Chapter 3. Meeting 3, Psychoacoustics, Hearing, and Reflections

3.1. Announcements

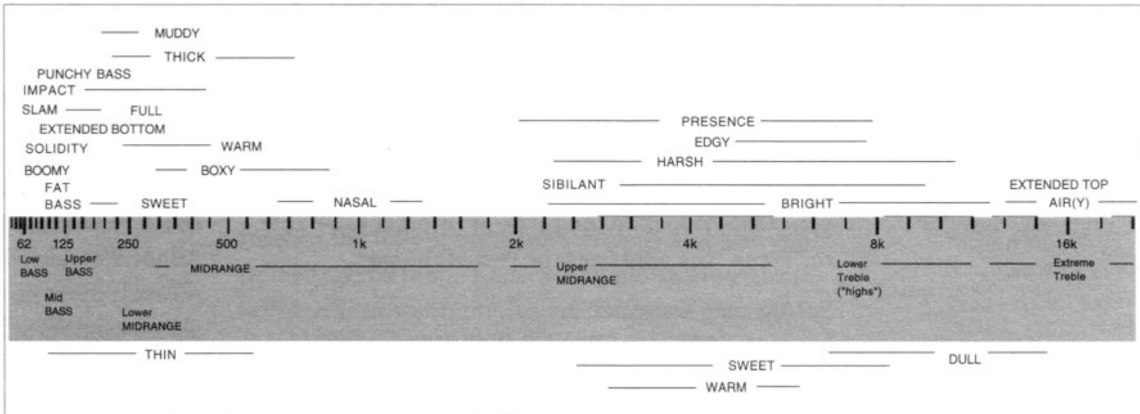
- Need schlep crew for Tuesday (and other days)
- Due Today, 15 February: Mix Graph 1
- Quiz next Tuesday (we meet Tuesday, not Monday next week) on material from this and the next class

3.2. Review

- What is sound?
- How long does it take sound to travel a foot?
- Where can we find sine waves in nature?
- How big is a 60 Hz wave?
- Doubling a signal results in a change of how many dB?
- What are the differences between dBSPL and dBu?
- What is timbre?
- How can we create a saw wave?
- What are inharmonic spectra?
- How do we graph the time domain and the frequency domain?

3.3. Qualitative Descriptions of Frequency

- Talking about sound is an imperfect art
- Descriptive frequency terms



Subjective Terms we use to describe Excess or Deficiency of the various Frequency Ranges.

Source: Katz, B. *Mastering Audio: The Art and the Science*. 2nd ed. Focal Press, 2007.

3.4. Basic DAW Operations and Viewing The Spectrum

- Track orientation and creating tracks
- Adding audio processors
- Setting loop points

3.5. Sine and Noise in the Frequency Domain

- A sine produces a single frequency in the frequency domain
- White noise is represented as all frequencies in the frequency domain
- Example: signalWaveforms.pd

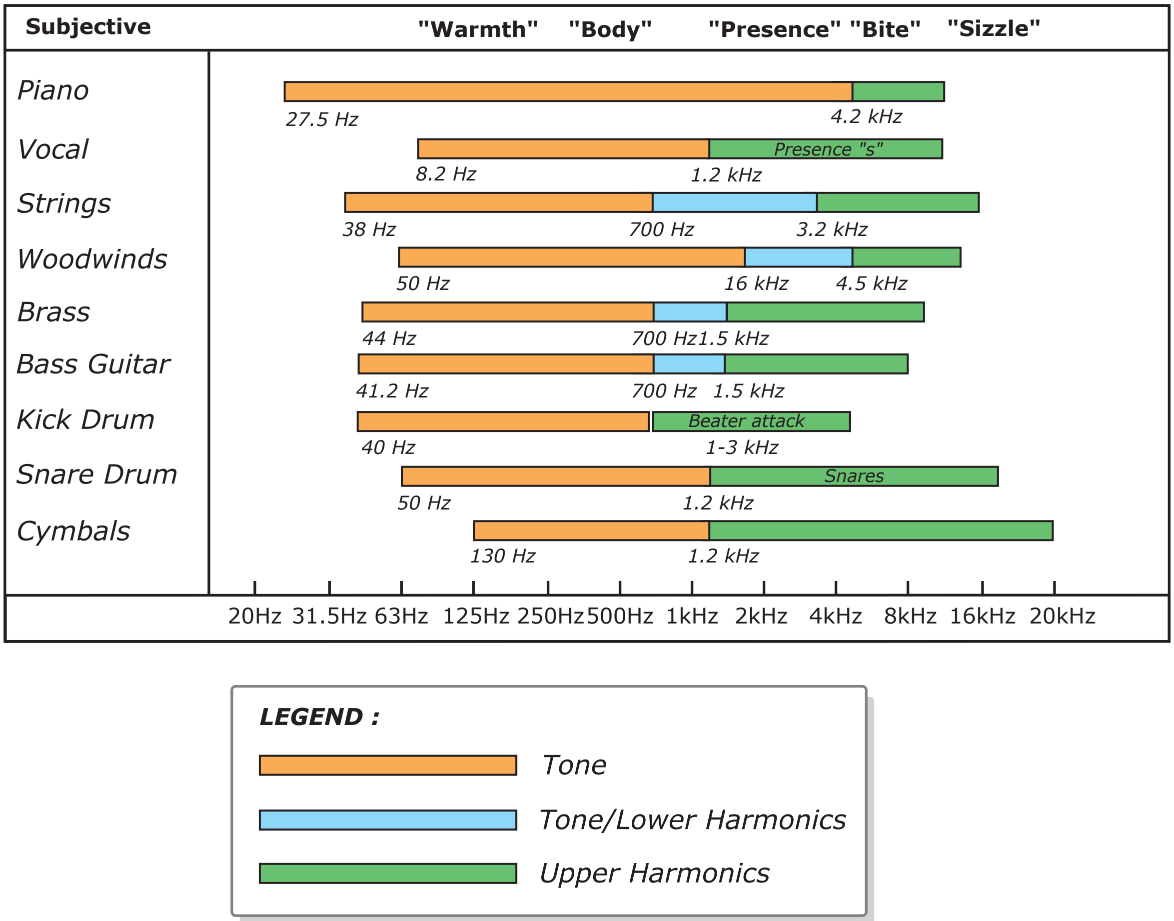
3.6. Timbre

- We hear in the frequency domain
- Our ears are designed to distinguish sounds based on timbre
- We must study the frequency (timbral) range of sound sources

Frequency Ranges of Musical Instruments and Voices

Instrument	Fundamentals	Harmonics
Flute	261-2349 Hz	3-8 kHz
Oboe	261-1568 Hz	2-12 kHz
Clarinet	165-1568 Hz	2-10 kHz
Bassoon	62-587 Hz	1-7 kHz
Trumpet	165-988 Hz	1-7.5 kHz
French Horn	87-880 Hz	1-6 kHz
Trombone	73-587 Hz	1-7.5 kHz
Tuba	49-587 Hz	1-4 kHz
Snare Drum	100-200 Hz	1-20 kHz
Kick Drum	30-147 Hz	1-6 kHz
Cymbals	300-587 Hz	1-15 kHz
Violin	196-3136 Hz	4-15 kHz
Viola	131-1175 Hz	2-8.5 kHz
Cello	65-698 Hz	1-6.5 kHz
Acoustic Bass	41-294 Hz	700 Hz-5 kHz
Electric Bass	41-294 Hz	700 Hz-7 kHz
Acoustic Guitar	82-988 Hz	1500 Hz-15 kHz
Electric Guitar	82-1319 Hz	1-15 kHz (direct)
Elec. Guitar Amp	82-1319 Hz	1-4 kHz
Piano	28-4196 Hz	5-8 kHz
Bass (Voice)	87-392 Hz	1-12 kHz
Tenor (Voice)	131-494 Hz	1-12 kHz
Alto (Voice)	175-698 Hz	2-12 kHz
Soprano (Voice)	247-1175 Hz	2-12 kHz

Image by MIT OpenCourseWare.



