Acoustical Measurements

Output-Based Testing

Challenges for Testing

- Active Systems combine transmission + DSP + amplification + transduction
- Support many input channels with different properties
- Limited access to electrical transducer terminals
- Input level, voltage, electrical input power become less important
- Assessing 3D sound output in near and far field for sound field control
- DSP generates latency, time variant behavior and irregular distortion

Blackbox Modeling

The reproduced sound $p(\mathbf{r})$ at evaluation point $\mathbf{r}$ is not identical with the input signal u. Linear, nonlinear, time-variant, and irregular properties which are not desired and intended (e.g., defects) generate different kinds of signal distortions that require particular test methods.

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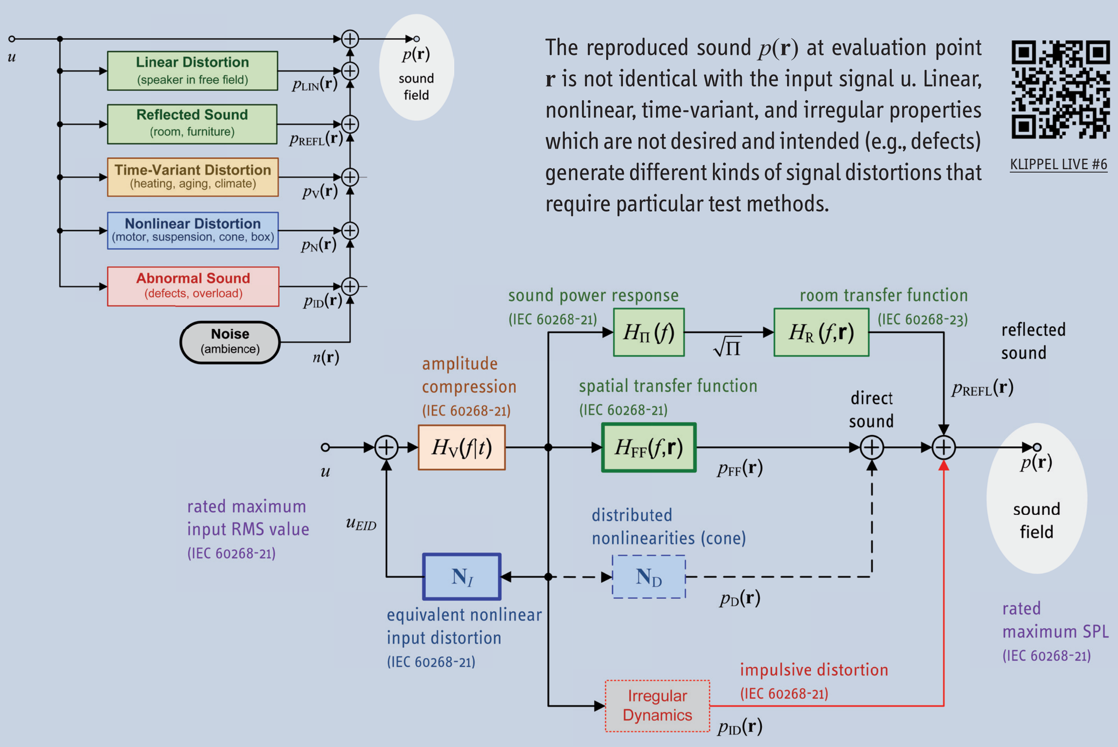
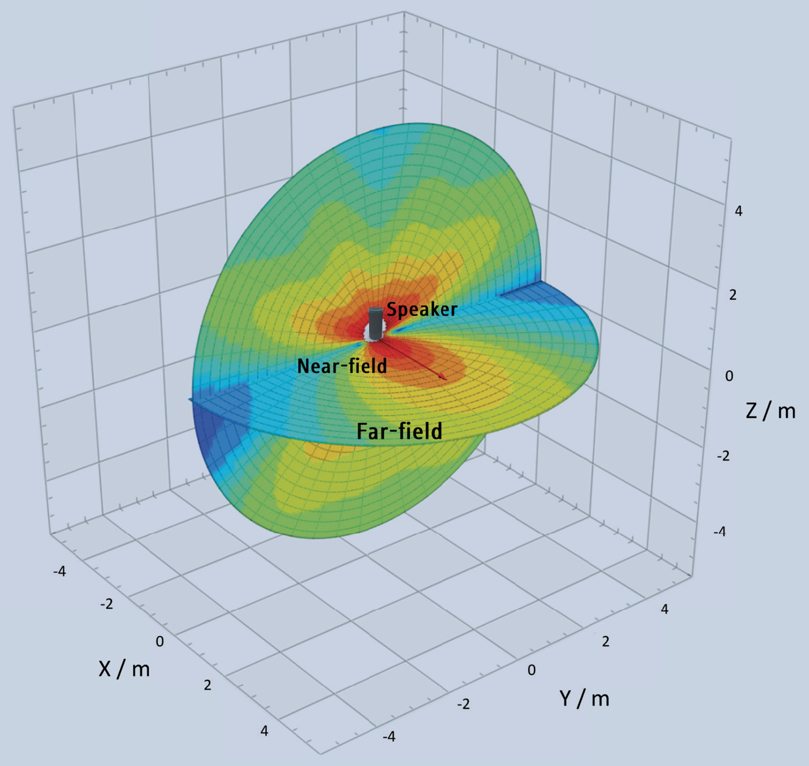


