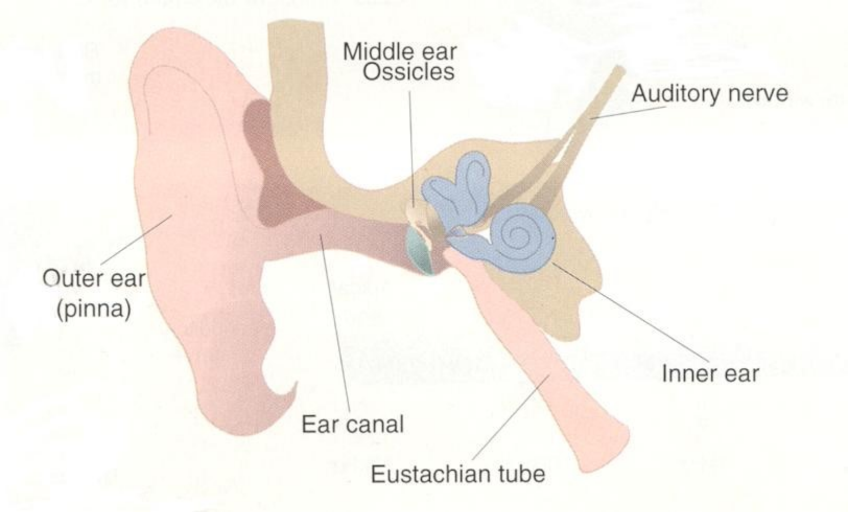
SOUND 1

ACOUSTICS
AND
PSYCHOACOUSTICS

The Ear:

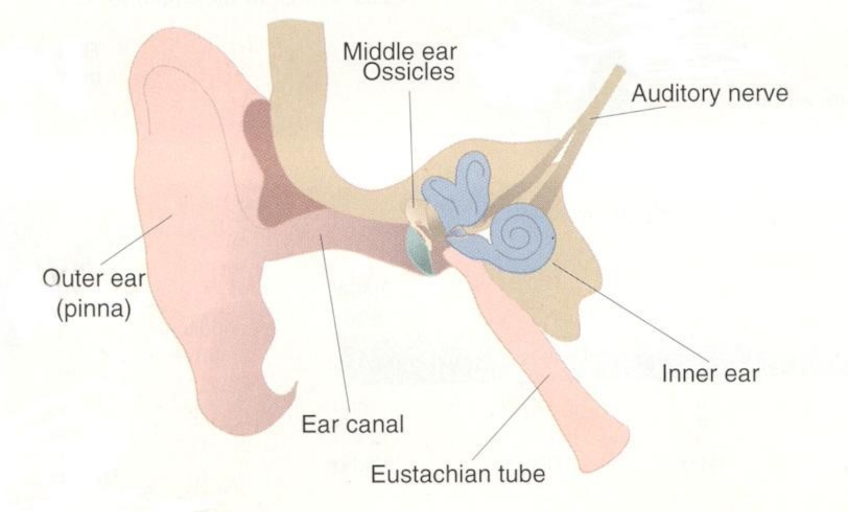
The Ear:

The ear is the organ of hearing.



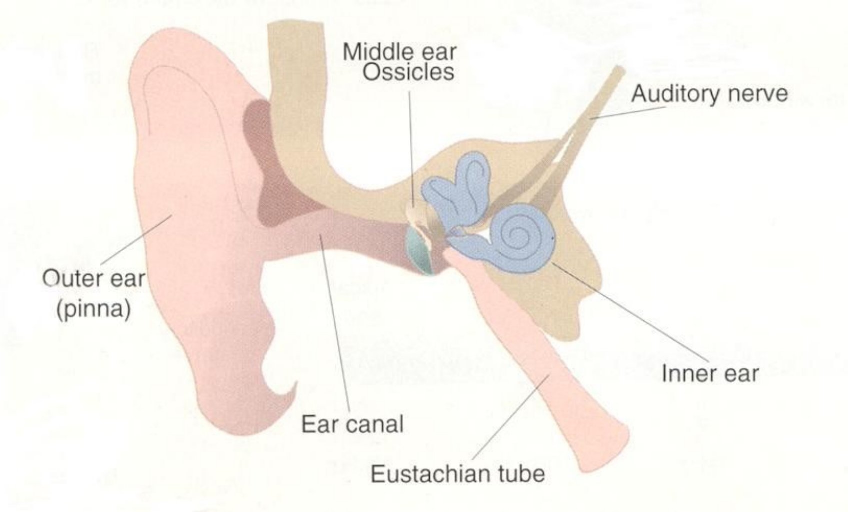
The Ear:

The outer ear or "pinna" collects sound waves and directs them into the "ear canal".



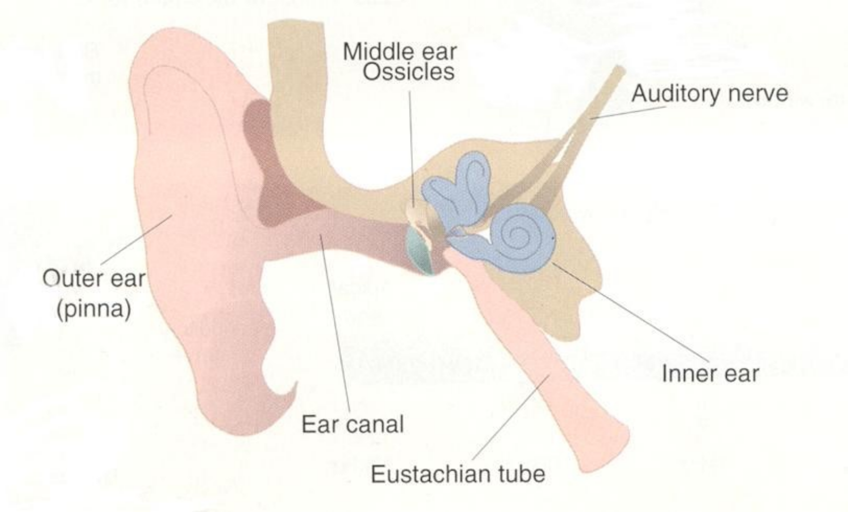
The Ear:

The ear canal conducts vibrations to the "inner ear".



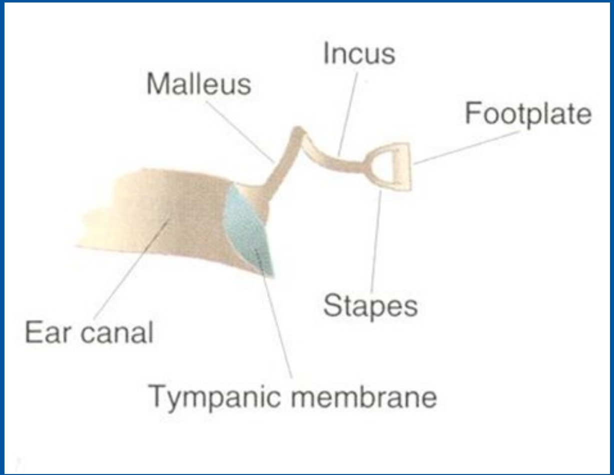
The Ear:

The "eustachian tube" serves to equalize air pressure differences between the inner and outer ear.



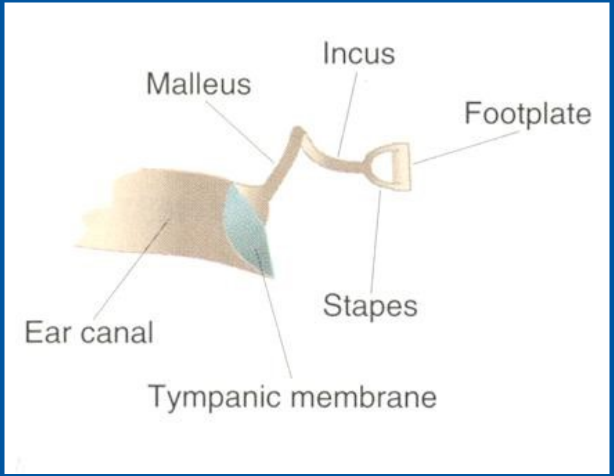
The Ear:

The ear canal ends in the ear drum or "tympanic membrane". Sound waves entering the ear canal cause the ear drum to vibrate.



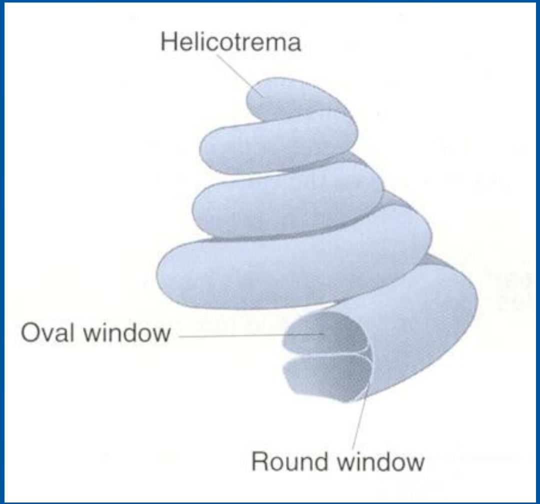
The Ear:

A series of small bones, the "ossicles“, attached to the ear drum, serve as a mechanical transformer, to maximize the transfer of energy from the ear drum to the liquid-filled "cochlea".



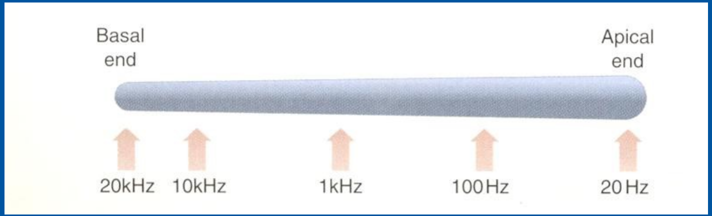
The Ear:

The cochlea is a spiral tube, filled with liquid and lined with small, hair-like fibres. Vibrations induced in the liquid, stimulate the auditory nerve which sends information to the brain.



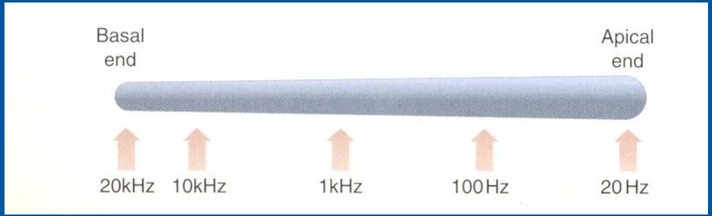
The Ear:

This is a view of the cochlea, uncoiled for clarity.



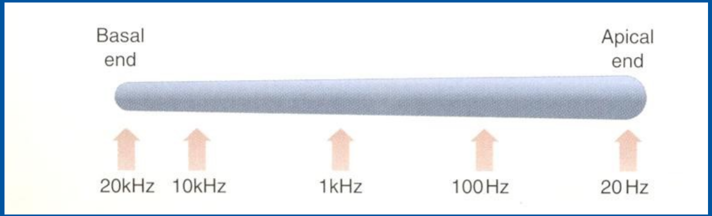
The Ear:

The lower or "basal" end is sensitive to high frequencies;



The Ear:

The lower or "basal" end is sensitive to high frequencies; while the upper or "apical" end is sensitive to low frequencies.

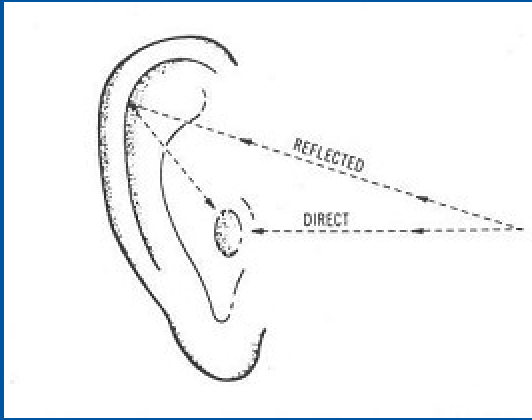


Vertical Localisation:

Reflections from the pinna (outer ear) make the ear directional in the vertical plane.

Vertical Localisation:

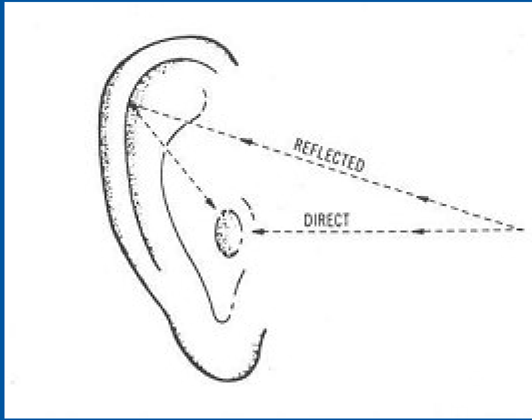
Sound originating in front of a listener arrives at the ear canal via two paths:



Vertical Localisation:

Sound originating in front of a listener arrives at the ear canal via two paths:

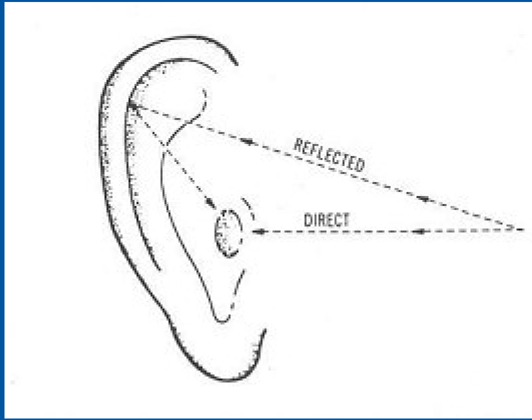
– directly



Vertical Localisation:

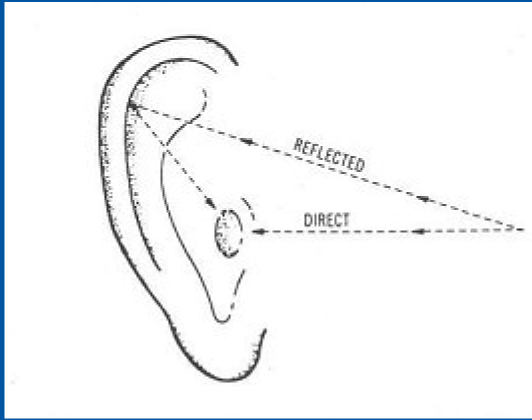
Sound originating in front of a listener arrives at the ear canal via two paths:

- directly
- reflected from the folds of the pinna



Vertical Localisation:

The reflected path is slightly longer than the direct path.

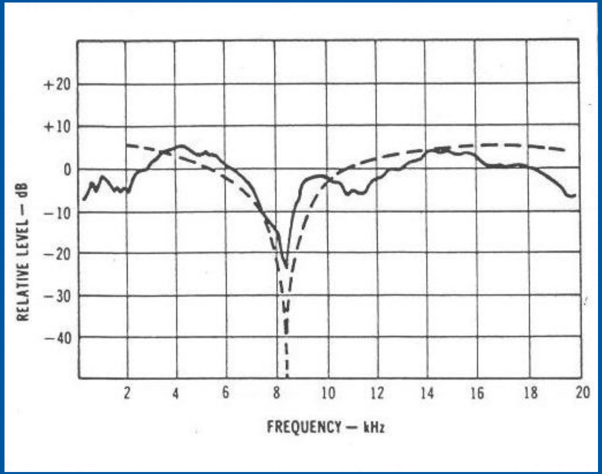


Vertical Localisation:

At some frequency, the two paths will differ by a half wavelength.

