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Architectural Acoustics

Lecture 26: Electro-Acoustics - I

Dr. Shankha Pratim Bhattacharya

Department of Architecture & Regional Planning

Learning Objective

Discuss the various component of electro-acoustics

Relate the fundamentals of electro-acoustical parameters to design

Definition

A **sound reinforcement** system is an **electro-mechanical system** that makes **live or pre-recorded sounds** louder and may also **distribute** those sounds to a larger or more distant audience.

Objectives

To **reinforce** the sound, which would otherwise be inadequate.

To provide **adequate** loudness and intelligibility.

To **reproduce** the sound, which was recorded earlier

Requirement

Travel to the audience at larger distance

Adequacy of sound level

Uniform sound level

No distorted frequency of sound

Durability and economy

Basic Components

Low Level Acoustic Energy

Input Transducer

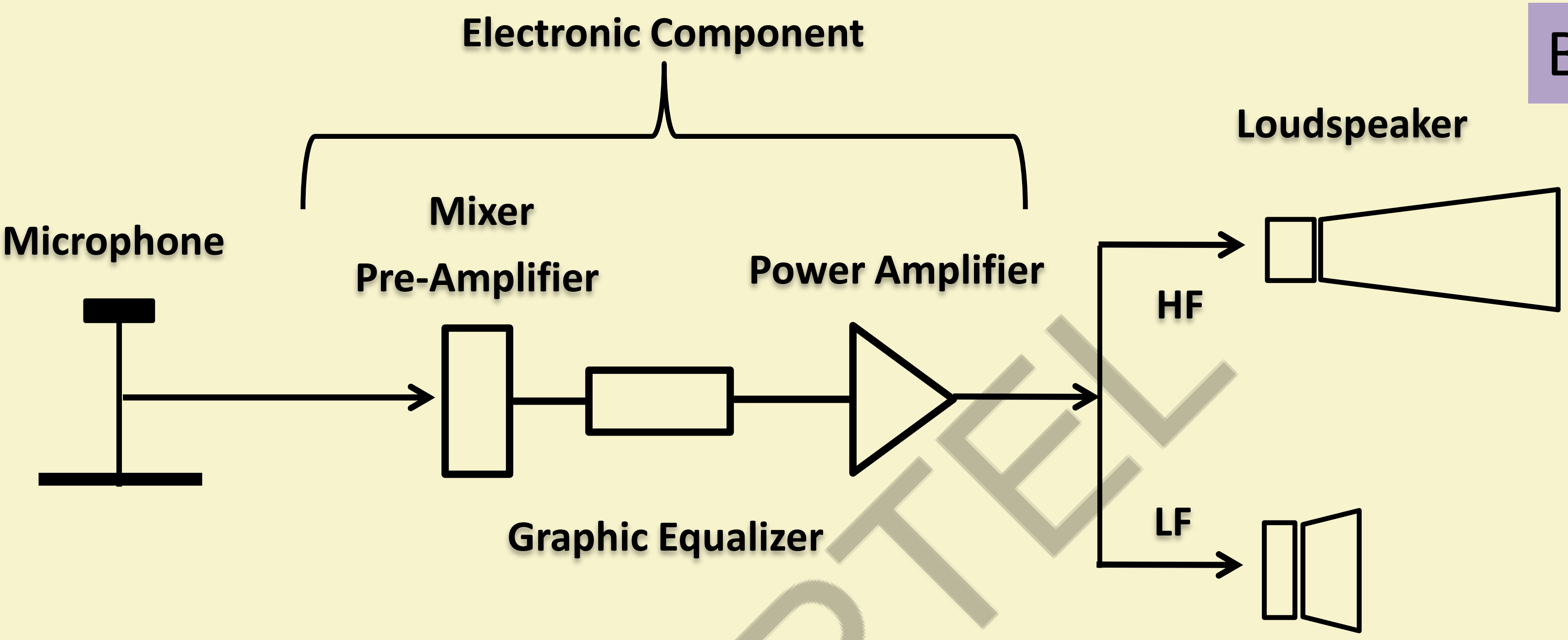
Signal Processing

High Level Acoustic Energy

Output Transducer

Microphone ⇨ Pre-Amplifier / Mixer ⇨ Power Amplifier / Graphic Equalizer ⇨ Loudspeaker

Basic Components



Convert Sound Energy to electrical energy

Increase the magnitude of electrical signal
Distribute electrical energy to HF and LF loudspeakers at proper level and character

Convert the electrical energy to airborne sound energy

Microphone

Microphone is an instrument that convert sound waves (such as speech or music) into electrical energy variations which may then be amplified, transmitted, or recorded.

Shape and Use	Directivity
Handheld Microphone	Omnidirectional
Shotgun Microphone	Bidirectional
Ribbon Microphone	Unidirectional
Condenser Microphone	
Dynamic Microphone	

Handheld Microphone

Entertainment / Reporter

Shotgun Microphone

extremely directional pickup pattern
popular for TV news and movie sets.

Photo source: https://ehomerecordingstudio.com

Ribbon Microphone

Speech, announcement, radio station

Condenser Microphone

Capture vocal or musical sound

Dynamic Microphone

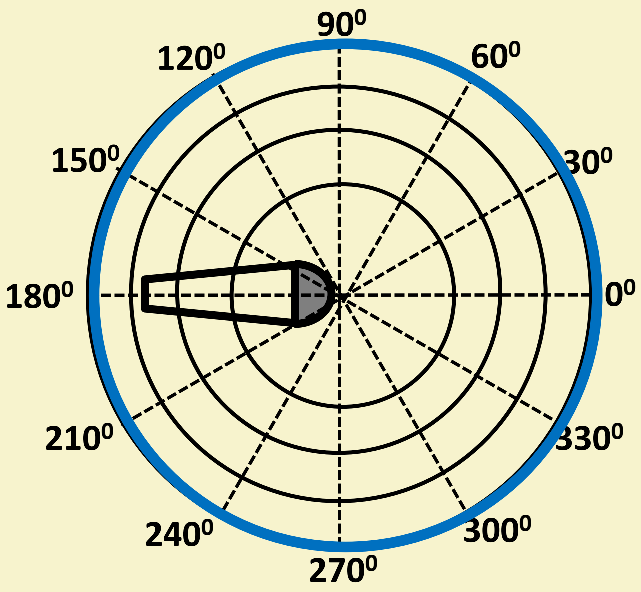
Mostly musical instruments like guitar drum etc

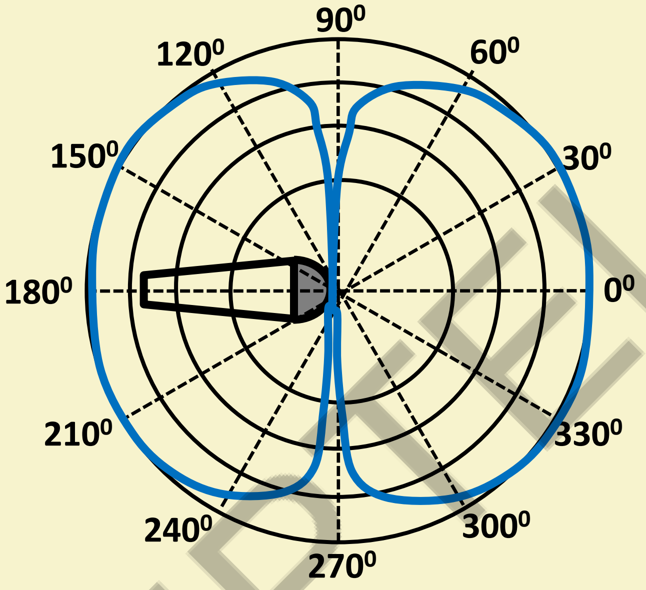
Photo source: https://ehomerecordingstudio.com

Omnidirectional

This type of microphone captures sound from all directions at once.

Types of Microphone



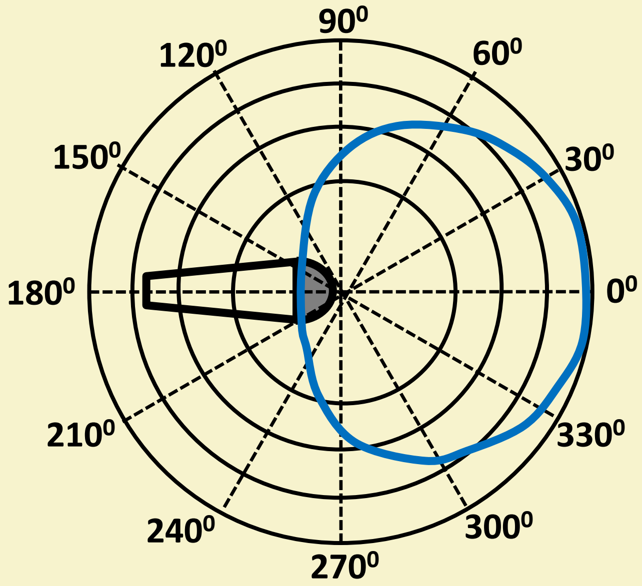


Bidirectional

This type of microphone captures sound from the front and back.

Unidirectional

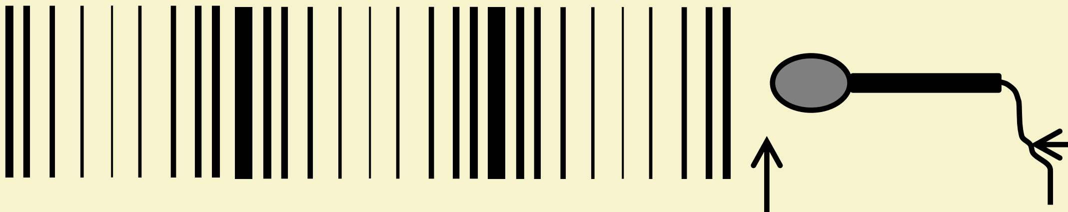
This type of microphone captures sound from the front only.



Microphone sensitivity is typical measurement of acoustical pressure conversion into electrical energy.

The microphone sensitivity is based on a 1 kHz frequency at 94 dB SPL or 1 Pascal (Pa) pressure conversion to milli-volts (mV) unit of electrical signal.

Microphone Sensitivity



Electrical Signal Output in mV

Sound Input: 1kHz, 94 dB = 1 Pa

$$20\log\frac{P}{P_{ref}} = 94dB \Rightarrow \frac{P}{P_{ref}} = 10^{\frac{94}{20}} = 10^{4.7}$$

$$\Downarrow$$

$$\frac{P}{P_{ref}} = P_{ref}\times 10^{4.7} = 2\times 10^{-5}\times 10^{4.7} = 1.002\text{Pa}$$

Pre-Amplifier

Mixer

Pre-amplifier amplifies low-level Signals

It also combines and select the signals as required (Mixer)

Pre-amplifier minimise the noise that may present in the signal

A pre-amplifier processes a signal to make it fit for the next stage in the signal chain.

Pre-Amplifier
Mixer
⇨
Power Amplifier
Graphic Equalizer

A **Power Amplifier** is an electronic device that can **increase the power** of a signal by increase the amplitude of a signal

A **Graphic Equalizer** is a high order **audio control** unit that control a number of different **frequency bands** at a specific audio range.

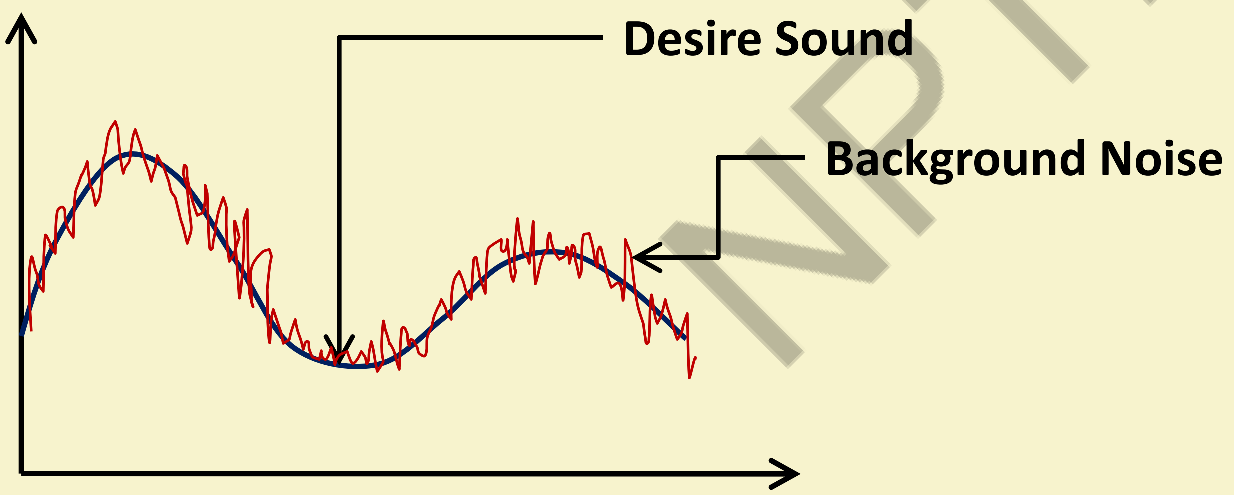
SNR

Signal-to-Noise Ratio (SNR or S/R)

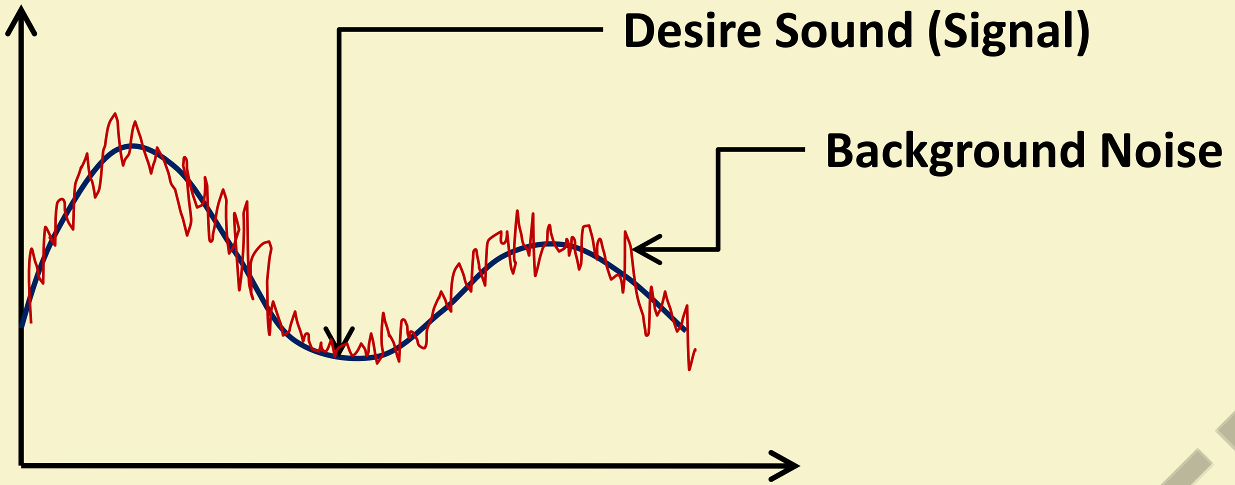
Signal – to – Noise Ratio is defined as the ratio of signal power to the noise power.

The ratio is usually measured in decibels (dB) using a signal-to-noise ratio formula.

It compares the level of a desired sound signal to the background noise level.



SNR



Sound Power	Sound Amplitude
W_{Signal}	A_{Signal}
W_{Noise}	A_{Noise}

$$SNR_P = \frac{W_{Signal}}{W_{Noise}} = \left(\frac{A_{Signal}}{A_{Noise}}\right)^2$$

$SNR_P = 1$ ……….. $SNR_{dB} = 0$

$SNR_P = 100$ ……….. $SNR_{dB} = 20$

$$SNR_{dB} = 10\log\left(\frac{W_{Signal}}{W_{Noise}}\right) = 20\log\left(\frac{A_{Signal}}{A_{Noise}}\right)$$

Loudspeaker is an equipment that converts **electrical input signals/ impulses into sound**. The term "loudspeaker" may refer to individual transducers, which are popularly known as **"drivers"** or to complete speaker systems consisting of an enclosure containing one or more drivers.

Use of Loudspeaker

Aural Communication :

Used for communicating sound to large audience

Sound Reinforcement :

Produce sufficient loud sound to all parts of the auditorium

Sound Production :

Various live performance, it supplement some part of musical playbacks

Sound Reproduction :

Recorded sound reproduced for some identified events

Type of Loudspeaker

Frequency Range	Shape
Woofer	Horn Loudspeaker
Mid-range Speaker	Cabinet Loudspeaker
Tweeter	Column Loudspeaker
Full-range driver	

Woofer

A **Woofer** is a loudspeaker unit designed to produce extremely **low-frequency bass sounds**.

It mainly covers the frequency range from **20 to 200 Hz**.

Woofers are also further classified as Pre-woofer, Woofer and Subwoofer

Mid-range Speaker

A **Mid-range speaker** reproduces sound in the **middle level frequency zones**.

It generally covers the frequency range from **250 to 2000 Hz.**

It is also known as a squawker.

Tweeter

A **Tweeter** is designed to produce **high frequency sound**.

It typically covers the frequency range from **2000 to 20,000 Hz**.

Full-range driver

A **full-range driver** is a combination of array of speakers designed to reproduce the sound covering and the **entire audio frequency range**.

Full-range driver is mostly adopted in column loudspeaker.

Type of Loudspeaker

Horn Loudspeaker

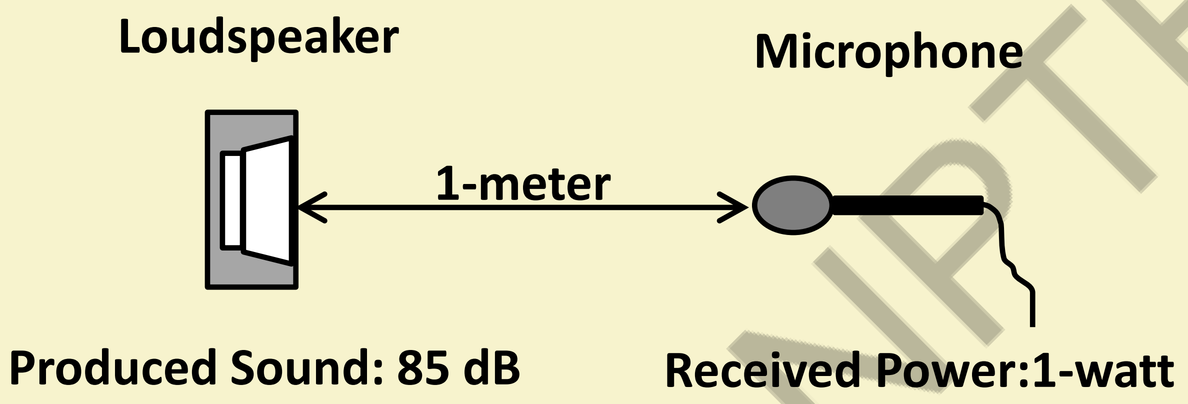
Cabinet Loudspeaker

Column Loudspeaker

Photo source: https://www.toa.jp and http://www.yamahaproaudio.com

It defines the loudspeaker's ability to effectively convert the electrical power to sound.

Traditionally speaker's sensitivity measures in a standard of 1 watt / 1 meter.



Loudspeaker Sensitivity = 85 dB

Directivity

In a loudspeaker system, the **directivity** is an indicator of how **effective** the speaker is at taking the sound it produces and sending it in one **particular direction**.

A loudspeaker that is a **high directivity** device is commonly called a **"long throw"** device.

A speaker with **low directivity** is a **"short throw"** device.

A **"short throw"** speaker system is used to cover the areas **nearer to the loudspeaker**

A **"long throw“** speaker system is used to cover the areas **furthest away from the loudspeaker.**

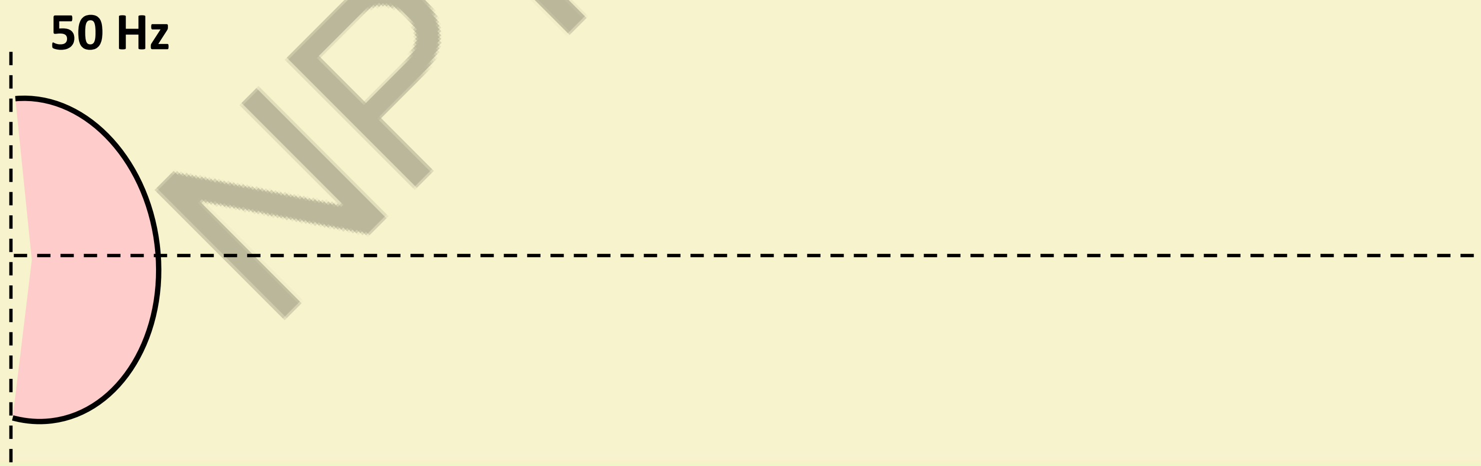
Directivity

The wave length of the sound varies within a wide range, usually 1cm to 18m.

So, the similar directivity or throw for all frequencies is not possible.