Spatial Transfer Function

The spatial transfer function models the sound pressure output $P_{FF}(f,\mathbf{r})$ at evaluation point $\mathbf{r}$ in near and far field of the loudspeaker under anechoic conditions using a spherical wave expansion:

$$\underline{H}_{FF}(f,\mathbf{r}) = \frac{P_{FF}(f,\mathbf{r})}{U(f)} = \mathbf{C}(f)\mathbf{B}(f,\mathbf{r})$$

The free parameters $\mathbf{C}(f)$ of this model weight the basis function $\mathbf{B}(f,\mathbf{r})$ which are solutions of the wave equation. The parameters $\mathbf{C}(f)$ are determined based sound pressure measurements on a double layer scan in the near field of the loudspeaker. The holographic method provides virtually infinite angular resolution by low scanning effort and separates sound reflections generated by the environment. A fitting error evaluates accuracy of the direct sound measurement.



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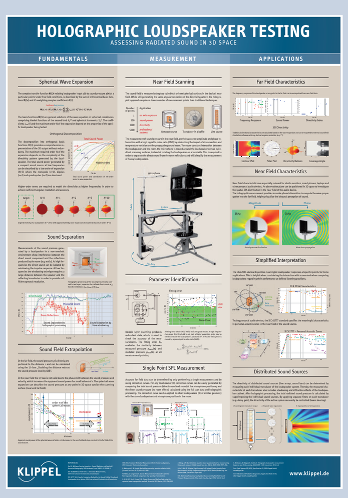
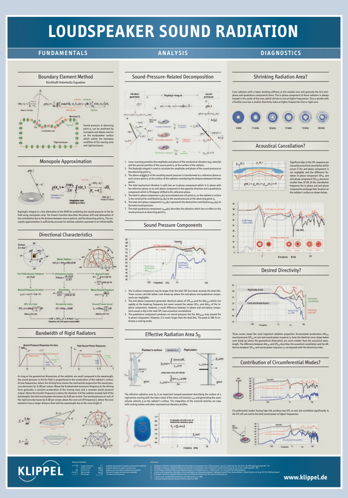
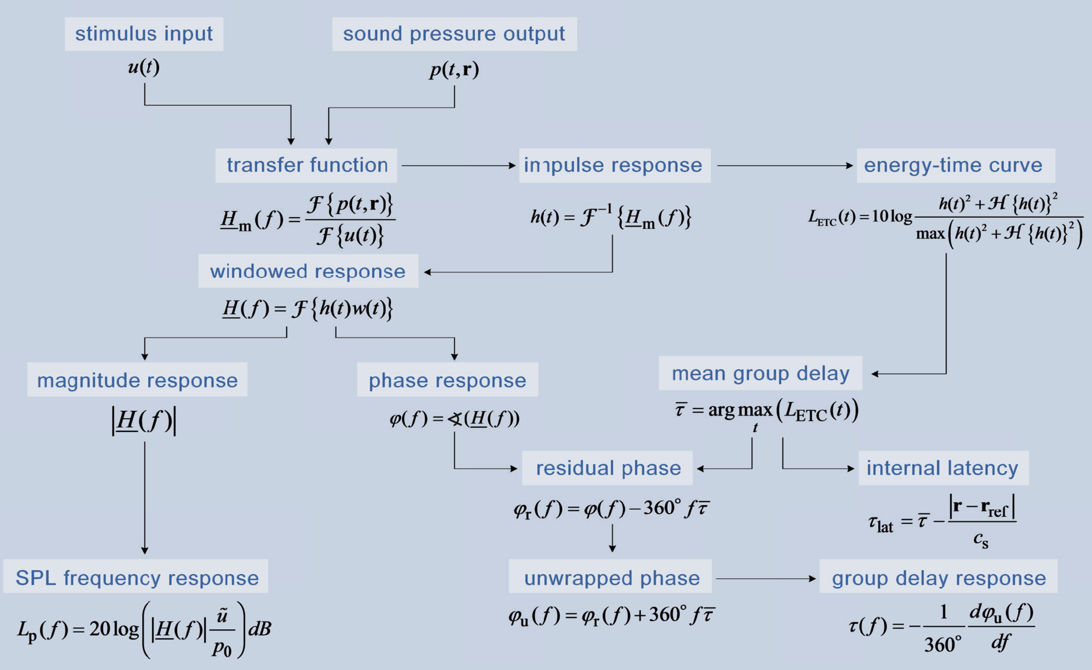
