# ECS614U/ECS749P: Sound Recording and Production

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# Sound Reproduction

# Sound reproduction

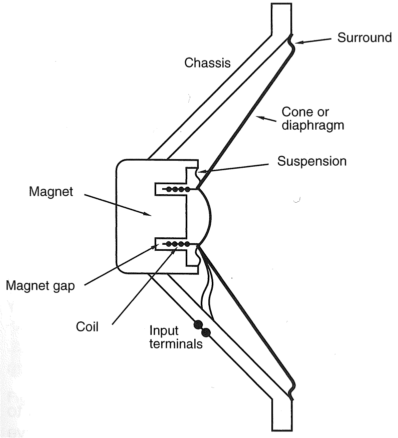
- Our perception of a mix is affected by the sound system it is reproduced on.
- This includes both the **loudspeakers** and the **room**.

# Diffraction

- Diffraction describes how sound waves bend around obstacles, and spread out beyond openings.
- How the wave behaves depends upon the relative size of its wavelength compared to the obstacle (or opening).
- *Diffraction Diagram.*
- *Ripple Tank Animation*

# Loudspeakers

# Moving coil loudspeaker

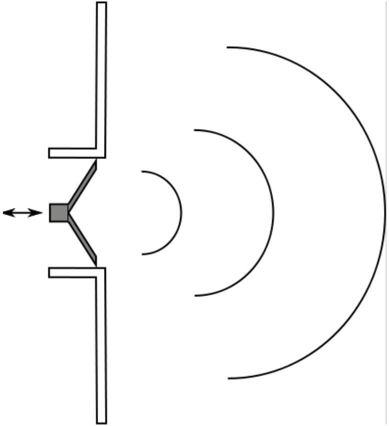



- Reverse process of a dynamic microphone.
- Coil of wire is wrapped around a cylindrical former, mounted in the gaps in a permanent magnet.
- Audio signal is passed through the coil, which induces motion.
- Coil is attached to a cone or diaphragm, and its movement causes compressions and rarefactions in the air (i.e. sound).

# Dipole Source

- A moving coil loudspeaker compresses the air on one side, and expands it the other.
- This is referred to as a dipole source, and it has the same (ideal) polar directivity (response) as the figure of eight microphone.
- A real loudspeaker has a finite width, so how does this affect directivity?

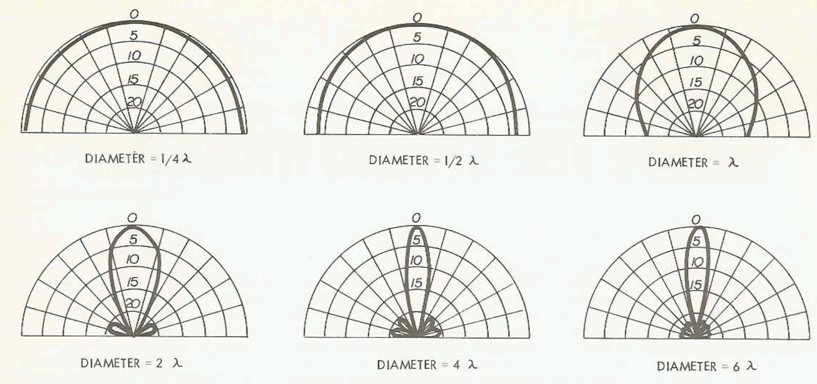
# Idealised Directivity Pattern



- A loudspeaker may be modelled as a circular piston in an infinite baffle.
- The baffle is a box of infinite size that separates the backward reflections for the forward reflections.
- The directivity is dependent on the relationship between the size of the piston, and the wavelength of the sound.

# Idealised directivity pattern (a single radiating piston mounted in an infinite baffle)

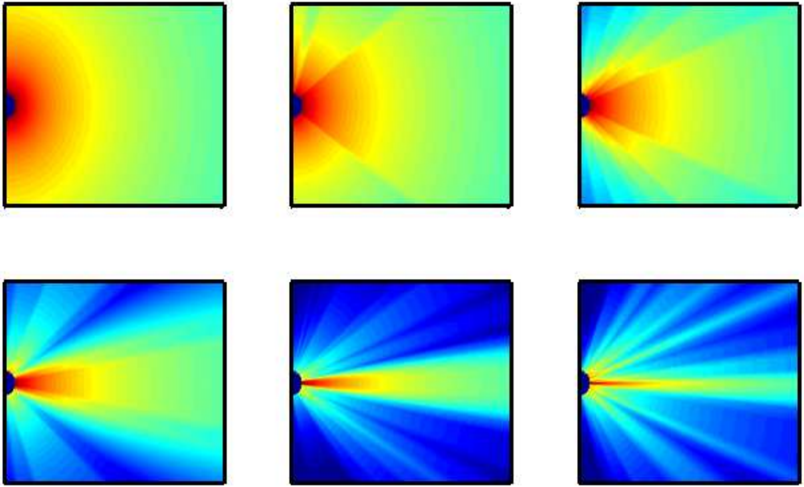
- Directivity is dependent upon frequency; high frequency is more directional.



