Acoustical Measurement of Sound System Equipment according IEC 60268-21

KLIPPEL LIVE

a series of webinars presented by

Wolfgang Klippel

Previous Sessions

1. Modern audio equipment needs output based testing
2. Standard acoustical tests performed in normal rooms
3. Drawing meaningful conclusions from 3D output measurement
4. Simulated standard condition at an evaluation point
5. Maximum SPL – giving this value meaning
6. Selecting measurements with high diagnostic value
7. Amplitude Compression – less output at higher amplitudes
8. Harmonic Distortion Measurements – best practice
9. Intermodulation Distortion – music is more than a single tone
10. Impulsive distortion - rub&buzz, abnormal behavior, defects
11. Benchmarking of audio products under standard conditions
12. Auralization of signal distortion – perceptual evaluation
13. Setting meaningful tolerances for signal distortion
14. Rating the maximum SPL value for a product
15. Smart speaker testing with wireless audio input

4th KLIPPEL LIVE:
Simulated standard condition at a single evaluation point

Topics today:

1. Simplifying standard measurements
2. Simulation of free-field and far-field condition according IEC 60268-21
3. Compensation for room influence, different positioning and distance
4. Creating a room compensation function for different types of speakers

Poll:

Most audio engineers share an anechoic room with others. Does this hinder your work ?

- not really 32%
- sometimes 42%
- frequently 17%
- always 9%

Searching for an Alternative

Targets:

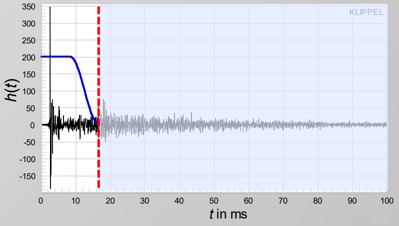
- Generating simulated far-field and free-field condition for one evaluation point in almost any acoustical environment.
- Allowing fast measurements (without scanning)
- Minimum equipment (mic only)
- Applicable to other measurements (nonlinear distortion, compression) and tuning work (DSP)
- Combination with perceptual evaluation (listening)

Simulated free field conditions

according IEC 60268-21

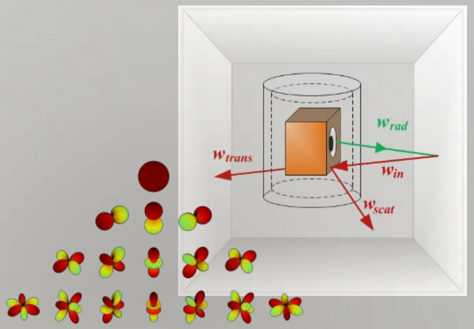
Time Windowing:

- cutting out reflections in impulse response
- fails at low frequencies



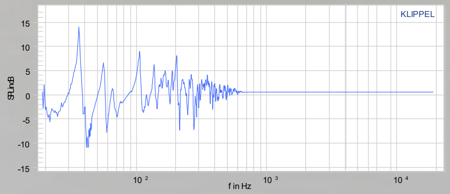
Holographic measurement technique:

- Direct sound separation (spherical wave expansion)
- Scanning requires robotics
- Longer measurement time



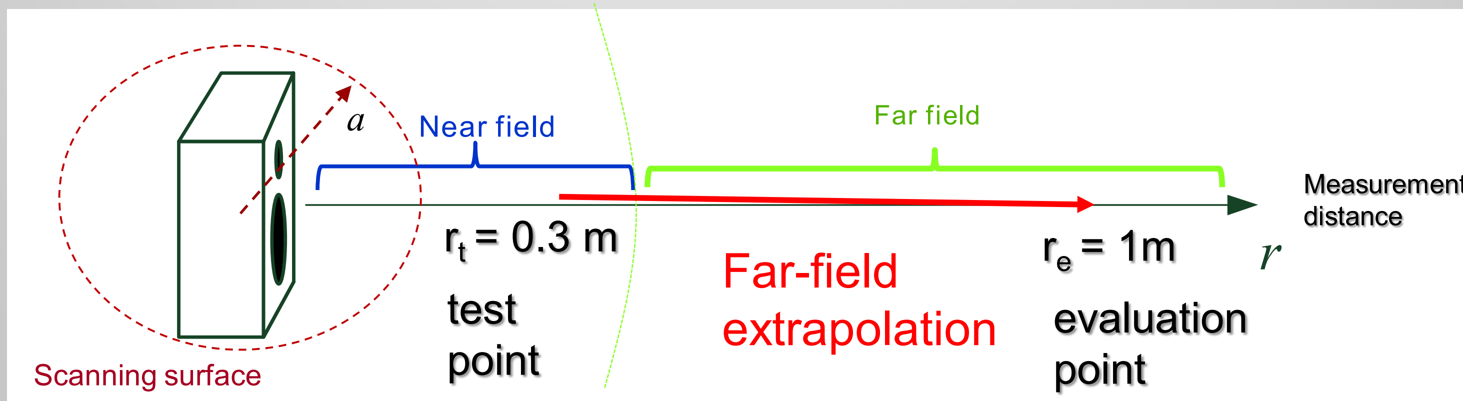
Compensation Function

- Fast measurement (only 1 point)
- Complex filtering the microphone signal
- requires accurate reference information