Bass frequencies (low frequency) have very **long wavelengths** and it is having **short throw**

The **High frequency** sound have **Short wavelength** and **long throw**



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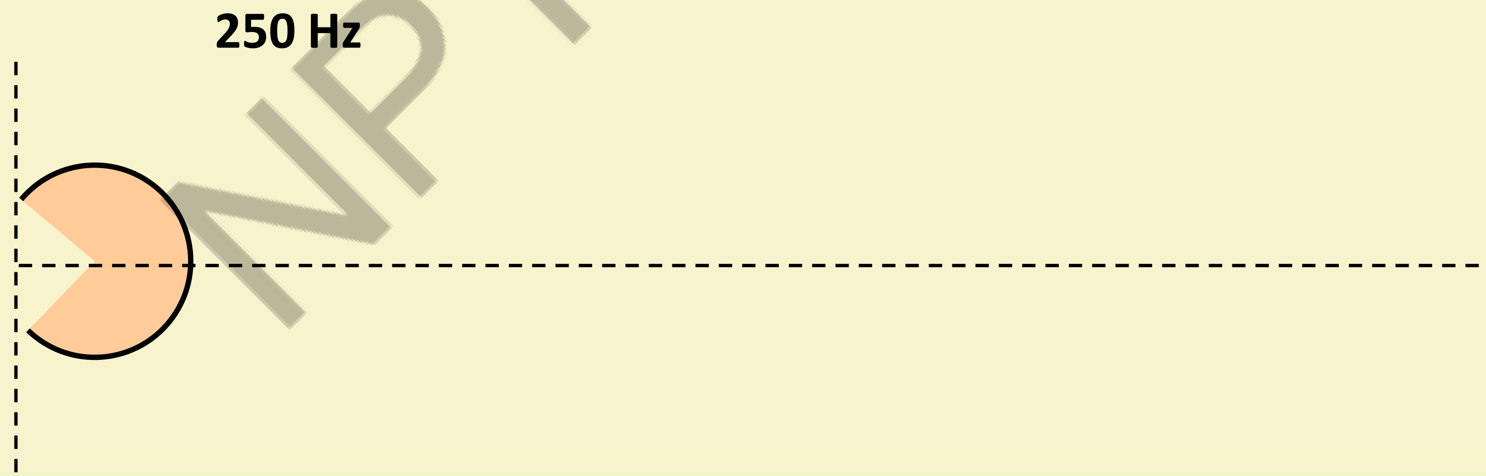

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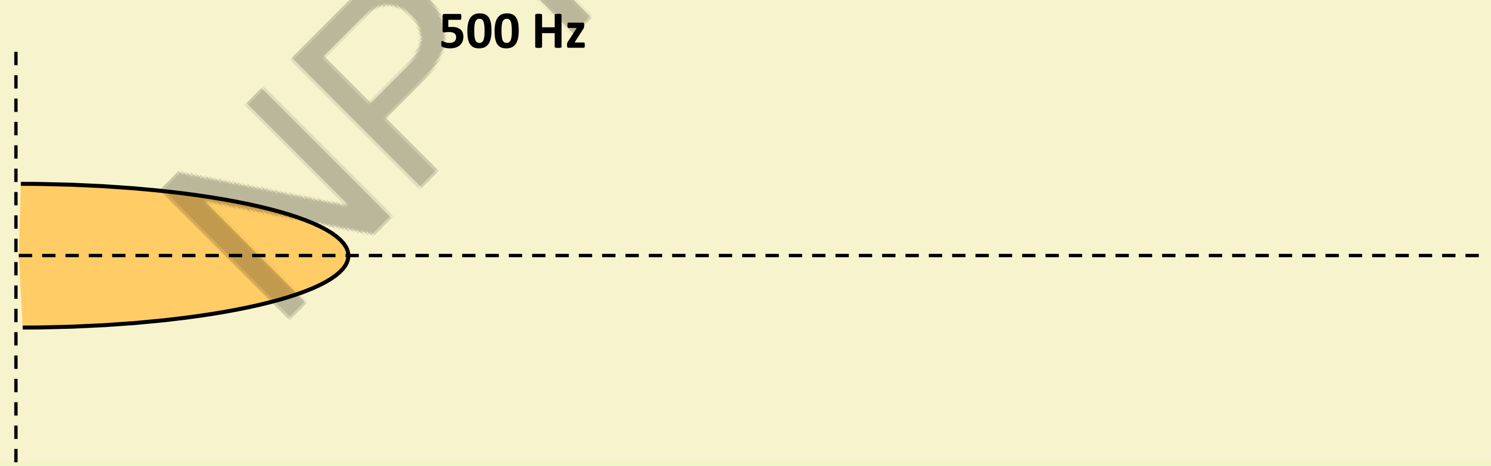

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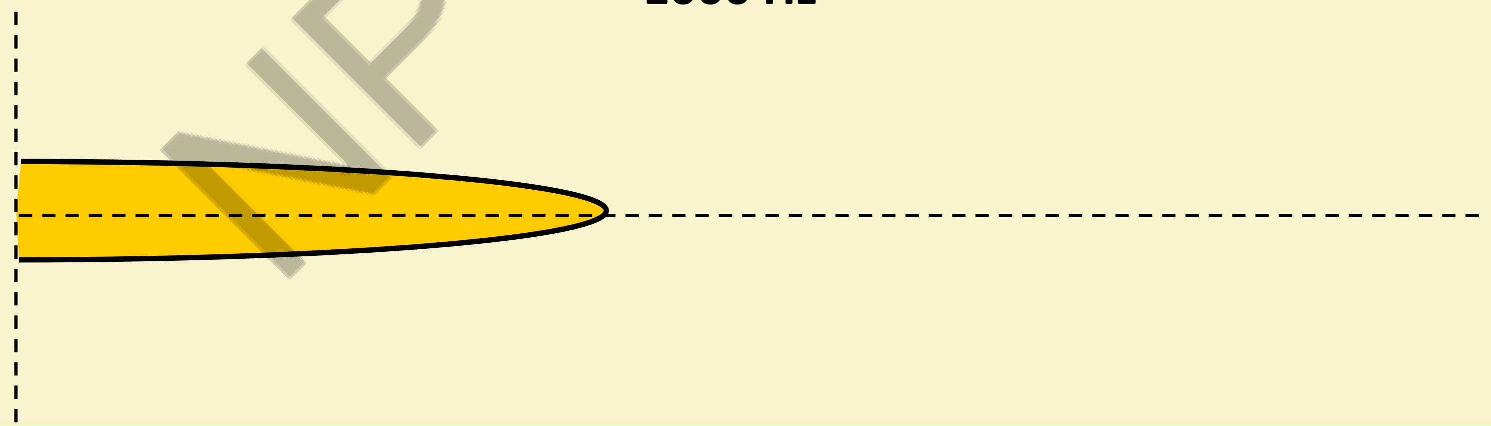

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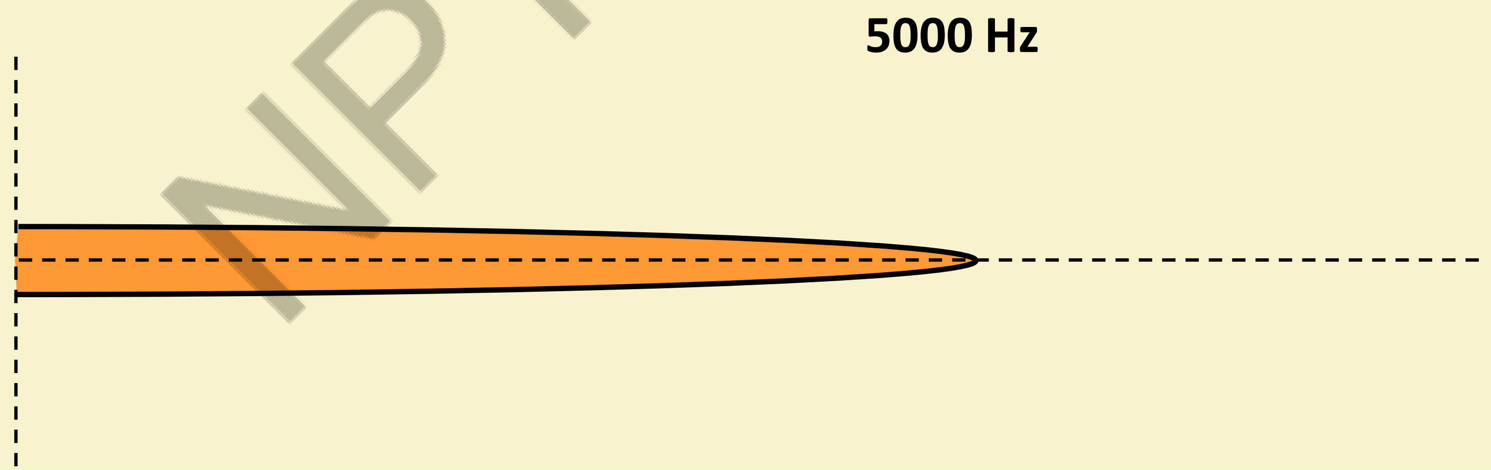


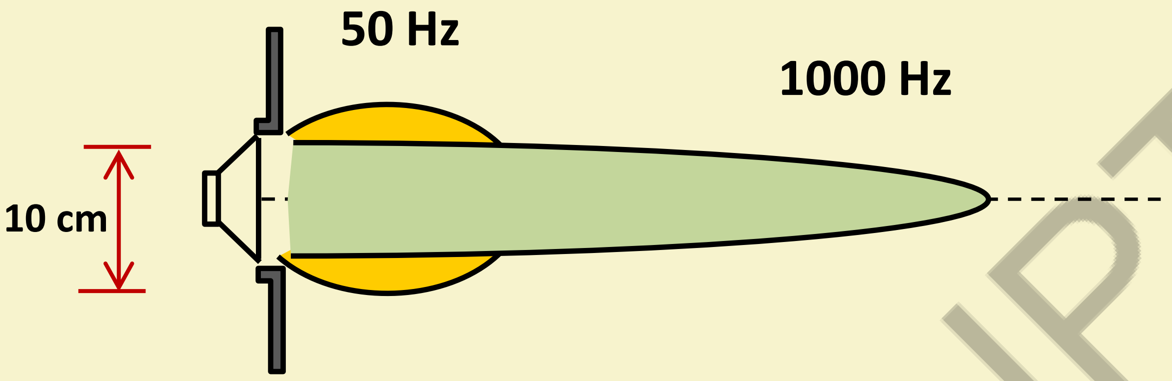
Directivity

$$\text{Dimensionless Number} = \frac{\text{Speaker Circumference}}{\text{Wavelength}} = \frac{\pi D}{\lambda}$$

c= 330 m/s

Wavelength (50Hz) = 660cm

Wavelength (1000Hz) = 33cm



$$\text{Dimensionless Number} = \frac{\pi D}{\lambda} = \frac{3.14 \times 10}{660} = 0.05$$

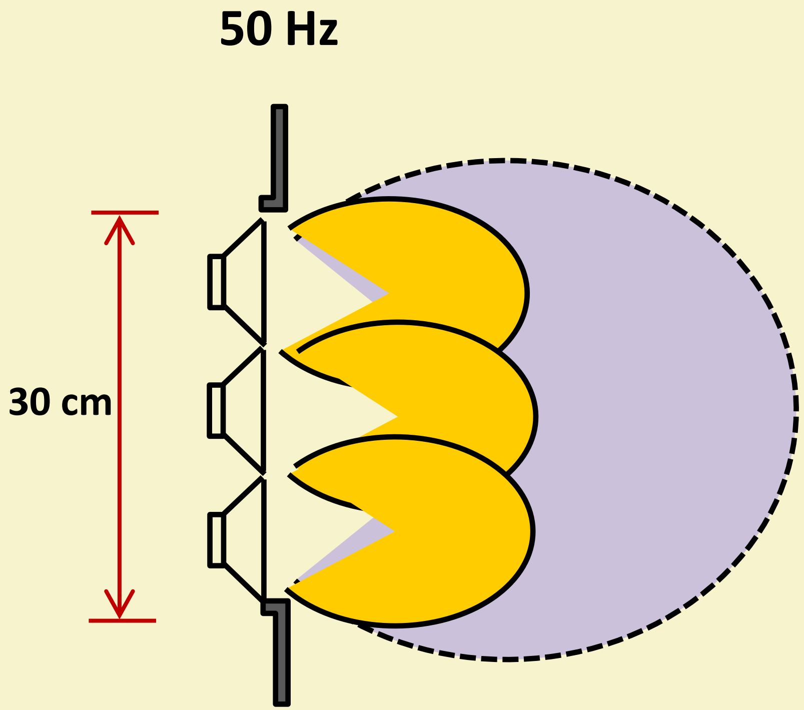
$$\text{Dimensionless Number} = \frac{\pi D}{\lambda} = \frac{3.14 \times 10}{33} = 0.95$$

Directivity

c= 330 m/s

$$\text{Dimensionless Number} = \frac{\text{Speaker Circumference}}{\text{Wavelength}} = \frac{\pi D}{\lambda}$$

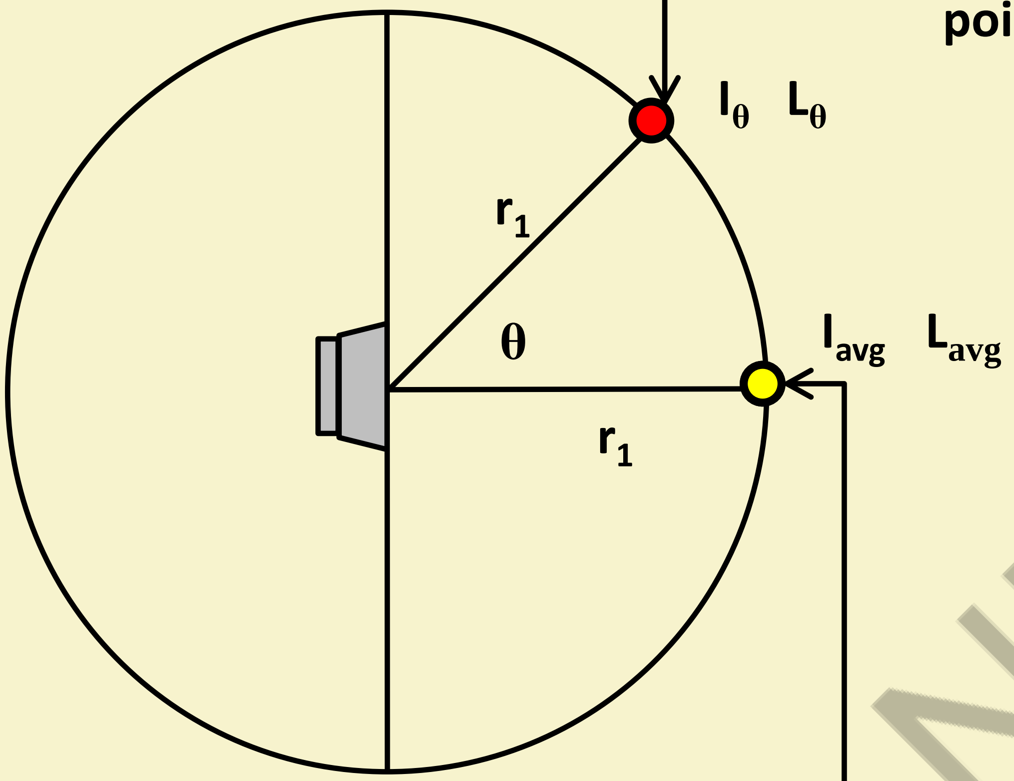
Wavelength (50Hz) = 660cm



$$\text{Dimensionless Number} = \frac{\pi D}{\lambda} = \frac{3.14 \times 10}{660} = 0.05$$

$$\text{Dimensionless Number} = \frac{\pi D}{\lambda} = \frac{3.14 \times 30}{660} = 0.14$$

Directivity Factor



I_θ = Intensity of Sound at the specific point of interest at radius r_1

By definition, Directivity Factor (Q) is represented by:

$$\boxed{Q_\theta = \left.\frac{I_\theta}{I_{avg}}\right|_{r_1}}$$

I_{avg} = Average Intensity of Sound over a spherical radius r_1

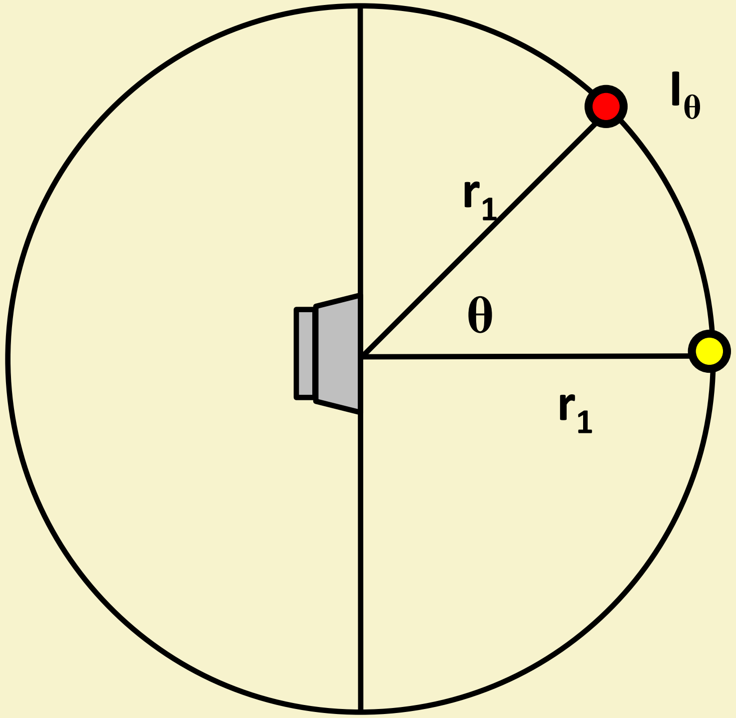
As, Directivity Factor is $Q_\theta = \left.\dfrac{I_\theta}{I_{avg}}\right|_{r_1}$

Expanding and replacing $\mathbf{I_\theta}$ & $\mathbf{I_{avg}}$

$$\left.\begin{array}{l} L_\theta = 10\log\dfrac{I_\theta}{I_{ref}} \Rightarrow I_\theta = I_{ref} \times 10^{\left(\frac{L_\theta}{10}\right)} \\ L_{avg} = 10\log\dfrac{I_{avg}}{I_{ref}} \Rightarrow I_{avg} = I_{ref} \times 10^{\left(\frac{L_{avg}}{10}\right)} \end{array}\right\} Q_\theta = \frac{I_\theta}{I_{avg}} = \frac{10^{\left(\frac{L_\theta}{10}\right)}}{10^{\left(\frac{L_{avg}}{10}\right)}} = 10^{\left(\frac{L_\theta - L_{avg}}{10}\right)}$$

Directivity Factor expressed in terms of SIL $\boxed{Q_\theta = 10^{\left(\frac{L_\theta - L_{avg}}{10}\right)}}$

Directivity Index



By definition, Directivity Index (DI) is represented by:

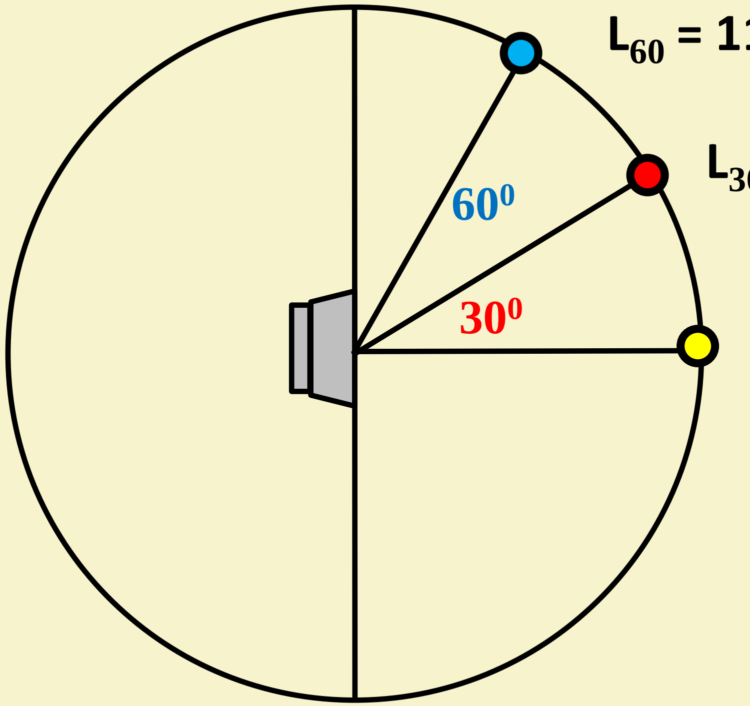
$$\boxed{\mathrm{DI}_\theta = 10\log\left(\mathrm{Q}_\theta\right)}$$

$$\mathrm{DI}_\theta = 10\log\left(\mathrm{Q}_\theta\right) = 10\log\left[10^{\left(\frac{L_\theta - L_{avg}}{10}\right)}\right] = 10\times\left(\frac{L_\theta - L_{avg}}{10}\right)\log 10 = \left(L_\theta - L_{avg}\right)$$

Directivity Index expressed in terms of SIL

$$\boxed{\mathrm{DI}_\theta = \left(L_\theta - L_{avg}\right)}$$

Polar Plot



L_{60} = 110 dB DI_{60} = -10dB

L_{30} = 116 dB DI_{30} = -4dB

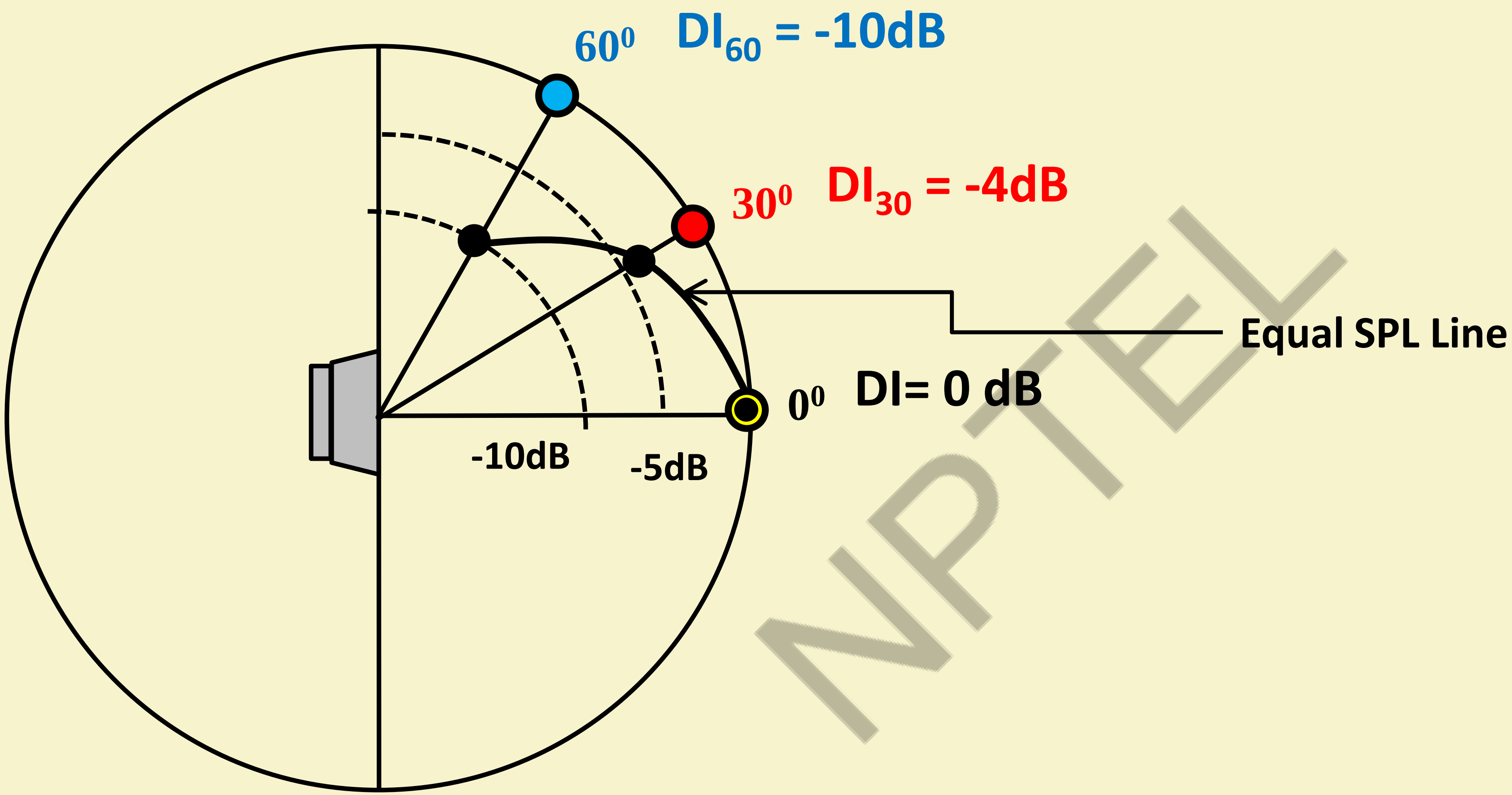
L_{avg} = 120 dB

$$Q_{30} = 10^{\left(\frac{L_\theta - L_{avg}}{10}\right)} = 10^{\left(\frac{116-120}{10}\right)} = 10^{-0.4} = 0.398$$

