MIT Art Design and Technology University

MIT School of Computing, Pune

Department of Applied Sciences and Humanities

First Year Engineering

23ASH1105-Engineering Physics

Class – F.Y. (SEM-I)

Unit - I

Chapter-1 Acoustics

AY 2025-2025, SEM-I

Unit I - Syllabus

Acoustics

- Characteristics of sound waves
- Noise and musical sound
- Reflection of sound waves
- Defects due to reflected sound
- Absorption of sound
- Reverberation
- Sabine's formula
- Factors affecting the architectural acoustics and remedies

Ultrasonics

- Classification of sound waves,
- Generation of ultrasonic wave : Magnetostriction oscillator, Piezoelectric oscillator
- Applications- SONAR, ultrasonic inspection method of non- destructive testing

What is Acoustics?

It's science of sound.

Origin, Propagation, Auditory sensation of sound

Acoustic Engineering or Sound Engineering

Study of design of musical instruments: Musical Acoustics

Technology of sound production and recording: Electro-acoustics

Use of Sound in medical diagnosis and therapy: Bio-acoustics

Design of Auditoriums, musics halls, lecture halls, recording rooms : Architectural acoustics

Architectural Acoustics: Behavior of sound waves in closed spaces and design of closed spaces to give best sound effects.

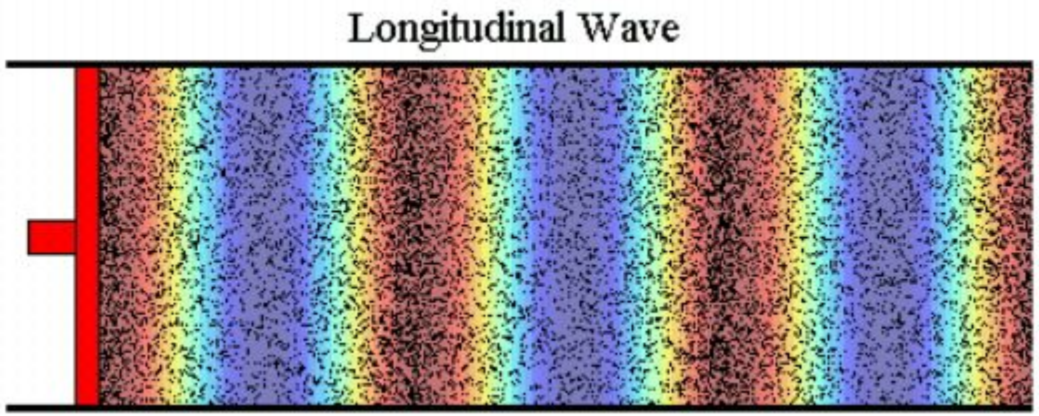
Fogg Lecture hall in Fogg Art Museum at Harvard University, USA established in 1895 turned out to be highly defective.

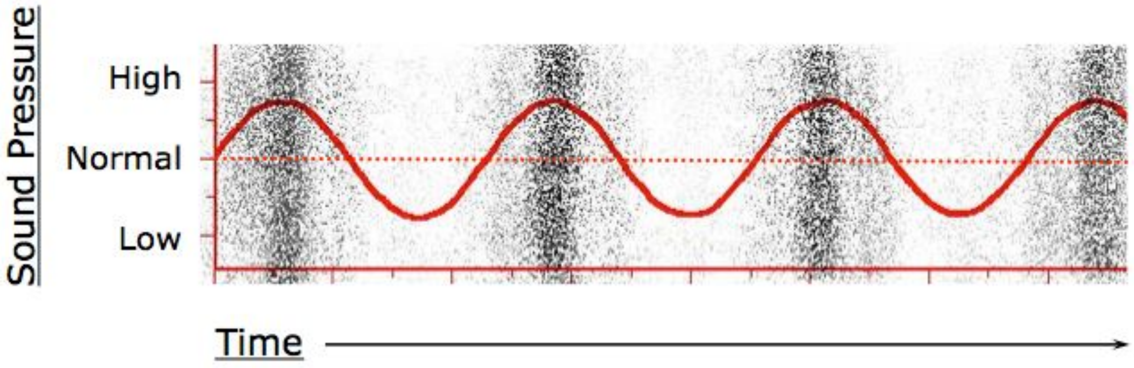
Prof. Wallace C. Sabine studied the problem through various experiments and obtained the conditions for satisfactory acoustic quality of a hall.

Prof. Sabine laid the foundations of acoustic engineering.

How is sound produced?

Sound is always produced by a vibrating body e.g Tuning fork





Properties of sound

- In air sound propagates in the form of series of compression and rarefactions.
- Sound waves can not travel in vacuum
- Mechanical, Longitudinal Waves
- The mean positions of vibrating particles do not change

Velocity of sound depends on the nature and temperature of medium

Gaseous medium

$$V = \sqrt{\frac{\beta}{\rho}}$$

β is bulk modulus, ρ is density

Bulk modulus : The measure of how incompressible / resistant to compression is the substance.