Frequency ranges of instruments, highlighting fundamental tones and harmonics, and how those frequencies contribute to an instrument's subjective character.

Image by MIT OpenCourseWare.

3.7. How the Ear Works: Components

- The components of the ear

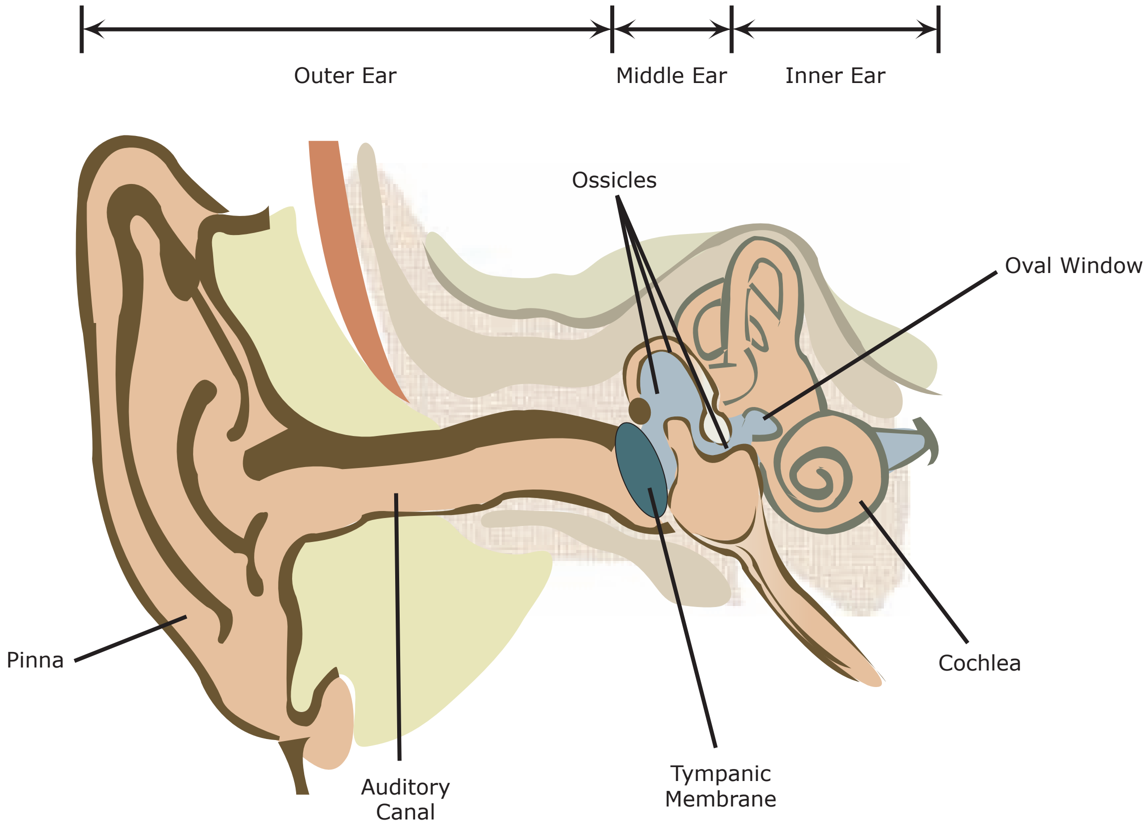


Image by MIT OpenCourseWare. Bear, Mark F., Barry W. Connors, and Michael A. Paradiso. Figure 11.3 in *Neuroscience: Exploring the Brain*. 2nd ed. Baltimore, Md. : Lippincott Williams & Wilkins, 2001. ISBN: 0683305964.

3.8. How the Ear Works: The Pathway of Sound

- Sound is transduced from air to skin (tympanic membrane), from skin to bone (ossicles), from bone to skin (oval window), from skin to fluid (perilymph), from fluid to hair (basilar membrane)

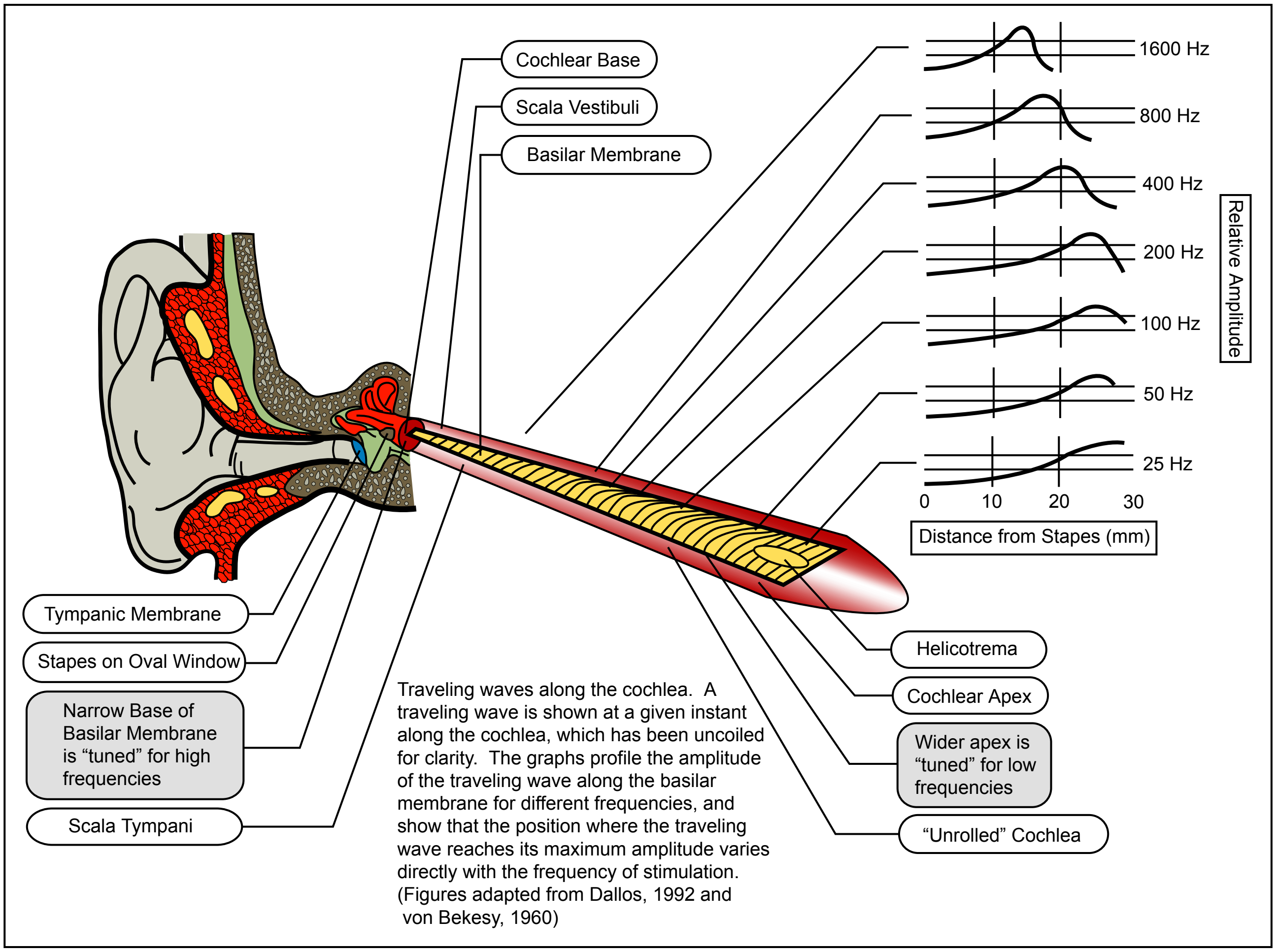


Image by MIT OpenCourseWare.

