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# L26 Ultrasound in medicine

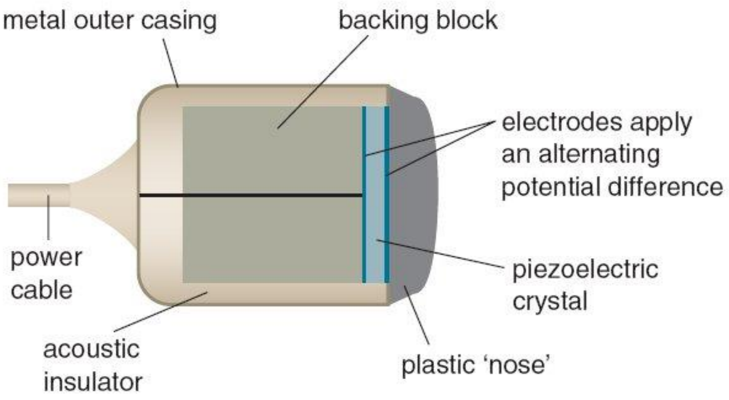
## What is ultrasound?

**Ultrasound** is a wave with frequency exceeding the upper limit of human hearing, greater than 20,000 Hz (hertz)
Ultrasound imaging frequency range 2-20Mhz
Sound waves with frequencies below 20Hz called **infrasonic.**

- Like normal sound, ultrasound echoes off objects
- So a whistle that only dogs can hear has a frequency higher than 20,000 but lower than 50,000Hz.
- The bat hears the echoes(30-100kHz and works out what caused them
- Submarines use a similar method called SONAR (SOund NAvigation and Ranging) a method of locating underwater objects.
- We can also use ultrasound to look inside the body.

## Generation and Detection of Ultrasound

- Ultrasound is produced and detected using an ultrasound transducer.
- Ultrasound transducers are capable of sending an ultrasound and then the same transducer can detect the sound and convert it to an electrical signal to be diagnosed
- The most important for application involves **the piezoelectric effect.**
- The piezoelectric effect and its converse are the primary means used in biomedical ultrasound for converting acoustical energy into electrical energy and *vice versa*.

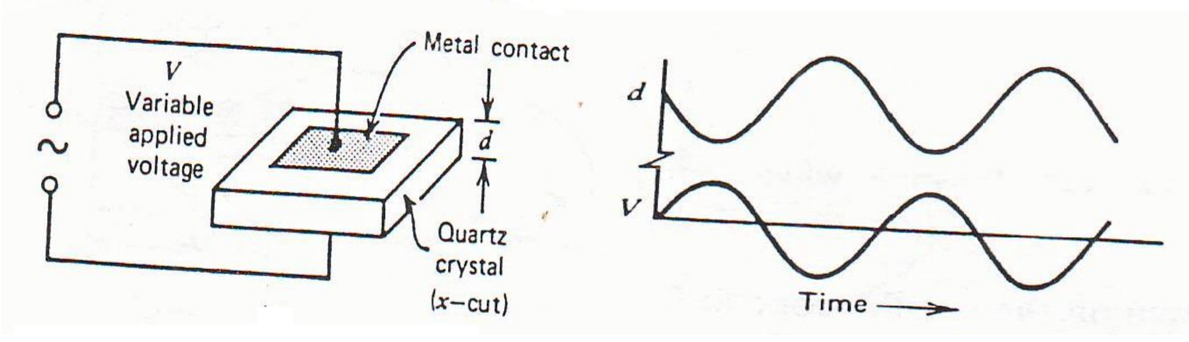



- Many crystals can be cut so that an oscillating voltage across the crystal will produce a similar vibration of crystal, thus generating a sound wave.
- The frequency that will produce from the piezoelectric element with thickness d is given by:

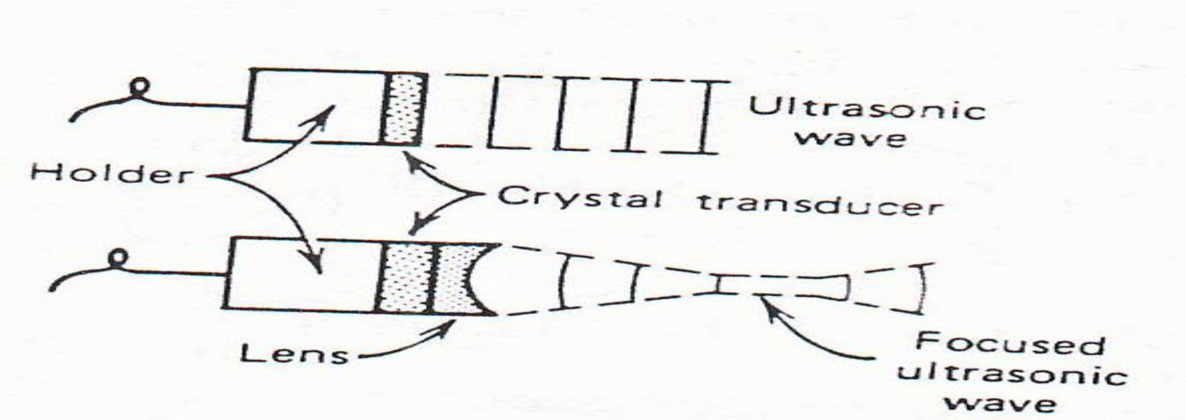
$$f\ (MHz) \approx \frac{2}{d(mm)}$$

For example **a 0.4 mm thick crustal resonate at a frequency 5 MHz**

- Each transducer has a natural resonant frequency of vibration .The thinner the crystal, the higher the frequency at which it will oscillate



**Change in crystal thickness d due to an applied alternating voltage V.**
**The crystals mounted in a holder to produce a beam of ultrasound. A focused beam produced when an acoustic lens is attached to the crystal.**




- **Typical frequencies for medical work are in the 1 to 5 MHz range.**
- **An average power level for diagnostic application is a few millwatts per square centimeter($mW/cm^2$ )**
- **Average speed of ultrasound in body is 1540m/sec**

## Physics of Ultrasound

- **Ultrasound transducer produces "pulses" of ultrasound waves**
- **Pluses of ultrasound are transmitted into body by placing the vibrating crystal in close contact with the skin, using water or jelly paste to eliminate the air.**
- **This gives a good coupling at the skin and greatly increases the transmission of US in the body**
- **These waves travel within the body and interact with various tissues**
- **The reflected waves return to the transducer(the echoes back to the detector) and are processed by the ultrasound machine**
- **An image which represents these reflections is formed on the monitor**
- **The basis of use US in medicine is the partial reflection of sound at the surface between two media that have different acoustical properties.**
- **The amount of reflection depends upon:**

1. **The difference in the acoustical impedances of the two materials.**
2. **The orientation of the surface with respect to the beam**

**In many diagnostic uses of US the echoes are very small signals due weak reflection and absorption of sound by tissue .**

## Quality of ultrasound imaging

**The quality of US imaging is determined by the interaction of the acoustic wave with the body tissue , these interaction includes :**

1. **Spatial resolution , which depends on wavelength of US.**
2. **Attenuation , which depends on absorption and scattering of US waves.**
3. **Reflection and transmission ,which depend on the impedance of the medium**

## Spatial resolution

**The Spatial resolution is limited by wavelength of sound:** $\Delta s \approx \lambda = \frac{v}{f}$

**For low frequencies in the audible range 10 kHz** $\longrightarrow$ $\lambda = \frac{1540}{10^4} = 0.154$ **cm**

**frequencies in the US range 10 MHz** $\longrightarrow$ $\lambda = 0.154$ **mm**

**so**

**low f** $\longrightarrow$ **high** $\Delta s$ $\longrightarrow$ **bad resolution** $\longrightarrow$ **bad image**

## Reflection and transmission

Perpendicular reflection originates the echo signal, while non- Perpendicular reflection causes an intensity loss in echo signal, as shown in the figure.

Smooth surface ⟶ low scattering ⟶ good image
Rough surface ⟶ high scattering ⟶ bad image

The choice of the US determined by a compromise between good resolution and deep penetration. The attenuation of high frequency acoustic waves limits the penetration depth, low frequency wave decrease resolution.

## Types of US imaging

## A-scan method of ultrasound (Amplitude scan)

- To obtain diagnostic information about the depth of structures in the body. We send pulses of US in to the body and measure the time required for the sound pulses to receive the reflected sound (echoes) from the various surfaces in it.
- Near Field Imaging Tissues closer appear on top and faster the waves return
- Far Field Imaging Tissues further appear at the bottom & slower the waves return
- This procedure called A-scan method of ultrasound diagnosis.
- Pulse for A- scan work typically a few microseconds long. They usually emitted at 400 to 1000 pulses/sec.