Simulated Far-Field Condition

according IEC 60268-21

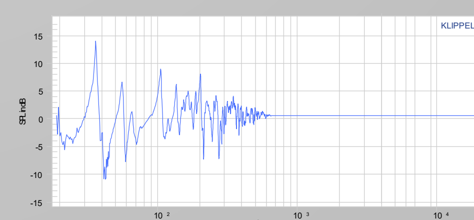


Holographic measurement technique:

- Extrapolation based on spherical wave expansion
- Scanning process requires robotics

Compensation Function

- Fast measurement (only 1 point)
- Complex filtering of the microphone signal
- requires accurate reference information



Standard Testing in My Office ?

I have to cope with the following problems:

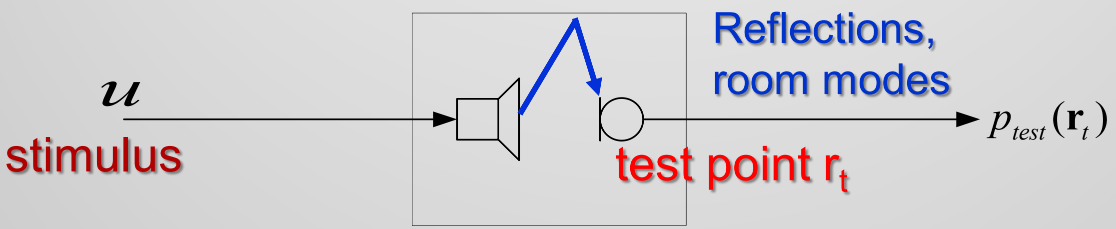
- Small room size (distance to the boundaries < 1.5 m)
- Typical reverberation time ≈ 0.5 s (books, carpet, chairs)
- Large table (3 m^2 in the middle of the room)
- Ambient noise (coworker, music school, traffic)

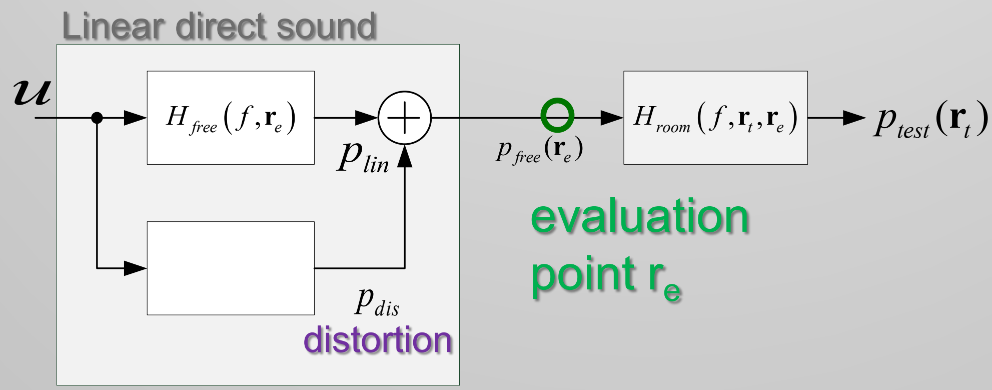
Making the best out of this

Consequences

- Small room size (distance to the boundaries < 1.5 m)
  → short window length (limits resolution at f < 500 Hz
  → microphone position close to the speaker (r_t=30 cm)
  → near-field condition for f < 200 Hz (far-field extrapolation required)
- Typical reverberation time ≈ 0.5 s (books, carpet, chairs)
  → room modes will affect the low frequency response
  → complex filtering of the mic signal required
- Large table (3 m^2 in the middle of the room)
  → ground floor measurement (half space)
  → reflections at the table edges (short window length)
- Ambient noise (coworker, music school, traffic)
  → short distance, near-field measurement

Modelling Speaker, Room, Position



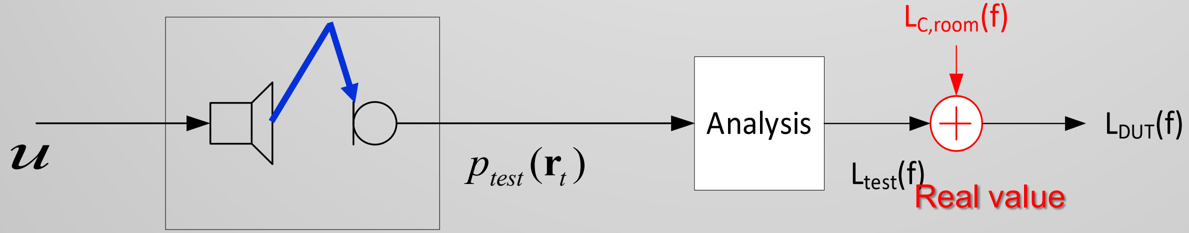


- Microphone at a <u>fixed test position</u> $\mathbf{r}_t$ (usually in the near field)
- Speaker generates <u>nonlinear</u> distortion (THD, IMD, rub & buzz)
- Generating accurate results at an <u>evaluation point</u> $\mathbf{r}_e$ under simulated free-field and far-field conditions
- Test point $\mathbf{r}_t$ and evaluation point $\mathbf{r}_e$ can be different

