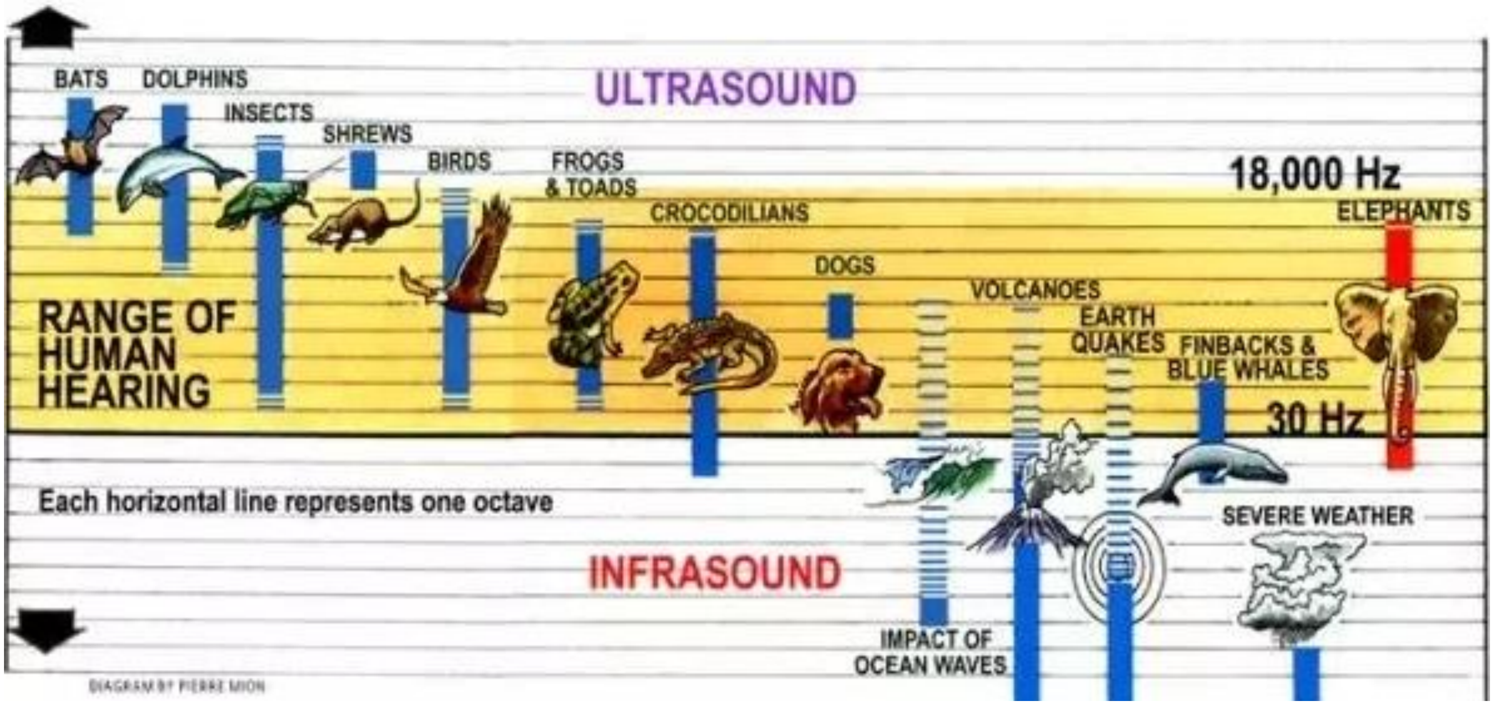
# Unit-5: Waves



# Unit-5: Waves

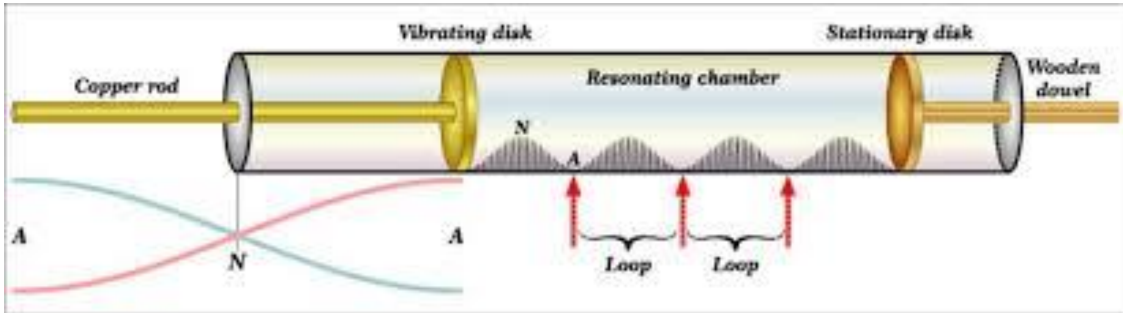
- Interference, resonance
- Audible, ultrasonic and infrasonic waves
- Production of ultrasonic waves (magnetostriction/piezoelectric method)
- Detection of ultrasonic waves (Kundt's tube method, sensitive flame method and piezoelectric detectors)
- Ultrasonic transducers
- Applications of ultrasonic waves

# Sound waves

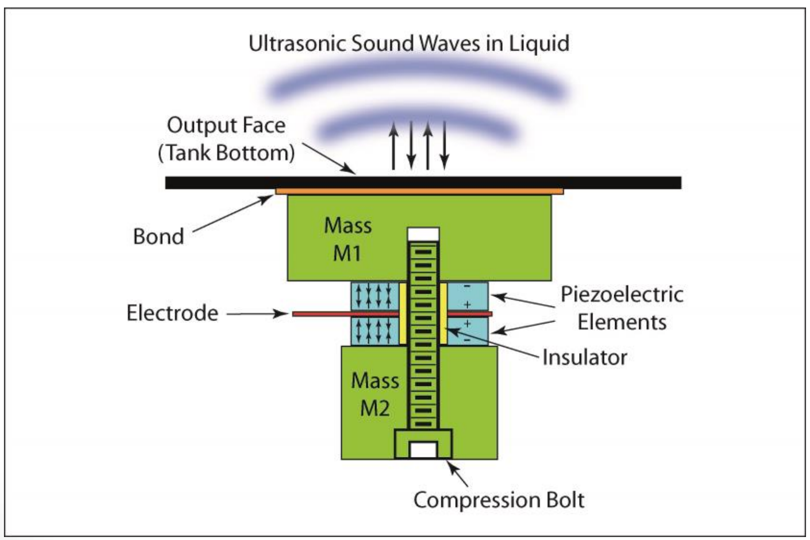


ULTRASOUND
BATS
DOLPHINS
INSECTS
SHREWS
BIRDS
FROGS & TOADS
CROCODILIANS
DOGS
VOLCANOES
EARTH QUAKES
FINBACKS & BLUE WHALES
ELEPHANTS
18,000 Hz
30 Hz
RANGE OF HUMAN HEARING
Each horizontal line represents one octave
INFRASOUND
IMPACT OF OCEAN WAVES
SEVERE WEATHER
DIAGRAM BY PIERRE MION

