Where we listen

The rules for acoustical design are not the same in all of these spaces.
How much **real** research has been done?

- **A LOT**
  - concert hall

- **SOME**
  - Office/factory

- **A LITTLE**
  - home theater

- **VERY LITTLE**
  - car interior
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

<table>
<thead>
<tr>
<th>FREQUENCY</th>
<th>WAVELENGTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Hz</td>
<td>56 feet = 17 m</td>
</tr>
<tr>
<td>100 Hz</td>
<td>11.3 feet = 3.44 m</td>
</tr>
<tr>
<td>1 kHz</td>
<td>13.6 inches = .35 m</td>
</tr>
<tr>
<td>10 kHz</td>
<td>1.3 inches = 3.3 cm</td>
</tr>
<tr>
<td>20 kHz</td>
<td>0.7 inch = 1.8 cm</td>
</tr>
</tbody>
</table>
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.

WOOFER          MIDRANGE          TWEETER
Wavelength, Speakers and Directivity Help to Define the Crossover Frequencies

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

The lowest contour is, by definition, the hearing threshold = the smallest audible sound, called here the MINIMUM AUDIBLE FIELD, or MAF.

ACCEPTABLE BACKGROUND NOISE LEVELS
- NC 25: TV STUDIOS, MOVIE THEATERS, SUBURBIA
- NC 20: CONCERT HALLS, RURAL HOMES
- NC 15: MUSIC RECORDING STUDIOS
Listening on the highway is very different from listening in the parking lot!

INTERIOR NOISE IN CARS AT HIGHWAY SPEEDS
The dynamic ranges of digital systems

![Graph showing the dynamic ranges of digital systems with 16, 20, and 24 bits, indicating sound pressure level (dB) and frequency (Hz).]
How much of music can we HEAR?

FUNDAMENTALS
- ORGAN
- STRINGS
- BRASS
- VOICES

OVERTONES
- PIANO
- WOODWINDS

FREQUENCY (Hz)
- 20
- 50
- 100
- 200
- 500
- 1K
- 2K
- 5K
- 10K
- 20K
How much of this can we RECORD?

**FUNDAMENTALS**

- **VOICE**
- **WOODWINDS**
- **BRASS**
- **STRINGS**
- **ORGAN**

**OVERTONES**

- **PIANO**

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??

**16 BITS@44.1 kHz**

IF EVERYTHING WORKS
THIS IS A PERFECTLY
ADEQUATE DELIVERY
SYSTEM FOR CONSUMERS.
In an ideal world, how much can we capture??

24BITS@96 kHz

The dynamic range is useful in recording studios. This is more than is required to guarantee no compromise for consumers.
Masking: when one sound prevents us from hearing other sounds.
THE ORIGINAL HEARING THRESHOLD

SOUNDS IN SHADED AREAS ARE NOT AUDIBLE
Bass signals mask a very wide frequency range
Low bass is hard to hear!

INTERIOR NOISE IN CARS AT HIGHWAY SPEEDS

POPULAR @ 85 dB
In cars, everything suffers when in motion.
In cars, everything suffers when in motion.

- Sound pressure level (dB)
  - Classical @ 85 dB
  - Popular @ 85 dB

35 dB

Dynamic range

Subtle musical, timbral and spatial effects are gone!
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 right kind of equalization based on the right kind 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 **everything** is fixed!

![Diagram showing variables and their relationships over time and frequency.](Image)
Parametric equalization fixes the frequency response

- Original Condition
- After Parametric Equalization: One Filter Only
And the transient response is also fixed!
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:

- **Wave Acoustics**
- **Modal Region**
- **Transition**
- **Geometrical Acoustics**
- **Statistical Region**

**FREQUENCY (Hz)**
- 20
- 50
- 100
- 500
- 1K
- 5K
- 10K
- 20K

**dB**
- 30
- 20
- 10
- 0
- -10
As rooms get larger:

- Geometrical Acoustics
- Statistical Region
- The loudspeaker assumes greater control
And in concert halls low-frequency room problems are minimal. Diffuse-field theory reigns!
As rooms get smaller e.g. cars:

- Wave Acoustics
- Modal Region
- Geometrical Acoustics
- Statistical Region

The enclosure assumes greater control.
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.

Soundfield management required to produce even bass, then eq to meet target.

Anechoic characterization of frequency response and directivity of the loudspeaker.

Equalisation required to correct room response.
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...