Simulated Standard Conditions

Correction Techniques defined in IEC 60268-21

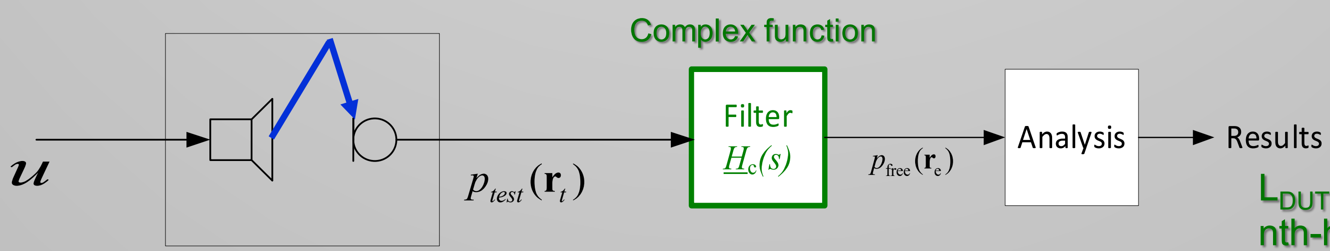
Method 1: Correction of the amplitude response (clause 19.5.2)



Frequency response of the fundamental component

- Used for generating a „room correction function“
- Not useful for distortion measurements (e.g. Farina) !

Method 2: Correction of the measured sound pressure signal (clause 19.5.1)



$L_{DUT}(f)$, THD, nth-harmonics, IMD

- Can be used to generate simulated free-field and far field condition
- Can be applied to any analysis (e.g. Farina)

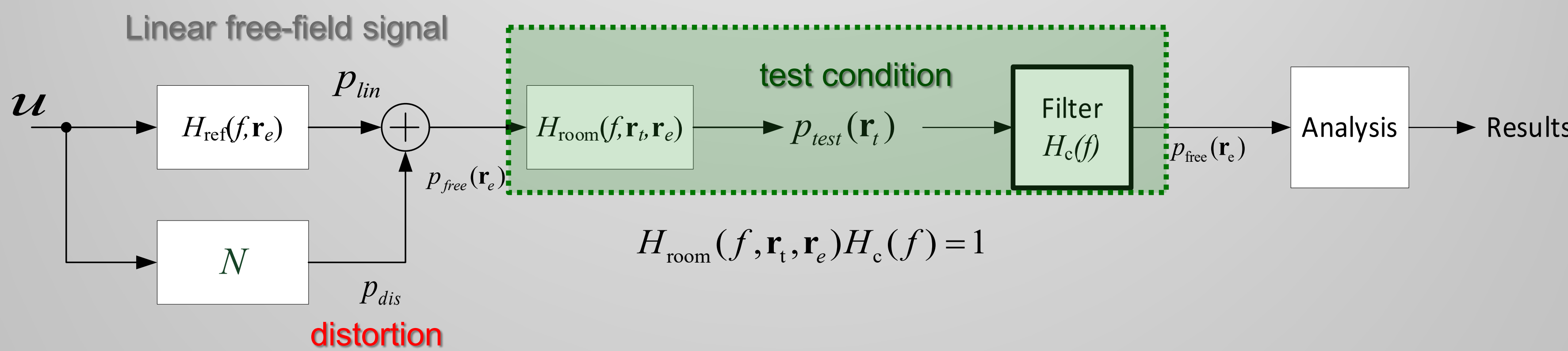
Poll:

Do you apply a correction function to the amplitude response to compensate insufficiencies of your anechoic room (method 1) ?

- Yes 59%
- No 41%

Correction of the measured sound pressure

method according clause 19.5.2 in IEC 60268-21



$$H_{\text{room}}(f,\mathbf{r}_{\text{t}},\mathbf{r}_{e})H_{\text{c}}(f)=1$$

$$H_{\text{c}}(f)=\frac{1}{\underline{H}_{\text{room}}(f,\mathbf{r}_{t})}\frac{\underline{H}_{\text{free}}(f,\mathbf{r}_{\text{e}})}{\underline{H}_{\text{free}}(f,\mathbf{r}_{\text{t}})}$$