Example: Sound pressure distribution in 3D space of the direct sound generated by a bluetooth® enabled loudspeaker under free-field condition at 5 kHz.

Get more information on holographic loudspeaker testing and important far field characteristics on these dedicated posters:





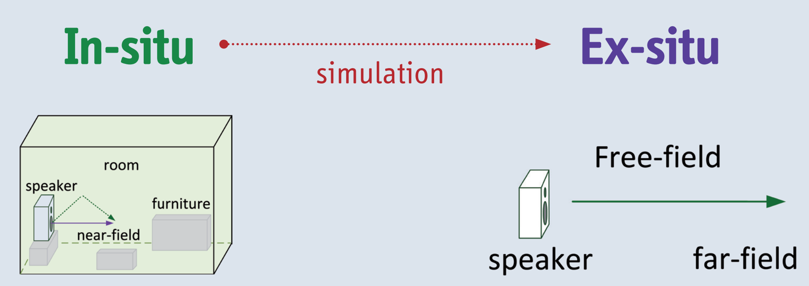
Frequency Responses



Symbol	Meaning	Symbol	Meaning
$\mathcal{H}\{\,\}$	Hilbert Transform	t	Time
$\mathcal{F}\{\,\}$	Fourier transform	f	Frequency
$\mathcal{F}^{-1}\{\,\}$	Inverse Fourier transform	$\mathbf{r}$	Evaluation point
$\lvert \underline{H}(f) \rvert$	Absolute value (modulus) of $\underline{H}(f)$	$\mathbf{r}_{REF}$	Loudspeaker reference point
$\sphericalangle(\underline{H}(f))$	Argument value (phase angle) of $\underline{H}(f)$	$p_0 = 20\mu Pa$	Reference sound pressure
$\tilde{u}$	RMS input voltage	$c_s = 344$ m/s	speed of sound

Acoustical Test Conditions

Simulated Ex-Situ Conditions



Testing under normal conditions such as listening room, office, production, service, target application.

