# In-Vehicle Audio System Distortion Audibility versus Level and Its Impact on Perceived Sound Quality

Patrick Dennis – Nissan

Steve Temme – Listen Inc.

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# Inspiration for Study

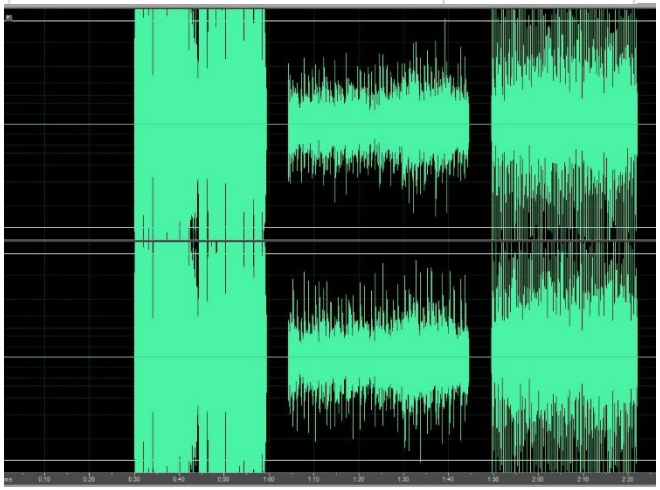
- Temme et. al. studied distortion audibility in headphones and its relation to listener preference in paper "The Correlation Between Distortion Audibility and Listener Preference in Headphones" 137th AES preprint no. 9118

- THD (Total Harmonic Distortion), IMD (Intermodulation Distortion) and NCD (Non-Coherent Distortion) metrics were compared to listener subjective preferences and found that the NCD metric had the best correlation

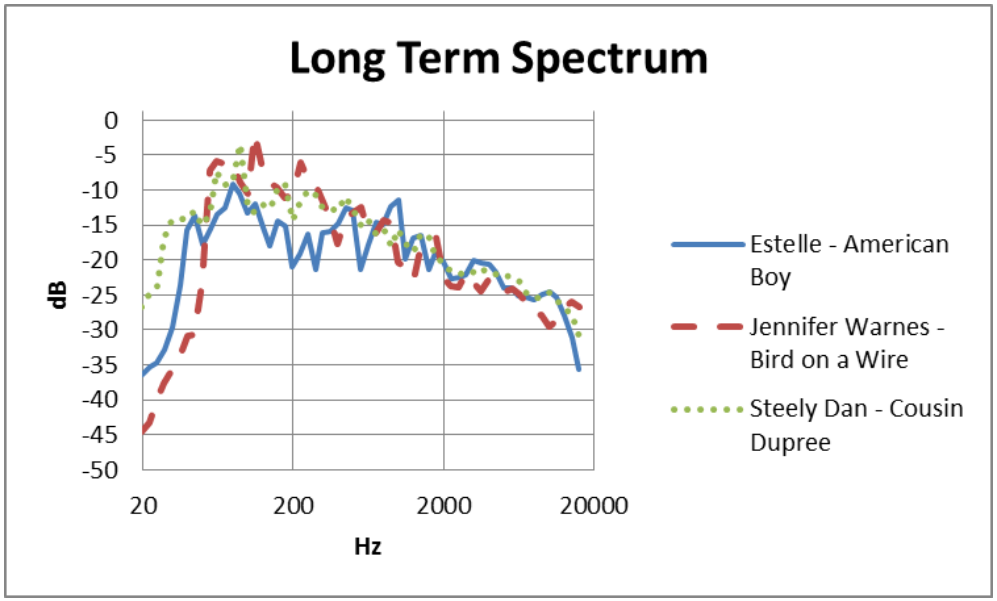
- This paper focuses on In-Vehicle audio systems because their distortion is typically higher than headphones

- The equalization and description challenges faced with headphones were eliminated by using the same audio system and recording at different volume levels to achieve different levels of distortion

| Program/Artist/Track/Album | Description |
|---|---|
| AB - Estelle w. Kanye West/ American Boy Shine/ Atlantic Records, 2008 | Male/Female Hip Hop |
| BW - Jennifer Warnes/Bird on a Wire/Famous Blue Raincoat/ Cypress Records, 1986 | Female Pop Vocal |
| CD - Steely Dan/Cousin Dupree/Two Against Nature/ Giant Records/ 2000 | Male Pop Vocal |