Standard evaluation point

test point

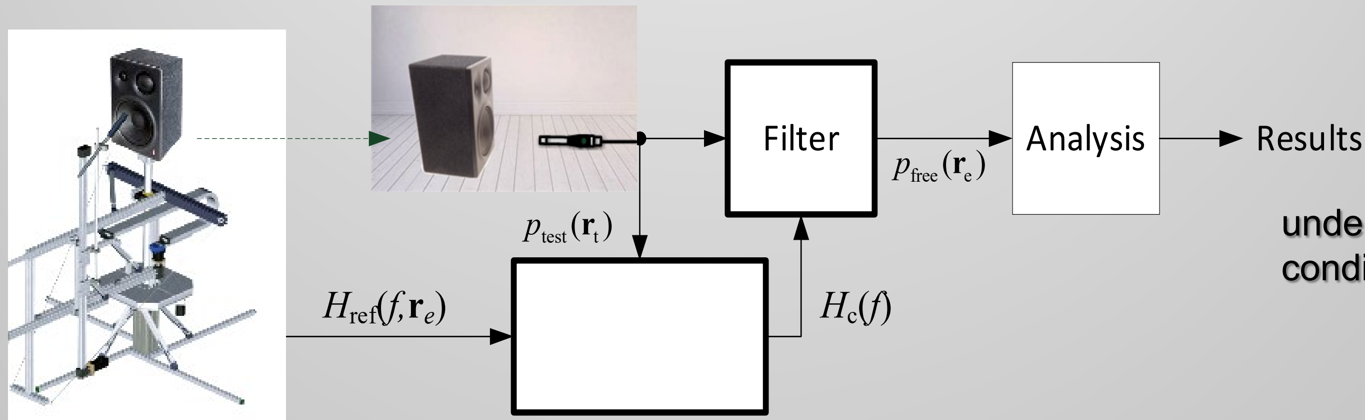
room influence

Solution: Filtering the microphone signal $p_{test}(\mathbf{r}_t)$ to compensate for

- room influence
- position of the measurement point (distance, angle)
- Complex compensation function $H_c(f)$ (phase and amplitude information)

Work Flow

with a compensation filter



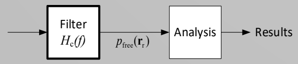
under standard condition

1. Provide an accurate **reference** response $H_{ref}(f,\mathbf{r}_e)$ at the desired **evaluation point r**$_e$ (e.g. in the far field)

2. Measure the sound pressure $p_{test}(\mathbf{r}_t)$ at the **test point** (e.g. in the near field) and calculate transfer function $H_{test}(f,\mathbf{r}_t)$ under test conditions without compensation filter

$$H_c = \frac{H_{\text{ref}}}{H_{\text{test}}}$$

3. Calculate the **compensation** function $H_c(f)$ based on the transfer functions $H_{test}(f,\mathbf{r}_t)$ and $H_{ref}(f,\mathbf{r}_e)$



4. Filter the measured sound pressure $p_{test}(\mathbf{r}_t)$ with the compensation function $H_c(f)$ to generated the **direct sound** $p_{free}(\mathbf{r}_e)$ at the evaluation point according standard condition

How to provide accurate reference response $H_{ref}(f,\mathbf{r}_e)$?

- Anechoic room (error caused at low frequencies)
- Outside free-field measurement (error caused by climate, wind, ambient noise)
- Holographic near field scanning (provides accurate data for any test point and evaluation point in 3D space)

recommended !