3.9. How the Ear Works: The Cochlea

- The basilar membrane gets more narrow and more thin from base to tip
- Lower frequencies resonate near the tip (least stiff); higher frequencies resonate near the base (most stiff, near the oval window)
- Basilar membrane resonates with component frequencies in the sound
- 20,000 hair cells on the basilar membrane

- The cochlea performs spectral analysis with hair

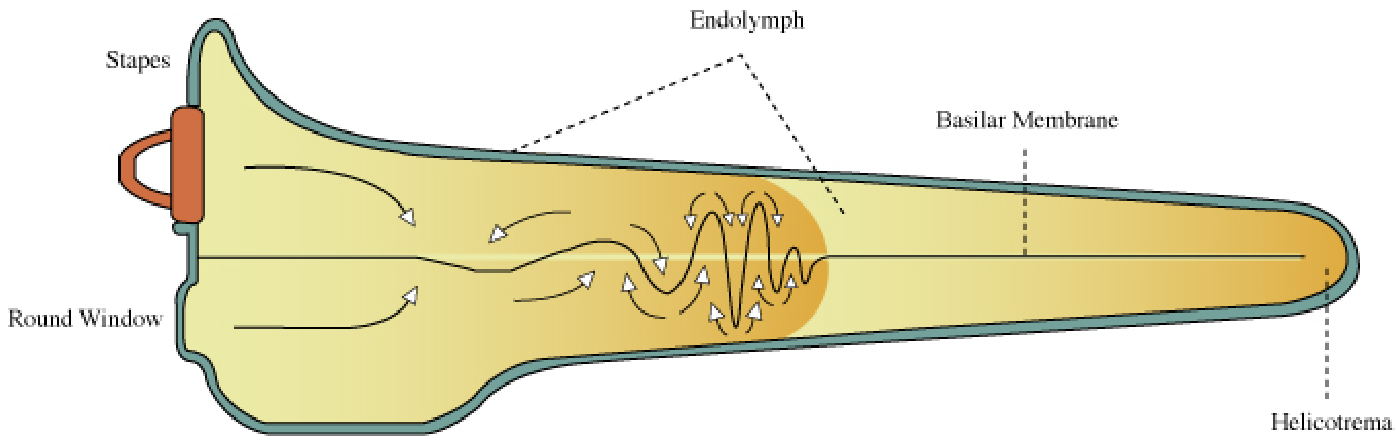


Figure by MIT OCW. After figure 11.9 in *Neuroscience: Exploring the Brain* Mark F. Bear, Barry W. Connors, Michael A. Paradiso. 2nd ed. Baltimore, Md.: Lippincott Williams & Wilkins, 2001. ISBN: 0683305964.

3.10. Limits of the Ear

- Time: 30 milliseconds

  Example: earLimits.pd

- Frequencies: 20 to 20,000 Hertz (about 10 octaves)

  Example: earLimits.pd

- Amplitudes: from 0 to 120 dB SPL, or 120 dB of dynamic range

3.11. Our Ear is Biased

- Amplitude (dB) is not the same thing as loudness (phons)
- Loudness is frequency dependent
- Fletcher-Munson (Robinson and Dadson/ISO 226:2003) equal loudness curves

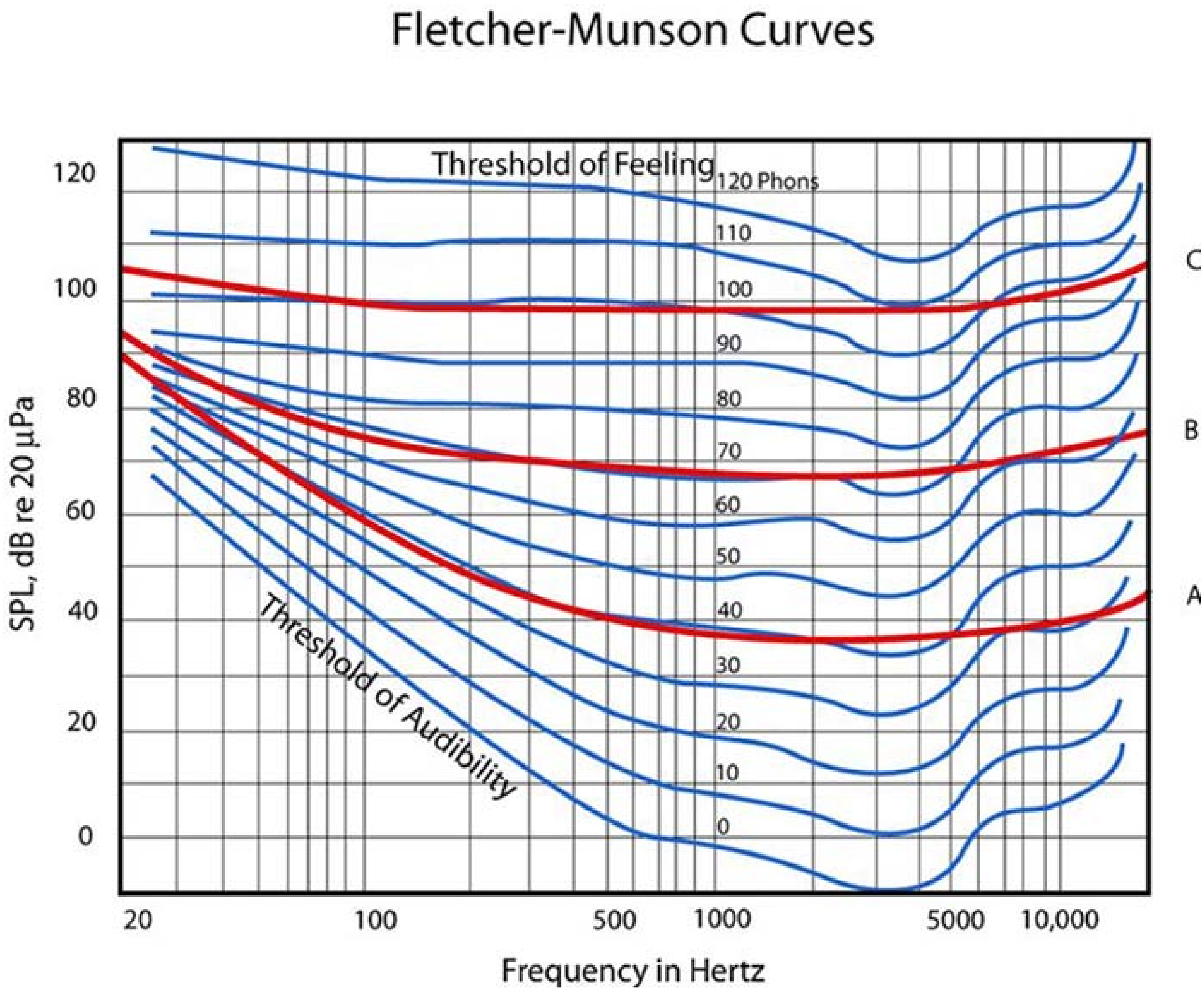
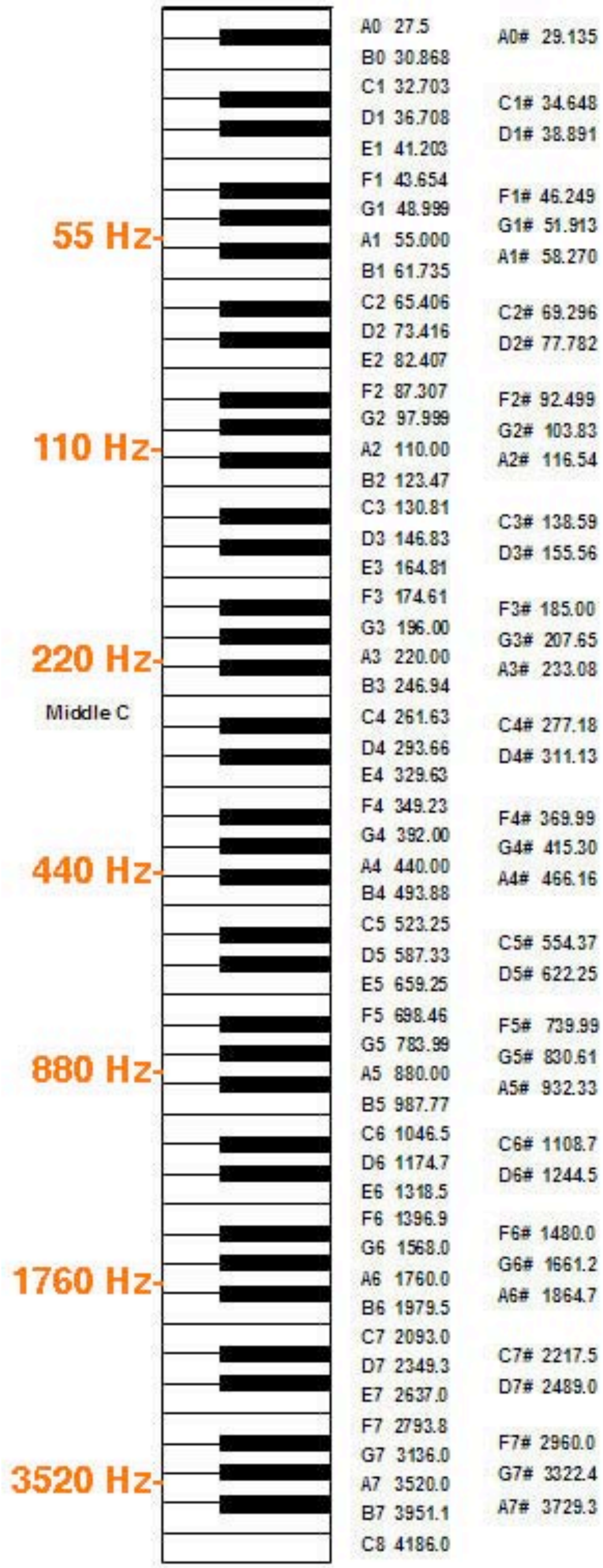