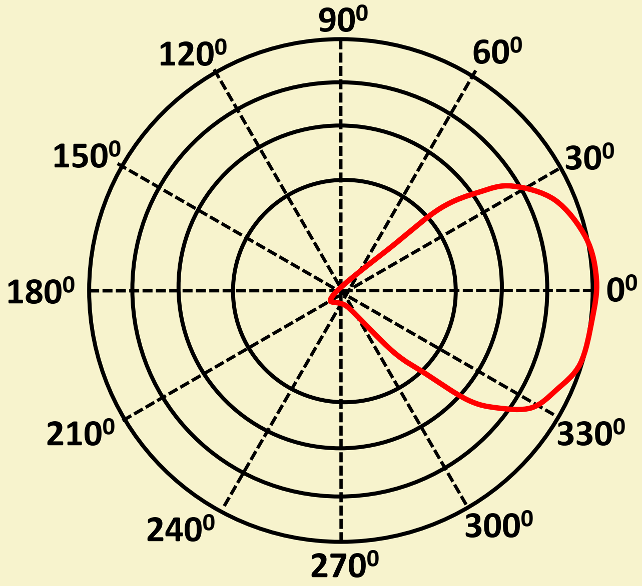
$$DI_{30} = (116 - 120) = -4dB$$

$$DI_{60} = (110 - 120) = -10dB$$

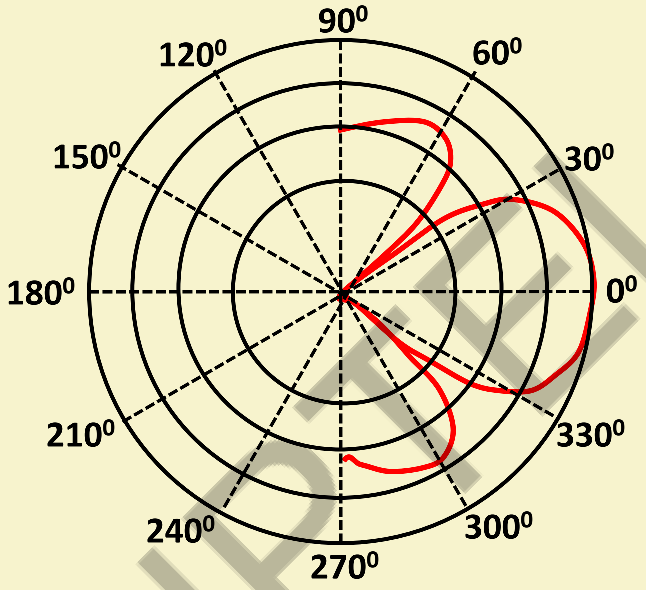
Polar Plot



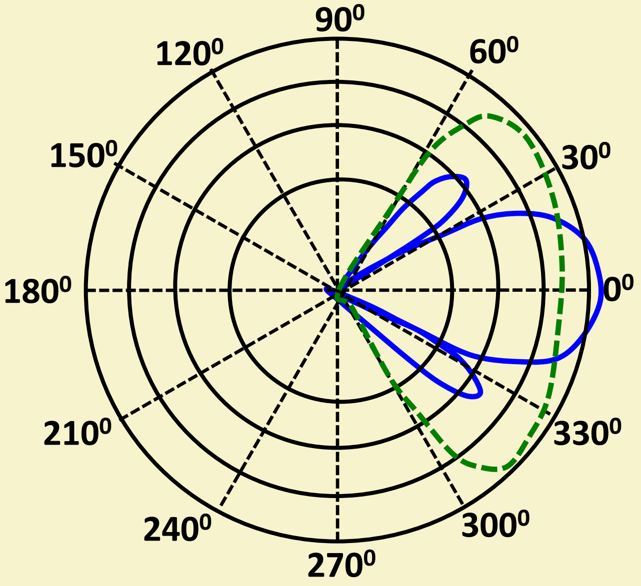
Polar Plot



90^0
120^0
60^0
150^0
30^0
180^0
0^0
210^0
330^0
240^0
300^0
270^0



90^0
120^0
60^0
150^0
30^0
180^0
0^0
210^0
330^0
240^0
300^0
270^0



90^0
120^0
60^0
150^0
30^0
180^0
0^0
210^0
330^0
240^0
300^0
270^0

Home Work

Differentiate between Microphone and Loudspeaker sensitivity

How the Directivity and Polar Plots of Loudspeakers are related. Also state its importance in electro-acoustical design.

1. **Acoustics in the Built Environment**, Duncan Templeton, Architectural Press; 2nd Edition
2. **Acoustical Engineering,** Harry F. Olson, D. Van Nostrand Company Inc.
3. **Architectural Acoustics**, K.B.Genn, Burel & Kjaer, 2nd Edition
4. **Mechanical and Electrical Equipment for Buildings**, Walter T. Grondzik, Alison G. Kwok, Benjamin Stein and John S. Reynolds, John Wiley & Sons, Inc. (11th Edition) [Part-IV]

End of Lecture 26: Electro-Acoustics - I

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Architectural Acoustics

Lecture 27: Electro-Acoustics - II

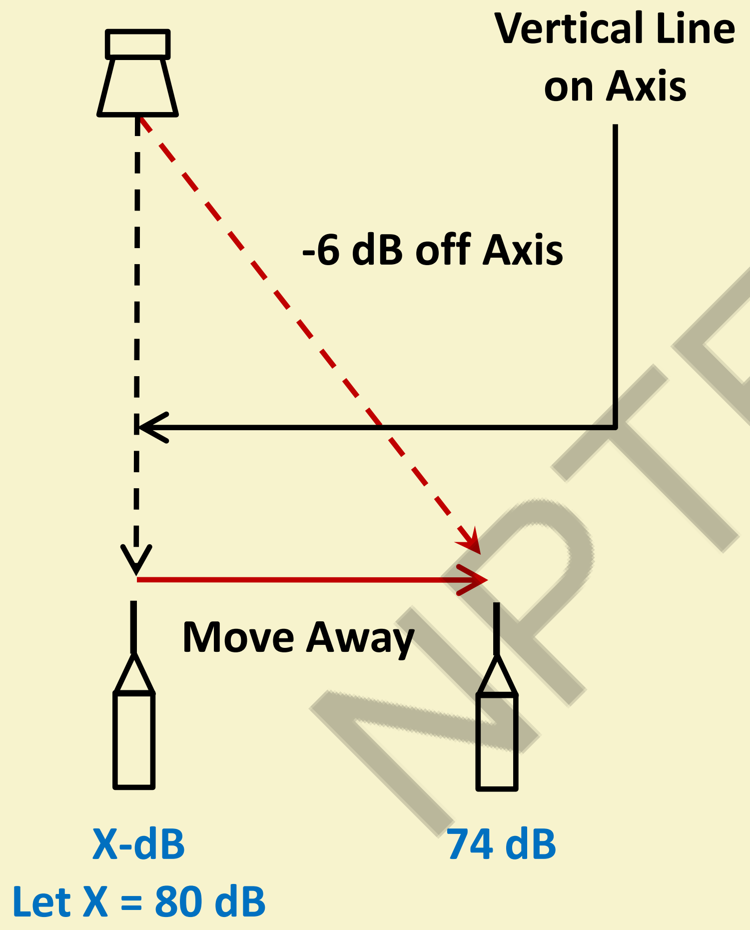
Dr. Shankha Pratim Bhattacharya
Department of Architecture & Regional Planning

Learning Objective

Differentiate between the electro-acoustical systems and its application to auditorium design

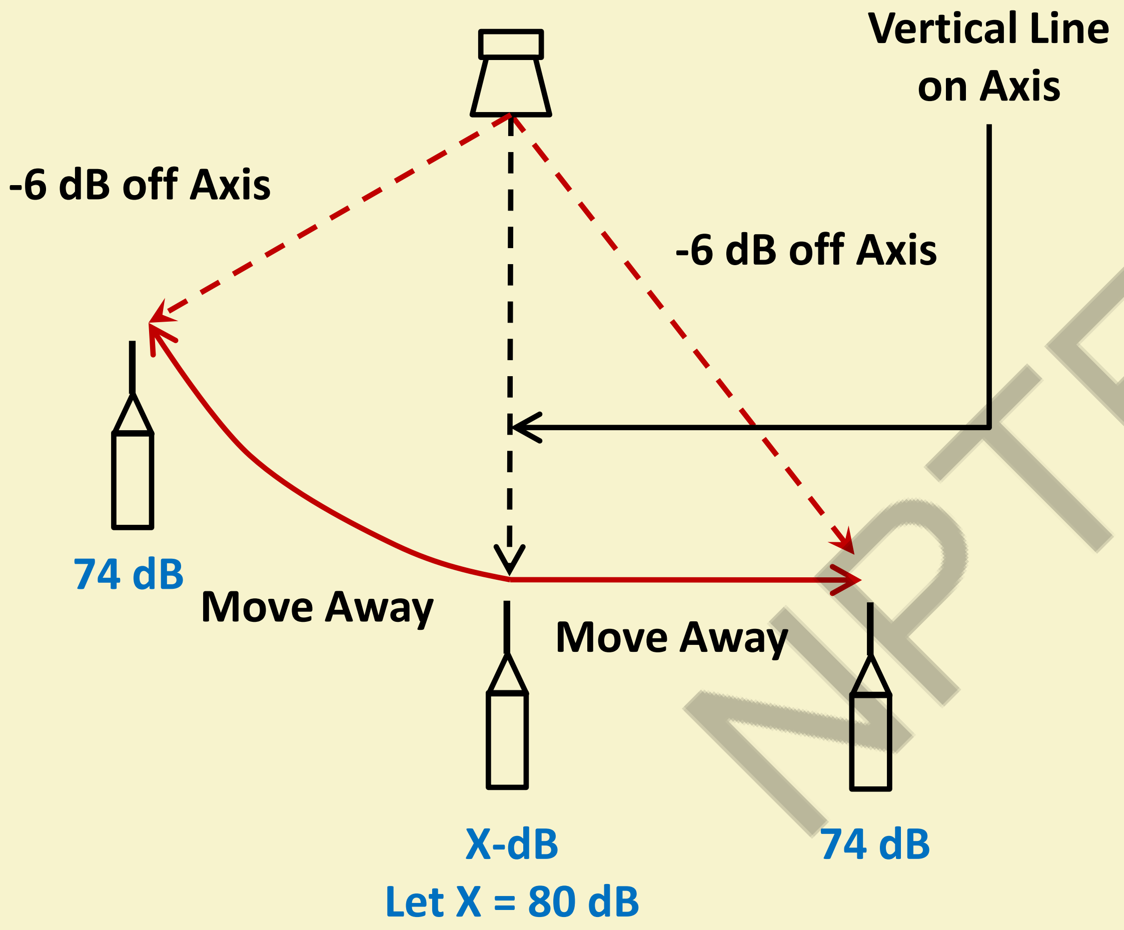
Apply the fundamentals of electro-acoustical parameters to loudspeaker arrangement

Coverage



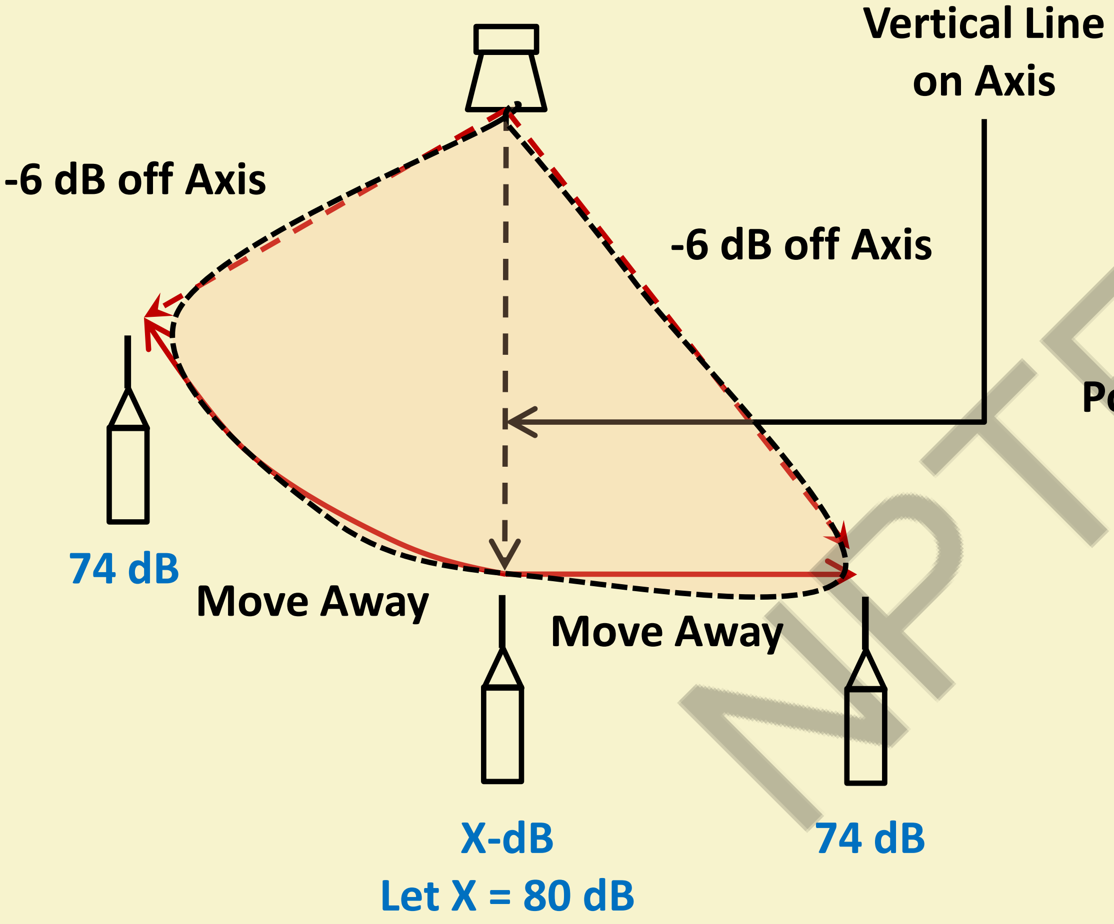
Vertical Line
on Axis
-6 dB off Axis
Move Away
X-dB
Let X = 80 dB
74 dB

Coverage



Vertical Line
on Axis
-6 dB off Axis
-6 dB off Axis
74 dB
Move Away
Move Away
X-dB
Let X = 80 dB
74 dB

Coverage



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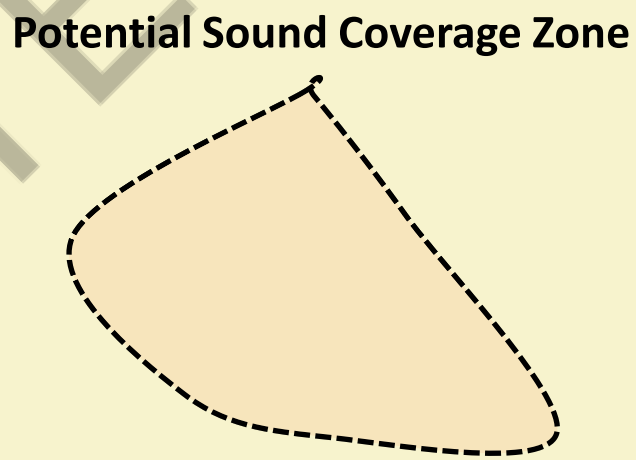
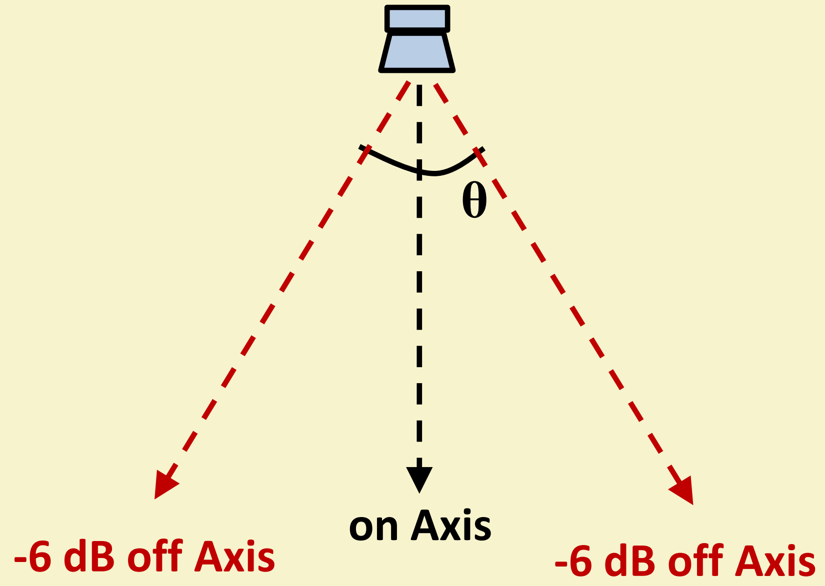


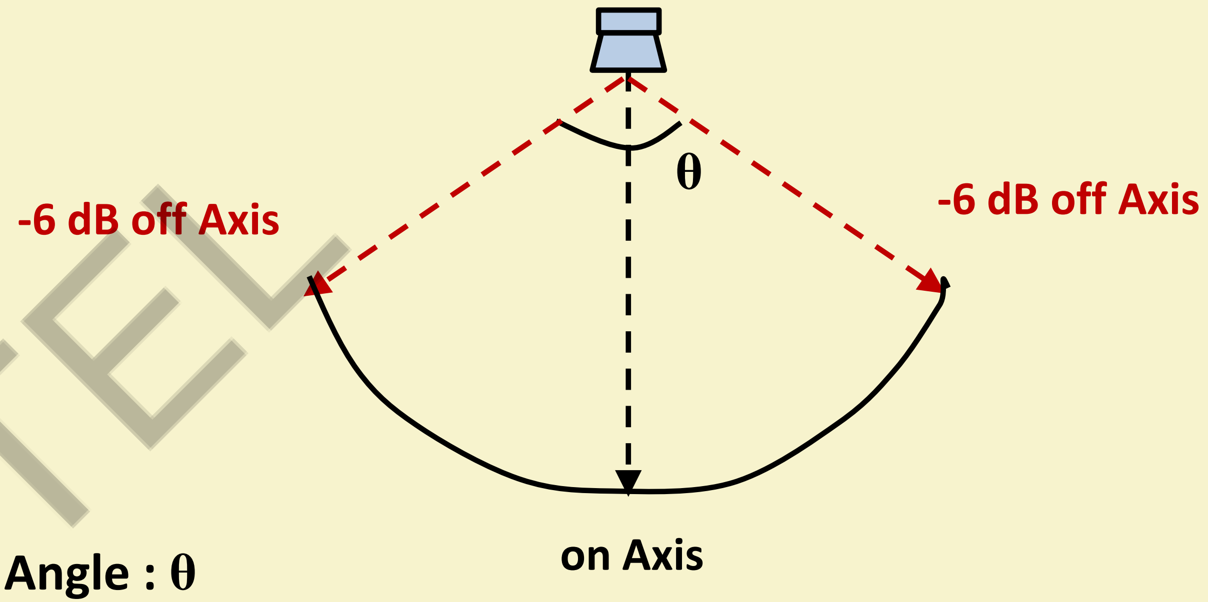
Potential Sound Coverage Zone

Coverage

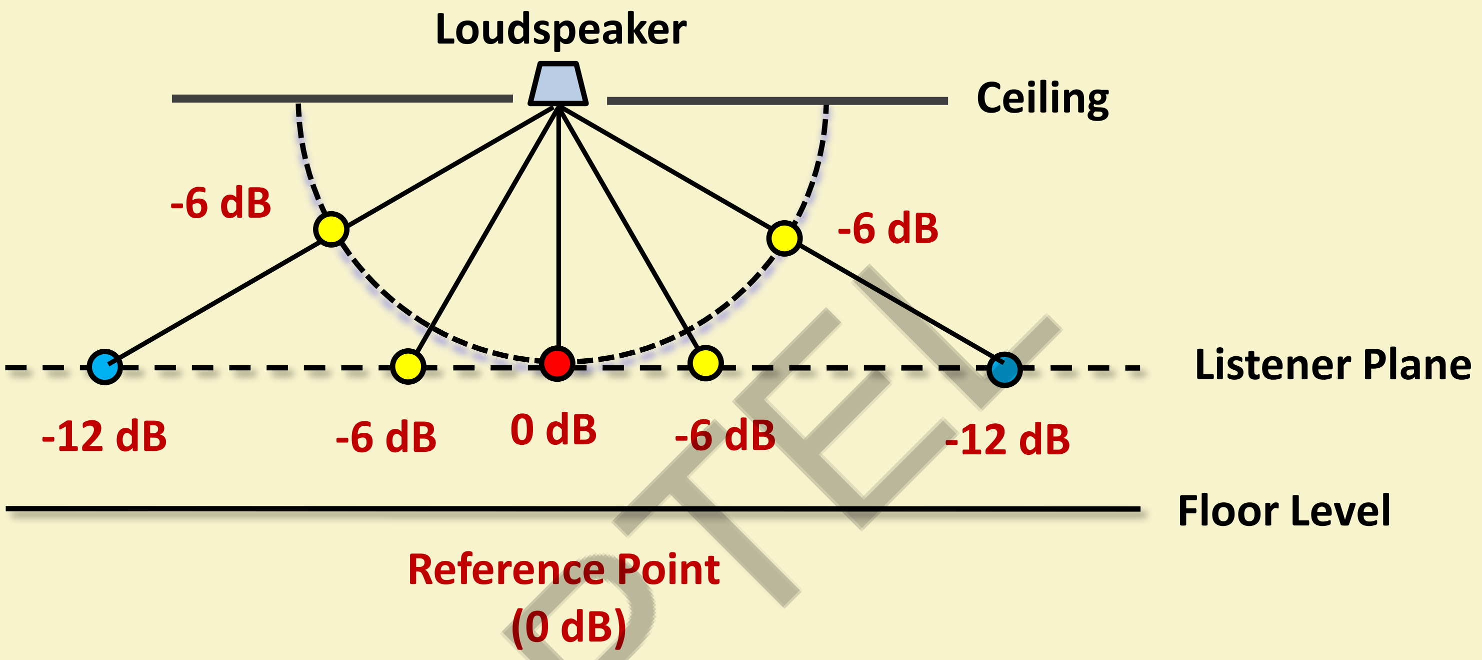


Linear Dispersion

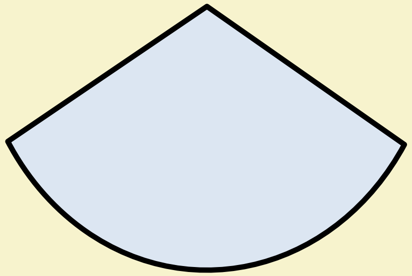
Coverage Angle : θ



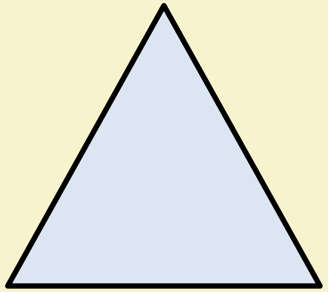
Conical Dispersion



Effective Coverage Angle = 70 – 80% of Nominal Coverage Angle



Nominal Coverage Angle



Effective Coverage Angle

Speech Transmission Index (STI) quantifies the effect of sound transmission system on speech intelligibility.

The analysis is based on the reduction of sound intensity modulation which occurs along the path of travel from source to receiver.

The analysis is carried out for 7 octaves, typically 125 to 8000 Hz frequencies.

A complex analysis is carried out and normalised value of STI is obtained within a range of 0 to 1 .

STI is a well-established objective measurement predictor of how the characteristics of the transmission channel affect speech intelligibility.

The following factors are taken into consideration during the speech intelligibility assessment of STI:

- **Source speech level (includes syllables, words and sentences)**
- **Sound distortions**
- **Background noise (Frequency, type and level)**
- **quality of the sound reproduction equipment**
- **Echo and Reverberation**
- **Phychoacoustical effects**

STI is a numeric representation within a range of 0 to 1.

STI	Quality
0 – 0.3	Bad
0.3 – 0.45	Poor
0.45 – 0.6	Fair
0.6 – 0.75	Good
0.75 – 1	Excellent

STI value of 0.5 is desirable for most applications.

Sound System Design Requirements:

Maximum and Minimum Sound Level

Speech Intelligibility

Sound Level Deviation

Localization of Sound Source

Elimination of Echo and Noise

Sound Reinforced Systems

Central Loudspeaker System

The central loudspeaker system locates the loudspeakers, or cluster of loudspeakers, above the actual source of sound.