Speed of sound in air : 344 m/s for normal conditions

Pure water : 1480 m/s, soft wood: 3350 m/s, concrete: 3400 m/s

Mild steel : 5050 m/s, Glass : 5200 m/s

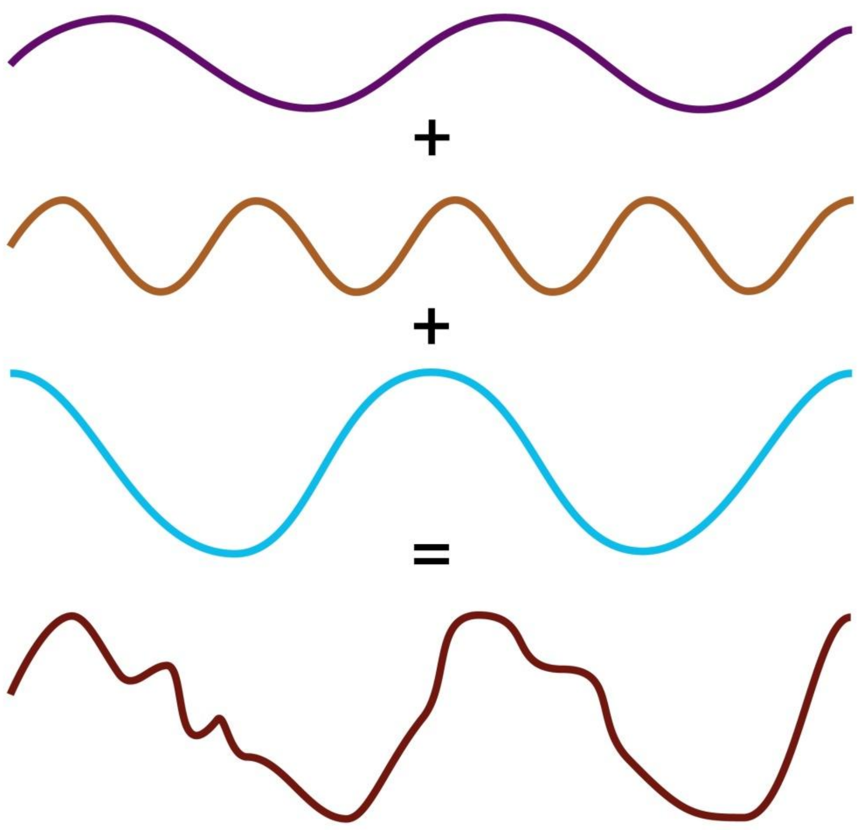
$$V = f\lambda$$

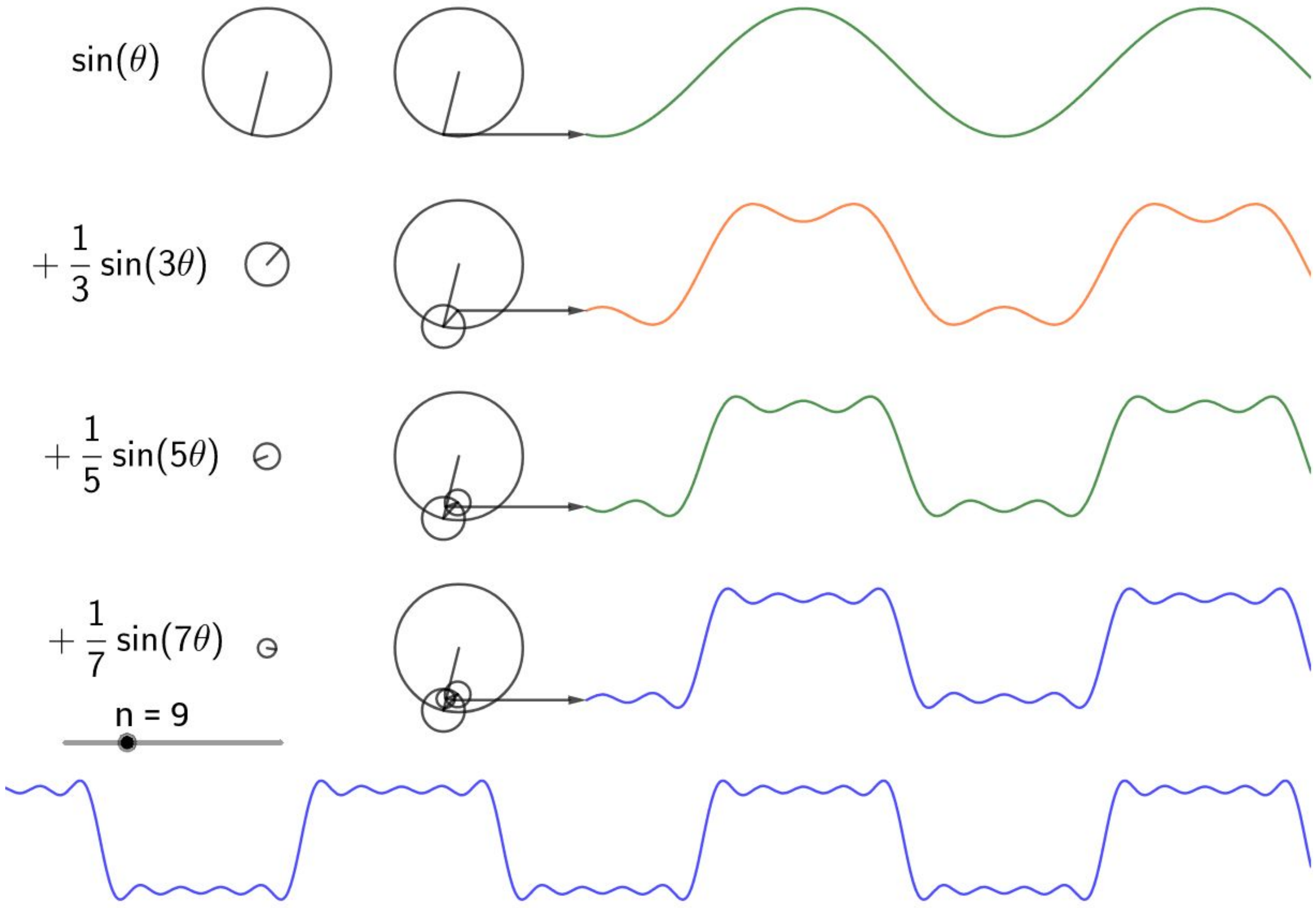
Classification of Sound

Sonic waves: 20 Hz to 20KHz (Audible range)
Infrasonic waves: Below 20 Hz
Ultrasonic waves: Above 20KHz

- A sound wave which has single well defined frequency is called a tone.
- Every sinusoidal sound wave is a pure tone.
- A musical note consists of of several tones. Lowest tones is called fundamental tone.
- Accompanying frequencies 2f, 3f, 4f are called over tones or harmonics.

