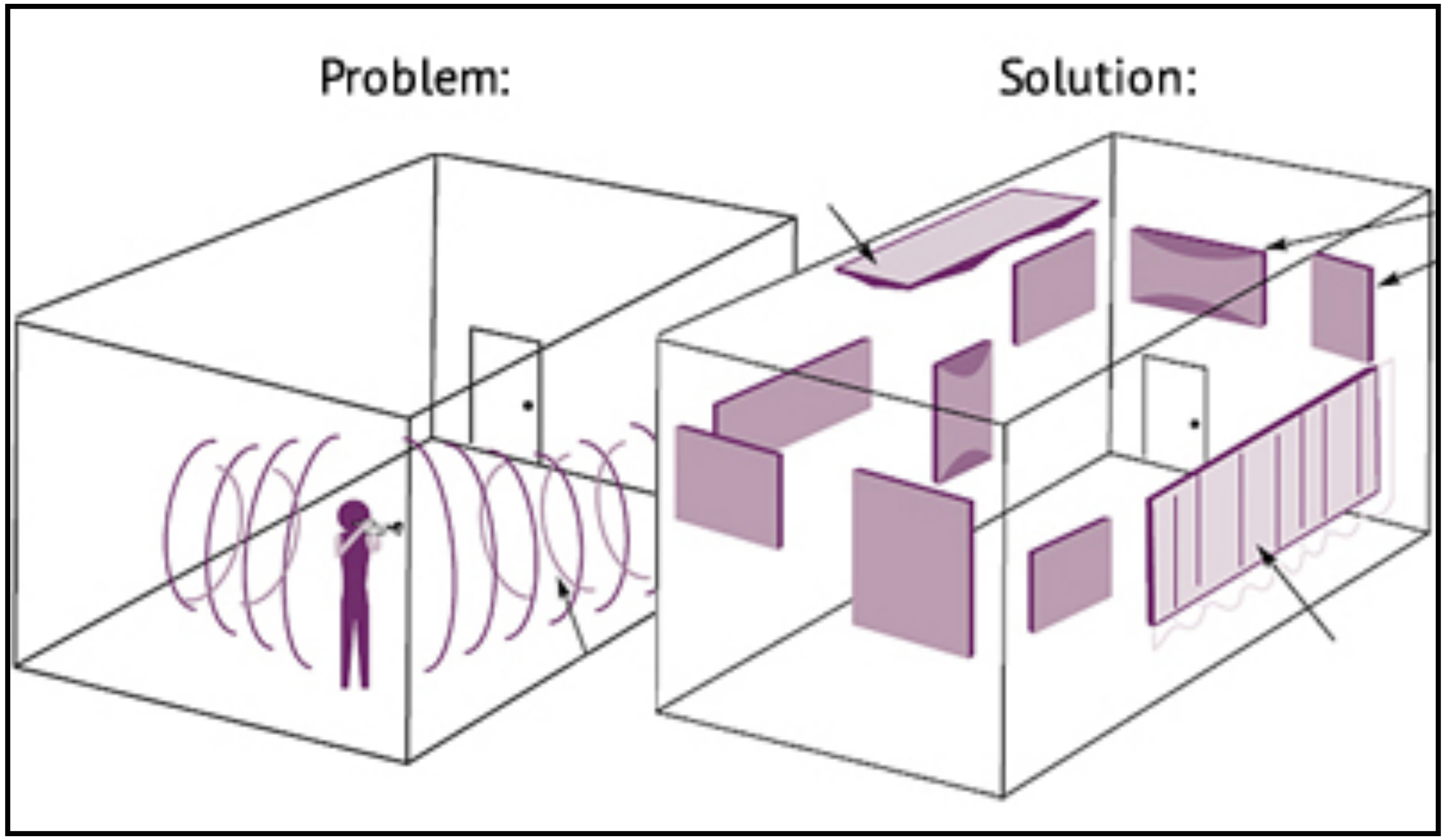
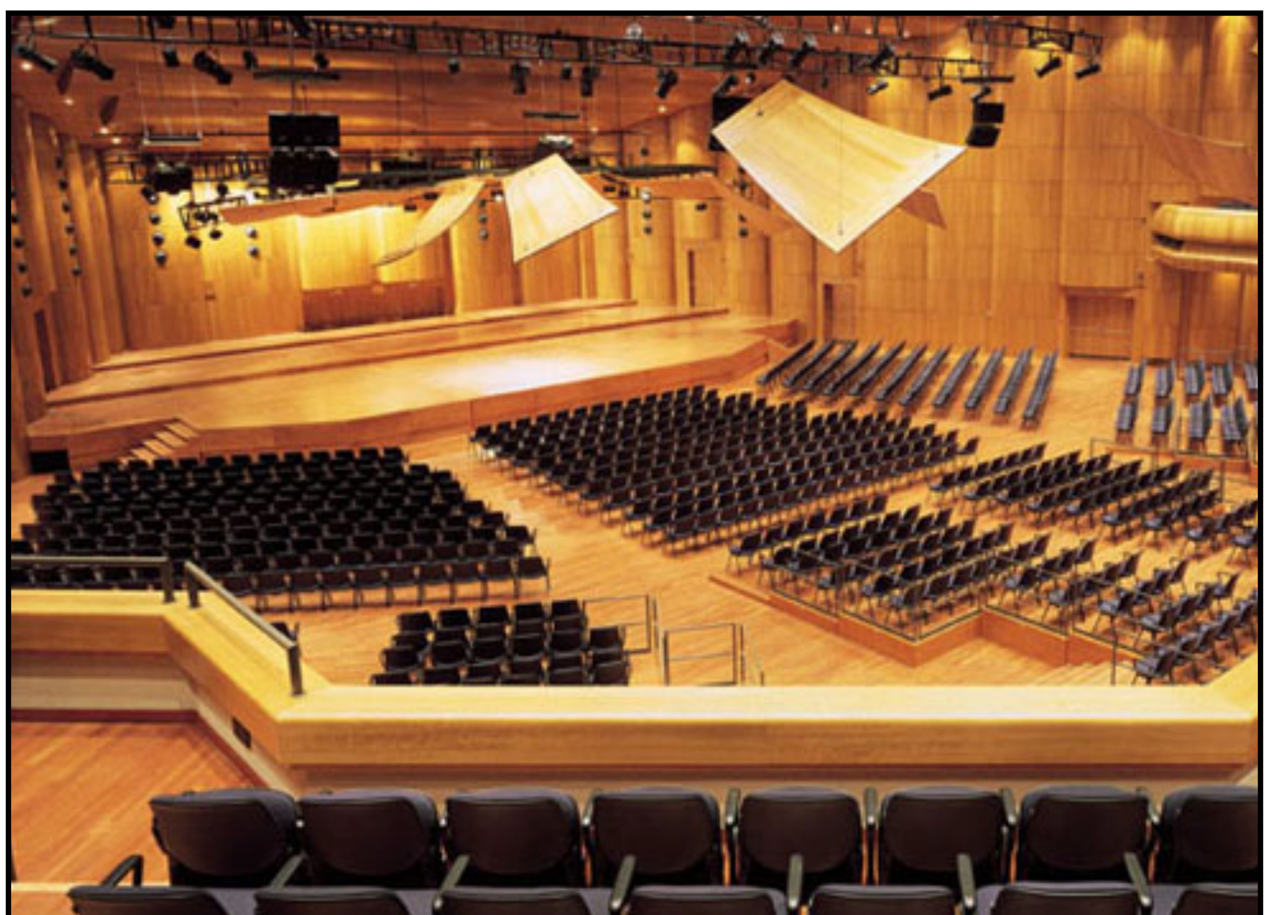
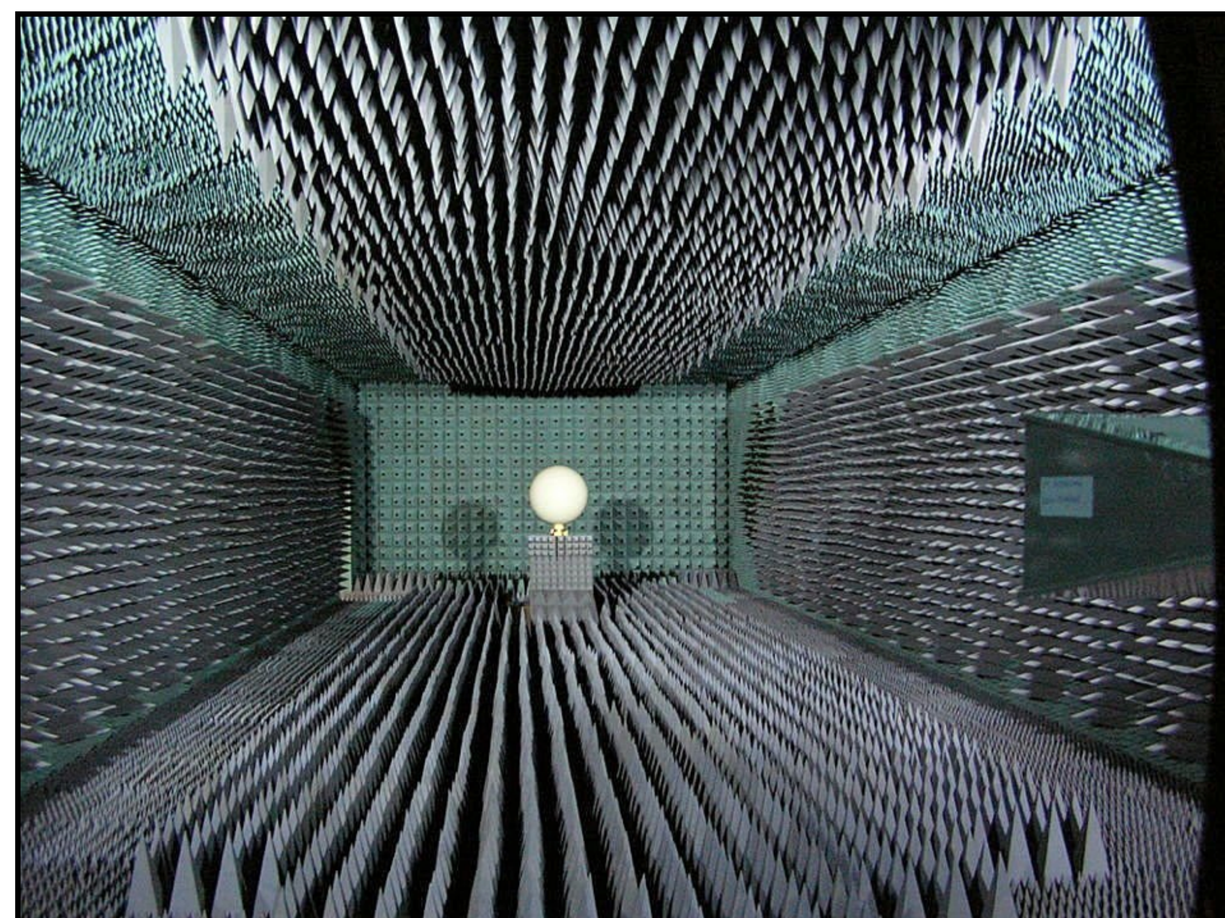
Room Acoustics