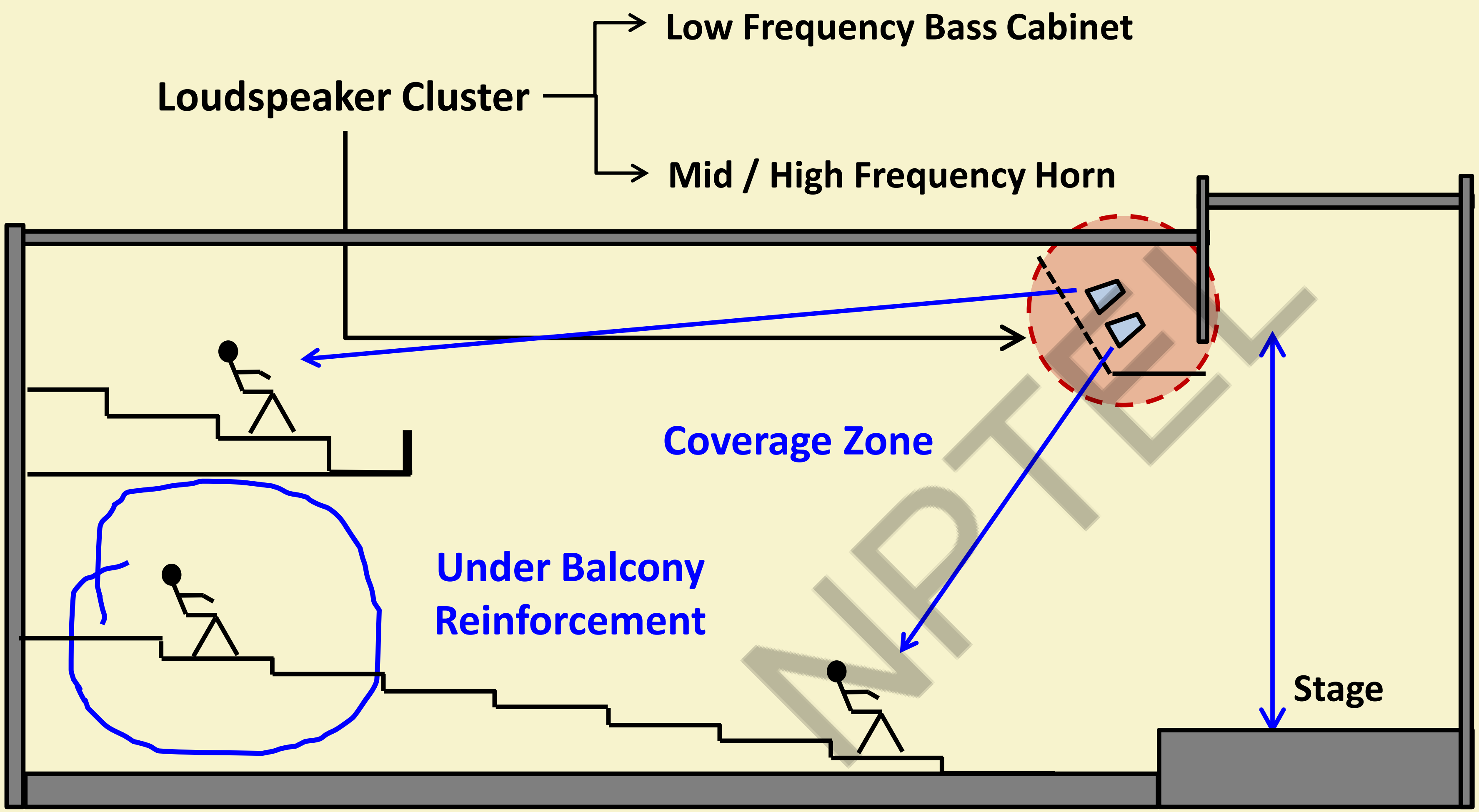
This system provides maximum realism, as the listener will hear amplified sound from the direction of the natural sound.

Distributed Loudspeaker System

The distributed system consist of number of loudspeakers located overhead.

Each supplies low level amplified sound to a small area. The individual loudspeakers used to situated in the ceiling or in the side walls.

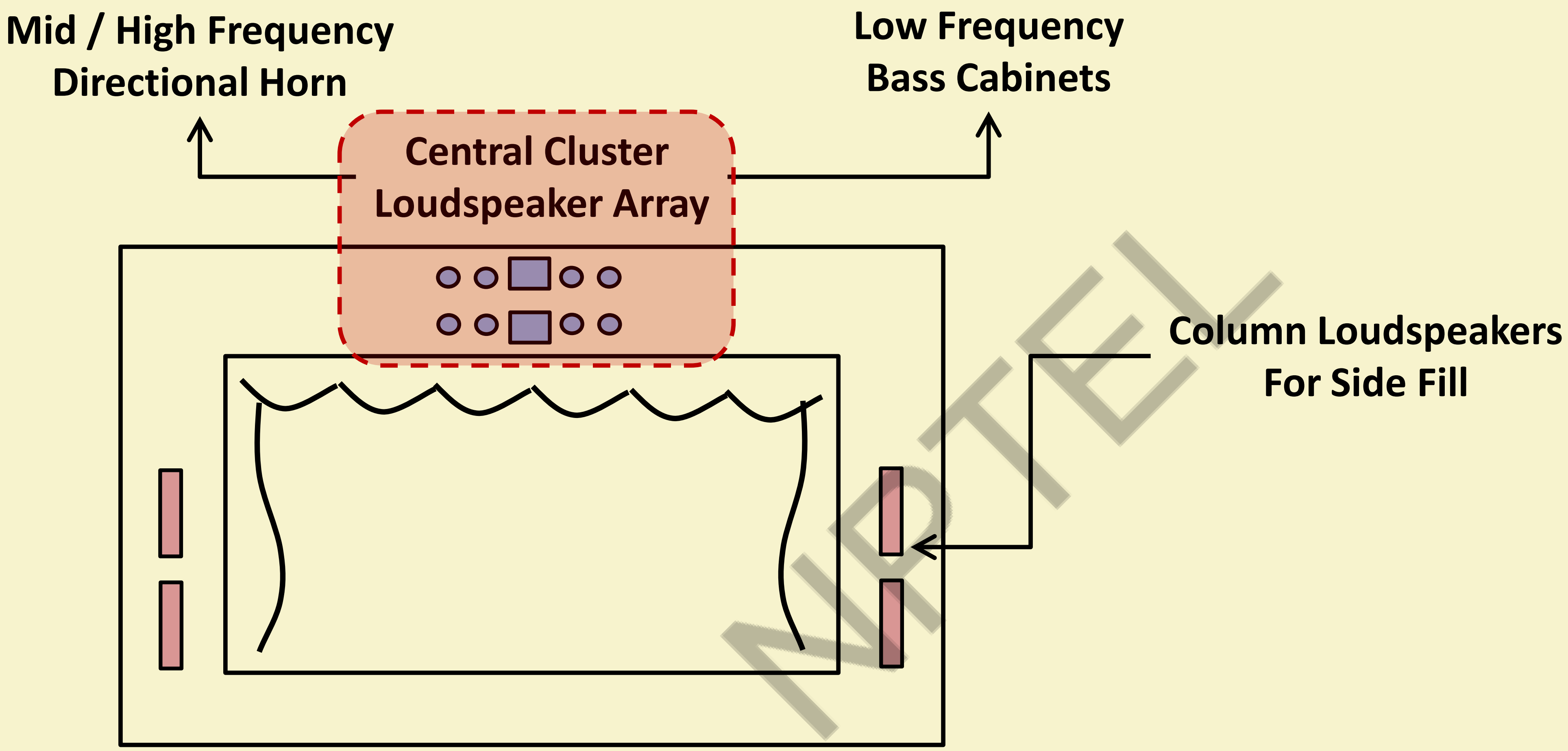
Central System



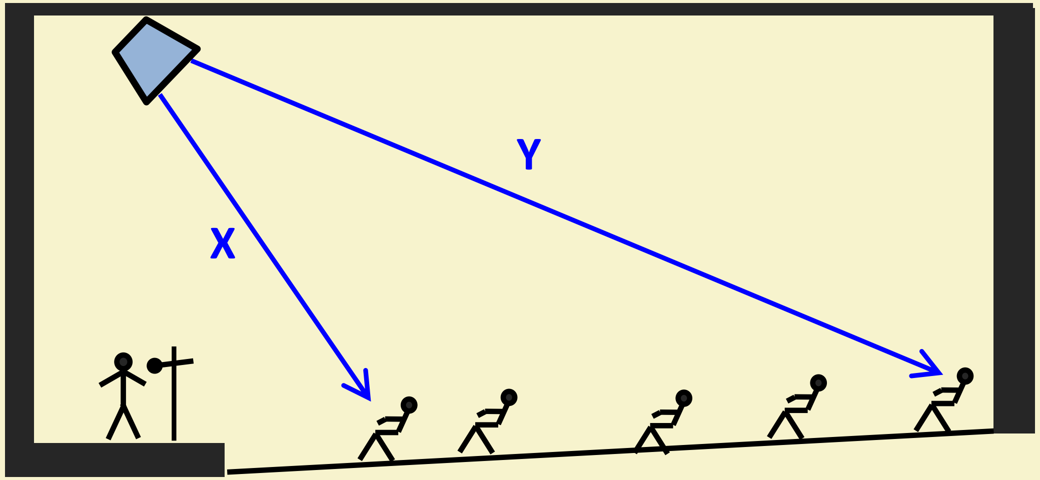
Design Parameters

Height of Installation

Central System



Stage Elevation



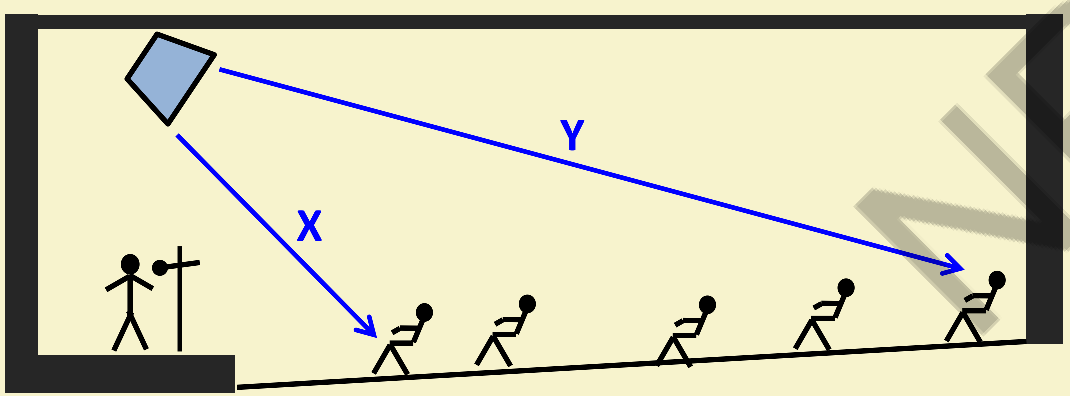
Consistent Coverage

2X >=Y
(Y/X) =<2

Central System

X = Shortest Distance

Y = Longest Distance

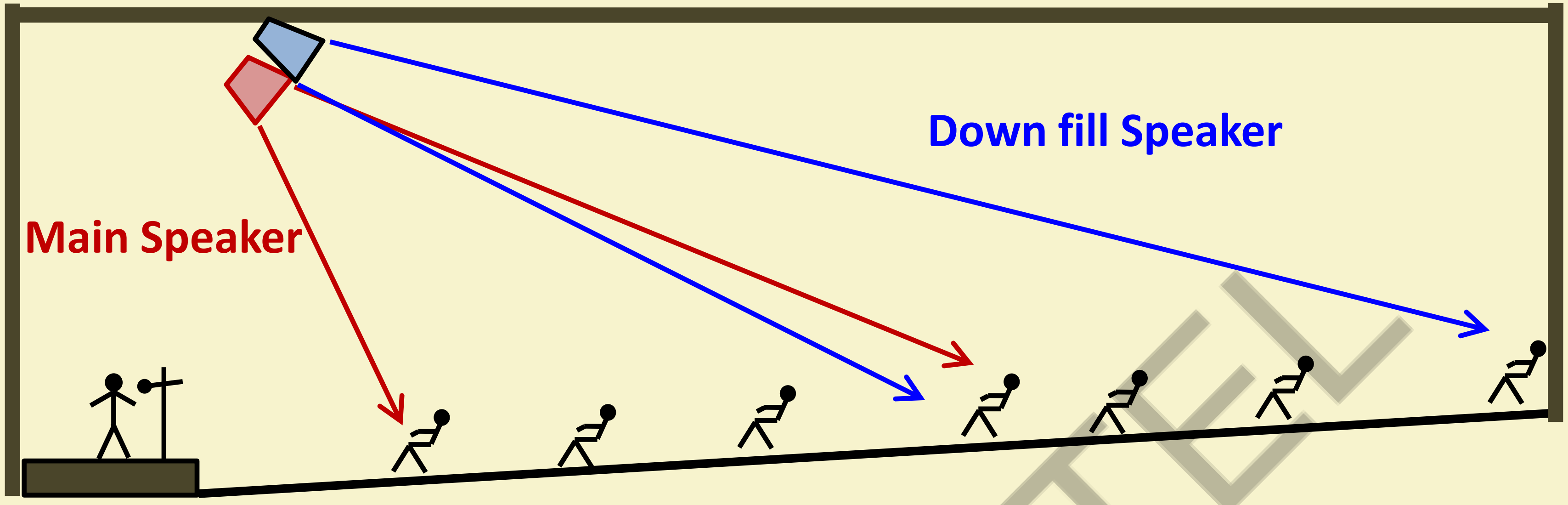


Inconsistent Coverage

2X < Y
(Y/X) > 2

Enough Volume and room height [(Y/X) =<2]
Audience should have 'line of sight' to the speaker cluster

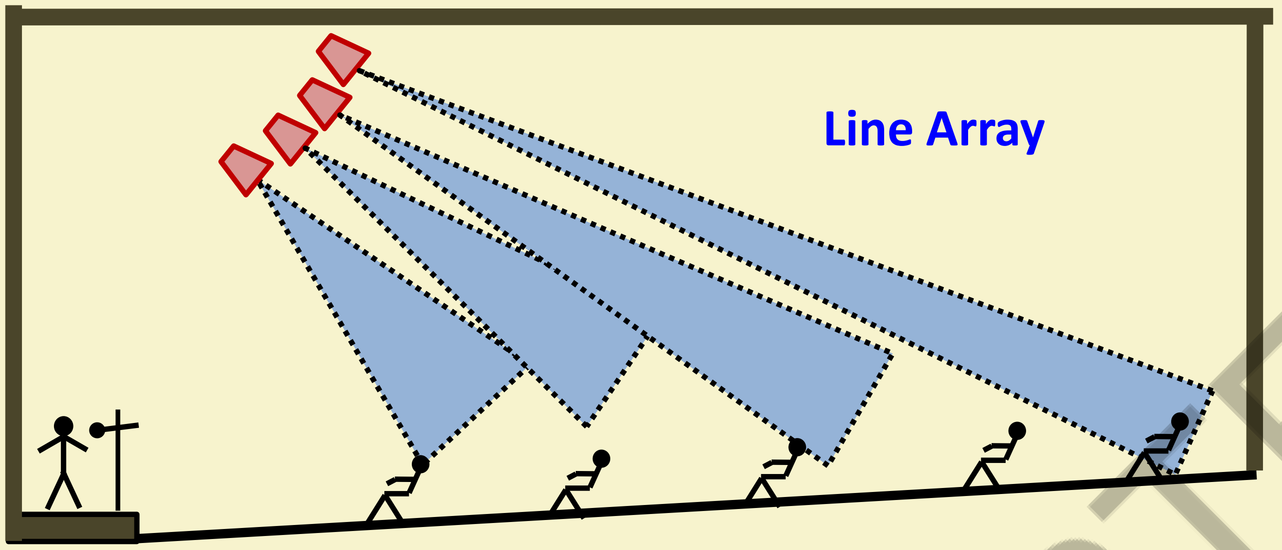
Vertical Coverage



Consistent vertical coverage can be achieve using **Down-fill Speakers**

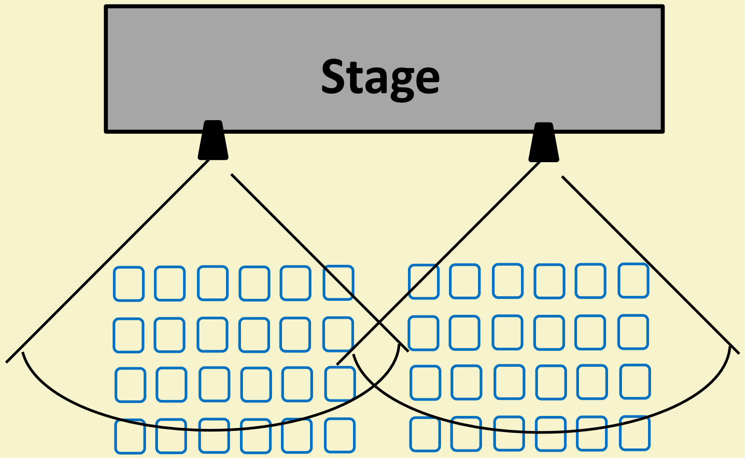
A down-fill speaker (placed with central cluster) is a second main speaker at a slightly different angle, covering a deeper section of the main seating

Vertical Coverage

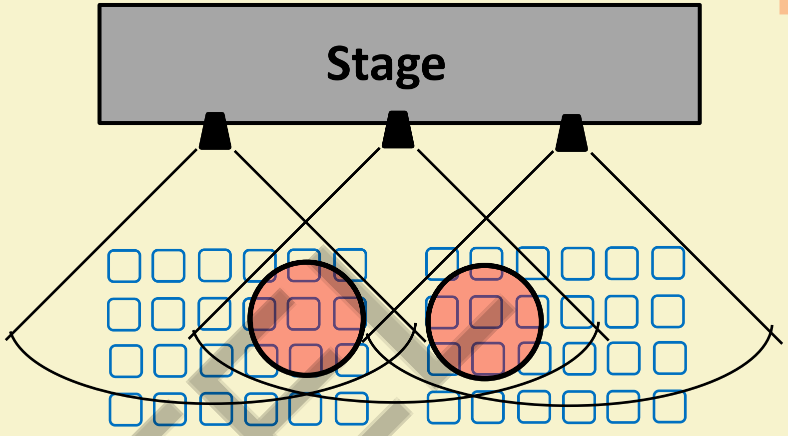


Consistent vertical coverage can be achieve using **Line Arrays**

Line arrays, are several numbers of small loudspeakers with narrow focus usually placed on either side of the stage. It provides greater consistency.



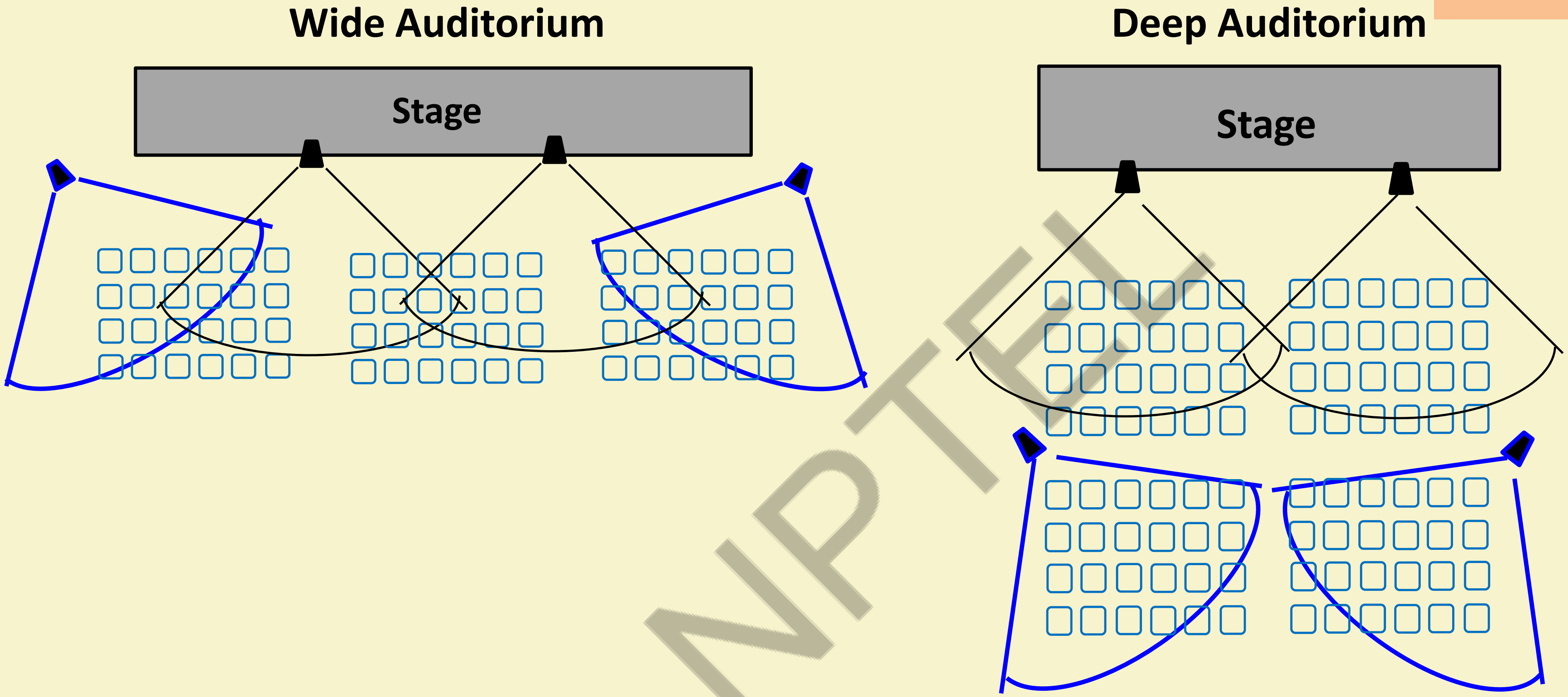
Uniform Distribution



Overlapping Distribution with Hot-Spots

The main consideration for Horizontal Coverage is covering both sides of the audience, without overlapping so heavily that you create a hot spot in the middle

