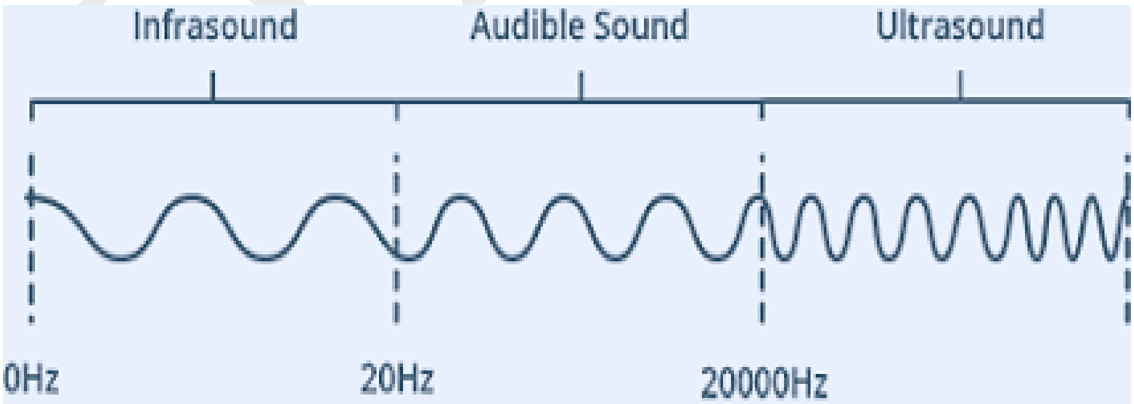
Unit 2. ULTRASONIC & OSCILLATIONS

INTRODUCTION

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 20000 Hz are called ***ultrasonic waves***. Generally these waves are called as ***high frequency waves***. The field of ultrasonics has applications for imaging, detection and navigation. The broad sectors of society that regularly apply ultrasonic technology in the medical sector, industrial sector, educational sector, and the defense sector and private citizens.

HISTORY

Acoustics, the science of sound, starts as far back as Pythagoras in the 6^{th} century BC, who wrote on the mathematical properties of stringed instruments. Echolocation in bats was discovered by Lazzaro Spallanzani in 1794, when he demonstrated that bats hunted and navigated by inaudible sound, not vision. Francis Galton in 1893 invented the Galton whistle, an adjustable whistle that produced ultrasound, which he used to measure the hearing range of humans and other animals, demonstrating that many animals could hear sounds above the hearing range of humans. The first technological application of ultrasound was an attempt to detect submarines by Paul Langevin in 1917. The piezoelectric effect, discovered by Jacques and Pierre Curie in 1880, was useful in transducers to generate and detect ultrasonic waves in air and water.



- Sound waves of frequency < 20 Hz called as infrasonic waves.
- Sound waves of frequency in between **20 Hz to 20 KHz** called as Audible waves.
- Sound waves of frequency > 20 KHz called as ultrasonic waves.

Unit 2. ULTRASONIC & OSCILLATIONS

- **PROPERTIES OF ULTRASONIC WAVES**

1. Ultrasonic waves are having frequencies higher than 20 KHz and hence they are highly energetic.
2. Ultrasonic waves travels over a long distances without any appreciable loss of energy.
3. When the ultrasonic wave is absorbed by a medium, it generates heat.
4. At room temperature, ultrasonic welding is possible.
5. Using ultrasonic wave, acoustic grating can be formed in a liquid.

- **PRODUCTION OF ULTRASONIC WAVE**

  Ultrasonic waves are produced by the following methods.

