

Acoustical Measurement of Sound System Equipment according IEC 60268-21

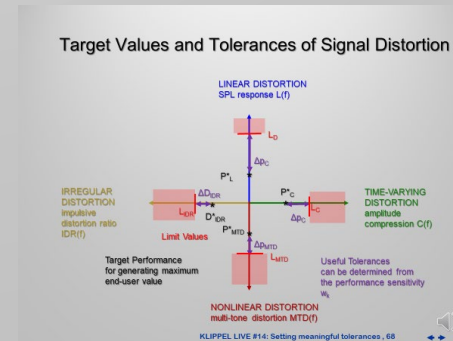
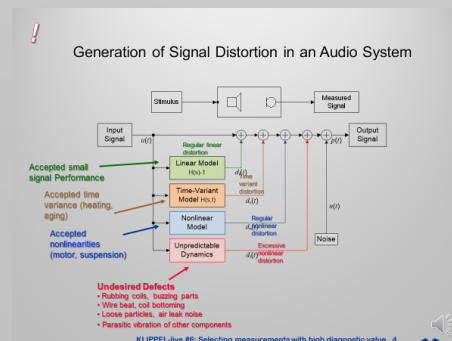
KLIPPEL LIVE

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 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 - rumble & buzz, abnormal behavior, defects
11. Pitfalls in Testing Wireless Audio Devices
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



15th KLIPPEL LIVE:

Rating the maximum SPL value for product

Topics today:

- Short overview of the definitions used in the industry (IEC, CEA, other quasi standard)
- How to choose the method satisfying my needs ?
- How to keep the measurements simple, fast and meaningful ?
- How to ensure best practice every day ?

Poll:

Which definition would you prefer for rating maxSPL?

- A. A rigid standard definition with clearly defined details (no or minimum freedom for any modification) 22%
- B. A standard definition with clearly defined framework giving enough freedom to consider the particularities of the product in the target application 78%
- C. I would like to create my own definition for maxSPL 0%
- D. I think we do not need maxSPL or a similar term 0%
- E. Other 0%



How to rate $u_{\max}$ and $SPL_{\max}$ according IEC 60268-21?

The manufacturer has **freedom to rate** $u_{\max}$ and $SPL_{\max}$ under the following requirements:

- standard measurement condition (rated frequency range, stimulus, evaluation point, ect.)
- DUT can reproduce the stimulus with maximum input voltage $u_{\max}$ at least for 100 h
- **sufficient sound quality** for the particular application
 - effective frequency range corresponds with the rated frequency range
 - acceptable regular nonlinear distortion (harmonic + intermodulation)
 - low compression of the fundamental (heating, mechanical limiting, protection)
 - negligible impulsive distortion (generated by rub & buzz or any other defects)

How to do the rating in practice ?

- 
1. Collect background information
 - Target application (customer expectations, typical usage)
 - Design details of the audio product (if possible)
 2. Specify standard test condition with performance limits
 3. Find a test voltage u_{test} as a candidate for maximum input voltage u_{max} corresponding to maxSPL by using performance limits.
 4. Apply the broadband stimulus at u_{max} to at least 1 DUT for 100h
 5. Check that the properties of the DUT after power test are in agreement with the technical specification. If check fails repeat sequence 3 – 5 with lower test voltage u_{max} .
 6. Assign the test input voltage to the maximum input voltage $u_{\text{max}} = u_{\text{test}}$. Determine the corresponding value of the maximum SPL output.
 7. Finished!