### A-scan method

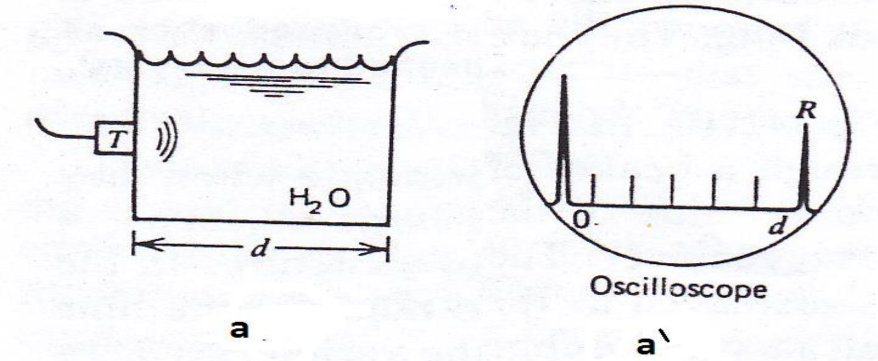
T: transducer     d: beaker diameter

The sound reflected from the other side of beaker of water and return to the transducer, which acts as a receiver.

Positional information is determined by knowing the direction of the pulse entering the patient and measuring the time that is takes the echo to return to the transducer. Range equation:

$$V = 2d / t$$

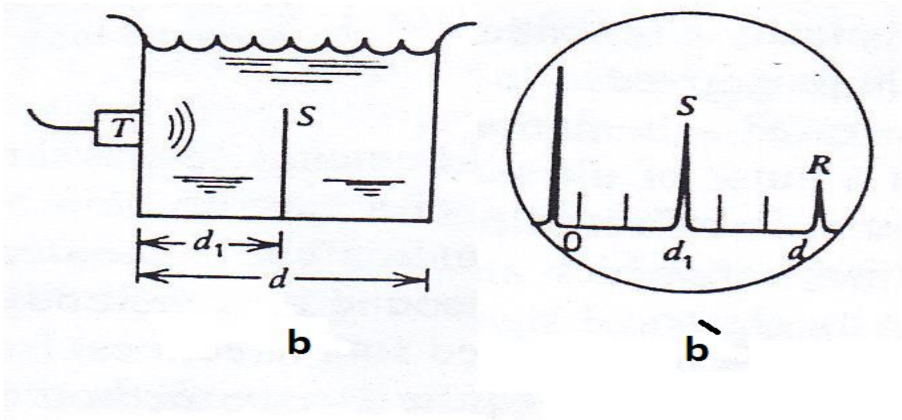
The detected echo converted to an electrical signal and displayed as the vertical deflection R on the cathode ray tube CRT of an oscilloscope.



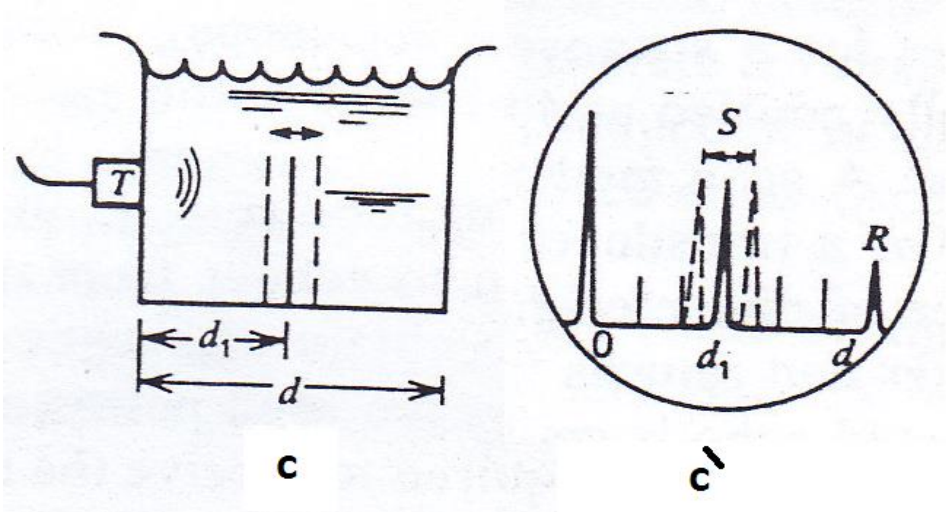

R is smaller in amplitude than the initial pules at 0 on CRT .