(1) Magneto-striction generator or oscillator

(2) Piezo-electric generator or oscillator

1) MAGNETO-STRICTION GENERATOR:

Principle

When a rod of ferromagnetic material like nickel is magnetized. Longitudinally, it undergoes a very small change in length. This is called Magnetostriction effect

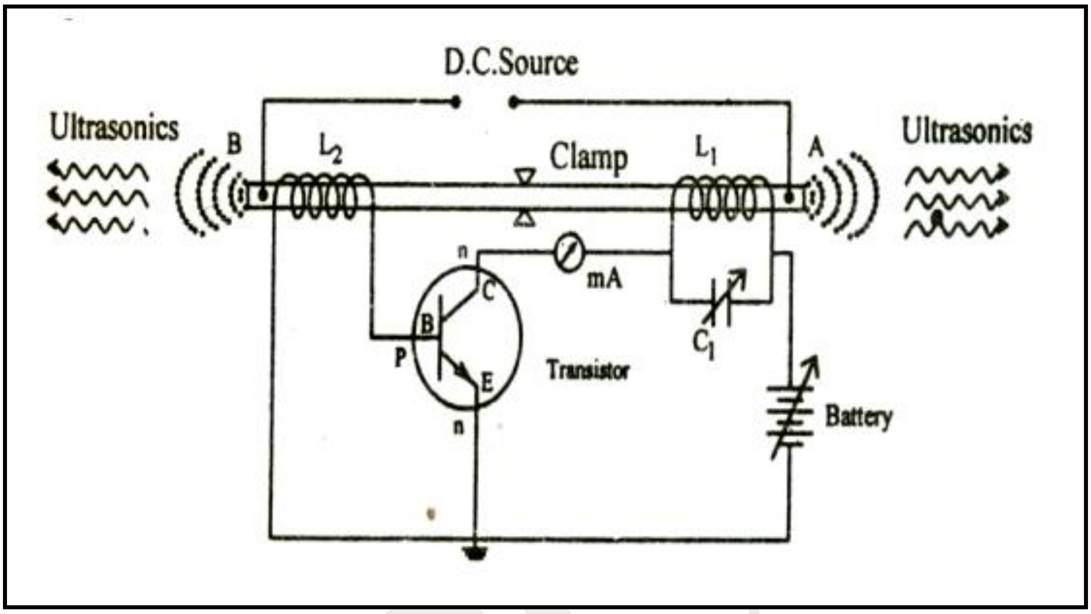
Construction and Working

- A short permanently magnetized nickel rod is clamped in the middle between two knife edges. A coil L_1 is wound on the right hand portion of the rod. C is a variable capacitor. L_1 and C_1 form the resonant circuit of the collector-tuned oscillator. Coil L_2 wound on the LHS of the rod is connected in the base circuit. The coil L_2 is used as a positive feedback loop.

- D.C. given to coil which magnetizes rod and that change in current passing through L_1 causes change in magnetization of rod hence length of rod changes its length longitudinally. This Variation in this length cause change in magnetic flux through L_2, which is called as Converse magneto striction effect. Now induced emf is set into L_2. This induced emf modify potential at transistor again positive feedback given to rod. Thus the current in milliameter increases frequency of oscillations of rod also increases.

- This frequency of oscillation of rod equal to frequency of alternating increasing current and resonance takes place produces ultrasonic waves of frequency KHz.

At the Resonance, frequency of wave produced by tank ckt by capacitance C and Inductance L is $f = \frac{1}{2\pi\sqrt{LC}}$



- **Condition for Resonance:**

Frequency of the oscillator circuit = Frequency of the vibrating rod

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

Where ‘l’ is the length of the rod, ‘Y’ is the Young’s modulus of the rod

‘ρ’ is the density of the material of the rod.

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

PIEZOELECTRIC EFFECT

- **Definition**: When a mechanical stress is applied to the mechanical axis with respect to optical axis, a potential difference is developed across the electrical axis with respect to optic axis

Inverse Piezoelectric Effect:

- **Definition**: When an alternating electric field is applied to electrical axis with respect to optical axis, expansion or contraction takes place in the mechanical axis with respect to optical axis.

2) PIEZO ELECTRIC GENERATOR

Principle:

This is based on the **Inverse piezoelectric effect.** When a quartz crystal is subjected to an alternating potential difference along the electric axis, the crystal is set into elastic vibrations along its mechanical axis. If the frequency of electric oscillations coincides with the natural frequency of the crystal, the vibrations will be of large amplitude. If the frequency of the electric field is in the ultrasonic frequency range, the crystal produces ultrasonic waves.