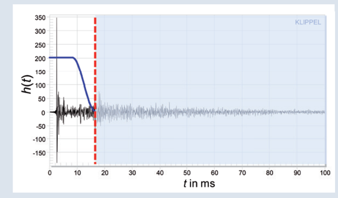
Benefits:
- Shows interaction with acoustical environment
- Simplicity (no anechoic room required)

Testing under idealized conditions such as sufficient distance in an anechoic room.

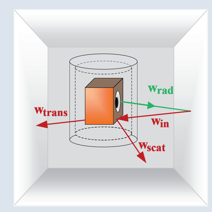
Benefits:
- Reveals loudspeaker properties without room influences
- Comparable results satisfy standard requirements

Methods according to IEC 60268-21

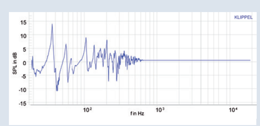
Time Windowing:
- Cuts out reflections in the impulse response
- Reduces frequency resolution at low frequencies
- Applicable to a single-point measurement
- Cannot provide simulated far-field condition



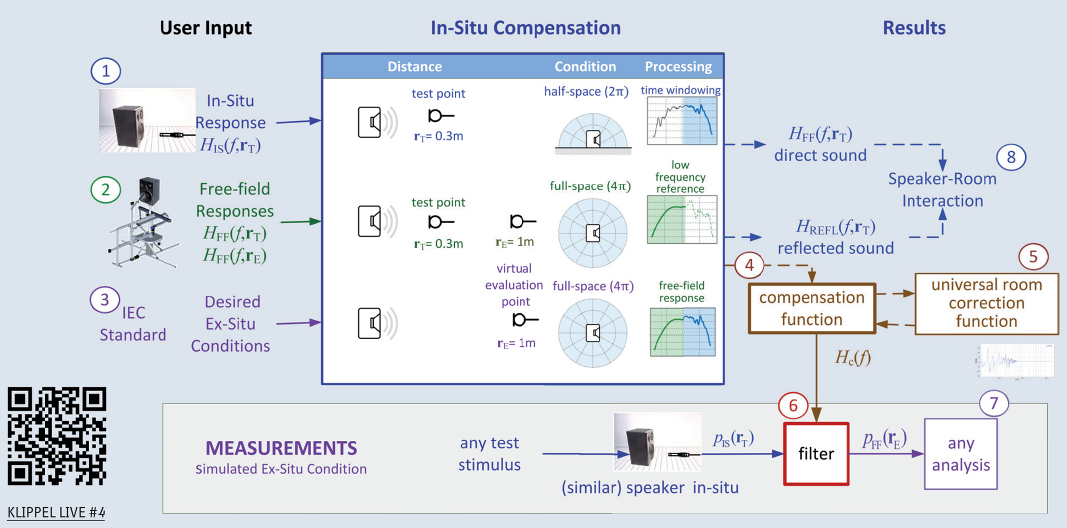
Wave Expansion:
- Separates direct sound from reflections
- Provides simulated far-field and free-field condition
- Requires near-field scanning



In-Situ Compensation Function:
- Filtering of the microphone signal (magnitude and phase)
- Compensation function depends on speaker and room properties and speaker and microphone position
- Provides simulated far-field and free-field condition
- Room correction function applicable to similar speakers
- Requires accurate reference information (free field)