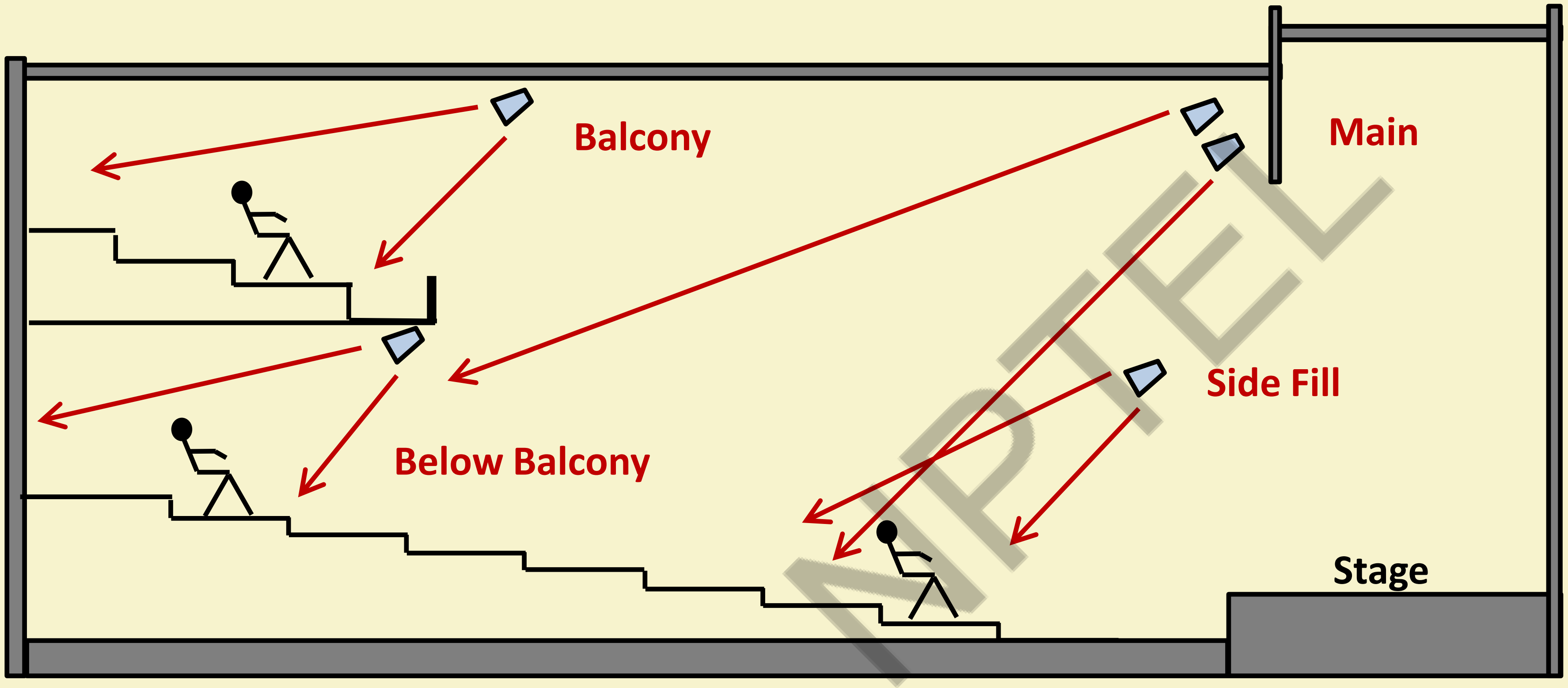
Horizontal Coverage



Central Cluster loudspeaker: Front & Central Coverage

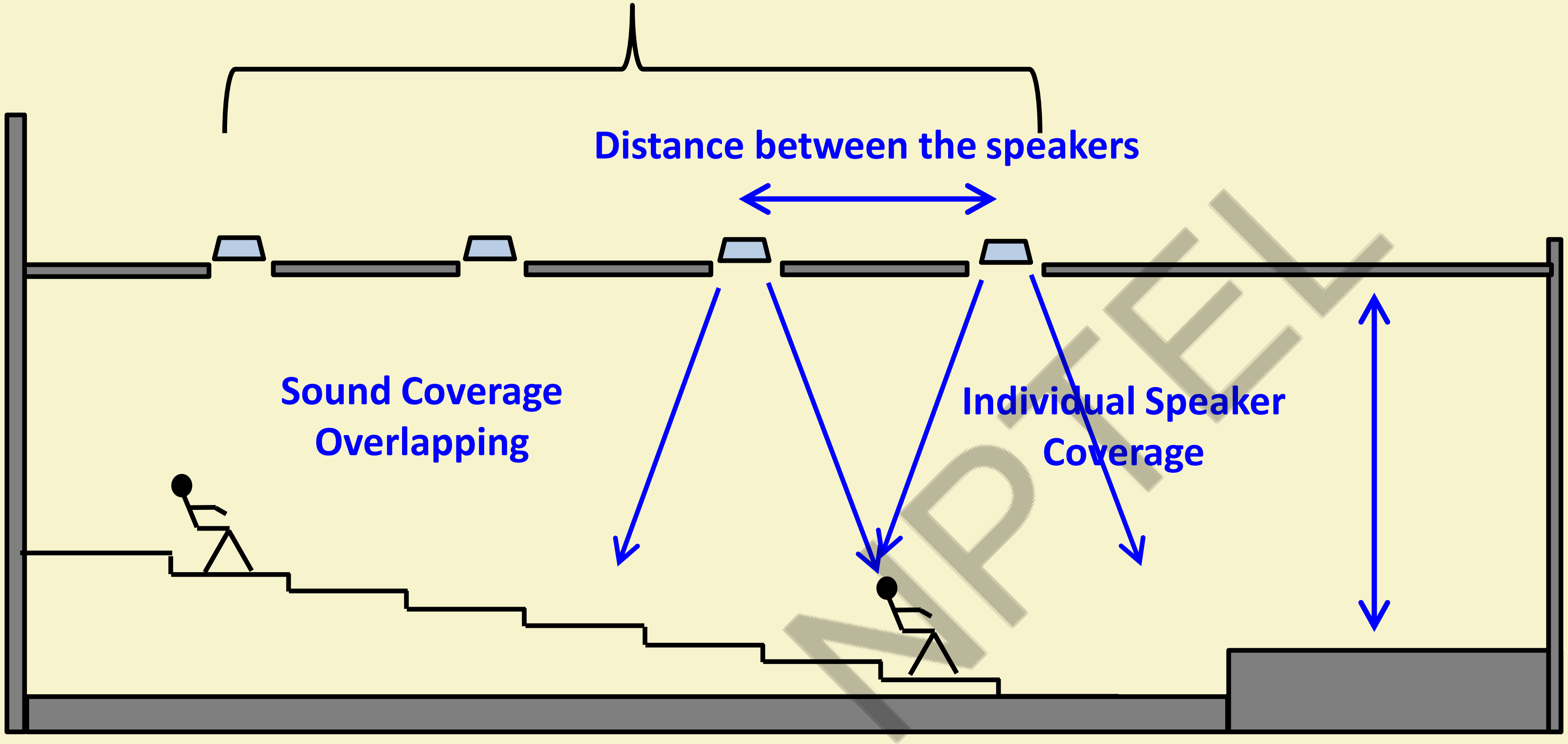
Fill – in Loudspeakers: Side & Deep sound reinforcement

Central System



Distributed System

Loudspeakers Distributed over the Audience Area



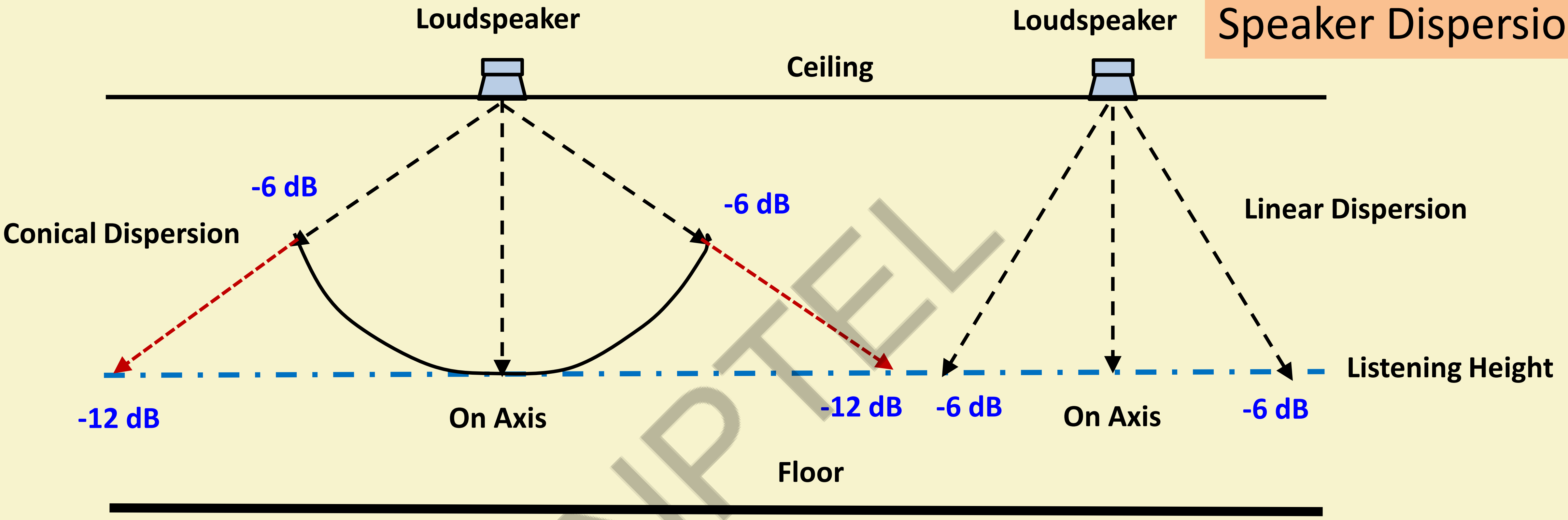
Design Parameters

Height of Installation

The pattern and density of the ceiling loudspeakers in a distributed system is an important consideration. The selection method for loudspeaker installation should take care of the following criteria

- **Speaker Coverage and its effectiveness**
- **Sound level capability of the system**
- **Sound or speech Intelligibility**
- **Power amplification requirements**
- **Cost of the system**

Speaker Dispersion



Listening Height

1.2m (4’) for Seating

1.5m (5’) for Standing

Square Pattern

Two most widely used loudspeaker patterns:

Hexagonal Pattern

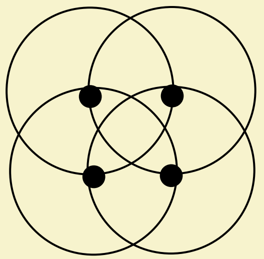
Square Pattern

A square pattern speakers are placed in grids of equal spacing

- The Square pattern is **easy to lay out**, especially on a suspended ceiling tile grid.
- It may also be **easier for zoning** large open spaces.
- Square pattern delivers **even sound coverage** with **fewer speakers**.
- It's usually the best starting point for a design and preferred choice

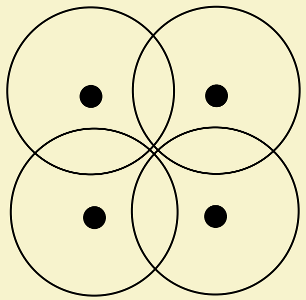
Square Pattern

Maximum Overlap



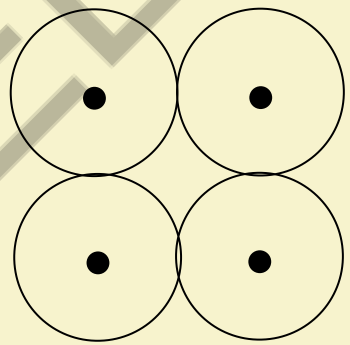
Speaker Spacing = R

Minimum Overlap



R<Speaker Spacing <2R

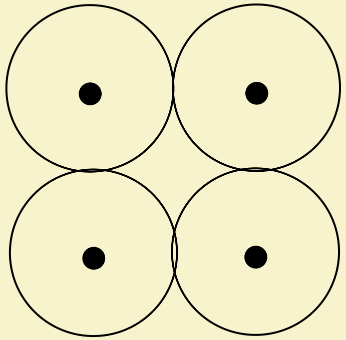
Edge-to-edge Overlap



Speaker Spacing =2R

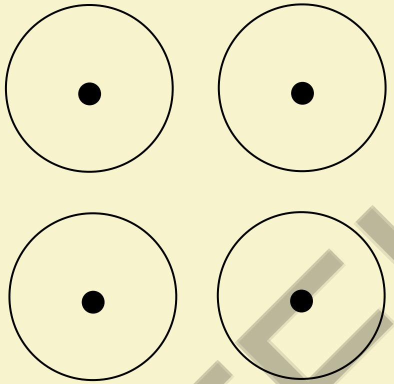
Square Pattern

Edge-to-edge Overlap



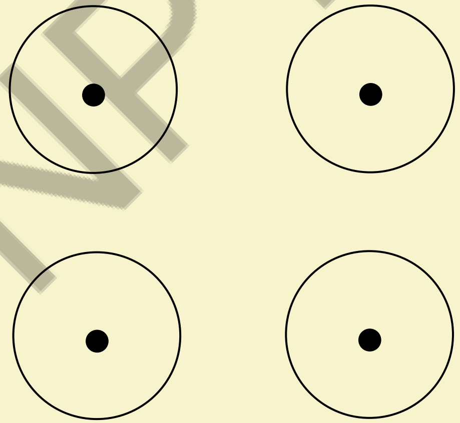
Speaker Spacing =2R

1.4 X Edge-to-edge Overlap



Speaker Spacing =1.4 times 2R

2 X Edge-to-edge Overlap



Speaker Spacing = 2 times 2R

Layout Pattern

Square Pattern

Two most widely used loudspeaker patterns:

Hexagonal Pattern

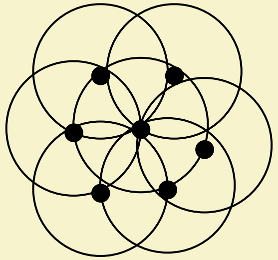
Hexagonal Pattern

In hexagonal layout pattern speakers are placed in rows with a specific offset.

- Hexagonal pattern typically uses **more loudspeakers**
- But it may use fewer in some particular cases (square pattern, it the end row of loudspeakers cover only a small area)
- Hexagonal pattern is **economical** and preferred in large halls with **non rectangular shape** (Circular, trapezoidal or octagonal)

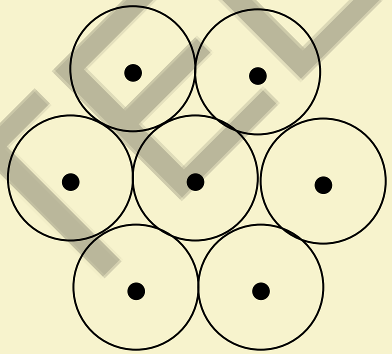
Hexagonal Pattern

Maximum Overlap



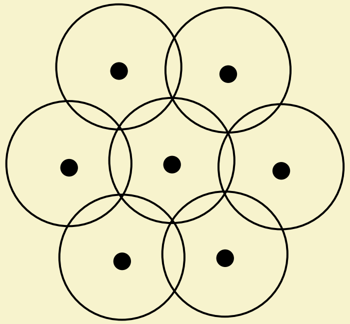
Speaker Spacing =R

Edge-to-edge Overlap



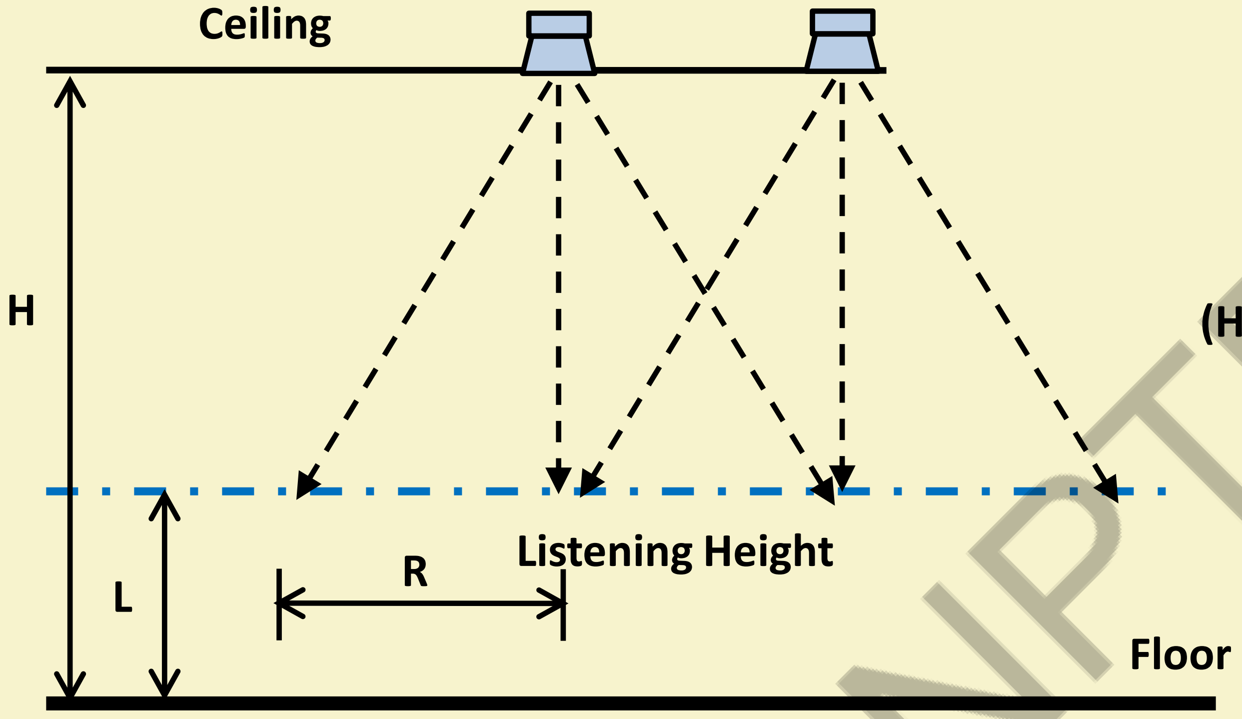
Speaker Spacing =2R

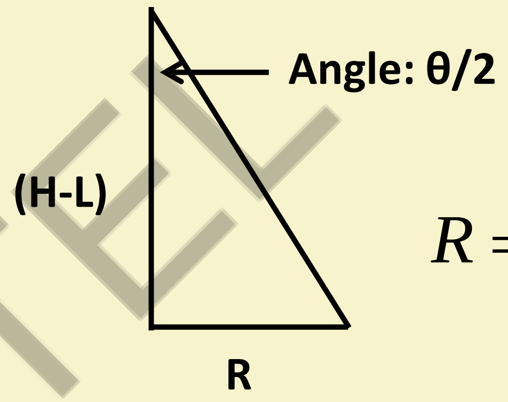
Minimum Overlap



R<Speaker Spacing <2R

Speaker Coverage



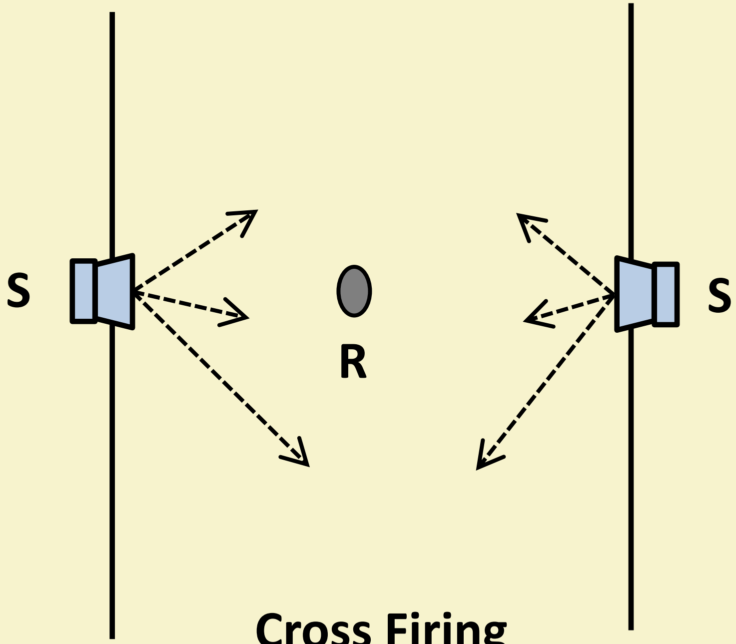


$$R = (H - L)\tan\frac{\theta}{2}$$

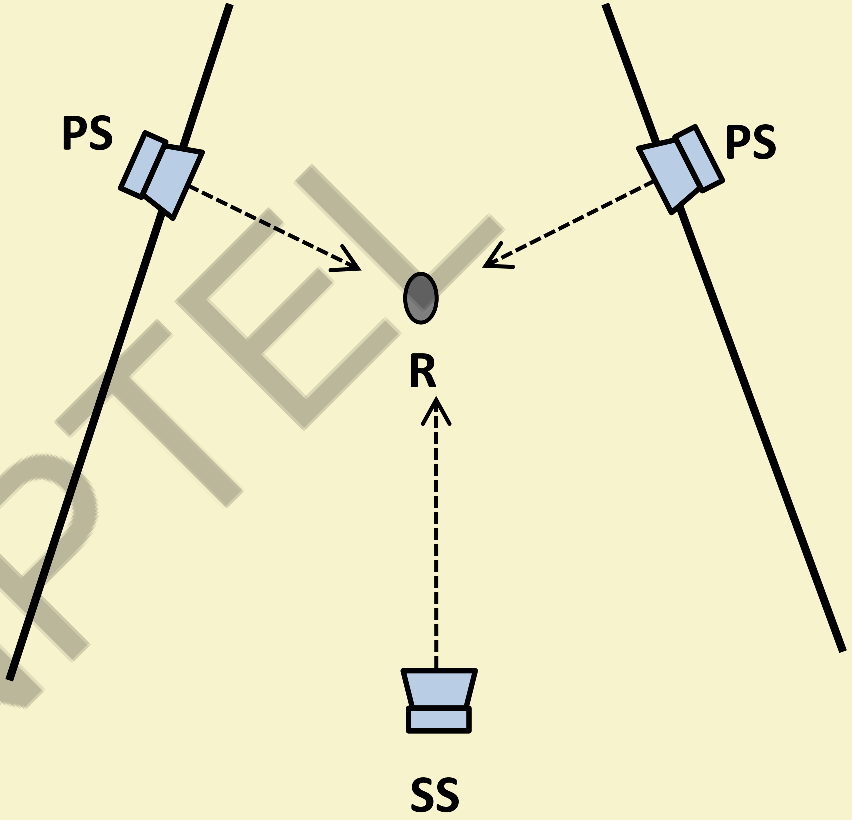
H = Speaker mounting height fro floor
L = Listening height
R = Coverage radius of the speaker
θ = Speaker coverage angle

Comparison Layout Pattern

Pattern type	Overlap type	Increase in SPL w.r.t. single speaker	SPL Variation
SQUARE	Maximum	+5.2 dB	- 1.4 dB
	Minimum	+2.0 dB	- 2.0 dB
	Edge – to- edge	+0.7 dB	- 4.4 dB
	1.4 X Edge – to- edge	+0.4 dB	- 6.8 dB
	2 X Edge – to- edge	+0.2 dB	- 10.4 dB
HEXAGON	Maximum	+5.4 dB	- 1.2 dB
	Minimum	+1.4 dB	- 2.6 dB
	Edge – to- edge	+1.0 dB	- 5.4 dB
	1.4 X Edge – to- edge	+0.5 dB	- 10.2 dB
	2 X Edge – to- edge	+0.3 dB	- 17.3 dB

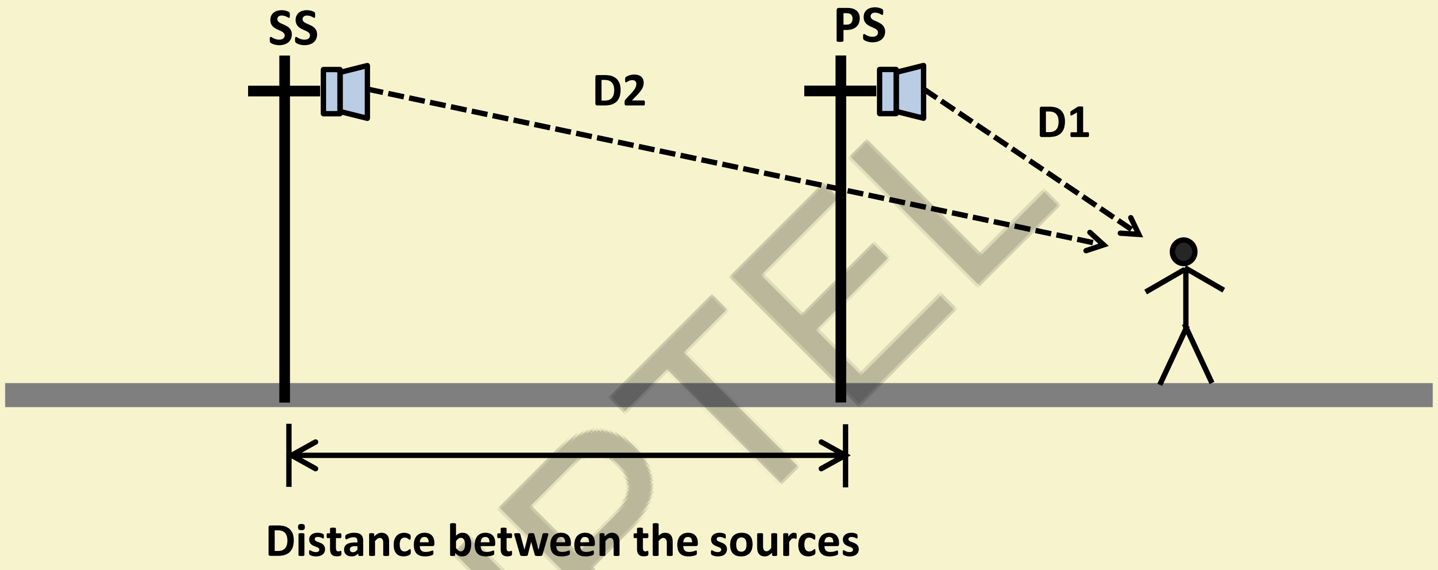


Cross Firing



Sound Delay: Confusion of hearing

Defects



The distance between the sources should be such that due to the arrival of sound to listener from two sources (D2 – D1) not very high

Sound Delay / Artificial Echo: Confusion of hearing

Home Work

Differentiate between Central cluster and distributed system of electro-acoustics

If a coverage angle of a loudspeaker is 60^0 . The speaker mounting height is 12’. Find the spacing of the loudspeakers for 1.4 X edge- to – edge hexagonal pattern.