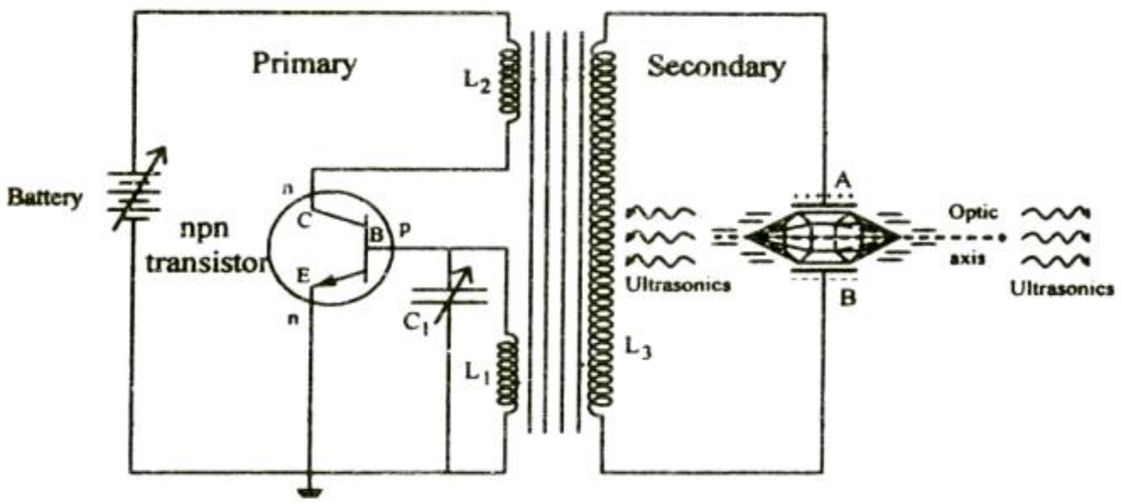


Figure Piezo-Electric Oscillators

Construction:

The circuit diagram is shown in the figure. It is base tuned oscillator circuit. A slice of Quartz crystal is placed between the metal plates A and B so as to form a parallel plate capacitor with the crystal as the dielectric. This is coupled to the electronic oscillator through the primary coil L_1 of the transformer. Coils L_2 and L_1 of oscillator circuit are taken for the primary of the transformer. The collector coil L_2 is coupled to base coil L_1. The coil L_1 and variable capacitor C form the tank circuit of the oscillator.

Working:

When the battery is switched on, the oscillator produces high frequency oscillations. An oscillatory e.m.f is induced in the coil L_3 due to transformer action. So the crystal is now under high frequency alternating voltage. The capacitance of C_1 is varied so that the frequency of oscillations of alternating current produced is in resonance with the natural frequency of the crystal. Now the crystal vibrates with larger amplitude due to resonance. Thus high power ultrasonic waves are produced.

Condition for Resonance:

Frequency of the oscillator circuit = Frequency of the vibrating crystal

$$f = \frac{1}{2\pi\sqrt{L_1C_1}} = \frac{P}{2l}\sqrt{\frac{E}{\rho}} \qquad\qquad f = \frac{1}{2\pi\sqrt{LC}} = \frac{p}{2t}\sqrt{\frac{Y}{\rho}}$$

Where ‘t’ is the thickness of the crystal, ‘E’ is the Young’s modulus o the rod

‘ρ’ is the density of the material of the rod, p = 1,2,3 …. Fundamental, first overtone, second overtone.

Advantages

1. Ultrasonic frequencies as high as 5 x 10^8 Hz or 500 MHz can be obtained with this arrangement.
2. The output of this oscillator is very high.
3. It is not affected by temperature and humidity.