Combination of tones (Fourier Transform)

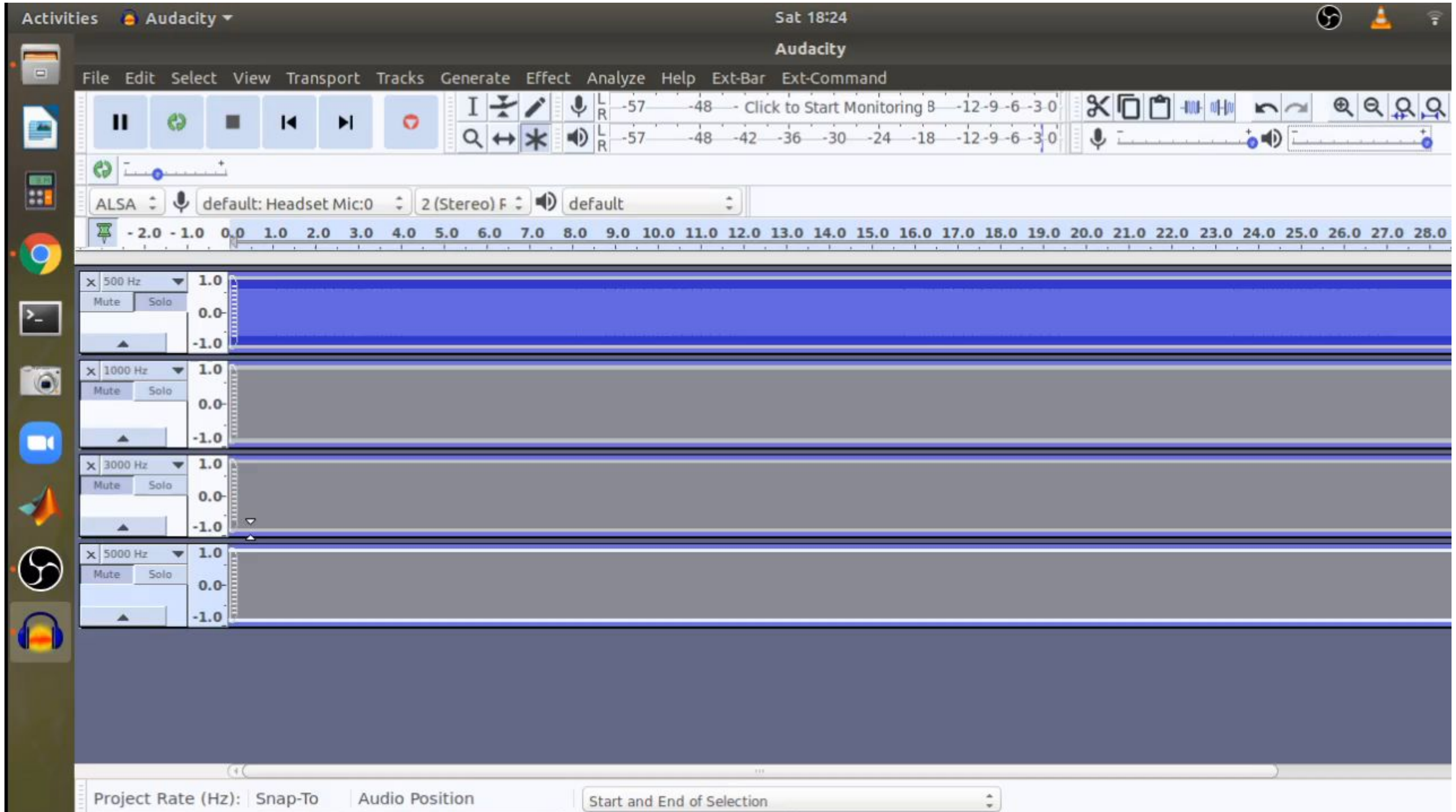




Characteristics of musical sound

Pitch

- Subjective sensation
- Greater frequency: higher pitch of a musical note.
- Its determined by the frequency, intensity and waveform.



Timbre (quality)

- Subjective sensation
- Enables us to distinguish between the same note played by different instruments or sung by different singers
- Presence of overtones (harmonics)
- Quality of a note depends upon the presence or absence of particular overtones and their relative intensities

Loudness

- It describes how loud is given sound
- Subjective perception, depends on intensity and frequency

Intensity

- Rate of flow of sound energy through a unit area normal to the direction of motion. Unit: W/m^2
- Intensity is proportional to Amplitude^2
- Lowest Intensity at 1 KHz to which human ear can respond :
  - $I_0 = 10^{-12}\ W/m^2$ (Threshold of hearing)

- Weber Fencher Law : The degree of sensation of sound is proportional to the logarithm of the stimulus producing the sound.
    - $L = k\,Log_{10}I$
- L is loudness, I is Intensity, k is proportionality constant
- k depends on sensitivity of ear, quality of sound
- Loudness is proportional to logarithm of intensity

- Instead of absolute intensity relative intensity is important
- Lowest Intensity at 1 KHz to which human ear can respond :
    - $I_0 = 10^{-12}\ W/m^2$ (Threshold of hearing)

Sound Intensity level (SIL)

The Logarithm of ratio of intensity of a sound to the threshold of hearing is defined as intensity level of sound

- $SIL = Log_{10}(I/I_0)$ Bel
- 1 Bel is defined as relative intensity between two sound notes if the intensity of one sound is 10 times more than other sound.
- Bel is a large unit. In practice we require a smaller unit.
- 1 deciBel = 1/10 Bel
- 1 Bel = 10 deciBel
- $SIL = 10\ Log_{10}\ I/I_0$ deciBel (dB)

- SIL for Threshold of hearing (I_0)

$SIL_{threshold} = 10\ Log_{10}\ I_0/I_0$ dB = 0 dB

- Loudest sound that can be heard without pain: Threshold of feeling or Pain threshold : 120 dB

Sound reflection

- Sound waves undergo reflection as well as diffraction when they encounter any obstacle.
- Reflection takes place when the size of the obstacle is large in comparison to wavelength of the sound wave, e.g. mountains, walls, ceiling