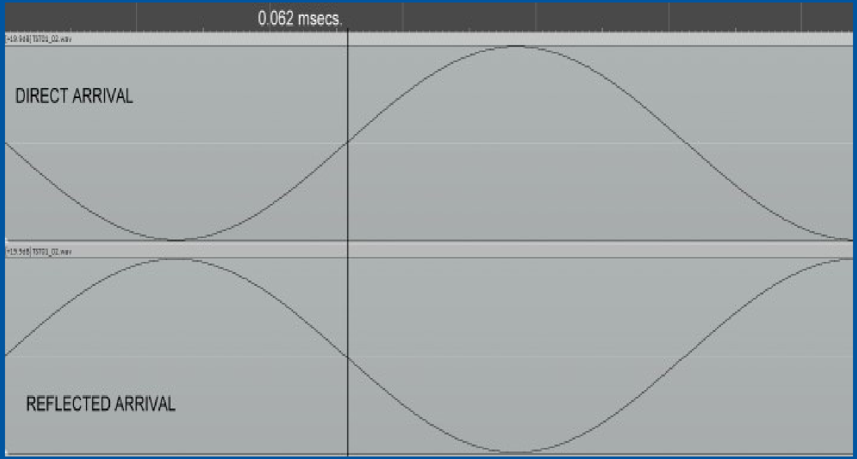
Vertical Localisation:

At that frequency, the two waves will cancel each other out.



Vertical Localisation:

For instance, if the difference is 0.8 inches, the reflected sound would arrive 0.062 msecs. after the direct sound.



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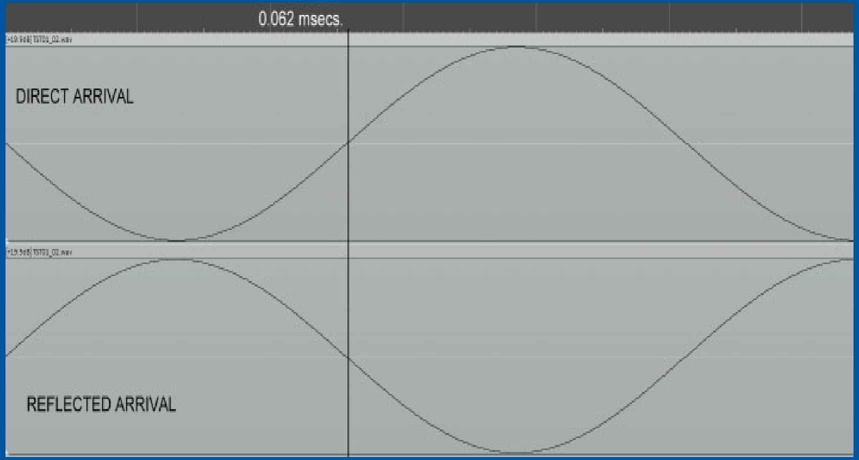
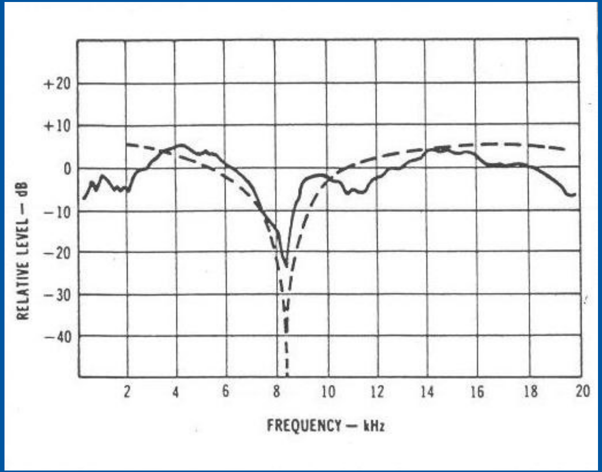


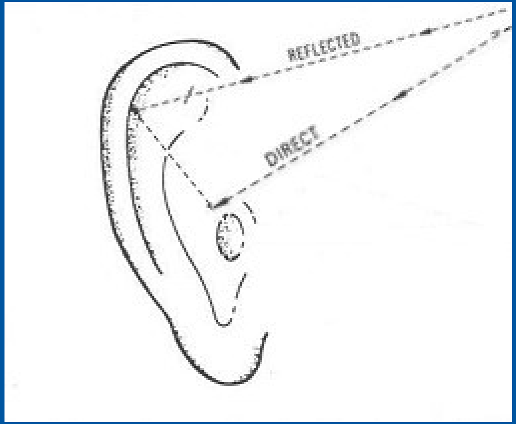
Vertical Localisation:

This would result in a cancellation at 8.1 kHz.



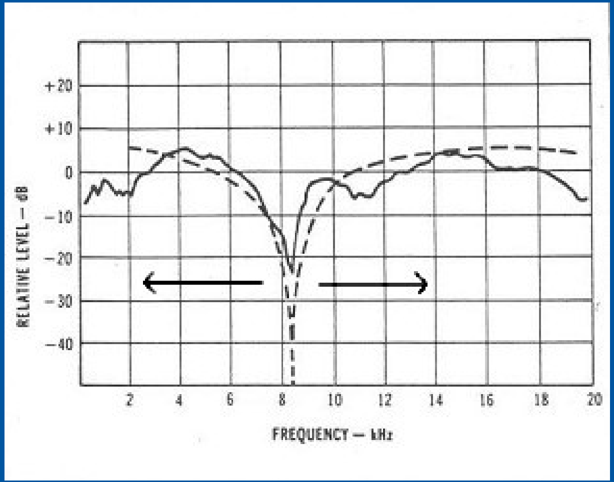
Vertical Localisation:

If a sound originated from a higher elevation, the difference between the two paths would change,



Vertical Localisation:

If a sound originated a higher elevation, the difference between the two paths would change, causing the cancellation to happen at a different frequency.



Horizontal Localisation:

In the real world, the ear-brain system uses two methods to identify horizontal direction:

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- relative amplitude

Horizontal Localisation:

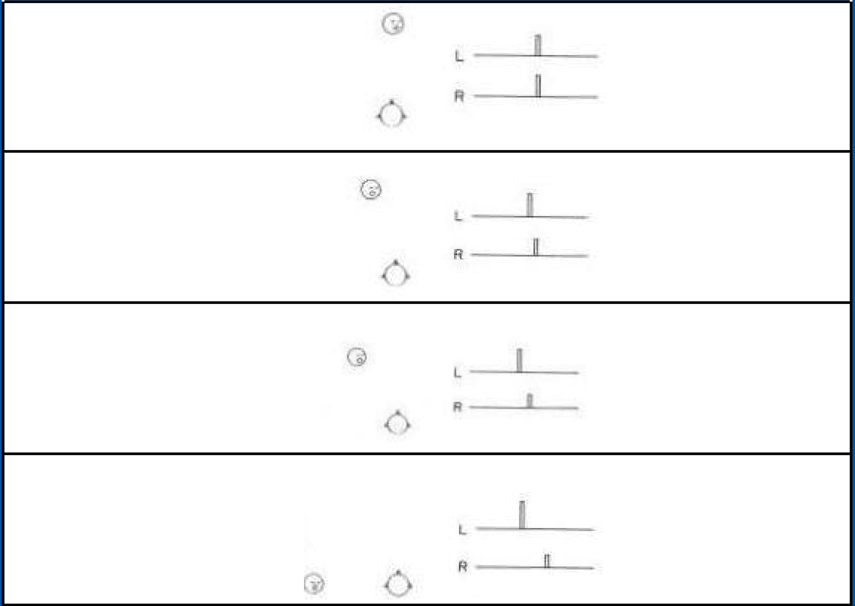
In the real world, the ear-brain system uses two methods to identify horizontal direction:

- relative amplitude
- arrival time

Horizontal Localisation:

Sound from a source directly in front of the listener will arrive at both ears:

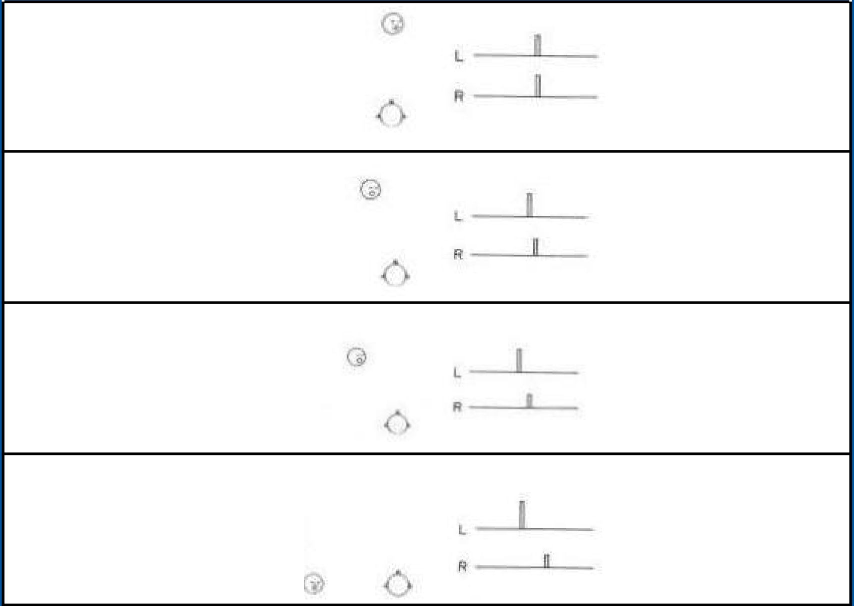
Natural Localisation



Horizontal Localisation:

Sound from a source directly in front of the listener will arrive at both ears:

– equal in loudness

Natural Localisation


Horizontal Localisation:

Sound from a source directly in front of the listener will arrive at both ears:

- equal in loudness
- coincident in time

Natural Localisation

Horizontal Localisation:

Sound from a source slightly to the left of the listener will arrive at the left ear :

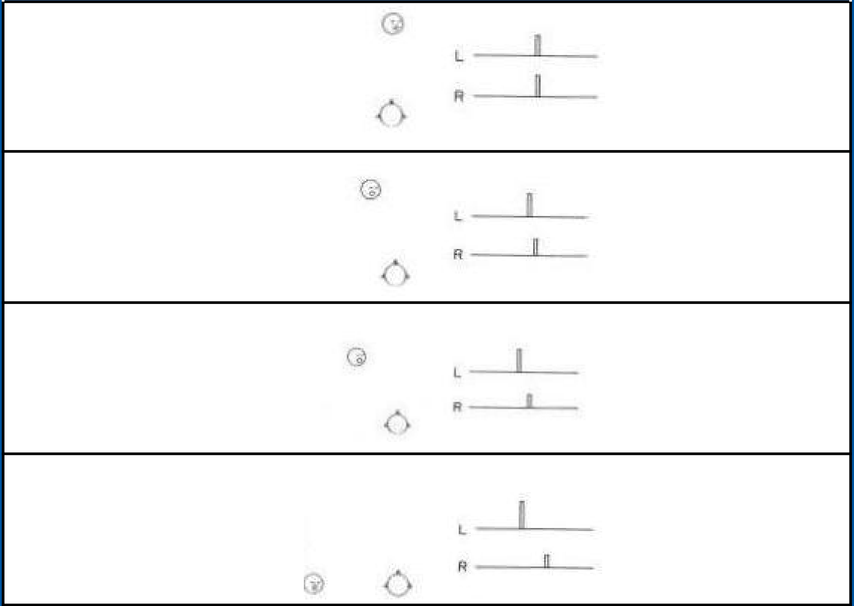
Natural Localisation

Horizontal Localisation:

Sound from a source slightly to the left of the listener will arrive at the left ear :

– slightly louder

Natural Localisation

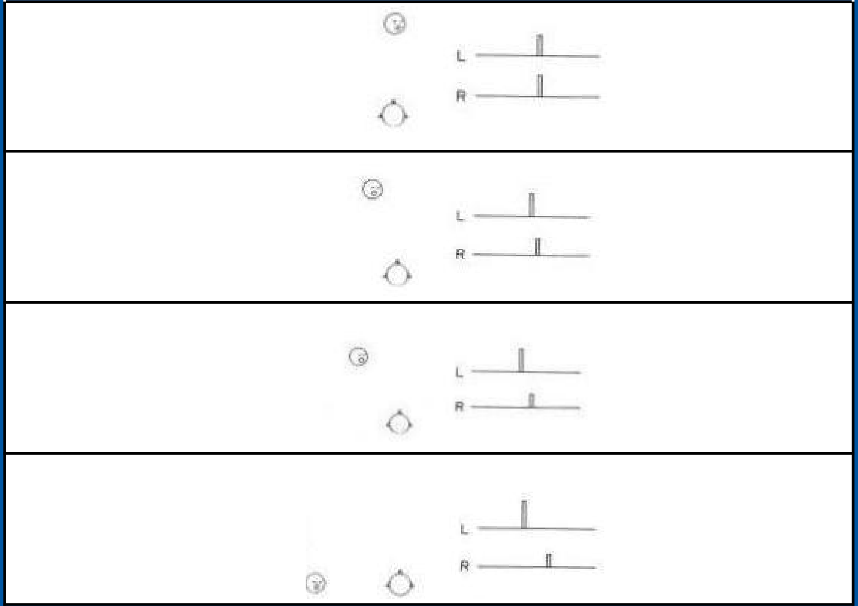


Horizontal Localisation:

Sound from a source slightly to the left of the listener will arrive at the left ear :

- slightly louder
- slightly earlier

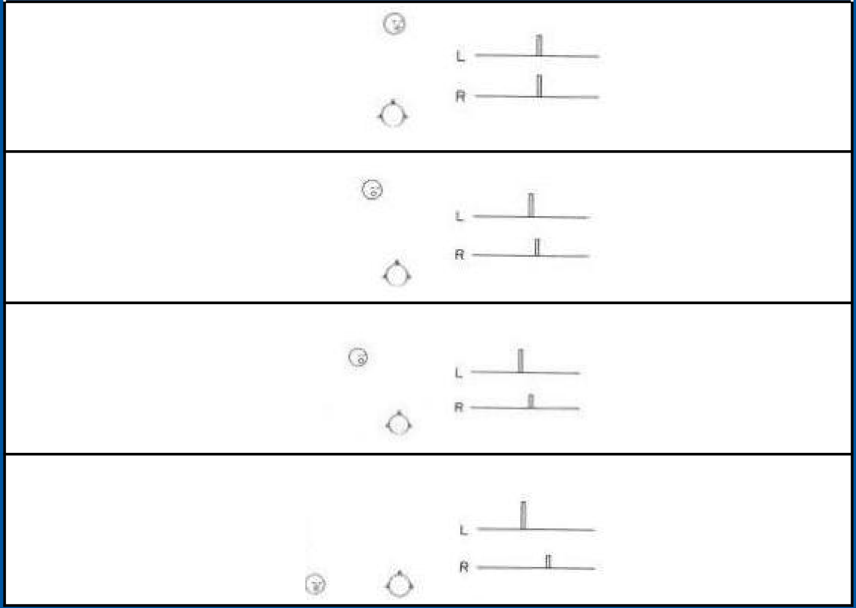
Natural Localisation



Horizontal Localisation:

Sound from a source extremely to the left of the listener will arrive at the left ear :

Natural Localisation

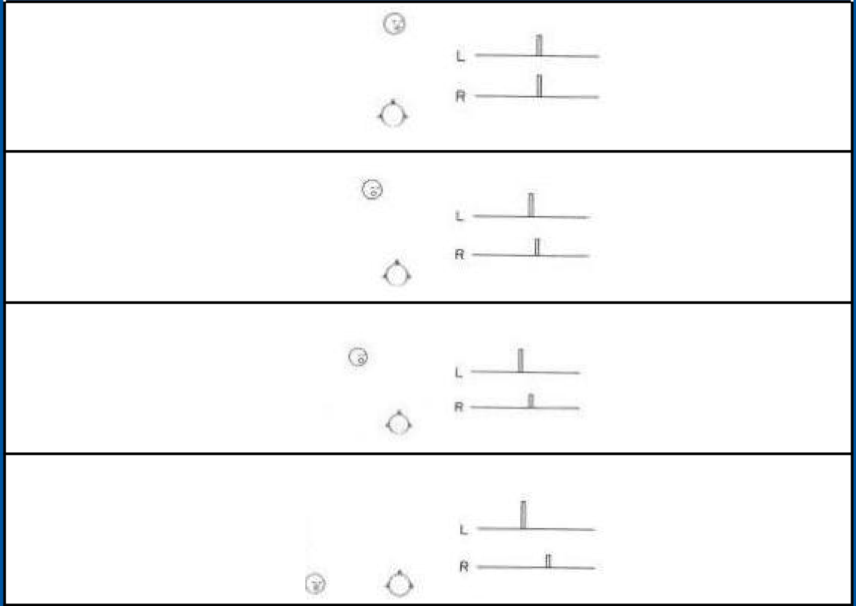


Horizontal Localisation:

Sound from a source extremely to the left of the listener will arrive at the left ear :

– much louder

Natural Localisation

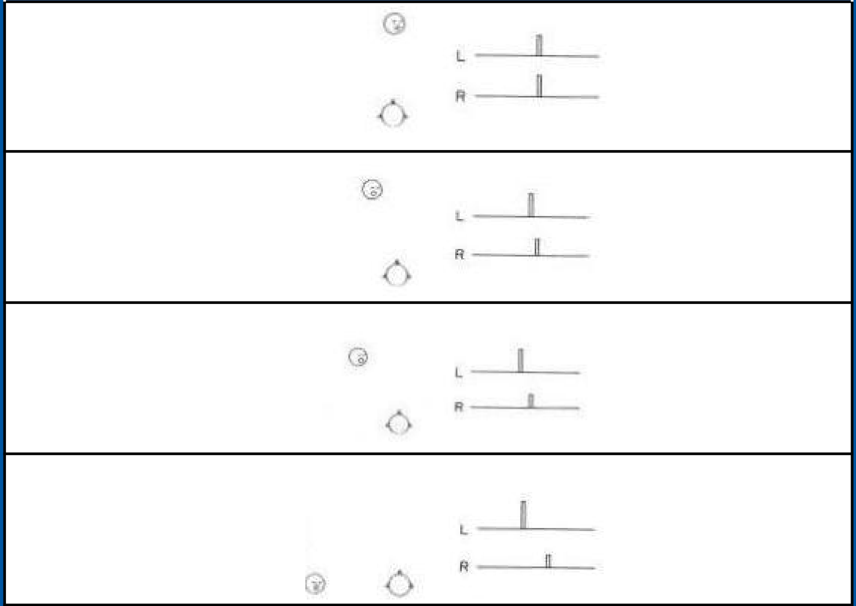


Horizontal Localisation:

Sound from a source extremely to the left of the listener will arrive at the left ear :

- much louder
- much earlier

Natural Localisation



Horizontal Localisation:

In the theatre, one could use an individual speaker to reproduce the location of every possible sound source.