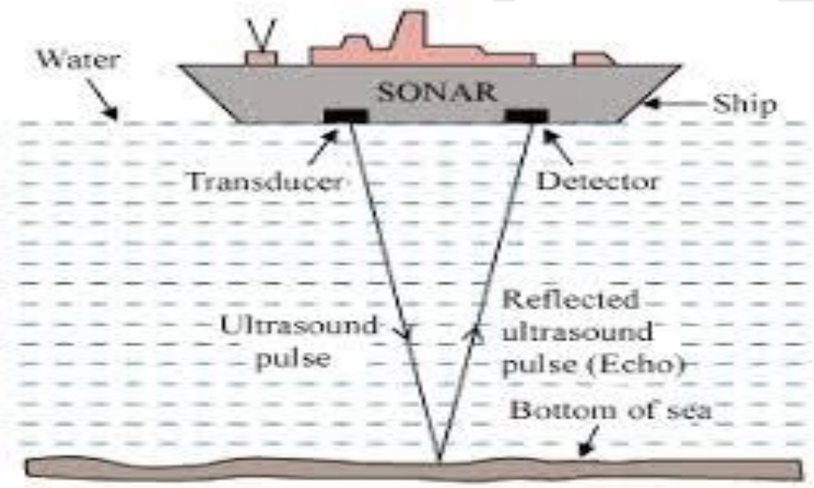
Disadvantages

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

- **APPLICATION OF ULTRASONIC WAVES AS SONAR**

SONAR is apparatus used to find depth of sea or to locate the underwater things like a shoal of fish, enemy submarines etc. SONAR works by sending short bursts of ultrasonic sound from ship down into sea water and then gets echo produced by the reflection of ultrasound from underwater objects like bottom of sea.(i)A transmitter (for emitting ultrasonic waves) and (ii) receiver (for detecting ultrasonic waves).

SONAR device is attached to underside of ship and we want to measure depth of sea (inside ship). The transmitter of SONAR is made to emit pulse of ultrasonic sound with frequency about 50000 Hz.



This pulse of ultrasound travels fast down in the sea water towards the bottom of sea. When it strikes at the bottom of sea, it is reflected back into the ship in the form of echo. This echo produced an electrical signal into the SONAR device. SONAR device measure the time by the ultrasonic waves to travel from ship to the bottom of sea.

$$\mathbf{v = 2d/t}$$

$$\mathbf{d = (v.t)/2}$$

d= depth of sea

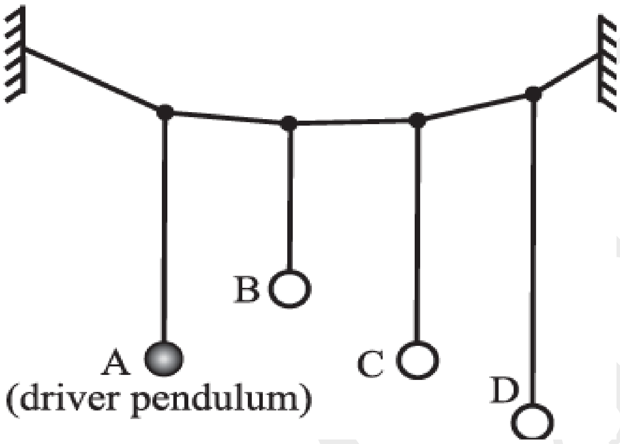
V= velocity of sound in water

t= time recorded by recorder

- **FREE OSCILLATIONS, FORCED OSCILLATIONS AND RESONANCE**

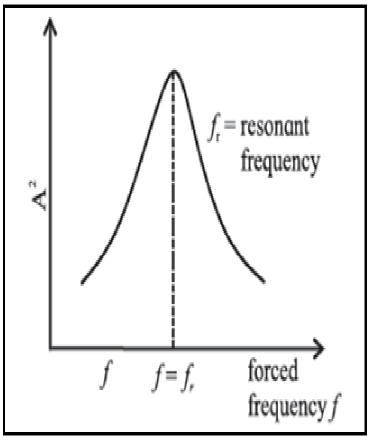
Free Oscillations

If an object is allowed to oscillate or vibrate on its own, it does so with its natural frequency (or with one of its natural frequencies). For example, if the bob of a simple pendulum of length l is displaced and released, it will oscillate only with the frequency $n = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$ which is called its natural frequency and the oscillations are free oscillations.



However, by applying a periodic force, the same pendulum can be made to oscillate with different frequency. The oscillations then will be forced oscillations and the frequency is driver frequency or forced frequency.