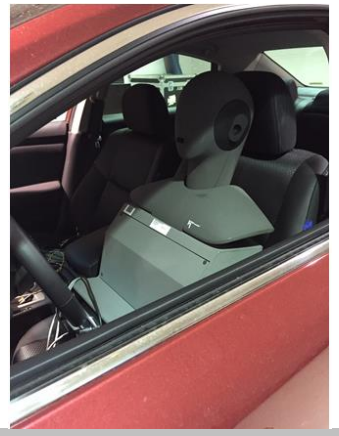


# Program Selections



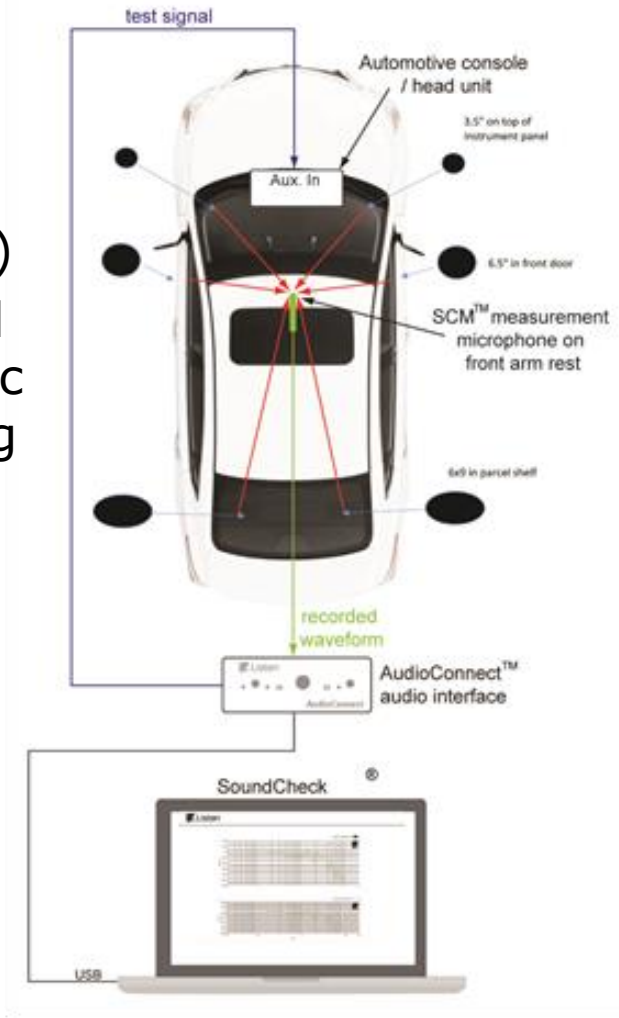
# Test Setup – Binaural Recordings

- Binaural recordings (48kHz, 24 bit) were made from volume step 20 to 40 (maximum) in 2 step increments using a Head Acoustics HMS II.6 Head and Torso simulator and BEQ II front end module
- Each recording was loaded into Head Acoustics Artemis software and exported with the HSU III ID (Independent of Direction) EQ applied
- Adobe Audition was then used to match each recording for overall loudness as well as spectrum in the bass region
  - Spectrum matching in bass region needed to offset the effect of dynamic loudness in the head unit
- The adjustments helped make the distortion artifacts the main distinguishing difference between the recordings

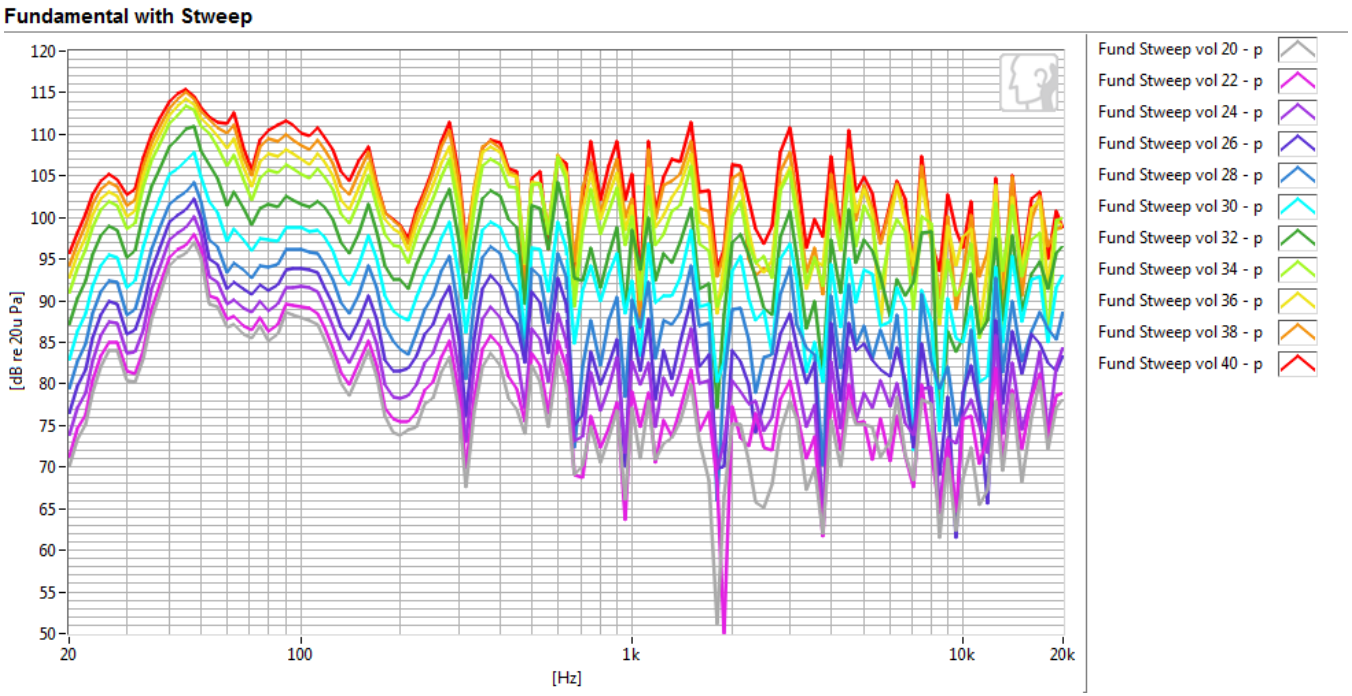


# Test Signals for Measuring Distortion

- Swept-stepped sine
  - Easy to calibrate and indicate type of non-linearity
- Two-tone intermodulation (one fixed, one moving)
  - More fully characterize a non-linear system and sum & difference components have no harmonic musical relationships and can be quite annoying
- Pink noise
  - Fast and excites all non-linearities simultaneously, more like music
- Music – same tracks used for listening tests
  - More realistic but the music needs to have a broad frequency spectrum in order to get a good signal to noise ratio