- Diffraction takes place when the size of the obstacle is small in comparison to wavelength of the sound wave, e.g. window door openings, uneven surfaces
- Diffraction tends to diffuse the sound uniformly

Reflection of sound results in two important effects

- Echo
- Reverberation

Echo

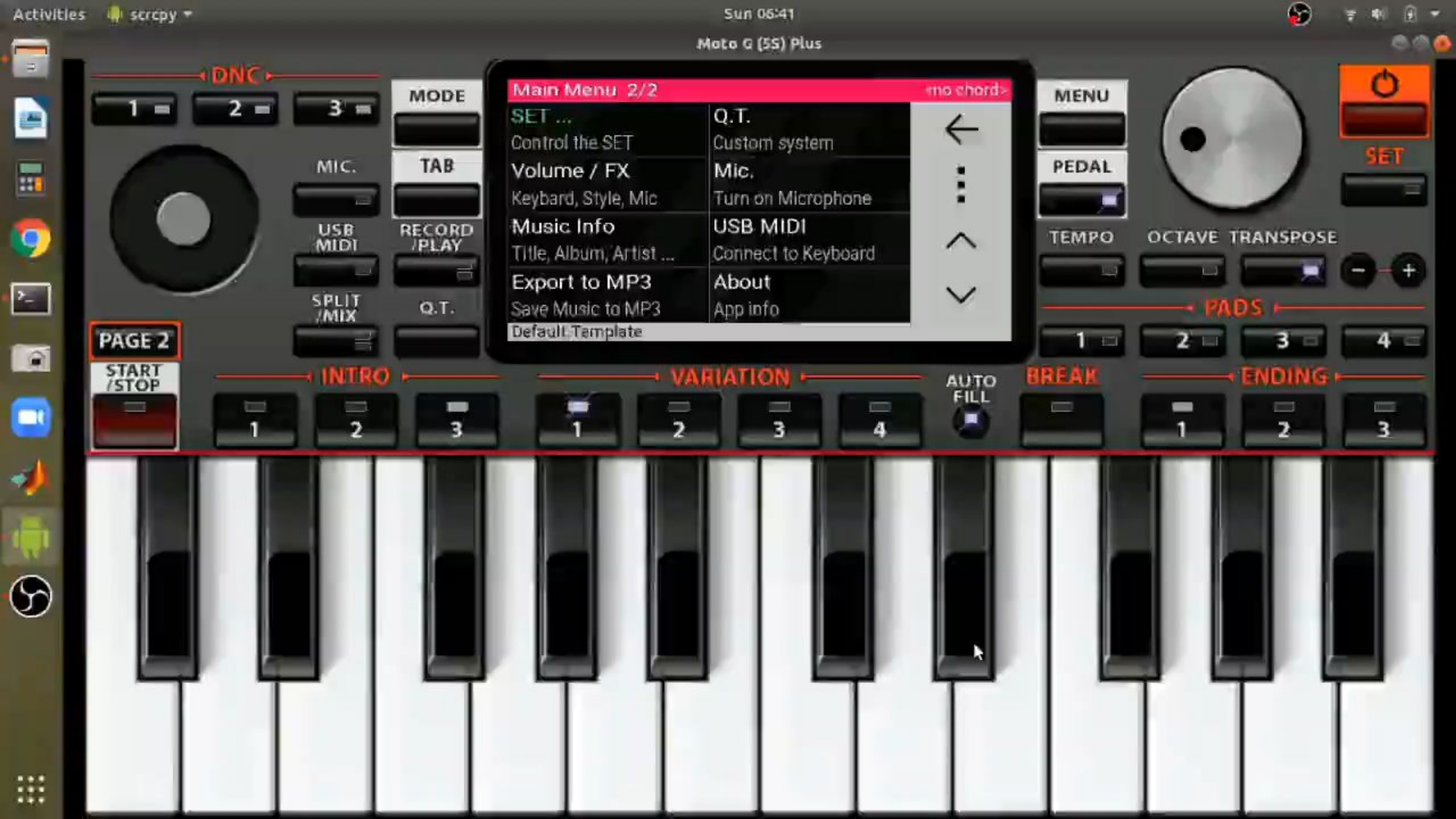
Echo is produced when reflection of sound from an obstacle reaches the ear after the sound from the source has been already heard

The sensation of sound persists for about 100 mili-second after the source has stopped producing the sound.

Conditions for echo

- The reflected sound should reach the ear 100 ms later than the direct sound
- The distance between the source and the obstacle should be 17 m or more.

- When sound is reflected from number of reflecting surfaces, multiple echoes will be heard. e.g. sound of thunder


Activities
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Moto G (5S) Plus
DNC
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USB MIDI
RECORD /PLAY
SPLIT /MIX
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START /STOP
Main Menu 2/2
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Control the SET
Q.T.
Custom system
Volume / FX
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Turn on Microphone
Music Info
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Save Music to MP3
About
App info
Default Template
MENU
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SET
TEMPO
OCTAVE
TRANSPOSE
PADS
INTRO
VARIATION
AUTO FILL
BREAK
ENDING

Reverberation

- Sound produced in enclosed space do not die out immediately after the source has stopped producing the sound

- In a hall the sound undergoes multiple reflections from walls, ceiling, floor before it becomes inaudible.

- A person in a hall continue to receive the successive reflections of progressively decreasing intensity.

- The successive reflection should reach the listener before 100 millisecond.

- This prolongation of sound before it decays to negligible intensity is called reverberation.

- Small amount of reverberation is desirable. It improves sound quality.