Consider the arrangement shown in the Fig 5.15. There are four pendula tied to a string. Pendula A and C are of the same length, pendulum B is shorter and pendulum D is longer. Pendulum A is having a solid rubber ball as its bob and will act as the driver pendulum or source pendulum. Other three pendula are having hollow rubber balls as their bobs and will act as the driven pendula. As the pendula A and C are of the same lengths, their natural frequencies are the same. Pendulum B has higher natural frequency as it is shorter and pendulum D is of lower natural frequency than that of A and C. Pendulum A is now set into oscillations in a plane perpendicular to the string. In the course of time it will be observed that the other three pendula also start oscillating in parallel planes.This happens due to the transfer of vibrational energy through the string. Oscillations of A arefree oscillations and those of B, C and D are *forced oscillations* of the *same* frequency asthat of A. The natural frequency of pendulum C is the same as that of A, as it of the samelength as that of A.



It can also be seen that among the pendula B, C and D, the pendulum C oscillates with maximum amplitude and the other two with smaller amplitudes. As the energy depends upon the amplitude, it is clear that Pendulum C has absorbed maximum energy from the source pendulum A, while the other two absorbed less. It shows that the object C having the same natural frequency as that of the source absorbs maximum energy from the source. In such case, it is said to be in *resonance* with the source (pendulum A). For unequal natural frequencies on either side (higher or lower), the energy absorbed (hence, the amplitude) is less. If the activity is repeated for a set of pendula of different lengths and squares of theiramplitudes are plotted against their natural frequencies, the plot will be similar to that shown in the Fig. The peak occurs when the forced frequency matches with the natural frequency, i.e., at the resonant frequency.

- **DAMPED OSCILLATIONS**

Periodic oscillations of gradually decreasing amplitude are called damped harmonic oscillations and the oscillator is called a ***damped harmonic oscillator****.*

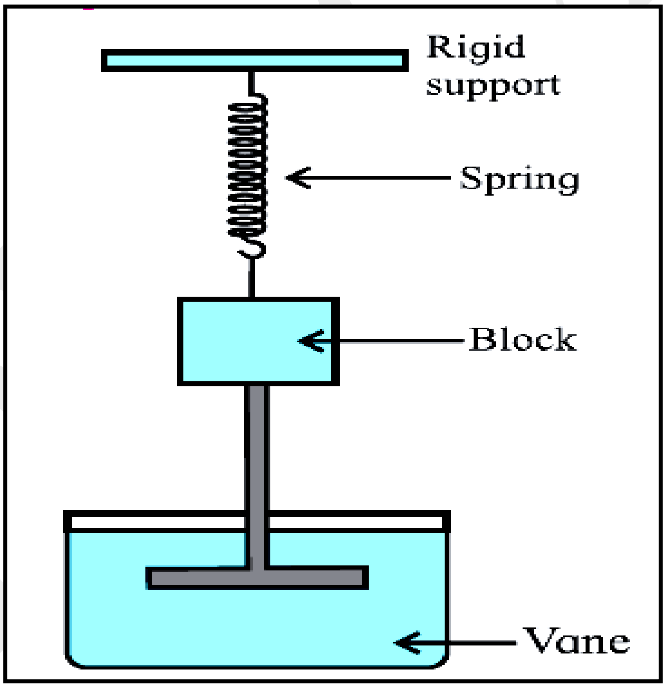


Figure shows a block of mass *m* oscillate vertically on a spring. e that From the block, a rod extends to vanis immersed liquid. As the vane moves up and down, the liquid exerts drag force on it, and thus on the complete oscillating system. The mechanical energy of the block-spring system decreases with time, as energy is transferred to thermal energy of the liquid and vane.

The damping force (Fd) depends on the nature of the surrounding medium and is directly proportional to the speed v of the vane and the block

$$\mathbf{F_d = -bv}$$

Where b is the damping constant and negative sign indicates that $F_d$opposes the velocity. For spring constant k, the force on the block from the spring is