Workflow for In-Situ Compensation Function



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1. Measure the sound pressure $p_{IS}(t,\mathbf{r}_T)$ at the test point $\mathbf{r}_T$ and calculate transfer function $H_{IS}(f,\mathbf{r}_T)$ under nonanechoic test conditions without compensation filter
2. Provide an accurate **reference** responses $H_{FF}(f,\mathbf{r}_T)$ and $H_{FF}(f,\mathbf{r}_E)$ measured under free-field condition (e.g., from anechoic room or near-field scanner (NFS))
3. Specify the evaluation point $\mathbf{r}_E$ and the acoustical standard environment (half-space or full-space)
4. Calculate the compensation function $H_C(f)$ based on the $H_{IS}(f,\mathbf{r}_T)$ and $H_{FF}(f,\mathbf{r}_E)$
5. Create a universal room correction curve and apply this to similar speakers (no reference required)
6. Filter the measured sound pressure $p_{IS}(\mathbf{r}_T)$ with the compensation function $H_C(f)$ to generate the **direct sound** $p_{FF}(t,\mathbf{r}_E)$ under simulated standard conditions
7. Apply any analysis to $p_{FF}(t,\mathbf{r}_E)$ to measure other characteristic (e.g., THD) under simulated standard conditions.
8. Inspect the reflected sound transfer function $H_{REFL}(f,\mathbf{r}_T)$ to evaluate the speaker-room interaction

There are three different in-situ compensation schemes for generating simulated far-field and free-field conditions using reference data from near-field scanning (NFS)

Schemes	Full Compensation with Full Reference	Full Compensation with LF-reference	LF-Compensation with LF-reference
Compensation filter	for all frequencies	for all frequencies	for low frequencies
Reference data	for all frequencies	for low frequencies	for low frequencies
Scanning Effort (for accurate reference)	normal NFS (> 20 min)	short NFS (> 7 min)	short NFS (> 7 min)
Acoustical Requirements	any condition (room, clamping, positioning)	any condition (distance to boundaries d > 1 m)	free-field condition (f > 1 kHz)
Spectral Resolution	not limited (no window applied)	not critical (windowing f > 500 Hz)	not limited (no window applied)
Universal (room) Compensation for similar DUTs	only amplitude response	amplitude + phase	amplitude + phase
Example	end-of-line test box	office, workshop	semi-anechoic room

Loudspeaker-Room Interaction

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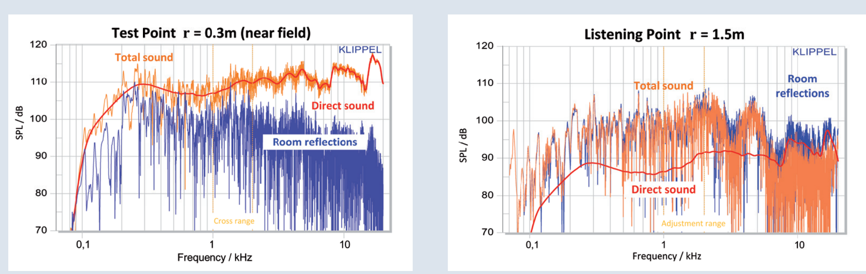
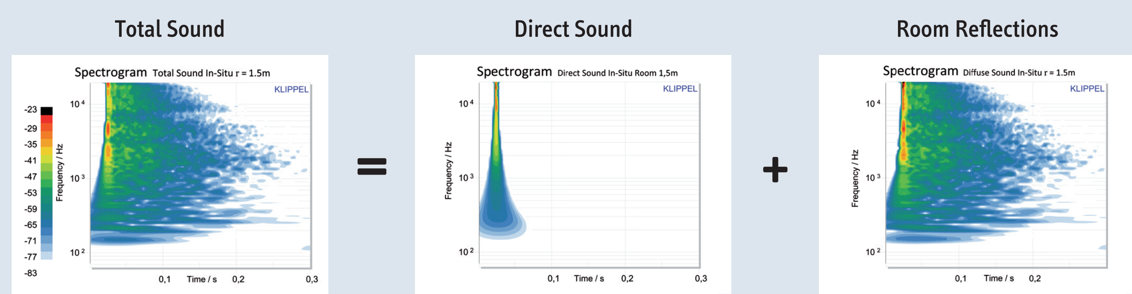
The in-situ compensation module can decompose the non-anechoic transfer function $\underline{H}_{NA}(f,\mathbf{r}_T)$ of total sound at test point $\mathbf{r}_T$ in the target environment (room, car, etc.) into transfer functions $H_{FF}(f,\mathbf{r}_T)$ and $H_{REFL}(f,\mathbf{r}_T)$ representing the direct sound and room reflections, respectively.