March 27th 2015

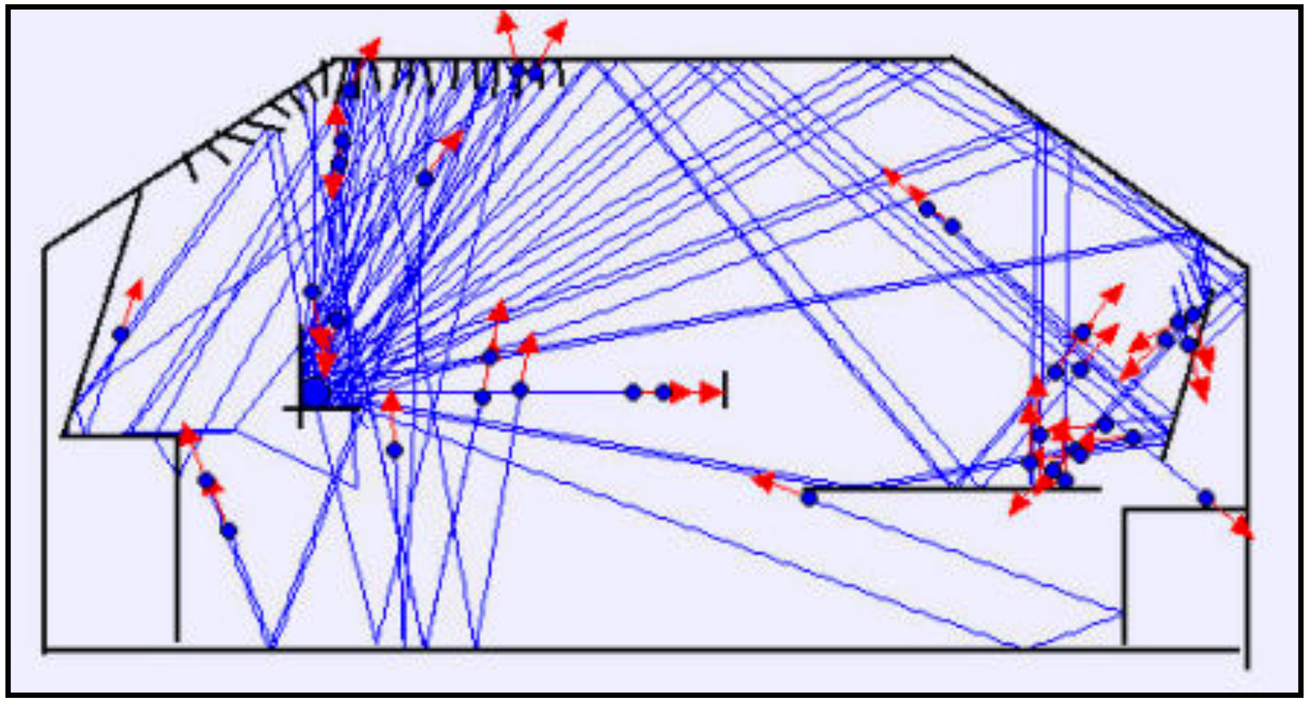

Problem:
Solution:





Question

How many reflections do you think a sound typically undergoes before it becomes inaudible? As an example take a 100dB sound. How long before this reaches 40dB?



Question

How many reflections do you think a sound typically undergoes before it becomes inaudible? As an example take a 100dB sound. How long before this reaches 40dB?

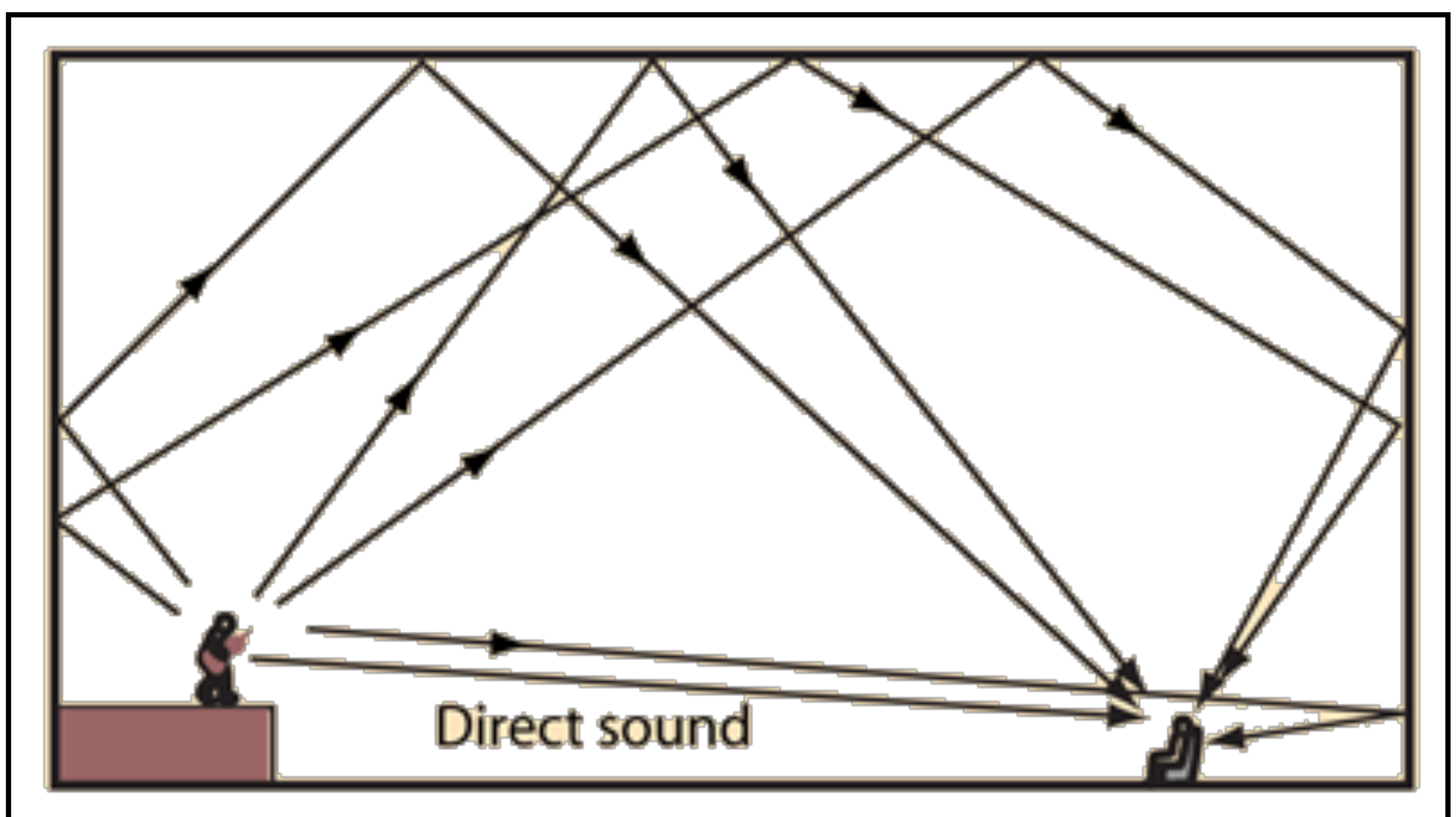
Dozens!

This means that the sound we hear is shaped to a large degree by the surrounding walls and surfaces.

The amount of reflection that occurs depends on the size of the room, the shape of the room and also materials that make up the walls, floor and ceiling.