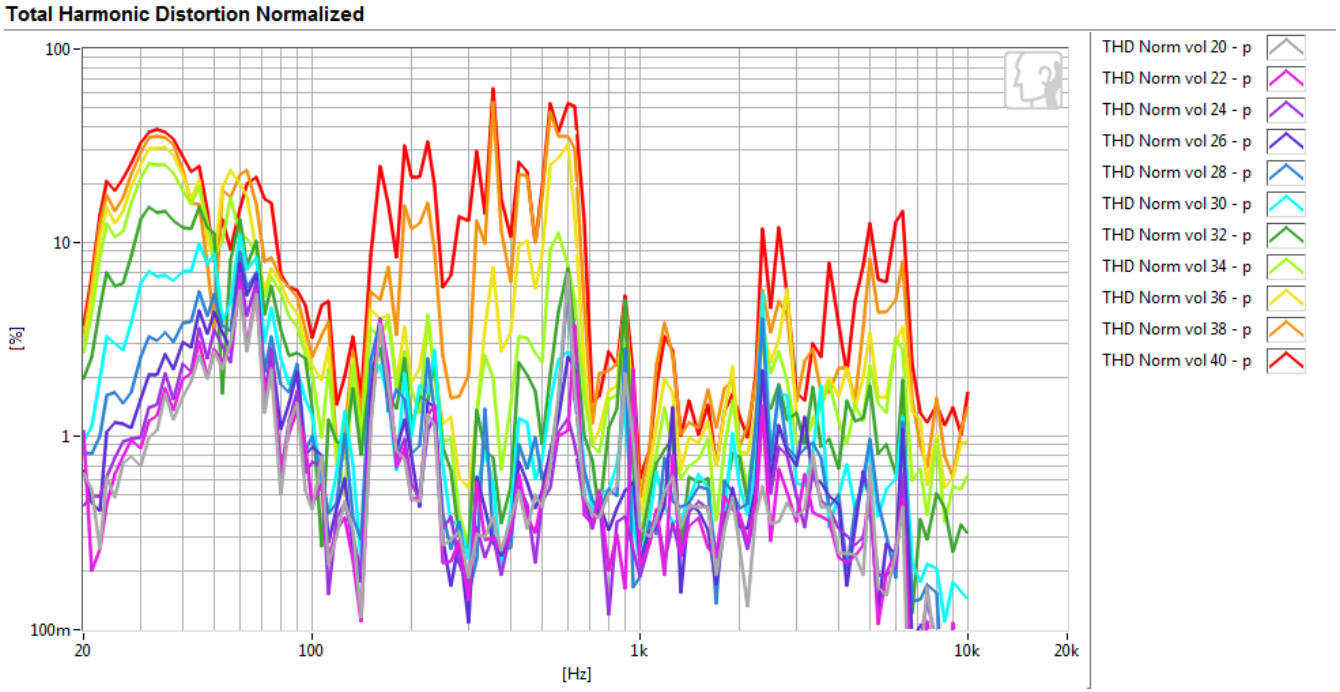
# Fundamental vs. Volume Level




1/12th Oct. Frequency response of sedan audio system measured at 11 different volume levels from average 76-102dB SPL (C-weighted)

