Acoustical Measurement of Sound System Equipment according IEC 60268-21

KLIPPEL LIVE
a series of webinars presented by
Wolfgang Klippel
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 a single 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

12. **Benchmarking of audio products under standard conditions**
13. Auralization of signal distortion – perceptual evaluation
14. Setting meaningful tolerances for signal distortion
15. Rating the maximum SPL value for product
12th KLIPPEL LIVE:
Benchmarking of audio products under standard conditions

Topics today:
• Selecting essential physical characteristics at low and high amplitudes
• Benchmarking based on supplier specification
• Benchmarking at the same maxSPL defined by customer
• Simple benchmarking by rating maxSPL based on defined performance limits
• Practical application of the methods to two Bluetooth speakers
Poll:

How do you benchmark your audio products? (multiple choices)

A. I have never done it 0%
B. Comparing technical specification provided by manufacturer 47%
C. Performing physical measurements on the device(s) and comparing the results 76%
D. Listening to the products reproducing my favorite audio samples 53%
Performance Metrics for Audio Devices

- cost
- size, volume, shape, weight
- maximum output \( (\text{max. SPL}, \text{max. power } P_{a,max}) \)
- efficiency (power consumption \( P_E \), heating, mobile operation time in battery powered devices)
- perceptual audio quality (spectral and spatial properties, distortion)
- reliability (probability of failure)
- endurance of external stress (overload, environment)
- artistic product design and ergonomics
- technical story
- reputation of the brand, personal identification with the product
- enjoyment or hedonistic preference

Our topic today: Special physical Measurement (under standard condition)
Poll:

What is important for your benchmarking?
(multiple choices)

A. **maximum output** (max. SPL, max. power $P_{a,max}$) 61%
B. **efficiency** (power consumption $P_E$, heating, mobile operation time in battery powered devices) 39%
C. **perceptual audio quality** (spectral and spatial properties, distortion) 87%
D. **reliability** (probability of failure) 39%
E. **endurance** of external stress (overload, environment) 26%
Reduce complexity!

The benchmarking of audio products can be simplified in the following way:

• Comparing similar products (e.g. headphones)
• Designed for a clear defined group of end-users (e.g. teenager)
• Specify final application condition (e.g. in-ear)
• Select a minimum of metrics evaluating the important properties
• Use metrics which are clearly defined (e.g. standards)
• Define the evaluation condition (e.g. input level)
**Important Standard Characteristics**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>output based testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-axis fundamental transfer response</td>
<td>*</td>
</tr>
<tr>
<td>3D output, directivity</td>
<td>*</td>
</tr>
<tr>
<td>Electrical impedance</td>
<td>-</td>
</tr>
<tr>
<td>Lumped parameters (linear, nonlinear, thermal)</td>
<td>-</td>
</tr>
<tr>
<td>Amplitude compression</td>
<td>*</td>
</tr>
<tr>
<td>DC-displacement $X_{DC}$</td>
<td>(*)</td>
</tr>
<tr>
<td>Harmonic distortion (THD, 2nd, 3rd-order)</td>
<td>*</td>
</tr>
<tr>
<td>Multi-tone distortion (HD + IMD)</td>
<td>*</td>
</tr>
<tr>
<td>Distortion in reproduced audio signal</td>
<td>*</td>
</tr>
<tr>
<td>Modulated noise</td>
<td>*</td>
</tr>
<tr>
<td>Impulsive distortion (rub &amp; buzz)</td>
<td>*</td>
</tr>
<tr>
<td>Destructive test</td>
<td>*</td>
</tr>
<tr>
<td>Maximum displacement $X_{MAX}$</td>
<td>(*)</td>
</tr>
<tr>
<td>Maximum SPL$<em>{MAX}$ or input voltage $U</em>{MAX}$</td>
<td>*</td>
</tr>
<tr>
<td>100h-long-term test</td>
<td>*</td>
</tr>
<tr>
<td>Accelerated life test</td>
<td>*</td>
</tr>
<tr>
<td>Environmental test</td>
<td>*</td>
</tr>
</tbody>
</table>

3 performed according IEC 60268-21
4 measured according IEC 62458
5 measured according IEC 60268-22 CDV

**Parameters of a model**
(independent of the stimulus)

**Symptoms measured with a defined test signal**

**Rated characteristics considering the particular application**

**Long term testing with stimulus representing program material**

Important for benchmarking
Evaluation Condition

The magnitude of the test stimulus has a high impact on performance of the audio system!