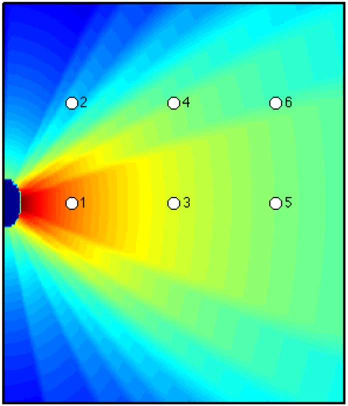
# Loudspeaker directivity

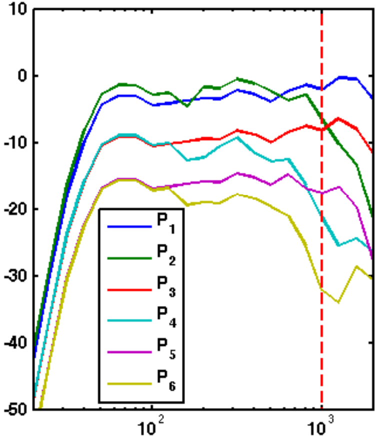
- The polar directivity pattern of a loudspeaker is analogous to the polar response pattern of a microphone.
- It describes how the sound is radiated by the loudspeaker as a function of angle and frequency.
- The angle of dispersion is often referred to as the Q-factor (like an EQ filter). A high Q means a narrow angle.
- Loudspeakers are either variable Q, or constant Q (most studio speakers are variable Q).

# Directivity Pattern of a real loudspeaker



# Frequency response at different locations



# Moving Coil Design Considerations

- **LF limit**
  - The size of the diaphragm determines how well low frequency sounds can be generated.
  - Small diaphragms cannot generate low frequency sounds in the same way that small obstacles can't obstruct low frequency sounds.
  - Soft suspension (in spring) is preferable to control low frequency oscillations.

# Moving Coil Design Considerations

- **HF limit**
  - A small diaphragm can generate high frequency sounds.
  - It is easier to generate high frequency oscillations in a lighter structure, i.e. smaller diaphragm.
  - Stiffer suspension is preferable to control high frequency oscillations.
- **Efficiency**
  - Large and light diaphragm improves efficiency, but it is hard to have both large and light.

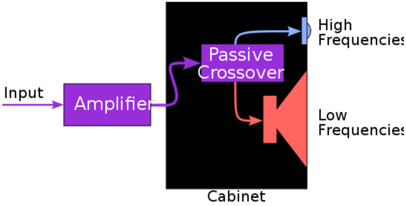
# Moving Coil Design Considerations

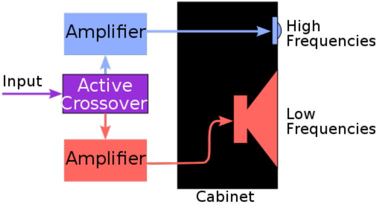
- **Linearity**: we want the frequency response to be the same at any signal level.
  - If coil and magnet gap are the same length, there is less of the coil in the magnetic field when it is displaced, so velocity becomes displacement-dependent.
  - Solve by making either the coil or gap longer, but this reduces efficiency.
  - Non-linearity also caused by non-perfect spring behaviour of the suspension.

# Crossovers

- The efficiency of good quality loudspeakers is around 5%.
- It is impossible to design an efficient (moving coil) drive unit with a flat frequency response over the full range.
- The strategy is to split the audio signal into frequency bands using a **crossover**, and to send each part to a separate driver that is tuned to work in a specific frequency range.
- For standard two-way speakers the drivers are referred to as “woofers” and “tweeters”.

# Passive and Active Crossovers




http://commons.wikimedia.org/wiki/User:Iainf

# Passive and Active Crossovers

| Type | Passive | Active |
|---|---|---|
| Advantages | • One amp per speaker<br>• Easy to realise cheaply<br>• HF drive unit protected from switch-on | • Easy to design accurate and sophisticated filters<br>• Components are cheap<br>• Direct connection of power amp to drive unit: good control<br>• Easy adjustment for different drive unit sensitivities<br>• Can use power amps with different power outputs<br>• Can easily incorporate EQ to compensate for drive-unit |
| Disadvantages | • Hard to design accurately<br>• Components large and expensive for high power systems<br>• Harder for amp to control drive unit at resonance<br>• Difficult to match drive units of different sensitivities<br>• Must have same LF and HF power output<br>• Components can saturate at high drive levels | • At least two power amps per speaker (expensive)<br>• More cabling<br>• Amp switch-on can damage tweeters. |

# Other Loudspeaker Types

- Other transducers used include:
  - Electrostatic
  - Ribbon
  - Distributed mode
  - Piezo-electric
- These are very rare. They are generally capable of very high sound quality, but with low power. They are also difficult and expensive to manufacture.