Image: "Fletcher-Munson Curves" from *Principles of Industrial Hygiene*. Available at: http://ocw.jhsph.edu.

3.12. Our Ear Hears Logarithmically: Pitch

- Octave: an equal unit of perceived pitch (not frequency)
- Octaves: a 2:1 ratio of frequencies
- A change from 55 to 110 Hz (a difference of 55 Hz) sounds the same to our ear as a change from 1760 to 3520 Hz (a difference of 1760 Hz)



Courtesy of Tom Irvine. Used with permission.

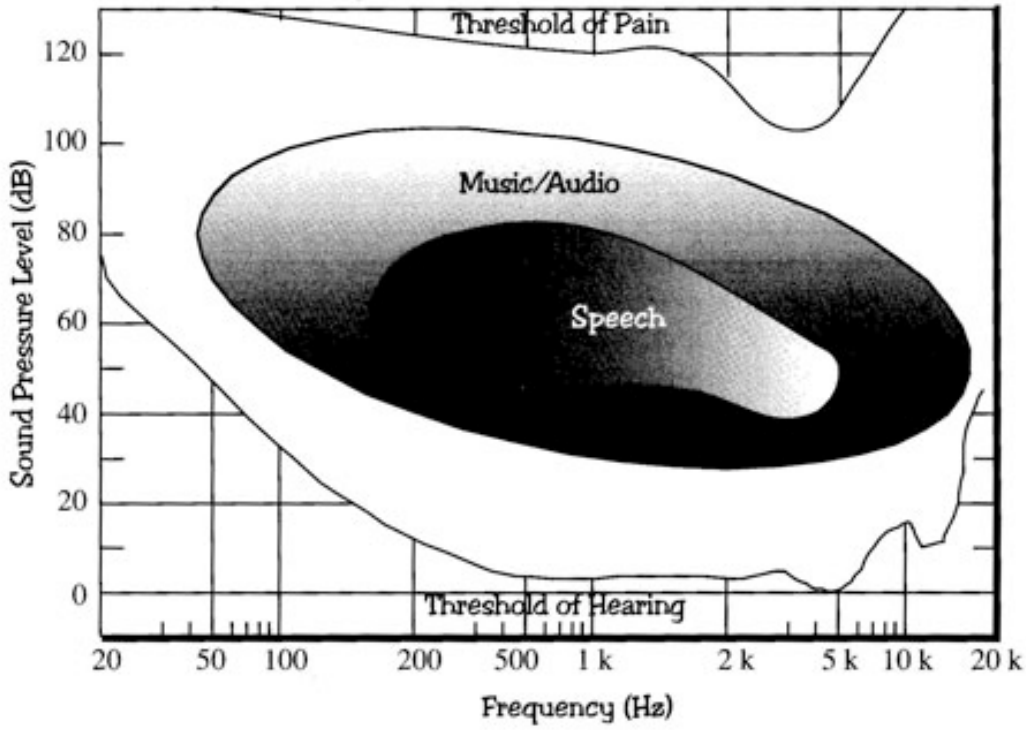


Fig. 11.1. A more detailed picture of our audio window. Most music does not exceed a range of level of about 75 dB from softest to loudest. Similarly, most recorded music does not contain much information above 18 kHz.

- A 1 Hz change from 70 to 71 Hz is more perceptially much more relevant than a 1 Hz change from 5000 to 50001 Hz
- Example: earLogFrequency.pd
- Some frequency displays are linear, others are logarithmic
- Example: Spectrum in Live: Scale X: Line, Log, ST
- High frequencies are always more accurately displayed

3.13. Our Ear Hears Logarithmically: Amplitude

- The ear can handle a range of pressure from .00002 to 1000000 pascals
- Example: earLogAmp.pd
- dB is a logarithmic measure: adding 6 dB doubles the audio power