Reflection of Sound

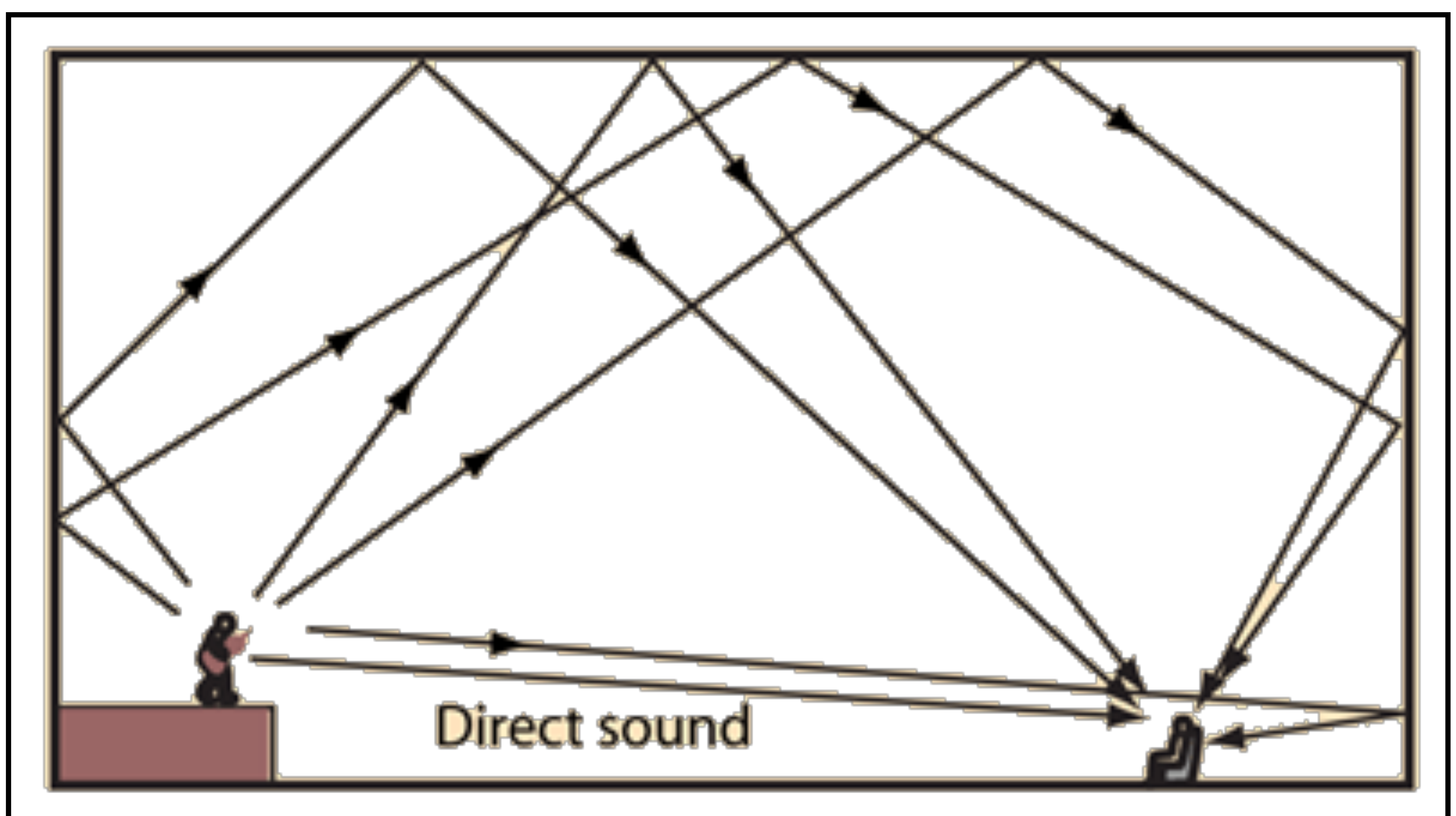
- What we hear is sound which is the combination of original (direct) sound and echoes from the walls, ceiling and floors.



Reflection of Sound

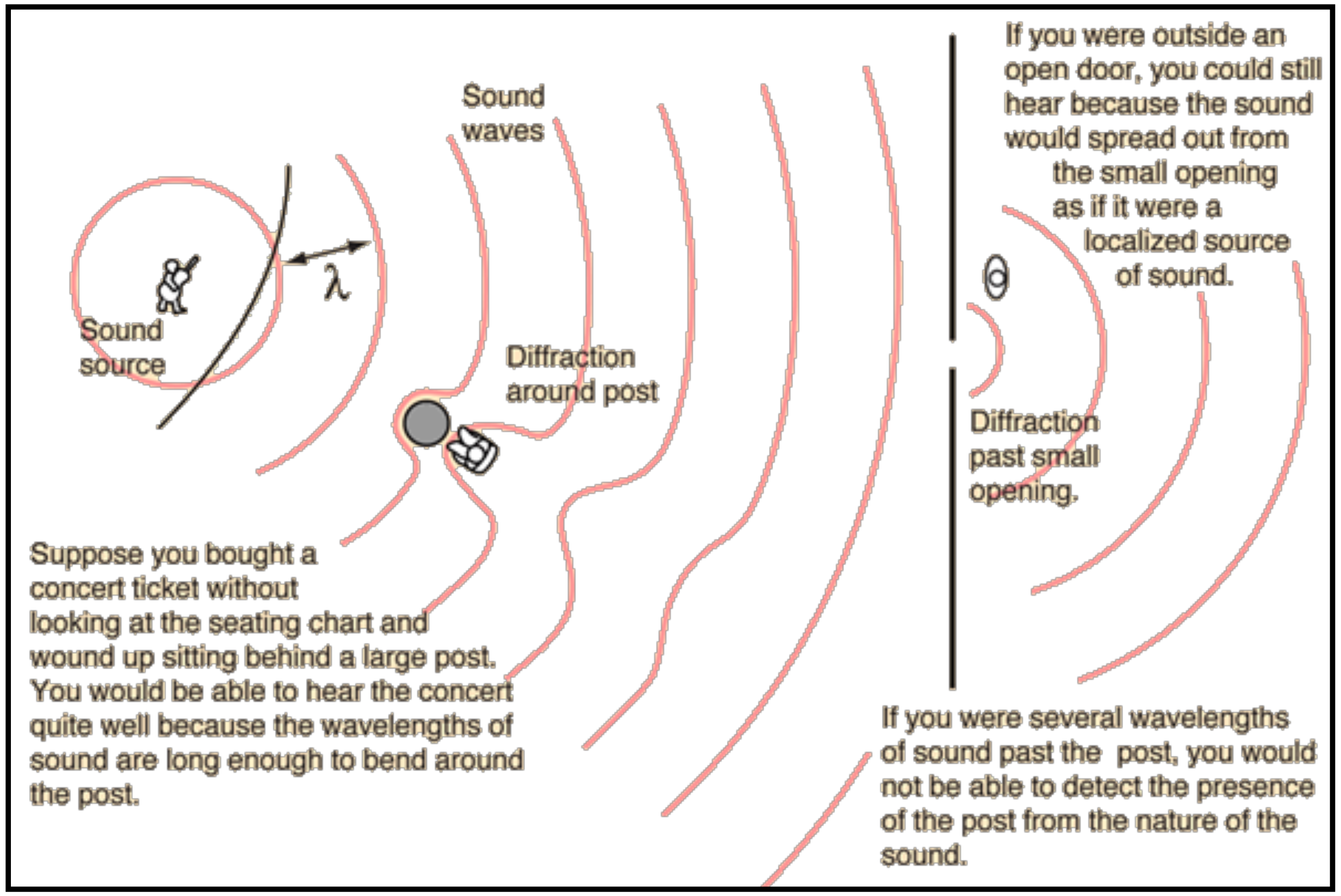
- Echoes are sounds that heard more than 50 ms after the direct sound. Large rooms (>17m) can have echoes.

- An initial wave that hits someone's ear may still be dying out as the reflected waves arrive, resulting in distorted sounds (think about loud music in a gym).



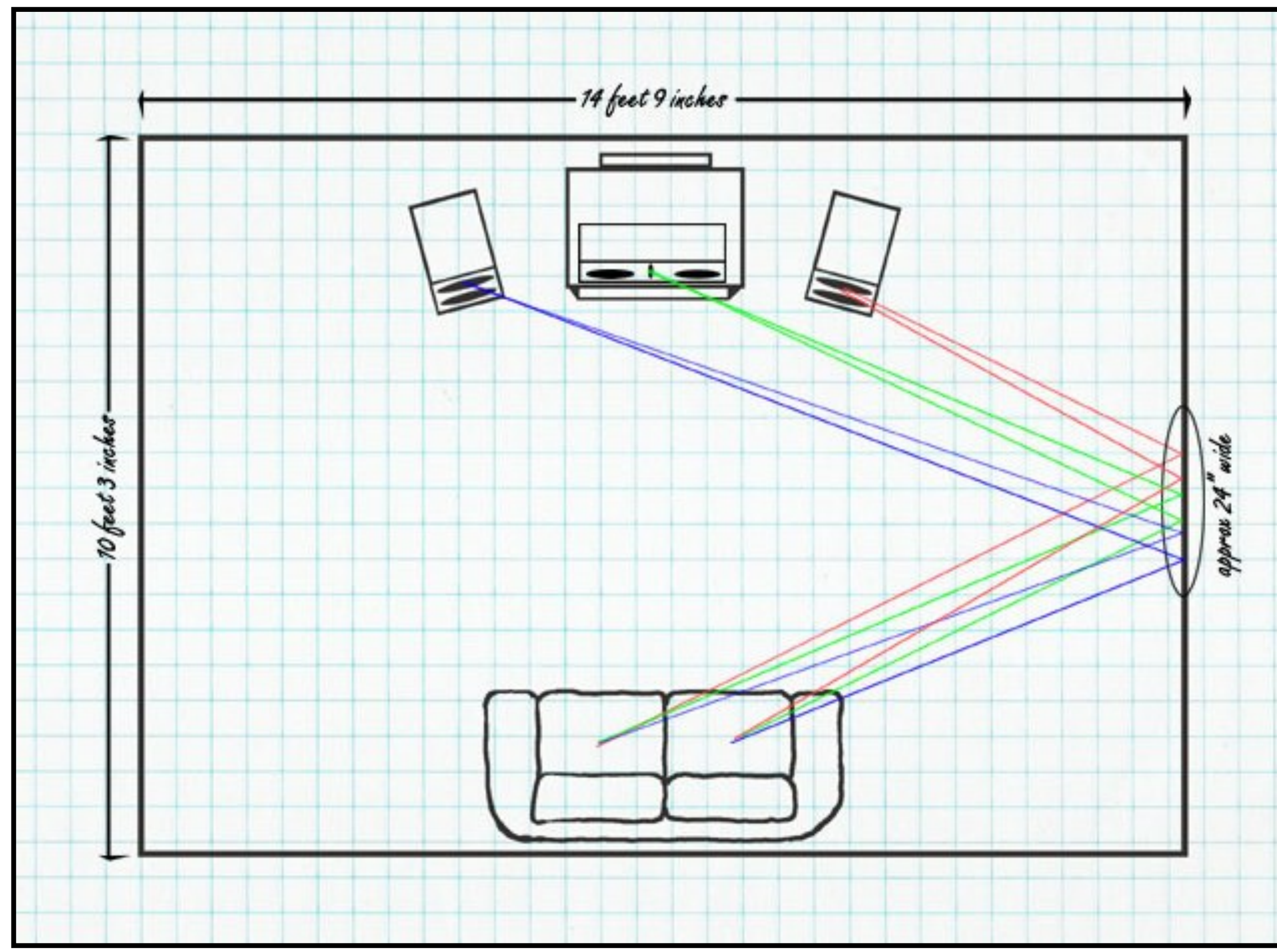
Reflection of Different Frequencies

- Low frequencies (long wavelength, up to 17m).
    - *Bend* around walls via diffraction
    - Less easily absorbed by air than high frequencies (think of thunder).
    - Ear is less sensitive to them.
    - Strong, uniform echoes for simple uncluttered rooms.