The time required for the sound pulses to travel from the T to the far side and return to the T is indicated on the horizontal scale:

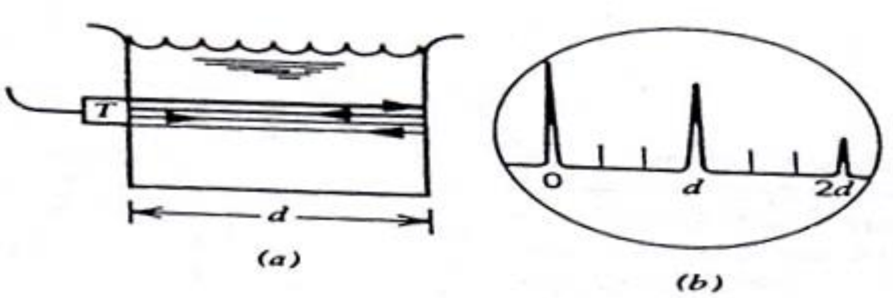
An object in the beaker can be located with *US*




**S :Surface at a distance $d_1$ . The echo R is now smaller**




**When the Surface (S) vibrates the position of the echo on the oscilloscope also move.**
**A-scan of multiple reflections taking place, a multiple echo appears as an object at a distance d and a second object at 2d**

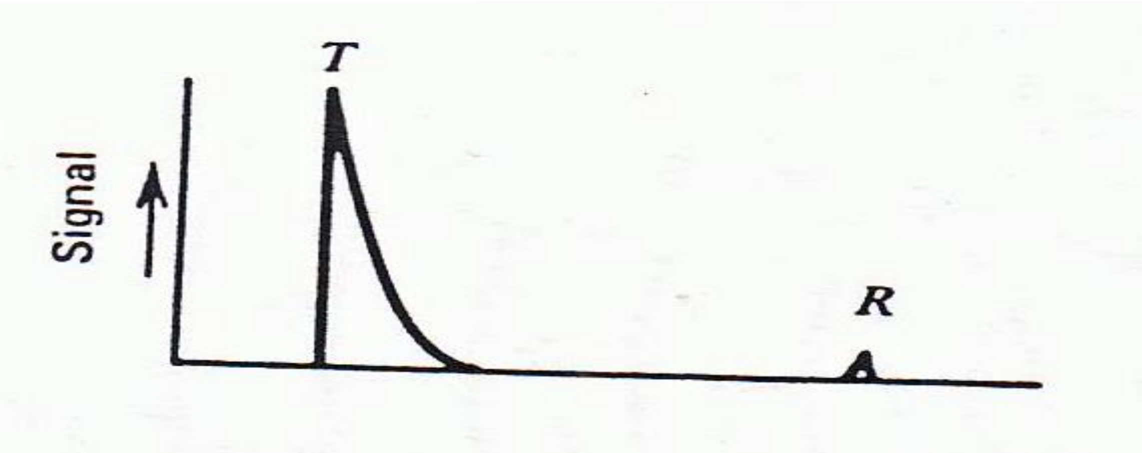



**The basis of use US in medicine is the partial reflection of sound at the surface between two media that have different acoustical properties.**
**The amount of reflection depends upon:**

- **The difference in the acoustical impedances of the two materials.**
- **The orientation of the surface with respect to the beam**

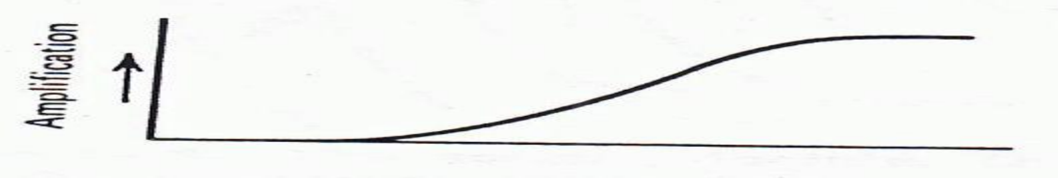
**In many diagnostic uses of US the echoes are very small signals due weak reflection and absorption of sound by tissue**