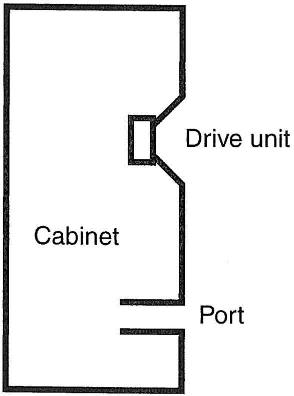
# Cabinets

- In free air the cone would radiate sound forwards and backwards in a figure-of-eight pattern with the lobes out of phase.
- This causes cancellation for wavelengths greater than the dimensions of the drive unit (bass frequencies).
- Drive units are usually mounted in closed cabinets to prevent cancellations.
- Cabinet design can have a great impact on the speaker performance.

# Closed-Back Cabinets (approx infinite baffle)

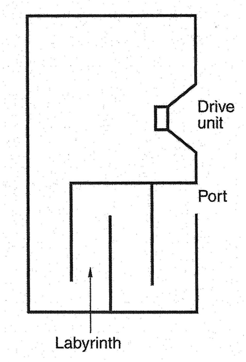
- Drive unit is mounted in one wall of a closed, stiff box.
- At LF the air in the box is a lumped acoustic stiffness. Stiffness is higher for small cabinets and for large cone radii, so large cones require large cabinets.
- At HF standing waves occur inside the cabinet, which can alter the forward radiation, so cabinets are lined and/or filled with a sound-absorbent material.

# Ported Cabinets (Bass Reflex)



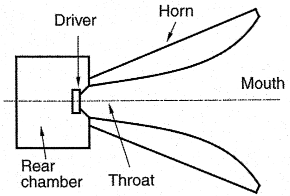

- Air in the hole has a mass and resonates at a particular frequency, reinforcing the forward projected sound from the drive unit.
- Below the resonant frequency the air motion causes sound to be radiated out of phase with the drive unit, so cancellation occurs.
- Above the resonant frequency the air movement is small so the cabinet behaves as if it were closed.
- With careful tuning of the resonant frequency the low frequency limit of the speaker can be extended.

# Transmission Line Cabinets




- Another form of bass loading.
- The resonant frequency is determined by the length of the labyrinth.
- Very good bass extension possible.
- Very large cabinet required.
- *Sound wave animation.*

# Horn Loading

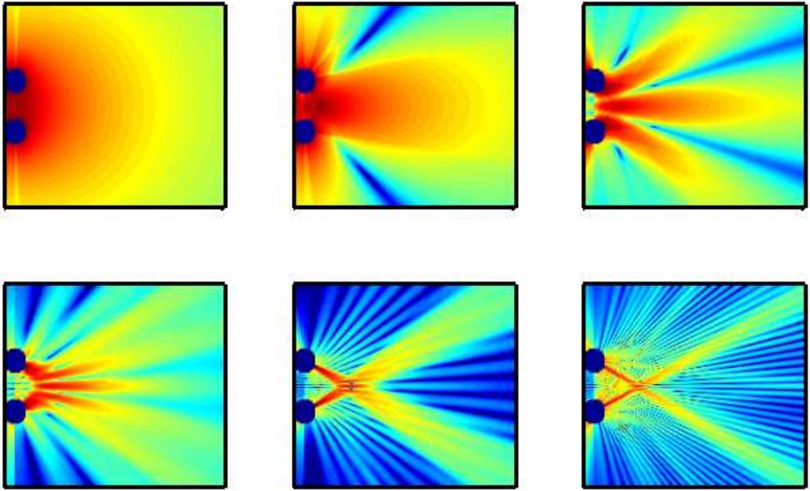



- Horn matches the air impedance at the throat with the impedance of the driver to increase transducer efficiency.
- High pressure / low amplitude sound waves are expanded by the horn into low pressure / high amplitude sounds waves at the mouth.
- Horn operates at a limited frequency range, so frequency response is compromised.
- Good when very high sound levels are required.
- Horns tend to be more directional than conventional speakers.

# Loudspeaker Interaction

- Most mixing is done on a pair of loudspeakers (left and right).
- The acoustic signals from each of the loudspeakers will interact.
- PHASE! PHASE! PHASE!

# Loudspeaker Interaction



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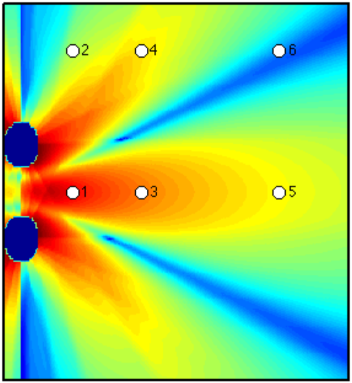


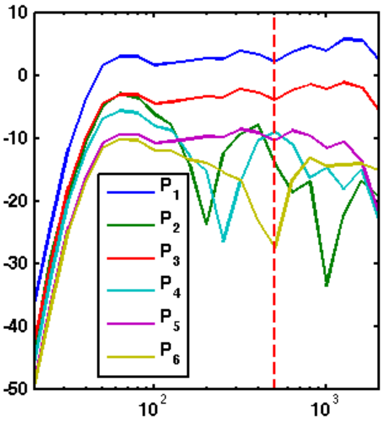

# Loudspeaker Arrays

- In large concerts the sound system must be able to cover a large audience area with sound.
- It is not practical to use one or two enormous loudspeakers, so multiple loudspeakers are used, and are typically arranged in line arrays.
- Their interactions are controlled and optimised to provide the best possible coverage, and to satisfy other requirements, e.g. leakage onto stage.