Activities
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Moto G (5S) Plus
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Title, Album, Artist ...
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Connect to Keyboard
Export to MP3
Save Music to MP3
About
App info
Default Template
MENU
PEDAL
SET
TEMPO
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VARIATION
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AUTO FILL
BREAK
ENDING
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Reverberation time

- It is defined as the time during which the sound energy density fall from its steady state value to its one millionth (10^{-6}) value when the source is shut off.

$$I_{final}/I_{initial} = 10^{-6}$$

- If initial sound intensity level is L_i and final sound intensity level is L_f

$$L_i = 10\ Log_{10}\ I_i/I_{0,} \quad L_f = 10\ Log_{10}\ I_f/I_0$$

$$L_i - L_f = 10\ Log_{10}\ I_i/I_f = 10\ Log_{10}\ 10^6 = 60\ dB$$

The reverberation time is the period of time in seconds, which is required for sound energy to diminish by 60dB after the sound is stopped

Sound absorption

- A sound incident on any surface of any medium splits into three part.

Reflection
Absorption
Transmission

- The properties by which the sound is converted in to other form of energy is called absorption

- Absorbed sound energy is converted into heat due to frictional resistance

- Fibrous and porous materials absorb more sound energy than solid materials

- Different surfaces absorb the sound by different amount

Absorption coefficient

$$\alpha = \frac{\text{(sound energy absorbed by the surface)}}{\text{(Total sound energy incident on the surface)}}$$

- Entire sound incident on an open window is transmitted
- Open window behaves as an ideal absorbent of sound
- A unit area of an open window is selected as standard for sound absorption
- Unit of absorption is made in reference to Open window unit (O.W.U). It is named **Sabin** after the scientist who established it.

- **1 m^2 Sabin** is the amount of sound absorbed by one square meter of fully open window.
- The value of α depends on the nature of the material as well as frequency of sound.
- The greater the frequency the large is the value of α for the same material
- In acoustic design it is common practice to use value of α at 500 Hz

- e.g. $\alpha = 0.5$ means that 50% of incident sound energy will be absorbed per unit area.

- If the material has the surface of S m^2, then total absorption provided by that material

$$a = \alpha S \quad \text{Sabins}$$

When there are different materials in a hall, then total sound absorbed

$$A = a_1 + a_2 + a_3 + \ldots$$

$$A = \alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \ldots$$

$$A = \sum_{i=1}^{n} \alpha_i S_i$$

α_1, α_2, ... are the absorption coefficients of materials with areas S_1, S_2, …

Sabine formula for reverberation time

Reverberation time depends on following factors.

- Reflecting properties of walls, floor, ceiling of the hall.
- Volume of the hall
- Absorption coefficient of various surfaces such as carpets, cushions, curtains
- Frequency of the sound

Reverberation time

$$T = 0.161\ V/A$$

Here V is volume in m^3 , A is total absorption of hall

$$T = 0.161\ V/\ (\alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \ldots)$$

- Sabine's formula works for large enclosures

- The value of reverberation time that is satisfactory for the purpose for which the hall is built is called optimum reverberation time.

- Optimum reverberation time for music or speech : 0.6 to 0.75 sec

- Optimum reverberation time for orchestra : 0.8 to 1 sec

- The reverberation time of a hall can be adjusted to a desired value by arranging the absorbent materials for various surfaces of the hall

Determination of absorption coefficient with the help of reverberation time

This method is based on measurement of reverberation times of room without any material and with materials under test.

If T_1 is the reverberation time of the empty room and A is total absorption

$$T_1 = 0.161\ V/A$$

Add certain amount of absorbing material of area S and absorption coefficient α.

If T_2 is the reverberation time of the room with materials then

$$T_2 = 0.161\ V/(A + \alpha\ S)$$

$$1/T_1 - 1/T_2 = (A + \alpha\ S - A)/(0.161\ V)$$

$$\alpha = (0.161\ V/S)\ (1/T_2 - 1/T_1)$$

(1) A hall has a volume of 1200 m^3. Its total absorption is equivalent to 480 m^2 of open window. Calculate reverberation time of the hall. What will be the effect on the reverberation time if audience fill the hall and thereby increase the absorption by another 480 m^2 of open window?

Solution:

Here $V = 1200\ m^3$

Total absorption of room is $A = 480\ m^2$

Sabine formula for reverberation time

$$T = 0.161\ V/A$$
$$= 0.161 \times 1200/\ 480$$
$$= 0.4025\ \text{sec}$$

When audience fill the hall

$$T = 0.161\ V/\ (A + A_{audience})$$
$$= 0.161 \times 1200/(\ 480 + 480\ )$$
$$= 0.20125\ \text{sec}$$

(2) A classroom has dimensions 20 x 15 x 5 m^3. The reverberation time is 3.5 sec. Calculate the total absorption of its surface and the average absorption constant.

Solution:

Here $V = 20 \times 15 \times 5\ m^3$

Reverberation time = 3.5 sec

Sabine formula for reverberation time

$$T = 0.161\ V/A$$

$$A = 0.161\ V/T$$

$$= (0.161 \times 20 \times 15 \times 5)\ /3.5$$

$$= 69\ m^2$$

Total Absorption of classroom can be written as

$$A = \alpha_{average}\ S$$

$$\alpha_{average} = A / S$$

$$= 69/(\ 2\ \ (20 \times 15 + 20 \times 5 + 15 \times 5))$$

$$\alpha_{average} = 69/950 = 0.0726$$

(3) The reverberation time is found to be 2 sec for an empty hall and it is found to be 1.5 sec when a curtain cloth of 20 m^2 is suspended at the center of the hall. If the dimensions of the hall are 10 x 8 x 6 m^3, calculate the coefficient of absorption of curtain cloth.

Solution.

$V = 10 \times 8 \times 6 = 480\ m^3$

Empty hall : $T_1 = 2$ sec

With curtain $T_2 = 1.5$ sec

area of curtain = a= 20 m^2

absorption coefficient of curtain = $\alpha = ?$

Sabine's formula

$$T = 0.161\ V/A$$

For empty hall

$$2 = 0.161\ (480)/A$$

$$A = 38.64\ m^2$$

With Curtain

$$T = 0.161\ V/(A + \alpha \times \text{area})$$

$$1.5 = 0.161\ (480)/(A + \alpha \times 2 \times 20)$$

$$\alpha = 0.322$$

(4) A hall has volume of 2265 m^3 and its total absorption is equivalent to 92.9 m^2. Calculate the reverberation time of the empty hall. How many persons should be seated in the hall so that the reverberation time becomes 2 seconds? Given that the absorption of one person is equivalent to 0.186 m^2 of the open window.