Bibliography

1. **Acoustics in the Built Environment**, Duncan Templeton, Architectural Press; 2nd Edition

2. **Acoustical Engineering,** Harry F. Olson, D. Van Nostrand Company Inc.

3. **Architectural Acoustics**, K.B.Genn, Burel & Kjaer, 2nd Edition

4. **Mechanical and Electrical Equipment for Buildings**, Walter T. Grondzik, Alison G. Kwok, Benjamin Stein and John S. Reynolds, John Wiley & Sons, Inc. (11th Edition) [Part-IV]

End of Lecture 27: Electro-Acoustics - II

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Architectural Acoustics

Lecture 28: Meteorological conditions and sound propagation

Dr. Sumana Gupta

Department of Architecture & Regional Planning

Learning Objective

Influence of meteorological conditions

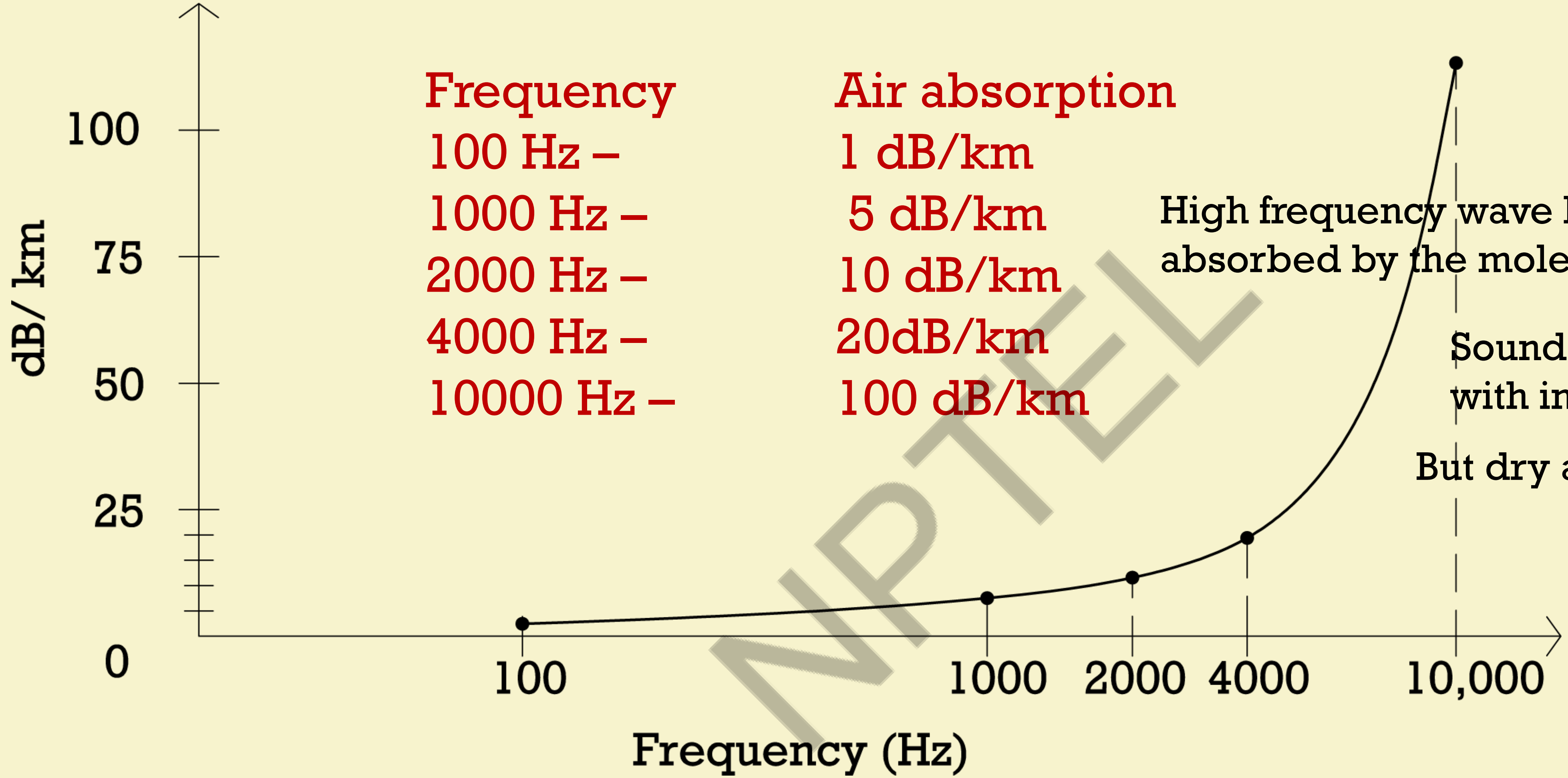
Sound and air absorption

Temperature and speed of sound

Humidity and speed of sound

Air Absorption

Frequency	Air absorption
100 Hz –	1 dB/km
1000 Hz –	5 dB/km
2000 Hz –	10 dB/km
4000 Hz –	20dB/km
10000 Hz –	100 dB/km



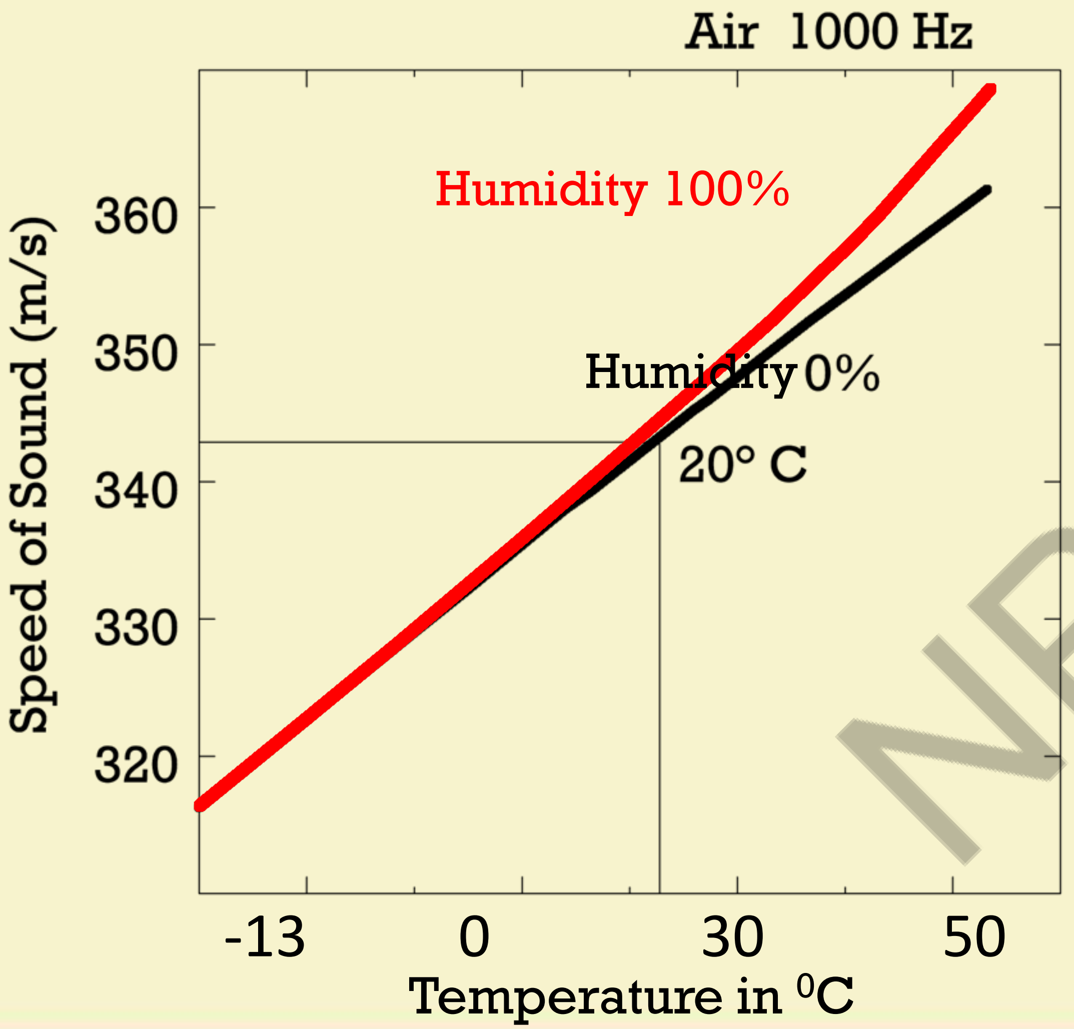
High frequency wave lengths are more easily absorbed by the molecules in the air.

Sound absorption decreases with increased humidity.

But dry air has least absorption.

Low frequency sound travels further

Temperature and speed of sound



Temperature velocity gradient
= 0.6m/sec/^{0}C
(1.98 ft/sec/^{0}C)

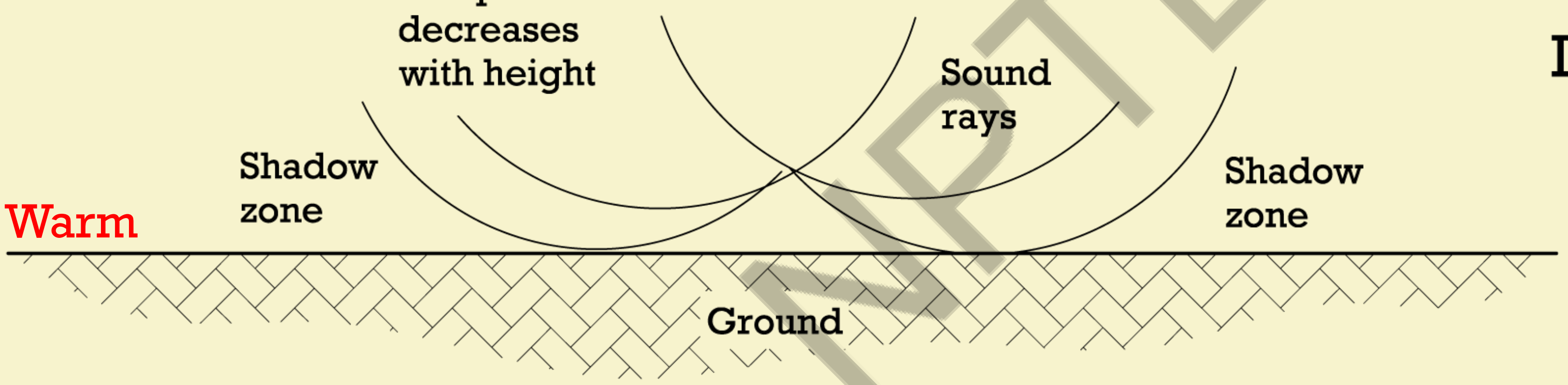
$V = 343m/sec + 0.6\ (T - 20)$

For 42^{0}C temperature:

$V = 343m/sec + 0.6\ (42 - 20)$
$= 343 + 13.2$ m/sec
$= 356.2$m/sec

Temperature gradient leads to bending up and down of the sound wave

Cool – Slower sound speed



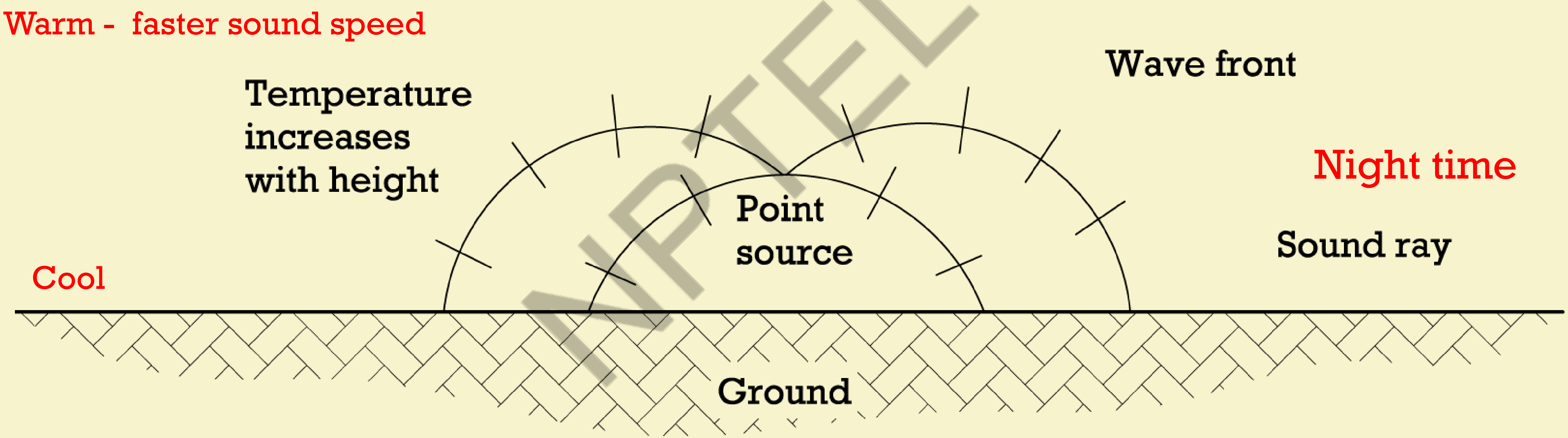
Warm

Daytime

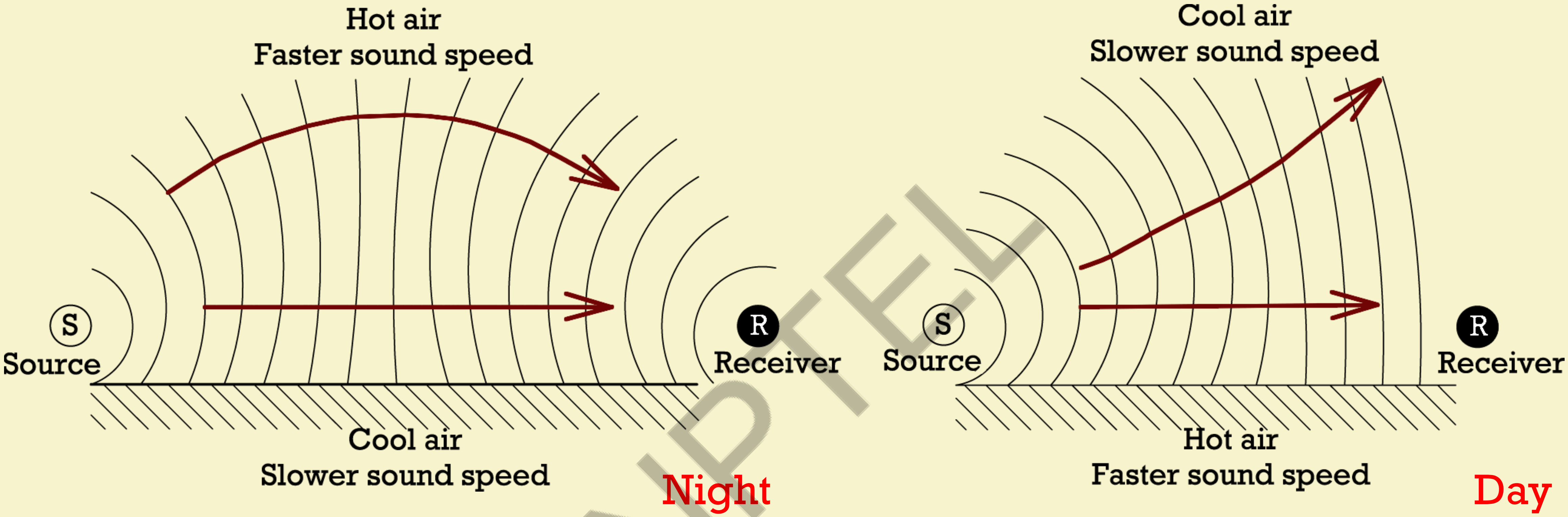
This is called a **temperature lapse or super adiabetic.**

Temperature and speed of sound

Temperature inversion is when the temperature is coolest right next to the ground and warmer as you increase in height above the ground.



This downward refraction of sound helps hear the conversations even across water bodies

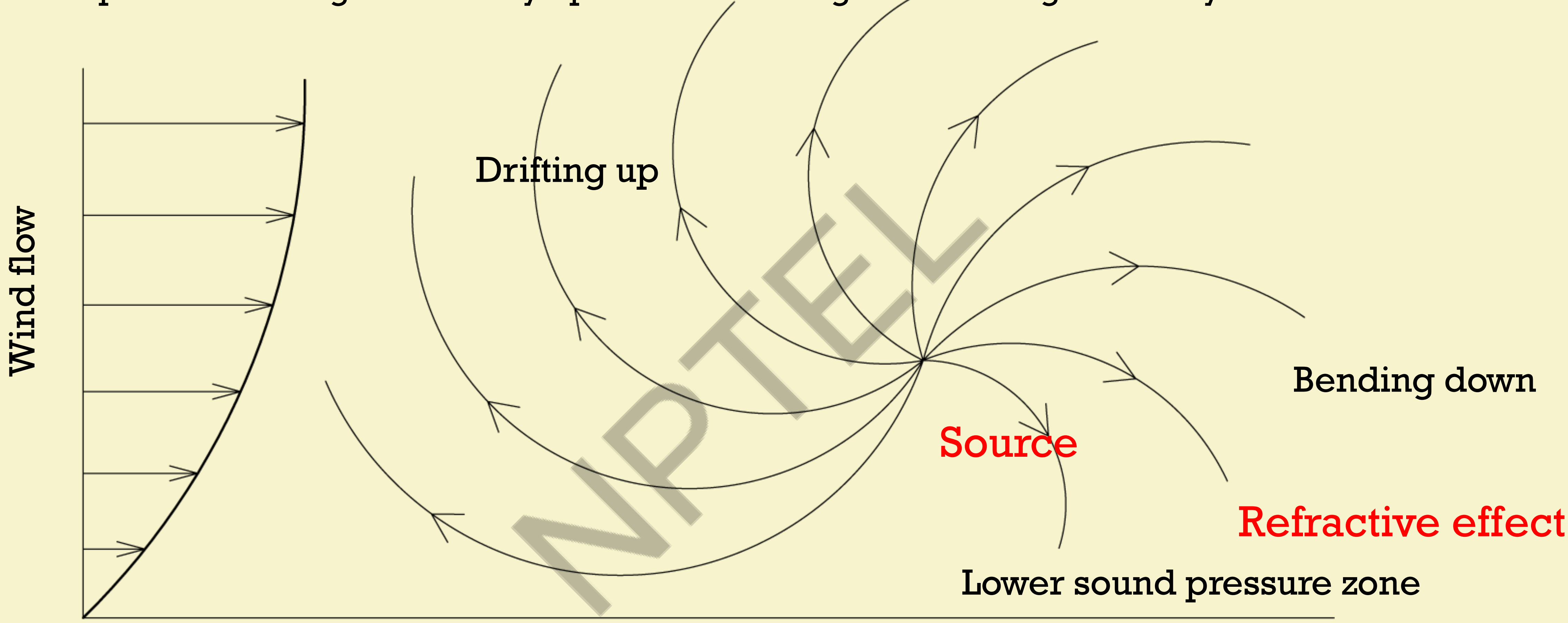


Formation of shadow zone for some frequencies towards surface in day time

We can hear distant sound at night time than at day time

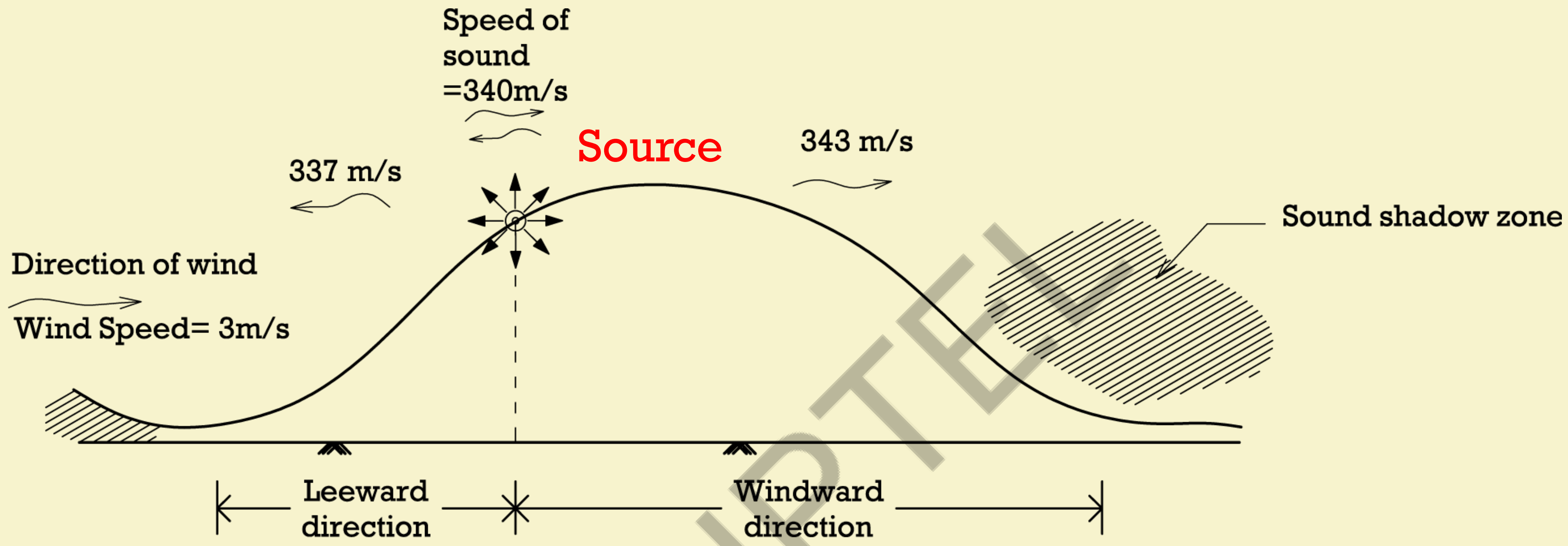
Influence of wind speed on sound

Wind speed varies logarithmically upto a certain height and then gets steady



As a rule, sound waves bend towards regions of lower sound speed

Influence of wind speed on sound



A sound wave propagating in direction of wind bends down

In upwind direction the sound speed decreases with altitude

In downwind direction the sound waves are bent towards the ground

Tasks

Using the equation provided, find out the difference in day time and night time sound speed in your location during summer time in still air condition.
Having wind speed of 8m/sec in the direction of source sound / opposite to source sound

Books:
Concepts in Architectural Acoustics, M. David Egan
Architectural Acoustics by M. Long
Internet sources