# Loudspeaker Arrays

- Line array loudspeakers generally contain more than two individual transducers, e.g. 4-way is typical.
- Each loudspeaker can be controlled by its position, and by individual processors to apply gain, delay, equalisation and delay.
- All of these controls are used to manage and optimise the loudspeaker interactions.

# Room Acoustics

# Room Acoustics

- How do sounds propagate within a space?
- How do sounds travel from their source to a receiver?

# Why Study Room Acoustics?

- To improve speech intelligibility, e.g. in a church.
- To improve the quality of music reproduction and performance, e.g. concert hall.
- To control sound in places of work, e.g. noise levels in factories.

# Why Study Room Acoustics?

- Modifying the acoustics of a room is incredibly expensive.
- Rooms are designed with their acoustics in mind:
  - Engineering rules of thumb.
  - Computational modelling.

# Greek Amphitheatres

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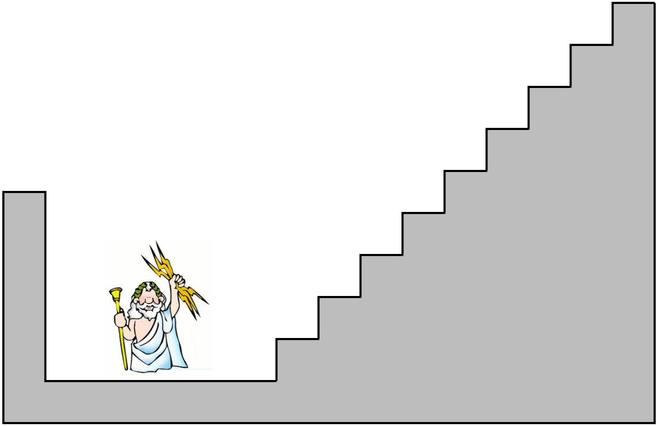

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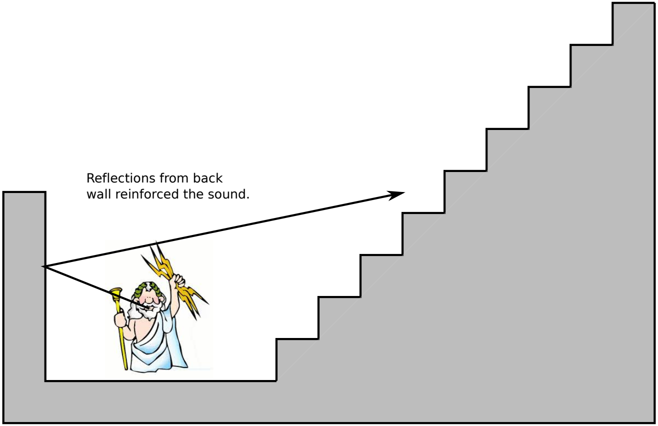

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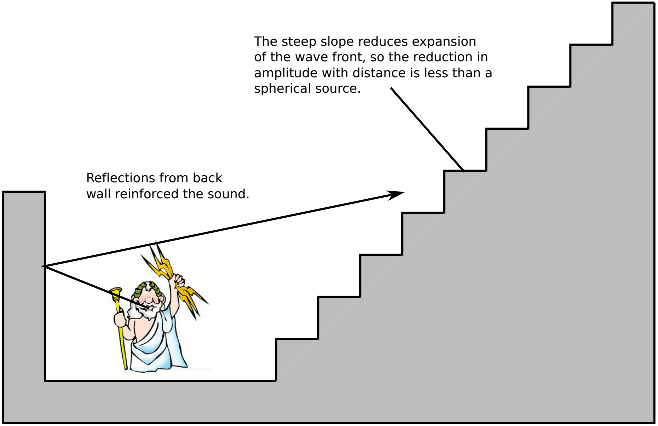