Horizontal Localisation:

For some productions, or for a moving source, this could result in an unmanageable number of speakers.

Horizontal Localisation:

It is more practical to use two loudspeakers to simulate left-right directionality in the horizontal plane.

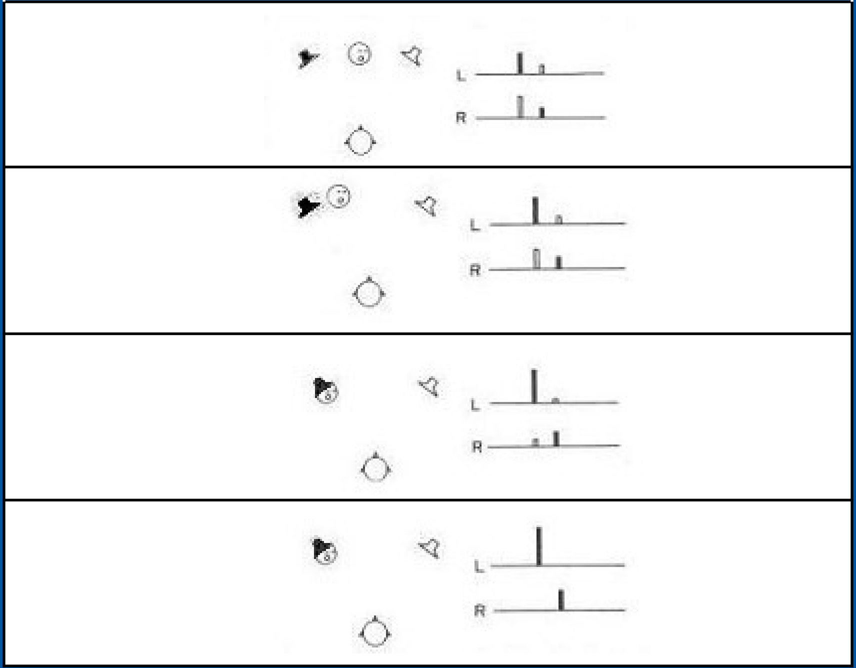
Horizontal Localisation:

In the Casgrain, for instance, we have speakers placed to the left and right of the proscenium.

Horizontal Localisation:

If a sound is played at equal level on two speakers, the sound seems to emanate from the centre line of the speakers.

Amplitude Difference

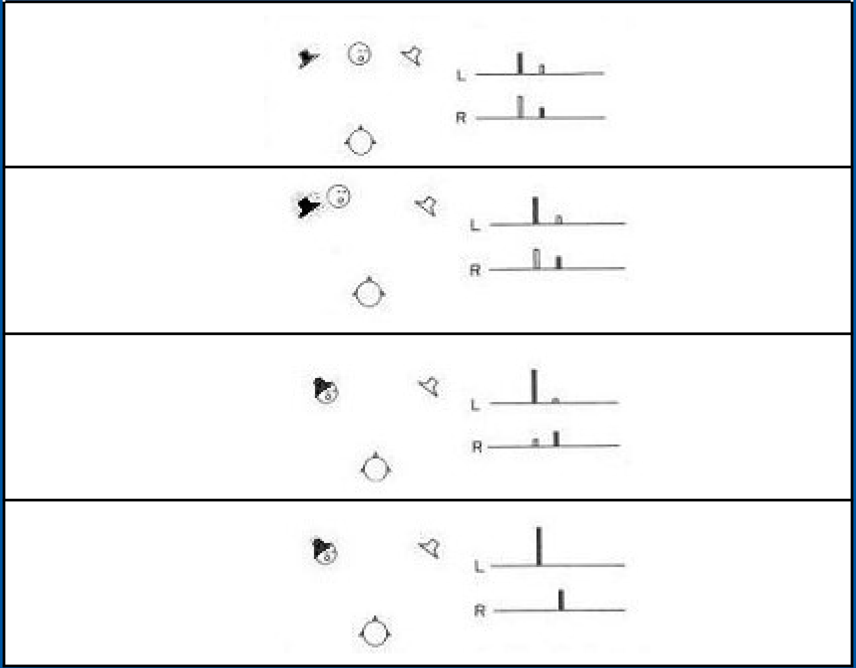


Horizontal Localisation:

If a sound is played at equal level on two speakers, the sound seems to emanate from the centre line of the speakers.

If a sound is played slightly louder on the left speaker, it seems to emanate from slightly to the left of the centre line of the speakers.

Amplitude Difference



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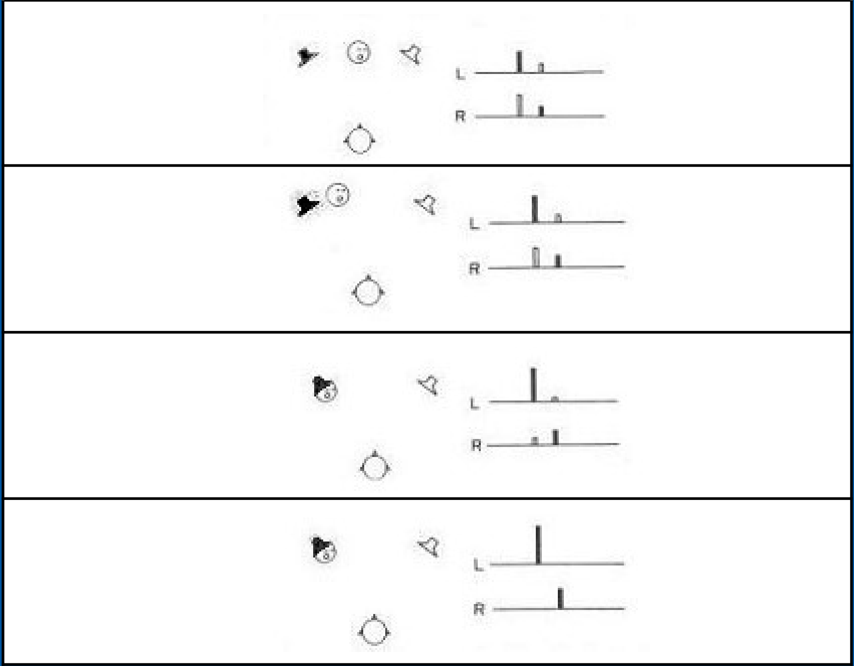
If a sound is played at equal level on two speakers, the sound seems to emanate from the centre line of the speakers.

If a sound is played slightly louder on the left speaker, it seems to emanate from slightly to the left of the centre line of the speakers.

If a sound is played much louder on the left speaker, it seems to emanate from the left speaker only.

Amplitude Difference



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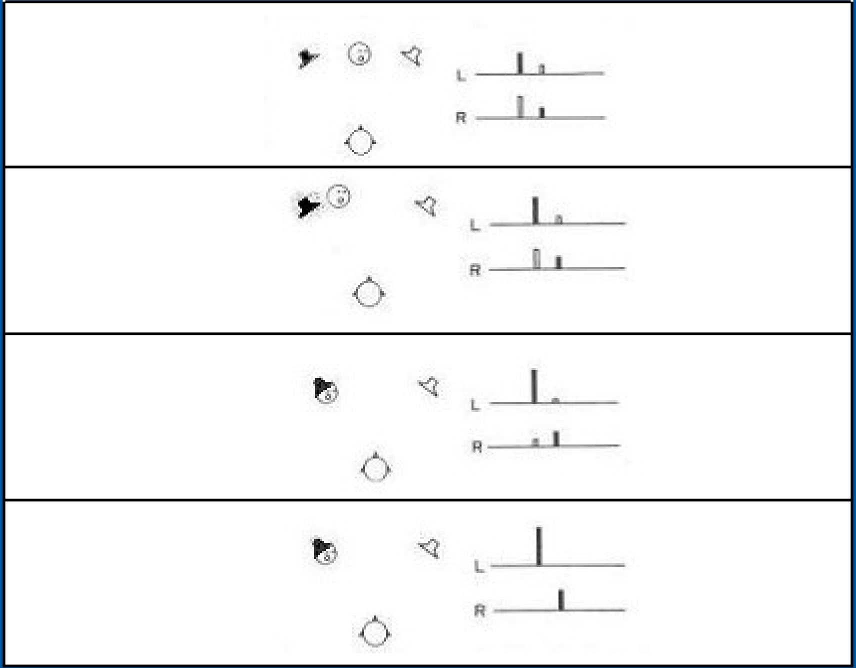
If a sound is played slightly louder on the left speaker, it seems to emanate from slightly to the left of the centre line of the speakers.

If a sound is played much louder on the left speaker, seems to emanate from the left speaker only.

No matter how much louder the sound is played on one speaker, we cannot make the sound appear to emanate from beyond the location of that speaker.

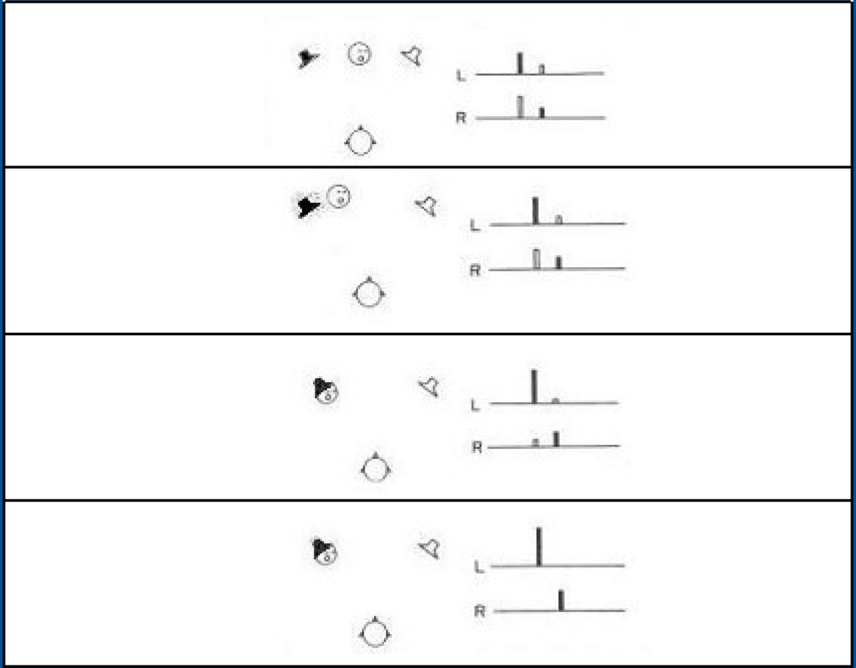
Amplitude Difference



Horizontal Localisation:

On the console, we use the "pan pot" to adjust the apparent left-right directionality of a sound.

Amplitude Difference



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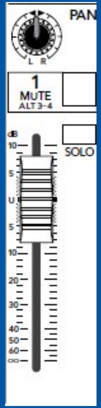

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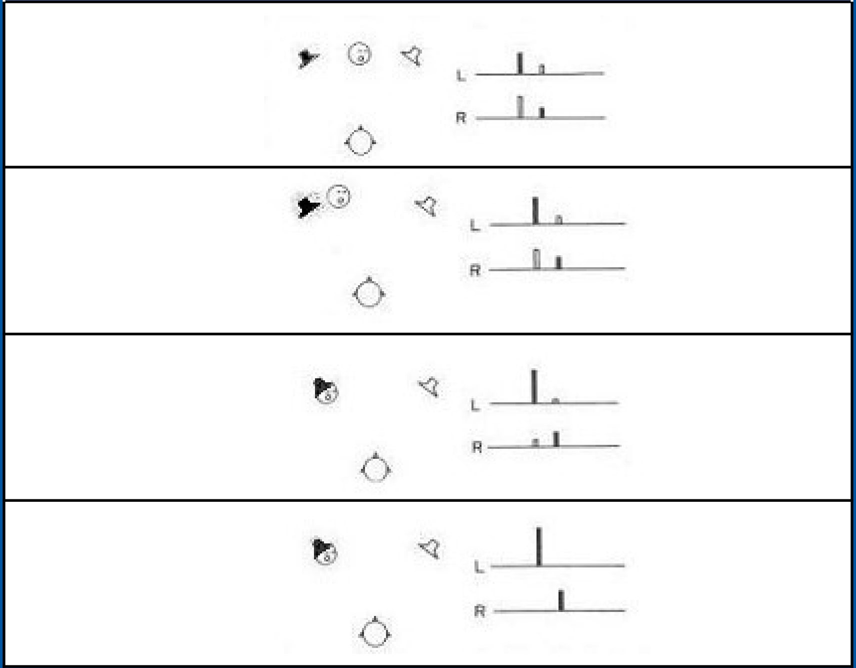

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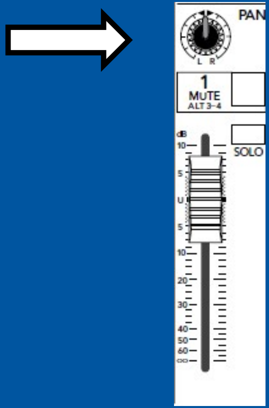