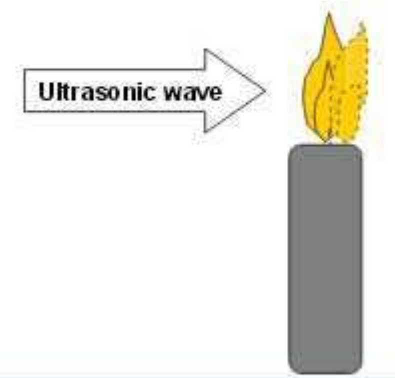
# Kundt's tube method



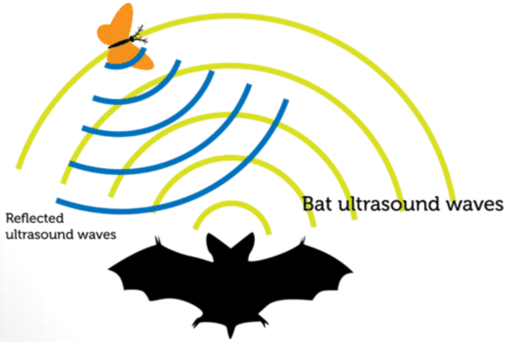

# Piezoelectric transducer

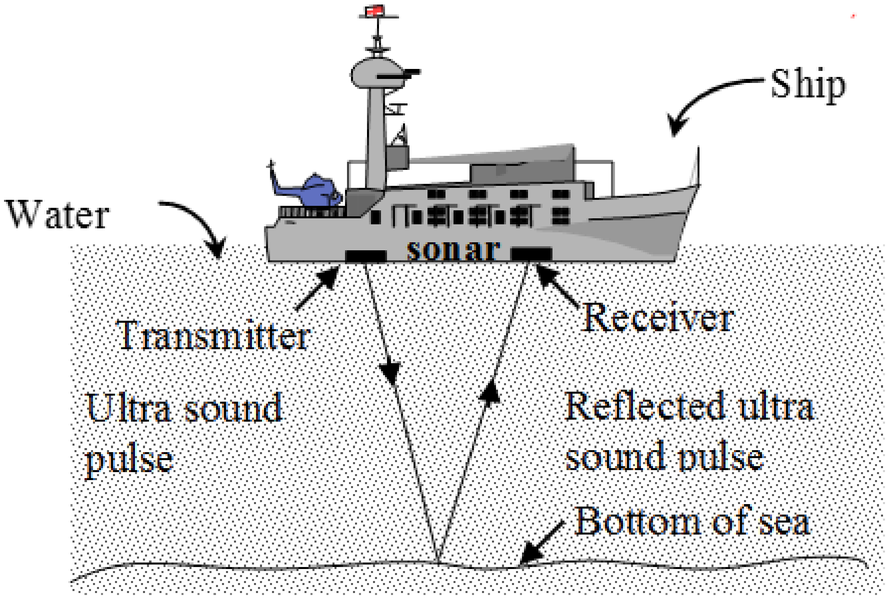



# Sensitive flame method



# Applications of ultrasonic waves

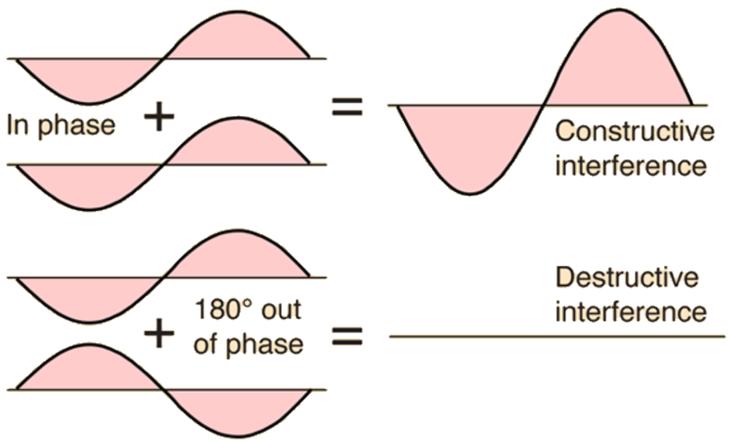

CO5: evaluate the need of ultrasonic waves and its generation mechanism

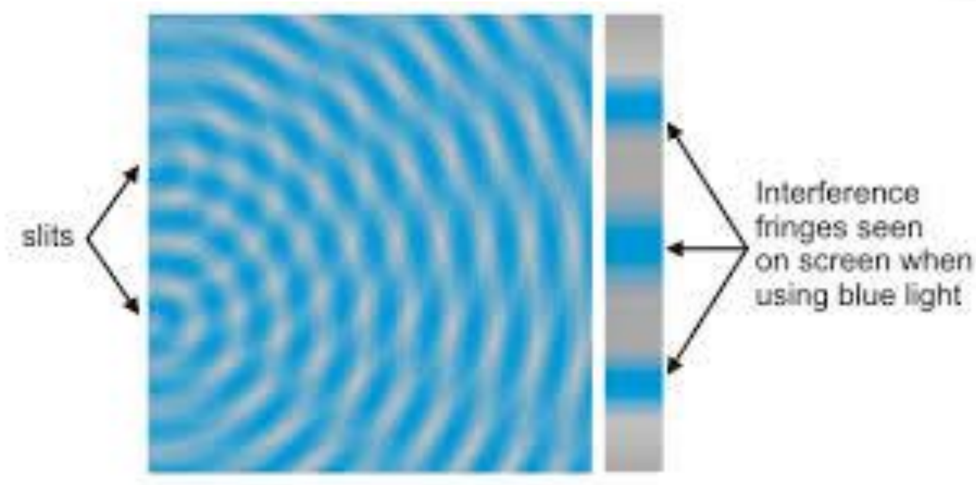
# Syllabus

- interference & resonance
- audible, ultrasonic and infrasonic waves
- production of ultrasonic waves
  - magnetostriction method
  - piezoelectric method
- detection of ultrasonic waves
  - Kundt's tube method
  - sensitive flame method
  - piezoelectric detectors
- ultrasonic transducers and their uses
- applications of ultrasonic waves
- absorption and dispersion of ultrasonic waves

