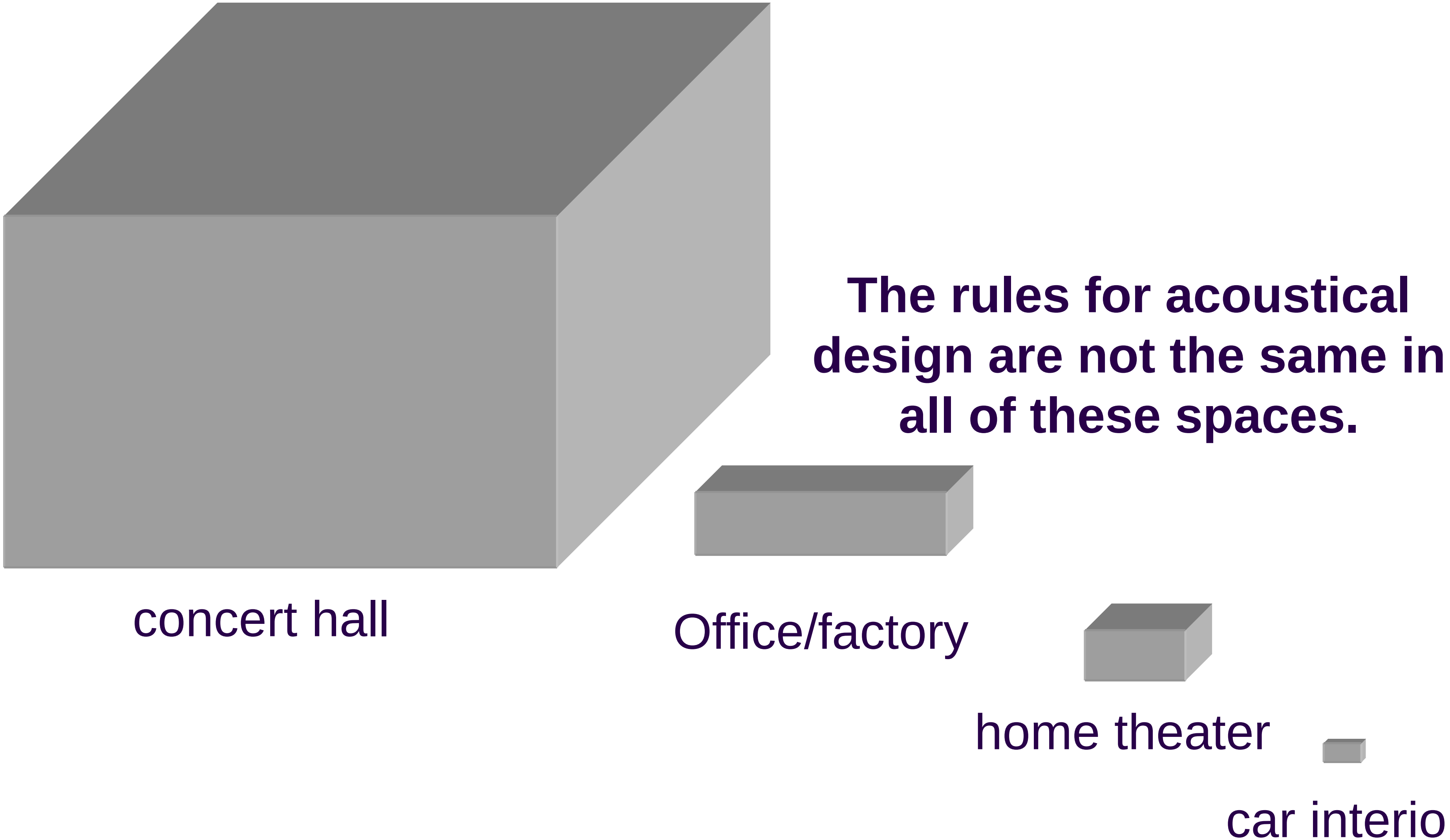
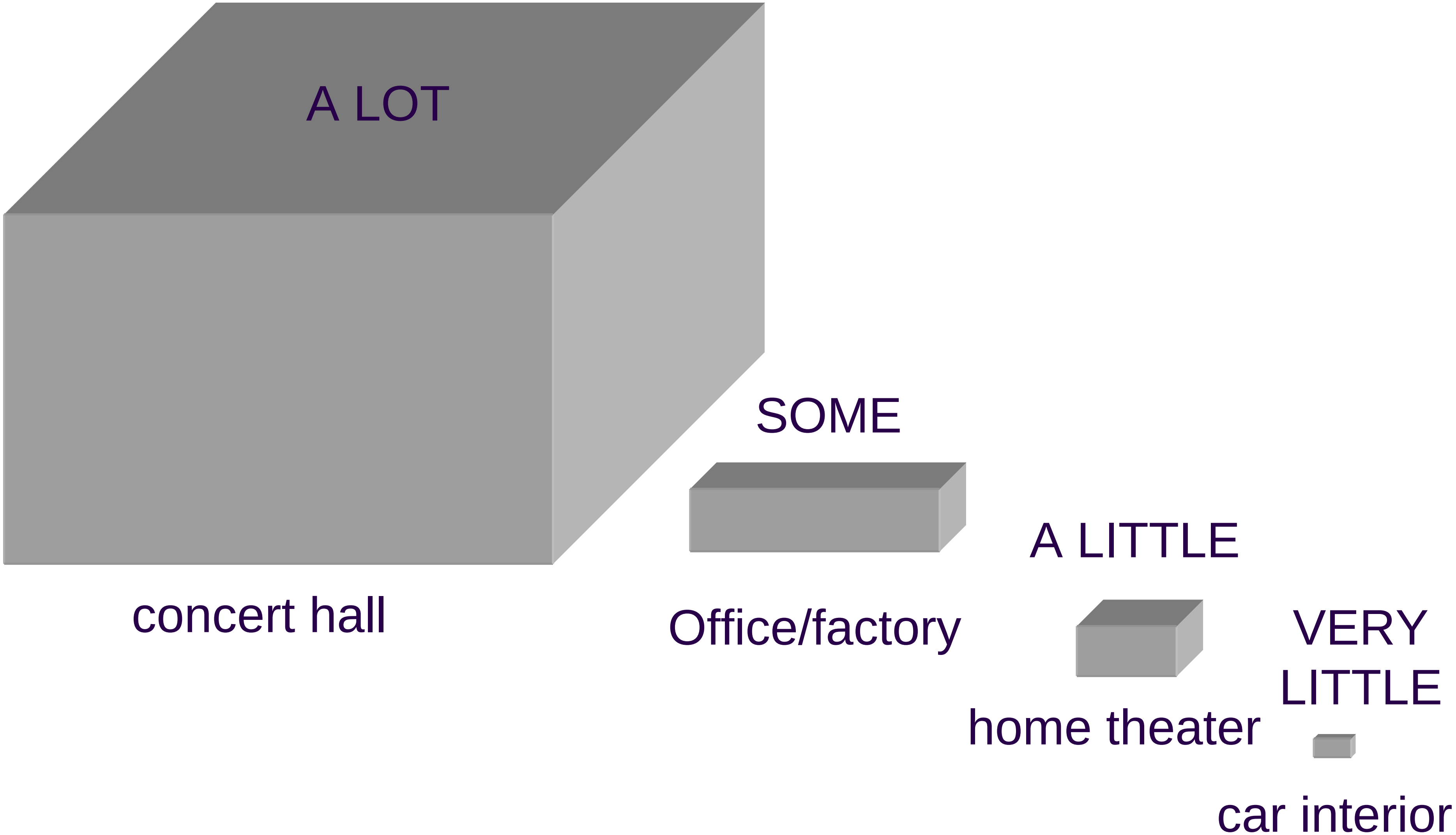
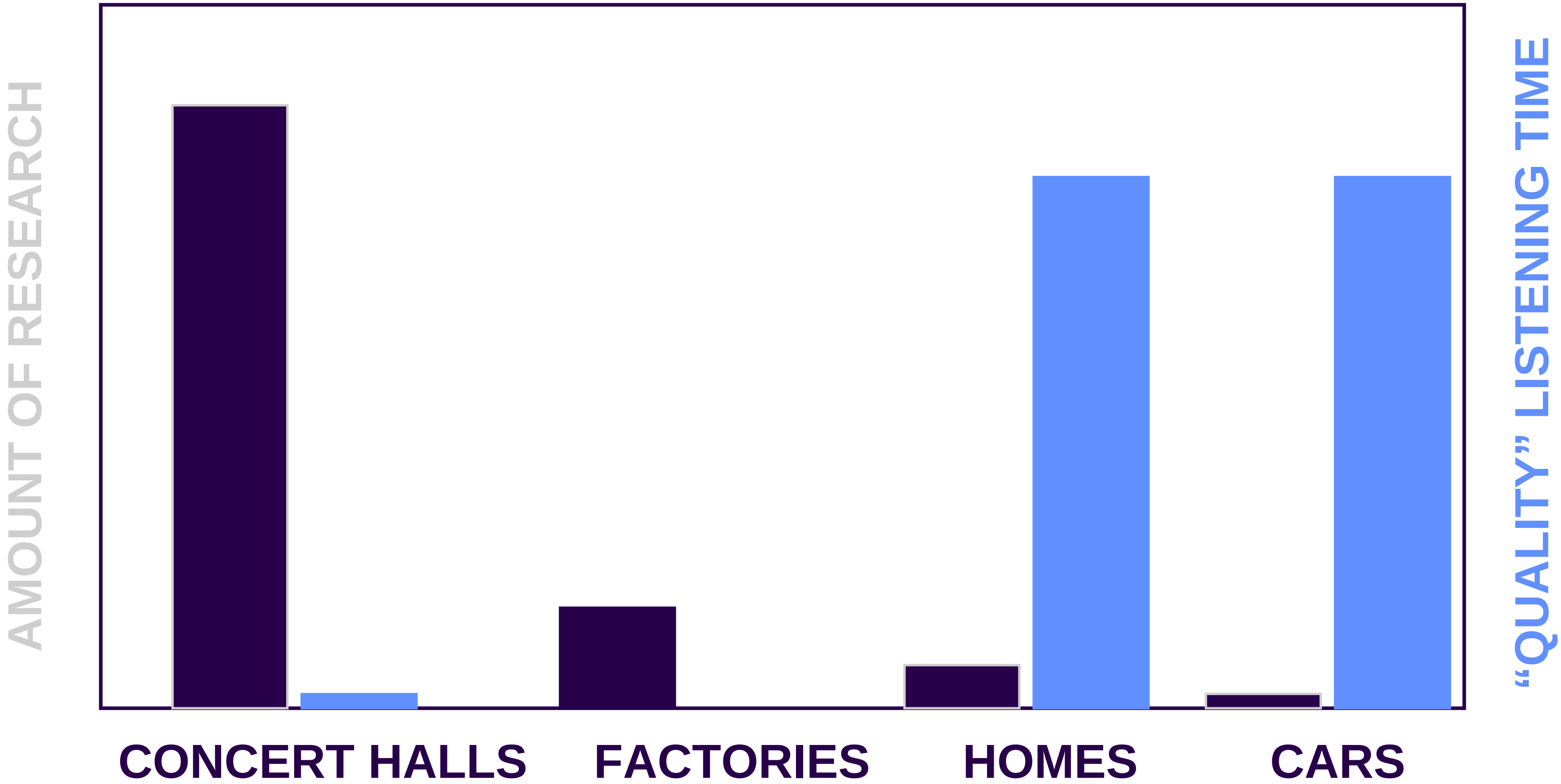
Where we listen



The rules for acoustical design are not the same in all of these spaces.

How much real research has been done?





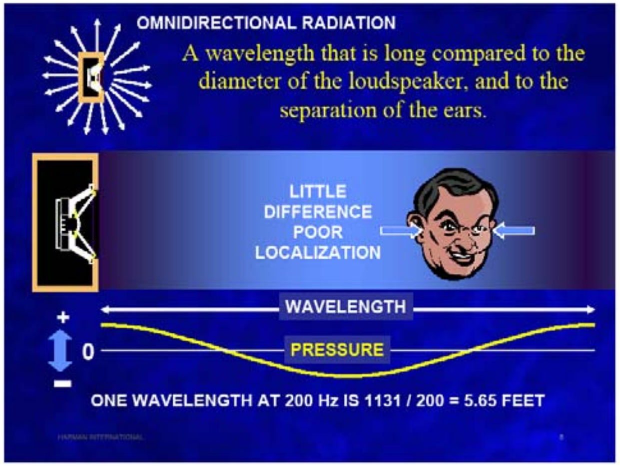
Which is why Harman puts so much effort into the science of sound in homes and cars.

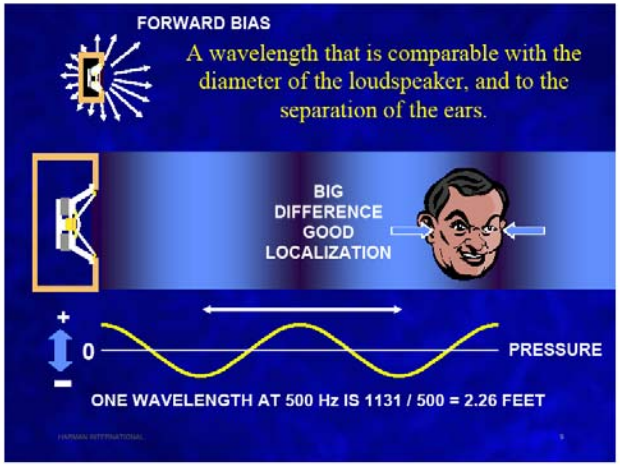
What is sound, and how much of it can we hear?

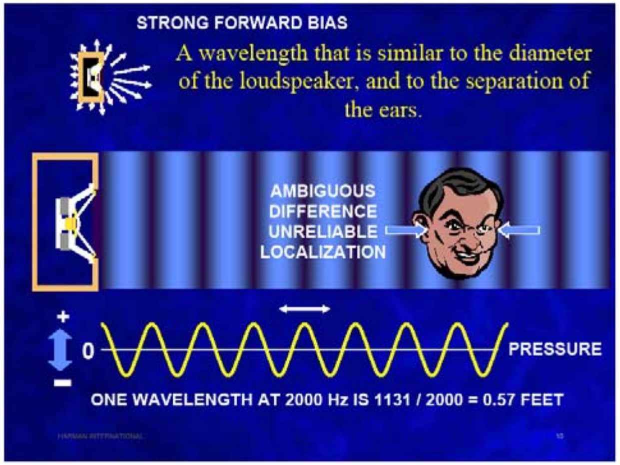
Audible Frequencies and Wavelengths

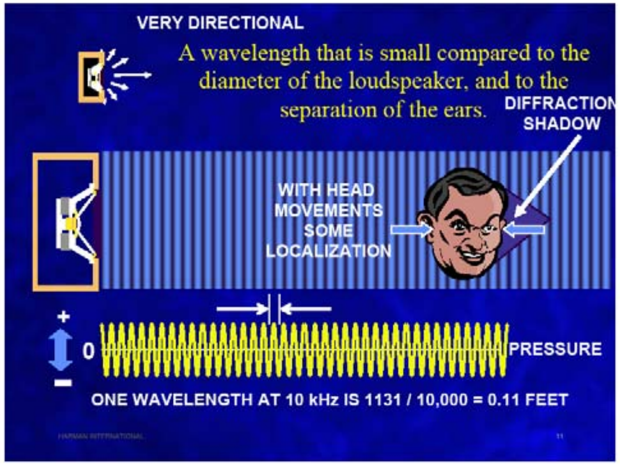
FREQUENCY	WAVELENGTH
20 Hz	56 feet = 17 m
100 Hz	11.3 feet = 3.44 m
1kHz	13.6 inches = .35 m
10 kHz	1.3 inches = 3.3 cm
20 kHz	0.7 inch = 1.8 cm

The wavelength affects how sound is radiated by loudspeakers and how it is heard by listeners