Solution.

Volume of the Hall V = 2265 m^3

Absorption of empty hall = 92.9 m^2

Reverberation time of empty hall T_1 = ?

Absorption of a person A_{person} = 0.186 m^2

Reverberation time of hall with audience T_2 = 2 sec

Number of person: n = ?

Sabine's formula (For Empty hall)

$$T_1 = 0.161\ V/A$$
$$= 0.161 \times 2265 / 92.9$$
$$= 3.92\ \text{sec}$$

In presence of Audience

$$T_2 = 0.161\ V / (A + n \times A_{person})$$

$$2 = 0.161 \times 2265 / (92.9 + n \times 0.186)$$

$$(92.9 + n \times 0.186) = 0.161 \times 2265 / 2$$

$$n \times 0.186 = 0.161 \times 2265 / 2 - 92.9$$

$$n \times 0.186 = 89.4$$

$$n = 89.4 / 0.186$$

$$n = 481 \text{ persons}$$

Conditions for right acoustical quality of Lecture hall, Auditorium

- The initial sound from the source of sound should be adequate intensity
- The sound should be evenly spaced over whole area covered by the audience
- The successive sounds in the speech or music should be clear and distinct
- Tonal quality of the music should not change
- All undesired sounds should be reduced to the extent that it will not interfere with the normal hearing or speech

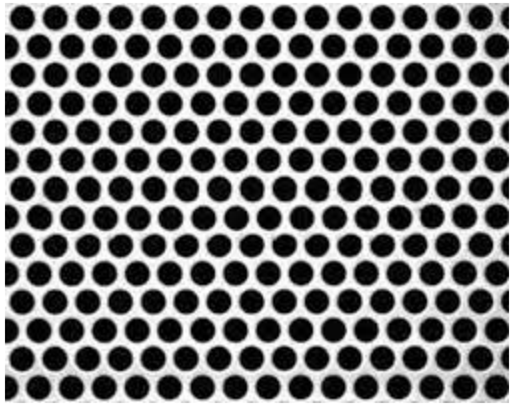
Factors affecting acoustics of building and their remedies

- **Reverberation**

- The reverberation time should be neither too short or too long.
- A short reverberation time makes a room dead.
- A long reverberation time renders speech unintelligible

- Acceptable reverberation time for speech or lectures is 0.6 sec
- Acceptable reverberation time for music concerts is 1-2 sec
- Optimum reverberation time for small theaters : 1.1 – 1.5 sec
- Optimum reverberation time for large theaters can go up to 2.3 sec

- Reverberation time can be controlled by suitable choice of building materials and furnishing materials
- If the reverberation time of a hall is too long it can be decreased by increasing absorption or reducing volume of the hall.
- If the reverberation time of a hall is too short it can be increased by decreasing absorption (replacing high absorbing materials by materials with low absorption) or increasing volume of the hall.
- There should be limited number of windows. They can be opened or closed to obtain the optimum reverberation time.



- Cardboard sheets, perforated sheets, heavy curtains, thick carpets are used to increase surface absorption
- Audience also contribute to the absorption of sound. The absorption coefficient of an individual is 0.45
- In order to compensate for increase or decrease in the audience strength, upholstered seats having the same absorption as an individual is to be provided in the hall.

Raj Auditorium at MIT - ADT University

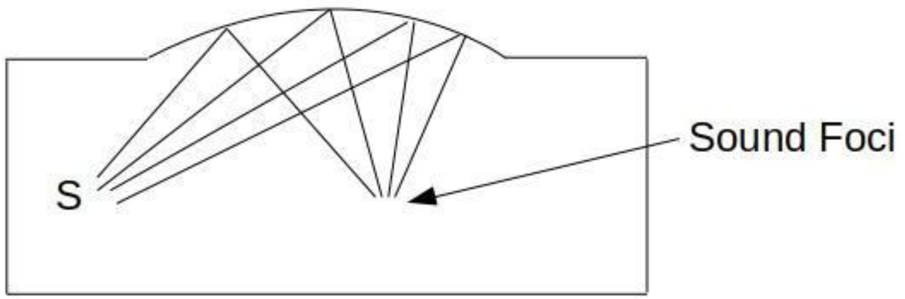
Factors affecting acoustics of building and their remedies

Loudness

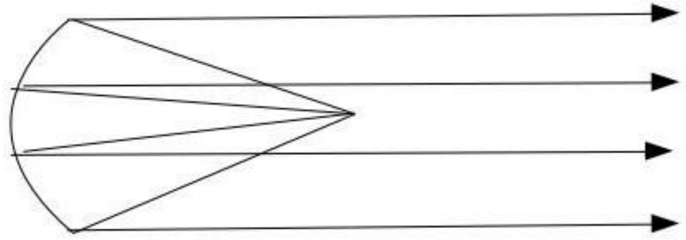
- Sufficient loudness at every point in the hall is required
- A high reflecting surface such as polished wood near the sound source improve loudness.
- Low ceiling is also helpful in reflecting the sound energy towards the audience.
- In large hall sufficient numbers of loud speakers are required to be installed