Exploiting Background Information

Target application

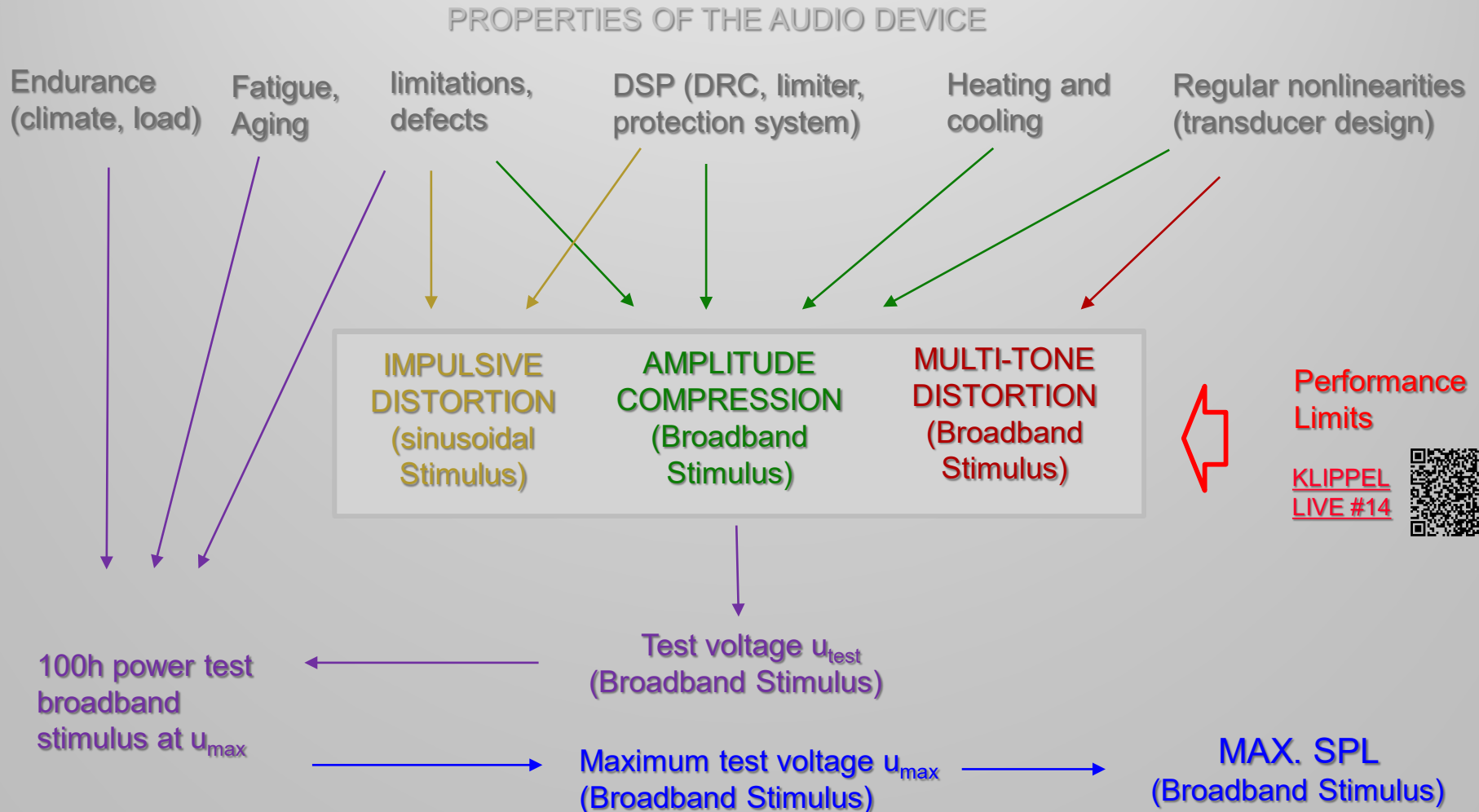
- Customer expectations (performance features) provided from marketing and benchmarking of competitive products
- Acoustical properties of the environment (room, car)
- Positioning of the audio device (listening area)
- Properties of audio material (speech, music)
- ...

Design Details

- DSP functionality for active transducer and amplifier protection,
- Sound shaping, artificial bass enhancement and other psychoacoustical processing
- noise gating and other smart capabilities
- Latency and artifacts in digital and wireless transmission
- Maximum signal input (e.g. 24 dBu)
- Transducer properties (e.g. maximum voice coil temperature)
- Amplifier properties (e.g. maximum peak voltage)