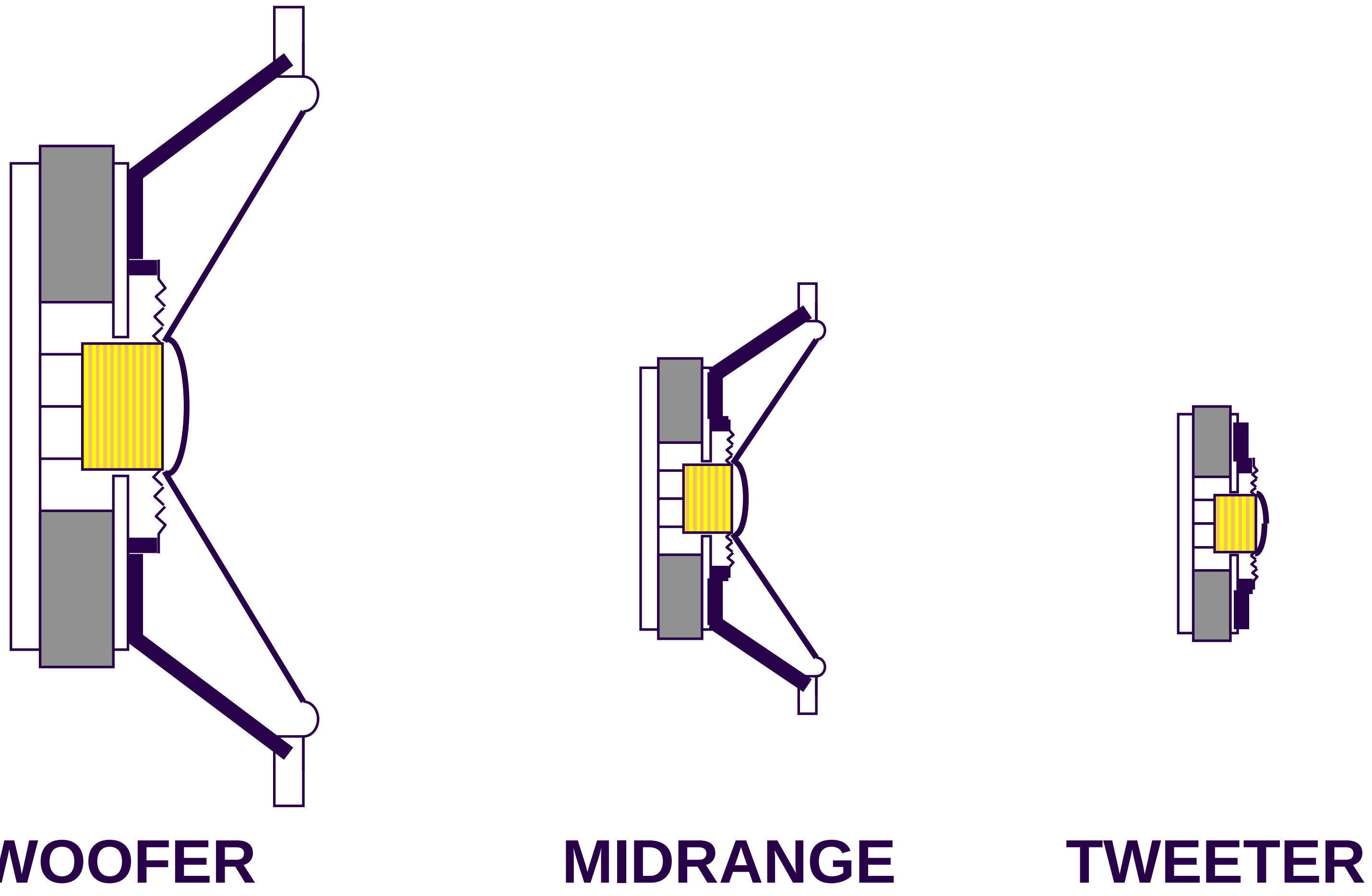




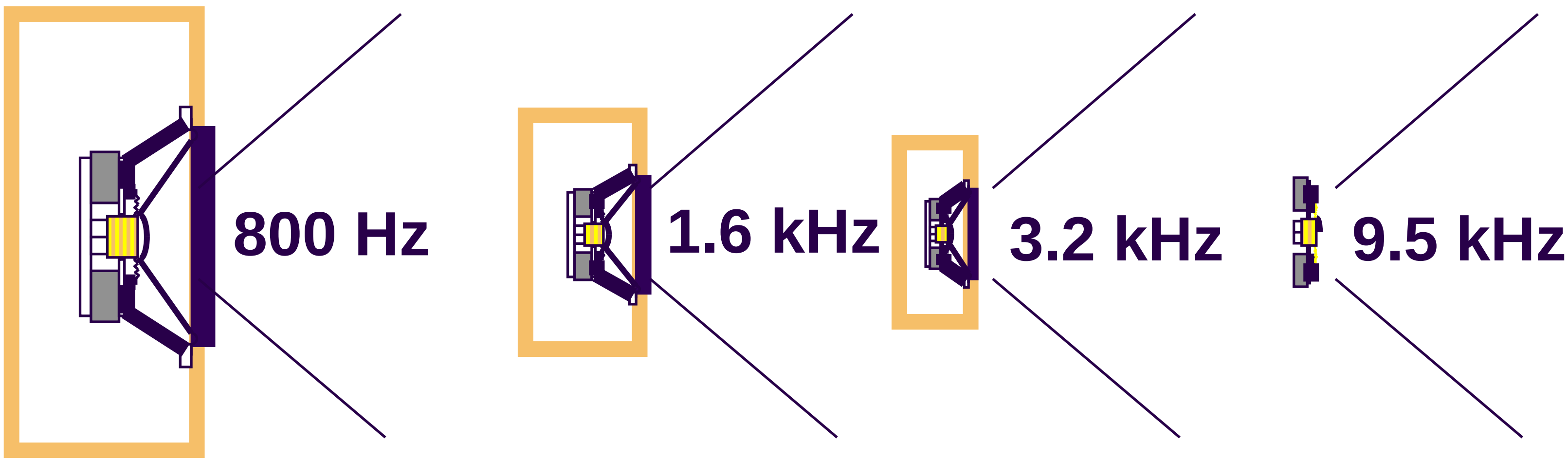




So we build different sizes of drivers to cover different frequency ranges.



Wavelength, Speakers and Directivity Help to Define the Crossover Frequencies

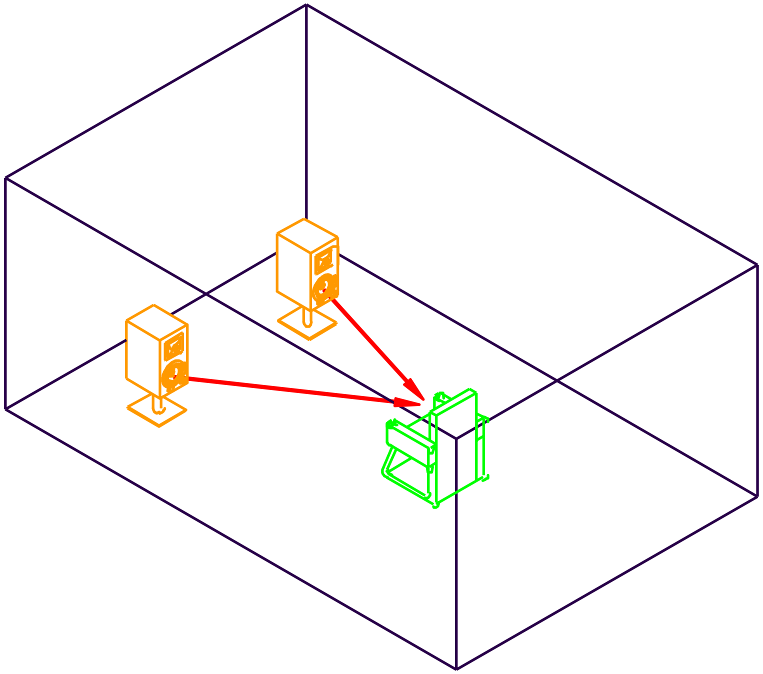


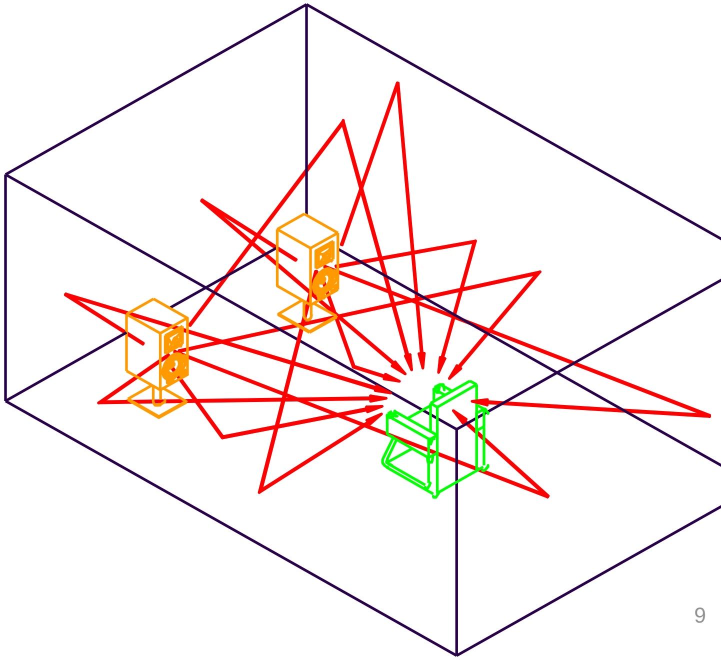
12 inch Ø 6 inch Ø 3 inch Ø 1 inch Ø

Highest crossover frequency to maintain a minimum dispersion angle of about ± 50 º

Why do we care about directivity?

- Because we listen in rooms and cars with reflective surfaces.
- Most of the sound we hear is reflected sound.
- Most of what we think about sound quality is determined by “off-axis” sound

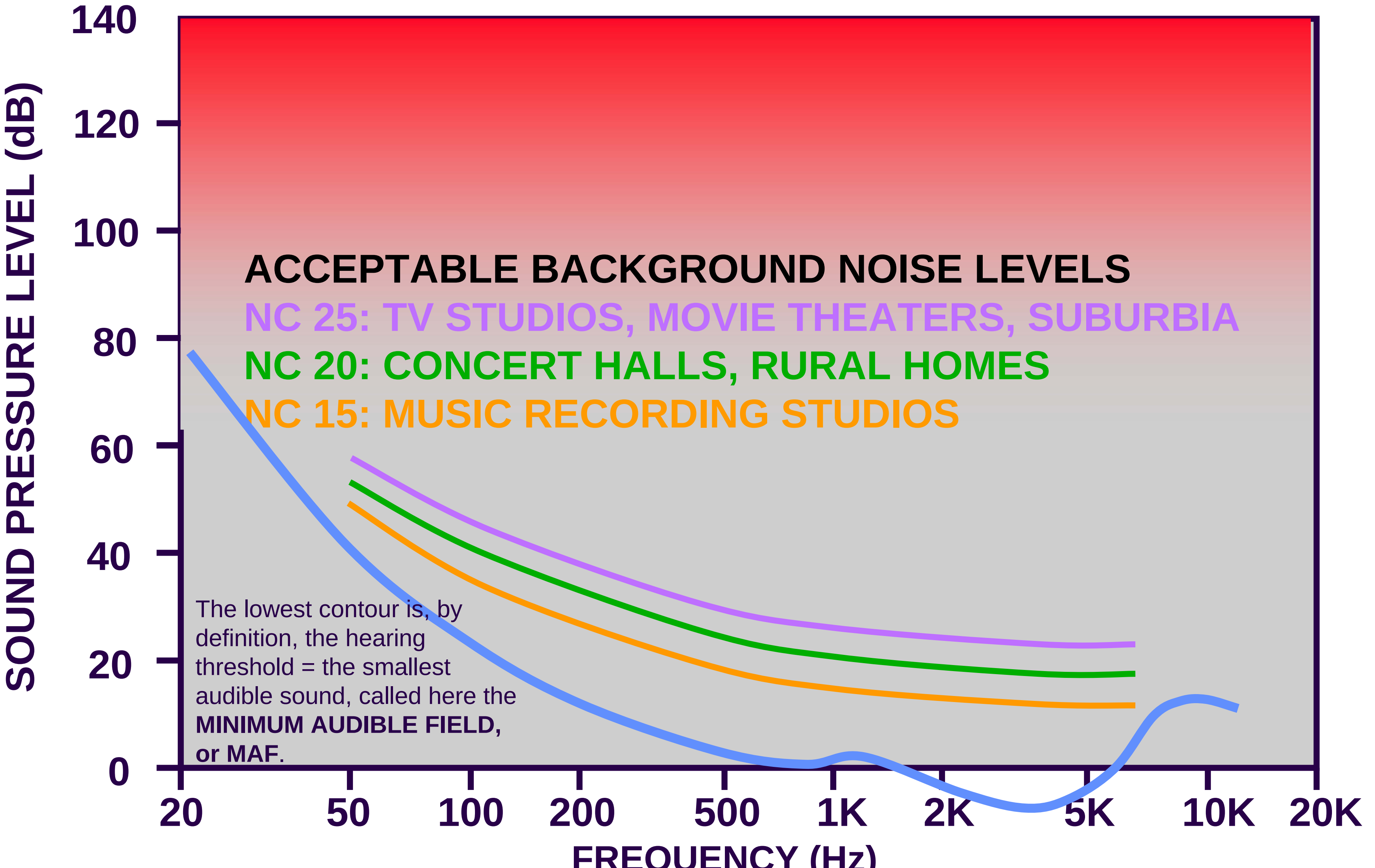




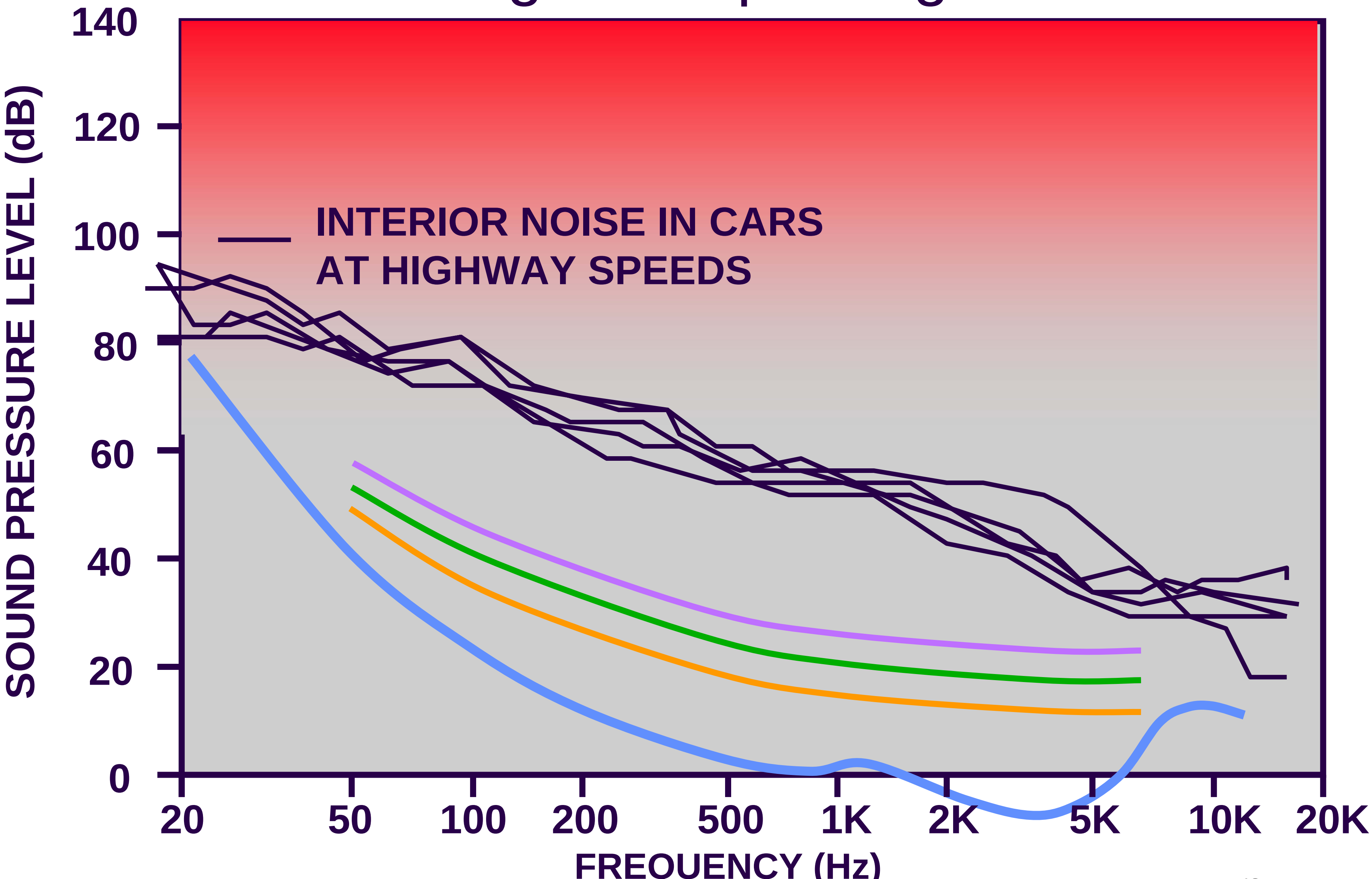
The Loudness of Sounds

- Loudness is the perceptual correlate of physical sound level (dB).
- But, loudness is also a function of
  - Frequency (bass, midrange, treble)
  - Duration (transient, short or long note)
  - Envelope (abrupt or gentle starts and stops)
  - Bandwidth (how much of the frequency range it covers)
- So, while we simplify it for explanation, it is not a simple concept.

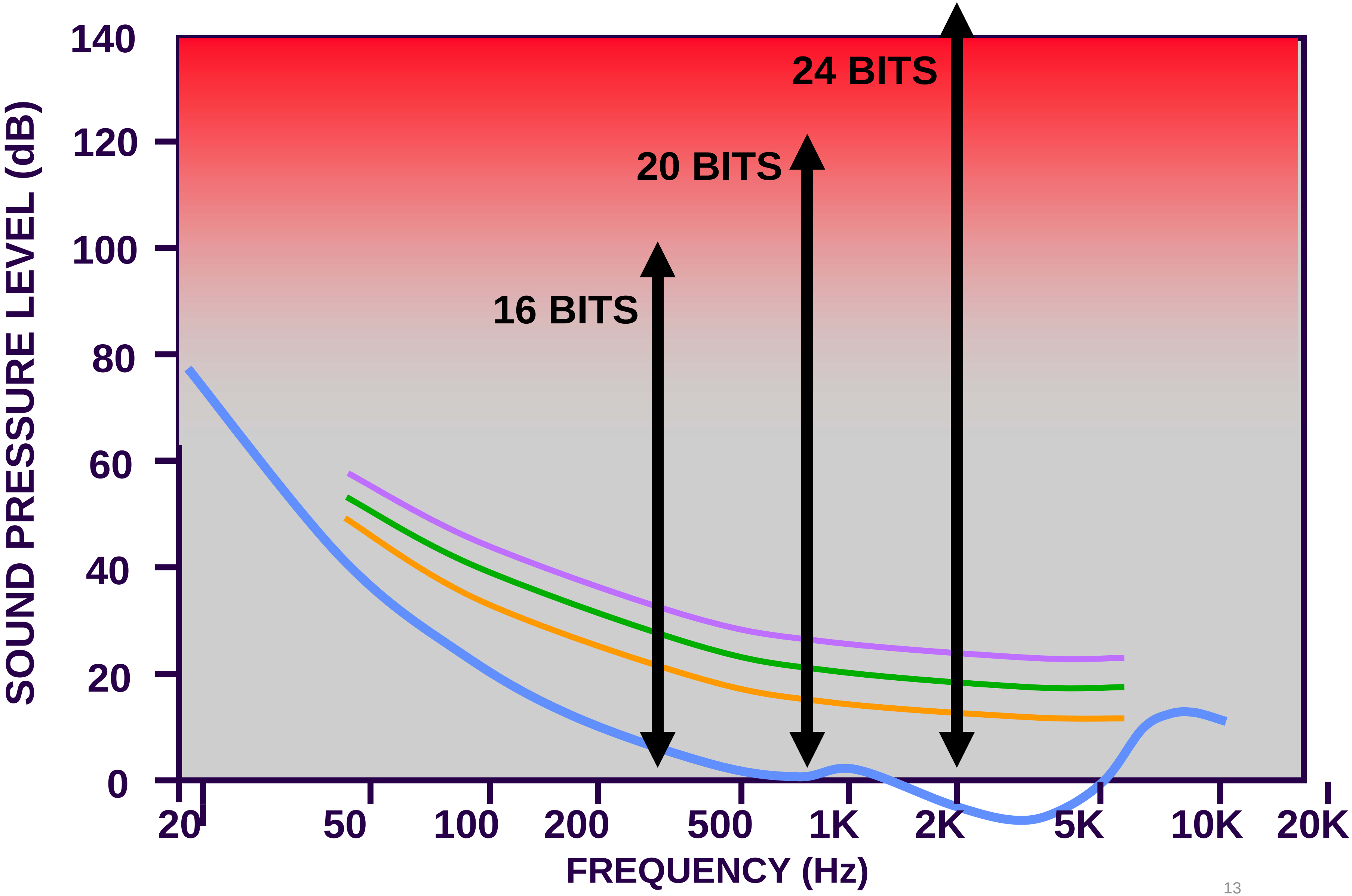
Background noise determines the smallest sounds we can hear