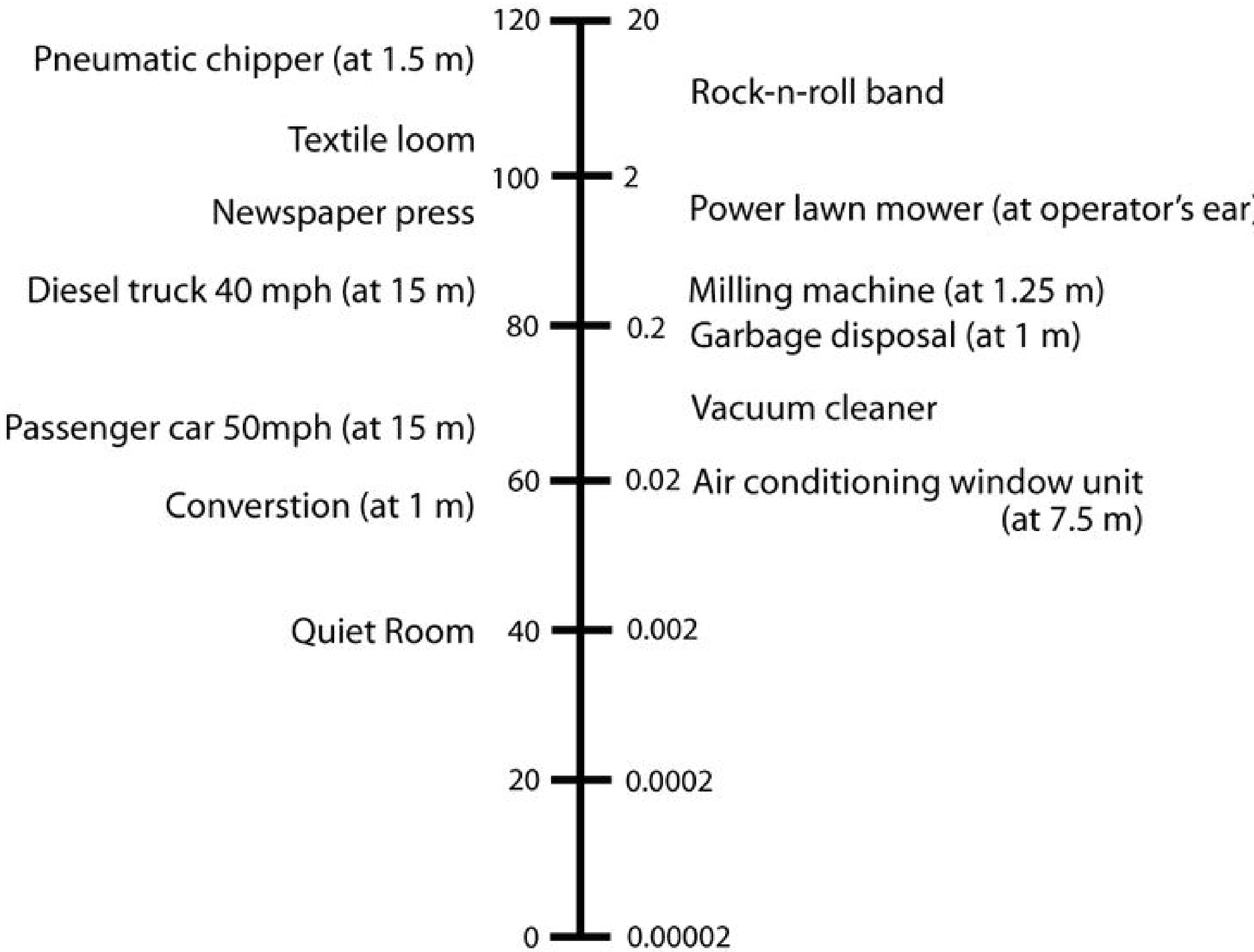


Image: "Sound Pressure Level (SPL) and Sound Pressure (Pa)." from *Principles of Industrial Hygiene*. Available at: http://ocw.jhsph.edu. Copyright © Johns Hopkins Bloomberg School of Public Health.

- dB is not the same as perceived loudness (the frequncies matter)

3.14. The Limits of Pitch Perception

- Different for different people

- Only relevant on a pitch/logarithmic scale, not a frequency scale
- The smallest conventional unit of pitch change (just noticeable difference [JND]) is 1 cent, or 1/100th of a halfstep, or 1/1200th of an octave
- Most people can probably hear 10 cent pitch changes

  Example: jndPitch.pd

- 1 Hz does not always have the same perceptual meaning

3.15. The Limits of Amplitude Perception

- Just noticeable difference (JND) is generally around 1 dB

Graph removed due to copright restrictions.
See Fig. 10.5 in Thompson, D. M. *Understanding Audio*.
Hal Leonard Corp., 2005.

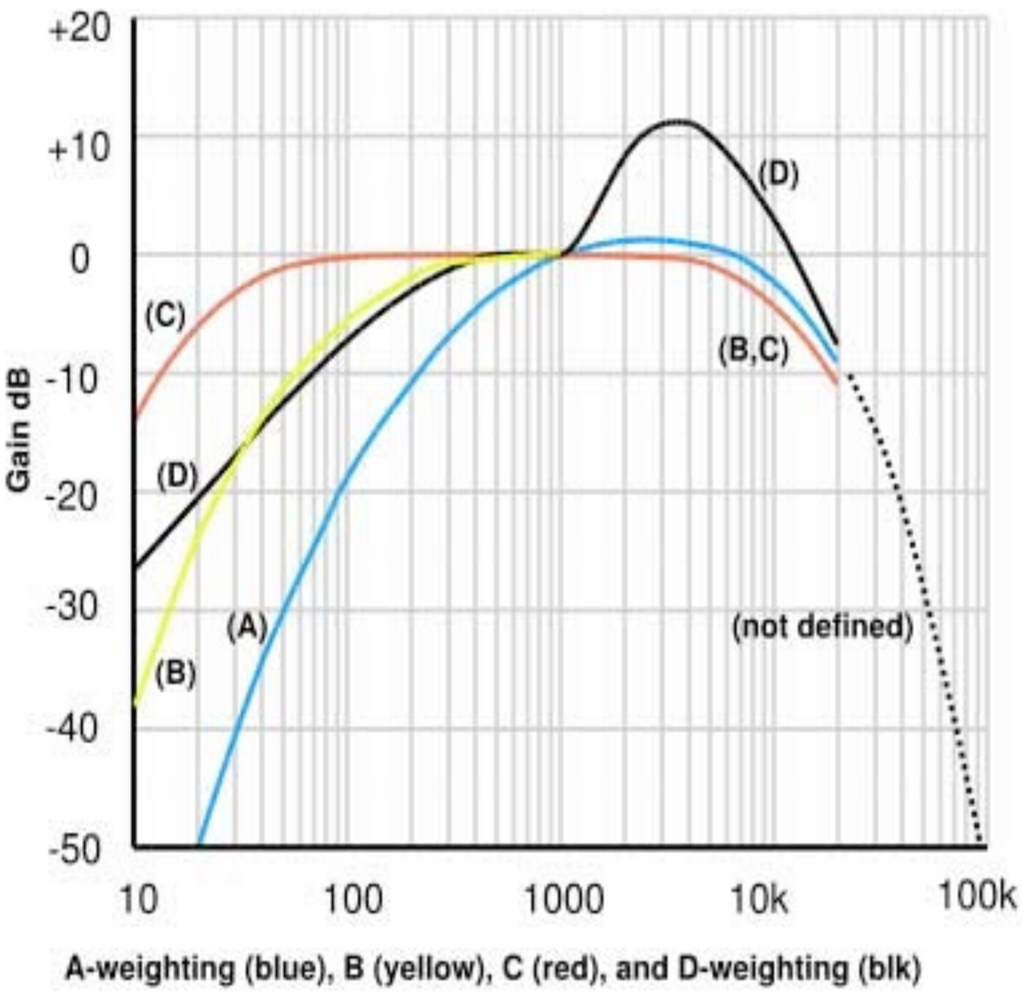
3.16. The Limits of Space Perception

- Minimum audible angle (MAA) is 1 degree along horizontal plane in front
- MAA is about 3 degrees in the vertical plane in front