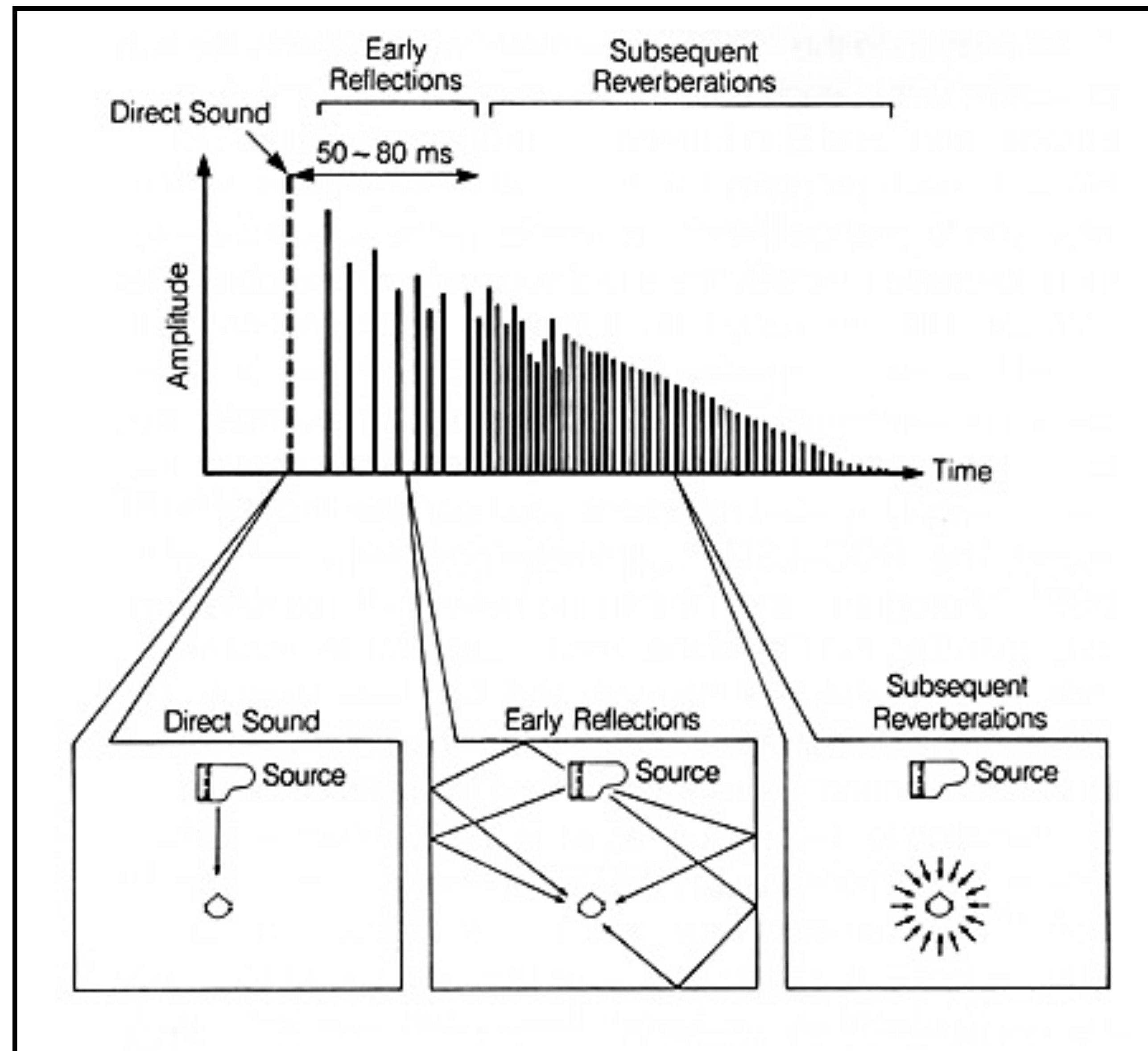
Reflection of Different Frequencies

- High frequencies (wavelengths as small as 20mm)
  - Short wavelengths have nice predictable reflections (forward)
  - Reflections can be inconsistent and garbled.



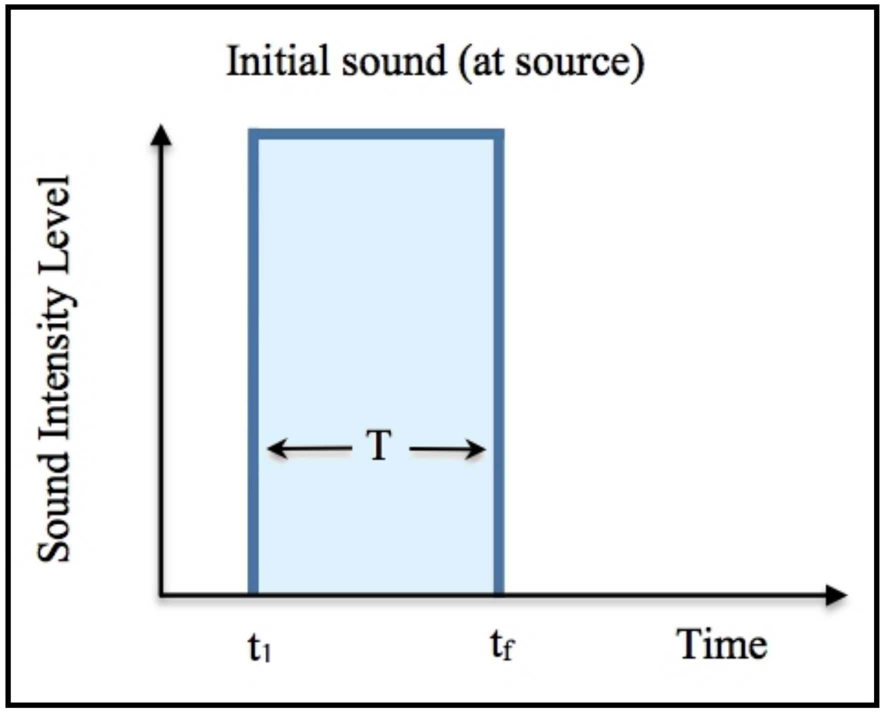
Direct, Early and Reverberant Sound

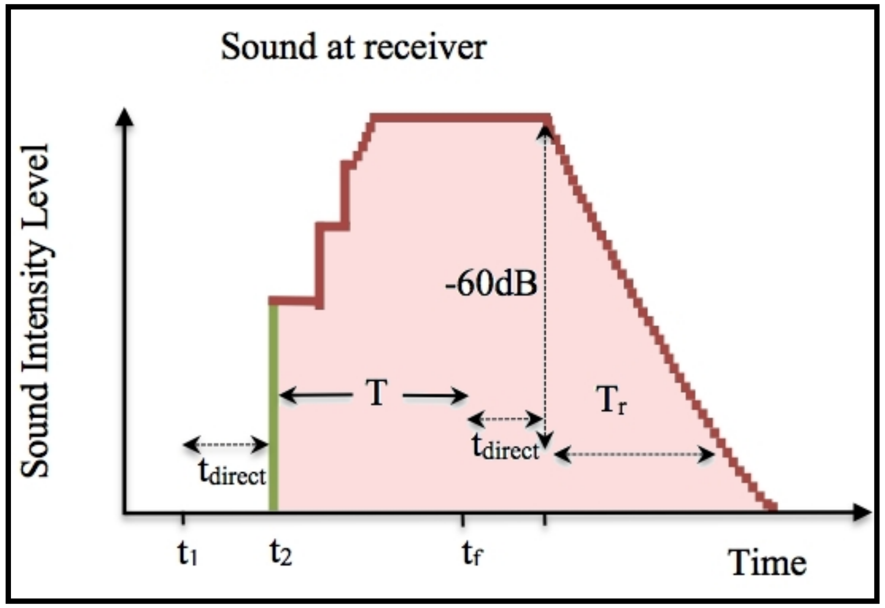
- Adjacent figure shows the sound heard from instantaneous source.
- Direct sound tells our brain the location of the sound source.
- Reflected sounds tend to reinforce the direct sound.
- In a good concert hall the direct sound should be substantially louder than background noise at all locations.

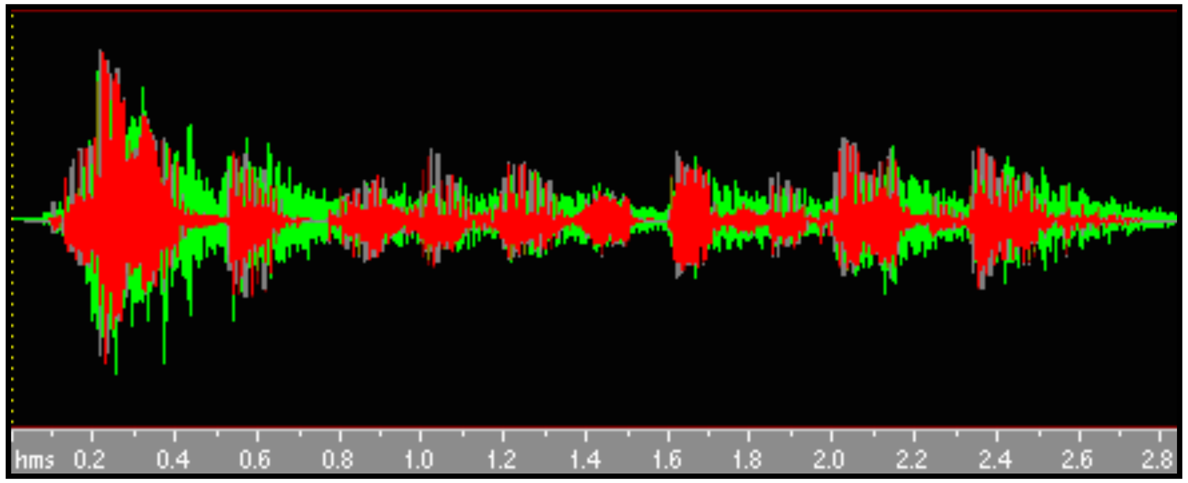


Reverb

- Reverberant sound, like early sound reinforces the direct sound and adds to overall loudness.
- Reverberant level is reached when source power is equal to the rate at which sound is absorbed.
- Too much reverb makes speech difficult to understand.