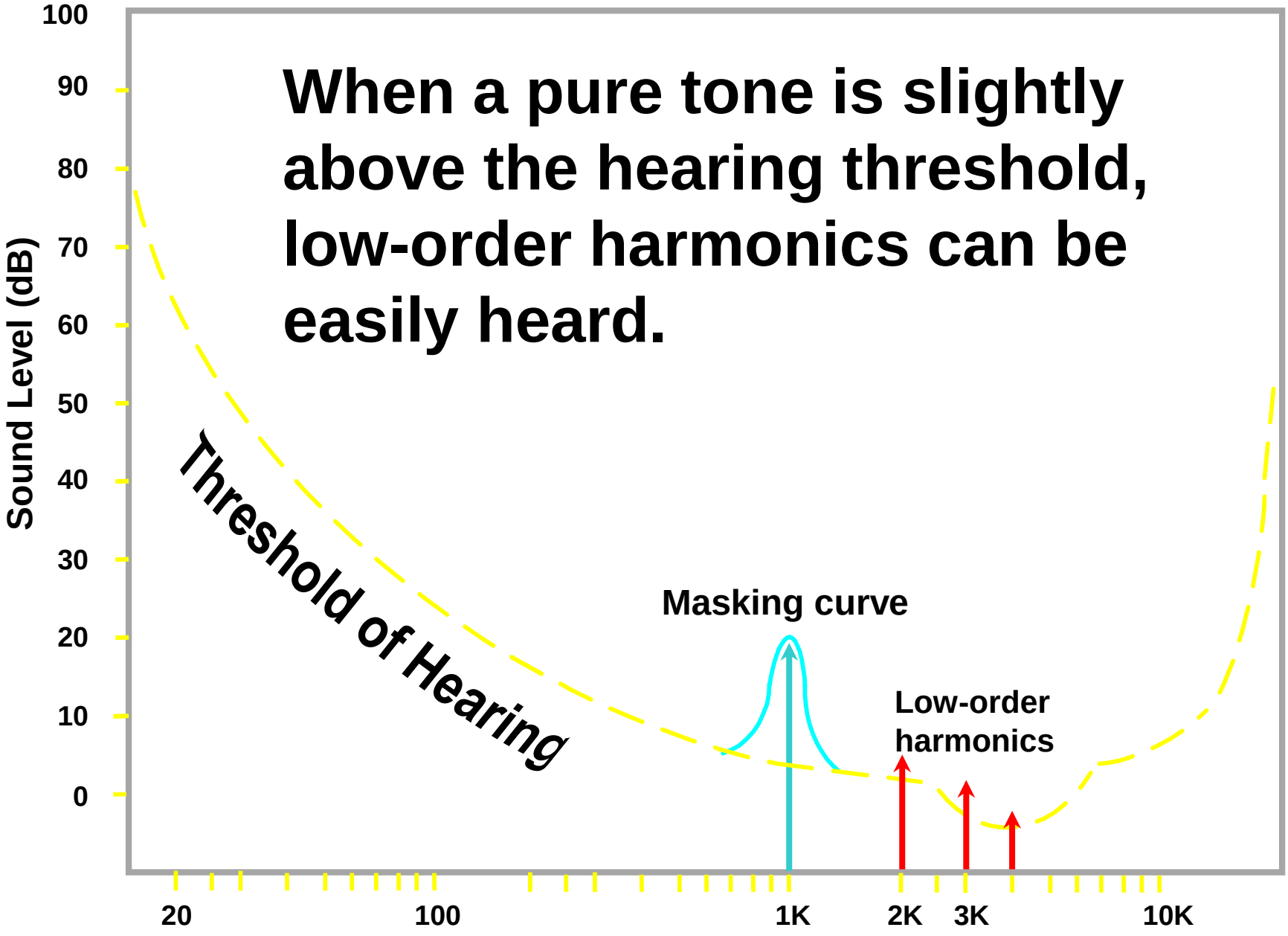
- Usual peaks and dips inside a car due to reflections and standing waves
- There starts to be some severe compression happening at high levels and low frequencies