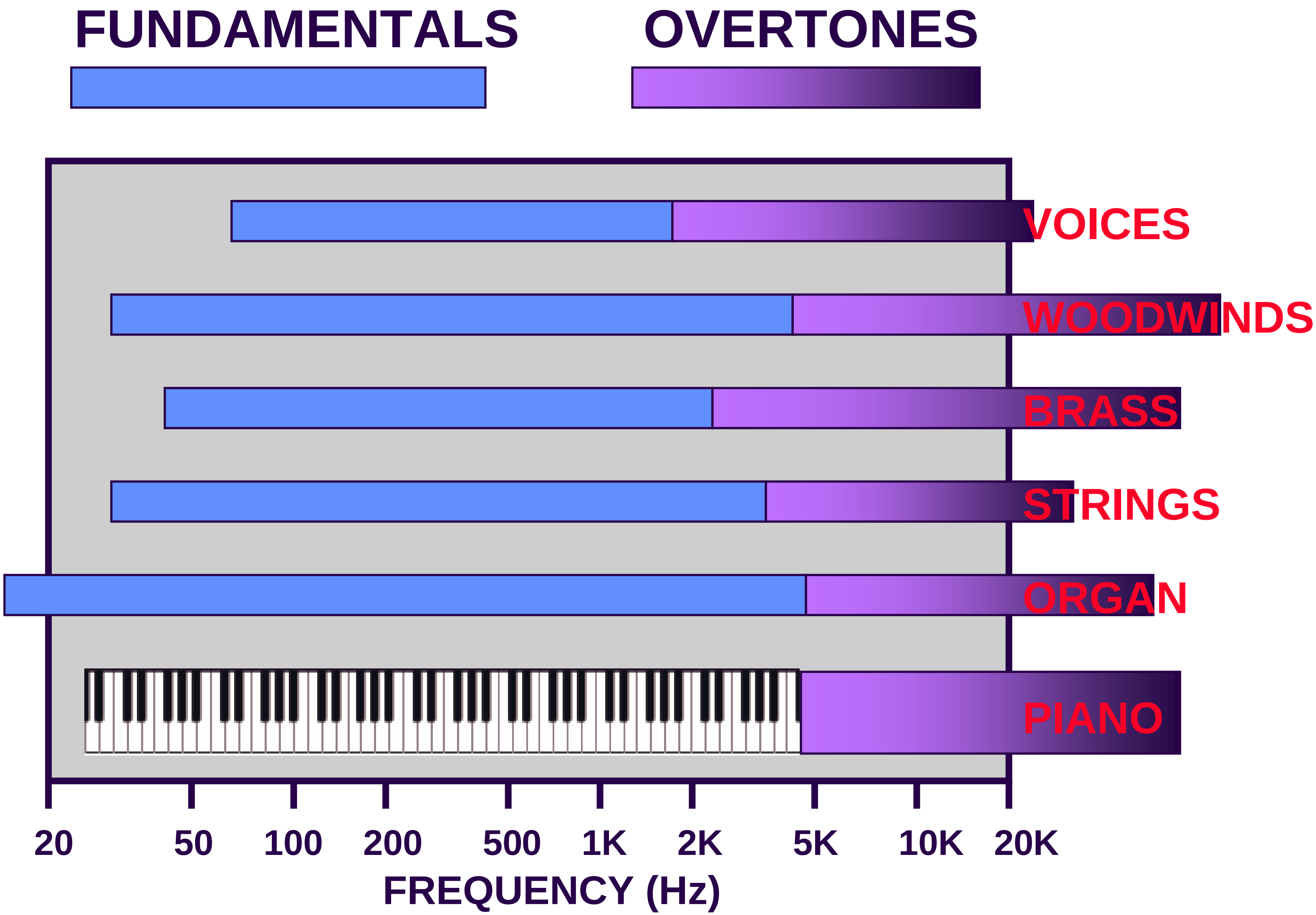
Listening on the highway is ***<u>very</u>*** different from listening in the parking lot!



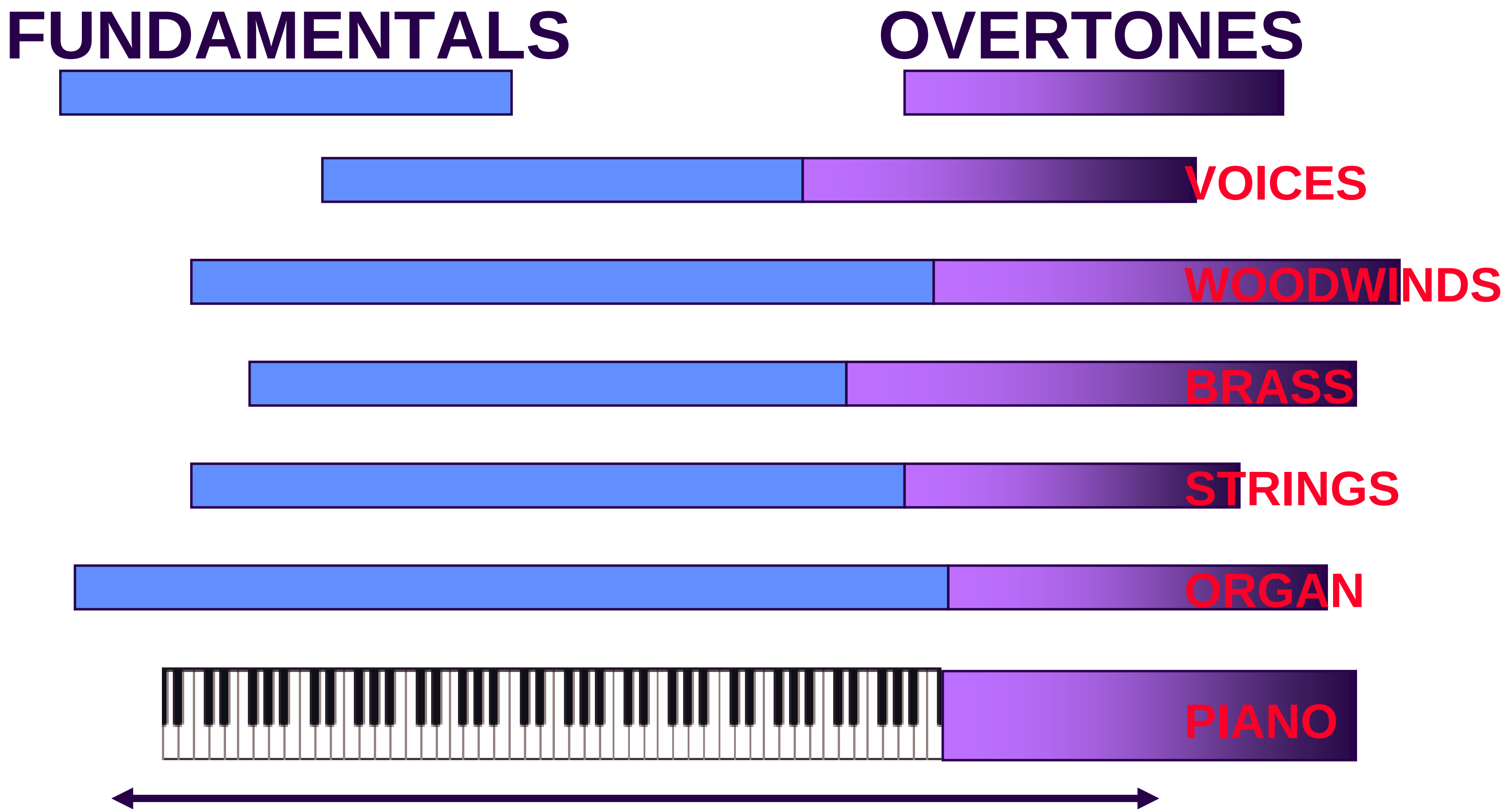
The dynamic ranges of digital systems



How much of music can we HEAR?



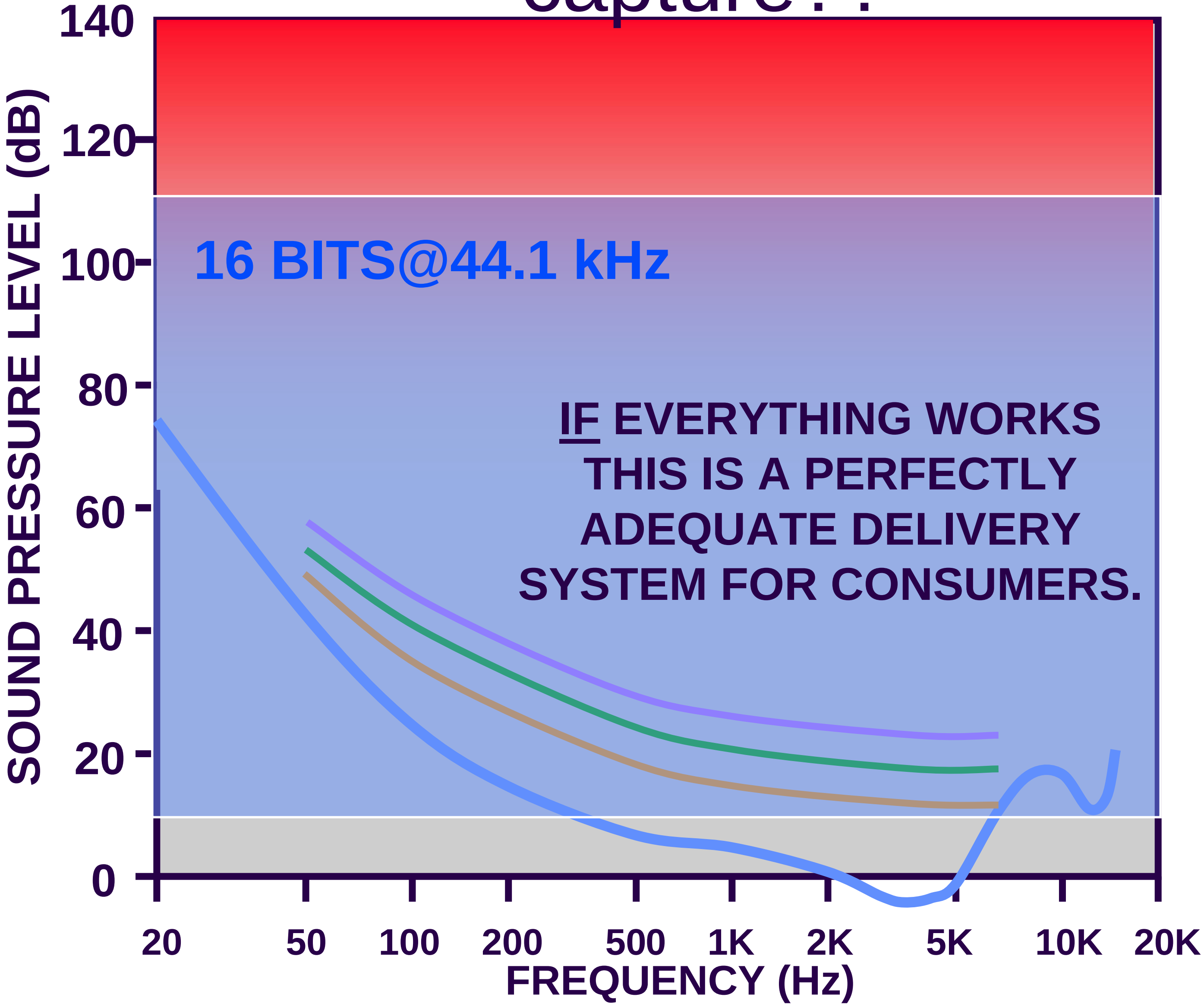
How much of this can we RECORD?



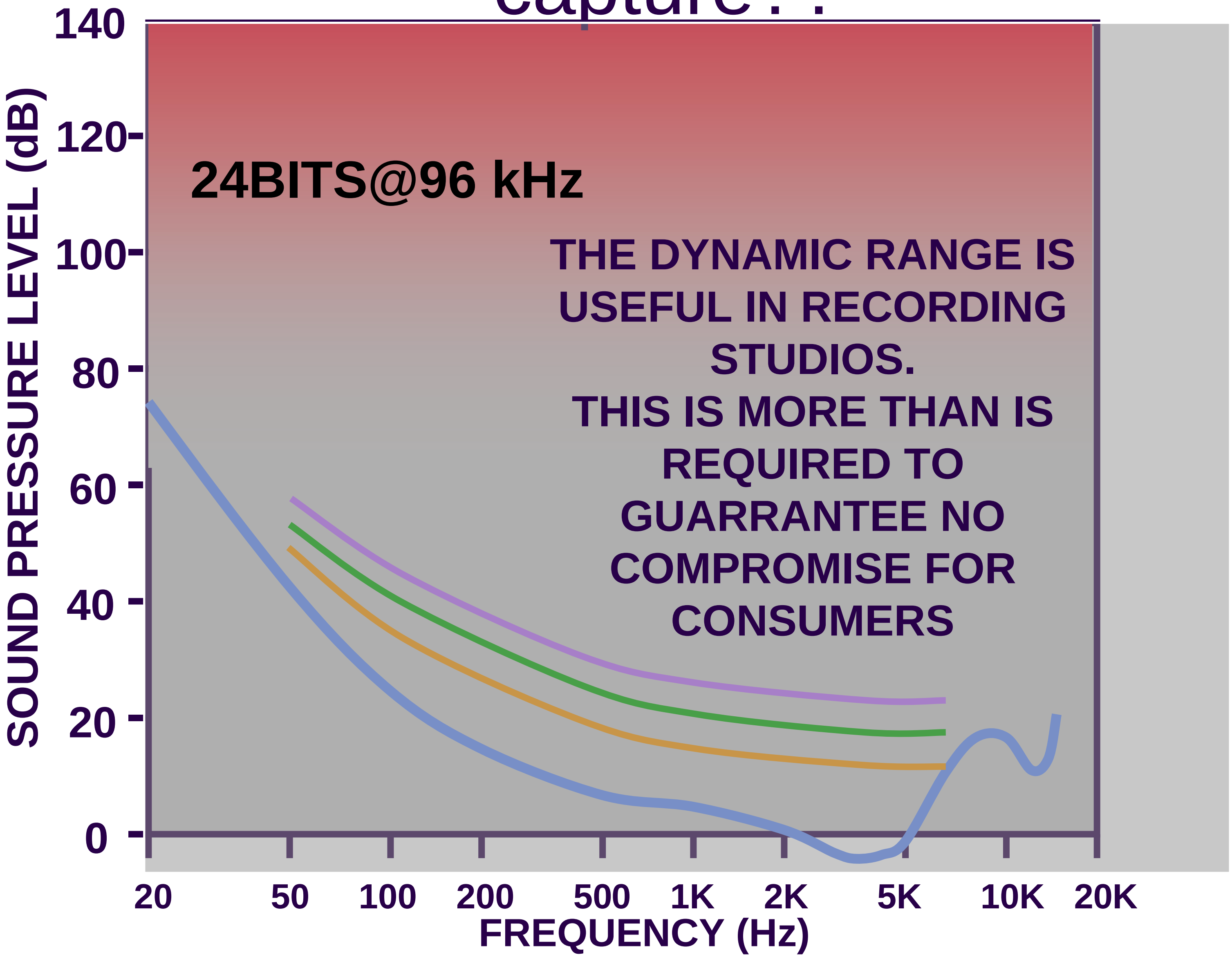
20 Hz to 20 kHz = Range of Normal Hearing
= Standard 44.1 kHz Sampled CD

20 Hz to 46 kHz = 96 kHz Sampled CD/DVD
High Resolution Audio

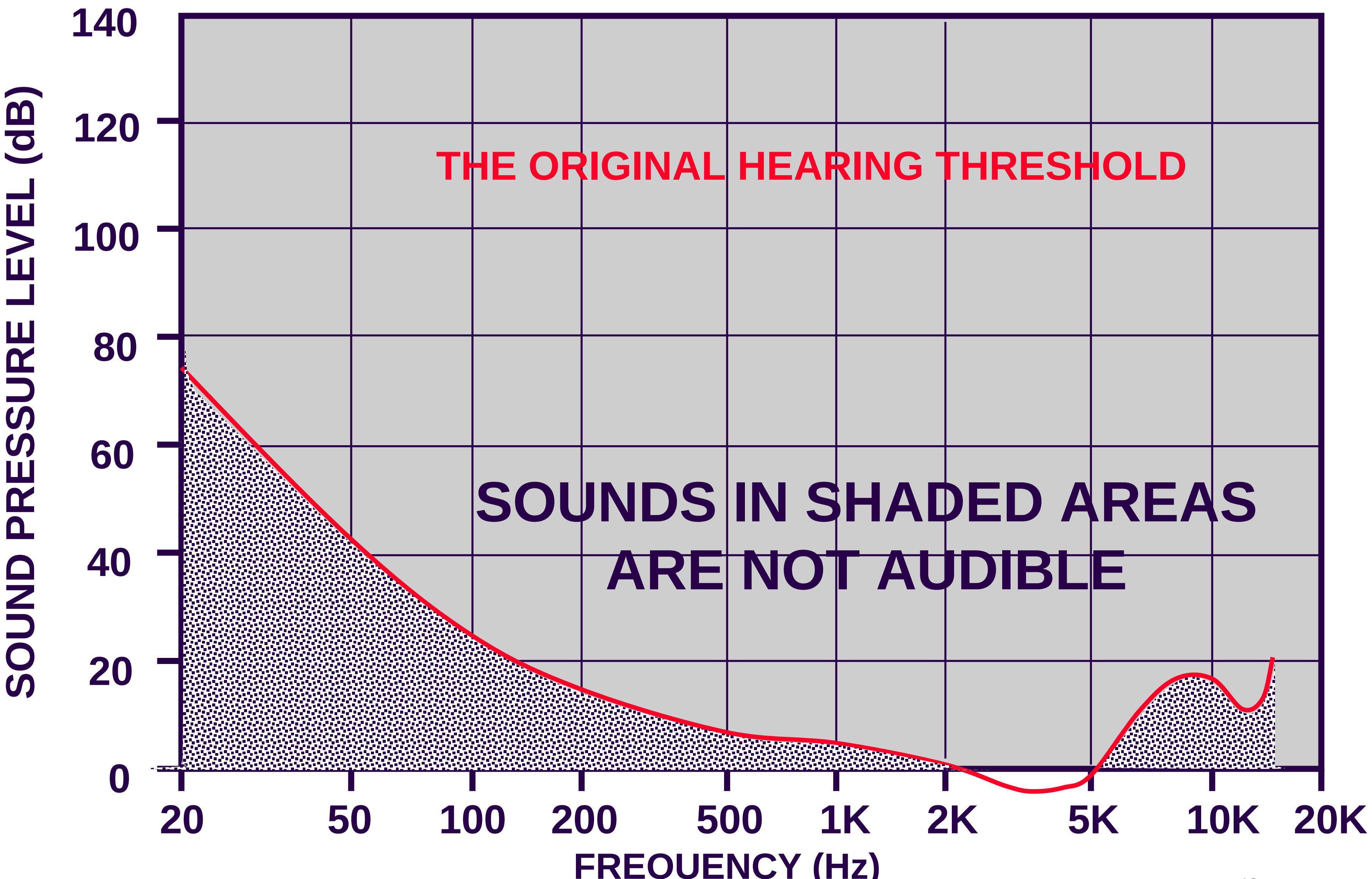
In an ideal world, how much can we capture??