The rated maximum SPL (maximum input voltage $u_{\text{max}}$) according to IEC 60268-21 simplifies the benchmarking!
Benchmarking at Low Amplitudes

Measurement Condition:
- Small Signal Domain \( (u=0.1 \, u_{\text{max}}) \)
- Any broadband stimulus
- Selected points (on-axis, listening zone) under far field /free field condition (CEA 2034 Standard)

Important Metrics for Linear Distortion:
1. Upper and lower limits of the effective frequency range (IEC 60268-21)
2. SPL response (e.g. estimated room response CEA 2034 Standard) smoothed with \( 1/3^{\text{rd}} \) octave
3. Mean deviation from a target response (new IEC project TV, monitor)
CEA 2034 Standard using Spino-a-rama

Application: Home audio devices, Hifi-Loudspeaker
**New Metrics for Linear Distortion**

Measurement methods for TV and monitor audio systems

New IEC Project: PT 100-31

<table>
<thead>
<tr>
<th>Measuring metric</th>
<th>Unit</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound Balance Index (SBI)</td>
<td>dB</td>
<td>The difference of SPL between different frequency band</td>
</tr>
<tr>
<td>Flatness</td>
<td>dB</td>
<td>Standard deviation of SPL in the and different frequency band</td>
</tr>
<tr>
<td>SPL uniformity</td>
<td>%</td>
<td>Uniformity of SPL at screen 9 points and speaker on axis</td>
</tr>
<tr>
<td>Effective Frequency Range (EFR)</td>
<td>Hz</td>
<td>Frequency band which the speaker can play at each location</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>dB</td>
<td>Average of SPL between EFR</td>
</tr>
<tr>
<td>Total Harmonic Distortion (THD)</td>
<td>%</td>
<td>Amount of output signal compared to input signal</td>
</tr>
<tr>
<td>Directivity index</td>
<td>dB</td>
<td>The ratio of the following two SPL values</td>
</tr>
<tr>
<td>Radiation angle</td>
<td>Degree</td>
<td>Angle of less than 10 dB below the SPL on the on axis</td>
</tr>
<tr>
<td>Coverage angle</td>
<td>Degree</td>
<td>Angle between direction 6 dB less than maximum SPL</td>
</tr>
</tbody>
</table>

![Sound Balance Index (SBI)](sound_balance_index.png)

![Flatness](flatness.png)

![SPL uniformity](spl_uniformity.png)
Essential Metrics according IEC Standards for Assessing Small Signal Performance

- **Lower limit of effective frequency range**
- **Upper limit of effective frequency range**
- **Variance of SPL response versus frequency (contra flatness)**
- **Sound Balance Index**

*affects the „Low bass performance”*

*Contributes to the „sharpness”*

*Perceived as „sound coloration”*

*There are other important metrics defined in various standards:*
  - Sound Power Directional Index IEC 60268-21
  - Latency IEC 60268-21
Benchmarking at High Amplitudes

IDEA: Using Rated MAXIMUM SPL as the basis for the Large Signal Measurement

There are three interesting ways:

1. Testing using individual maxSPL values for each DUTs rated by supplier
2. Testing at maxSPL target value defined by customer (product requirement)
3. Comparing maxSPL rated by customer
Essential Metrics according IEC 60268-21 for Assessing Large Signal Performance

- **Maximum Output**
- **MAX. SPL** (Broadband Stimulus)
- **AMPLITUDE COMPRESSION** (Broadband Stimulus)
- **MULTI-TONE DISTORTION** (Broadband Stimulus)
- **IMPULSIVE DISTORTION** (Chirp)

**Irregular properties (rub&buzz)**
- Low impact on audio quality but high impact on reliability

**Regular Nonlinearities (accepted by design)**
- High impact on audio quality

**Time-variant properties**
- High impact on audio quality but high impact on reliability
1st Method: Benchmarking at Individual Max. SPL

Supplier A
Max. SPL \( L_A \)
TEST

Supplier B
Max. SPL \( L_B \)
TEST

Supplier C
Max. SPL \( L_C \)
TEST

Customer
\( L_A \)
(TEST)
Result Evaluation

\( L_B \)
(TEST)
Result Evaluation

\( L_C \)
(TEST)
Result Evaluation

Comparison, Selection, Awarding

Results can be verified under same conditions

Supplier determines the test condition!