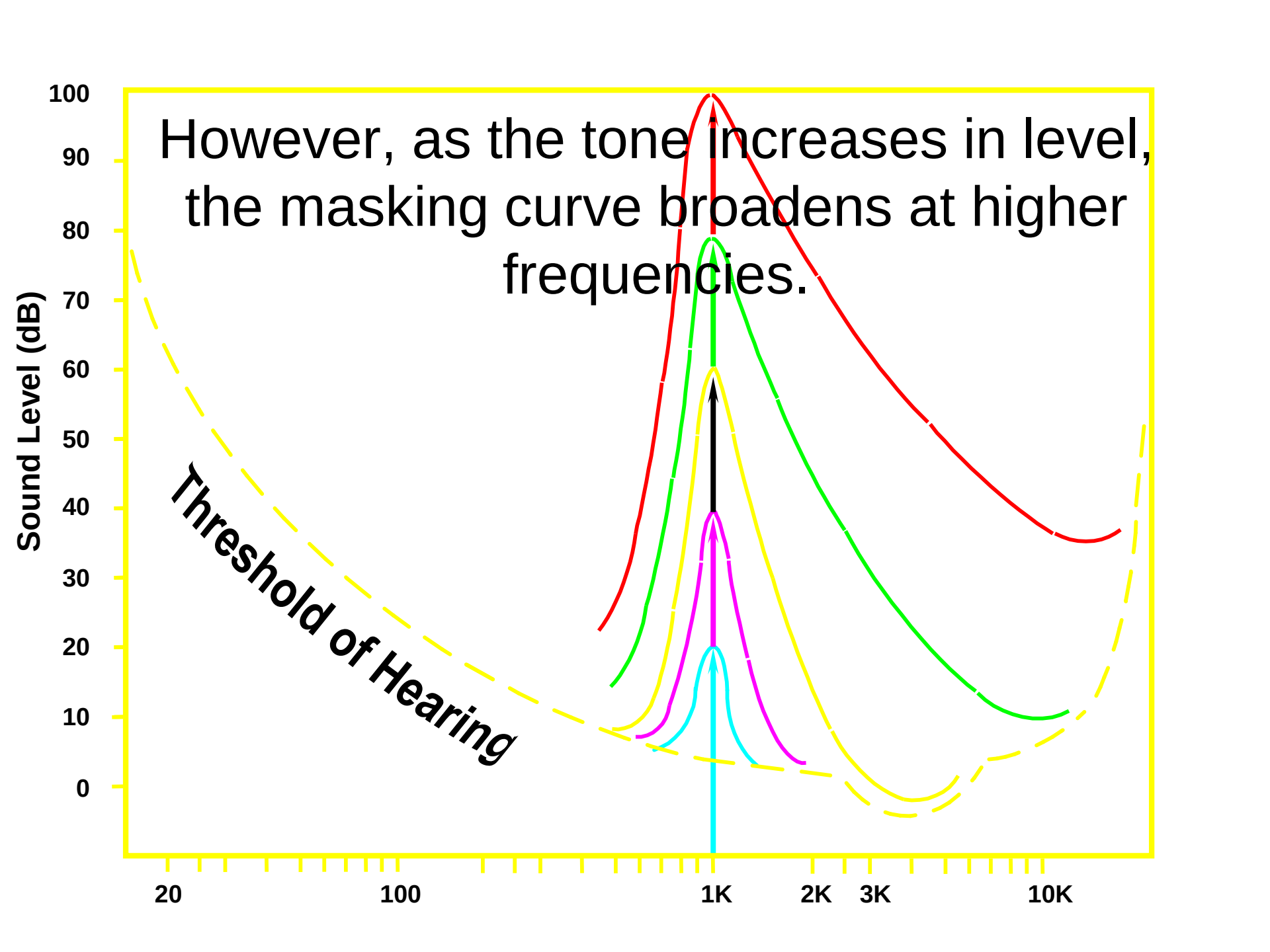
# THD Normalized vs. Volume Level

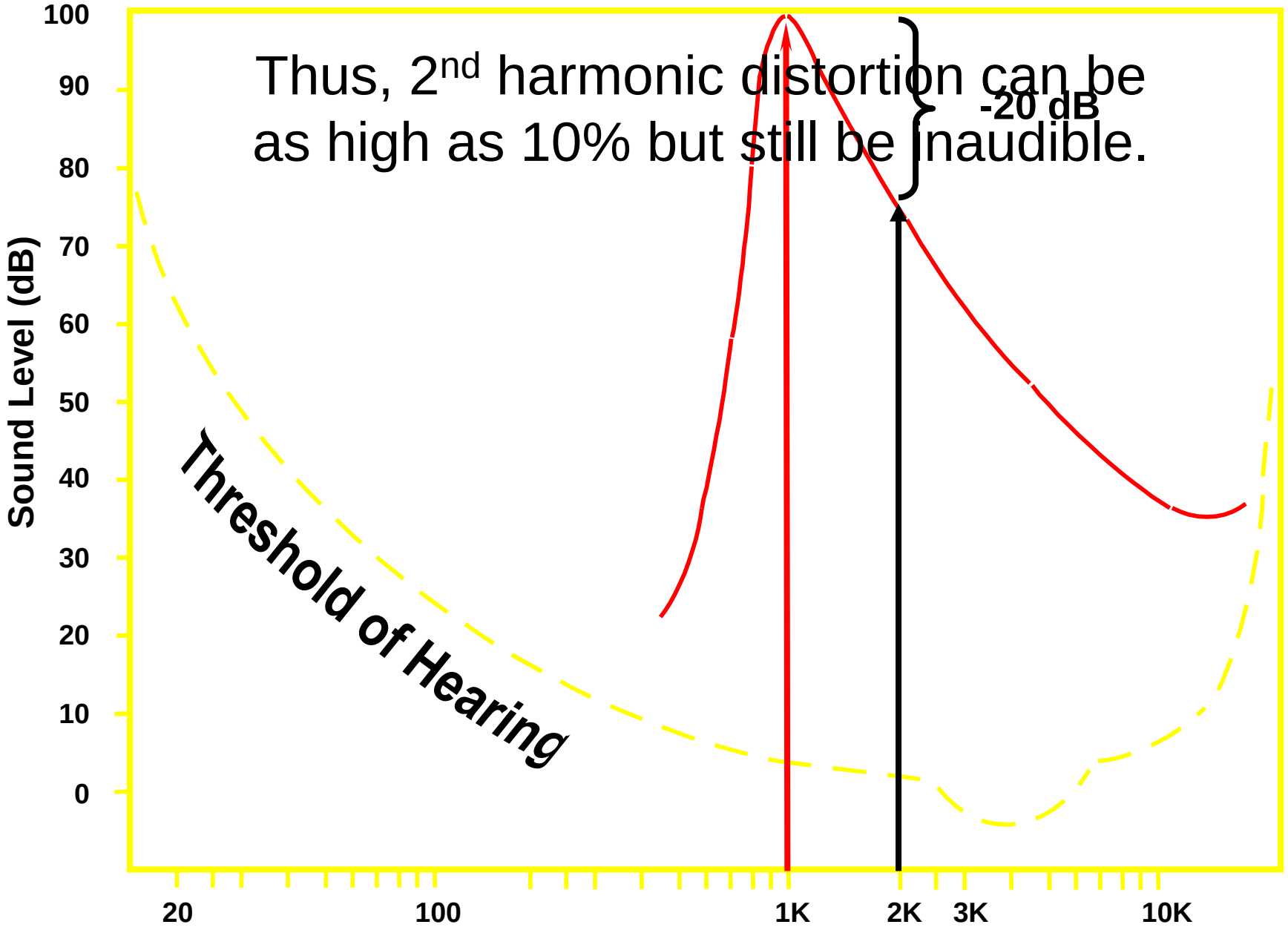


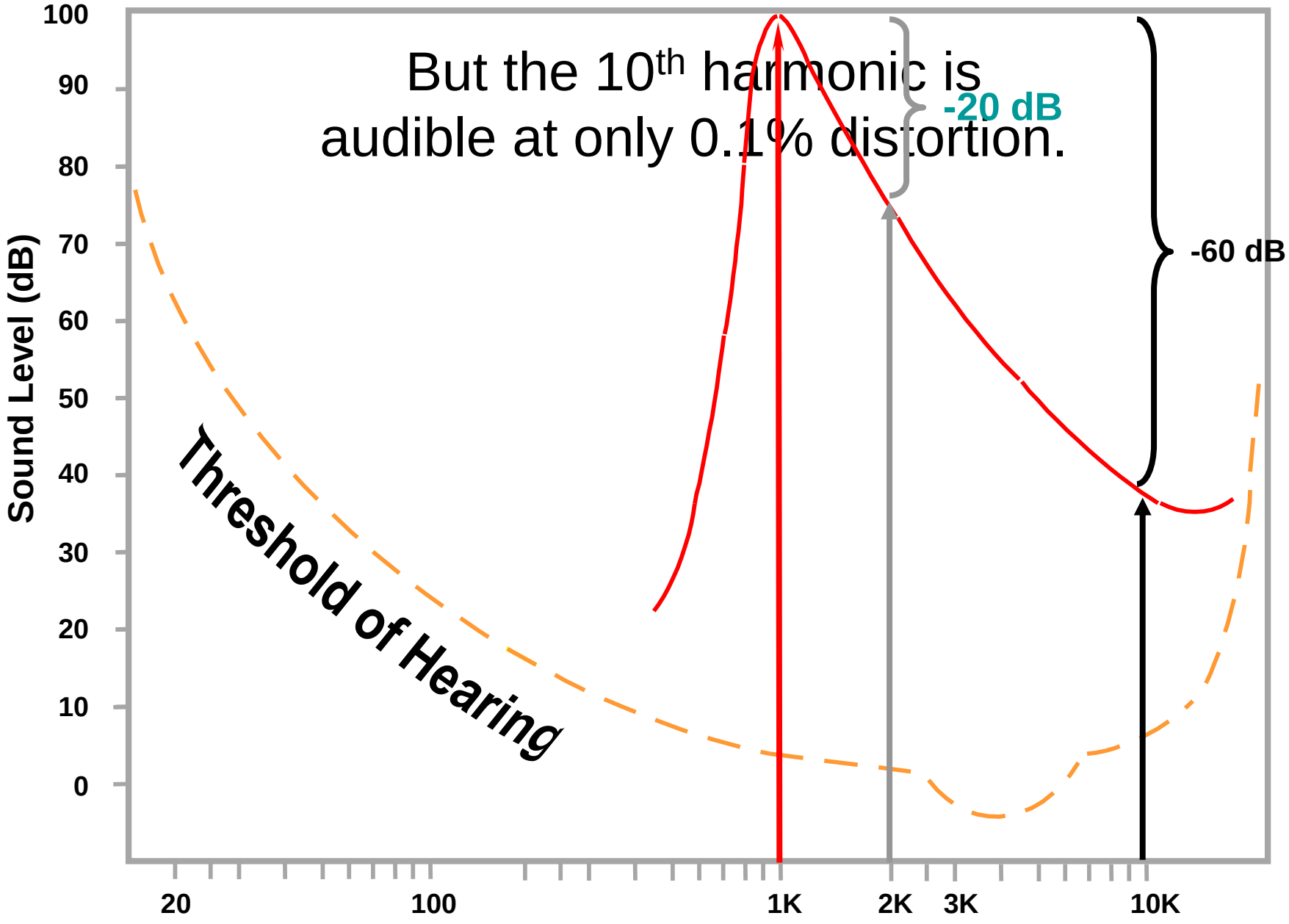

Harmonic Distortion, frequency normalized at their measured frequency, to remove the effect of reflections and standing waves before calculating THD.

- THD increases versus level but jumps significantly at volume 36 (100dBC) and above, especially from 200 – 700Hz


When a pure tone is slightly above the hearing threshold, low-order harmonics can be easily heard.
Sound Level (dB)
100
90
80
70
60
50
40
30
20
10
0
Threshold of Hearing
Masking curve
Low-order harmonics
20
100
1K
2K
3K
10K


However, as the tone increases in level, the masking curve broadens at higher frequencies.
Sound Level (dB)
100
90
80
70
60
50
40
30
20
10
0
Threshold of Hearing
20
100
1K
2K
3K
10K