In an ideal world, how much can we capture??

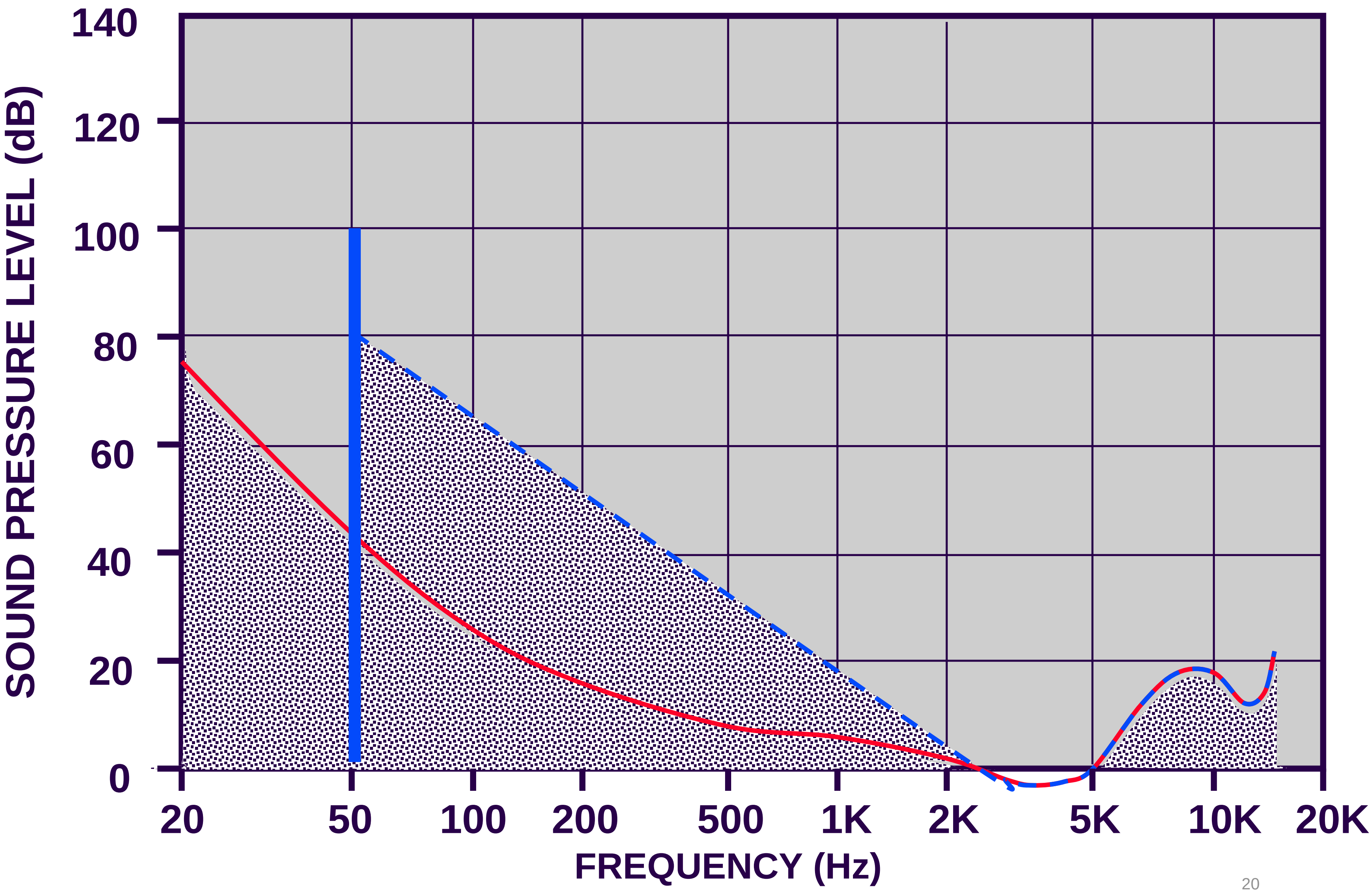


Masking: when one sound prevents us from hearing other sounds.

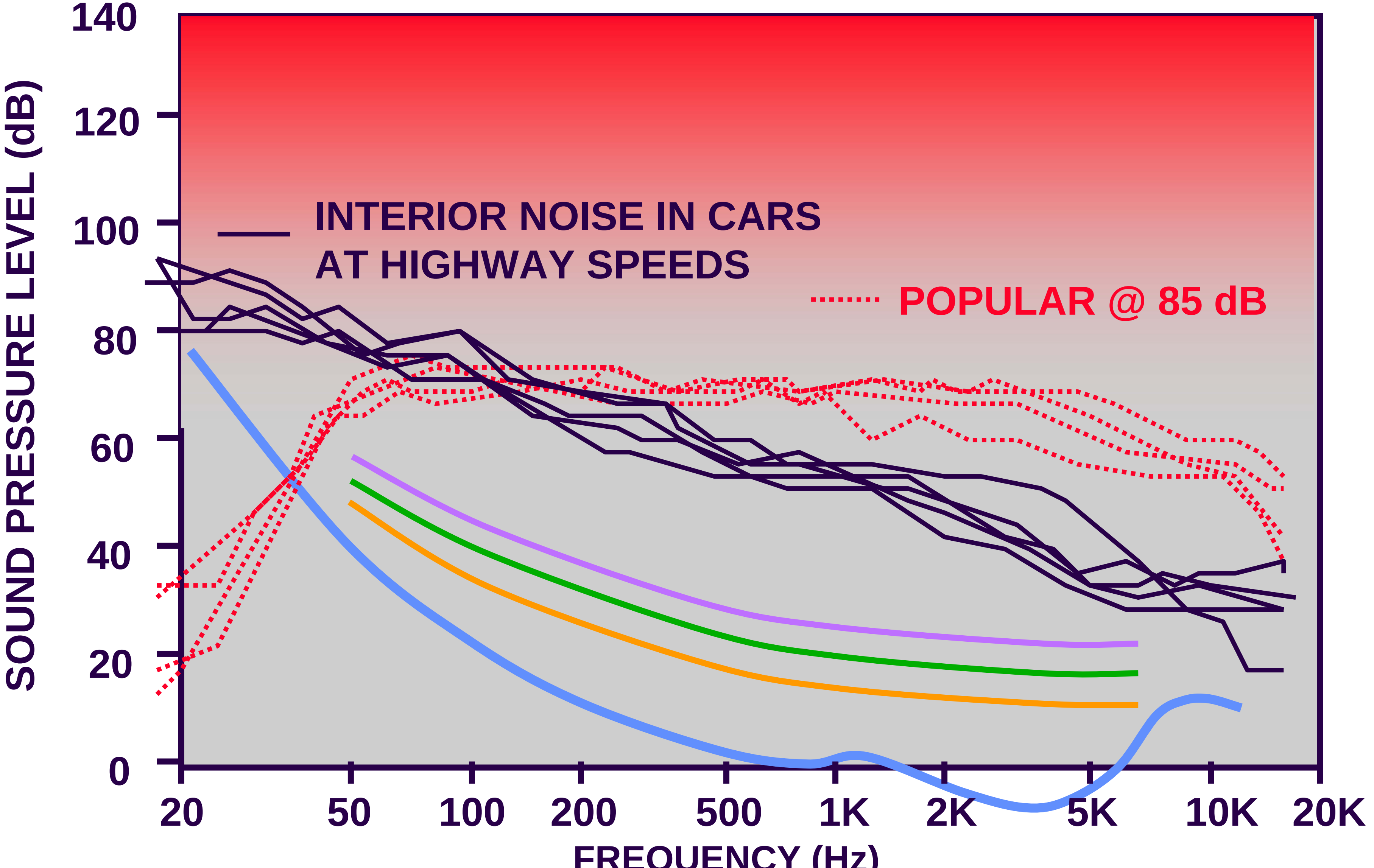


140
120
100
80
60
40
20
0
SOUND PRESSURE LEVEL (dB)
THE ORIGINAL HEARING THRESHOLD
SOUNDS IN SHADED AREAS ARE NOT AUDIBLE
20
50
100
200
500
1K
2K
5K
10K
20K
FREQUENCY (Hz)

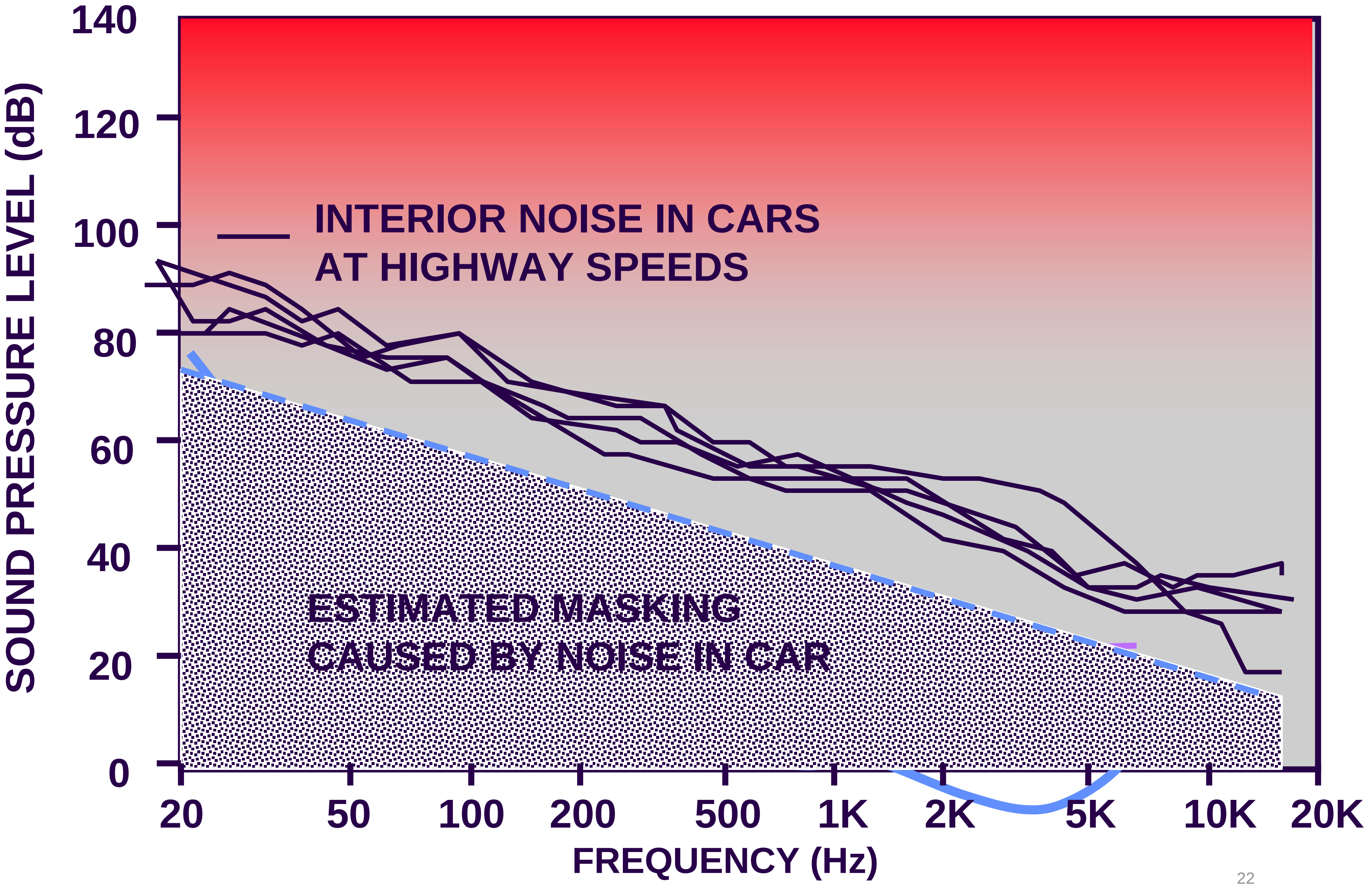
Bass signals mask a very wide frequency range



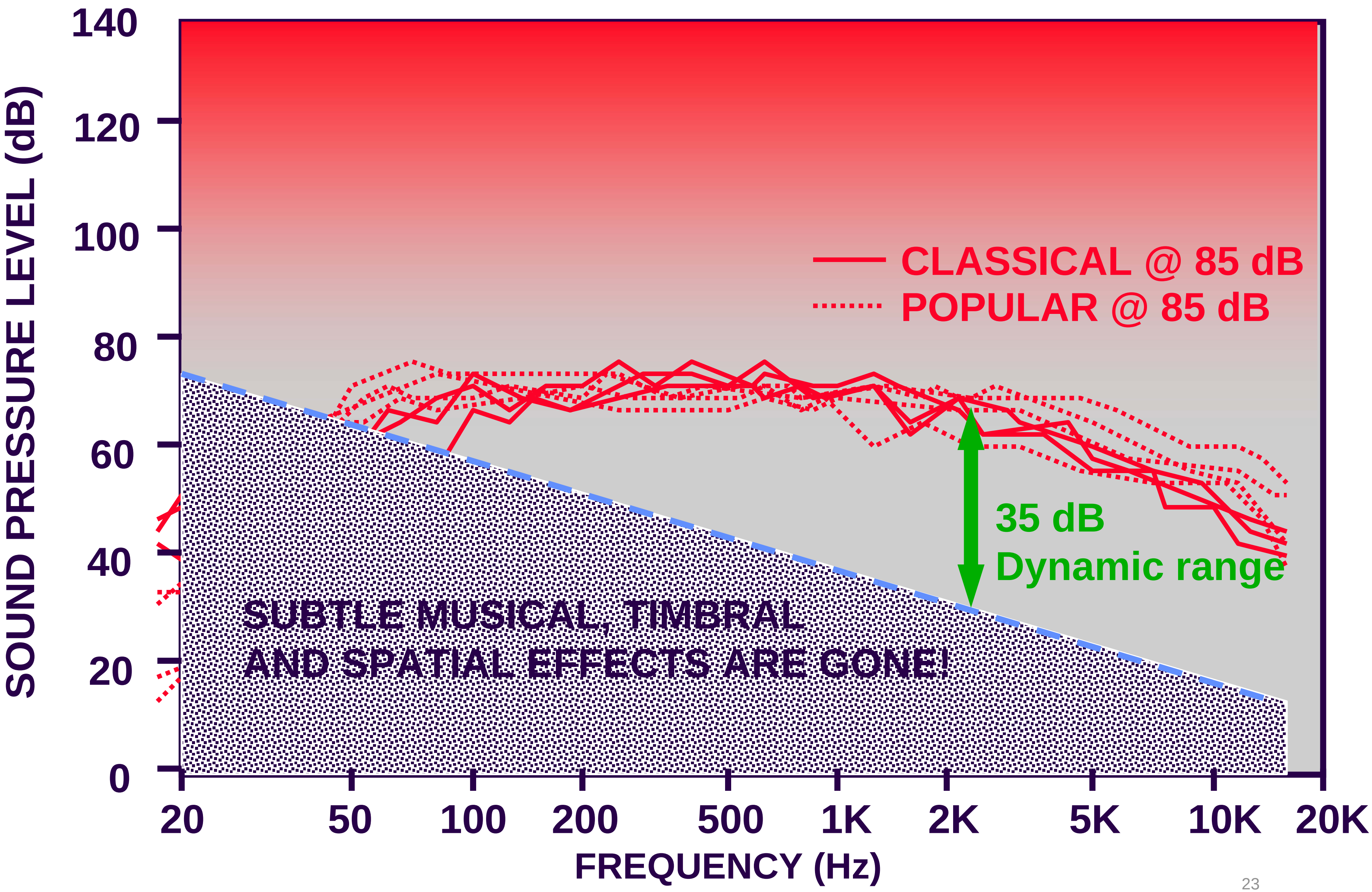
Low bass is hard to hear!



In cars, everything suffers when in motion.



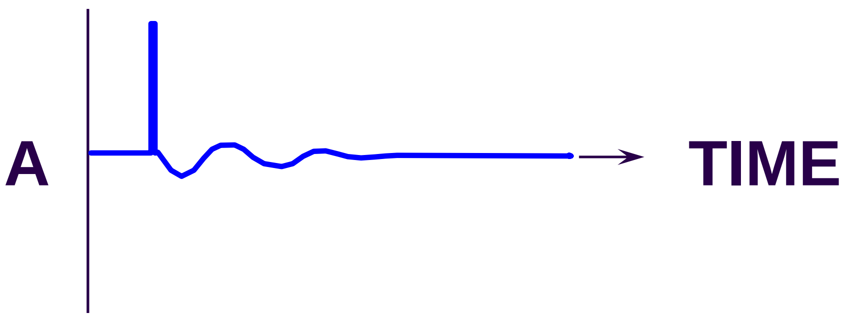
In cars, everything suffers when in motion.