$$A = A_0 e^{-\alpha x}$$

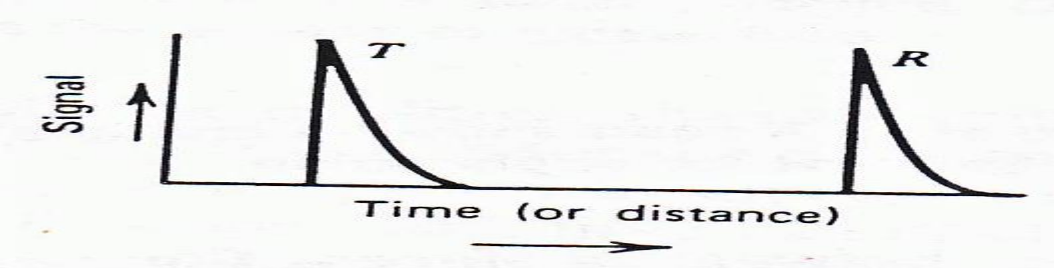



**The transmitted pulse T produces a weak echo R on the CRT**

**Weak echoes from deep structures can be electronically amplified to make them more visible.**



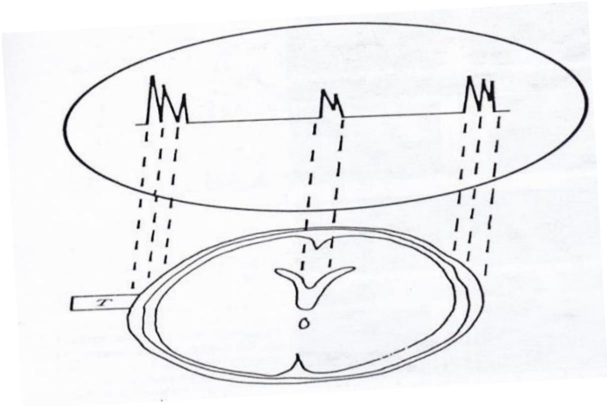

**The amount of amplification increases with time (or distance)**

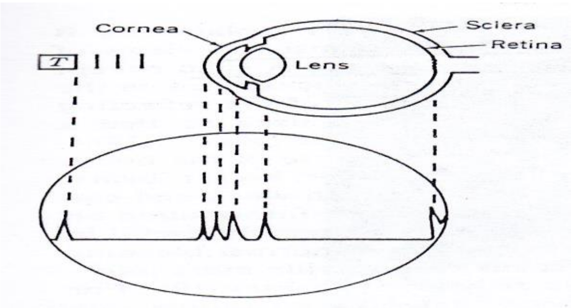



**The amplification increases the size of the echo R**

**Application of A scan**

- **Echoencephalography :-used in detection of brain tumors**




**In ophthalmology:-**

**1-Obtaining information for use in the diagnosis of eye diseases.**

**2- Biometry, or measurements of distances in the eye**

**EX : If a bat hears an echo 0.01 second after it makes a chirp, how far away is the object?**

**Answer:**

**1: the speed of sound in air is 330 $ms^{-1}$**

**2: The speed of sound equals the distance travelled divided by the time taken distance = speed x time**

**Put the numbers in: distance = 330 x 0.01 = 3.3 m**
**But this is the distance from the bat to the object and back again, so the distance to the object is 1.65 m.**

## B-scan method

**B-scan method used to obtain two – dimensional view of parts of the body. The principles are the same as for the A -scan except that the transducer moved. As a result, each echo produces a dot on the oscilloscope at a position corresponding to the location of the reflecting surface.**

**In B-Scan (Brightness Scan) the peaks of the reflected waves converted to electric signals, view it in a screen, and move the transducer on the skin can get picture of bright and dirk areas of the scanned object.**

### Application of B- Scan (Brightness Scan)

**In B-scan, method can be detect pregnancy as early as the fifth week and can provide information about uterine anomalies.**
**In many cases X-ray, provide less information than B-Scan and more risk.**


(a) As the transducer T moves to the right it produces ecches from the submerged object

(b) When the transducer is rocked as it is moved to the right it produced


(a') The storage oscilloscope shows a dot corresponding to the location of each echo received. The dots outline the top sutface of the object

(b') The resulting scan shows the sides of the object

### *Ultrasound To measure motion*

**Two methods are used to obtain information in the body with ultrasound :**

**1-The M-scan, (motion )**

- **The M-scan, (motion ) which is used to study motion such as that of the heart and the heart valves.**
  **The M- scan combines certain features of the A- scan (Amplitude Scan) and B-scan(Brightness Scan).**
  **The transducer is held stationary as in the A- scan and the echoes appears as dots as in B-scan.**
- **In M –scan (motion scan ) if we put an object in the middle of the beam way, we'll get three peaks and if we vibrate the object and record it in continuous chart we'll get a wave.**

**Ex: A pulsed *U/S* signal is transmitted through soft tissue to a tissue interface and reflected back. The time required from complete trip is 60 $\mu$sec. How deep the reflecting interface?**

**Solution:**

**Distance =V$\times t$**

**Depth =1450 $\times$60 $\times 10^{-6} \times \frac{1}{2}$**

**= 4.35 $\times 10^{-2}$ m**

**= 4.35 cm**