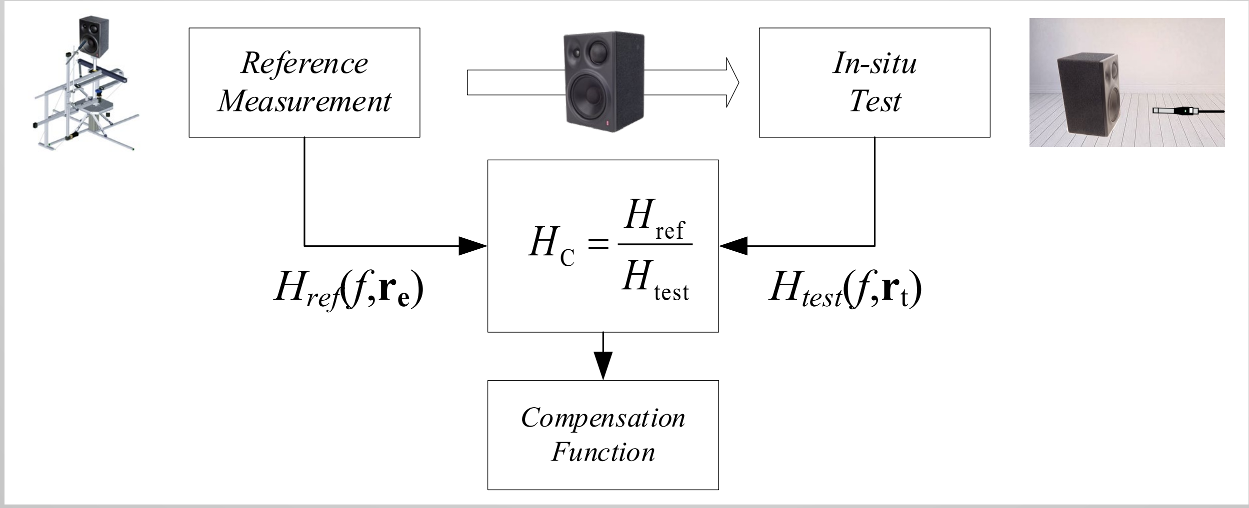
Overview

of the In-situ Compensation Schemes

Method	FC-FR Full compensation with full-band reference	FC-LR Full compensation with low frequency reference	LC-LR Low frequency compensation with low-frequency reference
Simulated free-field condition	in any environment (room, test box, stand)	Workshops, Offices sufficient distance to the Boundary (walls)	Small room with anechoic condition at higher frequencies
Simulated far-field condition provided	For all frequencies	For lower frequencies	For lower frequencies
Effort for providing accurate reference data	Normal Scan (20 min*)	Short Scan (7 min*)	Short Scan (7 min*)

*** Small Bluetooth speaker used in webinar KLIPPEL live**

Complete Compensation
based on a full-band reference measurement (FBR)



Features:

PROs
- compensates for room influence (reflections, half/full space, clamping)
- compensates for difference in test point $\mathbf{r}_t$ and evaluation point $\mathbf{r}_e$

CONs
- requires accurate reference response $H_{ref}(f,\mathbf{r}_e)$ with sufficient resolution at all frequencies
- Any shift of DUT and microphone position affects the compensation function $H_c(f)$

Overview
of the In-situ Compensation Schemes

Method	FC-FR Full compensation with full-band reference	FC-LR Full compensation with low frequency reference	LC-LR Low frequency compensation with low-frequency reference
Simulated free-field condition	Yes, in any environment (room, test box, stand)	Workshops, Offices sufficient distance to the Boundary (walls)	Small room with anechoic condition at higher frequencies
Simulated far-field condition provided	For all frequencies	For lower frequencies	For lower frequencies
Effort for providing accurate reference data	Normal Scan (20 min*)	Short Scan (7 min*)	Short Scan (7 min*)

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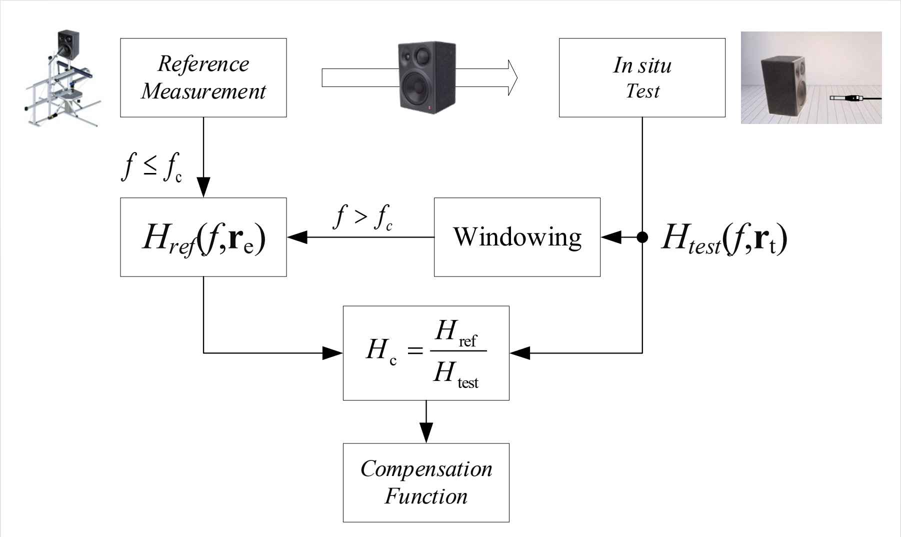
Full Compensation
based on a low-frequency reference measurement (FC-LR)



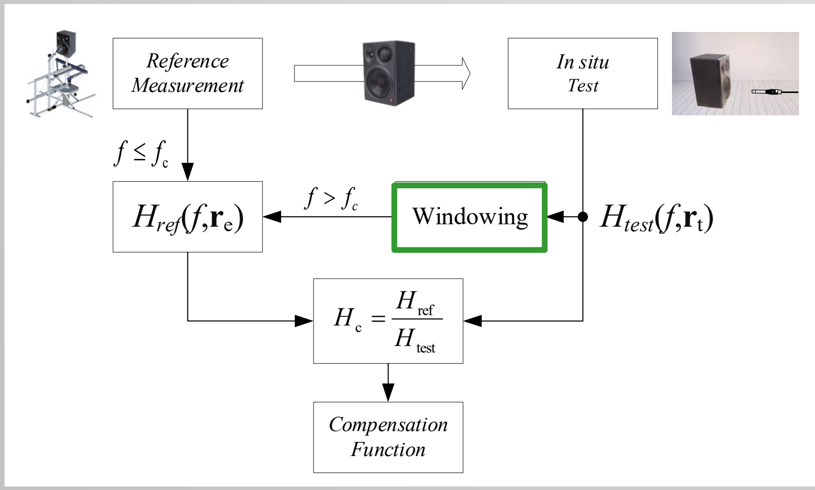
Features:

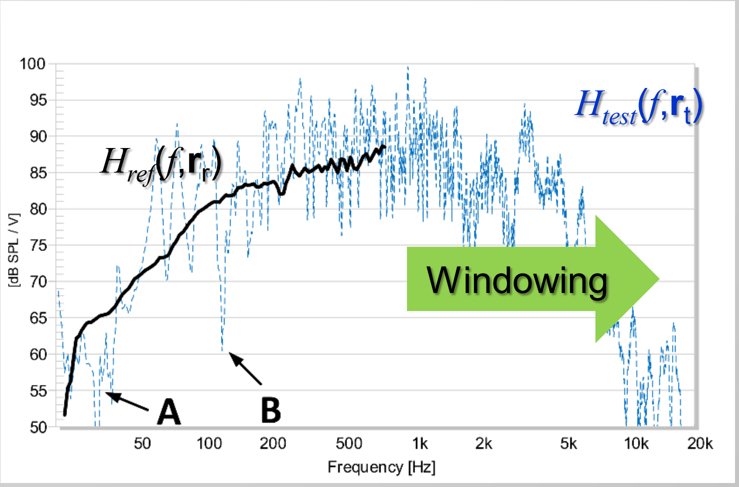
PROs
- requires accurate reference response $H_{ref}(f,\mathbf{r}_r)$ at low frequencies
- uses windowing at higher frequencies
- small positioning error is not critical

CONs
- windowing requires sufficient distance from boundaries at higher frequencies

Example of FC-LR Method

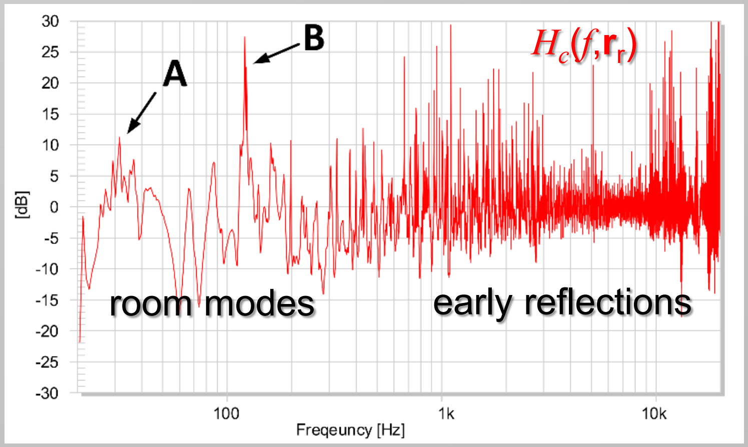
Low frequency reference (LR)





Compensation function $H_c(f)$

- changes amplitude and phase of the measured sound pressure signal (> 20 dB)
- only valid for a fixed test point



Overview

of the In-situ Compensation Schemes

Method	FC-FR Full compensation with full-band reference	FC-LR Full compensation with low frequency reference	LC-LR Low frequency compensation with low-frequency reference
Providing **simulated free-field** condition	In any environment (room, test box, stand)	In workshops, Offices, with sufficient distance to the boundaries (walls)	In small rooms with anechoic properties at higher frequencies
Providing **simulated far-field** condition	For all frequencies	For lower frequencies	For lower frequencies
Effort for providing accurate reference data	Normal Scan (20 min*)	Short Scan (7 min*)	Short Scan (7 min*)

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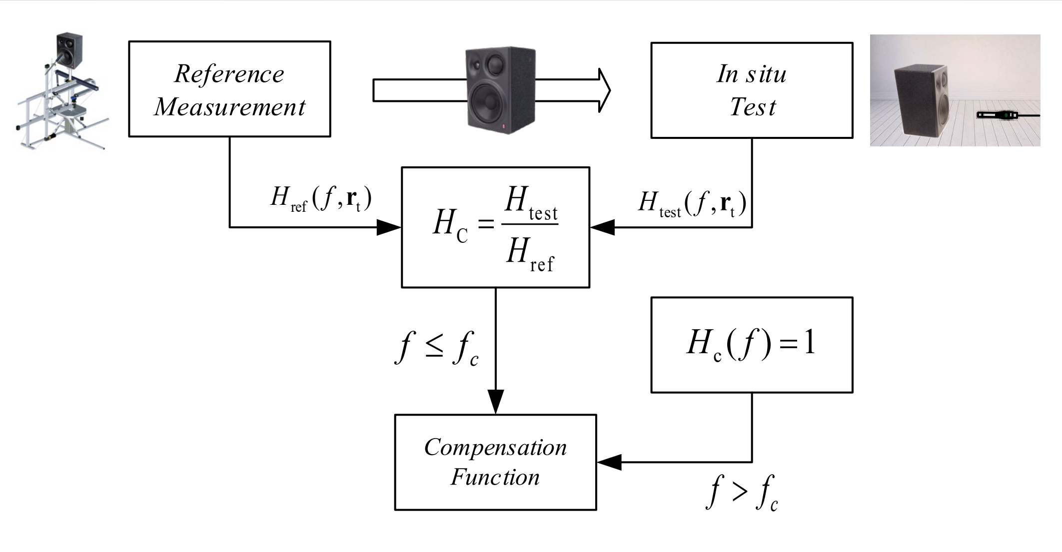
Low Frequency Compensation
based on a low-frequency reference measurement (LC-LR)