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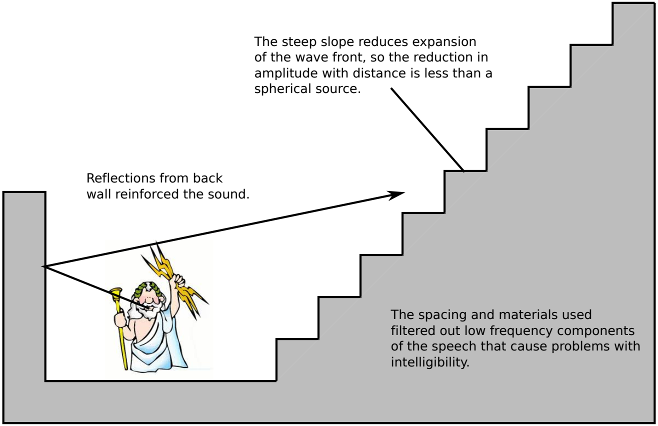
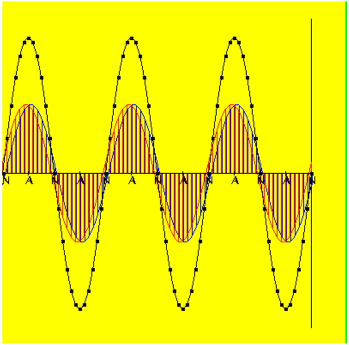


# Room Resonance

- A room can be thought of as a large box of air.
- Standing waves can form in a room, and are referred to as room resonances (or room modes).

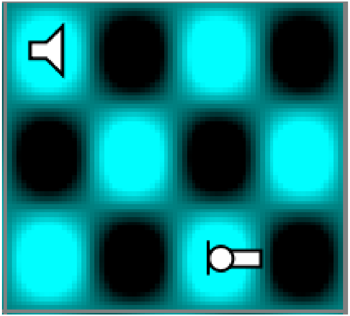
  http://www.walter-fendt.de/ph14e/stwaverefl.htm.
- The resonant frequencies are dependent on the room geometry.

# Room Resonance: Source and Receiver Position




- If a source is placed at the anti-node (A) the reflection will sum, and hence it will excite the standing wave.
- If a source is placed at the node (N) the reflection will cancel, and hence sound energy at the frequency of the standing wave will be lost.
- If a receiver is at a node (N) it will not detect sound energy at the the standing wave frequency.

# Room Resonance: Source and Receiver Position



- If I place my source and receiver on an anti-node I can deliberately use the room resonance to boost certain frequencies.
- This can be very useful for acoustic recordings of bass instruments, e.g. kick drum.

# Shroeder Frequency

- What happens to the room modes as the frequency is increased?

# Shroeder Frequency

- At high frequencies the density of the standing waves increases, and the spacing between nodes and anti-nodes decreases.
- This has a chaotic, randomising effect on the formation of standing waves, and they become less prominent and perceptible.
- The transition from discrete to randomised standing waves occurs at the Shroeder frequency.

# Shroeder Frequency

- What happens to the room modes as the volume of the room is increased?

# Shroeder Frequency

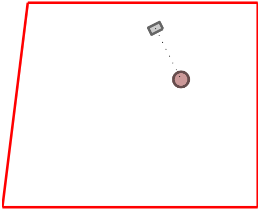
- In large rooms the first mode (the fundamental) has a much lower frequency
- The density of standing waves will reach the transition state at a lower frequency, i.e. Shroeder frequency is lower.
- In large rooms there may be no discrete room modes in the audible frequency range.
- In small rooms many discrete room modes will exist in the audible frequency range.

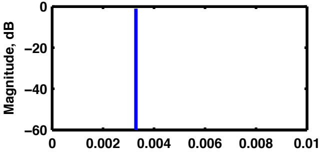
# Room Resonance

- What happens when a room is full of “stuff”, e.g. tables, chairs, people?
- What happens when a room geometry is non-symmetrical?

# Room Reflections

How can we model the signal path from loudspeakers to the listener, including the effect of reflections?





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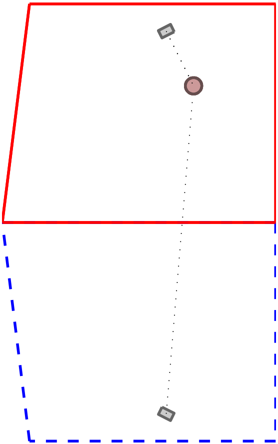

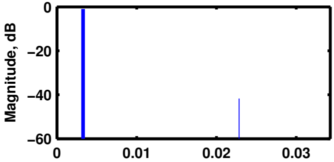

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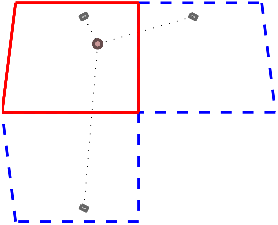

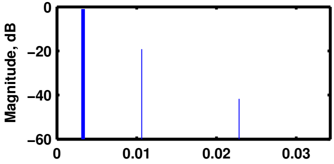

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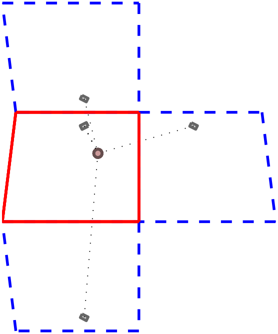