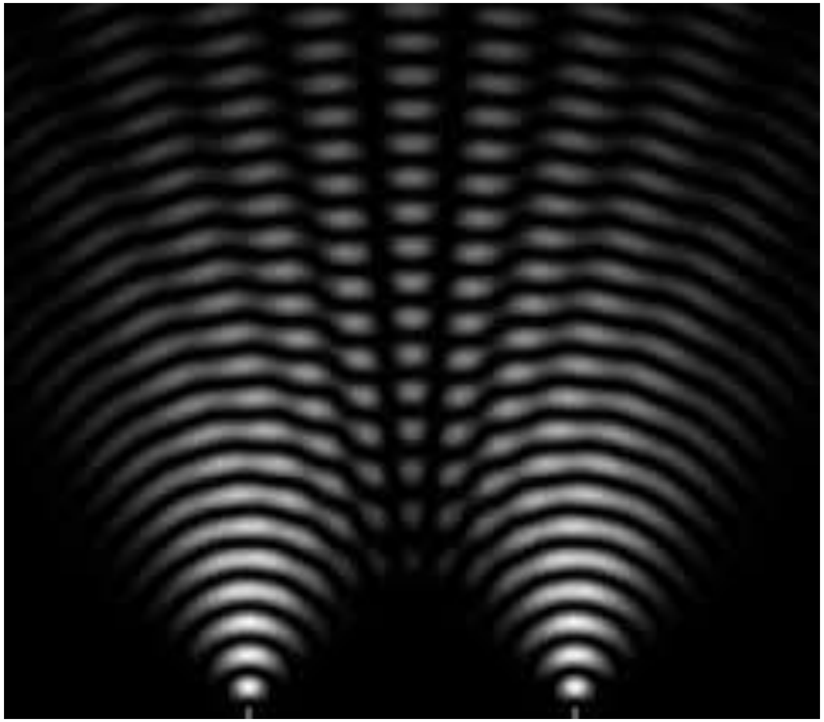
# Interference

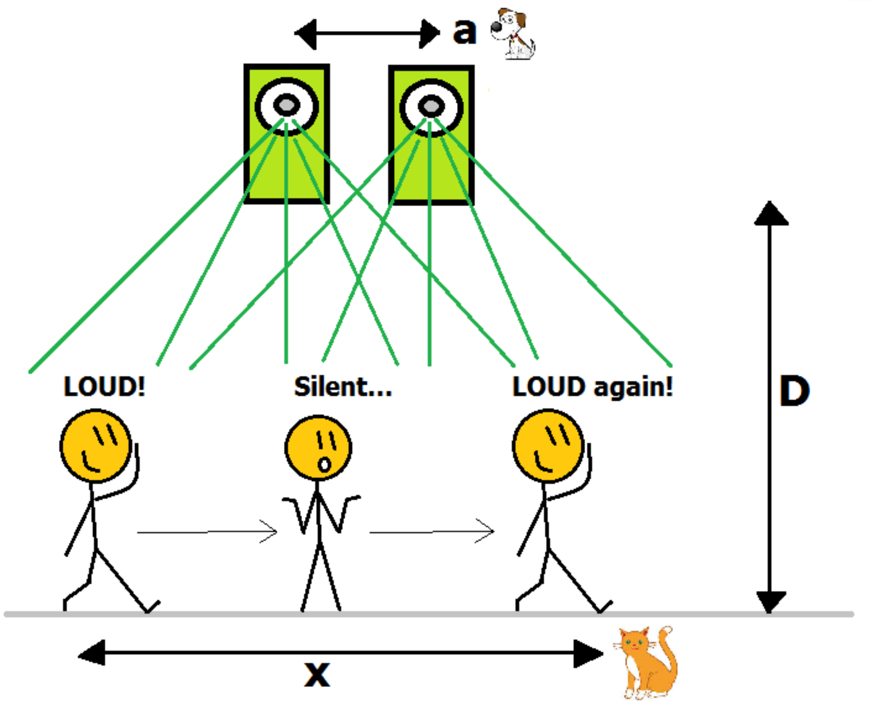
- Interference is a phenomenon in which two waves superpose to form a resultant wave of greater, lower, or the same amplitude.



# Interference





# Resonance

- Resonance is a phenomenon in which a vibrating system or external force drives another system to oscillate with greater amplitude at specific frequencies

- Frequencies at which the response amplitude is a relative maximum are known as the system's **resonance frequencies**

- At resonant frequencies, small periodic driving forces have the ability to produce large amplitude oscillations, due to the storage of vibrational energy

# Types of resonance

**Mechanical and acoustic resonance**

- Mechanical resonance is the tendency of a mechanical system to absorb more energy when the frequency of its oscillations matches the system's natural frequency of vibration

- Acoustic resonance is a branch of mechanical resonance that is concerned with the mechanical vibrations across the frequency range of human hearing (20 Hz and 20,000 Hz), in other words sound

# Types of resonance

**Electrical resonance**

- Electrical resonance occurs in an electric circuit at a particular *resonant frequency* when the impedance of the circuit is at a minimum in a series circuit or at maximum in a parallel circuit

- Resonance in circuits are used for both transmitting and receiving wireless communications (e.g., television, cell phones and radio)

# Types of resonance

**Optical resonance**

- An optical cavity, also called an *optical resonator*, is an arrangement of mirrors that forms a standing wave cavity resonator for light waves (e.g., LASER)

# Types of resonance

**Orbital resonance**

- In celestial mechanics, an orbital resonance occurs when two orbiting bodies exert a regular, periodic gravitational influence on each other, usually due to their orbital periods being related by a ratio of two small integers

- Orbital resonances greatly enhance the mutual gravitational influence of the bodies. In most cases, this results in an *unstable* interaction, in which the bodies exchange momentum and shift orbits until the resonance no longer exists.