Features:

PROs

- requires accurate reference response $H_{ref}(f,\mathbf{r}_r)$ with sufficient resolution <u>at low frequencies only</u> (below 1 kHz)
- compensation function $H_c(f)$ is valid for a wide range of speakers
- microphone positioning error has small influence on compensation function $H_c(f)$

CONs

- Evaluation point $\mathbf{r}_e$ and test point $\mathbf{r}_t$ shall be identical
- room must be sufficiently damped to suppress reflections for high frequencies

Fixed Room Compensation Function (1)

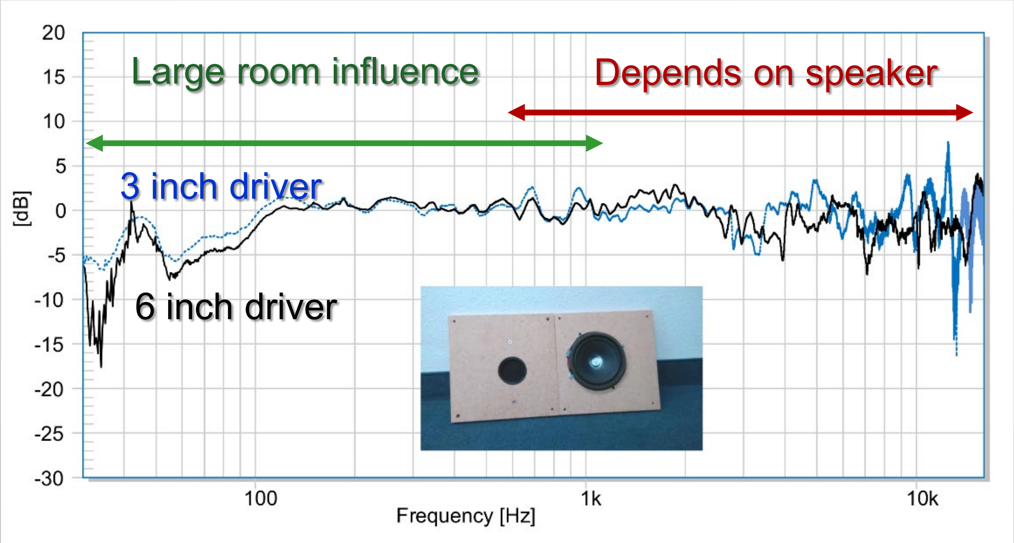
Targets:

- Generating a fixed room compensation function valid for multiple speakers
- Avoiding a reference measurement for each DUT (scanning)

Requirements:

- Properties of the hardware setup are constant (fixed microphone position)
- DUTs generate similar interactions with the room
- DUTs have similar near field properties or test point r_t is in the far field