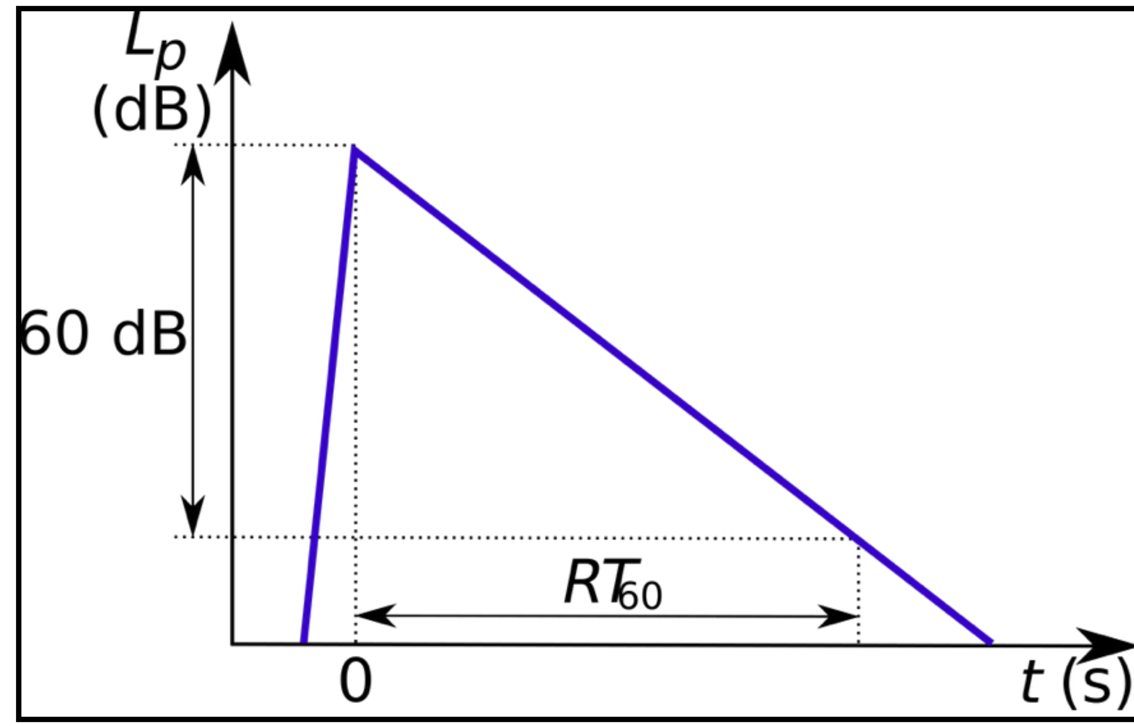


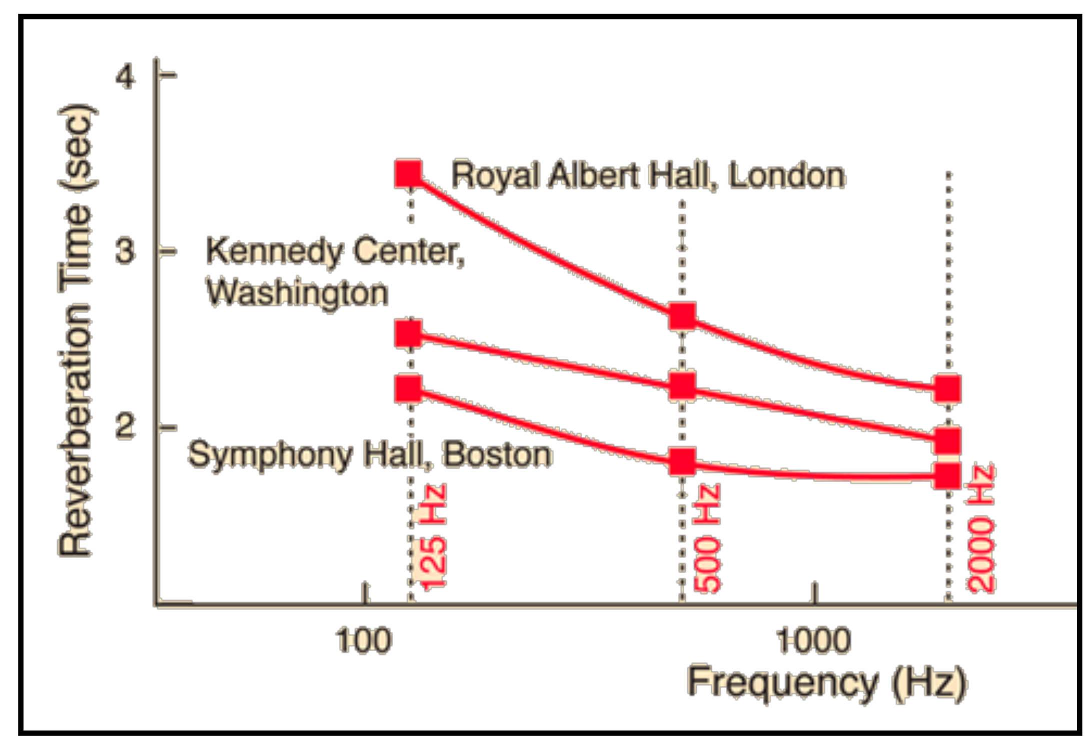




Reverberation Time

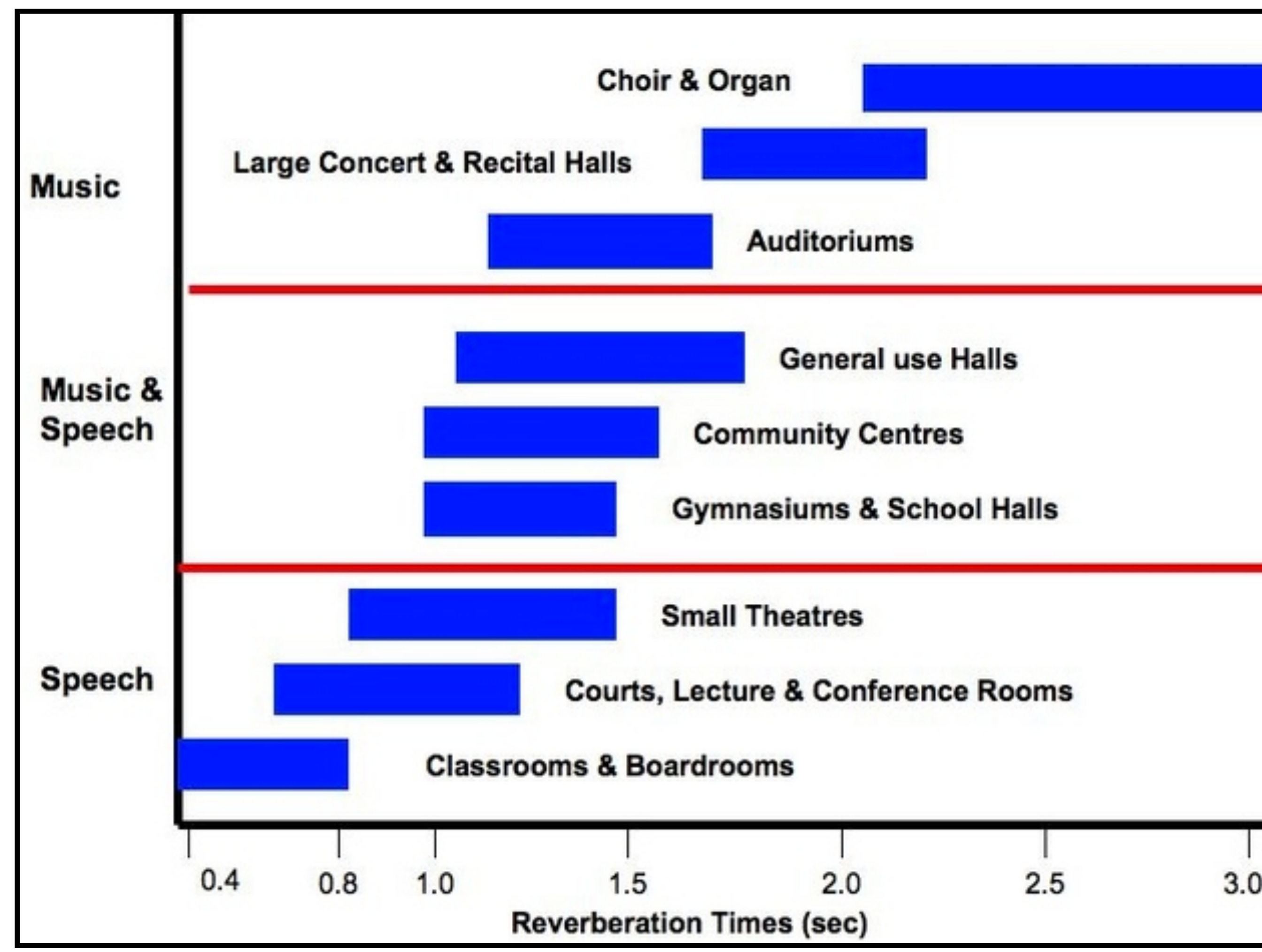
- Sound continues to reverberate around a room until its energy has been full absorbed by surfaces and the air.
- RT_{60} = Time for intensity to decay by 60dB.
- RT_{60} and also number of modes in room is proportional to the size of the room, and inversely proportional the the absorption in the room.
- Complex frequency spectra ring longer.
- **Goal is generally to design a room where all frequencies have same RT_{60}.**