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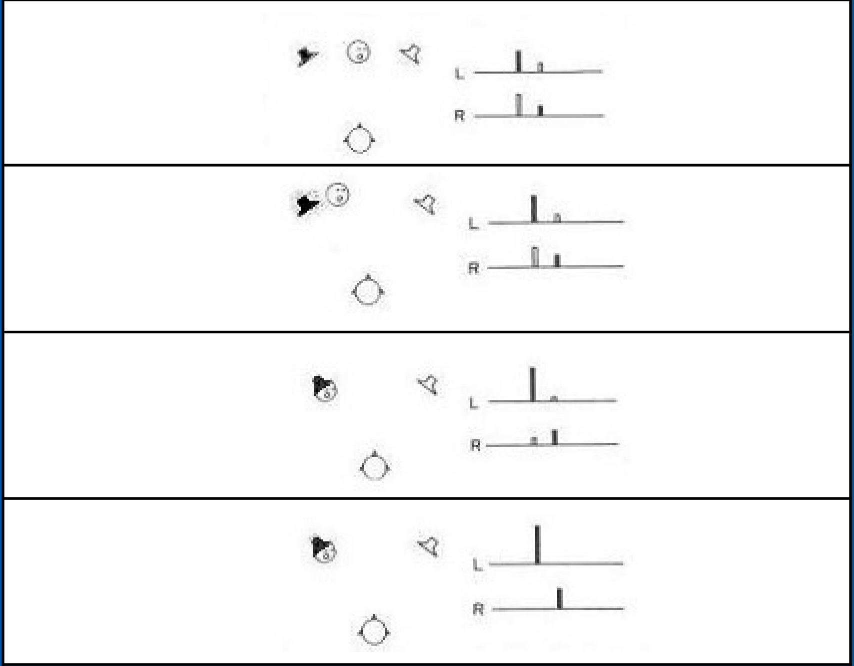

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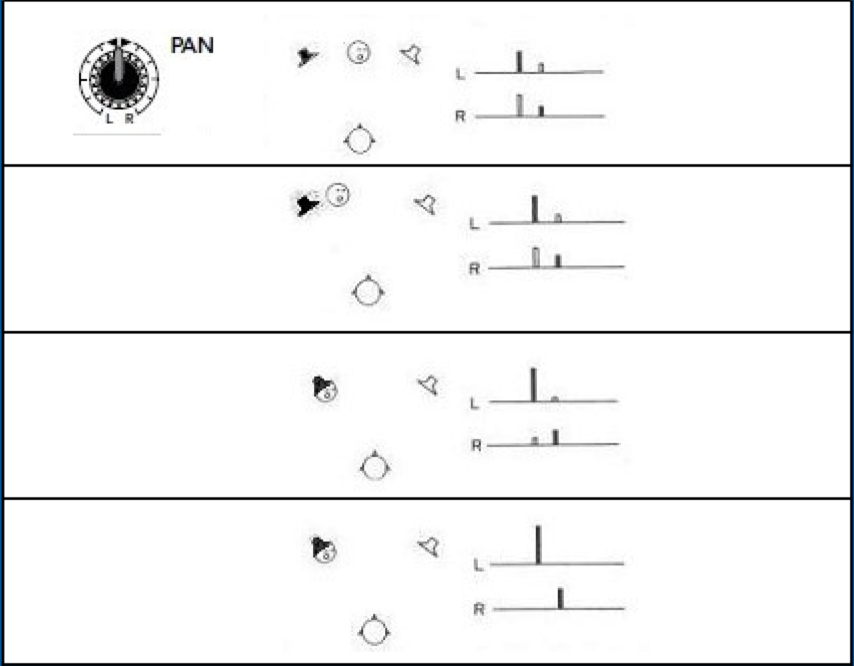

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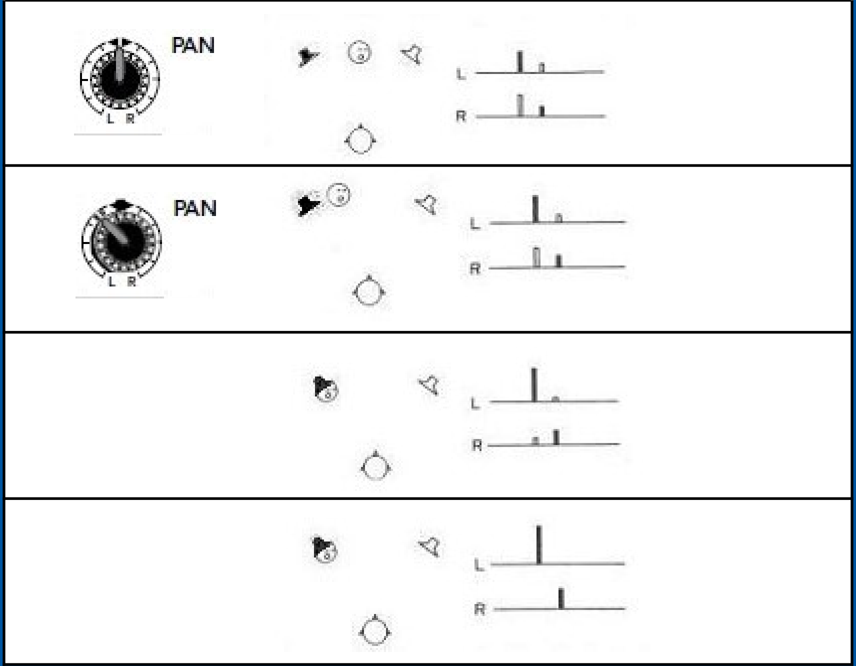

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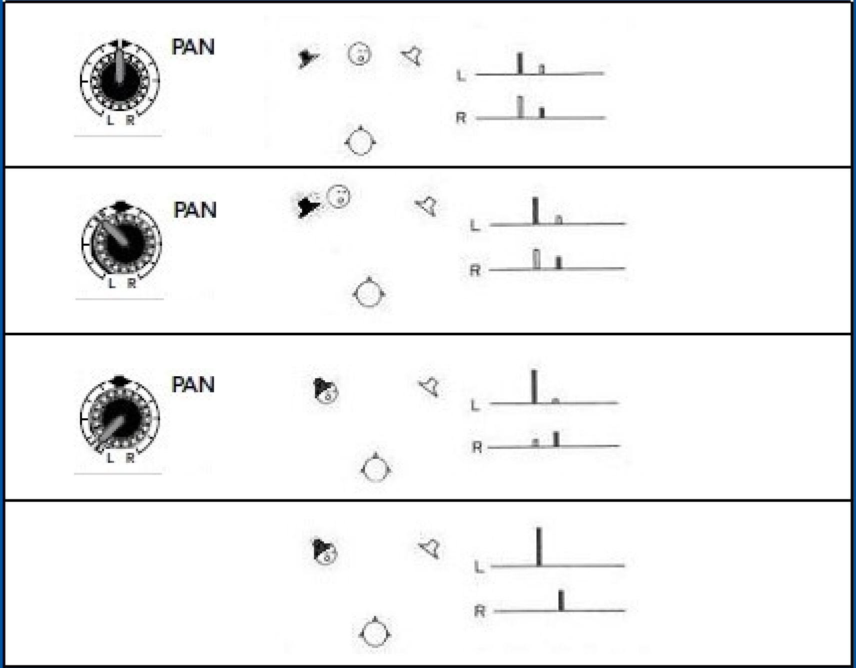

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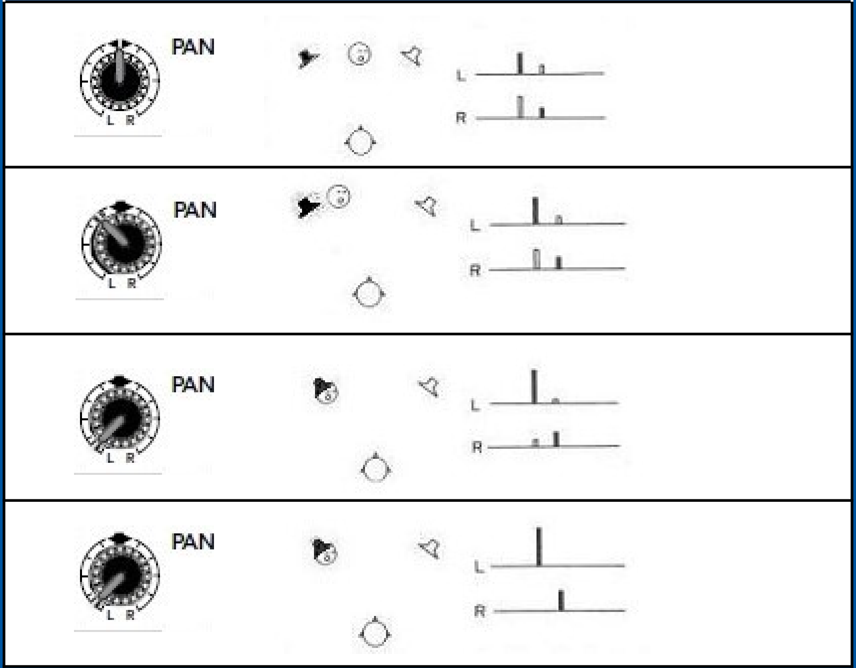

Haas Effect:

An acoustic or electronic delay can be used to mask the apparent direction of a sound source.

Haas Effect:

This is known as the precedence or Haas effect, after the Dutch acoustician who first studied it.

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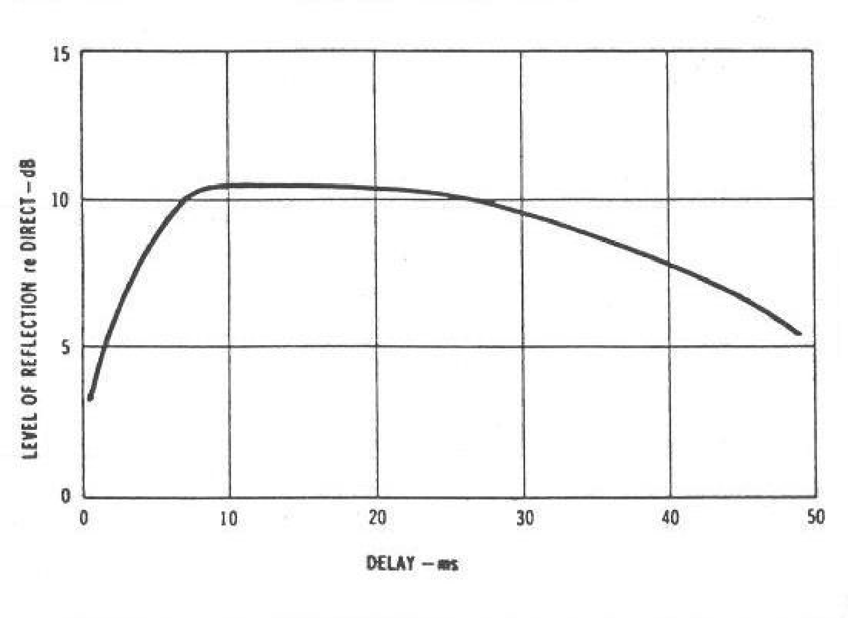
This is known as the precedence or Haas effect, after the Dutch acoustician who first studied it.

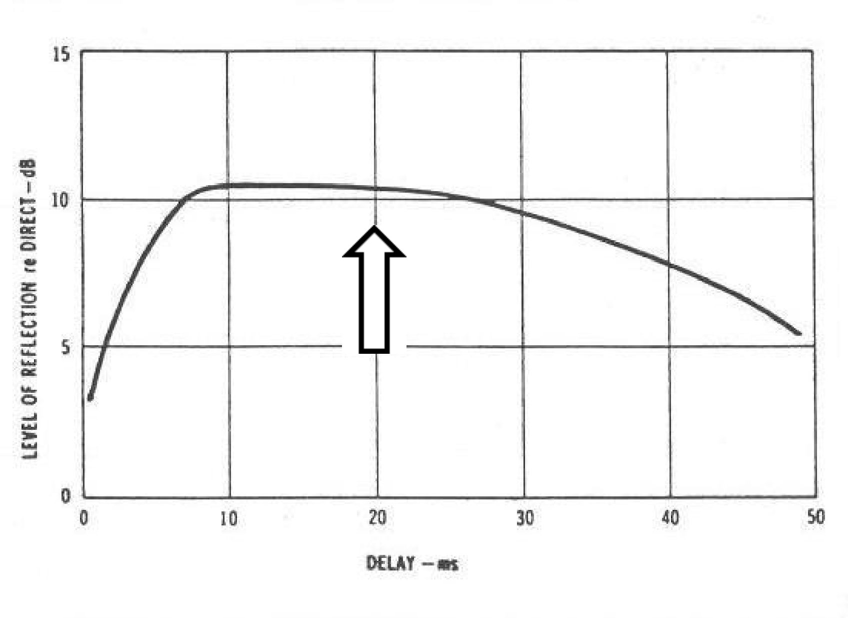
Haas Effect:

A sound, arriving at the listener's ears within a window of 5 to 30 msec. after another, will be interpreted as a reflection of the earlier sound.



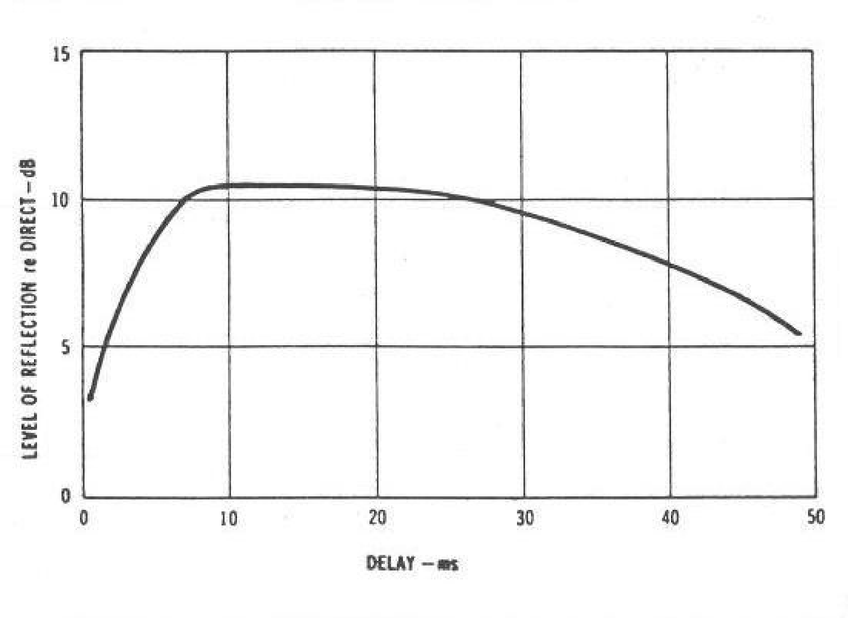
Haas Effect:

We often use a delay of 20 msec. , as this value falls in the centre of the range over which the effect is operative.



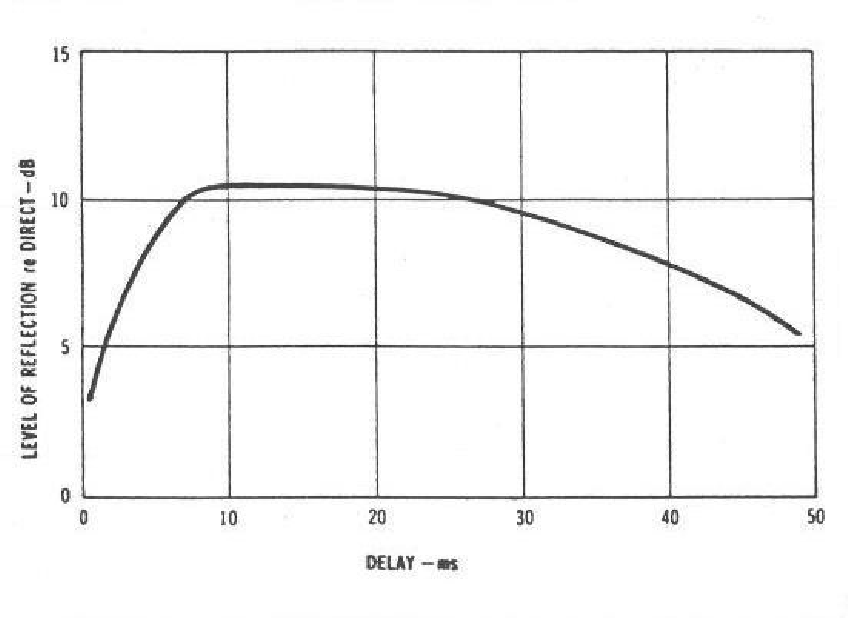
Haas Effect:

The ear-brain system will take the direction of the earlier sound as the point of origin.



Haas Effect:

The ear-brain system will take the direction of the earlier sound as the point of origin, even if the delayed sound is as much as 10 dB louder.