Example: Bluetooth speaker in an office evaluated at two points



Interpretation: The left-hand diagram above shows the transfer functions of the total sound and the components at a short distance r = 0.3 m (test point on the table) where the direct sound dominates the total sound. The right-hand diagram shows the test result at a larger distance r = 1.5 m (listening point), where the room reflections become dominant and generate significant variations in the total frequency response.

The spectrograms below show the time-frequency analysis (wavelet) of the impulse response of the total sound and the signal component at the listening point. The table and the wall generate significant early reflections. The room with a mean reverberation time $T_{60} \approx 0.2$ s generates room modes decaying smoothly with time.

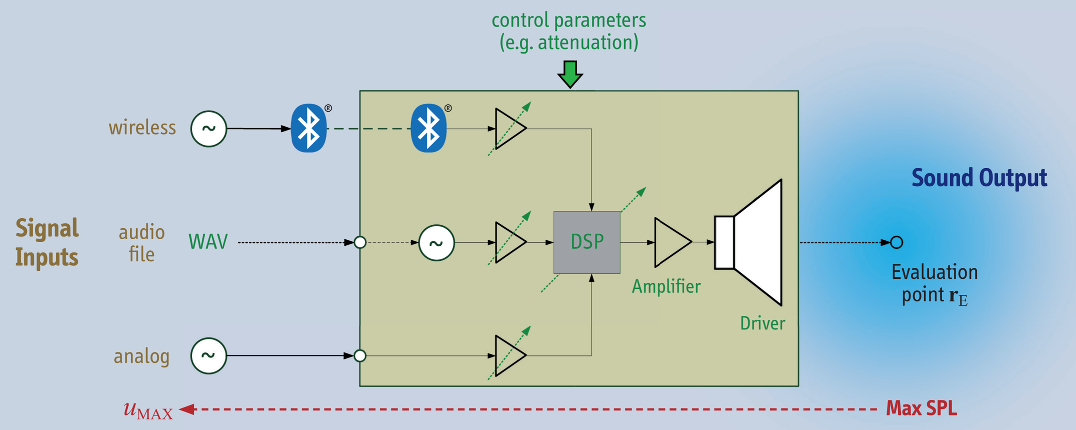


Maximum Sound Pressure Level

Max SPL according to IEC 60268-21

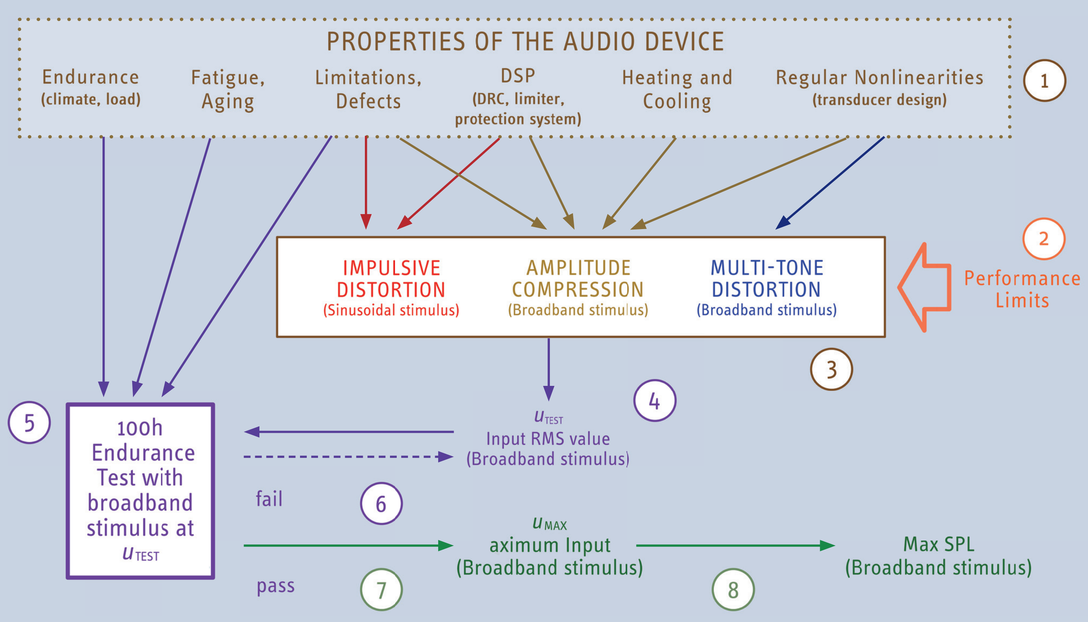
Definition:
- A single maximum sound pressure level (**Max SPL**) is the basis for acoustical testing of modern audio systems
- Manufacturer shall rate this Max SPL under specified measurement conditions (e.g., stimulus, position, environment)
- Manufacturer assures that the test stimulus generating Max SPL will not damage the device during a 100 h power test
- Manufacturer determines the physical and perceptual audio performance at the rated Max SPL according to the demands of the particular application

Benefits:
- The Max SPL can be used for calibrating any input channel and for determining a maximum input value (u_{MAX}) for selected control parameters (e.g. volume)