IEC 60268-21 or other standard

Individual modifications
Benchmarking of Two Products (A, B) at Individual Max. SPL

- **MAX. SPL**
  - (Broadband Stimulus)

- **IMPULSIVE DISTORTION**
  - (Chirp)

- **MULTI-TONE DISTORTION**
  - (Broadband Stimulus)

- **AMPLITUDE COMPRESSION**
  - (Broadband Stimulus)

Product B generates more output

But Product B generates more distortion

Product A generates more output
Benchmarking at Individual Max. SPL

IDEA: Best matching of Max. SPL and Audio Performance

Benefits:
• Supplier rates Max. SPL based on background information
• Benchmarking based on existing products
• No communication with supplier required
• Minimum test effort for customer

Drawbacks:
• Comparison of DUTs with different Max. SPL values and distortion values is more complicated

Application:
• Benchmarking based on datasheet published by supplier
Demo: Benchmarking at Individual Max. SPL

Tools: Using dedicated software modules of the KLIPPEL Analyzer
- Near Field Scanner (NFS)
- In-Situ Room Compensation (ISC)
- Transfer Function Measurement Pro (TRF-Pro)
- Transfer Function Measurement Stepping (TRF)
- Multi-Tone Measurement (MTON)

Comparable hardware used for one channel!
Benchmarking of the two Bluetooth Speakers at Individual Max. SPL

MAX. SPL (Broadband Stimulus)

75.5 dB
74 dB (JBL)

IMPULSIVE DISTORTION (Chirp)

IDR < -40 dB (JBL)
CID < 15 dB

IDR < -40 dB (JBL)
CID < 12 dB

Competitor small impulsive distortion

Competitor generates more regular distortion

MULTI-TONE DISTORTION (Broadband Stimulus)

-30 dB
-36 dB

AMPLITUDE COMPRESSION (Broadband Stimulus)

2 dB
1.3 dB

Competitor generates more output

Competitor causes larger compression

Different values

KLIPPEL LIVE #12: Benchmarking of audio products, 20
2nd Method: Benchmarking at Target Max. SPL

Customer

Max. SPL (+ other requirements)

Supplier A
TEST
(TEST)
Result Evaluation
Comparison, Selection, Awarding

Supplier B
TEST
(TEST)
Result Evaluation

Supplier C
TEST
(TEST)
Result Evaluation

Customer defines max. SPL!

IEC 60268-21 or other standards

Target Application

Test conditions, Criteria, priorities

Customer

Supplier

Application

Comparison, Selection, Awarding

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Benchmarking at Target Value
Essential Metrics according IEC 60268-21

MAX. SPL
(Broadband Stimulus)

Target value

IMPULSIVE DISTORTION
(Chirp)

Product B produces less distortion

AMPLITUDE COMPRESSION
(Broadband Stimulus)

But product B generates more compression

MULTI-TONE DISTORTION
(Broadband Stimulus)
Benchmarking at Target Value

IDEA: Best Audio Performance for given Max. SPL

Benefits:
- Customer defines Max. SPL value (target requirement)
- Customer and supplier define measurement condition
- Simplifies communication between customer and supplier
- Supplier can provide all test results to customer
- Minimum test effort for customer
- Test results of the DUTs are comparable

Drawbacks:
- Max. SPL is defined before product development begins

Application:
- Transducer Manufacturer – System Integrator (OEM business)
Demo

Benchmarking at Target Value

Tools: Using dedicated software modules of the KLIPPEL Analyzer

- **Near Field Scanner (NFS)**
- **In-Situ Room Compensation (ISC)**
- **Transfer Function Measurement Pro (TRF-Pro)**
- **Transfer Function Measurement Stepping (TRF)**
- **Multi-Tone Measurement (MTON)**

JBL Bluetooth Speaker (one channel)

Arctic Competitive Bluetooth Speaker (stereo, only left channel is used)

Comparable hardware used for one channel!
Benchmarking of the two Bluetooth Speakers at Target Max. SPL

MAX. SPL (Broadband Stimulus)

74 dB (JBL) 74 dB (Artic)

IMPULSIVE DISTORTION (Chirp)

IDR < -40 dB (JBL) CID < 15 dB
IDR < -40 dB (JBL) CID < 12 dB

Competition causes impulsive distortion (very small)

MULTI-TONE DISTORTION (Broadband Stimulus)

-36 dB (JBL) -33 dB

AMPLITUDE COMPRESSION (Broadband Stimulus)

1.3 dB 1.8 dB

Competitor causes impulsive distortion (very small)

Competition generates more regular distortion

Competition causes larger compression

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3rd Method: Benchmarking by maxSPL rated by customer under same condition

Supplier A

Supplier B

Supplier C

Customer

IEC 60268-21 or other standard

Test conditions, Criteria, priorities

Target Application

Max. SPL rated by customer is an important criteria!