# Types of resonance

**Atomic, particle, and molecular resonance**

- The observation of specific quantum mechanical magnetic properties of an atomic nucleus in the presence of an applied, external magnetic field (Nuclear magnetic resonance (NMR))
- NMR is used in advanced medical imaging techniques, such as in magnetic resonance imaging (MRI)

# Frequency of a Sound Wave

| Types | Range |
|---|---|
| Infrasonic waves | Sound waves with frequencies < 20 Hz |
| Audible Range | 20 Hz ----- 20,000 Hz |
| Ultrasonic waves | Sound waves with frequencies > 20,000 Hz |

**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 |

# Bats and ultrasonic sound waves

od sources

# Infrasonics

# Introduction to Ultrasonic

- The word ultrasonic combines the Latin roots **ultra**, meaning 'beyond' and **sonic**, or sound.
- The sound waves having frequencies above the audible range i.e. above 20,000 Hz are called ultrasonic waves
- Generally these waves are also called as high frequency waves
- The field of ultrasonic have applications for imaging, detection and navigation
- The broad sectors of society that regularly apply ultrasonic technology are the medical community, industry and military

# Properties of ultrasonic waves

(1) High energy waves

(2) Just like ordinary sound waves, ultrasonic waves get reflected, refracted and absorbed

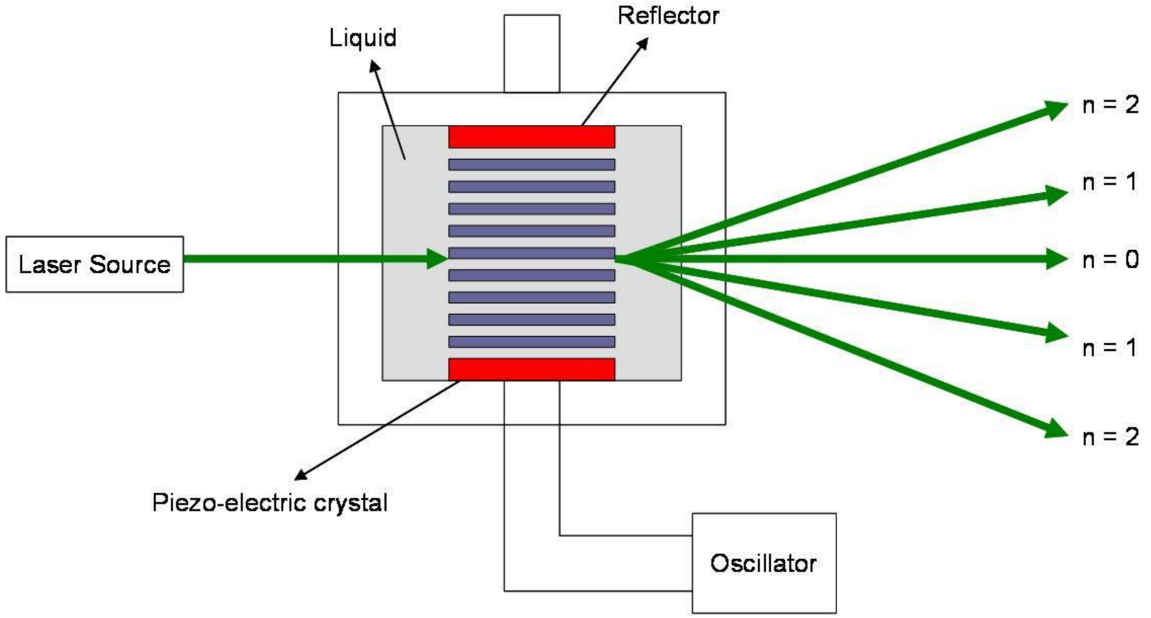
(3) They can be transmitted over large distances with no appreciable loss of energy

(4) If an arrangement is made to form stationary waves of ultrasonic in a liquid, it serves as a diffraction grating. It is called an acoustic grating

(5) They produce intense heating effect when passed through a substance

# acoustic grating

- A type of diffraction **grating** produced by interfering ultrasonic waves in a medium altering the physical properties of the medium, and hence the refractive index, in a grid-like pattern



# Ultrasonic Production

Ultrasonic waves are produced by the following methods:

(1) Magnetostriction generator or oscillator

(2) Piezoelectric (Electrostriction) generator or oscillator

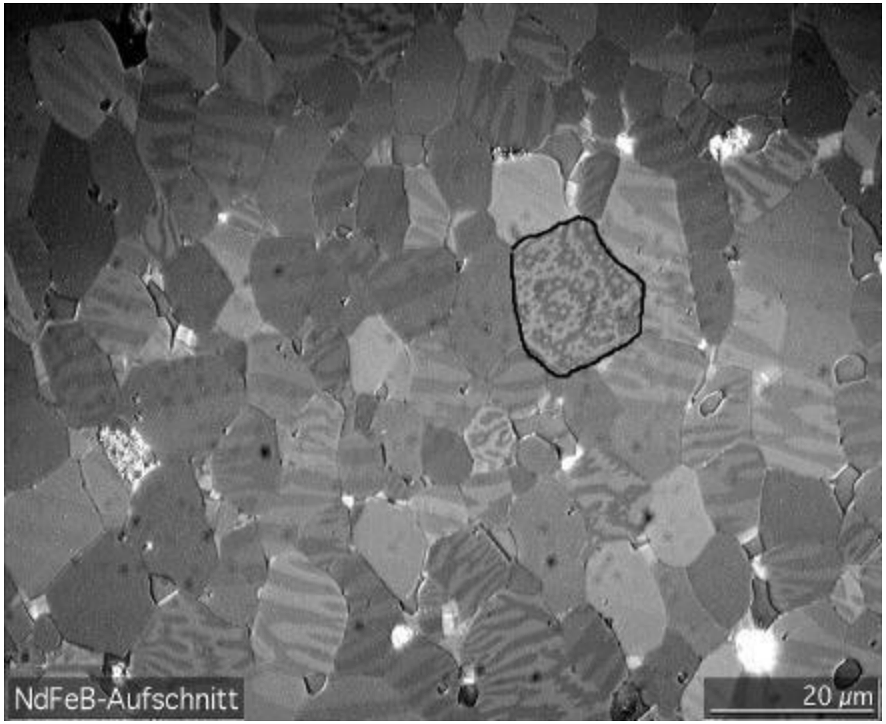
# Magnetostriction Generator

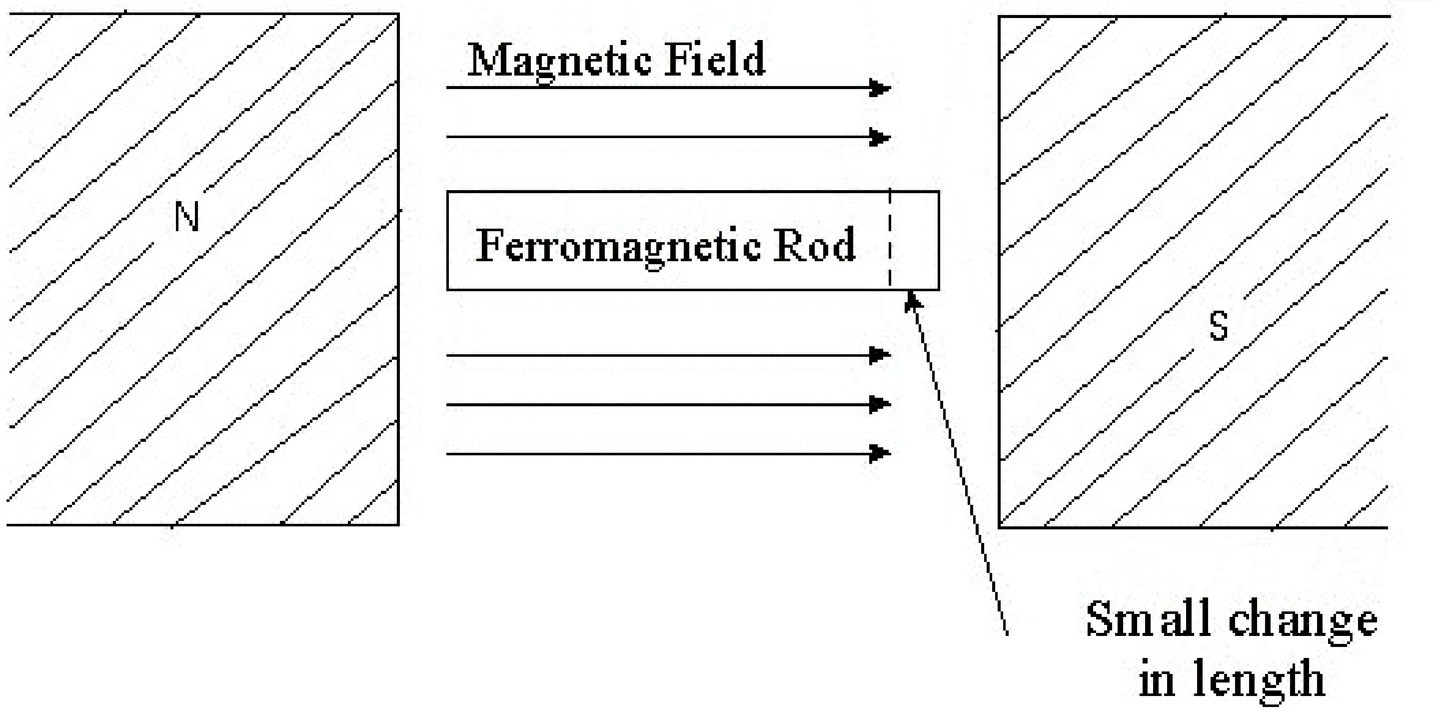
## Principle: Magnetostriction effect

- When a ferromagnetic rod made up of iron or nickel is placed in a magnetic field parallel to its length, the rod experiences a small change in its length
- This is called magnetostricion effect
- The change in length depends upon the <u>intensity of magnetic field</u> and <u>nature of the ferromagnetic material</u>
- The change in length takes place due to the presence of <u>domains in ferromagnetic material</u>

# Domains in ferromagnetic material

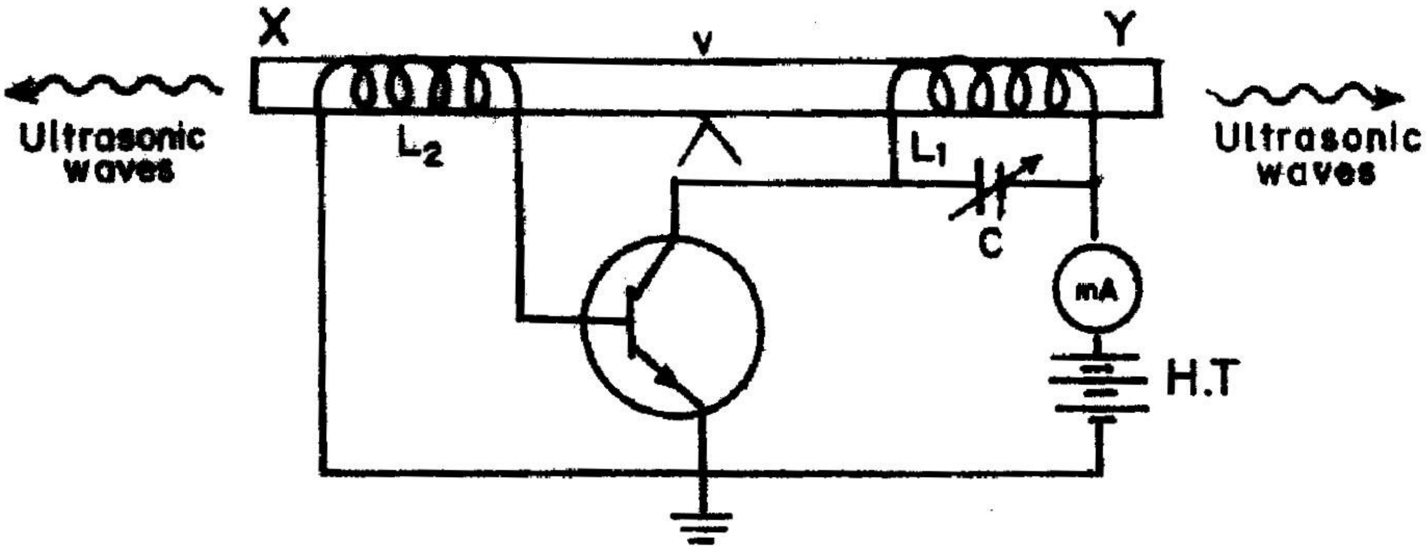
- A magnetic **domain** is a region within a magnetic **material** in which the magnetization is in a uniform direction






The change in length (increase or decrease) produced in the rod depends upon the strength of the magnetic field, the nature of the materials and is independent of the direction of the magnetic field applied

# Construction




An experimental arrangement of magnetostriction oscillator

- XY is a rod of ferromagnetic materials like iron or nickel. 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.
- 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*.

# 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 L1 produces an alternating magnetic field along the length of the rod.
- The result is that the rod starts vibrating due to magnetostriction effect.

The frequency of vibration of the rod is given by

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

where $l$ = length of the rod

$Y$ = Young's modulus of the rod material and

$\rho$ =density of rod material

- It vibrates at the frequency twice that of the frequency of the alternating current.
- The capacitor C is adjusted so that the frequency of the oscillatory circuit is equal to natural frequency of the rod and thus resonance takes plate.
- Now the rod vibrates longitudinally with maximum amplitude and generates ultrasonic waves of high frequency from its ends.