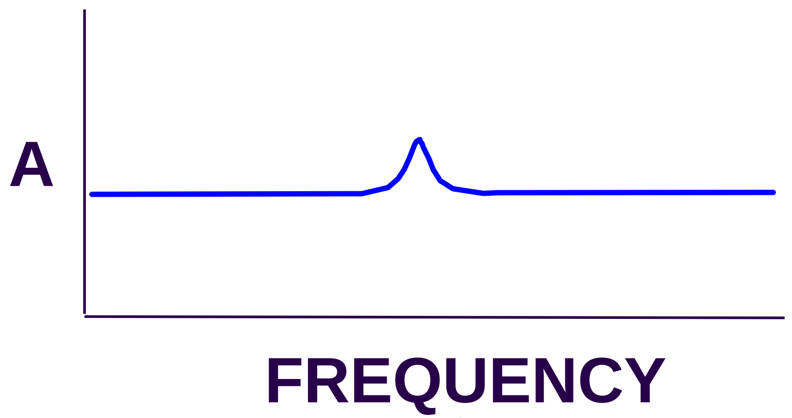


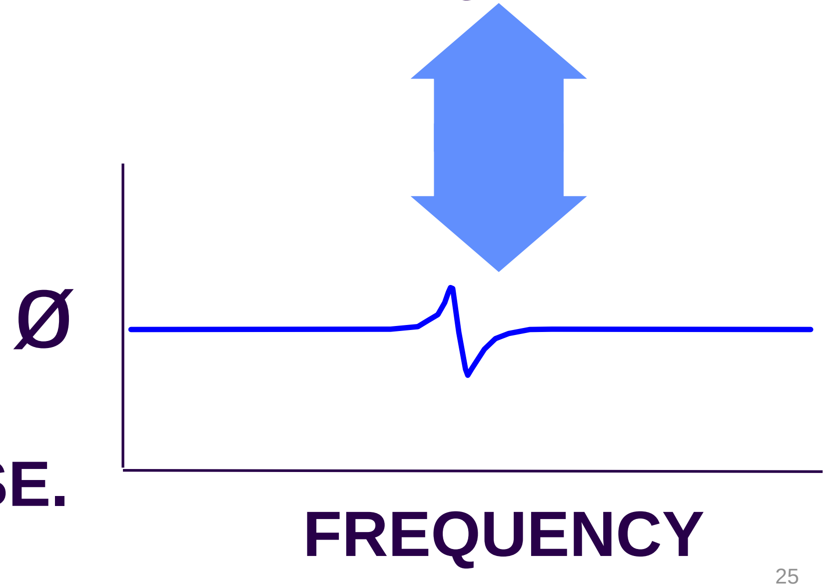
Transducers (woofers, midranges and tweeters) and low-frequency resonances in rooms and cars, behave as "minimum-phase" systems.

- *This means that the phase response and the transient response are both predictable from the (amplitude) frequency response!*
- *A smooth, flat frequency response ensures good behavior in the time domain.*
- *Problems in the frequency response of such systems can be corrected with the <u>right kind</u> of equalization based on the <u>right kind</u> of measurements.*

“Minimum-Phase” Systems

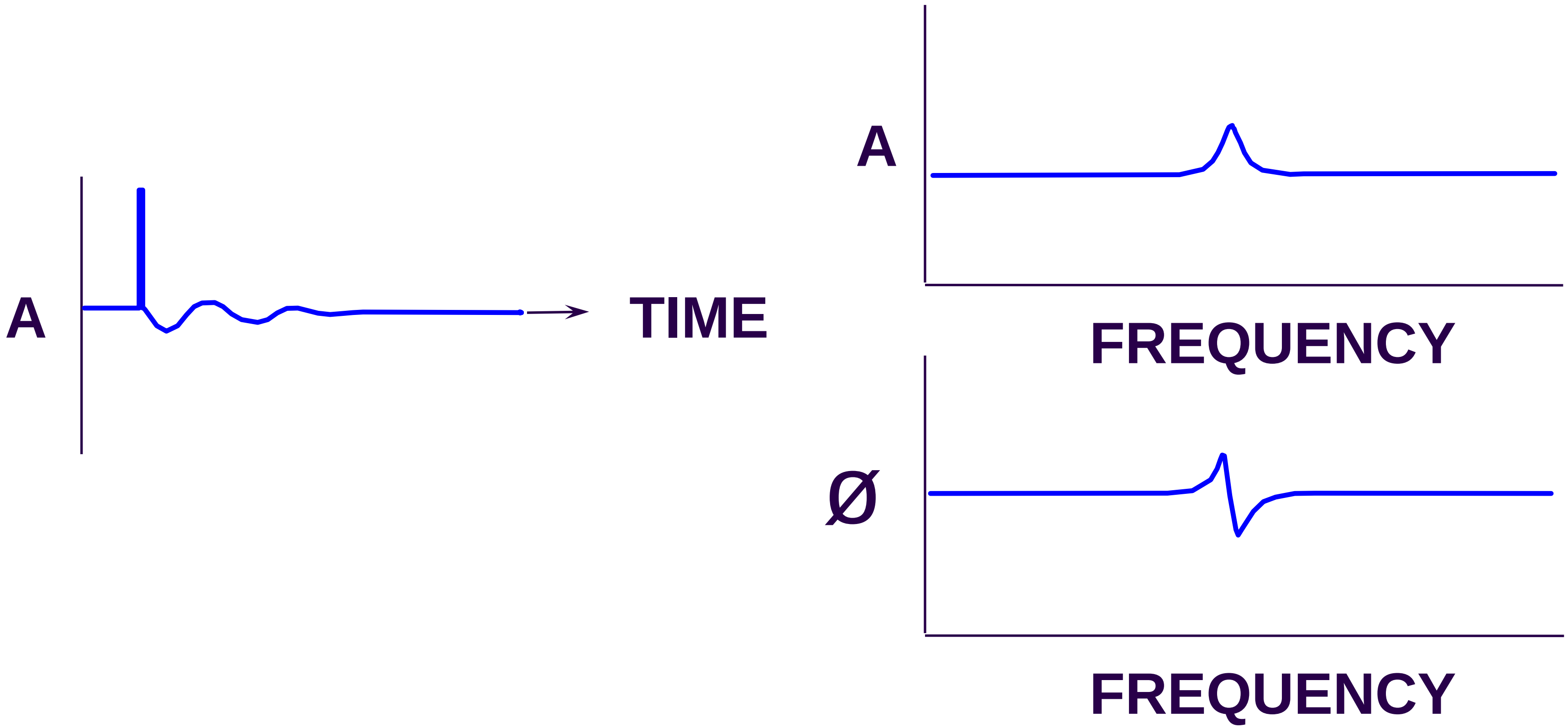






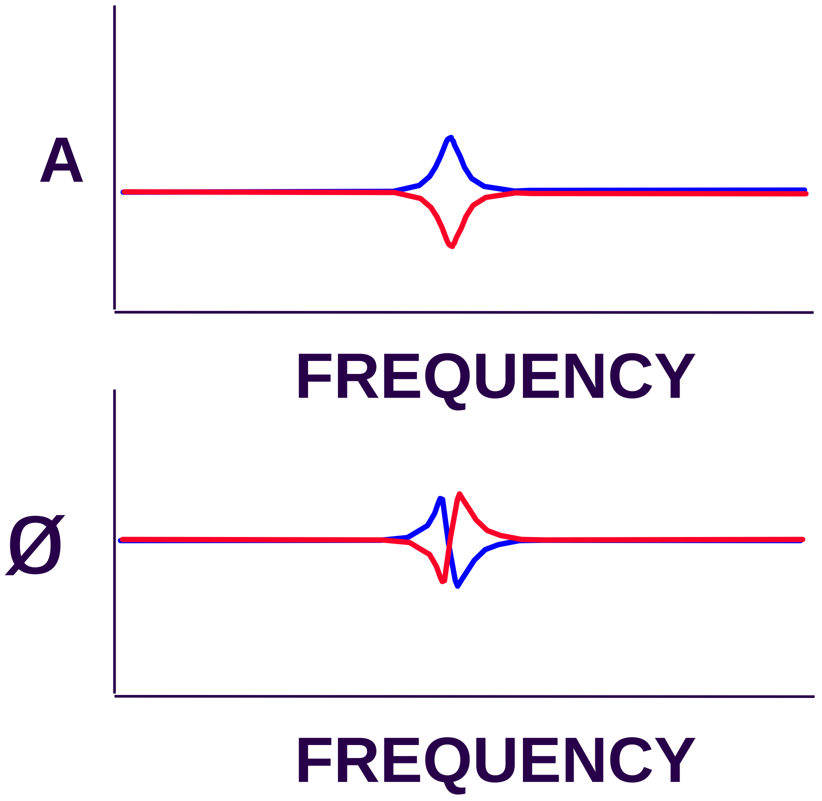
IN “MINIMUM-PHASE” SYSTEMS THE PHASE RESPONSE CAN BE CALCULATED FROM THE AMPLITUDE RESPONSE.

A minimum-phase system with a problem resonance.

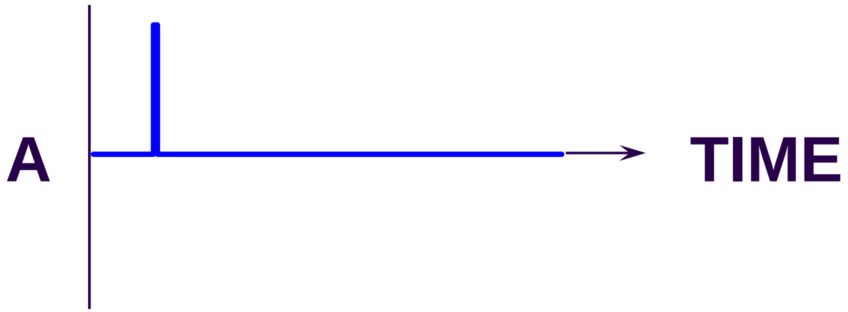


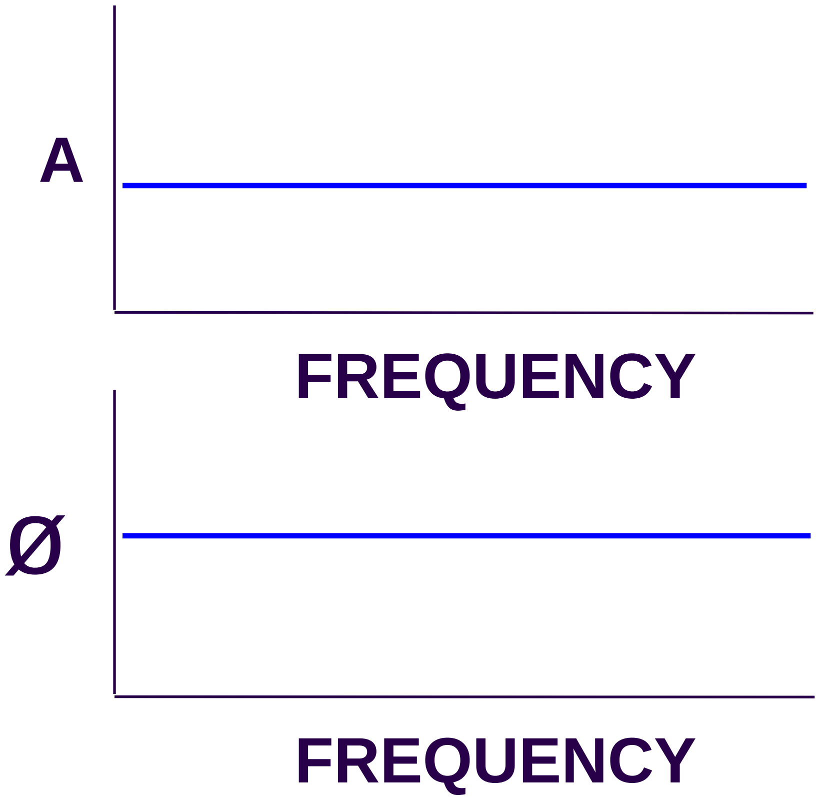
Address the resonance with an equal and opposite parametric EQ filter

WHEN THE CORRECT AMPLITUDE RESPONSE IS “DIALED IN”, THE PHASE RESPONSE IS AUTOMATICALLY CORRECTED.

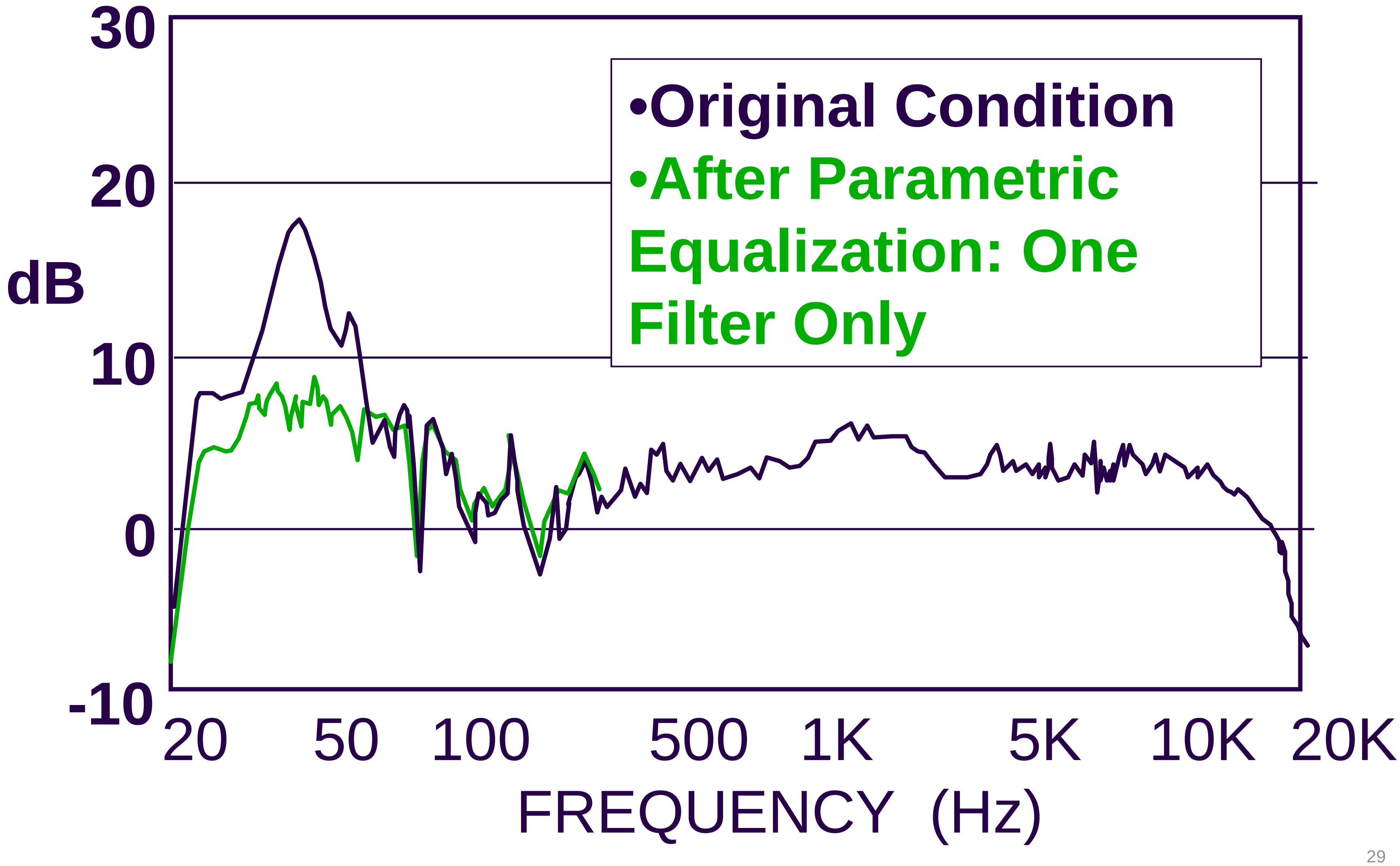


And <u>everything</u> is fixed!



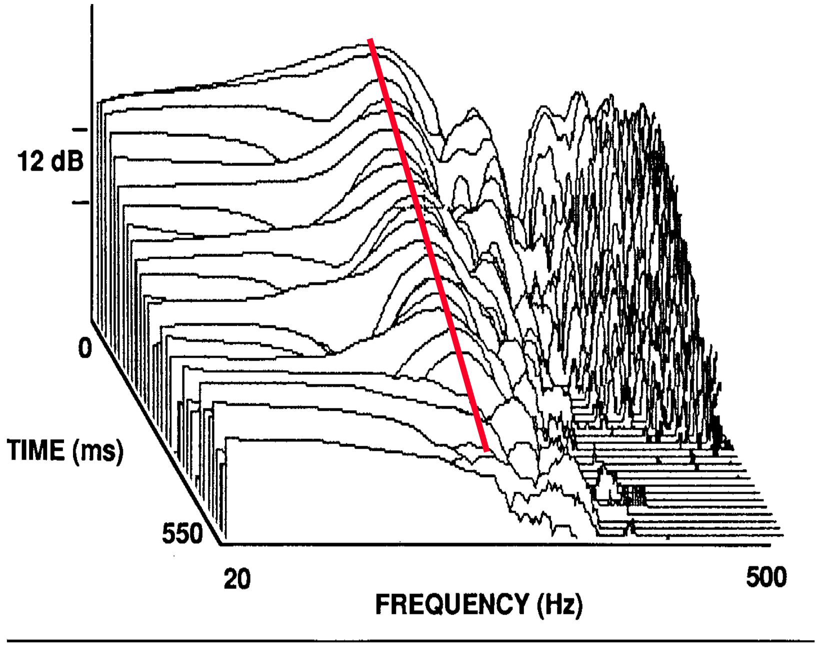


Parametric equalization fixes the frequency response

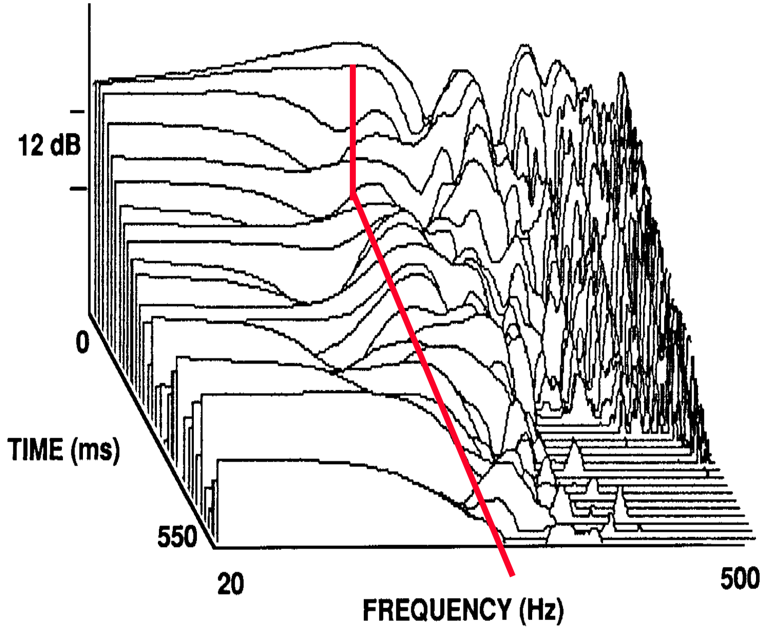


And the transient response is also fixed!