Reverberation Time

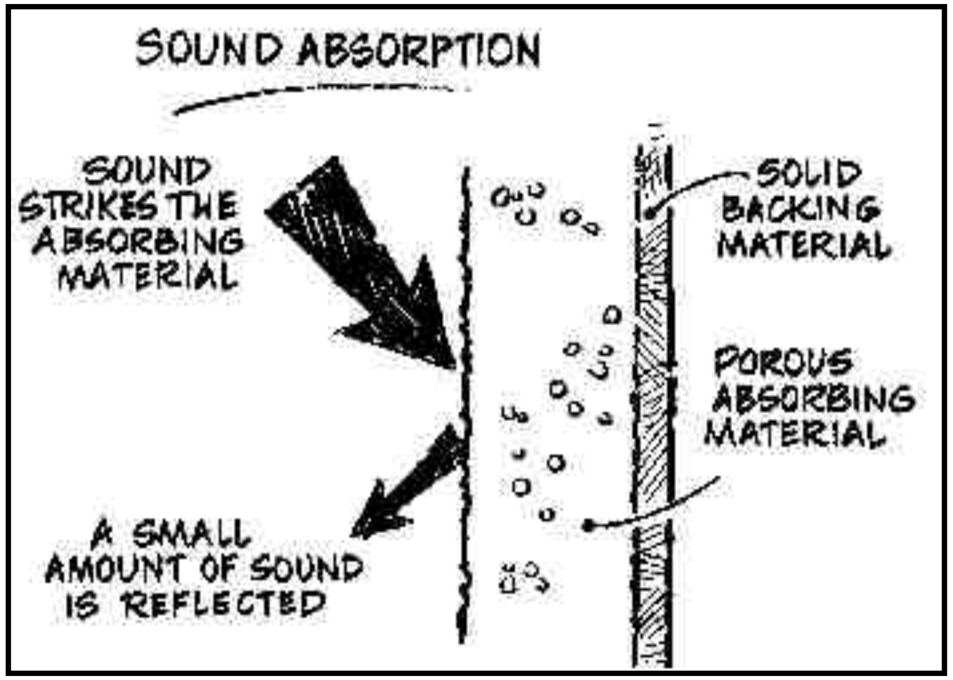
- RT_{60} is too short, everything sounds *dry* and hard to hear. Think about outdoor arenas where there's little reflection.
- Recording studio <1s.
- Speech audibility = 1s,
- Opera/concert halls 1.5s-2s.
- Old stone cathedrals 10s! (good for slow organ music as long as there are very slow changes in pitch, terrible for fast music/speech).



Different Materials Absorb Frequencies to Different Degrees

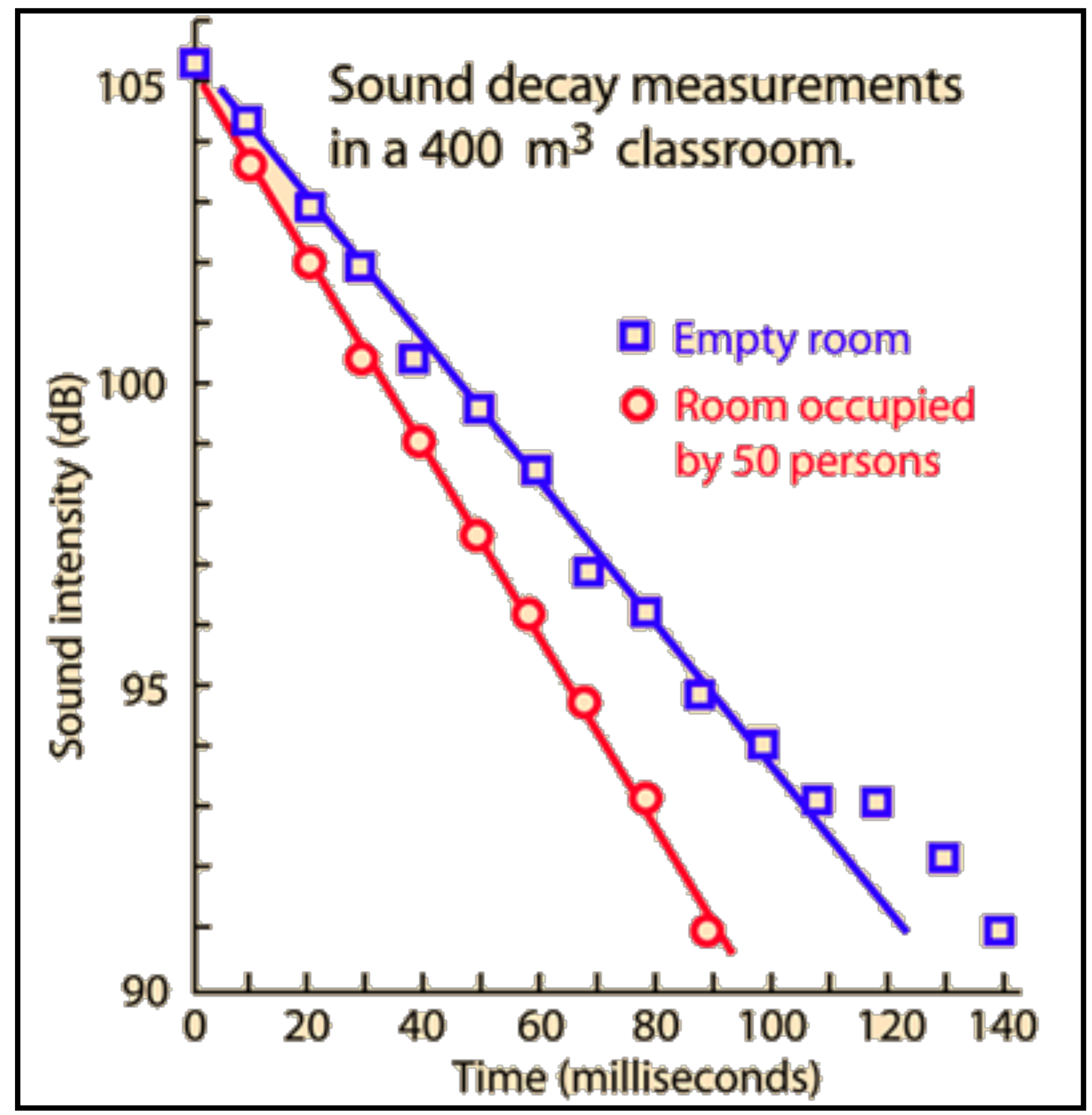
- Specialized materials and shape are used to control sound propagations.
- Reflection off flat walls preserves everything
- Fibrous material absorb high frequencies, but have trouble with low.

Material	Frequency (Hz)*					
	125	250	500	1,000	2,000	4,000
Acoustic Panels	0.15	0.3	0.75	0.85	0.75	0.4
Brick	0.024	0.024	0.03	0.04	0.05	0.07
Carpet	0.05	0.1	0.2	0.25	0.3	0.35
Concrete	0.01	0.01	0.02	0.02	0.02	0.03
Curtains	0.05	0.12	0.15	0.27	0.37	0.5
4” Fiberglass	0.38	0.89	0.96	0.98	0.81	0.87
Wood Floor (joists)	0.15	0.2	0.1	0.1	0.1	0.05
Glass	0.03	0.03	0.03	0.03	0.02	0.02
Seated Person	0.18	0.4	0.46	0.46	0.5	0.46
Plasterboard	0.3	0.3	0.1	0.1	0.04	0.02
Plywood on 2” Batten	0.35	0.25	0.2	0.15	0.05	0.05
3/4” Wood Panel	0.1	0.11	0.1	0.08	0.08	0.11

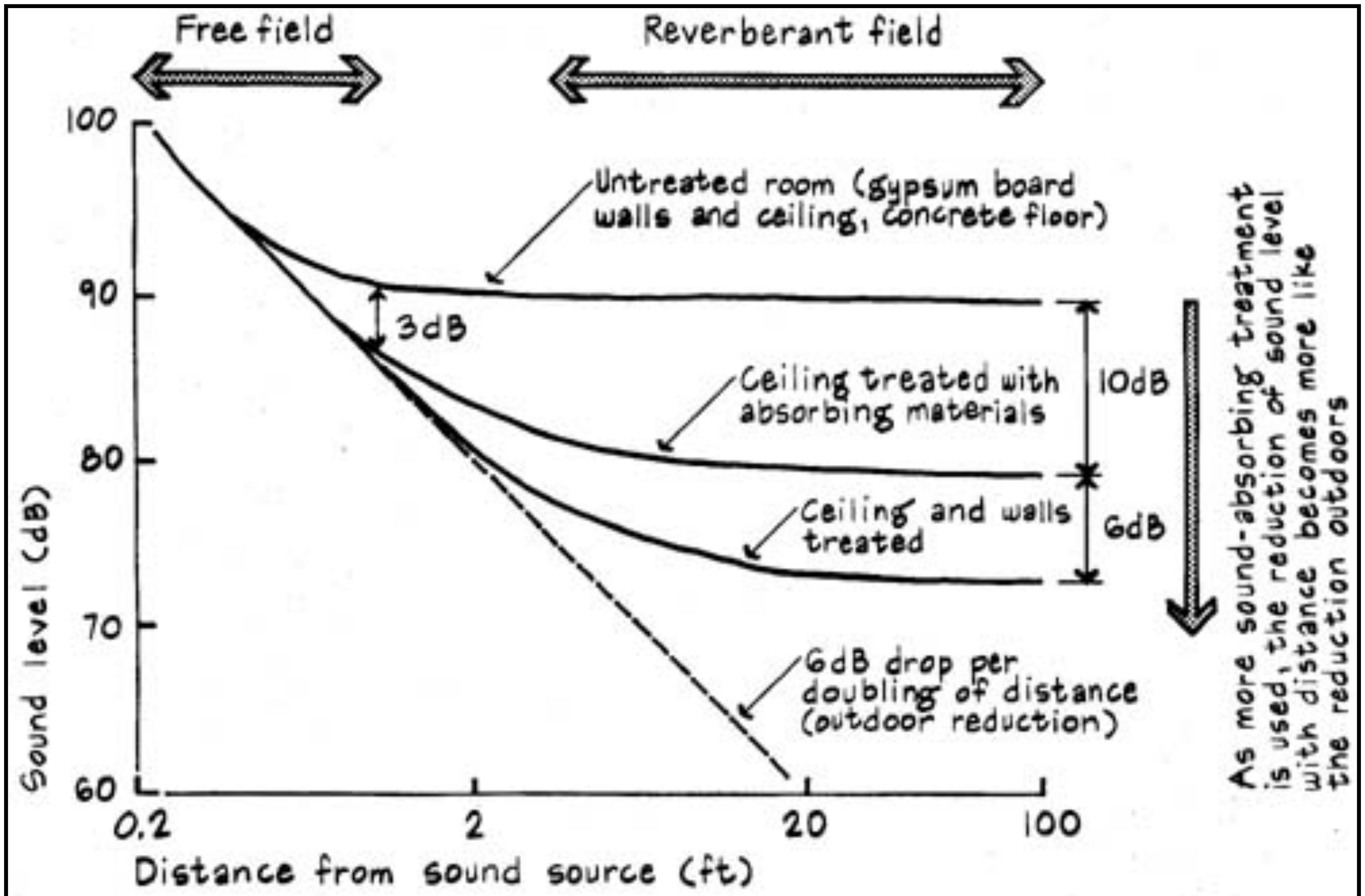


Different Materials Absorb Frequencies to Different Degrees

- People, seats, furniture can absorb waves of most frequencies, depending on their locations.
- They can cause selective frequencies to absorb more and decay faster.
- Clothing actually affects the acoustic of the room (fur coat vs bare skin).