# 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 (ie. 3 MHz).
2. The frequency of oscillations depends on temperature.
3. There will be loss of energy due to hysteresis and eddy current.

# Piezoelectric Generator or Oscillator

- Discovered in 1880, Pierre and Jacques Curie

***Piezoelectric effect***

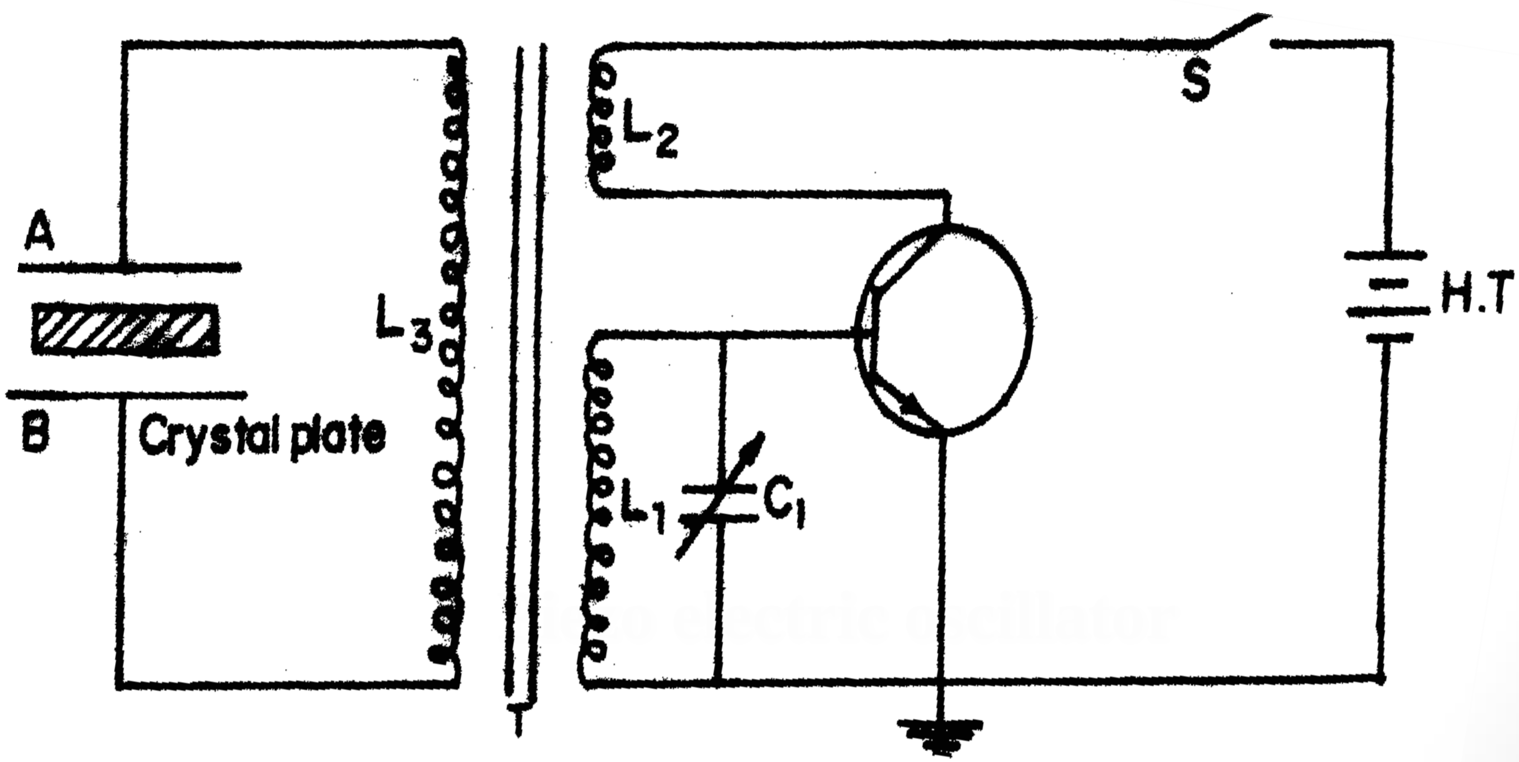
***v/s***

***Inverse 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 (Piezoelectric effect)
- 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 (Inverse piezoelectric effect)
- It is also known as electrostriction…

# Construction

- The circuit diagram is shown in Figure



# Construction

- The quartz crystal is placed between two metal plates A and B
- The plates are connected to the primary (L3) of a transformer which is inductively coupled to the electronics oscillator
- The electronic oscillator circuit is a base tuned oscillator circuit
- The coils L1 and L2 of oscillator circuit are taken from the secondary of a transformer T
- The collector coil L2 is inductively coupled to base coil L1.
- The coil L1 and variable capacitor C1 form the tank circuit of the oscillator
- Tank circuit: Parallel L-C (no resistance) circuit at resonating condition

# 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 L3. This high frequency alternating voltages are fed on the plates A and B.
- Inverse piezoelectric 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

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

where P = 1,2,3,4 … etc. for fundamental, first over tone, second over tone etc.,
Y = Young's modulus of the crystal and ρ = density of the crystal.

# Working

- The variable capacitor C1 is adjusted such that the frequency of the applied AC voltage is equal to the natural frequency of the quartz crystal, and thus resonance takes place.

- The vibrating crystal produces longitudinal ultrasonic waves of large amplitude.