- Max SPL value is meaningful for engineering, marketing, and end-user



Rating Max SPL in Practice

1. Collect background information (e.g., design, target application)
2. Define performance limits for permissible signal distortion
3. Measure amplitude compression, nonlinear and impulsive distortion versus input RMS value u
4. Find a broadband stimulus RMS value u_{TEST} as a candidate for maximum input RMS value u_{MAX} corresponding to Max SPL considering performance limits.
5. Apply the broadband stimulus at u_{TEST} to at least 1 DUT for 100h-endurance test
6. Check that the properties of the DUT after the endurance test are in agreement with the technical specification. If the check fails, repeat the test with lower value u_{TEST}.
7. Assign the approved test value to the maximum input value $u_{MAX} = u_{TEST}$.
8. Determine Max SPL at evaluation point (e.g., 1 m on-axis) under free-field conditions for broadband stimulus at u_{MAX}.



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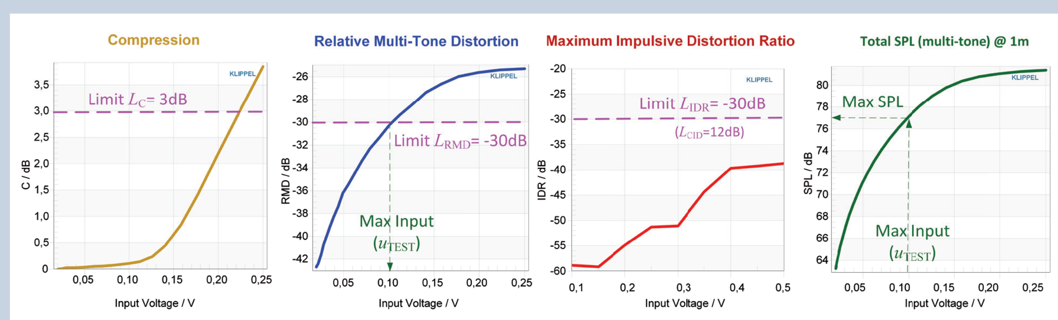
Example: The compression (C), multi-tone distortion (RMD), impulsive distortion (IDR) and total SPL are measured versus input voltage u. The RMD exceeds the permissible limit L_{RMD} = -30 dB at u_{TEST} = 0.1 V which is a meaningful test value for the 100 h-endurance test and for rating max input and the max SPL. The performance limits L_C, L_{RMD} and L_{IDR} depend on the particular target application and shall provide the maximum benefit-cost ratio to a typical end-user.