Factors affecting acoustics of building and their remedies

- **Focusing**



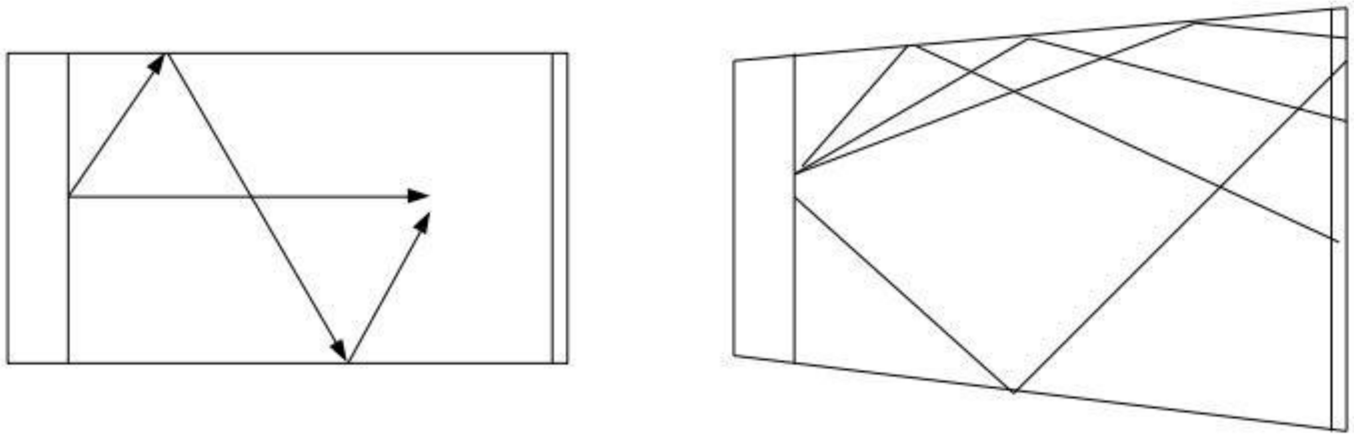
- Reflecting surfaces cause concentration of reflected sound creating sound of larger intensity at focal points. These points are called sound foci.
- This leads to deficiency of reflected sound at other points. These points are called dead spots.
- Sound foci and dead spots may be eliminated by avoiding curvilinear interiors or by covering them by highly absorptive materials.
- A parabolic reflecting surface arranged with speaker at its focus is helpful in directing a uniform beam of sound in the hall.



Factors affecting acoustics of building and their remedies

Echo

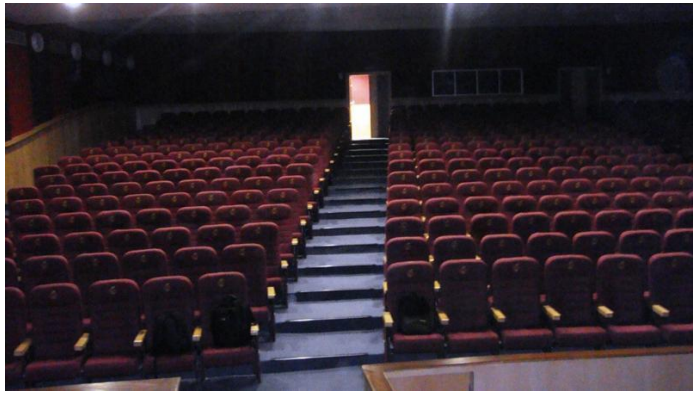
- When the walls of the hall are parallel, hard and separated by about 17m echoes will be heard.
- Curved surface of walls also produce echoes
- Use of splayed side walls instead of parallel walls greatly reduces the problem and enhances acoustical qualities.

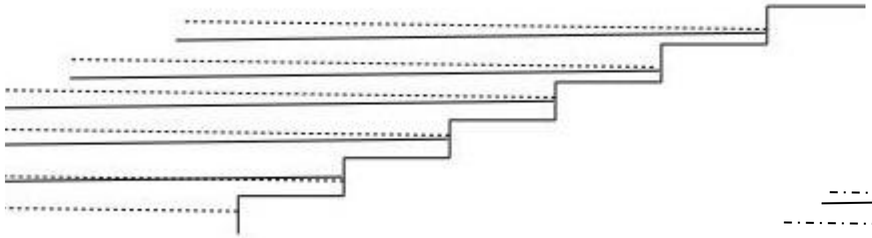


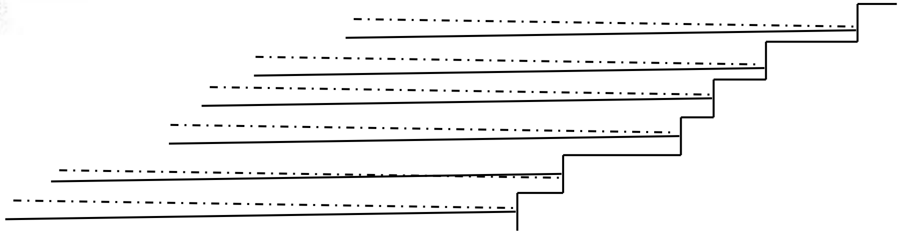
- Echoes can be avoided by covering the opposite walls and ceiling with absorptive materials.

Factors affecting acoustics of building and their remedies

• Echelon effect







- If a hall has flight of steps with equal width the sound waves reflected will have echoes with regular phase difference.
- These echoes will combine to produce a musical note which will be heard along with the original sound. This is called echelon effect
- It makes original sound unintelligible
- Echelon effect can be avoided by having steps of unequal width.
- The steps can be covered with sound absorbing material such as carpet

- **Factors affecting acoustics of building and their remedies**

Resonance

- Sound waves can set up vibration in the window pane, walls, enclosed air. (Forced vibrations)
- The vibrating object in turn produces their own sound
- If the frequency of forced vibrations matches with some frequency of the sound produced then resonance can take place
- Certain tones of the original music may get reinforced and will result in distortion of the original sound
- The vibrating body should be suitably damped to eliminate resonance effect
- For larger hall the resonance frequencies are quite low. Hence resonance effect can be eliminated