# Advantages

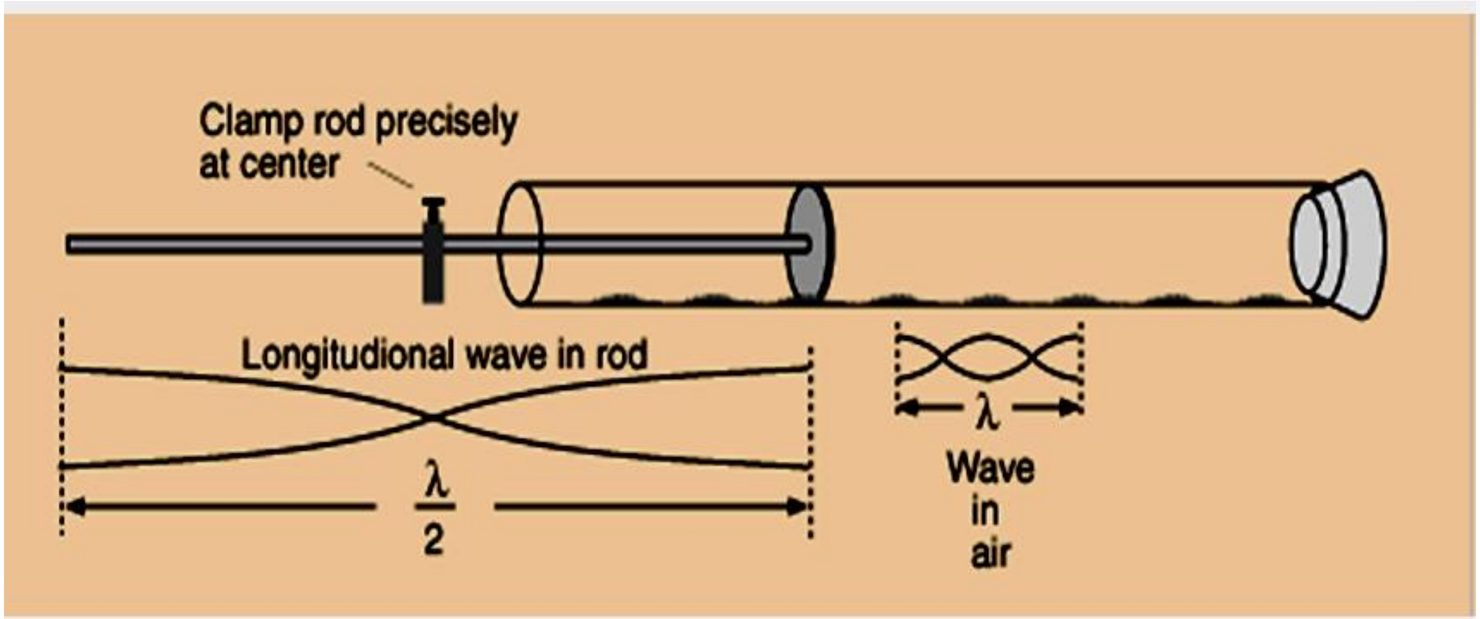
- Ultrasonic frequencies as high as 500 MHz can be obtained through this method.
- It is not affected by temperature and humidity.

# Disadvantages

- Piezoelectric quartz is very expensive
- The cutting and shaping of quartz crystal are very complex.

# Detection of Ultrasonic Waves

# Kundt’s tube method:




Lycopodium Powder is used

Heaps at the Nodes and blown off at Antinodes

Measure the Wavelength and Velocity of ultrasonic sound

# Wavelength:

The average distance btw two successive nodes or heaps is taken as ‘d’.
It should be equal to the half of the wavelength of ultrasonic waves.

$$d = \frac{\lambda}{2} \qquad \lambda = 2d$$

This method is suitable for measuring velocity of low frequency ultrasonic waves.
It can not be used for high frequency ultrasonic waves.

# Velocity:

Velocity of ultrasonic wave is V

$$V = \vartheta \lambda$$

$\vartheta$ frequency of ultrasonic wave

$$V = \vartheta 2d$$

# Sensitive flame method:

- A narrow sensitive flame is moved along the medium and change in its intensity is noticed.

- At the positions of antinodes, the flame is steady.

- At the positions of nodes, 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.

# Piezo electric oscillator:

Quartz crystal – for detection of ultrasonic

One pair of faces of quartz subjected to Ultrasonics.

Varying electric charges are produced.

These charges are very small and they can be amplified.


# Ultrasonic Transducers and Their Uses

# Transducers

- A transducer is an electronic device that converts energy from one form to another.

- Examples: microphones, loudspeakers, thermometers, position and pressure sensors, antenna, etc

# Ultrasonic Transducers

- An ultrasonic transducer is a device used to convert other type of energy into an ultrasonic vibration (mechanical energy) and vice versa.
- Ultrasonic transducers are divided into three broad categories: transmitters, receivers and transceivers.

***Transmitters*** *convert electrical signals into ultrasound,*
***receivers*** *convert ultrasound into electrical signals, and*
***transceivers*** *can both transmit and receive ultrasound.*

# Magnetostrictive Transducer

- A magnetostrictive transducer makes use of a type of magnetic material in which an applied oscillating magnetic field, creating a periodic change in the length of the material and thus producing a high-frequency mechanical vibration (20-40KHz)
- Magnetostrictive transducers are used to produce high intensity ultrasonic waves which are commonly used in ultrasonic cleaners and ultrasonic machining applications.

# Piezoelectric transducer

- By far the most popular and versatile type of ultrasonic transducer is the piezoelectric crystal, which converts an oscillating electric field applied to the crystal into a mechanical vibration.
- Piezoelectric crystals include quartz, Rochelle salt, and certain types of ceramic.
- Piezoelectric transducers are readily employed over the entire frequency range and at all output levels.
- Particular shapes can be chosen for particular applications.

  *For example, a disc shape provides a plane ultrasonic wave, while curving the radiating surface in a slightly concave or bowl shape creates an ultrasonic wave that will focus at a specific point.*

- An ultrasonic transducer is made up of *an active element, a backing, and wearplate.*
- The active element is the heart of the transducer which is usually a piezoelectric or single crystal material (transceiver).
- The backing is most commonly a highly attenuative and very dense material and is used to control the vibration of the transducer crystal by absorbing the energy that radiates from the back face of the piezoelectric element.
- The main purpose of the wearplate is simply to protect the piezoelectric transducer element from the environment. Wearplates are selected to generally protect against wear and corrosion.

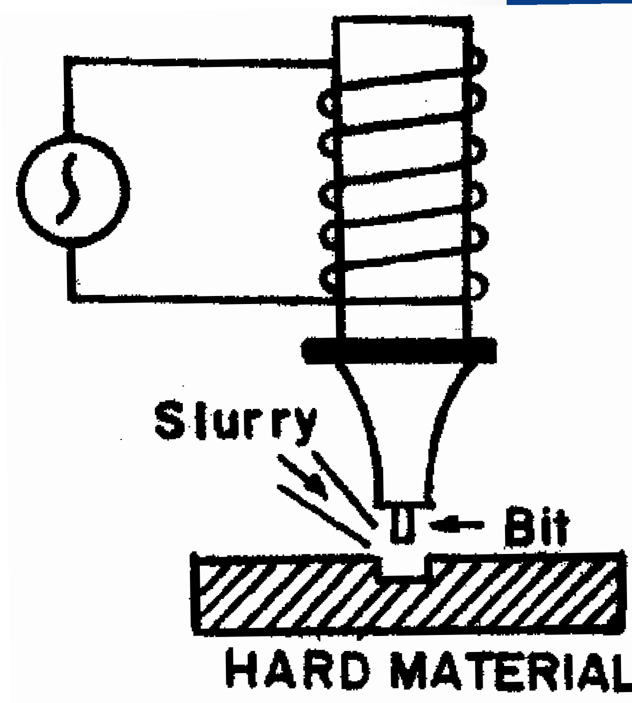
# Applications of Ultrasonic Waves in Engineering

## (1) Detection of flaws in metals

- 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.
- In flaws, there is a change of medium and this produces reflection of ultrasonic at the cavities or cracks.
- The method is very cheap and of high speed of operation.
- It is more accurate than radiography.