BEFORE



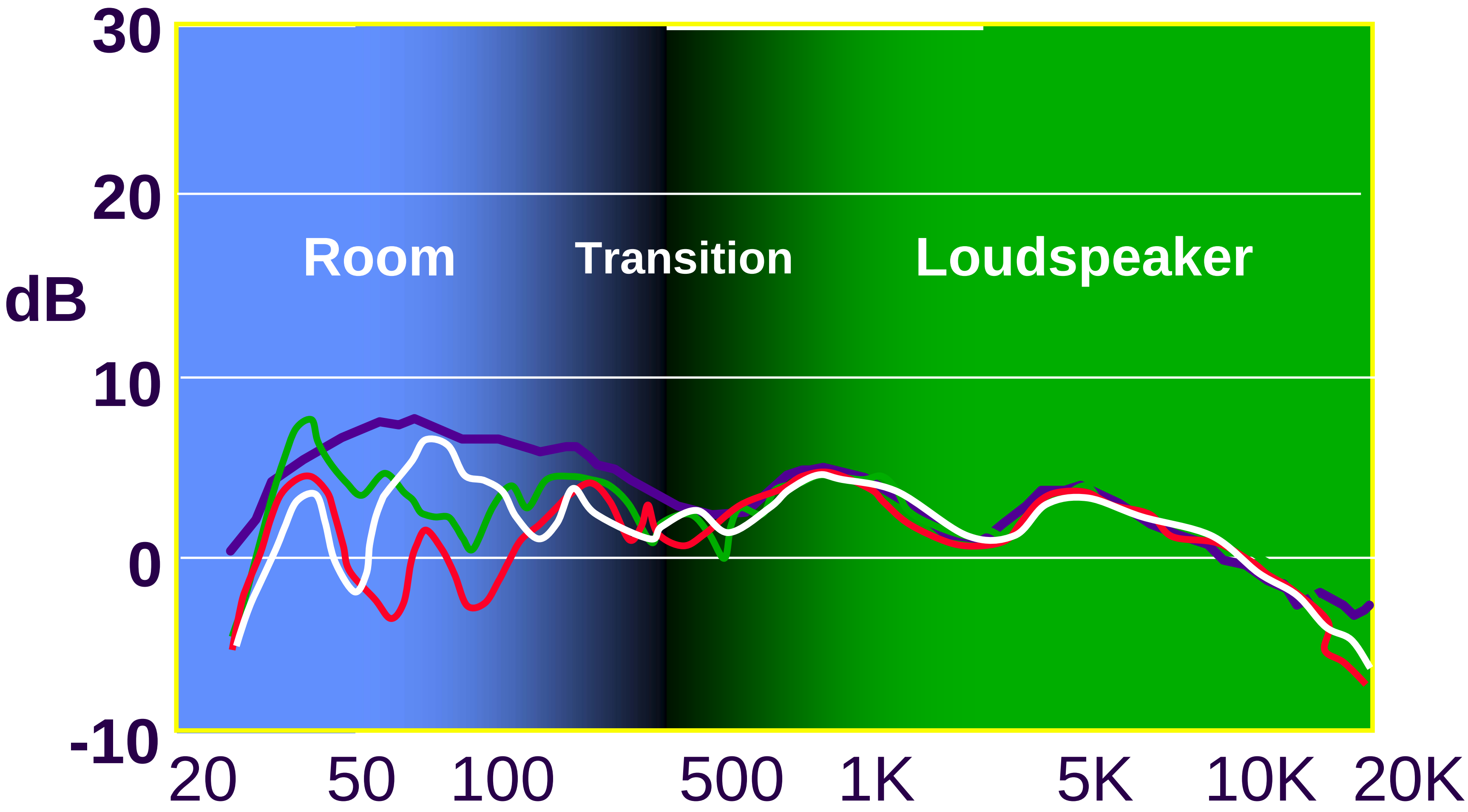
AFTER



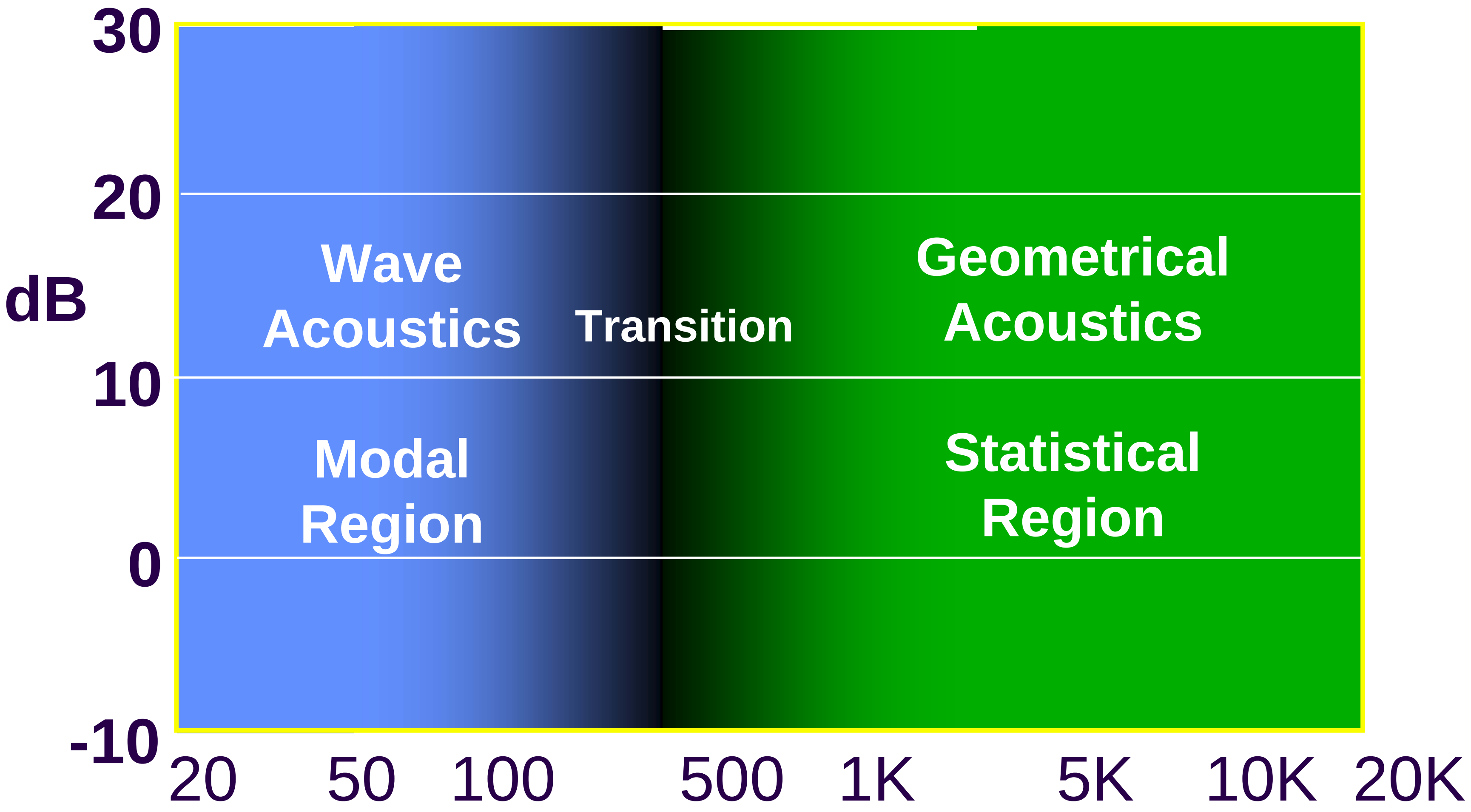
What happens when a speaker is placed in the room (or a car)?

- Predicting the in room response:

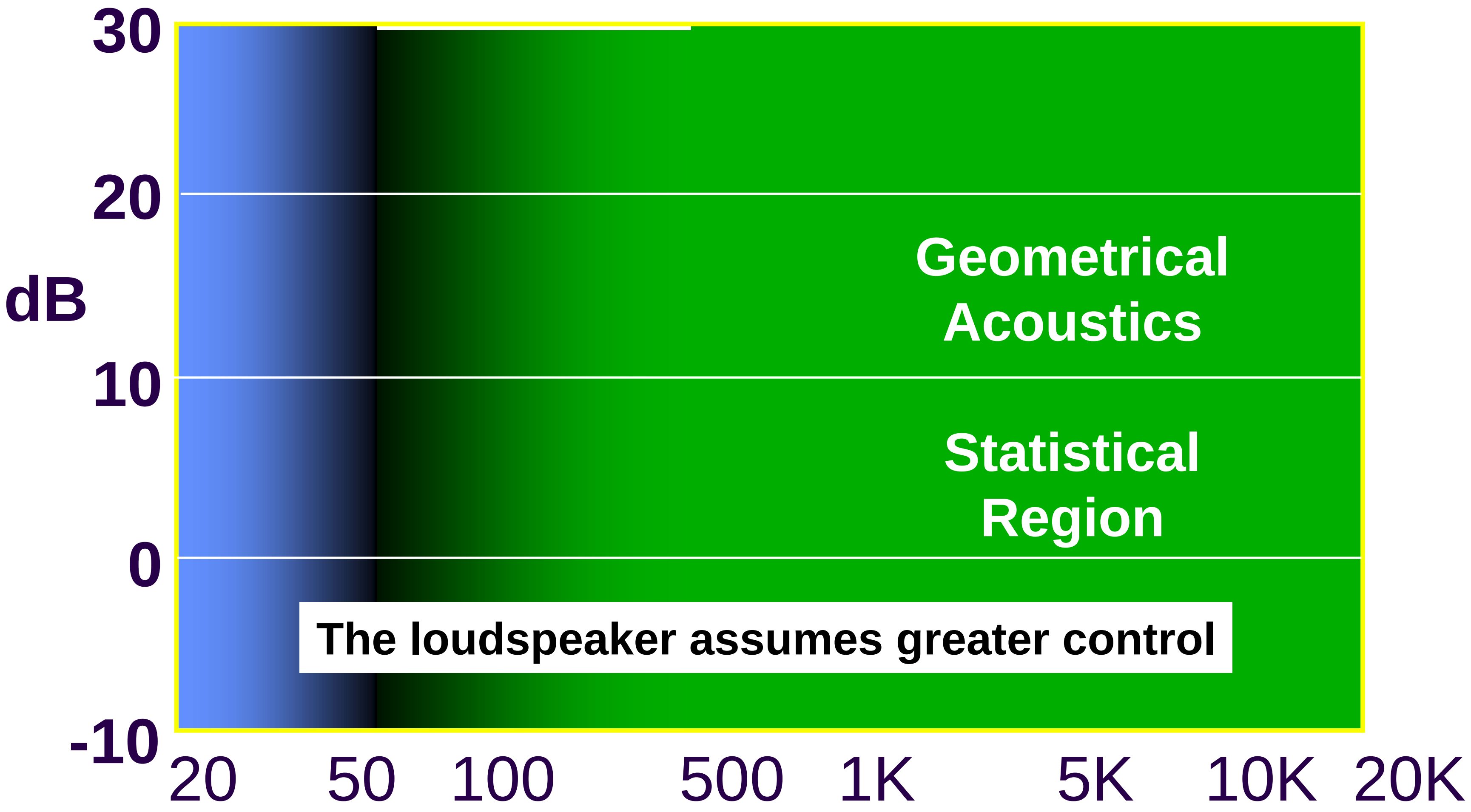
There is a region where the room dominates, and one where the loudspeaker dominates.



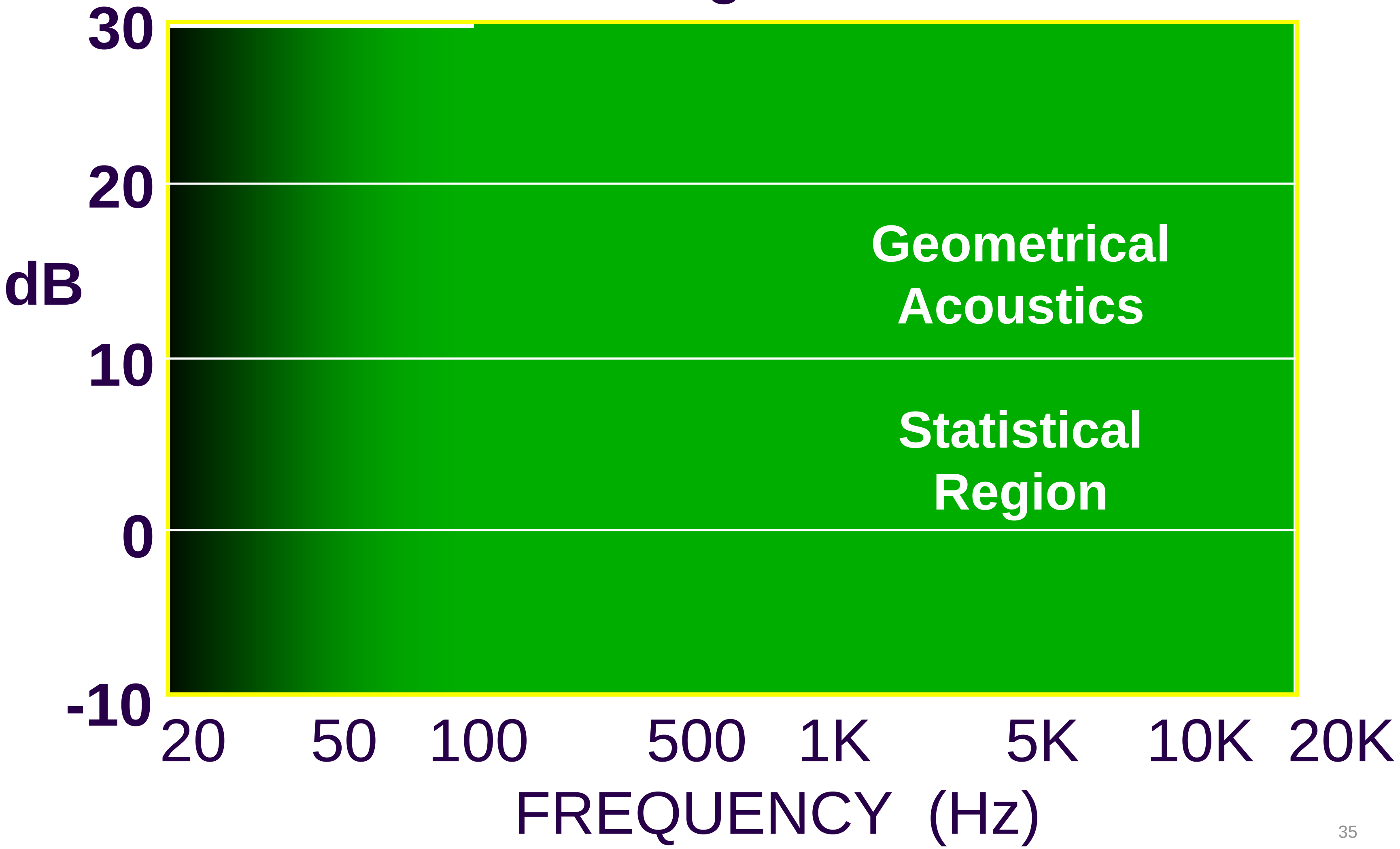
In terms of room acoustics:



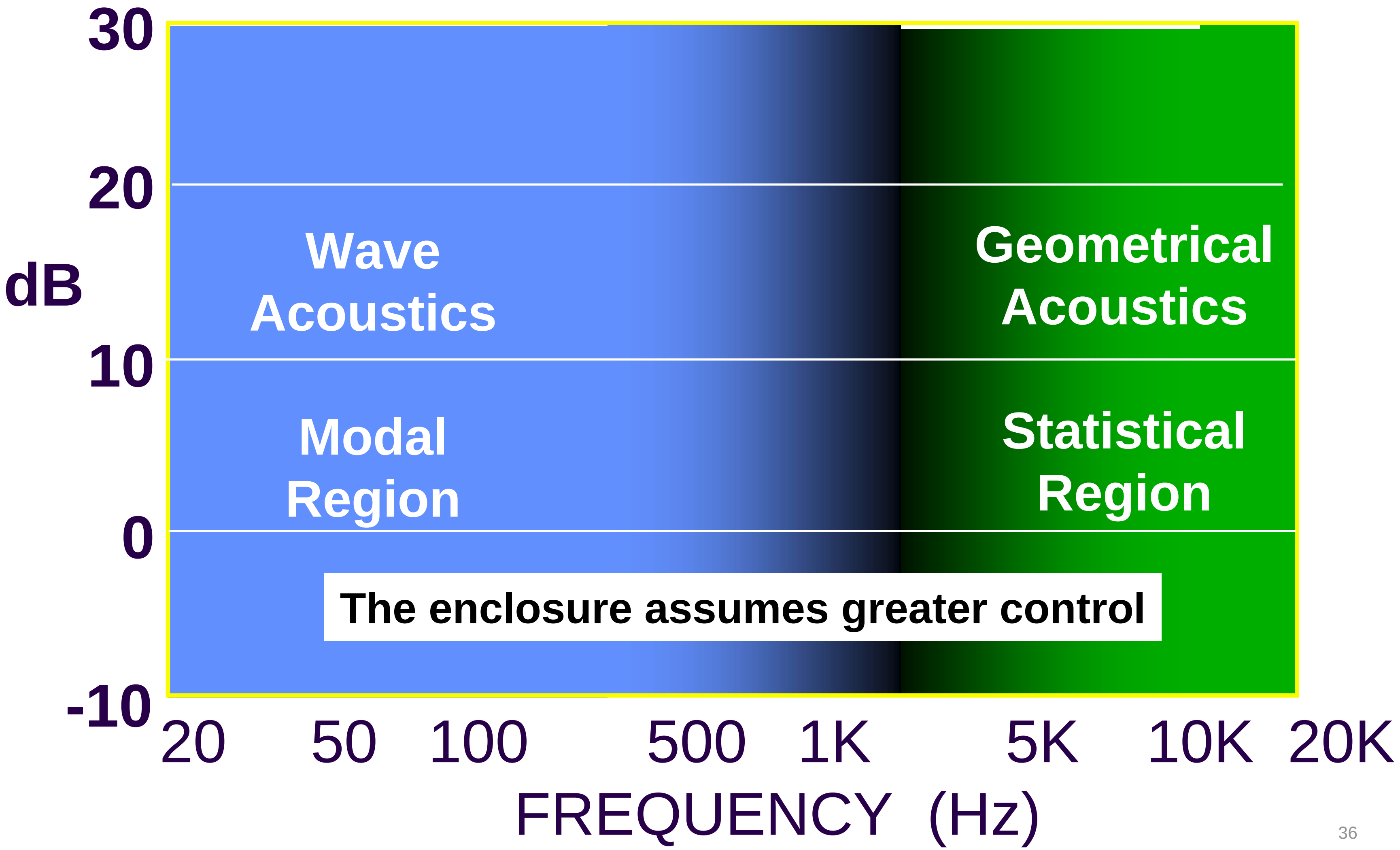
As rooms get larger:



And in concert halls low-frequency room problems are minimal. Diffuse-field theory reigns!