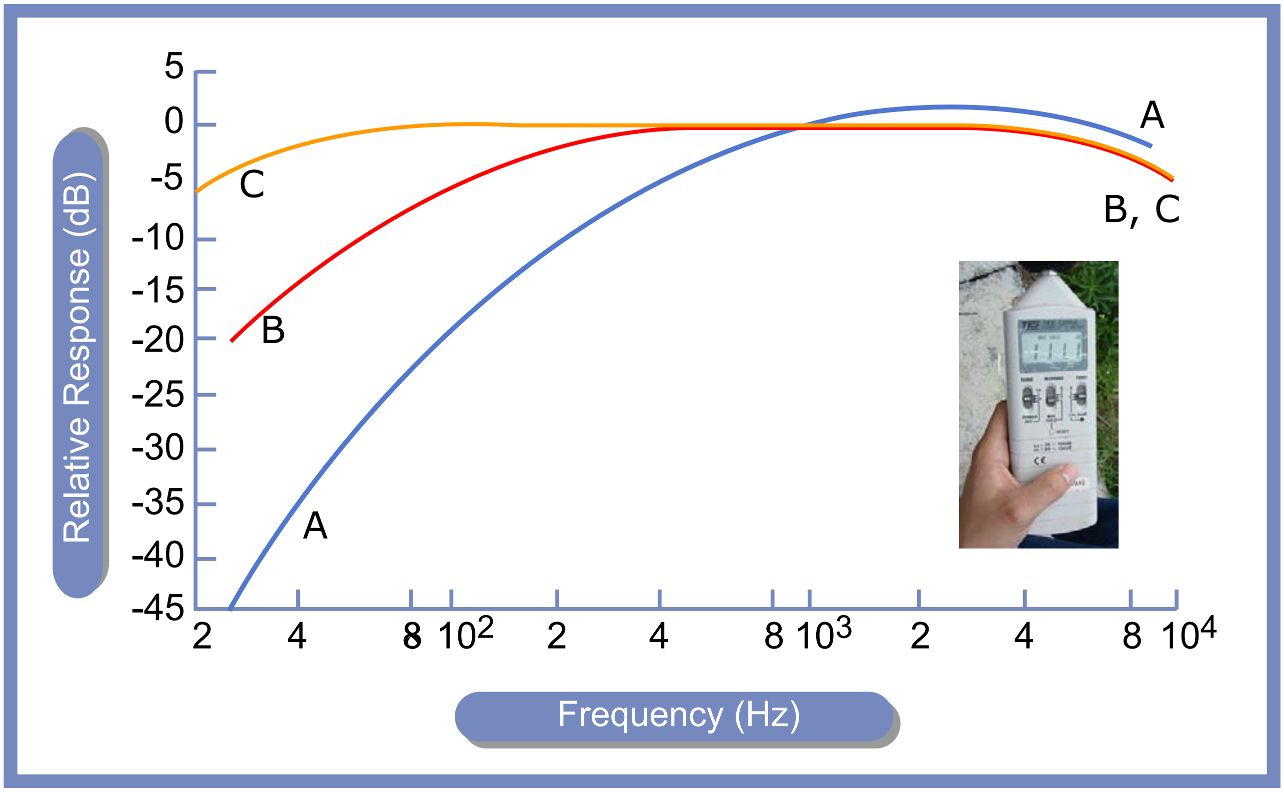
- MAA is greater (our perception is less good) towards side and back

3.17. Balancing Amplitude with Frequency Bias

- We can weight amplitude scales to better relate to the ear's frequency bias
- dB-A: A-weighting according to Fletch Munson / ISO 226
- dB-B and db-C: less low frequency offset



Public domain image (Wikipedia).



Graph by MIT OpenCourseWare. SPL meter photo courtesy of EpicFireworks on Flickr.

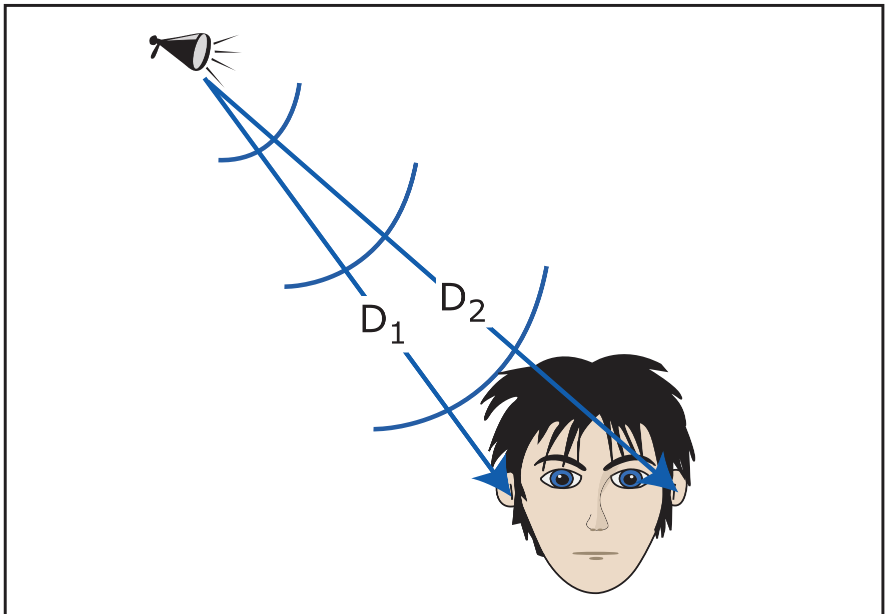
- Weights make the dB value closer to perceived loudness
- dB meters include A and C weightings

- Some spectral analysis tools include weightings

  Example: Elemental Audio Systems: IXL Spectrum Analyzer

3.18. How the Ear Determines Location

- Methods of determining spatialization
  - Intensity
  - Timing (our ears are seperated by distance)



A sound source at the listener's left is closer to the left ear (D_1) than the right ear (D_2). Sound will therefore have higher intensity in the left ear.

Image by MIT OpenCourseWare.

  - Spectral cues
  - Reflections off of the Pinna

Graph removed due to copright restrictions.
See Fig. 10.15 in Holmes, T. *Electronic and Experimental Music*.
3rd ed. Routledge, 2008.

- The ear has more directional sensitivity to high frequencies

Diagram removed due to copyright restrictions.
See Fig. 10.8 in Thompson, D. M. *Understanding Audio*.
Hal Leonard Corp., 2005.

Diagram removed due to copright restrictions.
See Fig. 10.7 in Thompson, D. M. *Understanding Audio*.
Hal Leonard Corp., 2005.

- Example: jndPanning.pd
- The ear has more directional sensitivity to sounds in front

3.19. Masking

- Given two sounds at similar frequencies, the loudest wins
- Basilar membrane only registers loudest signal at one place

3.20. Reflections

- Sound reflects (bounces), diffuses, and absorbs off of surfaces
- These factors create ambience or reverb; a space without these features is called anechoic
- Three steps: direct sound, early reflections, reverberations

