Quality Assessment of Loudspeaker Drive Units

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our roadmap today

Listener

Sound Quality (Preference)

Transfer Behavior (symptoms)

Parameter (Re, fs, Q)

Geometry, Material

Loudspeaker system, Room

Parts (motor, suspension, ...)

Drivers, Enclosure, Electronics,

Product Target

specification

development

prototype

final product

manufacturing

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Summary
Describing the Target Performance

Specifications

1. Small Signal Performance
   - Flatness of amplitude response
   - Ratio of direct and diffuse sound
   - Impulse accuracy

2. Large Signal Performance
   - Maximal acoustical output (SPL, power)
   - Distortion of regular nonlinearities (THD, IMD)
   - Distortion of loudspeaker defects (rub & buzz)
   - Durability, ageing, reliability

Critical Part
- room, driver, system
- room, driver, system
- room, system, driver

- driver, room, system
- driver, system
- driver, system
- driver, system
Audibility and Impact on Sound Quality

1. Generalizations are hardly possible (dependency on stimulus, loudspeaker, listener)
2. Some distortion (e.g. Kms(x) for a subwoofer) are acceptable
3. Other nonlinearities (e.g. Bl(x), L(x)) impair quality
4. Amplitude modulation is more critical than phase modulation
5. Masking effects make some distortion inaudible
6. Time domain analysis (envelope detection) is important
7. Defects (rub + buzz + loose particles) generate impulsive distortion which are easy audible
Ultimate Criteria: Preference

How important is sound quality?

→ What’s the overall benefit for the customer?
Loudspeaker Model
using a signal flow chart

Single Input

Multiple Outputs

Mechano-acoustical Transducer (Cone)

Sound radiation

Sound propagation

Room Interaction

p(r₁)

p(r₂)

p(r₃)

Sound propagation

Sound propagation

Sound propagation

Audio signal

Amplifier Crossover EQ

Electro-mechanical Transducer

x(t)

u(t)

i(t)
A good idea: (Linear) Transfer Functions

- Voltage
  - Motor/suspension
    - X_{coil}
      - Cone diaphragm
        - ξ(ϕ,r)
          - Radiation/propagation
            - p(r_1)
              - sound pressure
        - H(p_1)
          - Radiation/propagation
            - p(r_2)
              - sound pressure
          - Radiation/propagation
            - p(r_3)
              - sound pressure
      - Enclosure
        - Port
          - Horn
            - Panel
  - Z_{mech}
    - mechanical impedance
      - current
Interaction with the room

Which loudspeaker properties are important for this?
Influence of distance between Loudspeaker and listening position on SPL response in room
Directivity of the Loudspeaker
for example 16" Subwoofer

Total Sound Pressure Level

On-axis response

- 500 Hz
- 1 kHz
- 3 kHz
- 6 kHz

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Prediction of sound at listening position

Input Signal → Measured Signal

Input Signal → $H_{\text{direct}}$ → Direct sound

$H_{\text{power}}$ → Room reflections

Room modes

$H_{\text{FIR}}$ → Room reflections

$H_{\text{IIR}}$ → Room modes

Directivity index

$H_{\text{delay}}$ → Output Signal
Loudspeaker - a nonlinear system

Working range

Amplitude

X [mm]

0.3

1

3

10

30

Destruction

Large signal domain

Small signal domain

voice-coil displacement

MODELING

Nonlinear Model

Linear Model

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Assessing Loudspeakers in the Large Signal Domain

Stimulus → Output signal

nonlinear transfer function?

→ Volterra/Wiener Series are not practical!

Measurement of Symptoms
(distortion, compression, stability ...)

„SYMPTOMS“ are not parameters of a nonlinear system because they highly depend on the stimulus!
Nonlinear Distortion Measurements

**Stimuli**
- Single-Tone
- Two-Tone
- Multi-Tone
- Noise
- Audio Signal

**Spectral Analysis**
(Fourier Transform, High-pass and bandpass filter, ...)

**Incoherence**

**System Identification**

**Distortion metrics**
(depend highly on stimulus)
Relative Harmonic Distortion in percent

nth-order harmonic distortion

\[ d_n^{(p)} = \left( \frac{|P_n|}{P_t} \right) \times 100\% \]

Total output displayed versus excitation frequency
Optimal Two-tone Stimulus
Loudspeaker Systems and Drive Units

- bass tone
- voice tone

- harmonics
- difference tones
- summed tones

bass sweep: $0.5f_s \quad f_1 \quad 2f_s$
voice sweep: $f_1 = 0.5f_s \quad 5f_s \quad f_2 \quad 20f_s$
Dependence on Amplitude

Two-tone Signal
70 Hz+800Hz

-12 dB

\[ x_{\text{peak}} \approx \frac{x_{\text{max}}}{4} \]

-6 dB

\[ x_{\text{peak}} \approx \frac{x_{\text{max}}}{2} \]

0 dB

\[ x_{\text{peak}} \approx x_{\text{max}} \]
Loudspeaker in a High-Quality Product

![Graph showing SPL vs Frequency with annotations for fundamental, masking threshold, distortion, and high safety headroom.]
Loudspeaker in a Convenience Product

- **fundamental**
- **masking threshold**
- **Small safety headroom**
- **distortion**
Generation of Impulsive Harmonic Distortion

Example: voice coil rubbing

Crest factor is larger than 10 dB
→ reliable indicator for loudspeaker defect
Voice Coil Rubbing
Stimulus: sinusoidal sweep

- THD measures the rms value of all harmonics
- Regular distortion are dominant
- Distortion of defects have not much energy

→ THD is not sensitive for coil rubbing and other defects!!

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Voice Coil Rubbing
Stimulus: sinusoidal sweep

Peak value of higher order harmonics exceeds limit by 40 dB!!
Specification: Small Signal Performance

→ more interesting in final system

- Transfer function
- Efficiency
- Flatness of on-axis response
- Maximal decay time in cumulative decay spectrum
Specification: Large Signal Performance

Active and passive Loudspeaker System

- Maximal sound pressure level at 1 m on axis
- Harmonic distortion (total, 2nd, 3rd)
- Intermodulation distortion (total, 2nd, 3rd)
- Impulsive distortion generated by loudspeaker defects (PHD, CHD)
- Verification of durability in accelerated life test
Specification: Production Test

- SPL fundamental
- THD (2\textsuperscript{nd} and 3\textsuperscript{rd} order harmonics)
- Rub and Buzz (peak value of higher order harmonics)
- Polarity
- Impedance curve (T/S parameters)
- Voice coil offset (in mm)
- Asymmetry of the suspension (in percent)