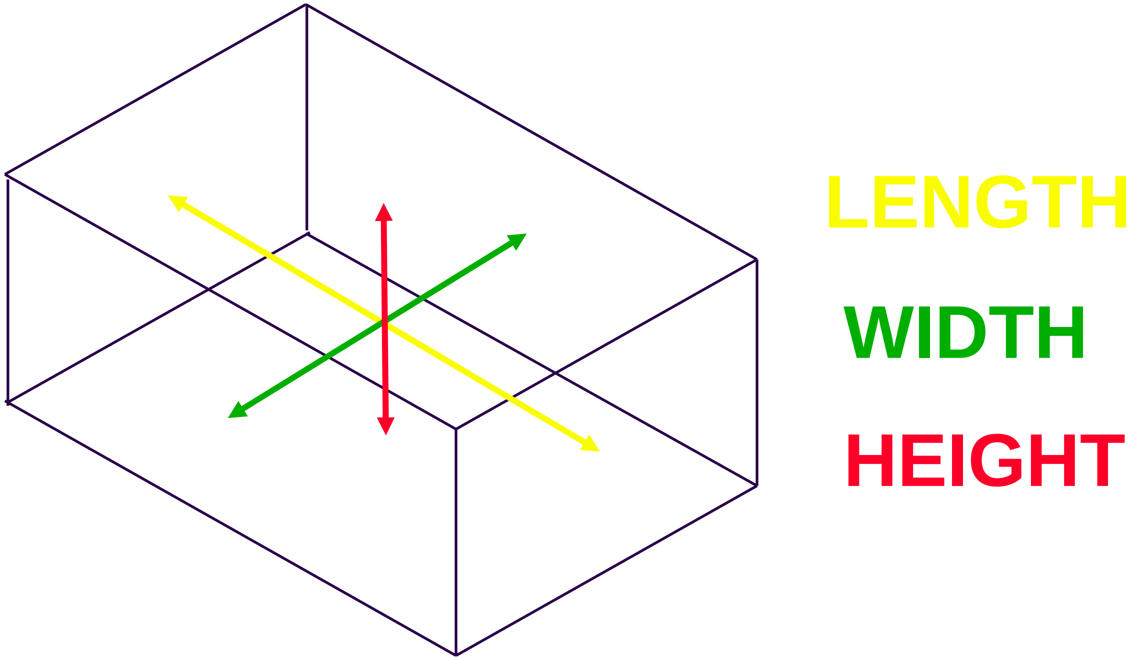
As rooms get smaller e.g. cars:



The problem here is Standing Waves, Room Resonances, Room Modes, Eigentones, etc.

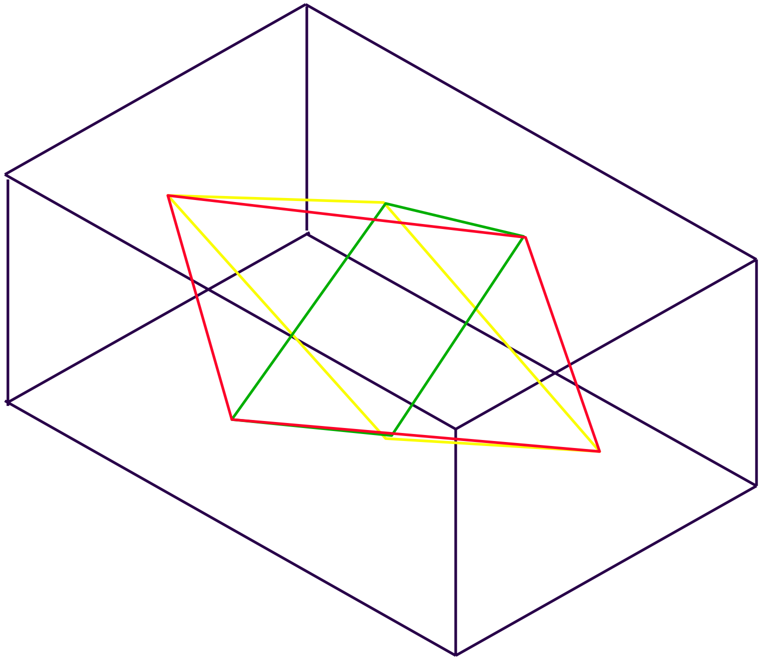
These are all the same phenomenon.

Classes of Room Modes

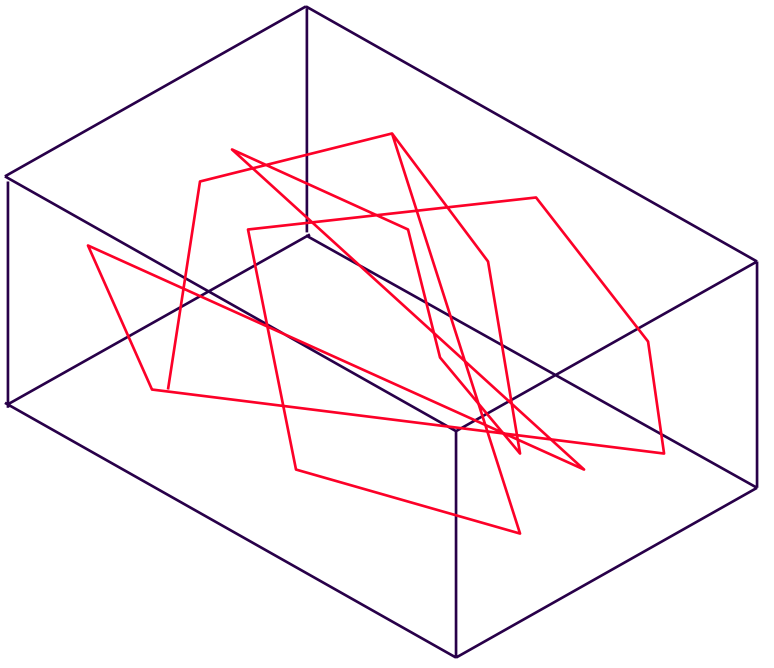


- AXIAL: occurring between opposite parallel surfaces

- TANGENTIAL: occurring among four surfaces, avoiding two that are parallel



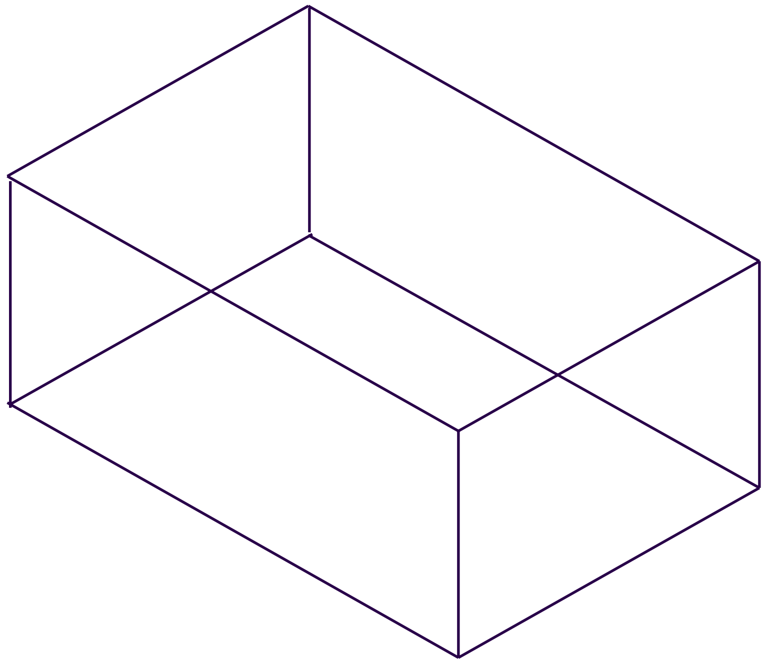
- OBLIQUE: occurring among any and all surfaces

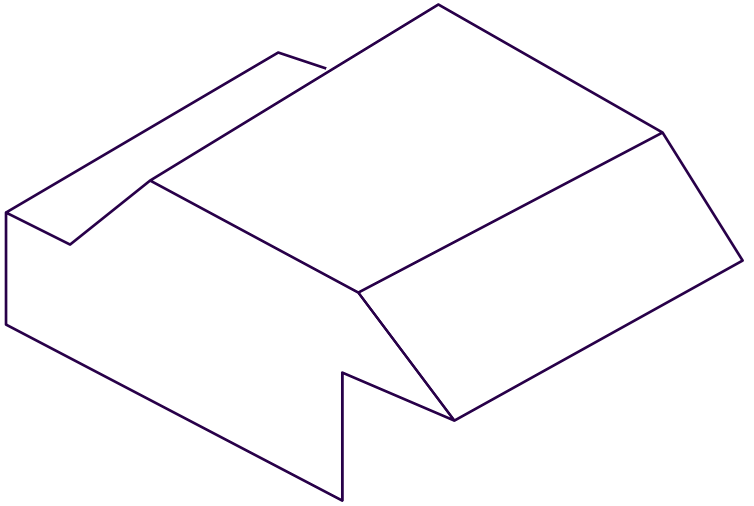


And we thought rooms were difficult!

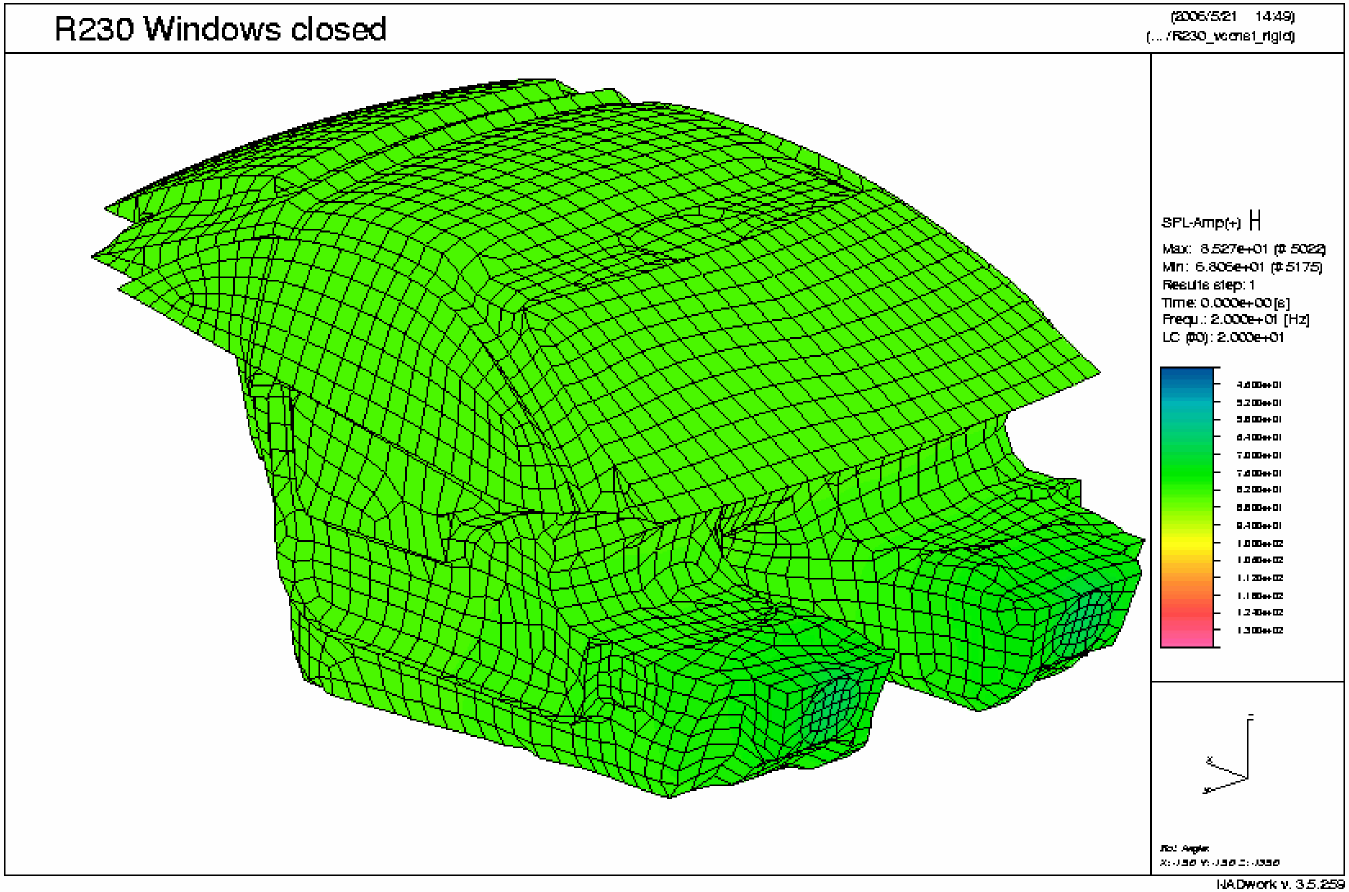
Predicting what happens in a rectangular space with uniformly flat rigid surfaces is one thing, . . .

. . . doing it in an irregularly shaped space with surfaces that are not smooth, and that have differing absorption properties is quite another!