Variance of the Compensation Function

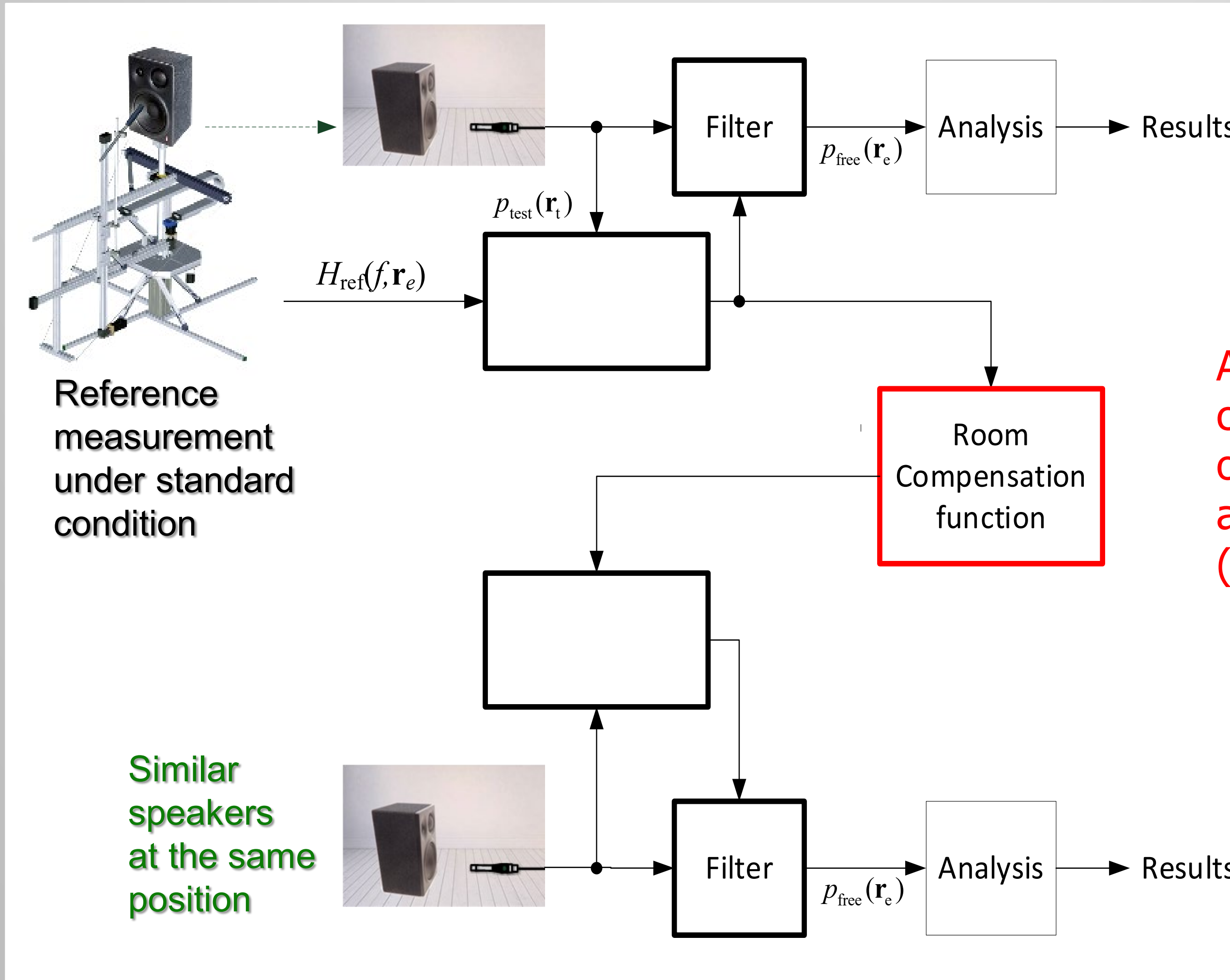


→ The same (room) compensation function $H_{c,r}(f)$ can be applied to similar loudspeakers at low frequencies (below 1 kHz)

→ Windowing can generate the optimum compensation function at high frequencies

→ Reference measurements on a few selected speakers are required for determining a room compensation function $H_{c,r}(f)$

Fixed Room Compensation Function (2)



Averaging the compensation function over similar speakers at low frequencies (below 1 kHz)

Overview
of the In-situ Compensation Schemes

Method	FC-FR Full compensation with full-band reference	FC-LR Full compensation with low frequency reference	LC-LR Low frequency compensation with low-frequency reference
Providing **simulated free-field** condition	In any environment (room, test box, stand)	In workshops, Offices, with sufficient distance to the boundaries (walls)	In small rooms with anechoic properties at higher frequencies
Providing **simulated far-field** condition	For all frequencies	For lower frequencies	For lower frequencies
Effort for providing accurate reference data	Normal Scan (20 min*)	Short Scan (7 min*)	Short Scan (7 min*)
Generating a **fixed room compensation** (applied to other DuTs)	~~not recommended~~	for lower frequencies	for lower frequencies

No scanning of similar devices required !

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Practical Tips

Other interesting applications of a fixed room compensation function:

- Semi-anechoic (small, cheap, good > 400 Hz) with microphone array at fixed positions (distance r > 1m)
- Ground floor measurement of speakers in large rooms (workshop, distance to the walls > 3 m) at fixed positions (distance r > 1m)
- Similar DUTs (transducer, system) measured in EoL in a QC test box with fixed positions for DUT and microphone
- Transducer measured in a baffle (distance to other walls > 3 m) with a fixed microphone position (distance > 1m)

Practical Demo

Simulated Free-field condition at test point 30 cm (near field)

- Problems with the Windowing Technique
- In–situ FC-FR Technique (scanning time 7 min)

Simulated Free-field, Far-field condition at evaluation point (1m distance)

- In-situ FC-FR technique (scanning time 20 min)
- In-situ FC-LR technique (scanning time 7 min)

Fixed Room compensation function

- Using room compensation function for similar DUT (no additional scanning)

Summary

- Standard measurement condition (free-field, far-field) can be simulated in any acoustical environment
- The microphone signal has to be filtered before signal analysis using a complex correction function $H_c(f)$
- The correction function $H_c(f)$ has to be generated in-situ for the particular test point r_{test} using accurate reference data
- The spherical wave model gives accurate reference data at any point in the 3D space outside the scanning surface
- A fixed (room) correction function can be generated for a class of speakers

Open Questions

Now, we are ready for performing standard measurements in my office!

The 5th KLIPPEL LIVE webinar entitled
Maximum SPL – giving this value meaning

will address

- Selecting a broadband test stimulus representing typical program material
- Consequences for long-term testing (100h power test, reliability, endurance)
- Calibrating the input channel of the active system with SPLmax

Next Section

1. Modern audio equipment needs output based testing
2. Standard acoustical tests performed in normal rooms
3. Drawing meaningful conclusions from 3D output measurement
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