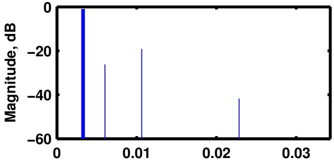

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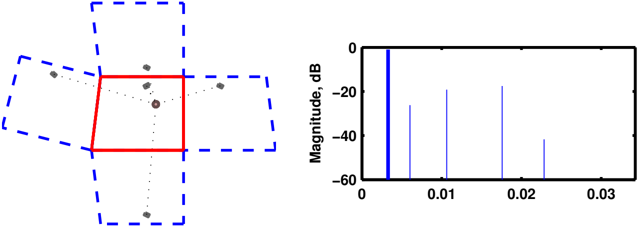

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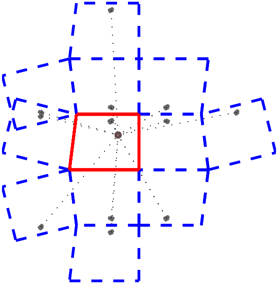

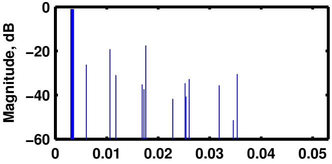

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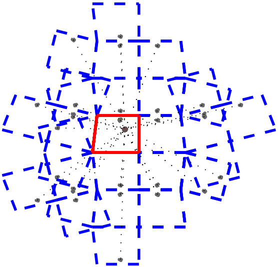

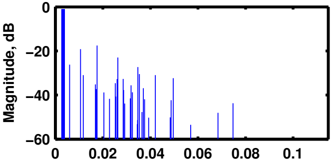

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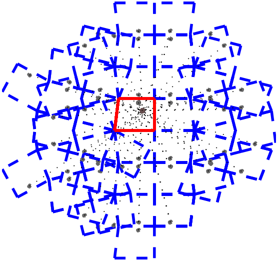

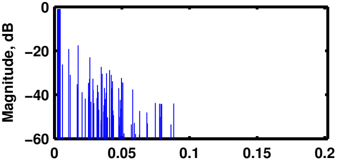

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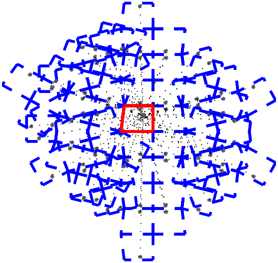
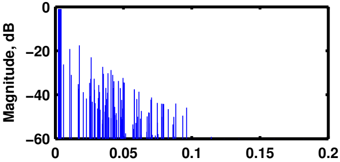
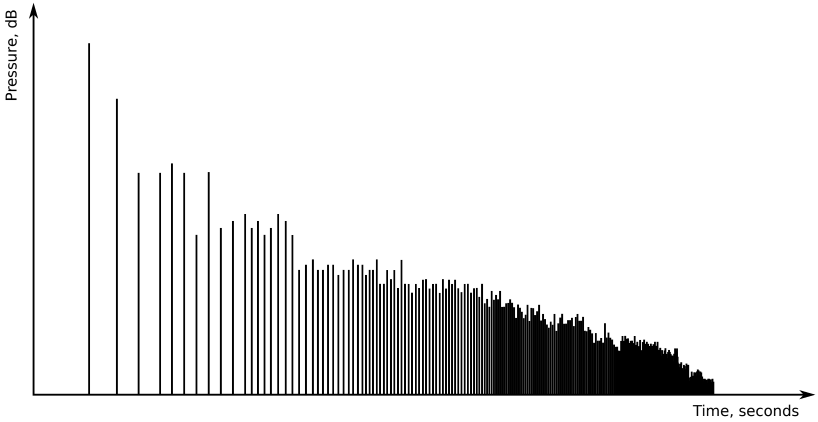




# Room Impulse Response

If my source produces and impulse, what does my receiver measure?



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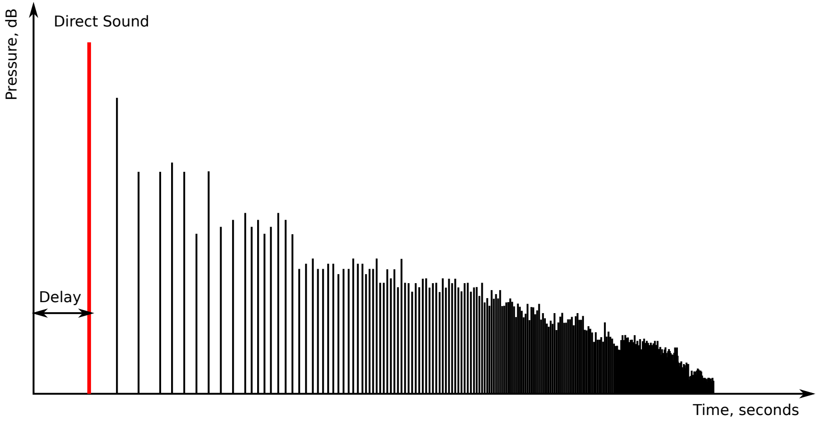