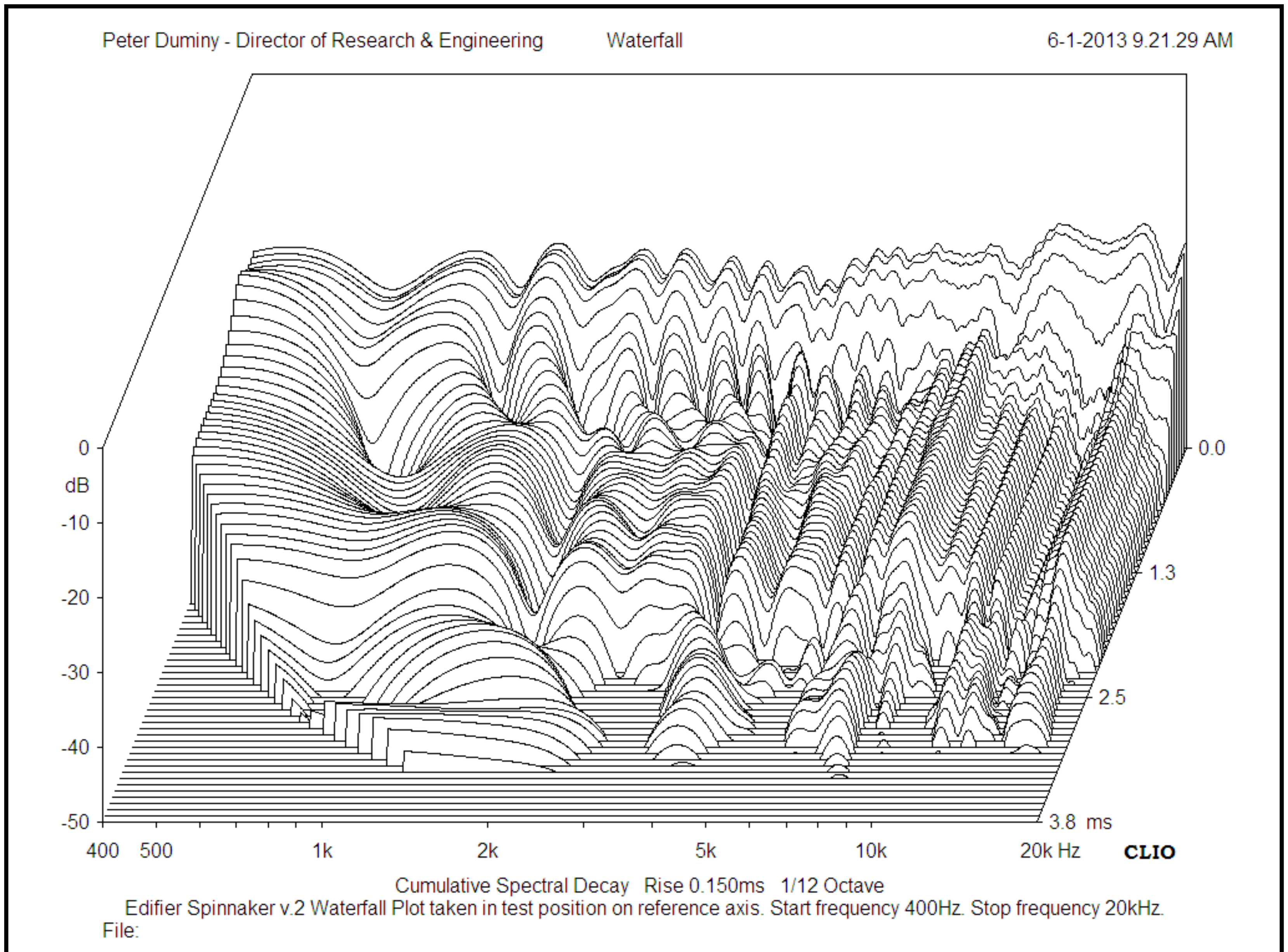


Sound Level



Free field
Reverberant field
100
90
80
70
60
Sound level (dB)
0.2
2
20
100
Distance from sound source (ft)
Untreated room (gypsum board walls and ceiling, concrete floor)
3dB
Ceiling treated with absorbing materials
10dB
Ceiling and walls treated
6dB
6dB drop per doubling of distance (outdoor reduction)
As more sound-absorbing treatment is used, the reduction of sound level with distance becomes more like the reduction outdoors

Room Frequency Response



Architectural Acoustics

Chan center;

- Adjustable height chandelier/acoustic canopy over the stage made of steel and cork reflects sound as desired.
- Sound absorbent fabric banners acoustically mask walls
- Cello-like shape of the hall allows for even distribution of sound.
- Concrete walls are convex with a stippled surface which helps to break down sound and prevent reverb.
- Wood seen in the concert hall has been sealed to the concrete to prevent any sympathetic vibrations.

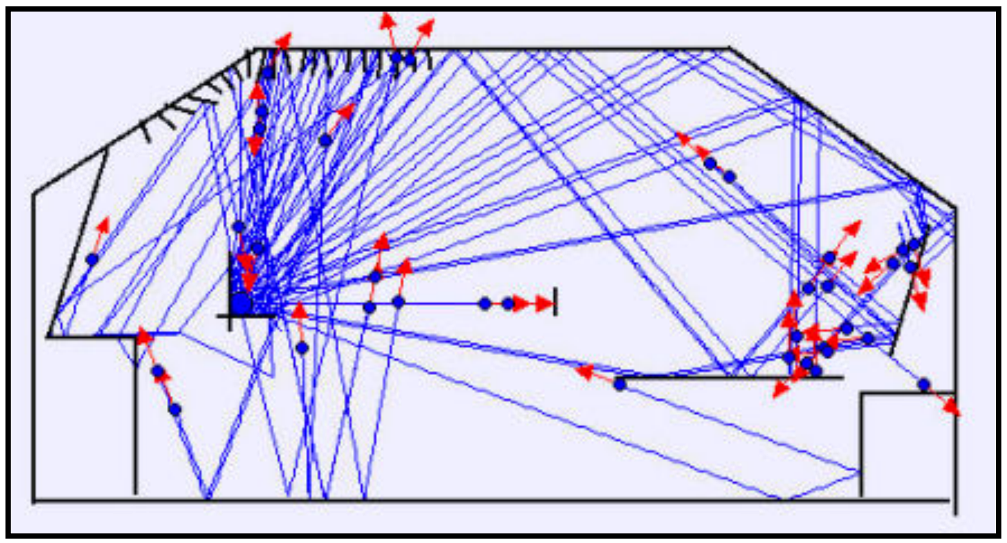
Important Features

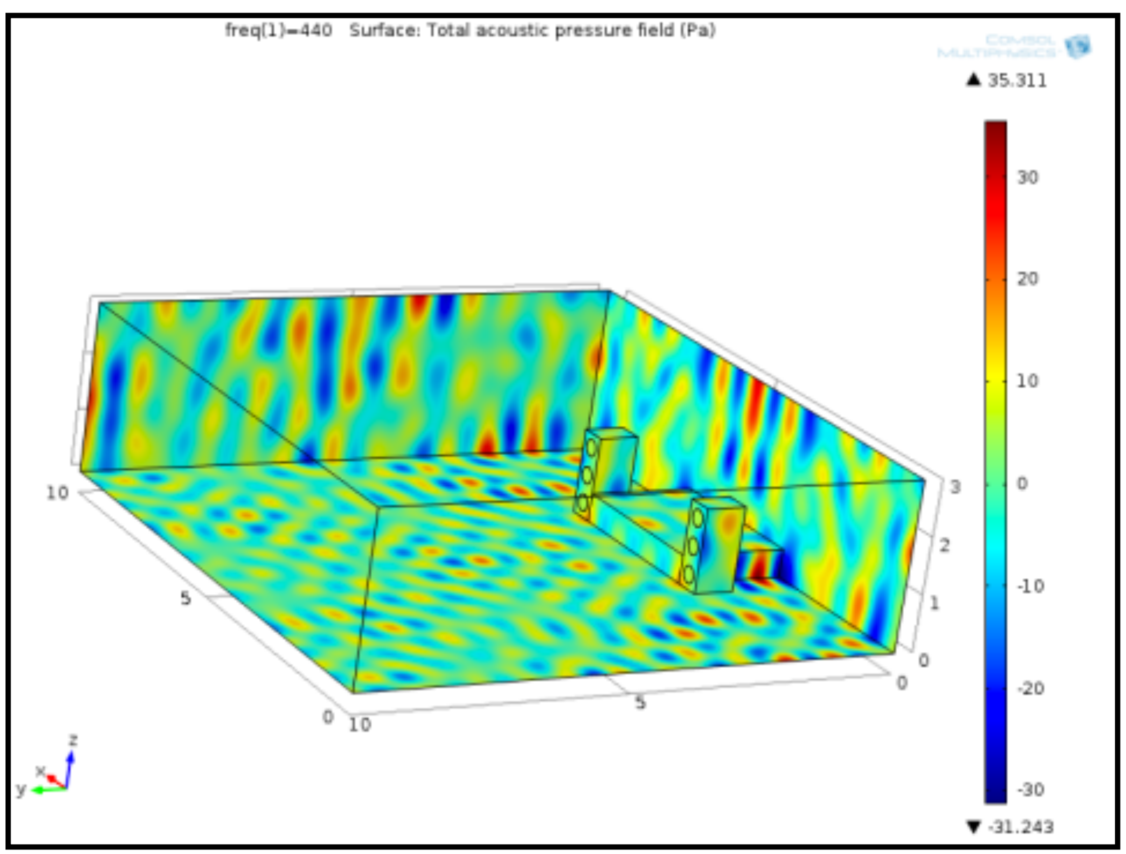
1. **Intimacy** (time between direct and first reflected sound < 20ms)
2. **Liveness** (reverberation time for middle and high frequencies)
3. **Warmth** (reverberation time at bass frequencies, 250 Hz and below, should be longer)
4. **Loudness of direct sound** (not too far from sound source)
5. **Reverberant sound level** (depends on the power of the source and reverberation time)
6. **Definition / clarity** (level of early+direct sound should be greater than reverberation at all locations)
7. **Diffusion or uniformity (**good spatial distribution of sound achieved by diffuse or irregular reflecting surfaces, and by the avoidance of focused sound or sound shadows)
8. **Balance and blend** (depends on stage design)
9. **Ensemble** (ample reflecting surface to the sides and above performers so they can hear each other)
10. **Freedom from noise** (no loud external sources such as ventilation systems, traffic nearby)