Haas Effect:

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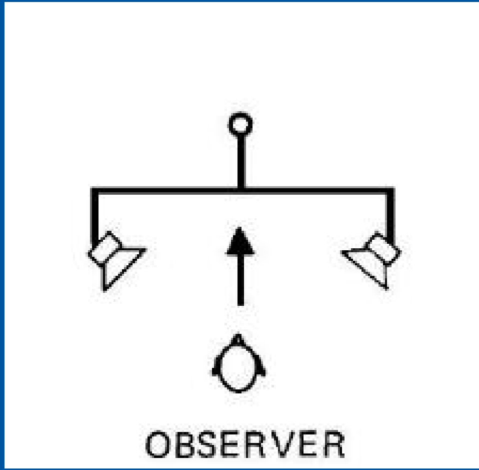
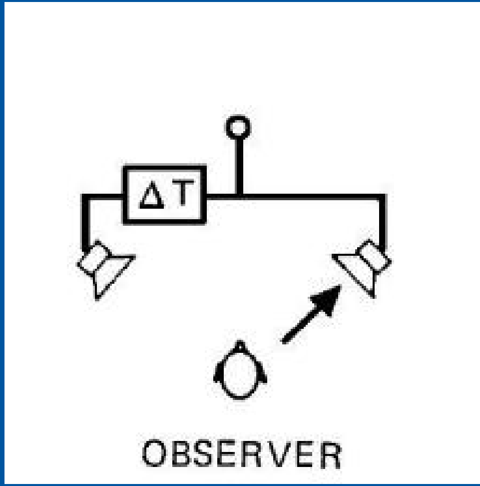


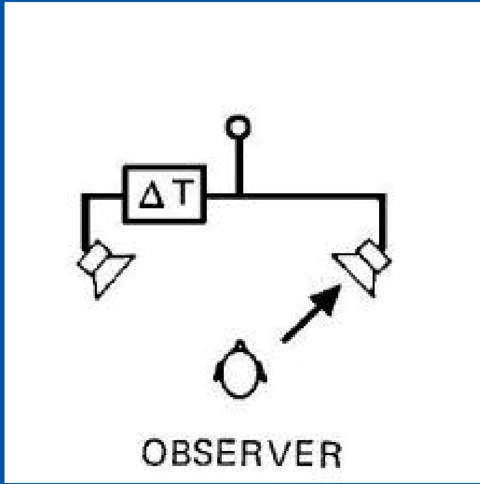
Haas Effect:

If the sound to the left speaker is delayed by 20 msec. , the sound will appear to come from the direction of the right speaker.



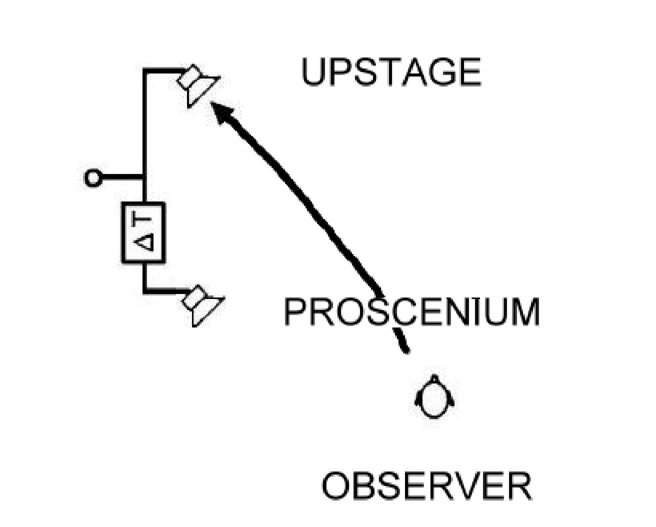
Haas Effect:

If the sound to the left speaker is delayed by 20 msec. , the sound will appear to come from the direction of the right speaker, even if the left speaker is 10dB louder.



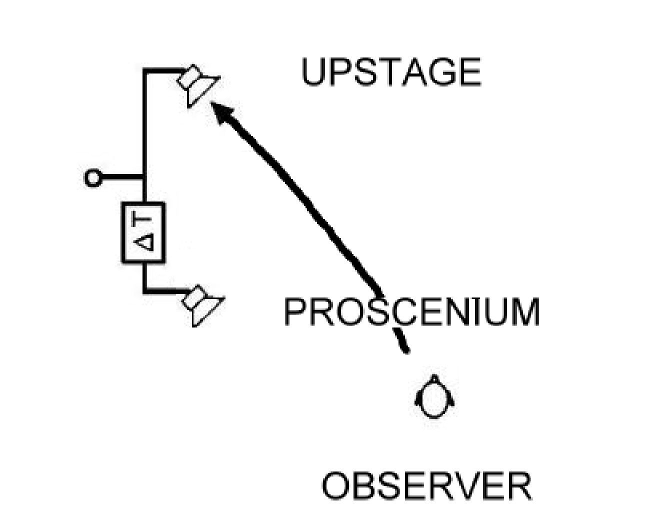
Haas Effect:

If we feed a sound to an upstage speaker, while delaying the same sound to a proscenium speaker, the sound will appear to come from the direction of the upstage speaker.



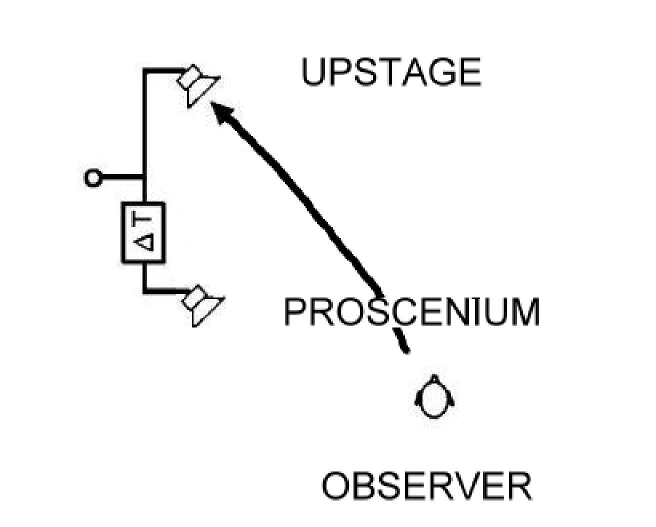
Haas Effect:

We can use this effect to simulate an onstage radio or television. The audience will perceive the sound as coming from the upstage source.



Haas Effect:

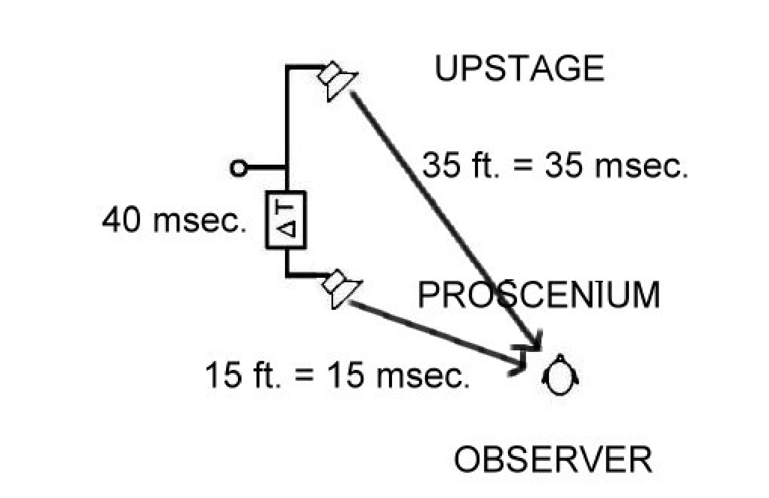
The time delay to the proscenium speaker would have to be 20 msec. longer than the travel time from the upstage speaker.



Haas Effect:

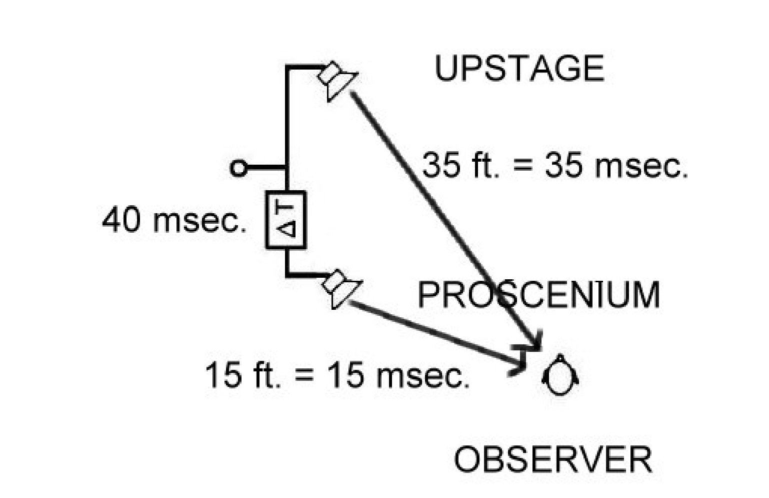
At 35 ft., the travel time for the upstage speaker would be about 35 msec.

At 15 ft., the travel time for the proscenium speaker would be about 15 msec.



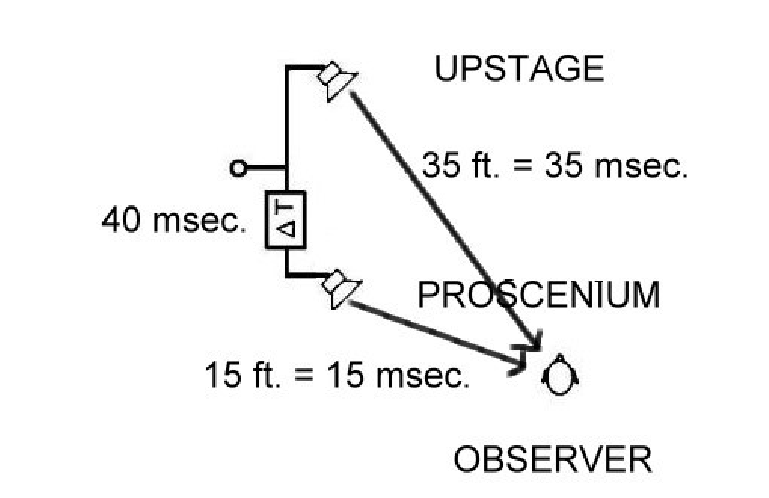
Haas Effect:

If we want the sound from the proscenium speaker to arrive 20 msec. after the sound of the upstage speaker, we would have to set the electronic delay to 40 msec.



Haas Effect:

This would make the sound appear to arrive from the upstage speaker, even though it is much louder coming from the proscenium.

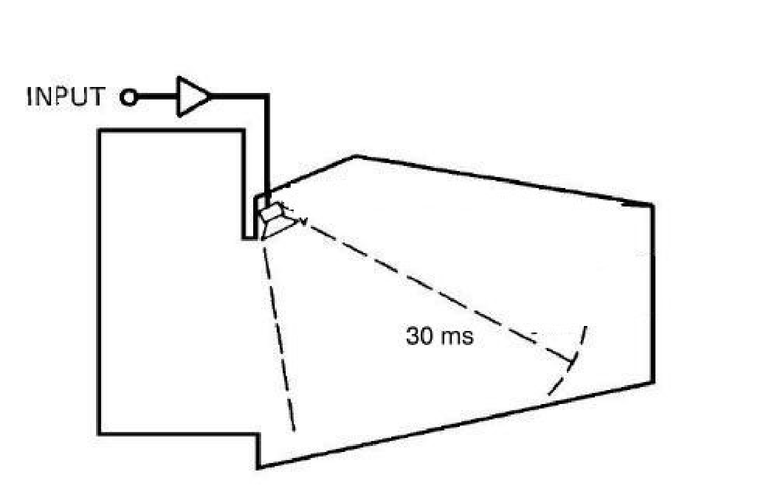


Haas Effect:

To invoke the Haas effect, we could use an acoustic, rather than electronic delay.

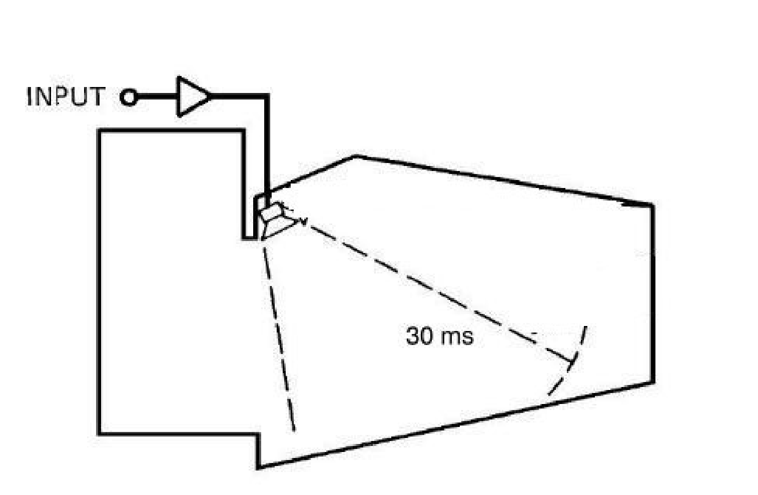
Haas Effect:

The centre proscenium speaker in the Casgrain, is flown at a height that results in an acoustic travel time of 30 msec. at the centre of the house.



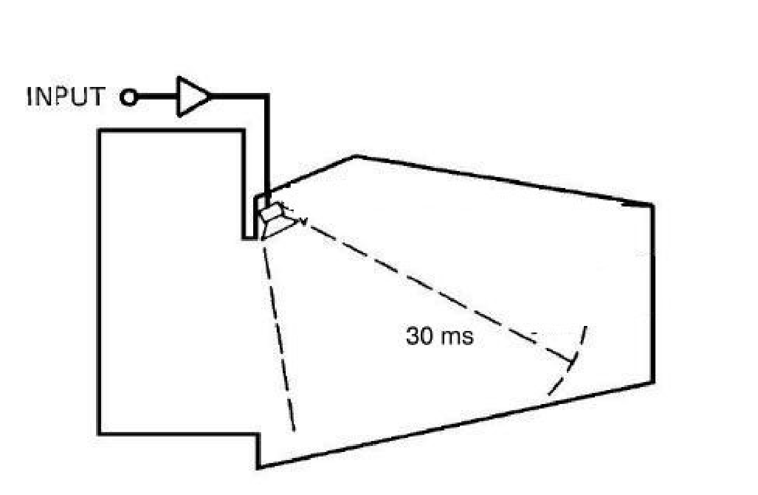
Haas Effect:

This is 5-10 msec. longer than the direct travel time throughout most of the house.



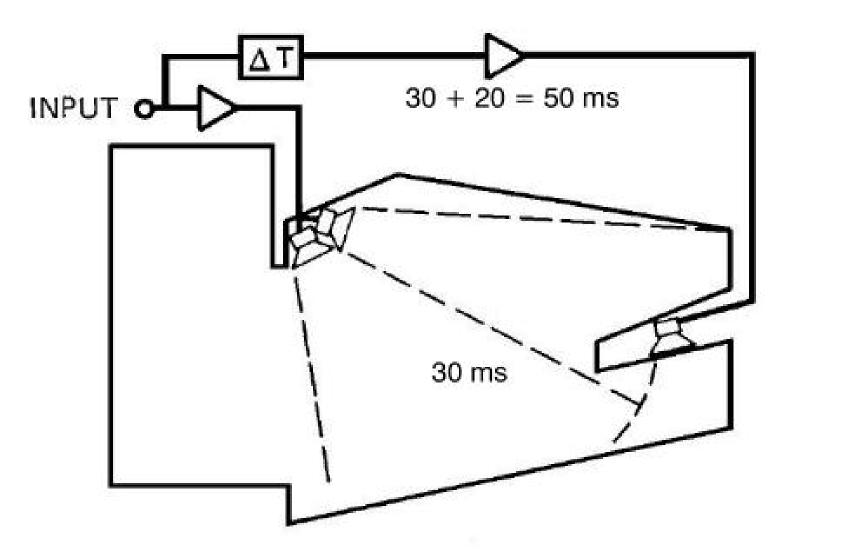
Haas Effect:

If we use the centre speaker to reinforce vocal mics., the audience will perceive the vocals as coming from the stage, rather than the speaker.