Comparison, Selection, Awarding

Supplier A

Supplier B

Supplier C

Customer

TEST

Result Evaluation

rating
Max. SPL $L_A$

TEST

Result Evaluation

rating
Max. SPL $L_B$

TEST

Result Evaluation

rating
Max. SPL $L_C$

Evaluation

Result

Result

Result

Evaluation

Evaluation

Evaluation

Target Application

TEST

Result Evaluation

rating
Max. SPL $L_A$

TEST

Result Evaluation

rating
Max. SPL $L_B$

TEST

Result Evaluation

rating
Max. SPL $L_C$

Evaluation

Result

Result

Result

Evaluation

Evaluation

Evaluation

Target Application

TEST

Result Evaluation

rating
Max. SPL $L_A$

TEST

Result Evaluation

rating
Max. SPL $L_B$

TEST

Result Evaluation

rating
Max. SPL $L_C$

Evaluation

Result

Result

Result

Evaluation

Evaluation

Evaluation

Target Application
Benchmarking by maxSPL rated by customer

Essential Metrics according IEC 60268-21

- **MAX. SPL**
  - (Broadband Stimulus)

- **IMPULSIVE DISTORTION**
  - (Chirp)
  - Limits
    - IDR=-30 dB
    - And
    - CID=12 dB

- **MULTI-TONE DISTORTION**
  - (Broadband Stimulus)
  - Limit -30 dB

- **AMPLITUDE COMPRESSION**
  - (Broadband Stimulus)
  - Limit 3 dB

Best product

KLIPPEL LIVE #12: Benchmarking of audio products, 27
Benchmarking by maxSPL rated by customer

IDEA: Highest Max. SPL for given Audio Performance

Benefits:
• Can be applied to any product
• Customer defines test condition (IEC 60268-21)
• Sufficient Audio Performance
• Simplified decision in benchmarking

Drawbacks:
• Test effort on customer side
• Less useful for applications where audio performance is more important than Max. SPL

Application:
• Professional equipment, small portable-personal audio equipment where larger Max. SPL is desired
Demo

Benchmarking: Rating maxSPL by customer

Tools: Using dedicated software modules of the KLIPPEL Analyzer

- Near Field Scanner (NFS)
- In-Situ Room Compensation (ISC)
- Transfer Function Measurement Pro (TRF-Pro)
- Transfer Function Measurement Stepping (TRF)
- Multi-Tone Measurement (MTON)

JBL Bluetooth Speaker (one channel)

Arctic Competitive Bluetooth Speaker (stereo, only left channel is used)

Comparative hardware used for one channel!
Benchmarking of the two Bluetooth Speakers by customer using same limits

MAX. SPL (Broadband Stimulus)

- Competitor arctic generates 1 dB more maxSPL
- JBL at compression limit

IDR < -40 dB (JBL) CID < 15 dB

- Limits IDR = -30 dB
- And CID = 12 dB

Both speakers generate small impulsive distortion

Steady state condition (with preloop)

Limits IDR = -30 dB

Significant distortion limit

AMPLITUDE COMPRESSION (Broadband Stimulus)

MULTI-TONE DISTORTION (Broadband Stimulus)
Summary

- IEC 60268-21 provides useful methods and meaningful characteristics for benchmarking audio products
- Rated maxSPL is an important characteristic for testing and benchmarking
- Effective frequency range and the mean deviation from target response are important small signal characteristics
- Amplitude compression, multi-tone distortion and impulsive distortion give essential information of assessing the large signal performance
- Limits and permissible tolerance have to be defined for each metric considering the particular target application
Open Questions

The scope of IEC 60268-21 is limited to physical measurements. How can standard tests be linked to perceptual evaluation?

The next 13th KLIPPEL live webinar entitled Auralization of signal distortion – perceptual evaluation will address the points:

• How to test audio systems with ordinary audio stimuli (music, speech)
• How to separate linear, time-variant and nonlinear distortion in stimuli with a dense spectrum
• How to combine physical and perceptual testing
• How to evaluate the masking of signal distortion
Next Section

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