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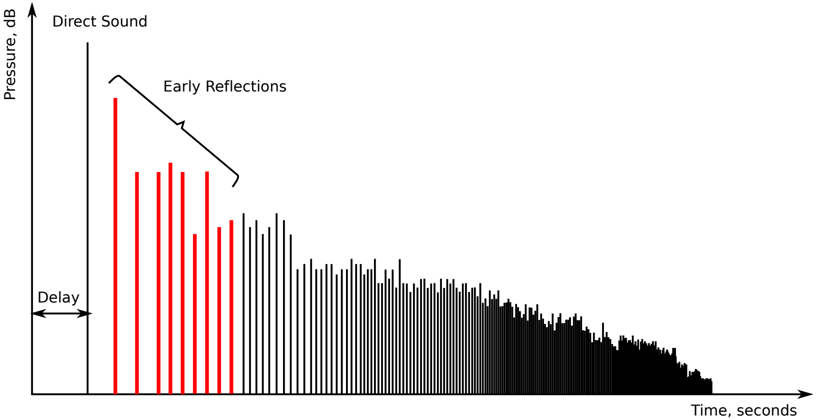

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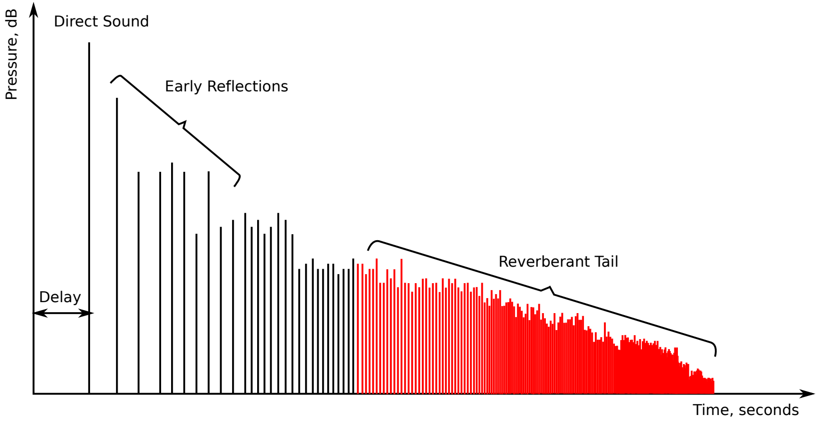

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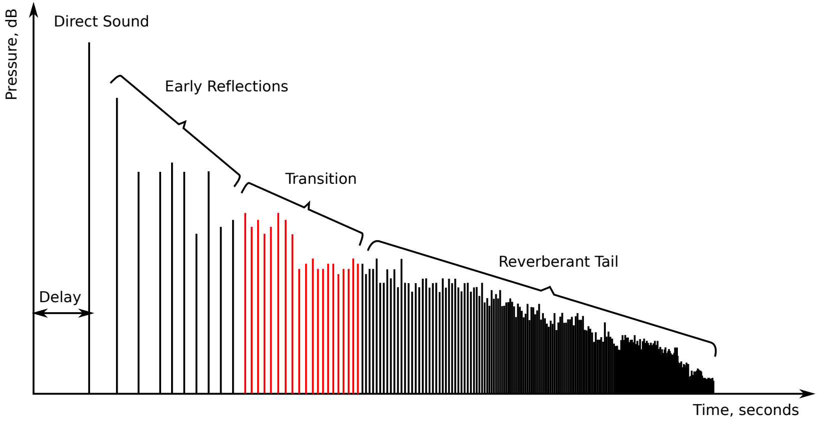


# Room Acoustic Terms

- **Direct sound**: the sound reaching the receiver via a direct path from the source, i.e. no reflections.
- **Indirect sound**: the sound reaching the receiver from all reflected paths.
- **Early reflections**: discrete low order reflections.
- **Reverberant tail**: high density, high order reflections.
- **Transition phase**: region where the impulse response changes from early reflections to the reverberant tail.

# Room Acoustic Metrics

- **$RT_{60}$ ($RT_{30}$)**: the time it takes for the energy in in the impulse response to drop by 60 (30) dB.
- **Direct to reverberant ratio**: the ratio of energy in the direct sound versus the reverberant tail.
- **Frequency response**: the effect that the room has on the frequency spectrum of a signal.

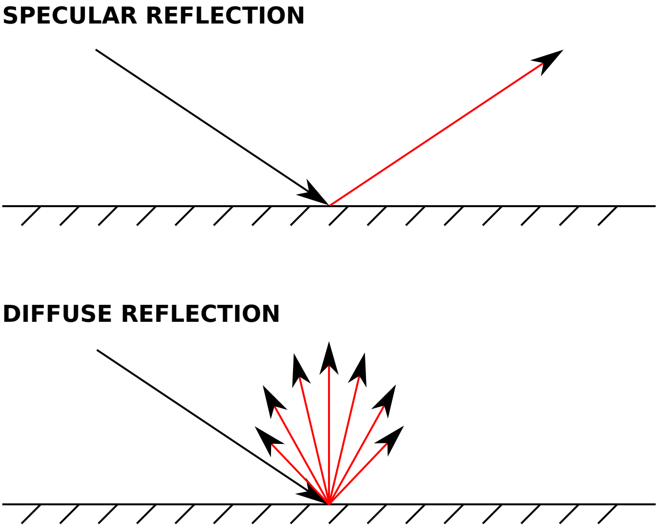
# Reflections

- Sound energy is invariably absorbed by the reflecting surface $\rightarrow$ the reflected sound wave has a lower magnitude compared to the incident wave.
- The phase of the sound wave can also be altered by the reflection.
- The effect on both magnitude and phase can be frequency dependent.