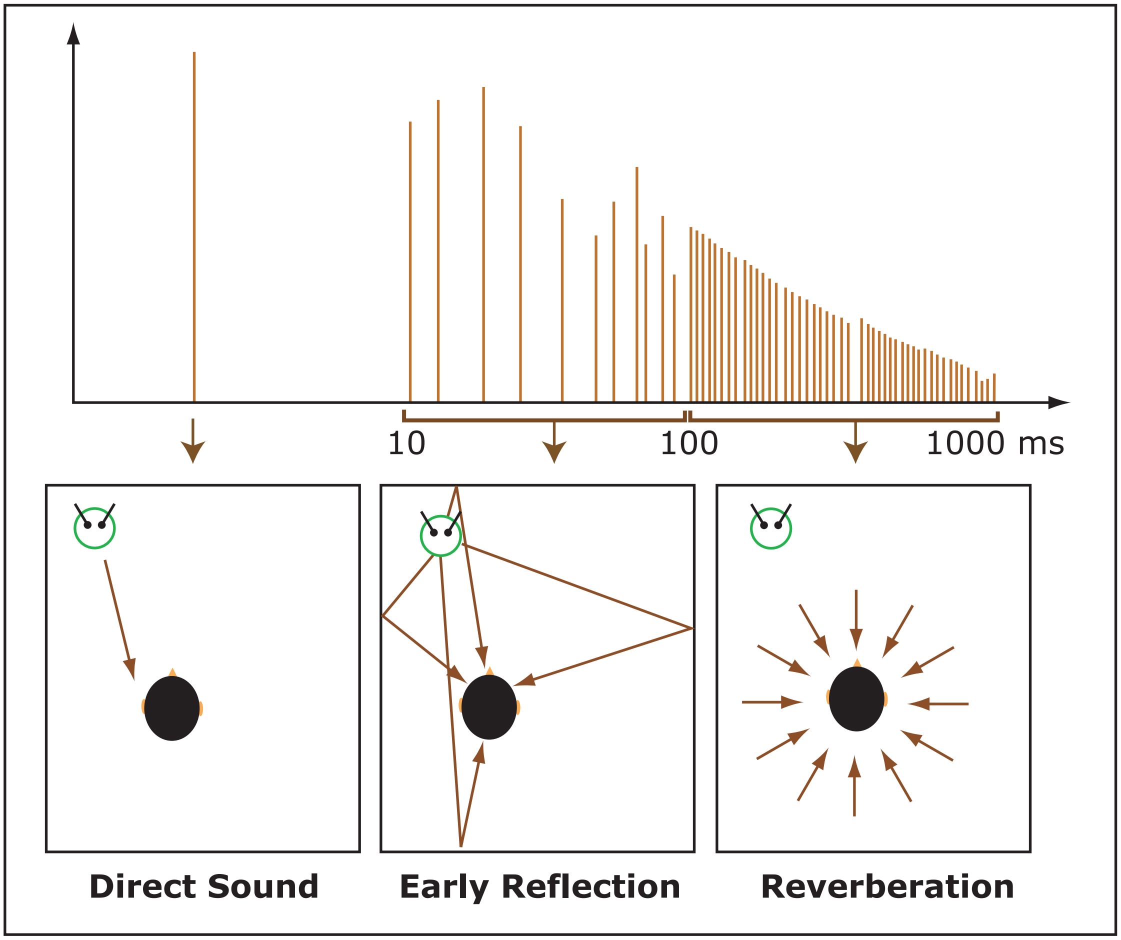
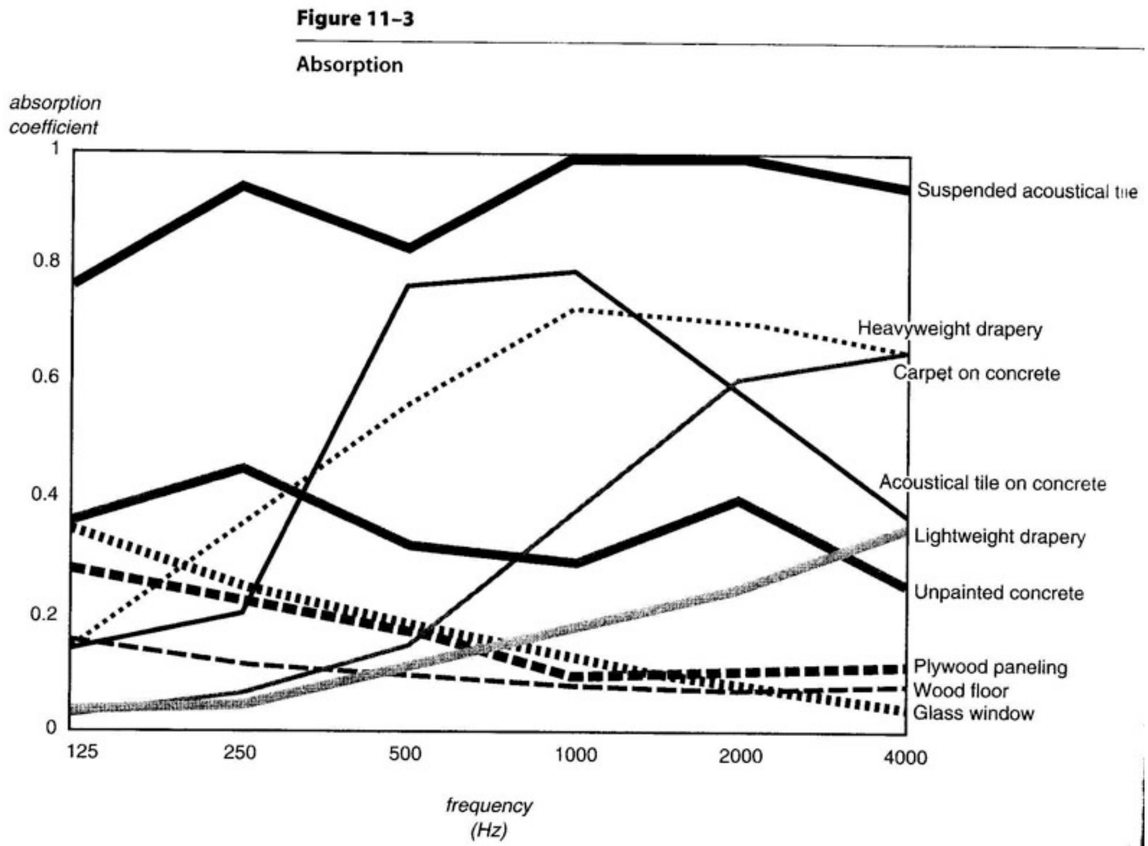


Image by MIT OpenCourseWare.

- Eearly reflections are discrete echos
- Reverberations are echos that are so close to gether (less than 30 msec apart) that they form a continuous sound

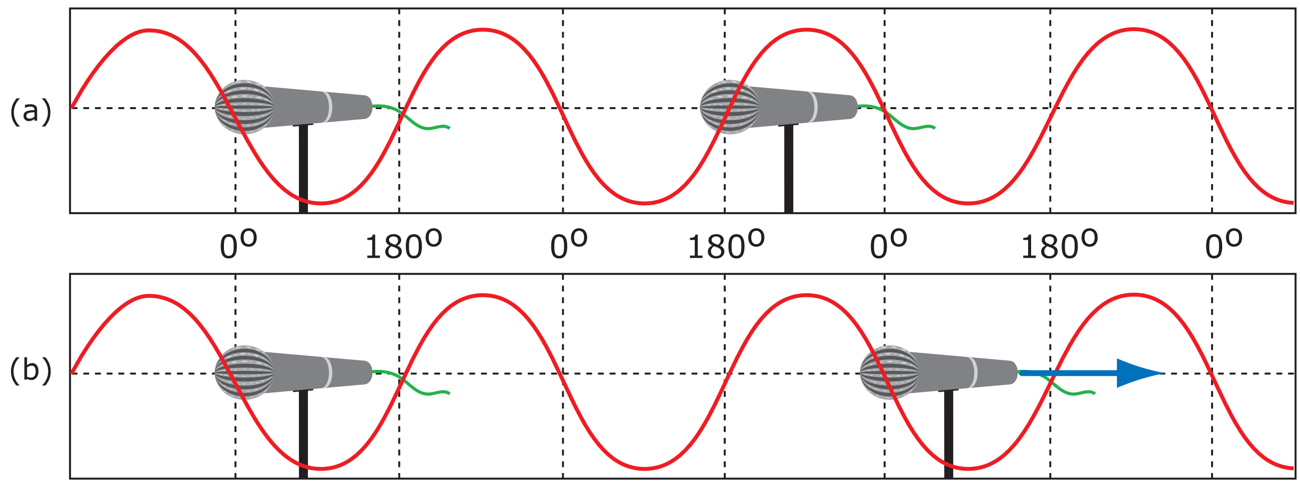
3.21. Absorption

- Absorption consumes the energy of sound
- Sound does not absorb equally for all frequencies