Benchmarking of Audio Products

The characteristic Max SPL plays an important role for assessing loudspeaker systems at high amplitudes, where heat and nonlinear distortion limit the maximum output. The table below compares three methods for benchmarking audio products:

	Benchmarking at Common Max SPL	Benchmarking by Rating Max SPL	Benchmarking at Individual Max SPL
Target	Best audio performance for given Max SPL	Highest Max SPL with acceptable audio performance	Best combination of Max SPL and audio performance
Max SPL	Defined as target requirement	Rated based on target audio performance	Rated based on background information
Benchmarking Decision	Based on essential metrics describing audio performance	Single value (Max SPL) simplifies ranking	Requires trading Max SPL for audio performance
Benefit	Max SPL is defined before product development begins	Can be applied to any product	Minimum test effort for customer
Typical Application	OEM business between supplier and system integrator	Audio equipment (professional) where Max SPL is important	Benchmarking based on supplier's datasheet

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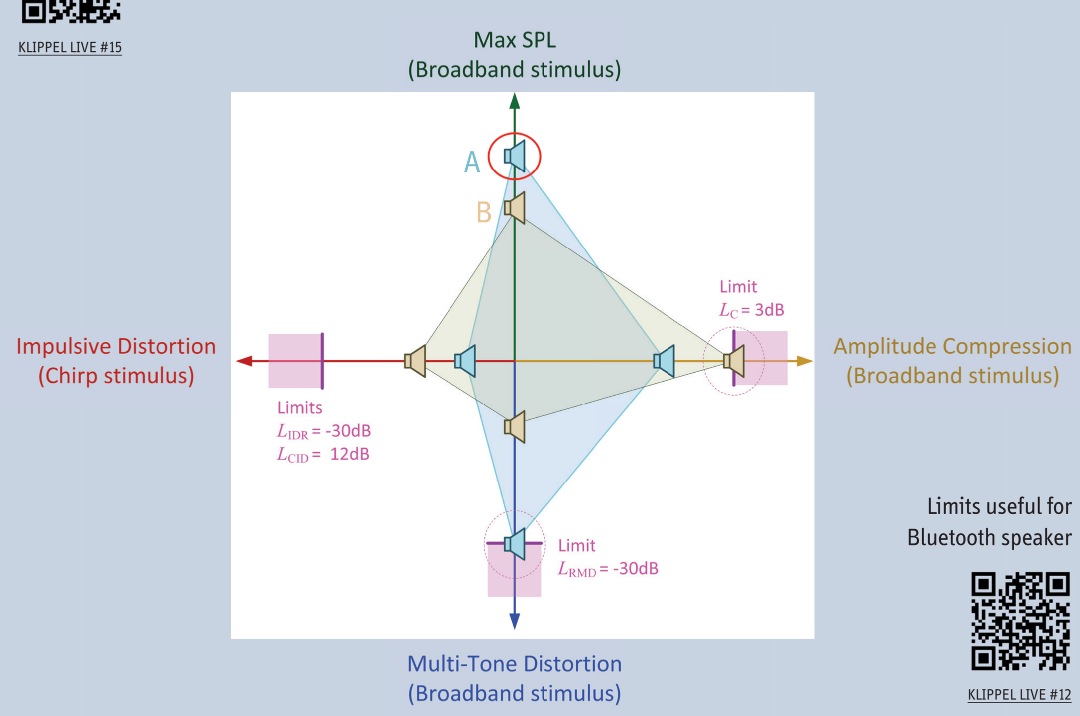
Example: The diagram illustrates the second method **Benchmarking by Rating Max SPL** applied to two wireless speakers (A and B).



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