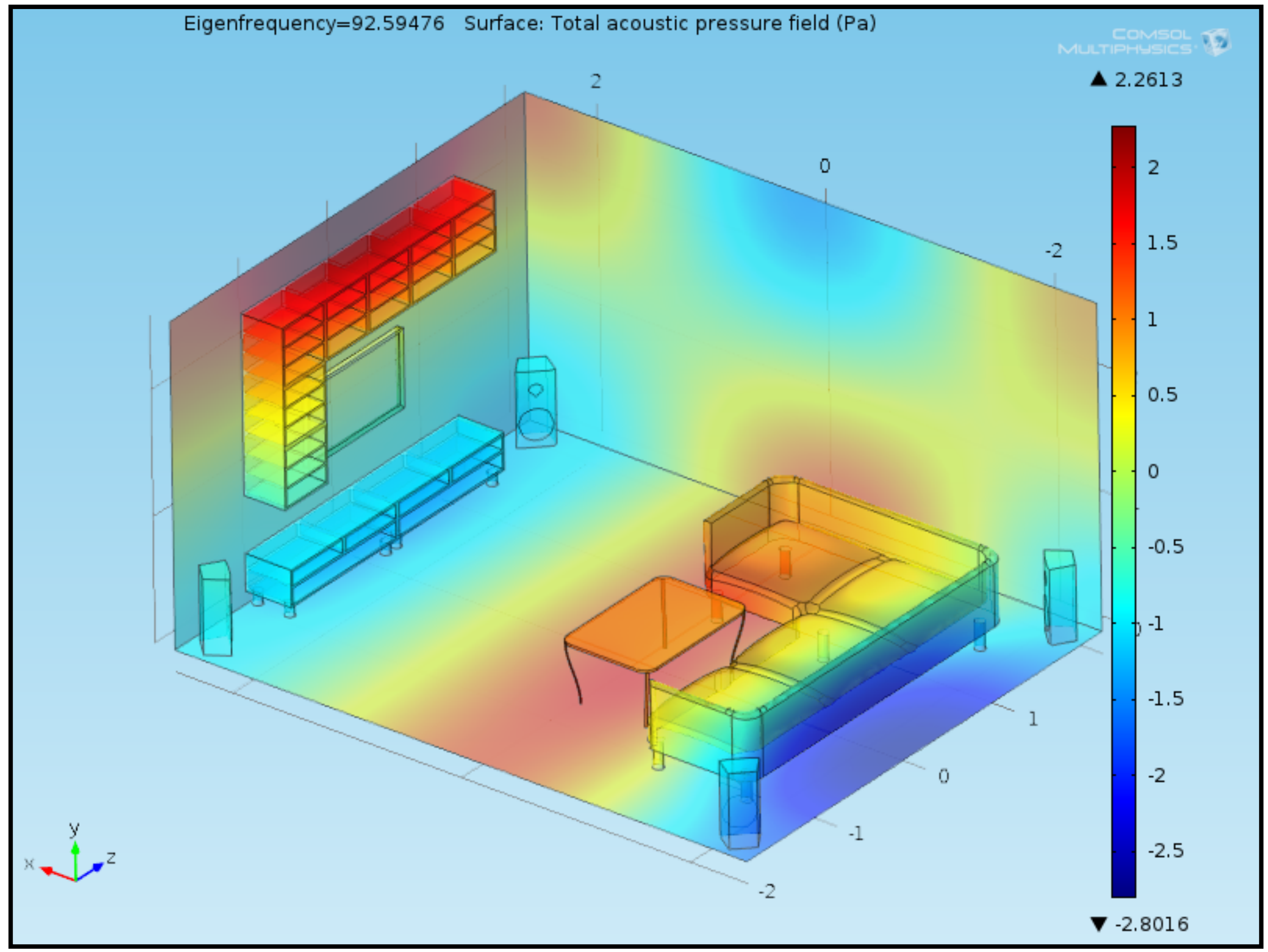
Standing Waves

- Waves propagating through the room overlap and cause interference.
- Standing waves develop due to;
  - Natural acoustic resonance of the room.
  - Location of nodes and antinodes remaining after interference of the modes of sound.
- Some point in the room end up louder than others.
- If you are sat at the node of a standing pressure wave, it’s very quiet.

Room Acoustic Modes







Experiment

- Use loudspeaker with function generator at around 1 kHz, so distance between nodes is around 17 cm.
- Close one ear and move head around.
- Try to find nodes in the room.

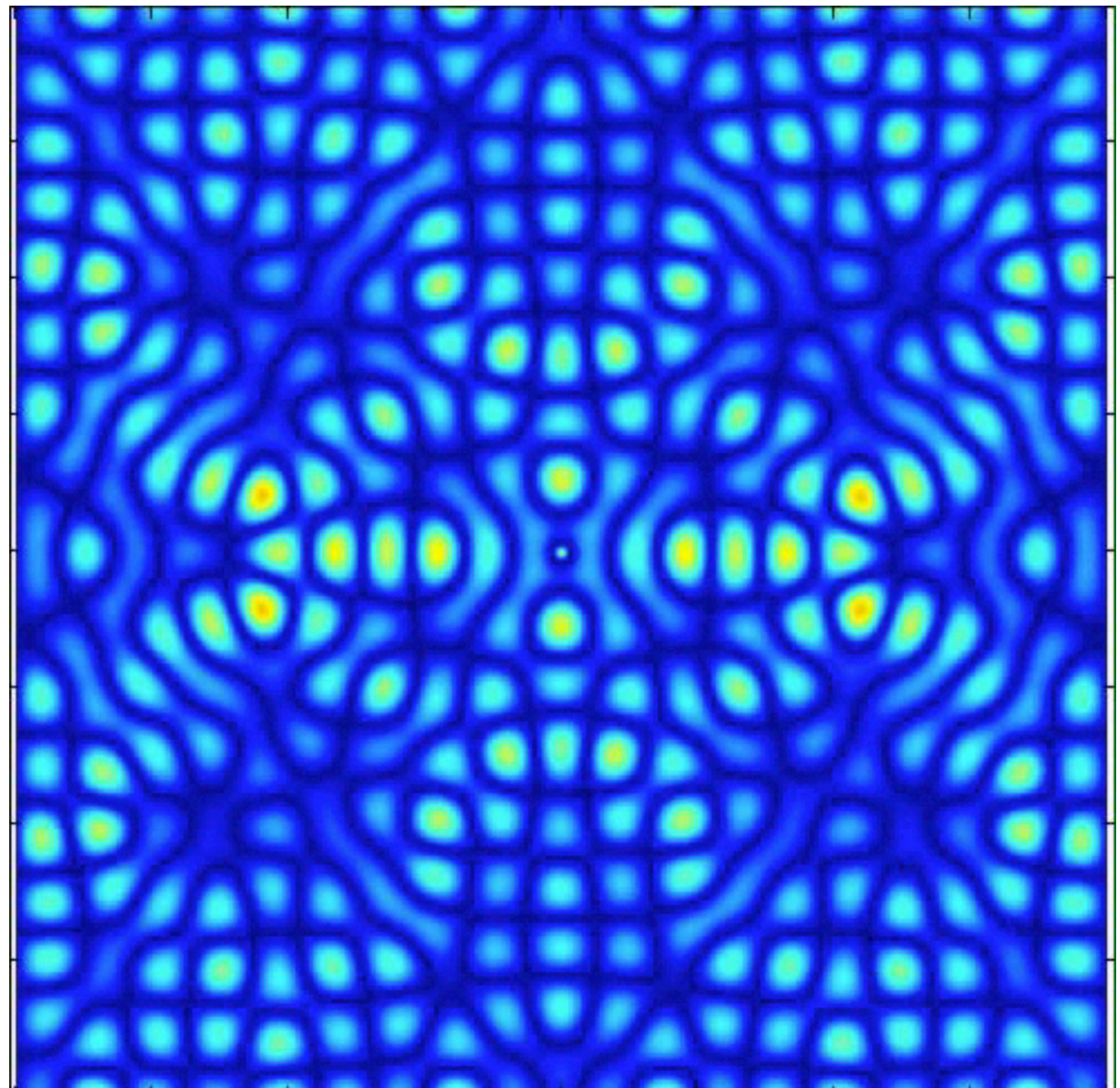
Standing Waves

Square room

Source in center of room

Perfectly reflecting walls

Changing sound wavelength creates different standing waves in the room (which get progressively more complex)



Spectrogram