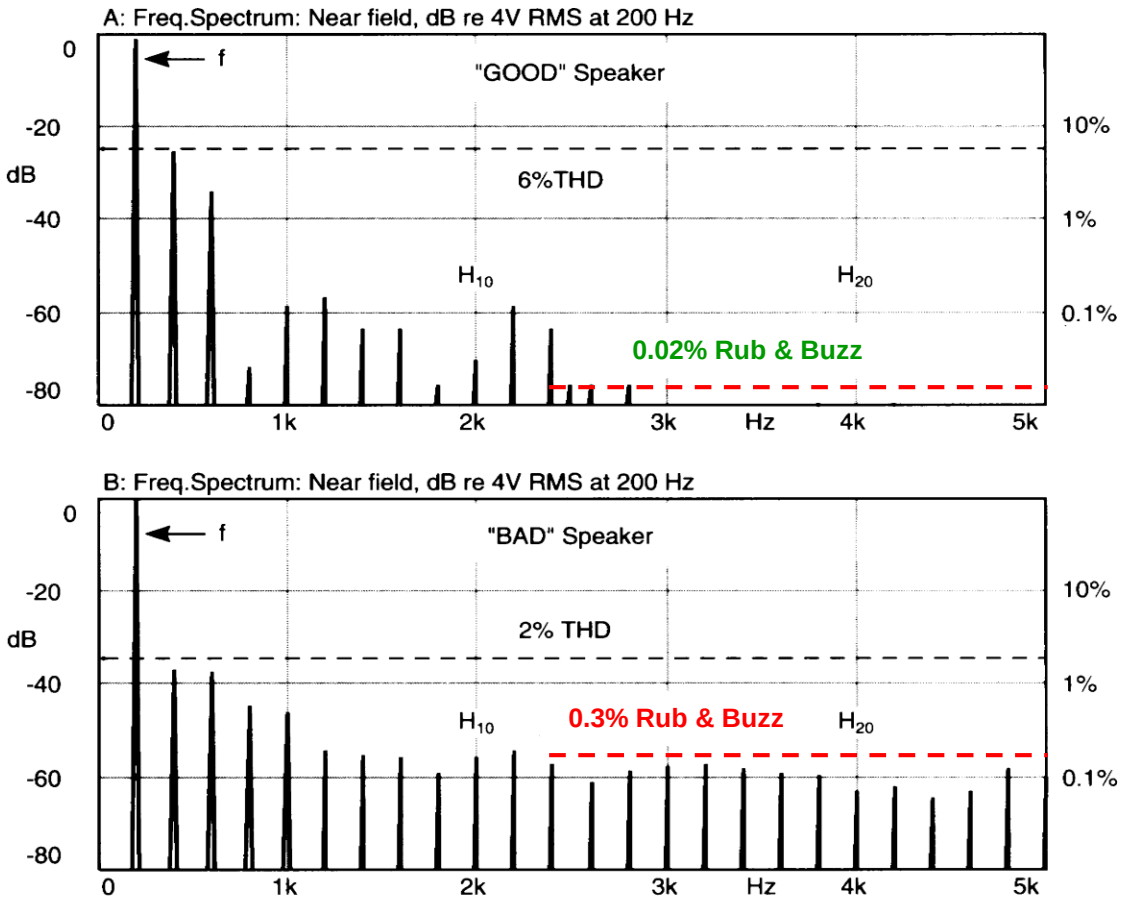

Thus, 2nd harmonic distortion can be as high as 10% but still be inaudible.
-20 dB
Sound Level (dB)
100
90
80
70
60
50
40
30
20
10
0
Threshold of Hearing
20
100
1K
2K
3K
10K


But the 10th harmonic is audible at only 0.1% distortion.
-20 dB
-60 dB
Threshold of Hearing
Sound Level (dB)
100
90
80
70
60
50
40
30
20
10
0
20
100
1K
2K
3K
10K

# Typical Rub & Buzz

**Resulting spectrum for a pure tone excitation (f) at 200 Hz**

- **Upper curve shows a distortion spectrum of a normally functioning loudspeaker. THD = 6%, Rub&Buzz = 0.02%**
- **Lower curve shows a distortion spectrum containing high order harmonics resulting from a "rubbing" voice coil caused by a bent frame. THD = 2%, Rub&Buzz = 0.3%**