- **Factors affecting acoustics of building and their remedies**

Noise

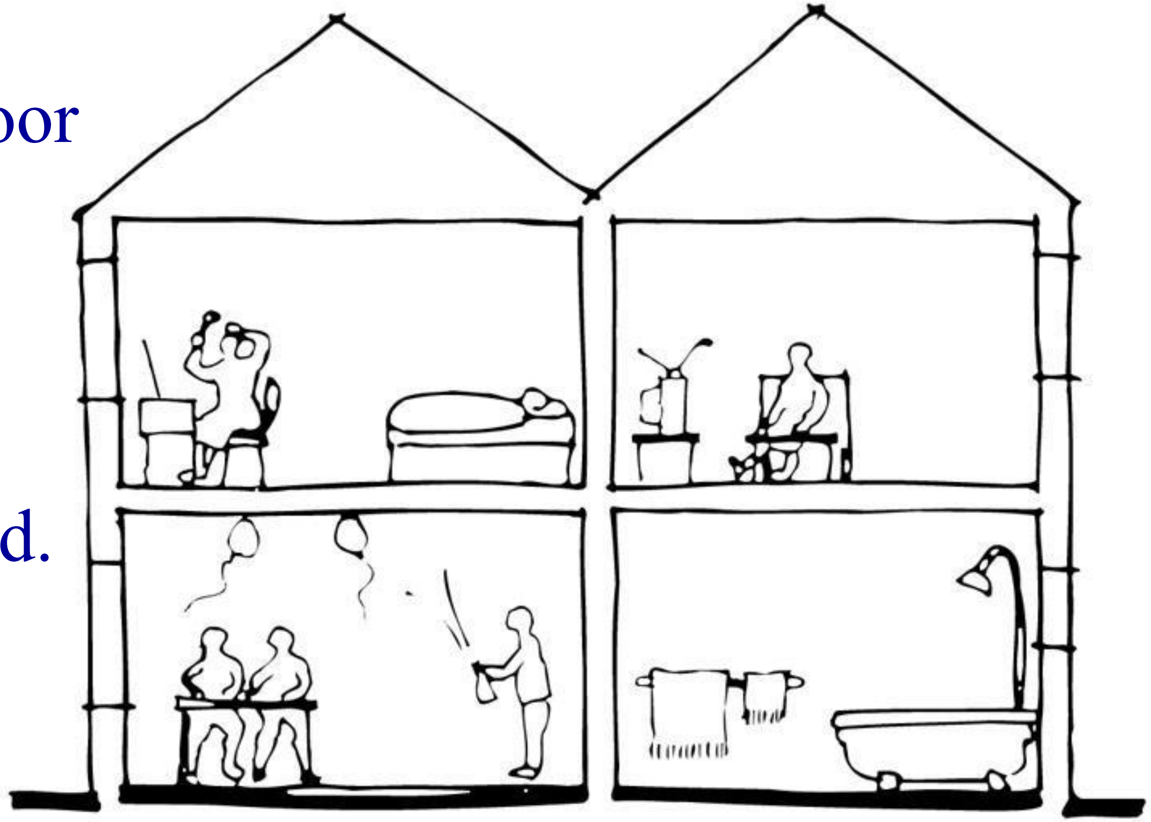
- It is unwanted sound which masks the satisfactory hearing of speech or music

- Types of noise

a) Internal noise
b) Air borne noise
c) Structure borne noise

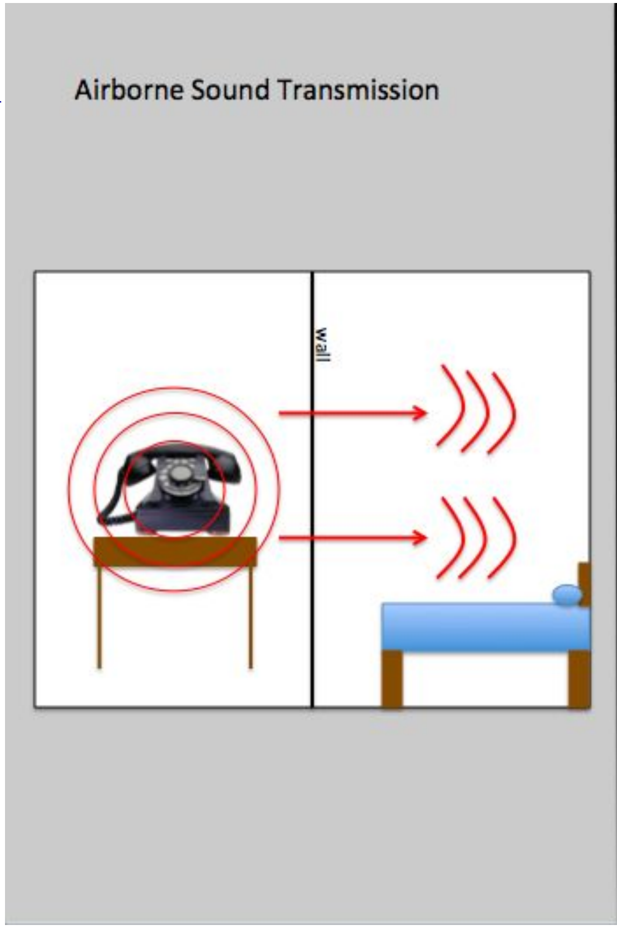
Internal noise

- Internal noise is the noise present in the hall, office, auditorium. They may be produced air conditioners, movement of peoples, operation of machines.
- It can be reduced by adding sound absorbing materials on walls, ceiling, floor
- The noise making gadgets or machines should be placed on sound absorbing materials.
- Split type air conditioners should be used.



Air borne noise

- The noise that comes into the building through air from distant sources is called air borne noise e.g. Noise from Traffic, Trains, Planes
- A part of the air borne noise enters the hall directly through open windows, doors and other openings while other part enters by transmission through the walls and floors.
- Absorptive material can only minimize reflection. They can not decrease transmission of sound.
- The building may be located away from heavy traffic, railway station, airport.
- These type of noise can be reduced by interposing a buffer zone of trees, gardens.



Structure borne noise

- The noise which come from impact sources on structural extents of the building is known as structure borne noise
- It is transmitted by vibrations in the structure.
- Common sources: Foot steps of people, movement of furniture, operation of machinery and domestic appliances
- Remedies: Noise due to machinery and domestic appliance can be overcome by placing vibration oscillators between machines and their supports.
- Cavity walls, compound walls may be used to increase the noise transmission loss