# Reflections

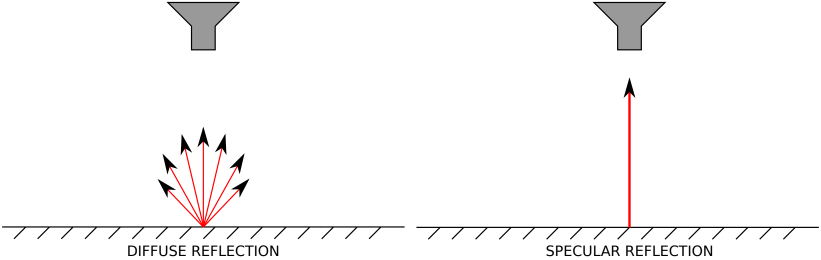
- The directional distribution of sound energy after a reflection will lie between two extremes:
  - **Specular** - the energy is reflect at an angle equal to the angle of incidence.
  - **Diffuse** - the energy is smeared in many directions and is independent of the angle of incidence.

# Reflections



# Reflections

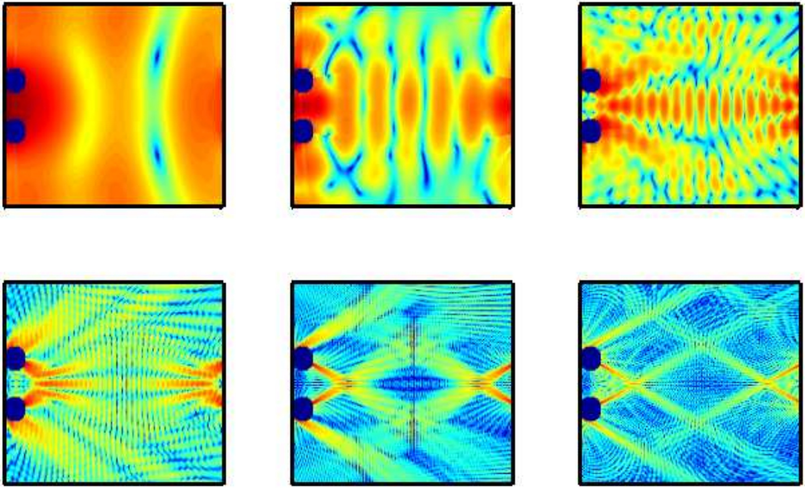
- Diffuse reflections scramble the sound wave so it is a less perfect copy to the original.
- A specular reflection is a perfect copy of the original sound.
- How does this effect sound reinforcement and cancellation due to a reflection?



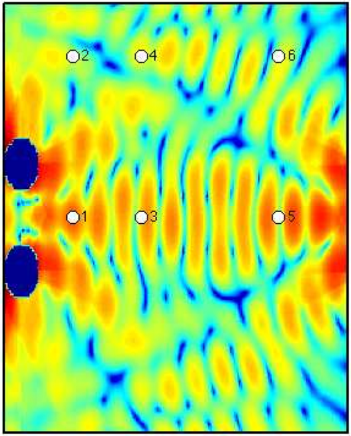
# Absorbers and Diffusers

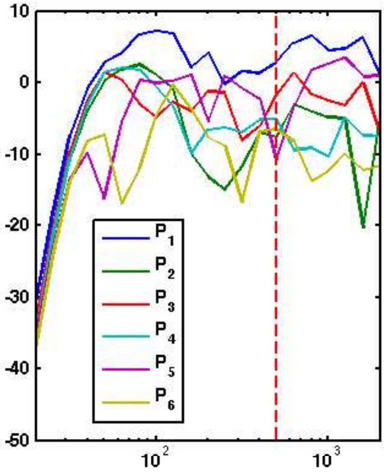
- **Absorbers** are placed in rooms to remove sound energy from reflected waves. They are generally tuned to specific frequencies.
- **Diffusers** are used to scatter the energy and randomise the phase of a reflected sound. This reduces the comb filter effect compared to specular reflections.

# (Loudspeaker Pair + Room) Response



# (Loudspeaker Pair + Room) Response



# Measure System Responses

- To measure a loudspeaker + room (+ microphone + interface) response:
  - Play a test signal through a loudspeaker (noise or sine sweep).
  - Record the signal using a microphone.
  - Compare the two signals to extract the impulse and frequency response.
- A 30 day trial of Smaart can be download from *www.rationalacoustics.com*.