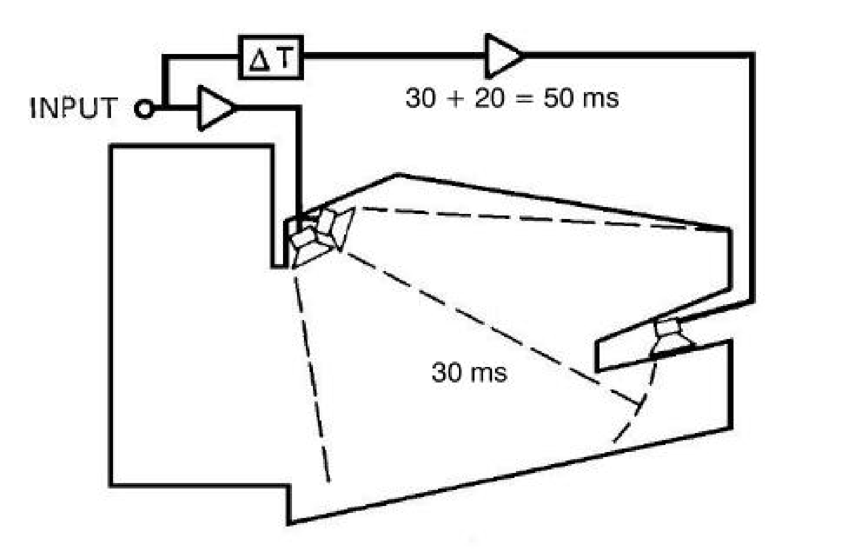
Haas Effect:

In a large theatre, to fill in the acoustic shadow under the balcony, additional speakers can be added.



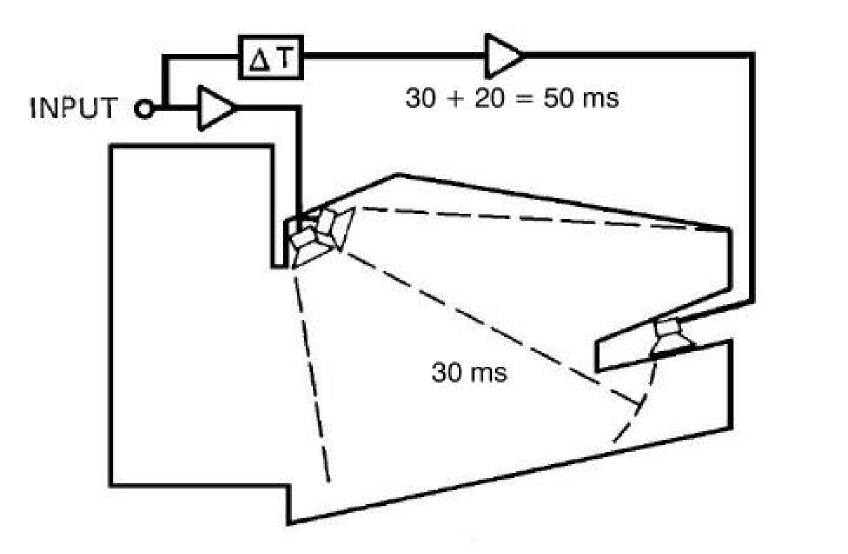
Haas Effect:

The signal to these speakers can be delayed electronically – 20 msec. longer than the acoustic delay from the main speakers.



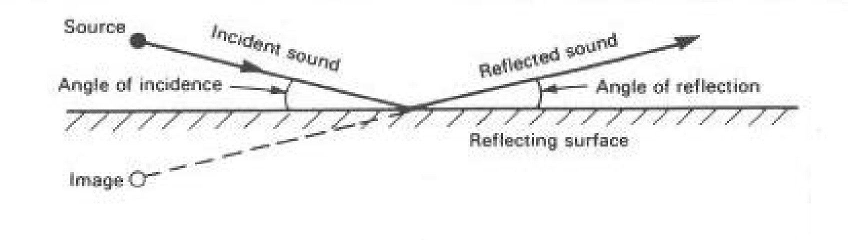
Haas Effect:

The sound will appear to come from the main speakers, even if the level from the under-balcony speakers is 10 dB louder.



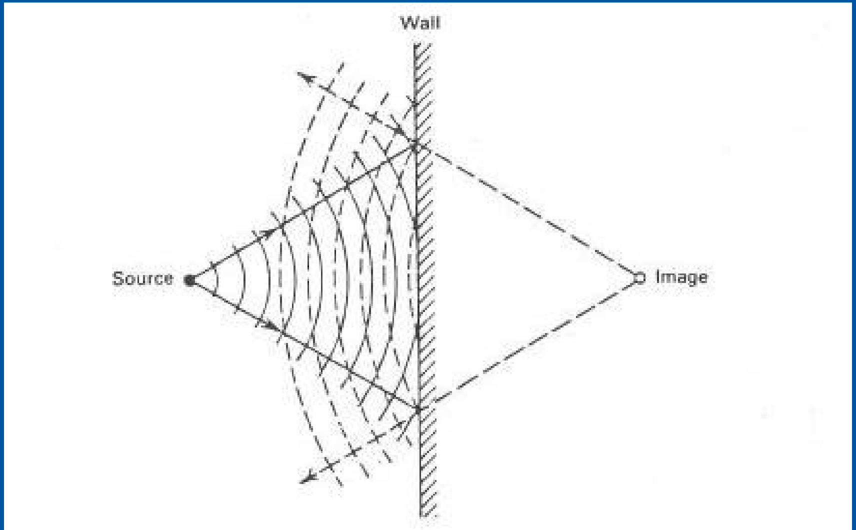
Modes of Propagation:

Reflection:



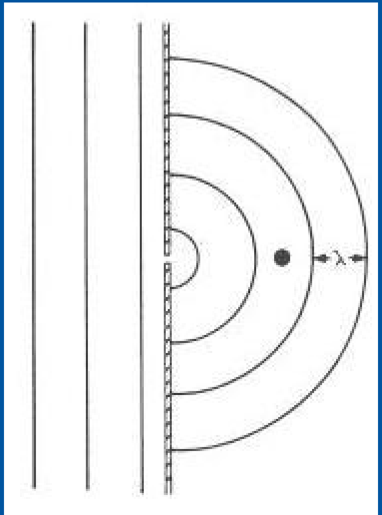
Modes of Propagation:

Reflection:



Modes of Propagation:

Diffraction:



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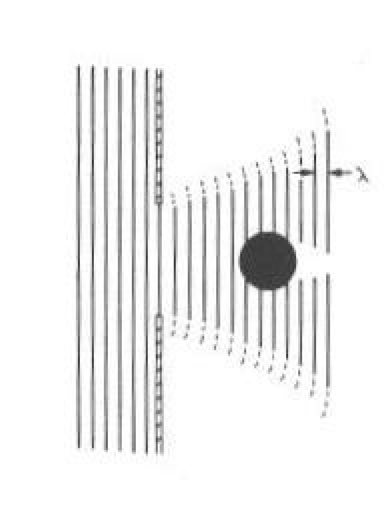
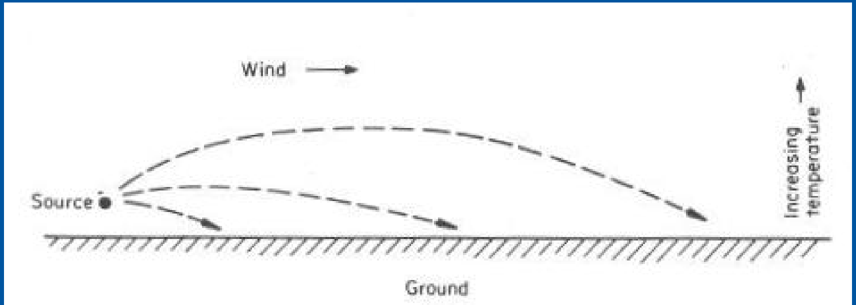
Diffraction:



Modes of Propagation:

Refraction:



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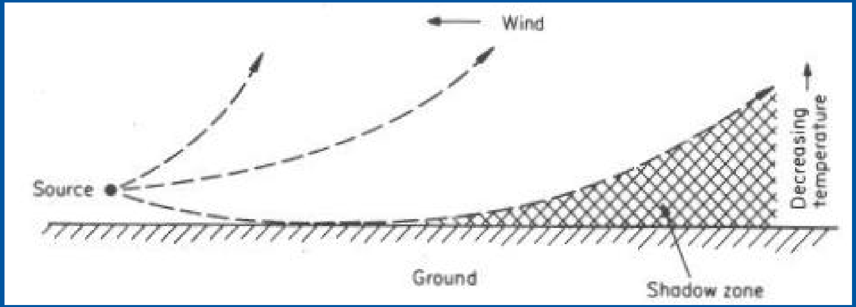
Refraction:



Reverberation:

In an enclosed space, the sound heard by the audience is comprised of:

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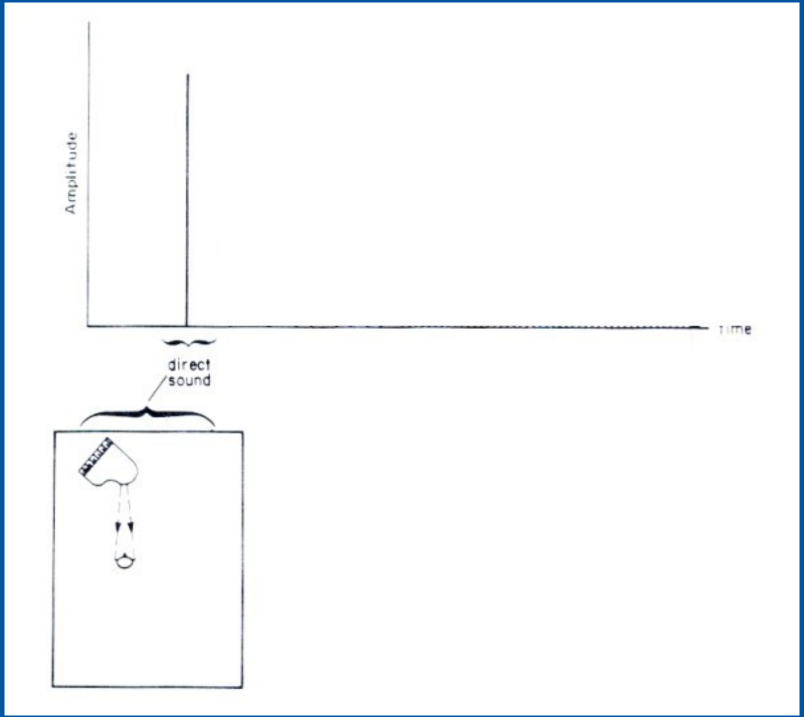
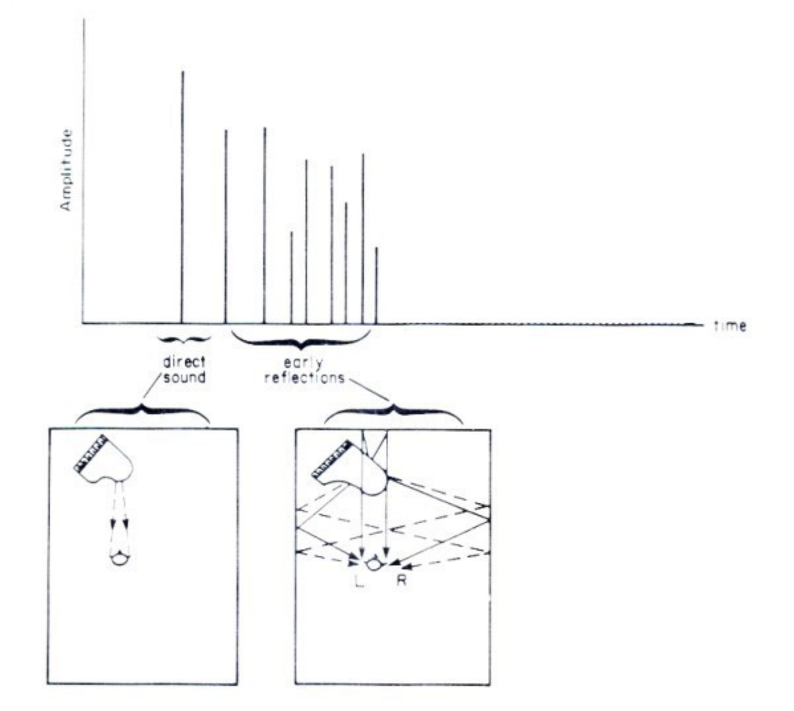
- direct sound



Reverberation:

In an enclosed space, the sound heard by the audience is comprised of:

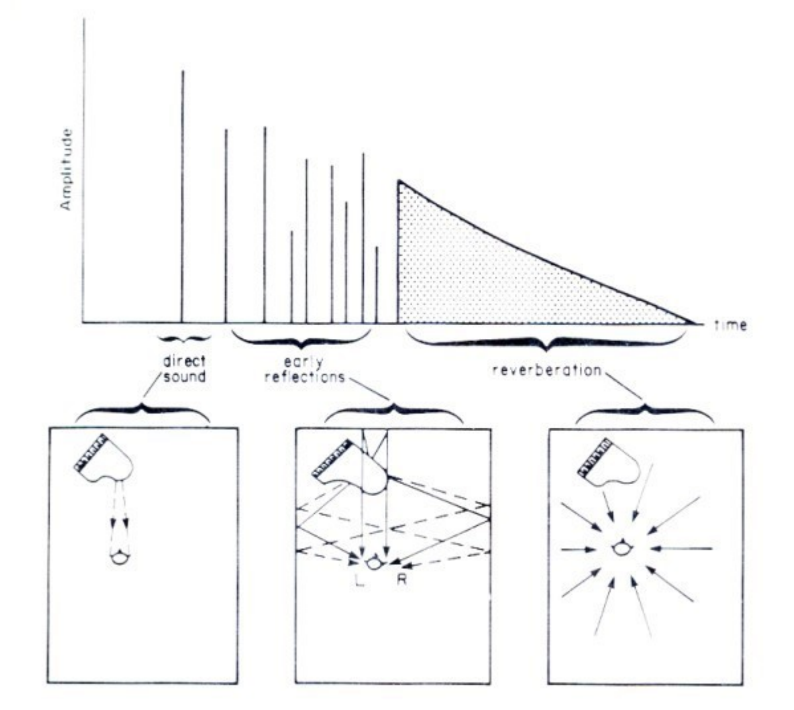
– direct sound
– early reflections



Reverberation:

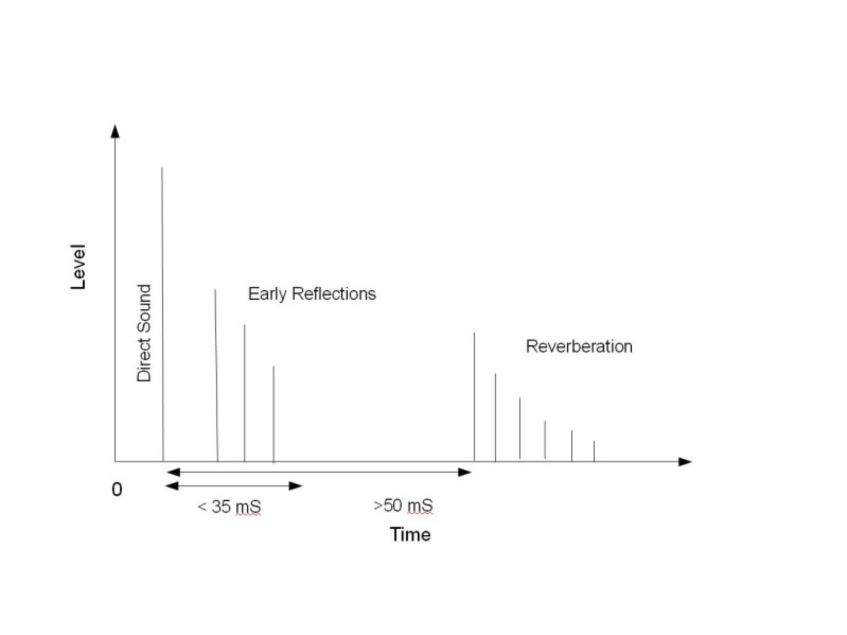
In an enclosed space, the sound heard by the audience is comprised of:

– direct sound
– early reflections
– reverberation



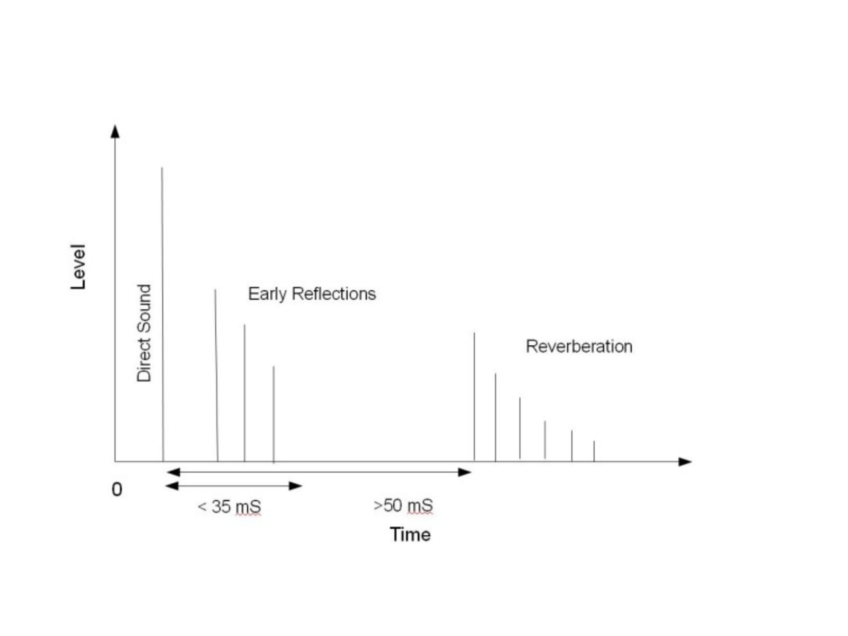
Reverberation:

Early reflections, which arrive at the listener within 35 msec. of the direct sound, are perceived by the ear-brain as adding to the intensity of the direct sound.