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Architectural Acoustics

Lecture 29: Topography and sound propagation Historical contexts

Dr. Sumana Gupta

Department of Architecture & Regional Planning

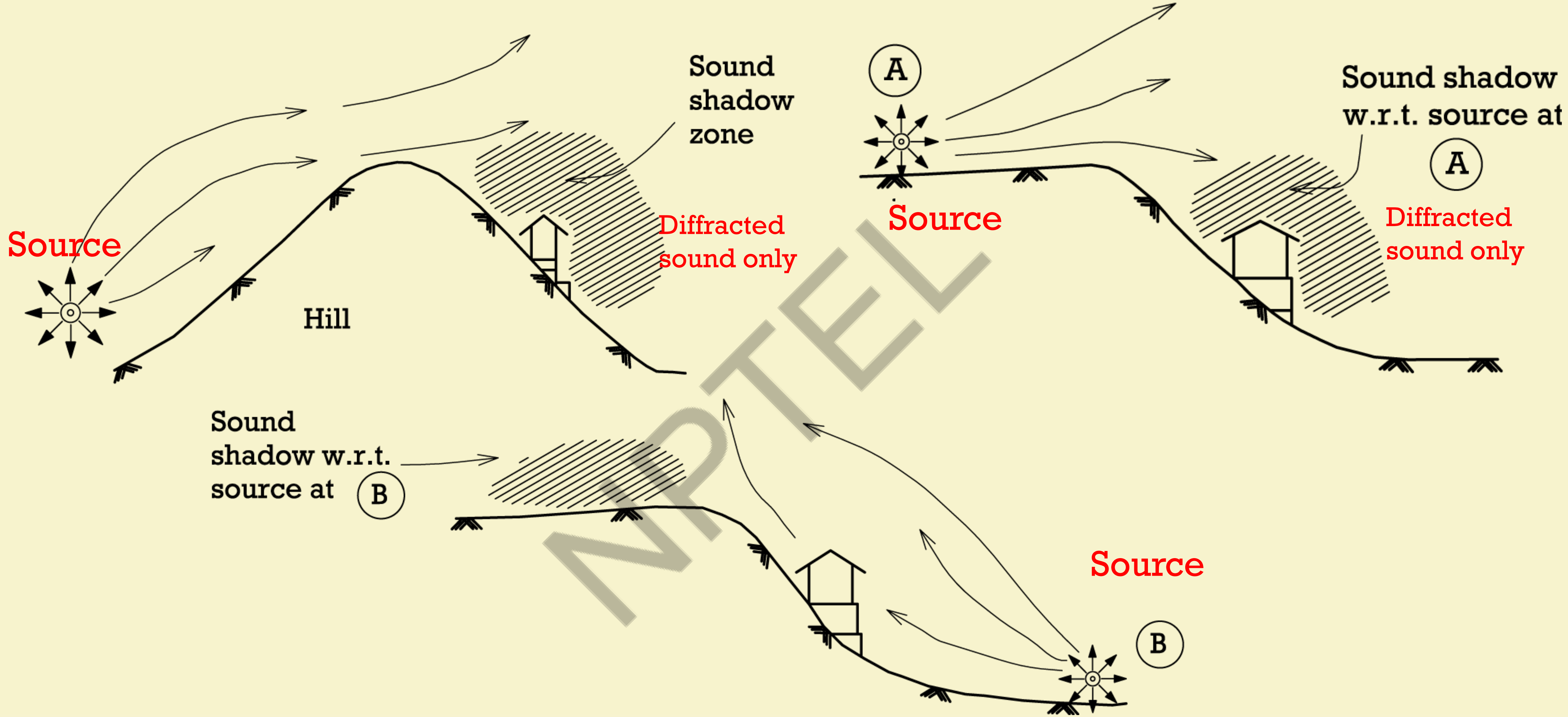
Learning Objective

Influence of topographical conditions

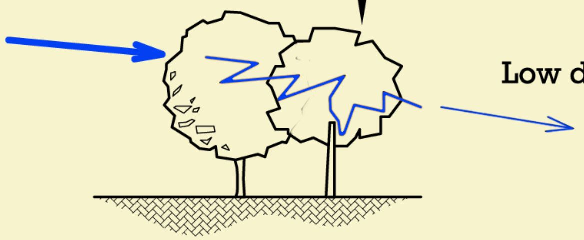
- Slopes along hills
- Plantation and vegetation

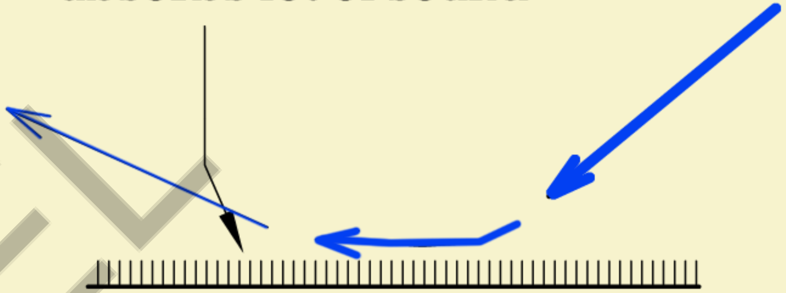
Historical context

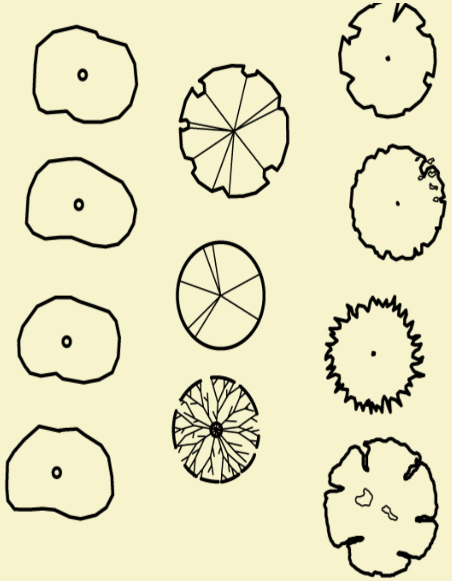
Influence of topography



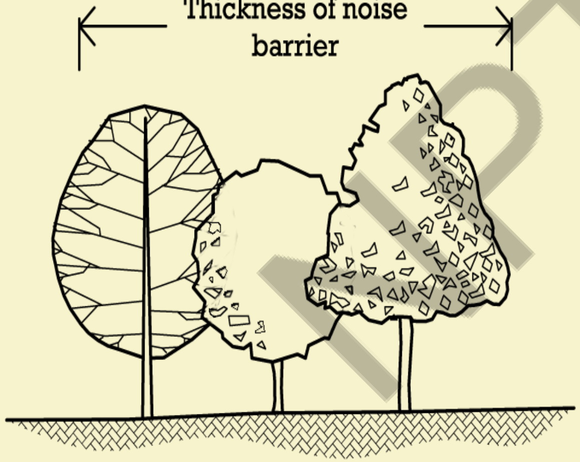
Plantation/ Vegetation







PLAN



ELEVATION

Different types of foliages provide better sound absorption

Plantation/ Vegetation

Dense belts of trees 15 – 30 m absorb sound 5-10dB
(Cook and V. Haverbeke (1970), Leonard and Parr (1972); Reethof, 1975)

Dense belts can reduce noise by 6dB (Huddurt, 1990)

Different types of leaves provide better sound absorption

Rustling of leaves may help to mask noise

Noise reduction tends to increase with tree height up to 10-12m

Height of sound source and distance from source is also important

Early Greek

Greek Theatre characterised by

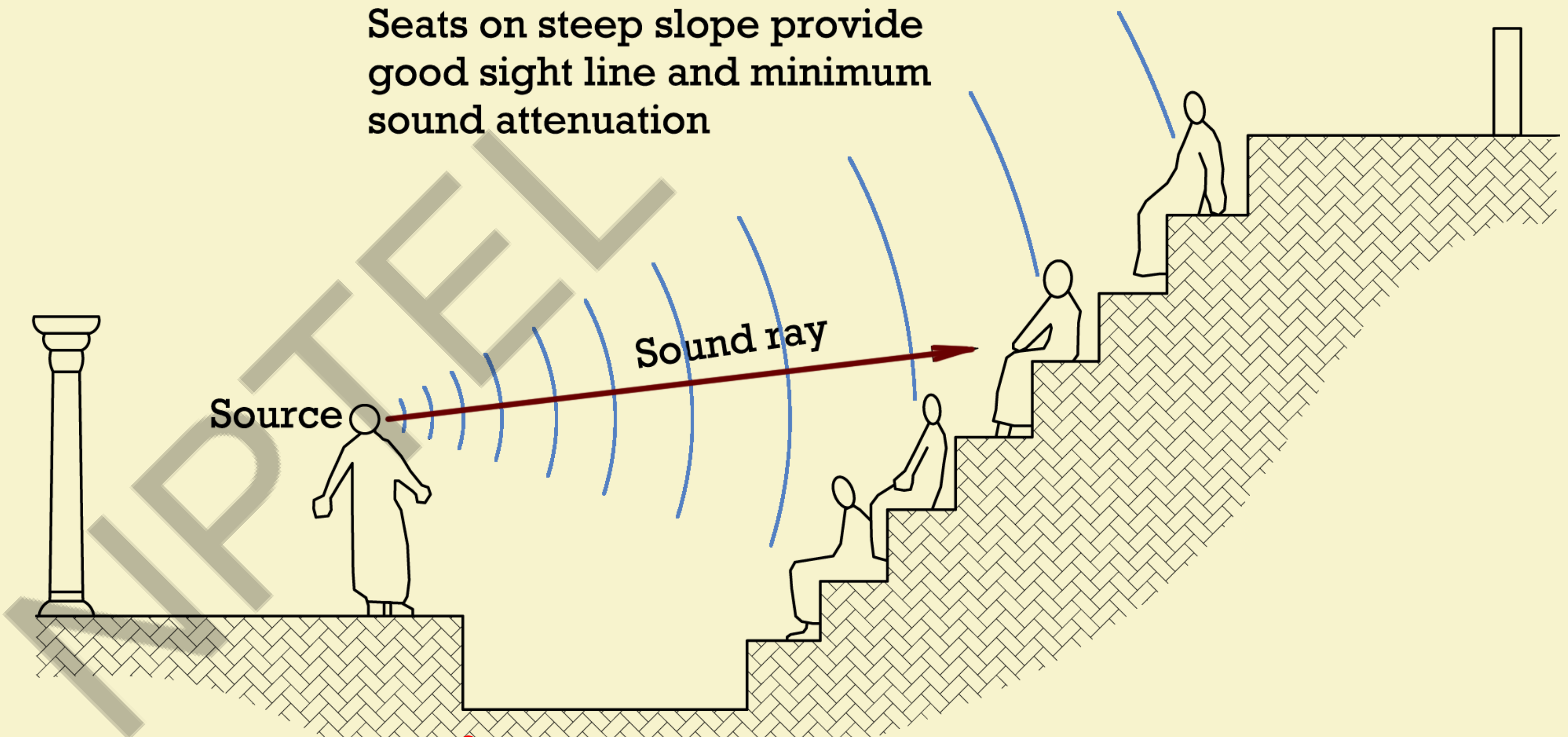
Open air

Direct sound

No sound reinforcement

Minimal reverberation

Ex: Epidaurus, 330BC



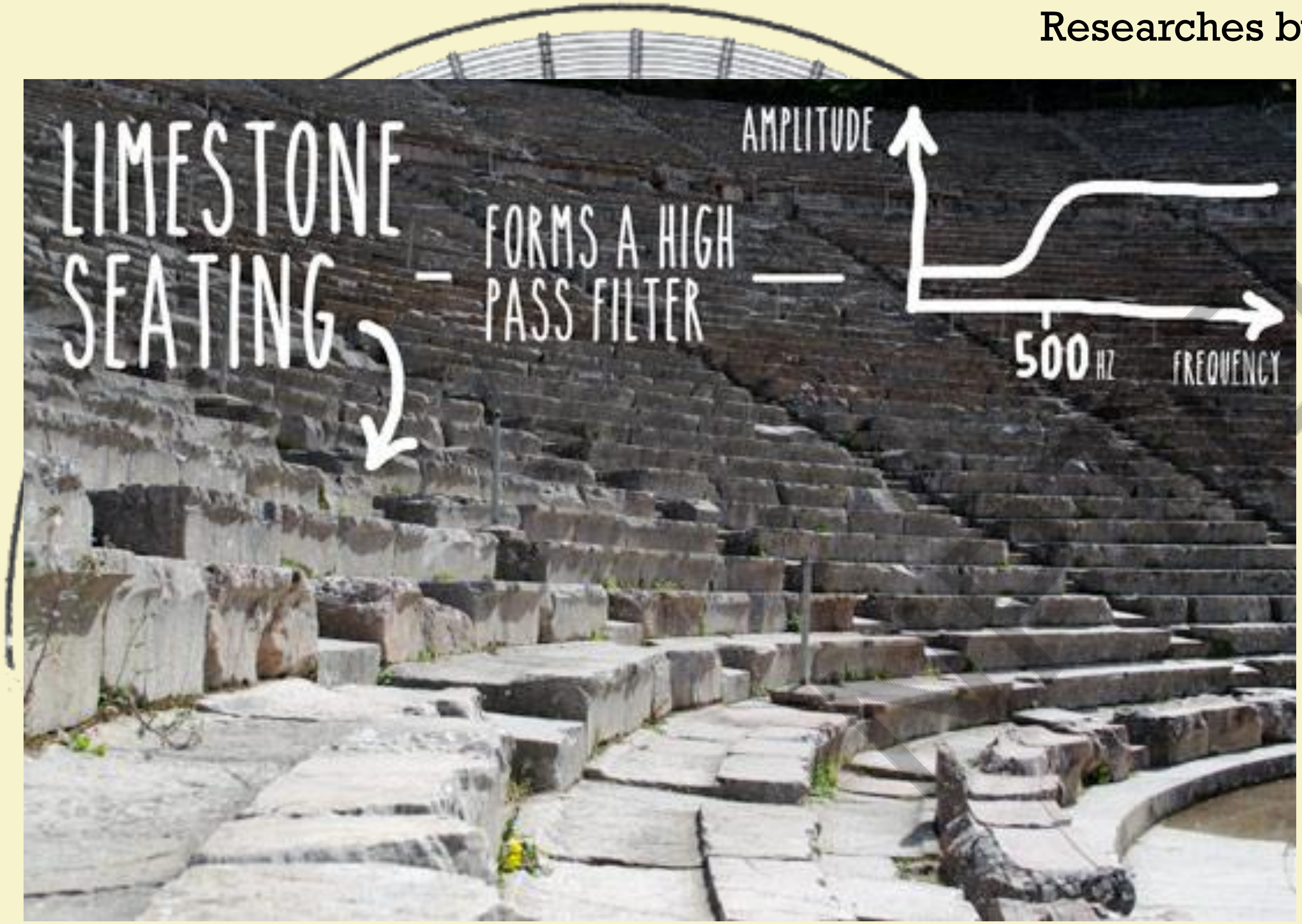
Seating plan: segmented circle, more than 180°, mostly on hill-sides facing the sea.

Steeply raked seats, low background noise, increased intelligibility

Early Greek

Source: Wikimedia Commons

Early Greek



Researches by Georgia Institute of Technology (2007) finds:

limestone seats filter out low frequency sounds

amplifies high frequency sounds from the stage

Seating formed corrugated surfaces
acted as filters to emphasize certain frequencies

prevailing direction of the wind blows mainly
from the stage to the audience

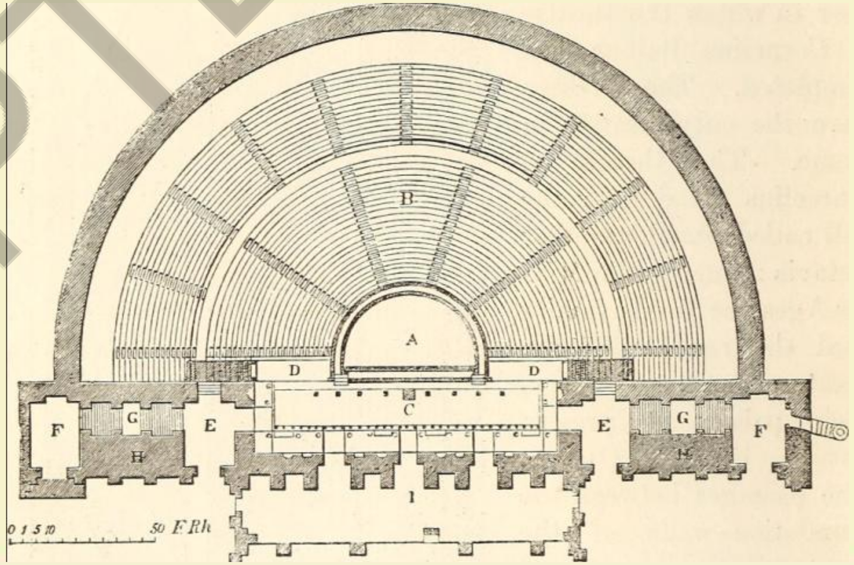
Source: Wikimedia Commons

Early Greek

The thick vegetation behind which absorb sound, Epidaurus, 330BC

Early Roman

- Seating arc limited to 180°.
- Used arch features instead of hill slopes
- Added a stagehouse (*skiene*) behind the actors, a raised seating area (*proskenion*), hung awnings (*valeria*) to shade the patrons
- Aspendius Roman theatre, Turkey



Typical Plan During Roman Period

Source: Wikimedia Commons

Observations from past

Conclusions

Minimisation of external noise – selected sites along hill slopes

Sufficient directly propagated sound – considered wind direction

Sound from first reflections – made steps along hill slopes
– used material like limestone

Control of late reflections and elimination of echoes – trees and vegetation

Orientation for acoustical advantage – facing the sea, wind direction

Tasks

Revisit Lecture 1 and find the planning considerations followed in the ancient amphitheaters which are scientifically proved and also applicable in todays context

Books:
Concepts in Architectural Acoustics, M. David Egan
Architectural Acoustics by M. Long
Room Acoustics by Heinrich Kuttruff, Applied Science Publishers Ltd, London
https://www.poseidonion.com/en/ancient-epidaurus-theatre
https://nl.wikipedia.org/wiki/Theater_van_Epidaurus

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Architectural Acoustics

Lecture 30: Open Air Theatre design & Acoustics

Dr. Sumana Gupta

Department of Architecture & Regional Planning

Learning Objective

Site location

Orientation

Seating plan and section

Acoustical plan

Site location

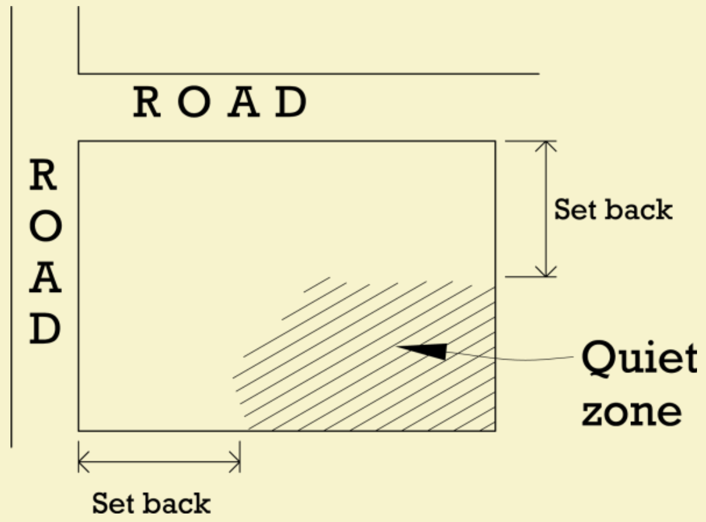
Minimisation of external noise

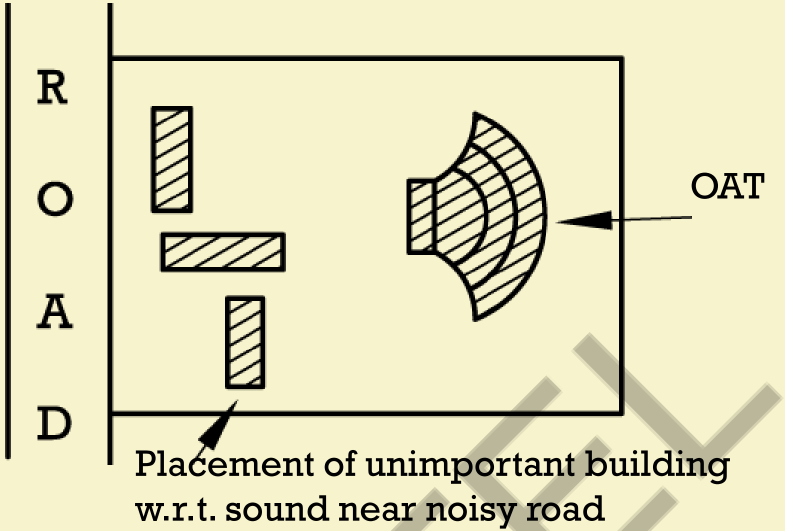
Noise level should be below 40dB

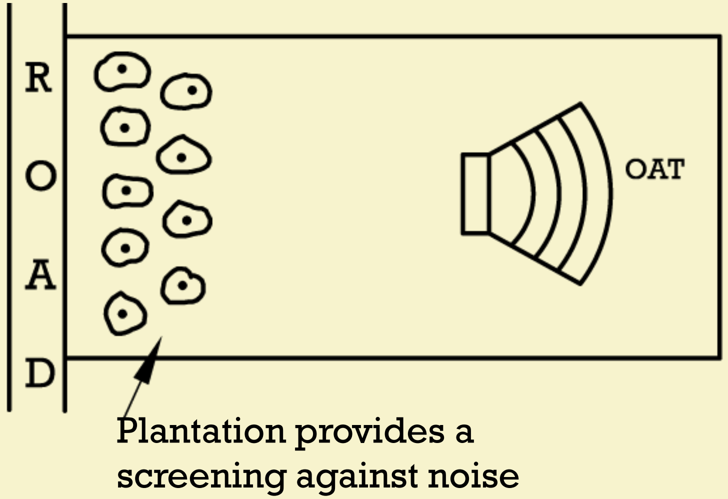
Topographical aspects

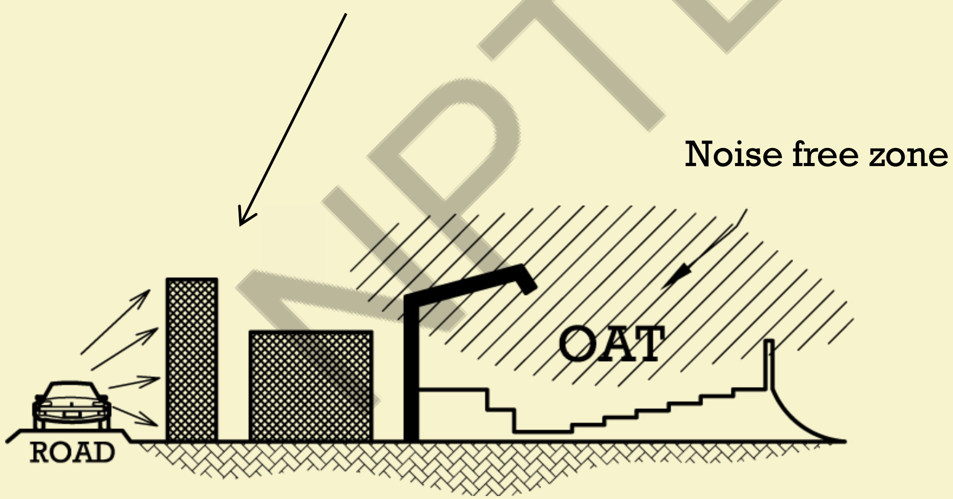
Quite zone in flat site
Down hill slope against noise
Raised location within site