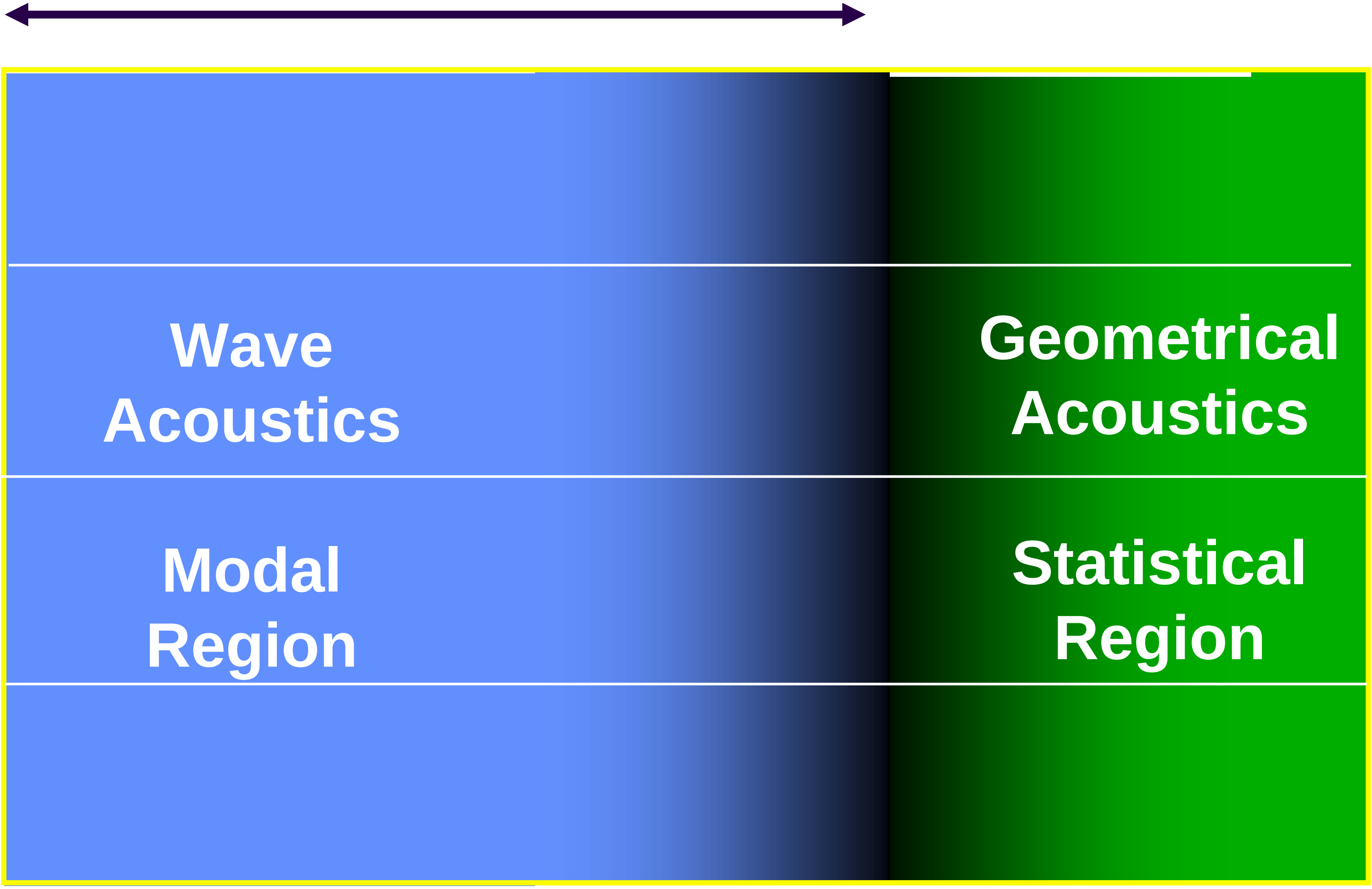




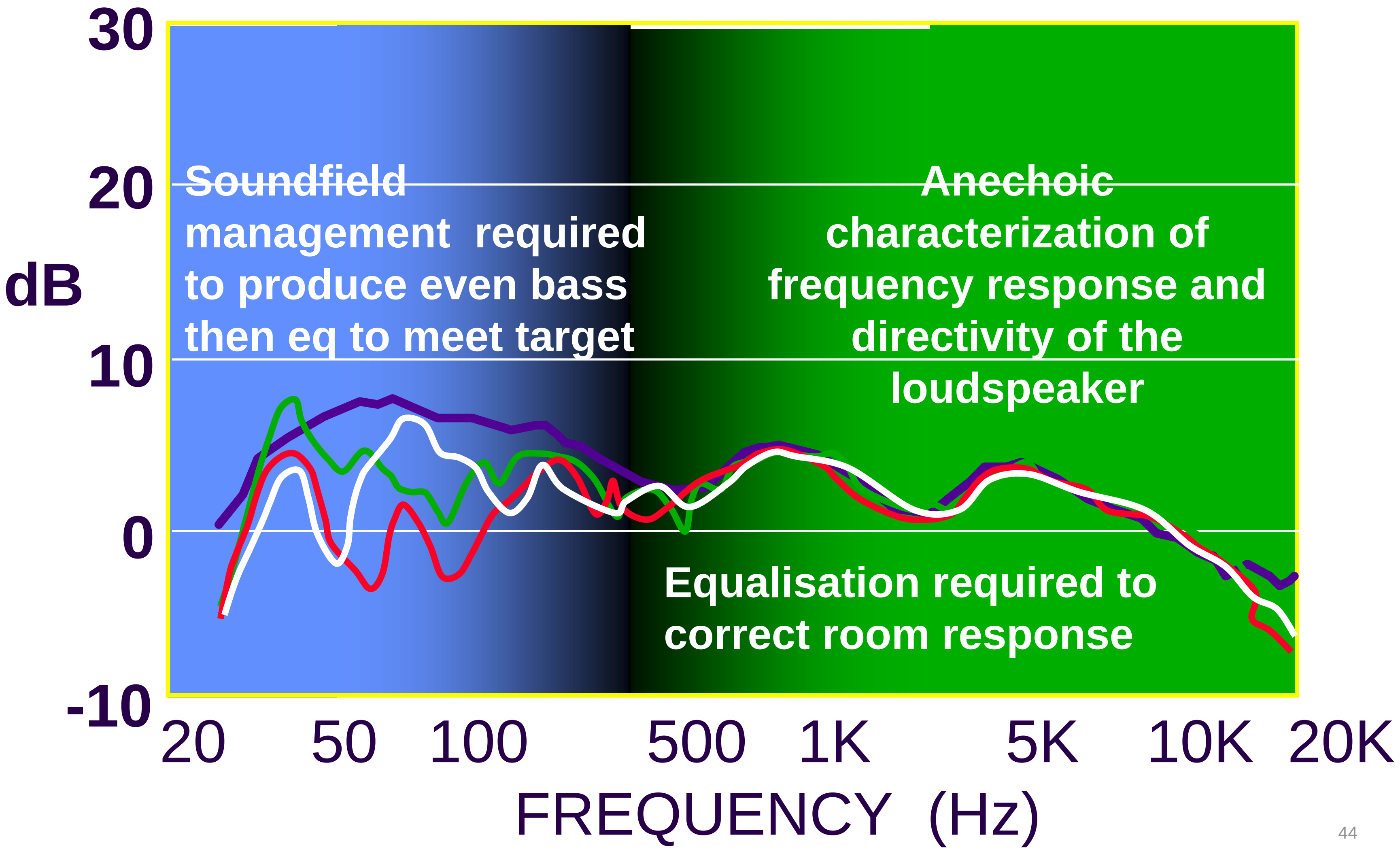
Simulation example



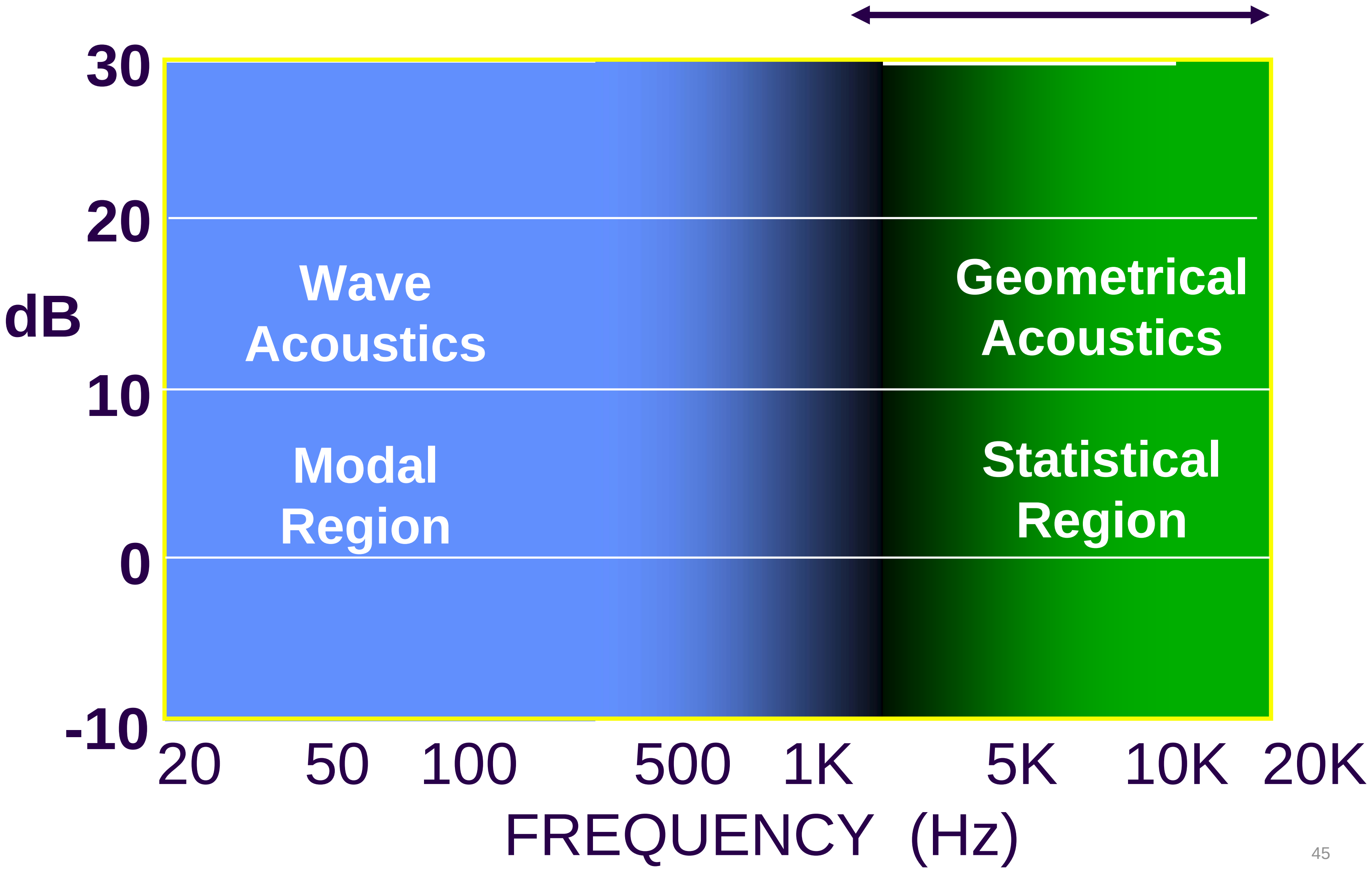
In this frequency range good sound is the result of good transducers, appropriately located to even out room modes and seat to seat variations, with proper equalization based on good measurements. Only predictable through simulation for real rooms and cars.



Mid / High frequency sound quality *is* predictable from anechoic data

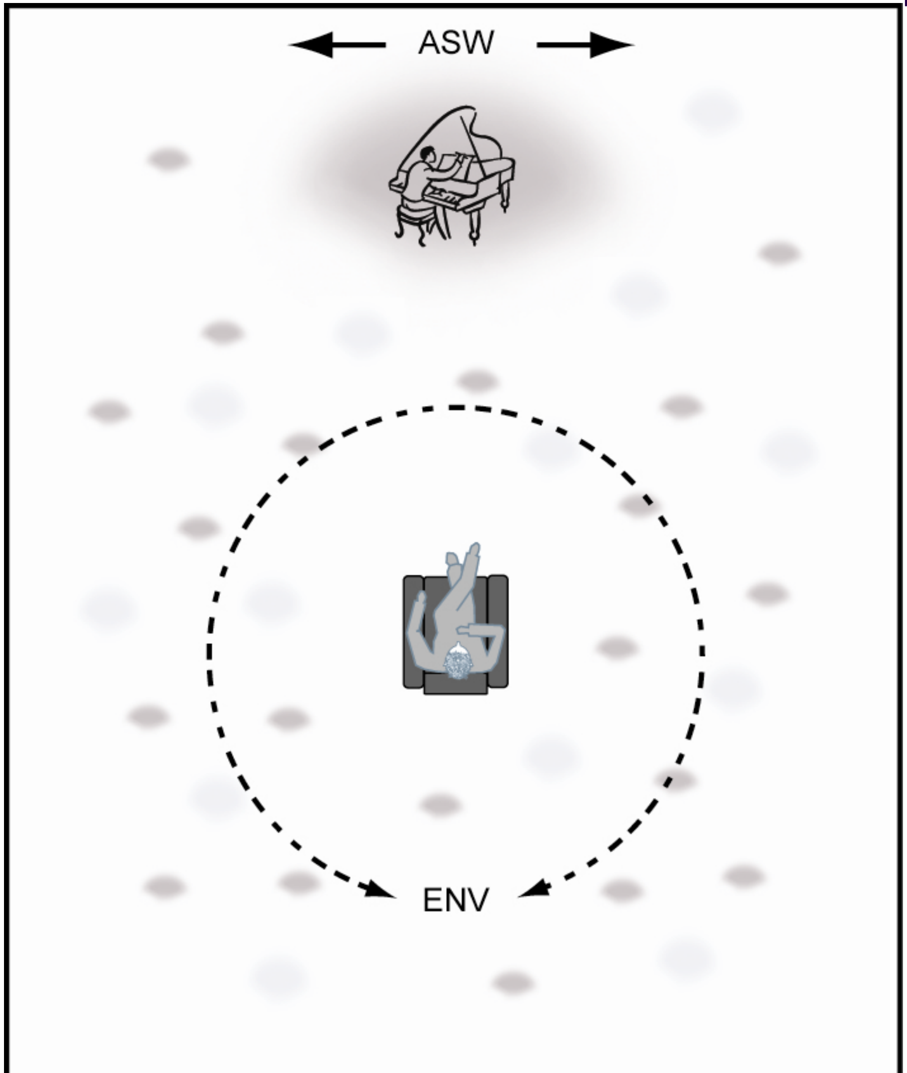


In this frequency range good sound is the result of good transducers, correctly located, aimed and mounted, with proper equalization based on good measurements. Somewhat predictable in advance from anechoic data.

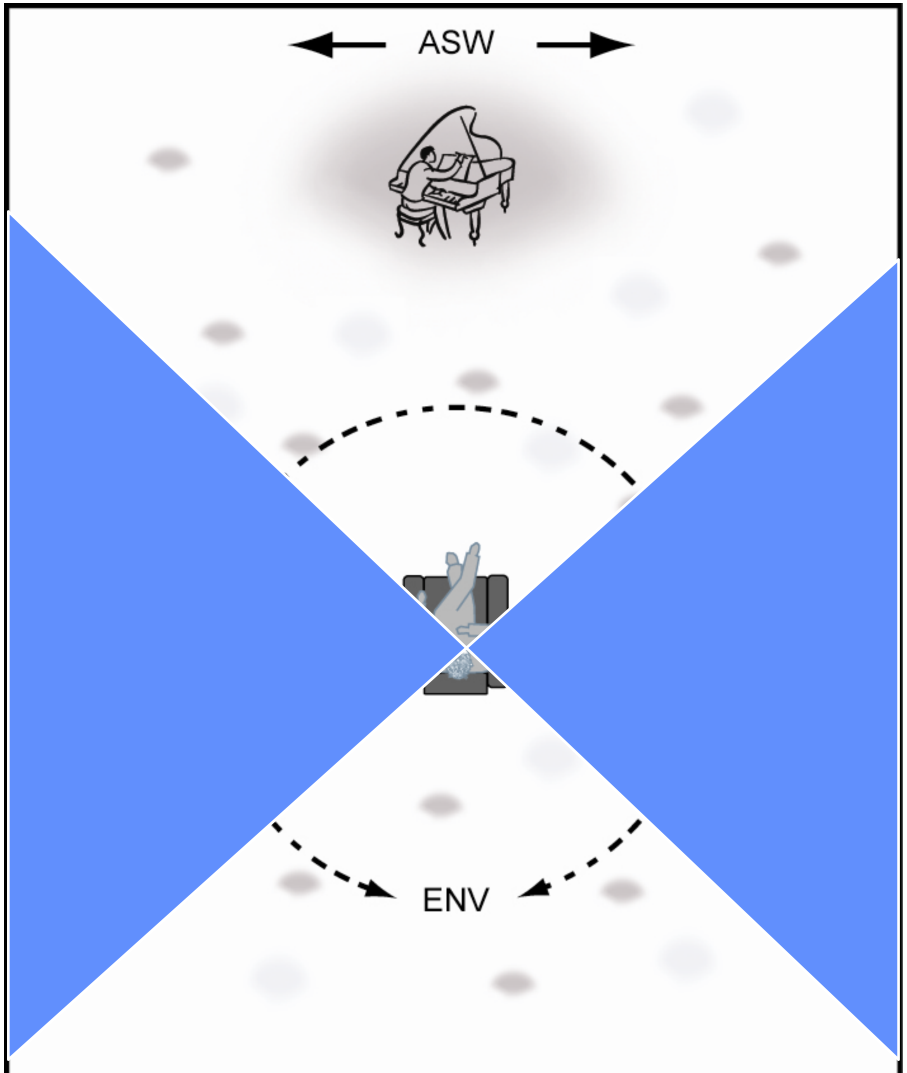


One other comment: The perception of space and the difference between hearing the live performance and the reproduction of this in a room or a car….

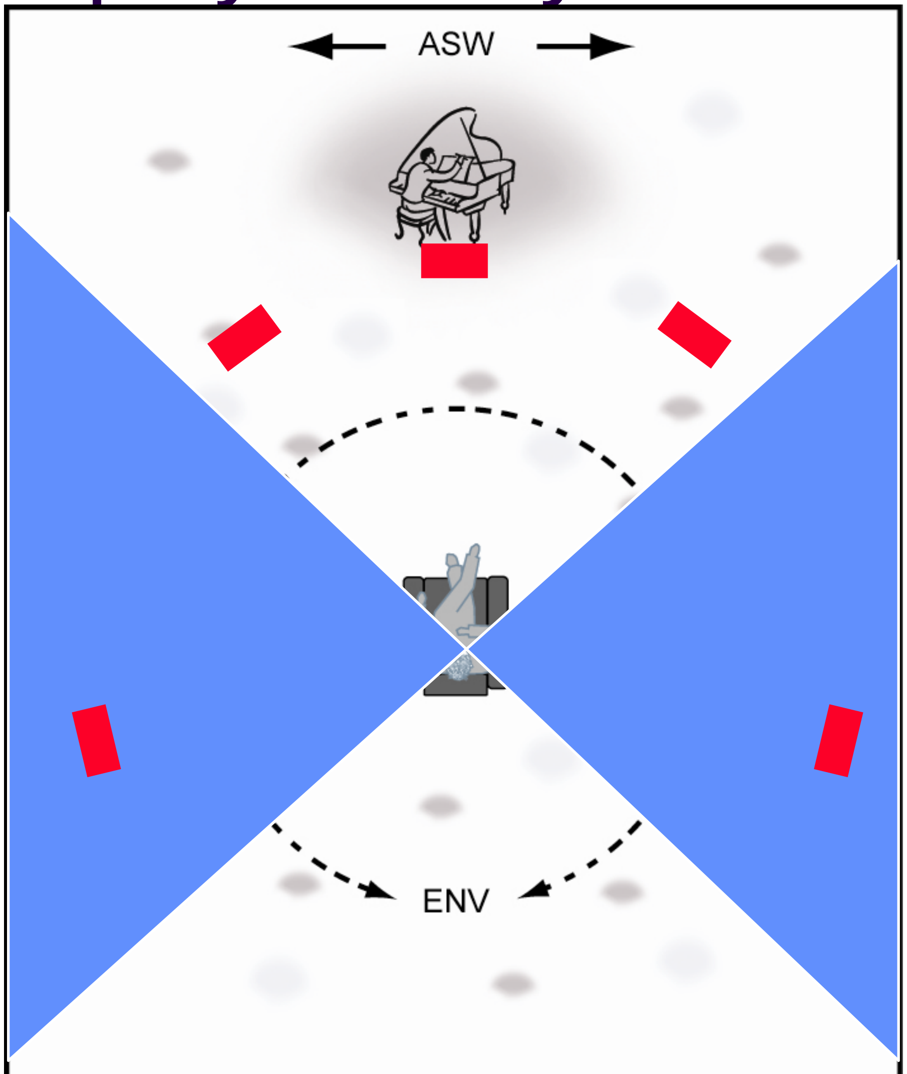
Two highly desirable perceptual attributes:
ASW = apparent source width
ENV / LEV = listener envelopment



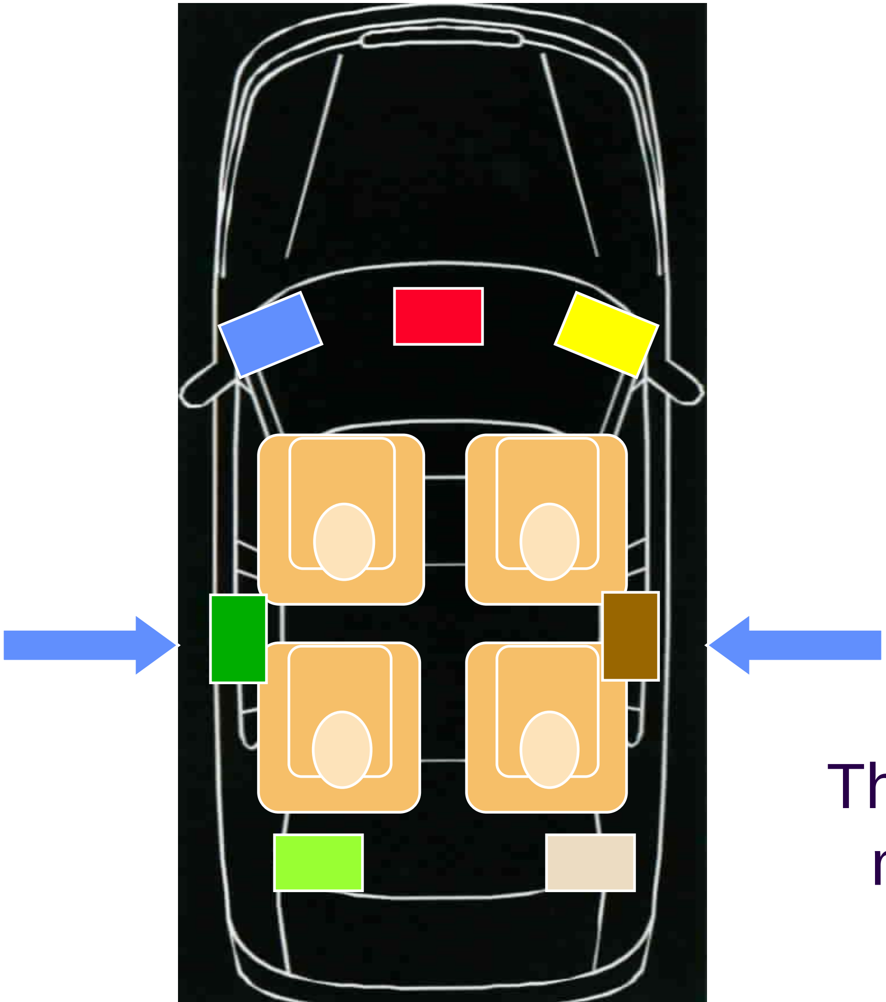
Both of these are directly the result of sounds arriving from the sides of the listener



Which explains the locations of the surround speakers in 5.1 channel playback systems.



And why in a car, the rear door loudspeakers are so important – for both front and rear seat passengers.



This leads us to multichannel playback…