Reverberation:

Reflections arriving at the listener later than 50 msec. after the direct sound, tend to decrease intelligibility of the direct sound.



Reverberation:

In general:

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– early reflections = good

Reverberation:

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- early reflections = good
- late reflections = bad

Reverberation:

The time it takes for the reverberant field to die away to 60 dB less than the original sound, is called the reverberation time or RT_{60} of a space.

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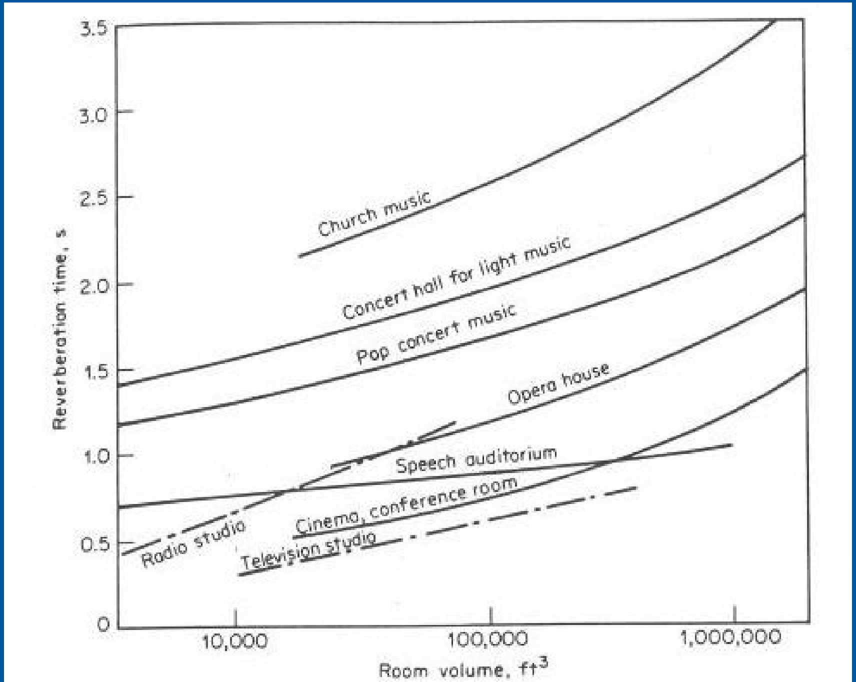
Reverberation:

Ideal RT_{60} for a space varies depending on its:

- intended use
- volume



Reverberation:

Ideal RT_{60} for a space varies depending on its:

– intended use

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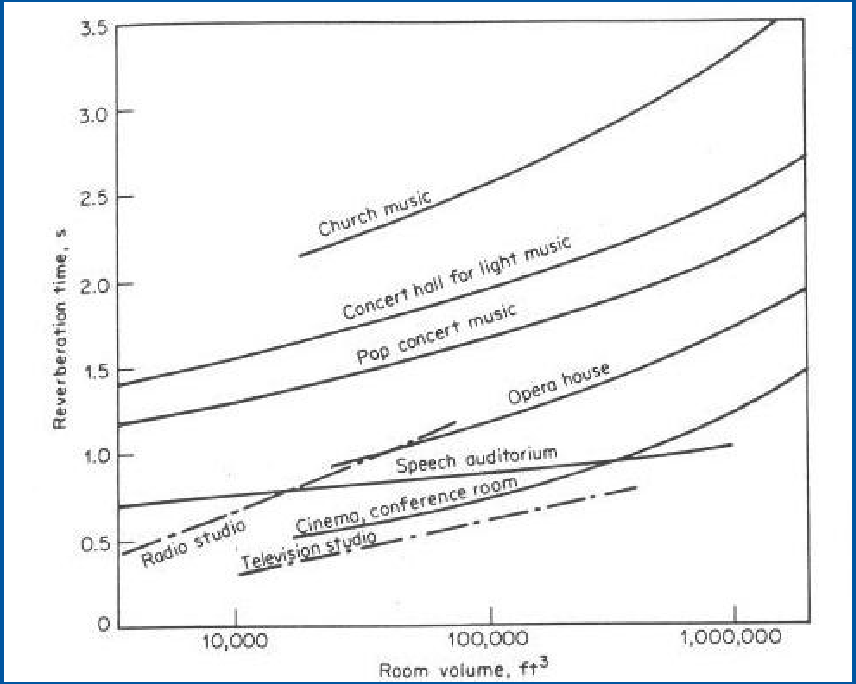

Reverberation:

The RT_{60} of the Casgrain is
1.75 sec.:

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The RT_{60} of the Casgrain is 1.75 sec.:

- excellent for spoken word

Reverberation:

The RT_{60} of the Casgrain is 1.75 sec.:

- excellent for spoken word
- somewhat short for music

Reverberation:

Because of this, for a musical, we often mic. the singers’ voices in order to add artificial reverberation.

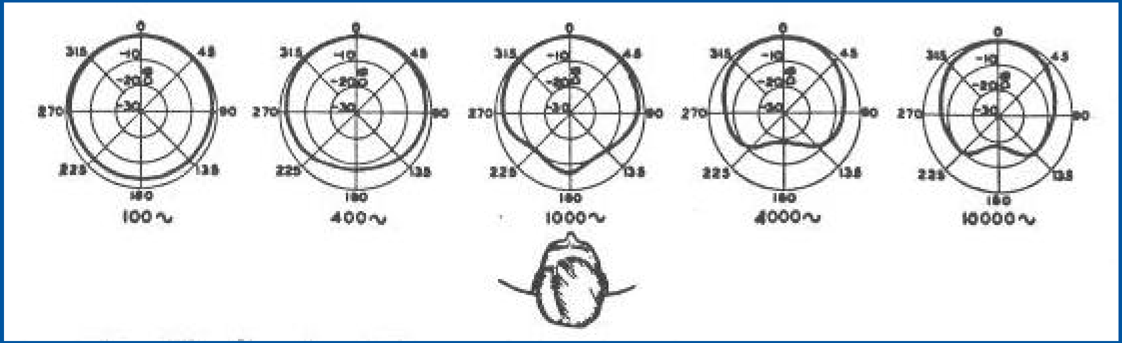
Directivity:

Human voice:

Directivity:

Human voice:

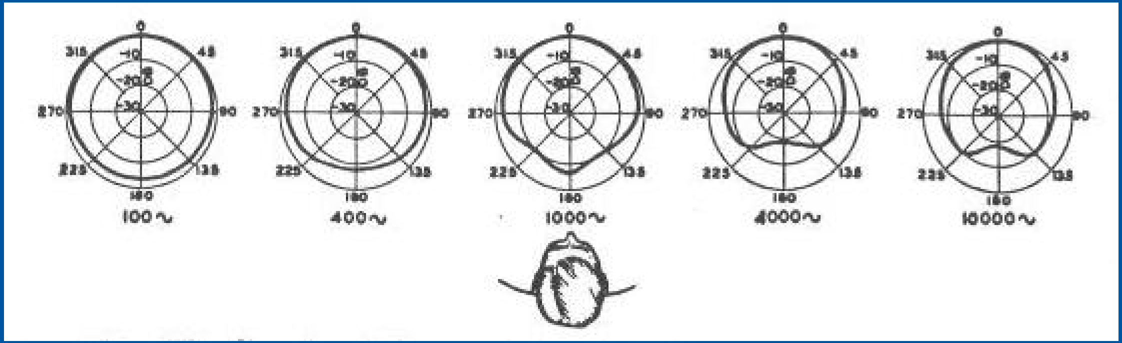
– Horizontal Plane



Directivity:

Human voice:

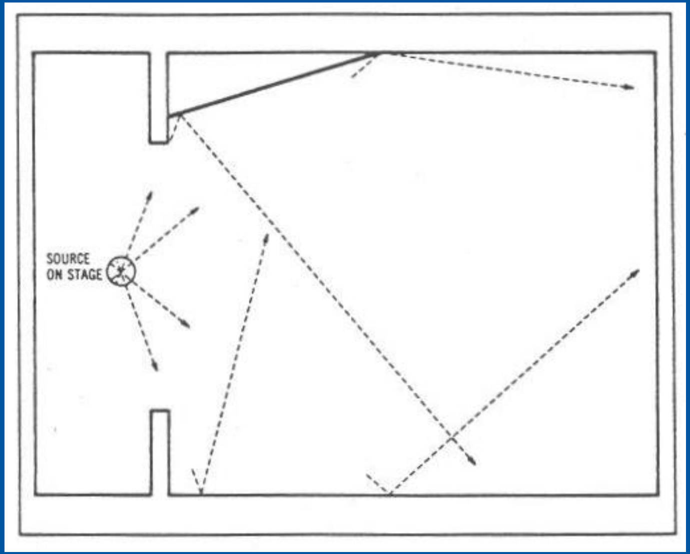
- Horizontal Plane
- approx. 90° @ 4 kHz



Directivity:

Human voice:

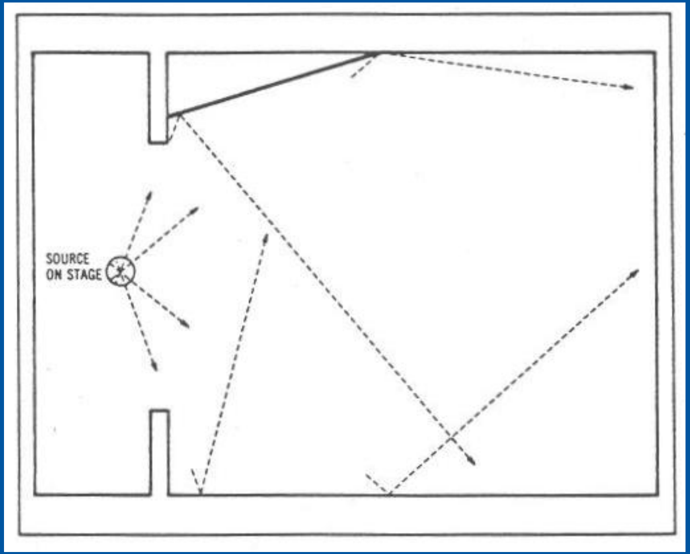
- Horizontal Plane
- splayed side walls



Directivity:

Human voice:

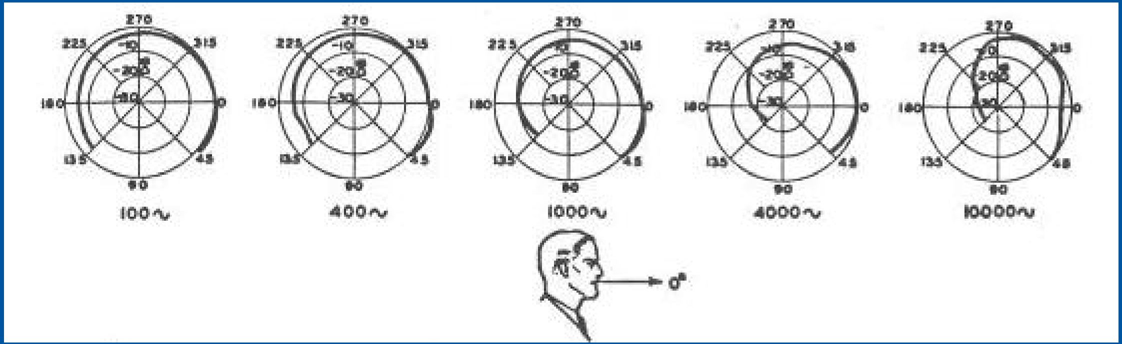
- Horizontal Plane
- splayed side walls
- redirect early reflections to audience



Directivity:

Human voice:

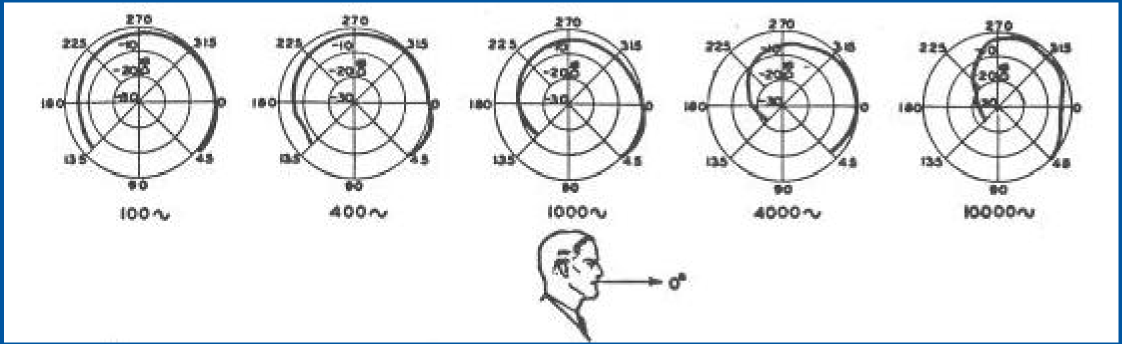
– Vertical Plane



Directivity:

Human voice:

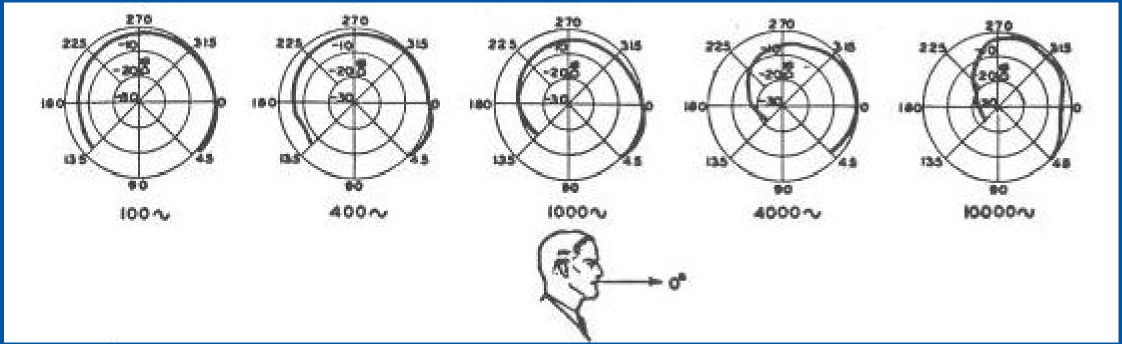
– Vertical Plane
– approx. 60° @ 4 kHz



Directivity:

Human voice:

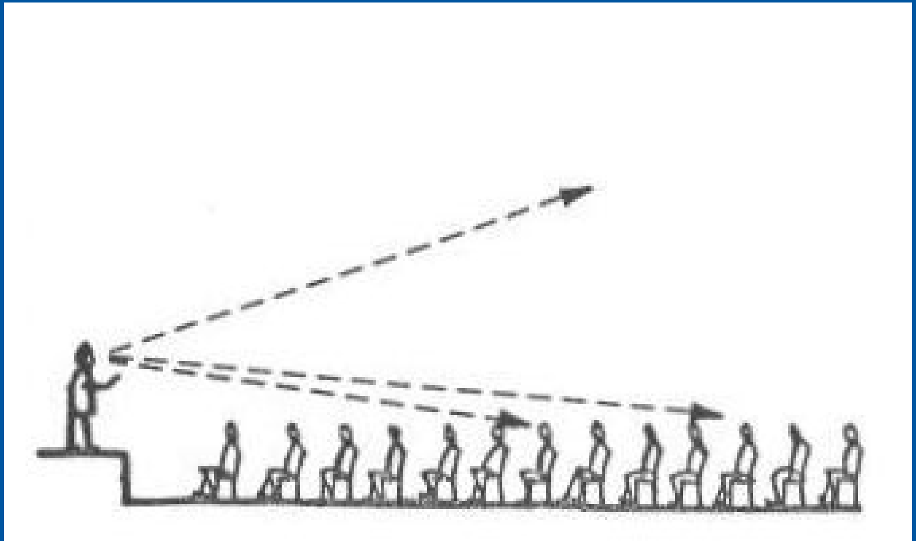
- Vertical Plane
- approx. 60° @ 4 kHz
- 15° above horizontal



Directivity:

Human voice:

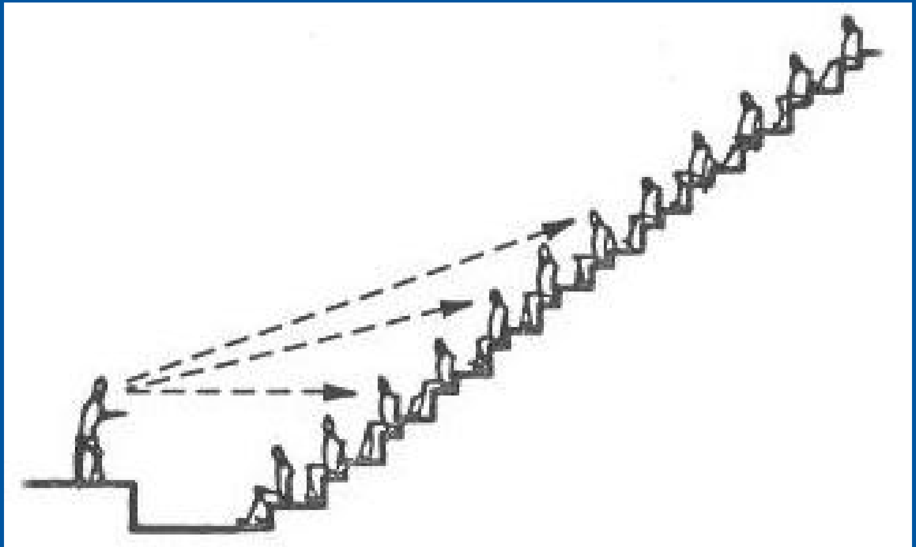
– Vertical Plane



Directivity:

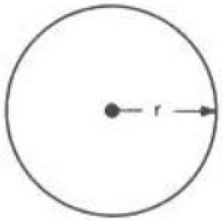
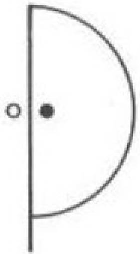
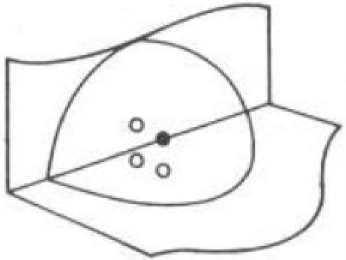
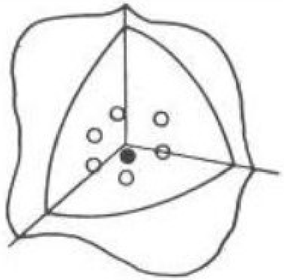
Human voice:

- Vertical Plane
- raked seating



Directivity:

Directivity Factors of Bounded Sources

Source/Boundary Configuration				
Solid angle seen by source	4π	2π	π	π/2
Relative sound pressure	0dB	+6dB	+12dB	+18dB
Directivity Factor (Q)	1	2	4	8

Directivity:

Directivity Factors of various sound sources.

Source	**Directivity Factor (Q)**
Point Source (Non-directional)	1
Cone Loudspeaker (in baffle)	2
Human Voice	2.5
Loudspeaker (in box on floor against wall)	4
Horn (Short Throw)	10
Horn (Long Throw)	20

Inverse Square Law:

Sound intensity decreases with the square of the distance from the source:

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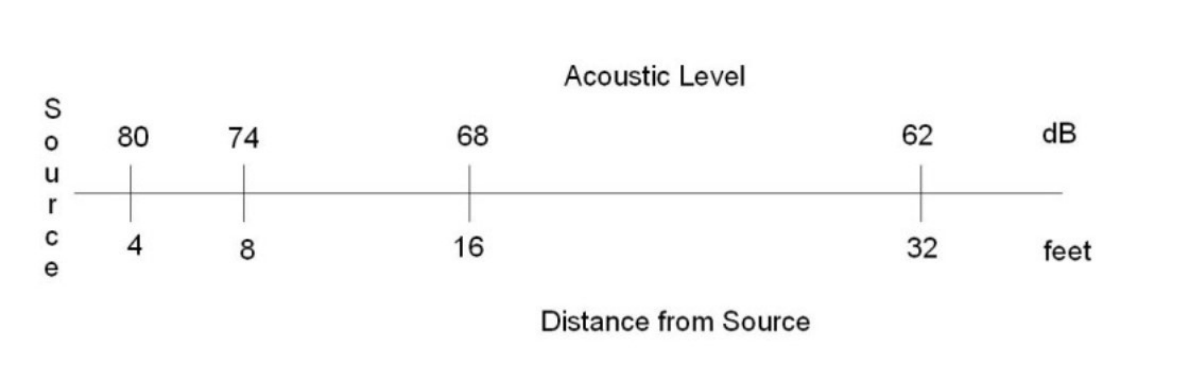
- -20dB for factor of 10x

Inverse Square Law:

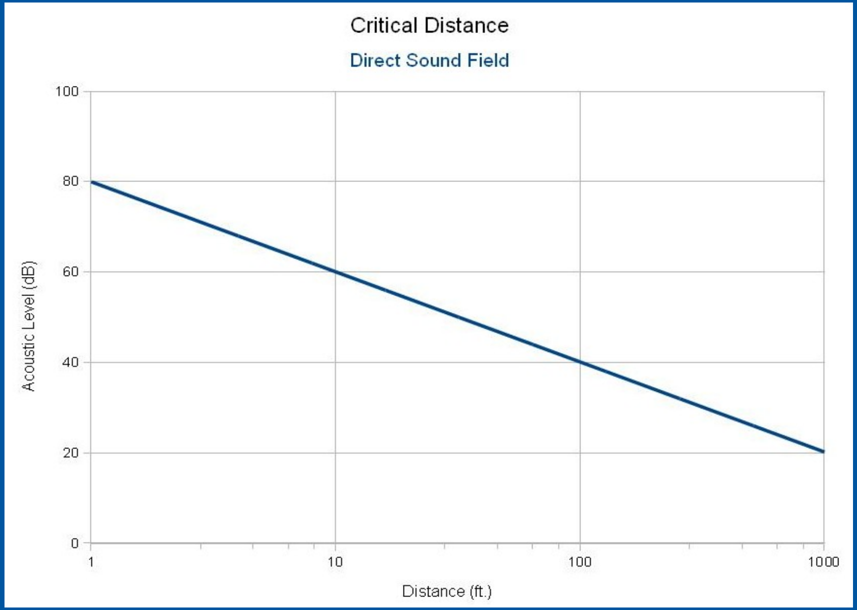
Sound intensity decreases with the square of the distance from the source:

– -6 dB for each doubling



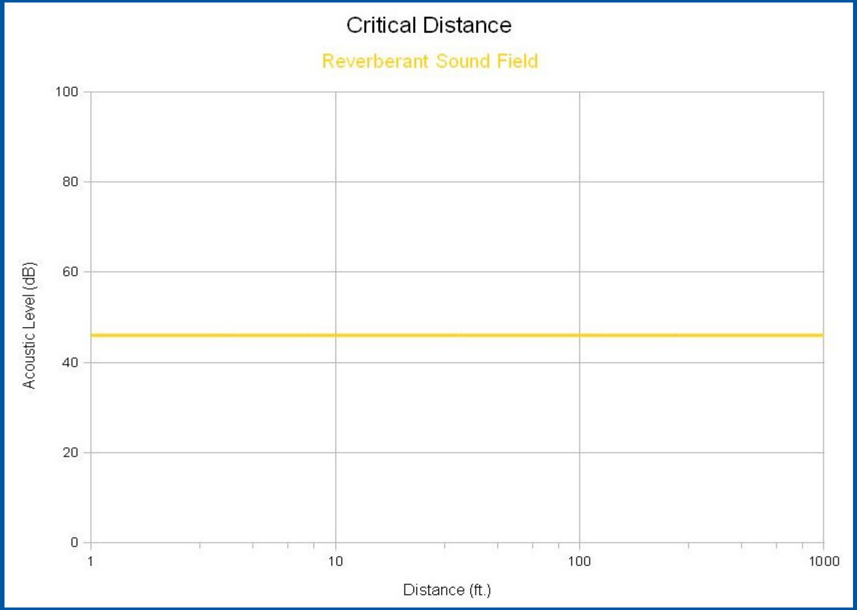
Critical Distance:

Indoors or out, direct sound decreases with the square of the distance from the source -- 6 dB less for every doubling, or 20 dB for every factor of 10.



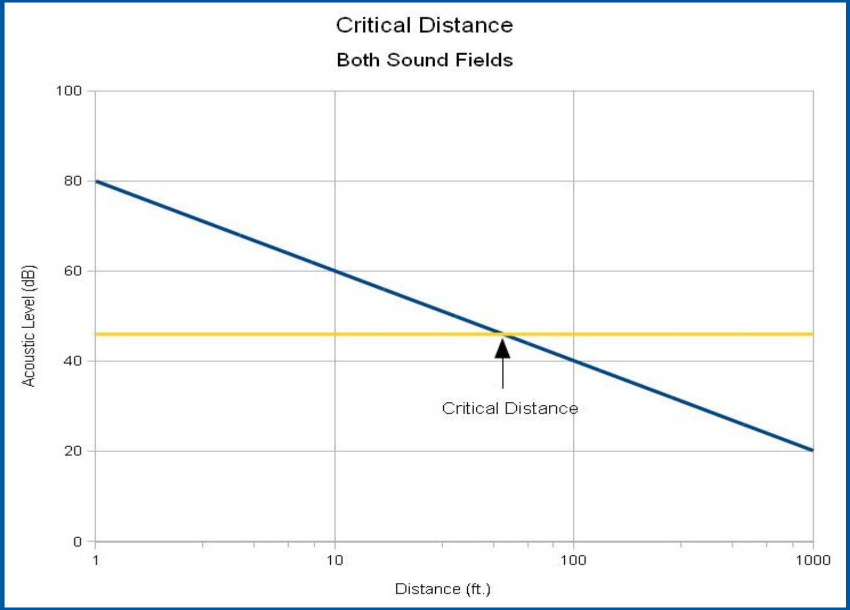
Critical Distance:

The reverberant sound field is constant. It doesn't vary with distance from the source.



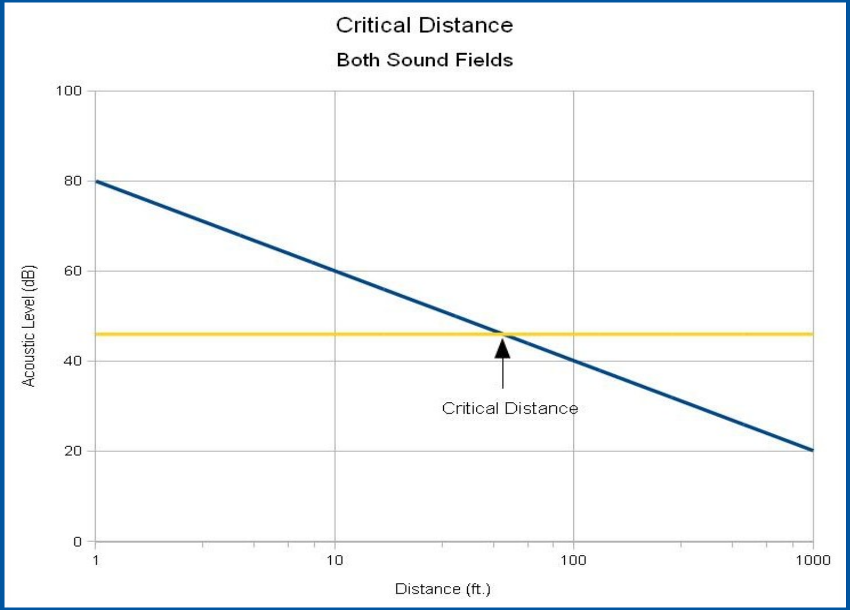
Critical Distance:

At some distance from the source, both direct and reverberant sound fields are equal in level.



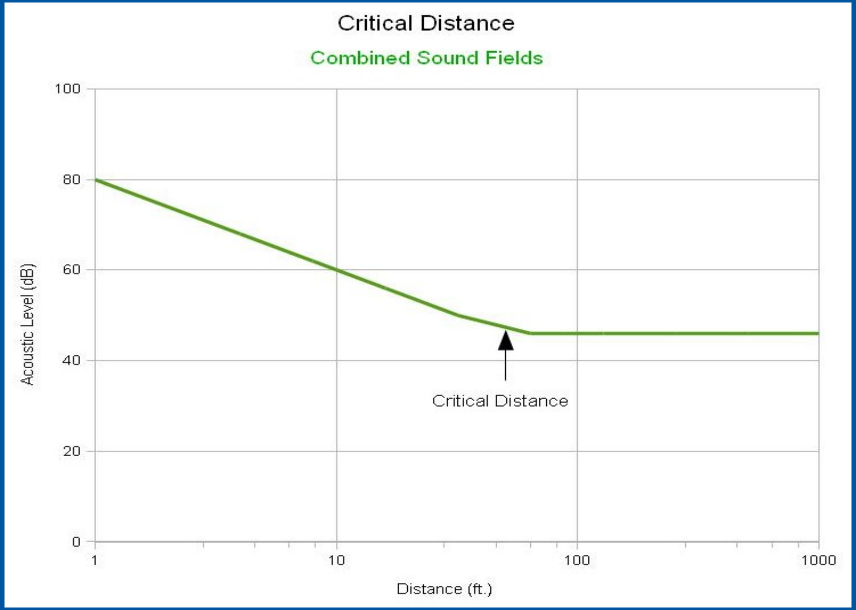
Critical Distance:

We call this the critical distance. Beyond this distance, the listener hears more reverberant sound than direct sound.



Critical Distance:

Critical distance (Dc) can be increased by increasing the directivity (Q) of the source, or by decreasing the reverberation time (RT_{60}) of the room.



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