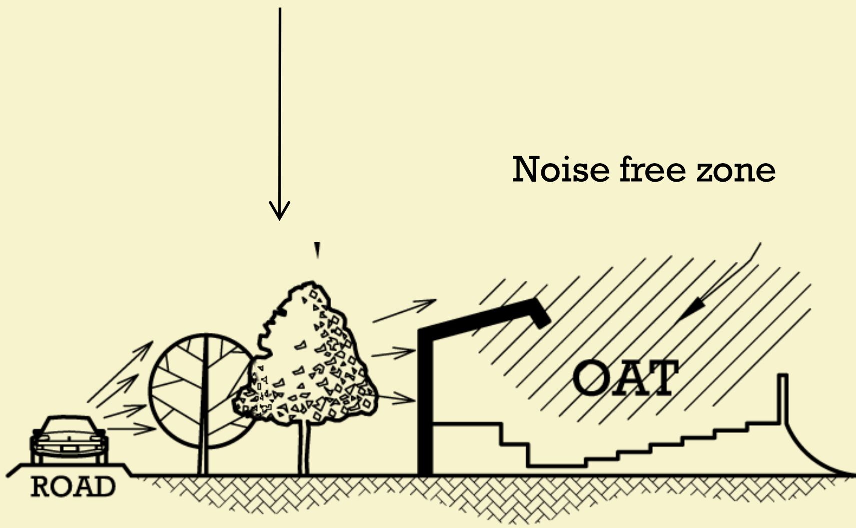
Locating open air theatre











Capacity up to 600 for unreinforced sound

Orientation

Time of performance and sun path

- performer and sun path - use of awnings, shadings
- audience should not face sun

Effect of Temperature

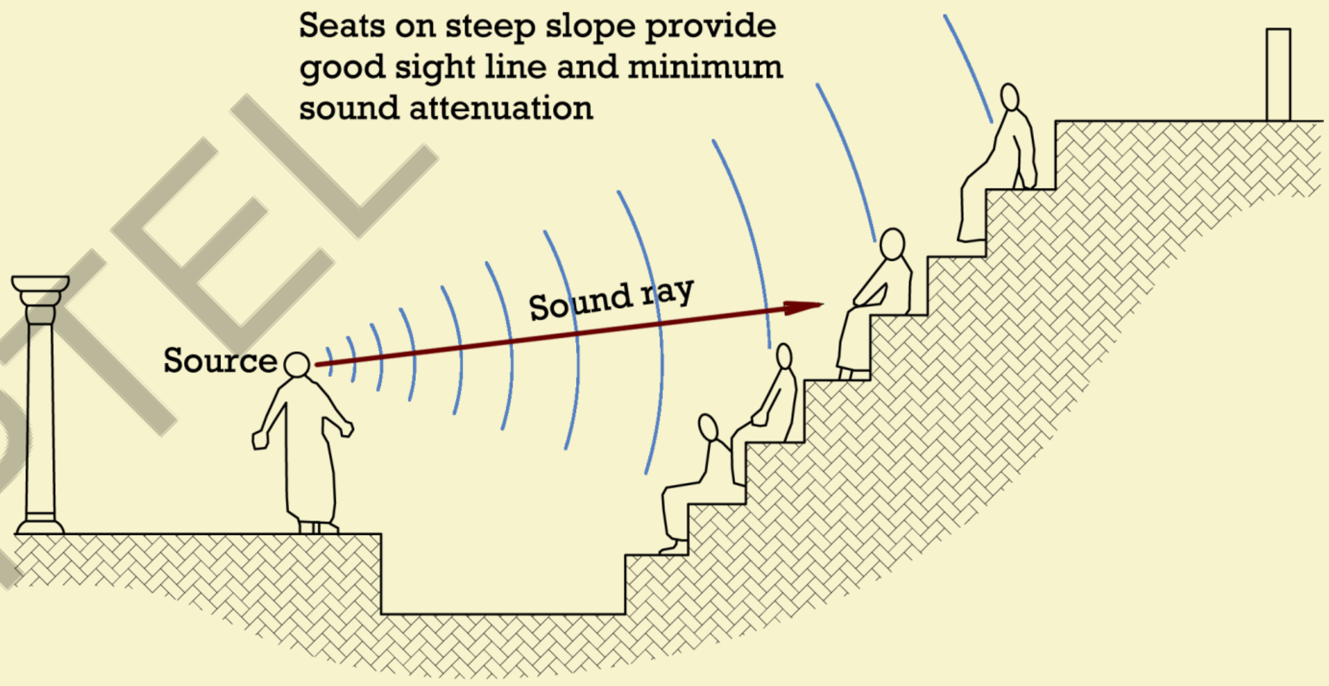
- should be accounted if it is day time gathering under open sky ex. Public (youth, devotees)gatherings addressed by political, religious leaders

Control of late reflections and elimination of echoes avoiding buildings in backdrops

Source: internet pictures

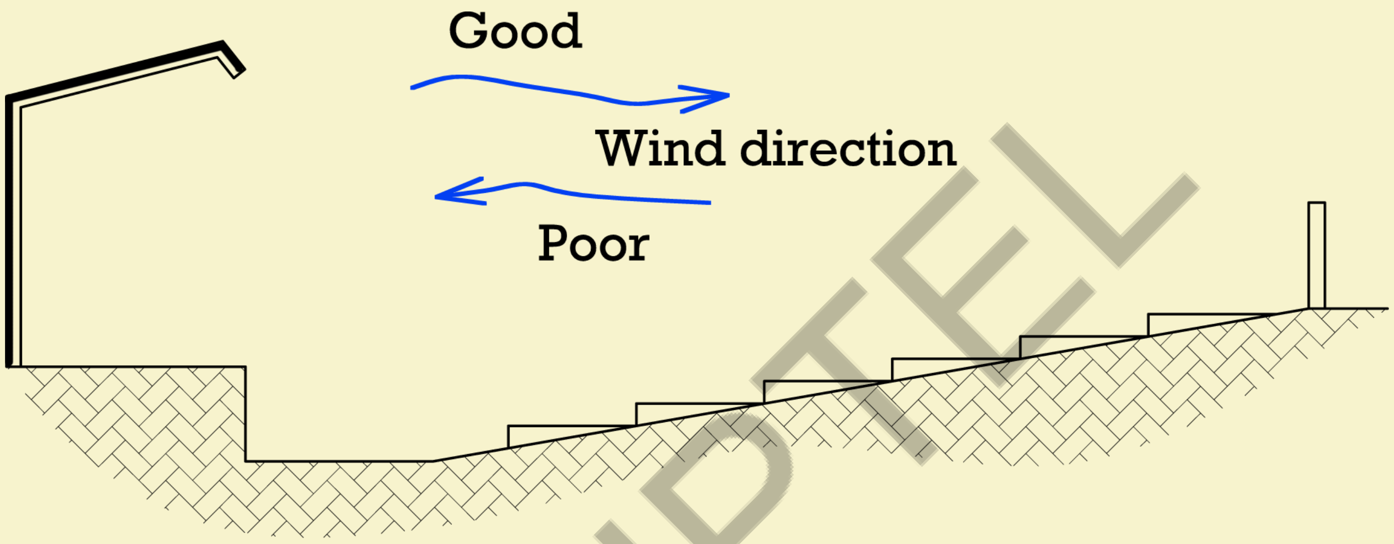
Greek Theatre were characterised by

- Open air
- Direct sound
- Steep slope
- No sound reinforcement
- Minimal reverberation



Accounting wind direction for acoustical advantage

- Sufficient directly propagated sound



A hard surface in between stage and first row seating

Wind helps carrying sound to the back seats

Stepped seating helps in early reflections to reinforce sound

Seating

Stepped seating allows reflection from proscenium (stage).

To get sufficient directly propagated sound – need for compact planning

welcome sound from first reflections

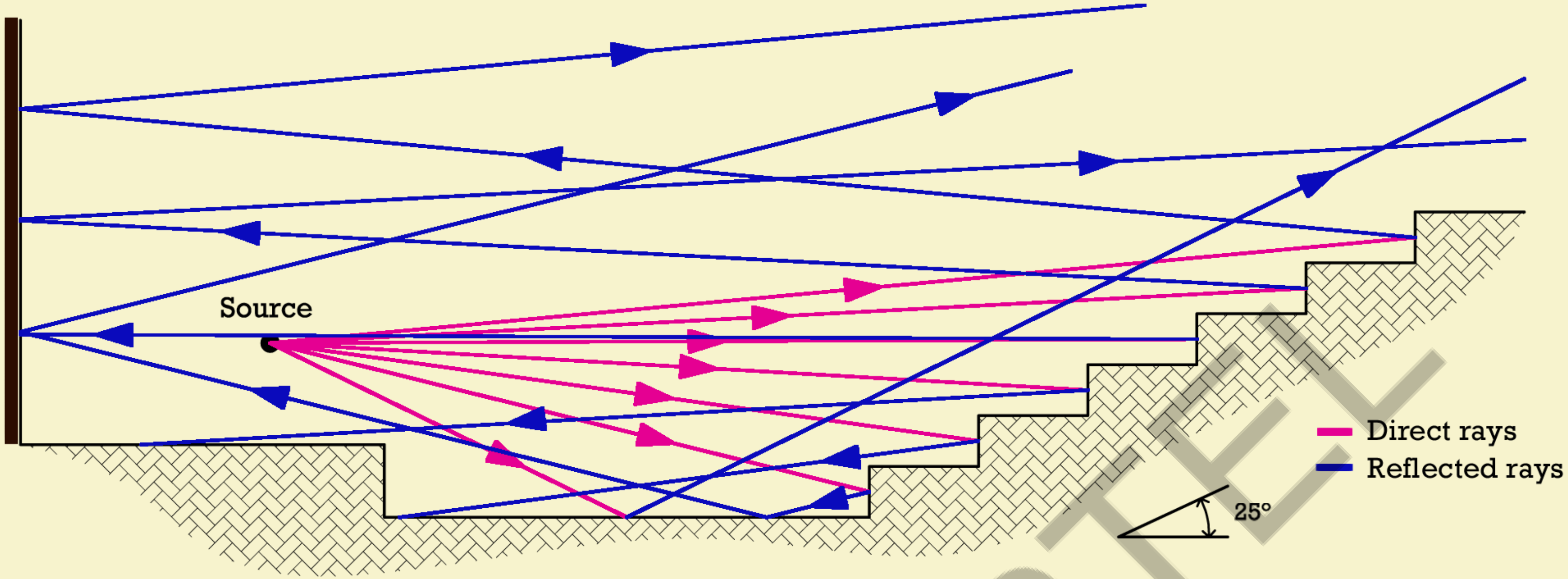
Sound bounces back and forth from vertical risers and stage wall.

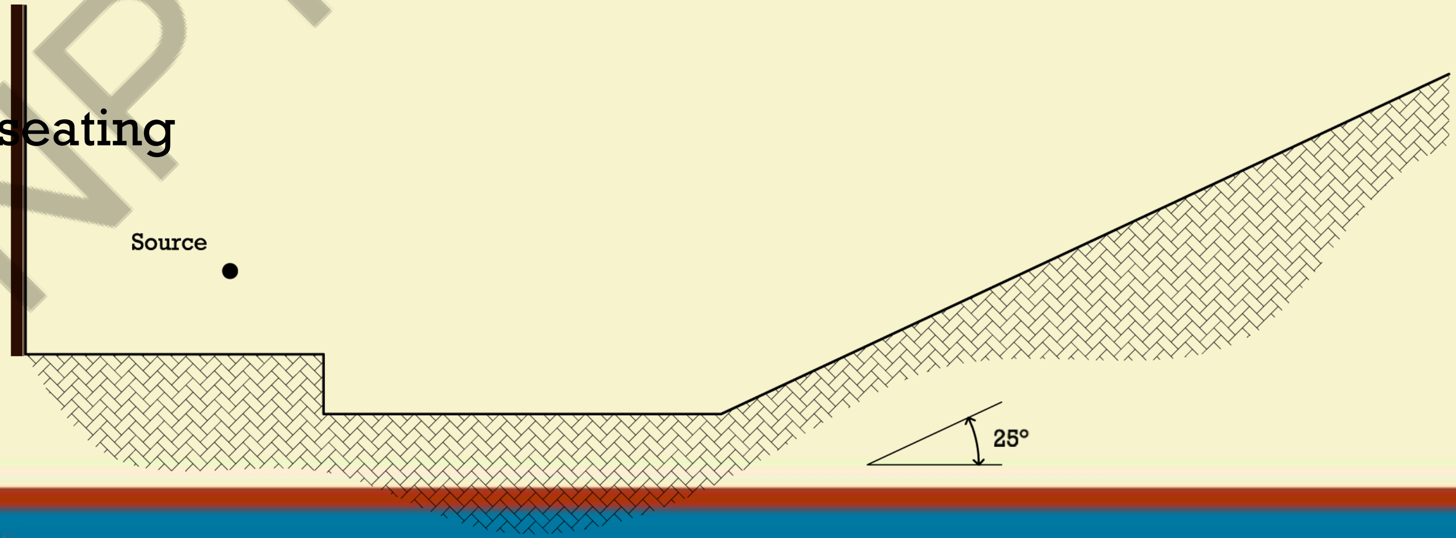
Delayed reflection may happen from back wall to be checked.

Scattered energy is required to fill in the gaps between fewer reflected sound unlike closed space design.

Diffraction and scattering from seating areas help to achieve a smooth sound decay curve.

Seating





The same cannot be achieved by sloped seating

Inverse cone directs sound upward, loss of energy and fewer reflected sound undesired design

Sound reflected from the tiers of benches, if at a distance, produces a sustained echo.

Pitch can be determined by the distance separating the risers.

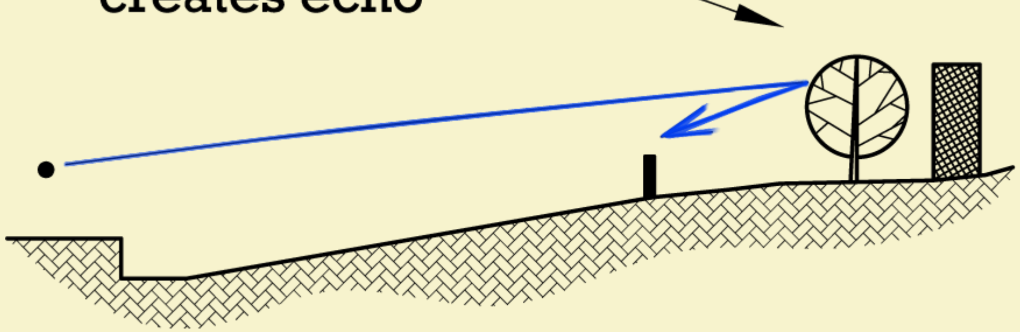
This causes distortion in some frequencies and affects sound quality

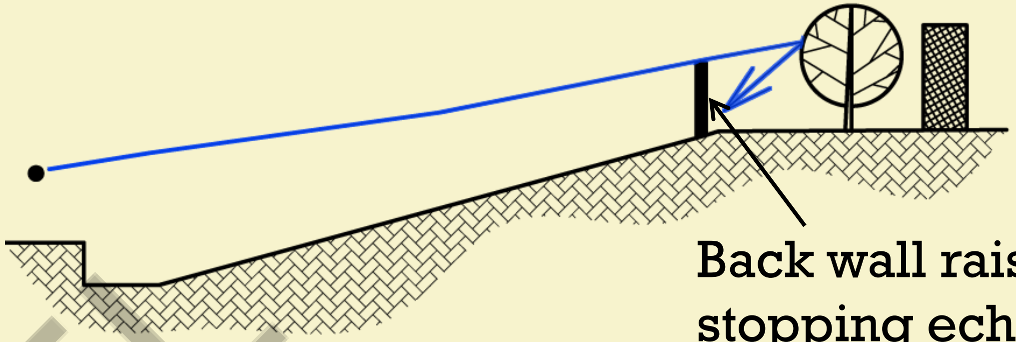
In OAT the frequency dependent reflections generally can pass overhead but they can converge to the stage disturbing the performers

Provision for covering stage - Performer audibility and directing sound

Condition for stopping echo

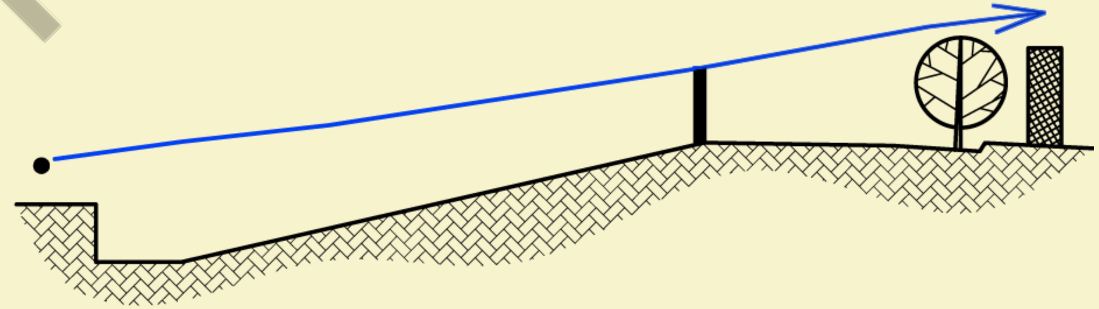
Building/forest at the back creates echo





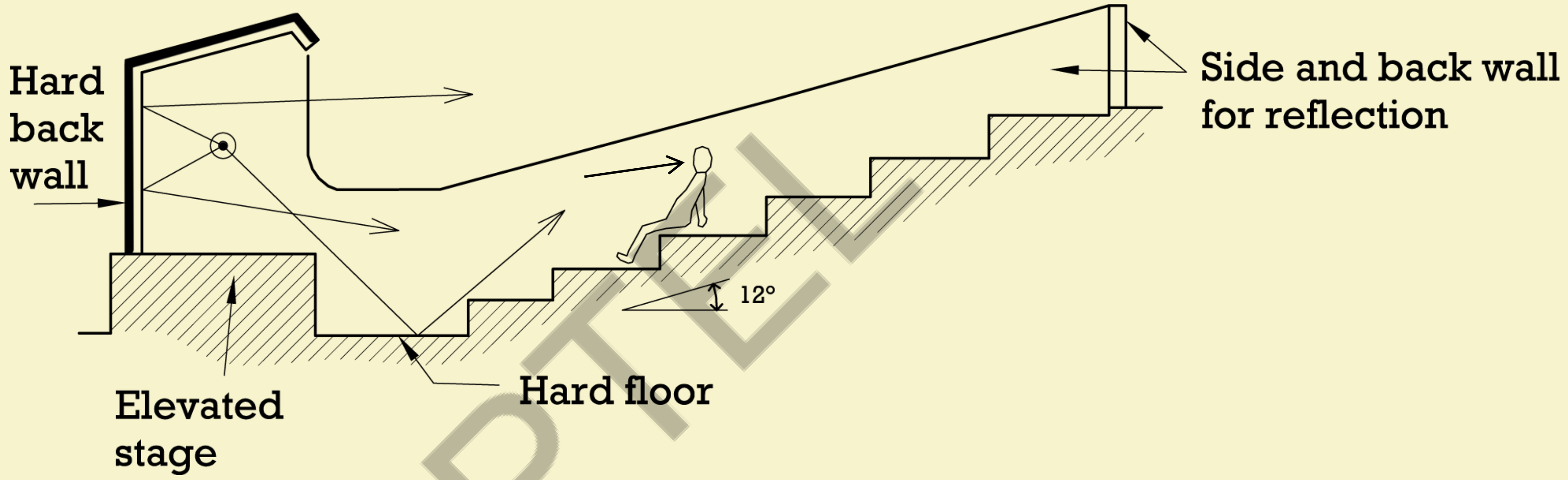
Back wall raised stopping echo

Dense foliage reflects sound



Steep slope and high back wall stops echo

Provision of Back wall/ side wall

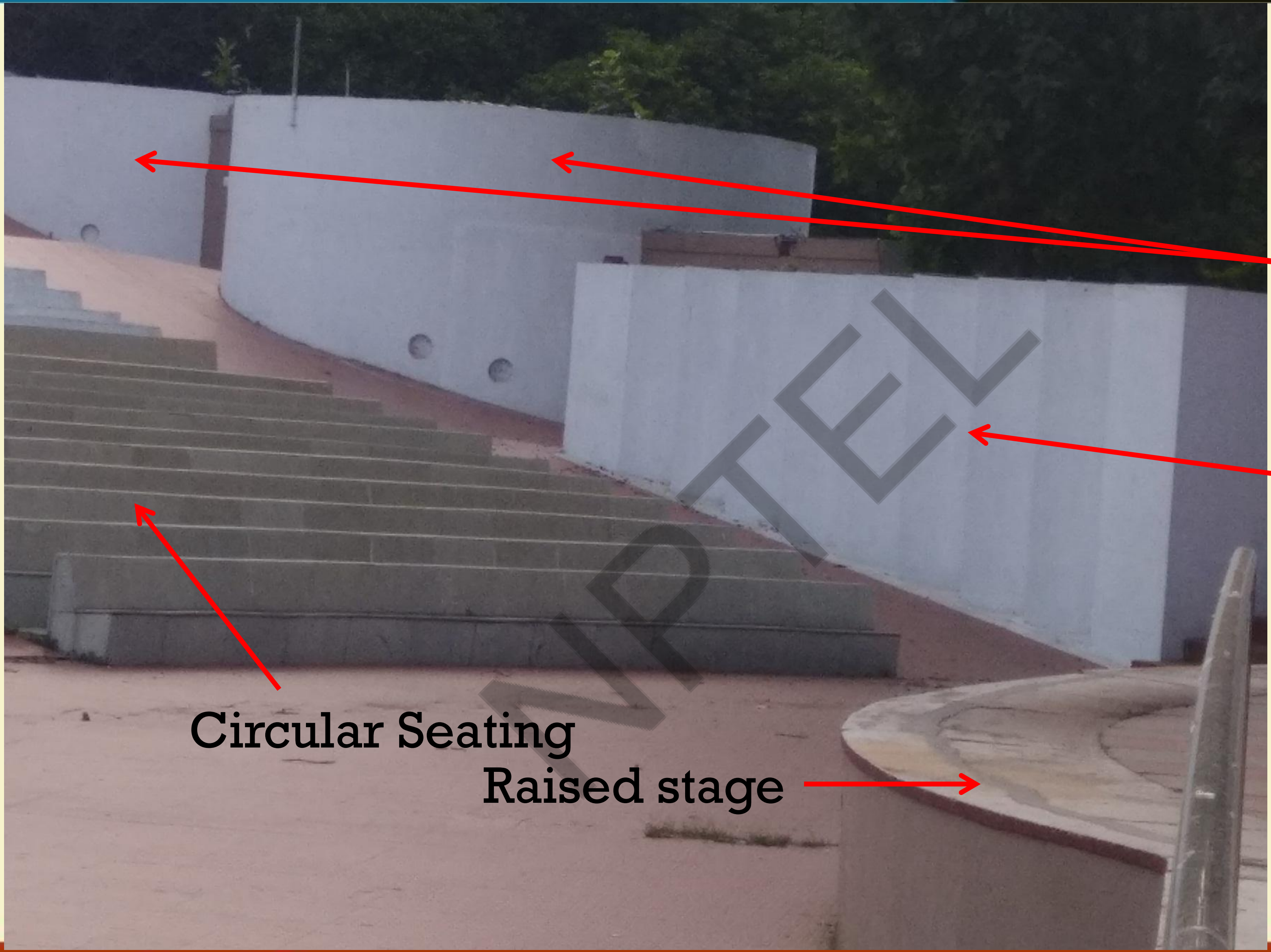


Creation of a closed space plan with
limitation of the lateral openings at the side entrances

Lateral walls may be diffusive / convex surface to help scatter sound to floor

Dense foliage to partly absorb & partly reflect sound

Circular compact seating plan with gradient



Two entries on lateral wall

Curved surface to disperse sound

Folded surface for sound diffusion

Open air stadiums require cut down on reverberations that can interfere with announcements and other speech.

In stadiums designers often use fiberglass and other porous materials to absorb sound. Roof should direct sound to field.

Crowd noise in stadiums during moments of high excitement in games is typically between 95 to 105 dB and even 110dB.

Steeper grandstands make more noise since the fans are all closer to the playing field. A roof or dome holds noise in and directs it towards the field.

Giant open air bowl configuration dissipates noise.

Melbourne Cricket Ground

Source: Wikimedia Commons