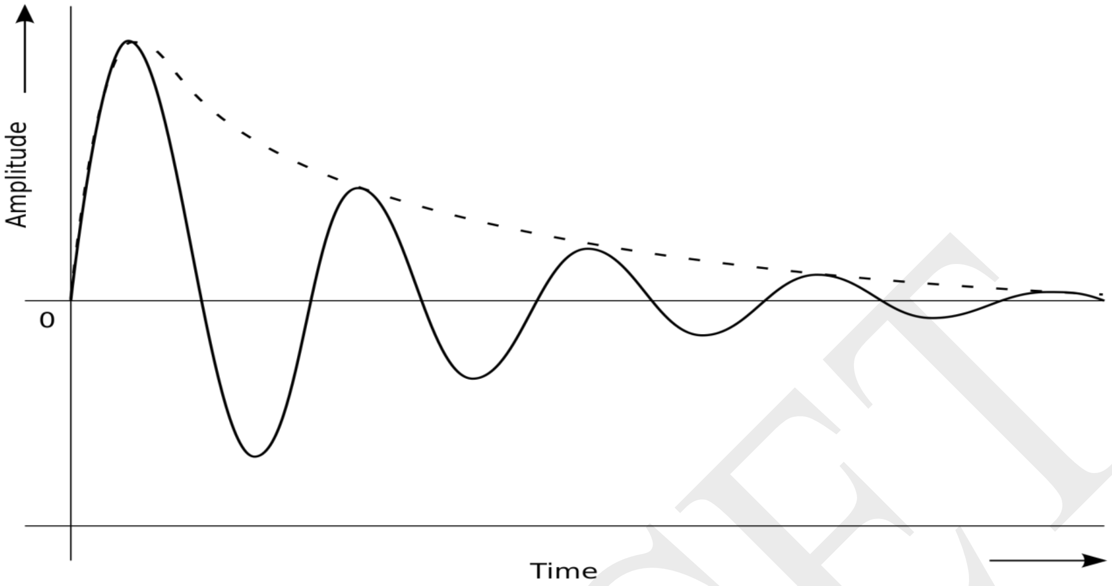
$$\mathbf{F_s = -kx}$$

Assuming that the gravitational force on the block is negligible compared to $Fd$and Fs, the total force acting on the mass at any time t is

$$F = F_d + F_s$$
$$\therefore ma = -bv - kx$$
$$ma + bv + kx = 0$$
$$\therefore \quad m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0 ......(1)$$
$$\frac{d^2x}{dt^2} + \frac{b}{m}\frac{dx}{dt} + \frac{k}{m}x = 0$$
$$put\ \frac{b}{m} = 2S\ and\ \frac{k}{m} = \omega^2 \qquad \therefore \frac{d^2x}{dt^2} + 2S\frac{dx}{dt} + \omega^2 x = 0.........(2)$$

equation (2) is of second order and we assume its solution as,

$$x = Ae^{\alpha t} \quad ......(3)$$
$$where\ A\ \&\ \alpha = const.$$
$$differentiate\ eqation\ (3) w.r.t.\ 't'$$
$$\frac{dx}{dt} = A\alpha e^{\alpha t} \quad \& \quad \frac{d^2x}{dt^2} = A\alpha^2 e^{\alpha t}$$
$$equation\ (2)\ becomes$$
$$\therefore A\alpha^2 e^{\alpha t} + 2SA\alpha e^{\alpha t} + \omega^2 Ae^{\alpha t} = 0$$
$$\therefore Ae^{\alpha t}\left[\alpha^2 + 2\alpha S + \omega^2\right] = 0$$
$$As\ Ae^{\alpha t} \neq 0\ then \left[\alpha^2 + 2\alpha S + \omega^2\right] = 0,$$
$$\therefore \alpha = -S \pm \sqrt{S^2 - \omega^2}$$
$$\therefore \alpha\ has\ two\ roots \quad i.e.\ \alpha_1 = -S + \sqrt{S^2 - \omega^2} \quad and\ \alpha_2 = -S - \sqrt{S^2 - \omega^2}$$
$$\therefore General\ solution\ of\ equation\ (2)\ is$$
$$x = A_1 e^{(-S + \sqrt{S^2 - \omega^2})t} + A_2 e^{(-S - \sqrt{S^2 - \omega^2})t} \quad ......(4)$$



Links for study

http://hyperphysics.phy-astr.gsu.edu/hbase/oscda.html

https://en.wikipedia.org/wiki/Harmonic_oscillator

http://hyperphysics.phy-astr.gsu.edu/hbase/Sound/usound.html

DYPCET