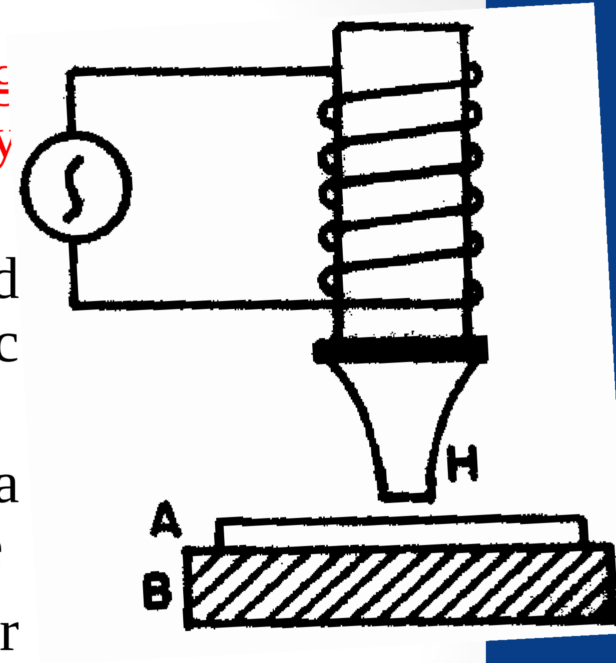
# (2) Ultrasonic Drilling

- 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 welding / cold welding

- The properties of some metals change on heating and therefore, such metals cannot be welded by electric or gas welding.
- In such cases, the metallic sheets are welded together at room temperature by using ultrasonic waves.
- For this purpose, a hammer H is attached to a powerful ultrasonic generator as shown in Figure
- The metallic sheets to be welded are put together under the tip of hammer H.




- The hammer is made to vibrate ultrasonically. As a result, it presses the two metal sheets very rapidly and the molecules of one metal diffuse into the molecules of the other.
- Thus, the two sheets get welded without heating. This process is known as ***cold welding***.

# (4) Ultrasonic soldering

- Metals like aluminium cannot be directly soldered (due to fast oxidation of surface).
- 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.

## (5) Ultrasonic cutting and machining

Ultrasonic waves are used for cutting and machining.

## (6) 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.

# (7) SONAR

- SONAR is a technique which stands for ***Sound Navigation and Ranging***.
- It uses ultrasonics 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 between the emission and receipt of beam after reflection, the distance of the object can be easily calculated.
- The change in frequency of the echo signal due to the Dopper effect helps to determine the velocity of the body and its direction.

- 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., where v is the velocity of sound in sea water.

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

- The same principle is used to find the depth of the sea.

## Applications of SONAR

1. Sonar is used in the location of shipwrecks and submarines on the bottom of the sea.
2. It is used for fish-finding application .
3. It is used for seismic survey.

# (8) Applications of Ultrasonics in Medicine

- Medical sonography (ultrasonography) is an ultrasound-based diagnostic medical imaging technique used to visualize muscles, tendons, and many internal organs, their size, structure and any pathological lesions.
- They are also used to visualize the fetus during routine and emergency prenatal care. Ultrasound scans are performed by medical health care professionals called sonographers. Obstetric sonography is commonly used during pregnancy.

- More power ultrasound sources may be used to clean teeth in dental hygiene or generate local heating in biological tissue, *e.g.* in occupational therapy, physical therapy and cancer treatment.

- ***Extracorporeal shock wave lithotripsy*** uses a powerful focused ultrasound source to break up kidney stones.

- Focused ultrasound sources may be used for ***cataract*** treatment.

- Doppler ultrasound is being tested for use in aiding tissue plasminogen activator treatment in stroke sufferers. This procedure is called Ultrasound-Enhanced Systemic Thrombolysis.

- Ultrasound has been shown to act synergistically with antibiotics in bacterial cell killing.

# Some Other Applications of Ultrasonics

**(1) Ultrasonic guidance for the blind**

- Ultrasonic waves are used for guiding the blind who carries a walking stick containing an ultrasonic transmitter and receiver.

- Ultrasonic signals reflected from any obstacles are fed to the head phones through a suitable electronic circuit which enables the blind person to detect and estimate the distance of the obstacle.

# (2) Ultrasound in research

- Scientists often use in research, for instant to break up high molecular weight polymers, thus creating new plastic materials.
- Indeed, ultrasound also makes it possible to determine the molecular weight of liquid polymers, and to conduct other forms of investigation on the physical properties of materials.
- Ultrasonic can also speed up certain chemical reactions. Hence it has gained application in agriculture, that seeds subjected to ultrasound may germinate more rapidly and produce higher yields.

# Absorption and dispersion of ultrasonic waves

- Two main mechanisms namely absorption and dispersion are responsible for the ultrasound attenuation.

- When an ultrasonic wave passes through a medium, a part of its energy is converted into heat due to the alternative compression and rarefaction taken place and hence its intensity decreases.

  *The process is termed as absorption of the waves in the medium and wave is said to be attenuated.*

- The dispersion of the ultrasonic wave is referred to as the change in its velocity with frequency.

# Factors responsible for ultrasonic absorption

- Thermal conductance effect
- Chemical effects
- Viscous effects
- Nonlinearity of medium

- The attenuation of the ultrasonic waves is characterized by the exponential decrease of the pressure amplitude *p* and of intensity amplitude *I* with the propagating distance *z*, such that

$$p = p_0 e^{-\alpha z}$$

$$\text{and} \;\; I = I_0 e^{2-\alpha z}$$

where $p_0$ and $I_0$ are the pressure and intensity at $z = 0$.

- The quantity $\alpha$ is called the pressure-frequency dependent attenuation coefficient, expressed in $cm^{-1}$
- The factor of 2 in the exponential term of the intensity equation results from the transformation of the pressure into intensity, as intensity is proportional to the square of pressure.
- The commonly used units for in biomedical ultrasonics are dB (decibel).


Good luck