3.22. Phase Filtering and Cancellation

- Combining two signals slightly out of phase causes a timbral change: called comb filtering
- Combining two signals 180 degrees out of phase cuases signal cancellation
- Combining two signals with delays less than 30 msec results in coloration
- Example: processorsDelay.pd (samples, then noise)
- Always possible when mixing multiple microphone captures

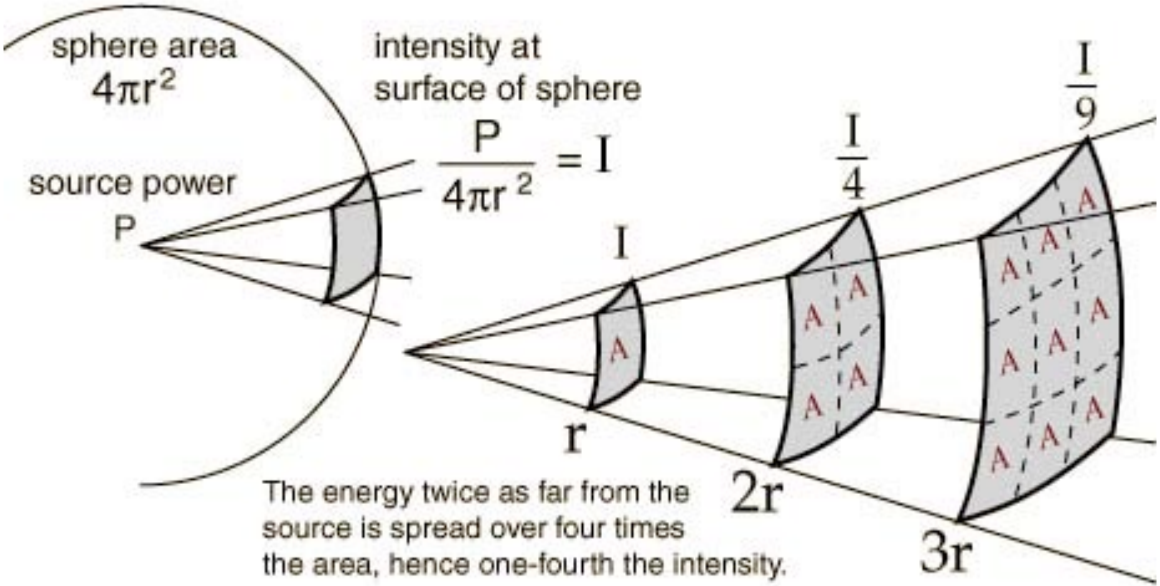


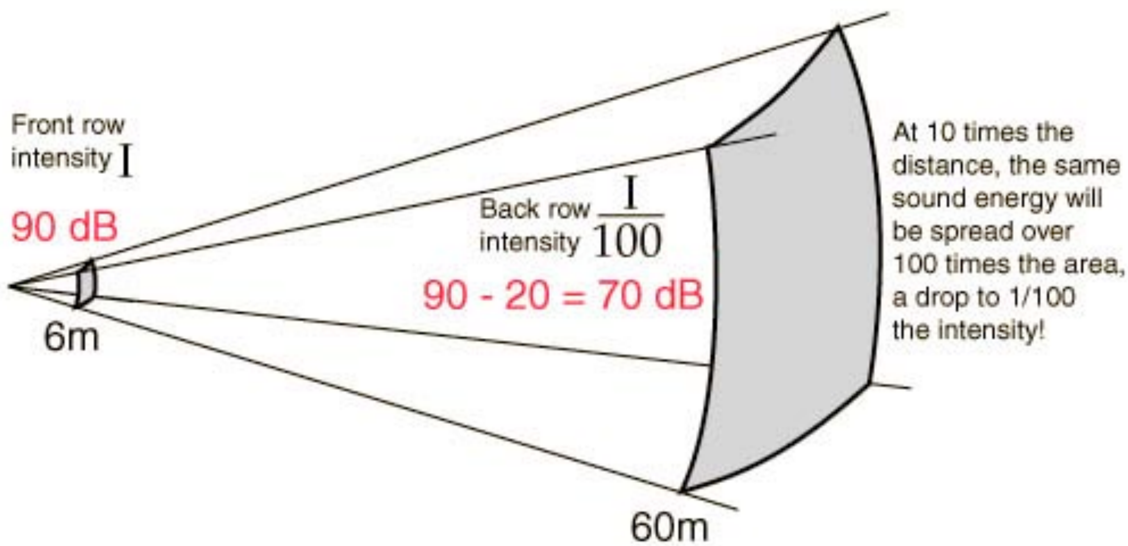
(a) 180° out of phase = cancellation. (b) Move mic to minimize phase cancellation.

Image by MIT OpenCourseWare.

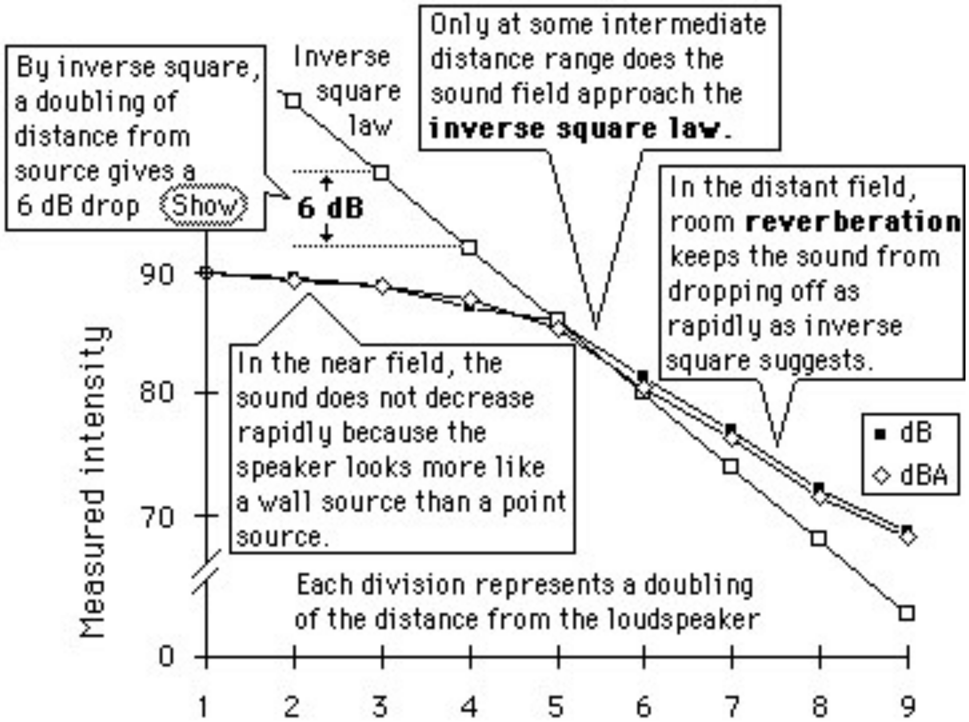
3.23. Inverse Square Law

- Amplitude diminishes with distance
- Theoretically, sound in three dimensions diminishes in power according to the inverse square law
- Three-dimensional radiation





- Doubling the distance from a source reduce the amplitude by 6 dB
- Real-world measures differ



Source: http://hyperphysics.phy-astr.gsu.edu/hbase/acoustic/roomi.html

3.24. Reading: Eargle: Basic Sound Transmission and Operational Forces on Microphones

- When comparing the RMS of sine and square waves, what does the difference in values tell us?
- Reverb time measured as the time between the start of the sound and a decrease in how many dB?
- The term "gradient" is used to refer to what?
- Which reduces high frequencies more: dry air or wet air?
- What is diffraction?
- In general, what will happen to sound captured by a directional microphone off axis?