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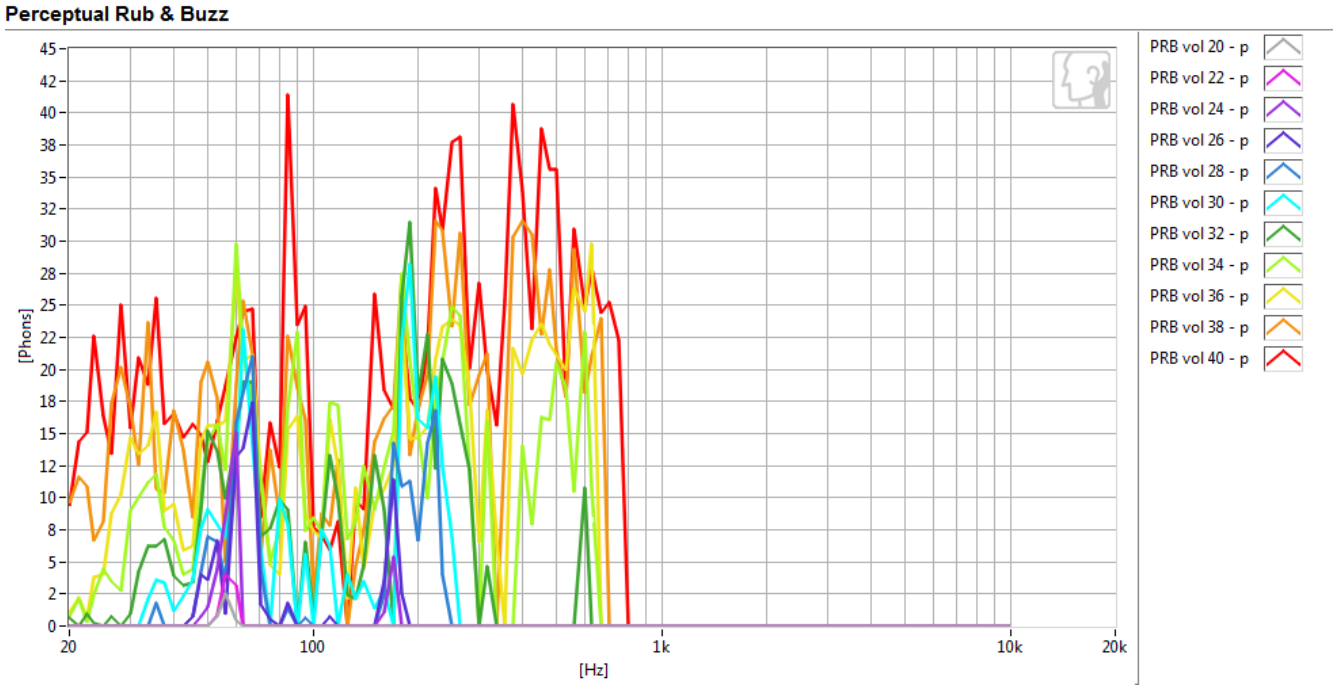
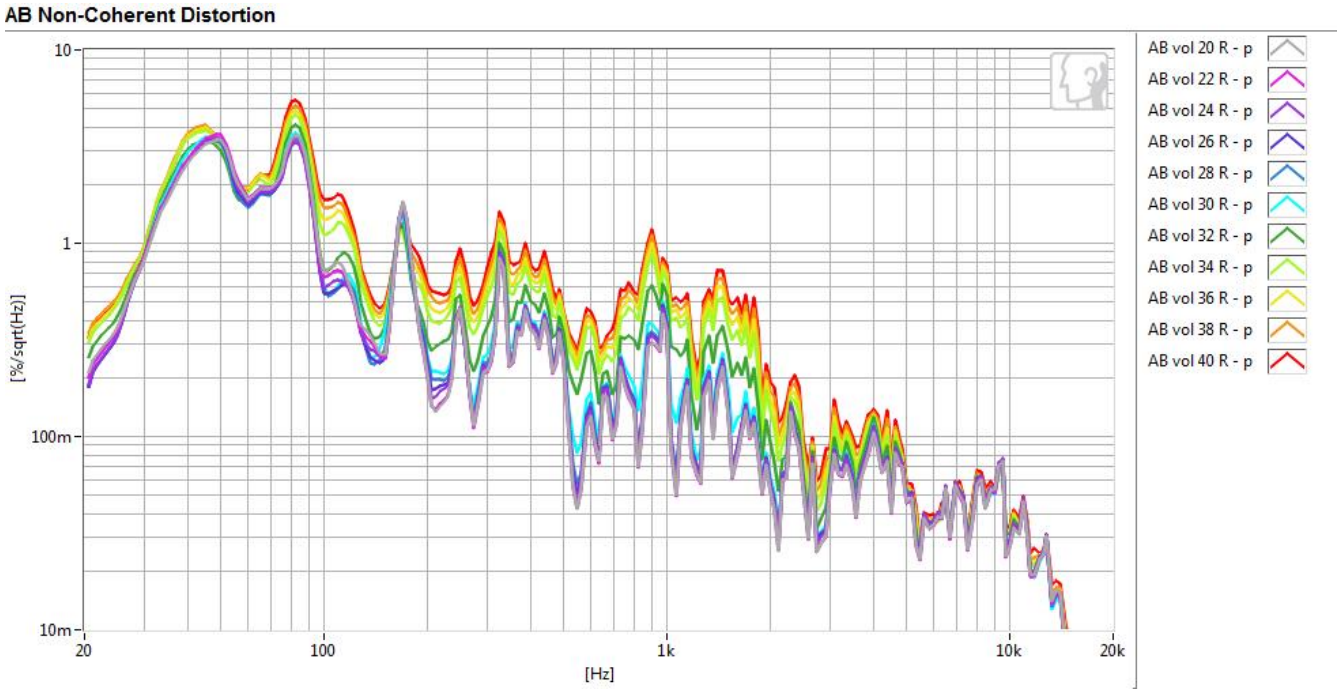
# Perceptual Rub & Buzz vs. Volume Level




Perceptual Rub & Buzz in phons for better correlation to human hearing (AES 127th Convention, preprint 7905)

- Audible distortion above volume 34 (26 phons)
- Hard to tell if buzzing is coming from the speakers, door panels, center console, rear parcel shelf or a combination there of

# NCD Distortion (American Boy) vs. Level




NCD with Estelle music as the test signal. The average SPL for volume level 30 was a loud 105dBC!

- Distortion curve shapes are similar with the previous songs but the distortion jumps at volume level 24 and above. This is probably due to the higher recording level

# Conclusions

- Music material and volume level were significant compared to listener age and experience for perceived severity
- This car audio system sounds noticeably distorted with most music above 100dBC in the frequency range of 200 – 2kHz and above 0.2% NCD
- American Boy with its highly compressed and distorted recording made it more difficult to discern distortion threshold because it sounded distorted to begin with
- Probably most of the distortion heard was high order distortion from Rub & Buzz
- Non-coherent distortion using music as a stimulus showed better correlation to human perception than traditional harmonic and intermodulation distortion measurements