→ Basis for specifying the performance limits and test conditions

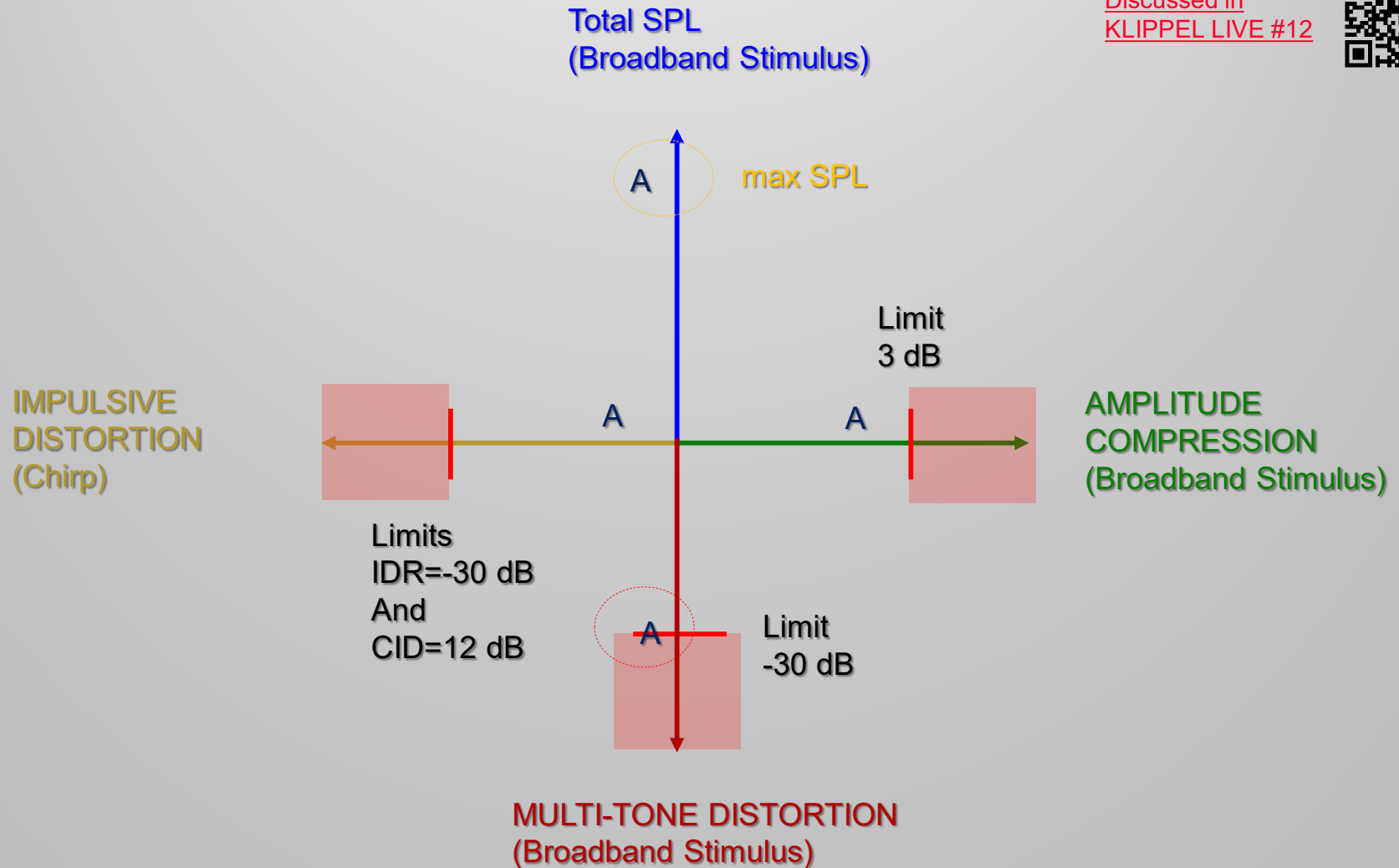
Essential Test according IEC 60268-21



Benchmarking by maxSPL rated by customer

Essential Metrics according IEC 60268-21

Discussed in
[KLIPPEL LIVE #12](#)



Limits for Compression

caused by heat in different components

Thermal compression C in pass band caused by the increase of mean temperature ΔT_v in a copper coil:

$$C(\Delta T_v) \approx 20 \lg \left(\frac{R_E(\Delta T_v)}{R_E(0)} \right)$$

$$= 20 \lg (1 + 0.0045 \cdot \Delta T_v)$$

→ C= 3,2 dB for $\Delta T_v = 100$ Kelvin

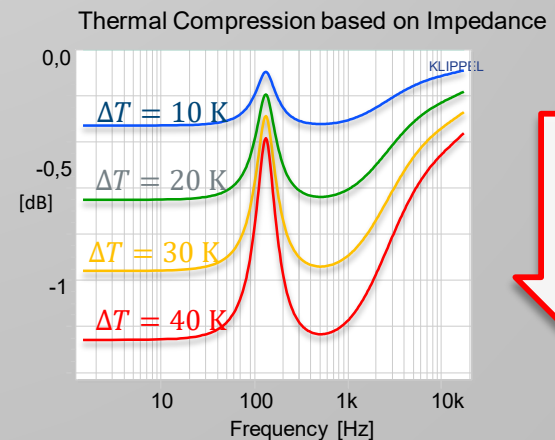
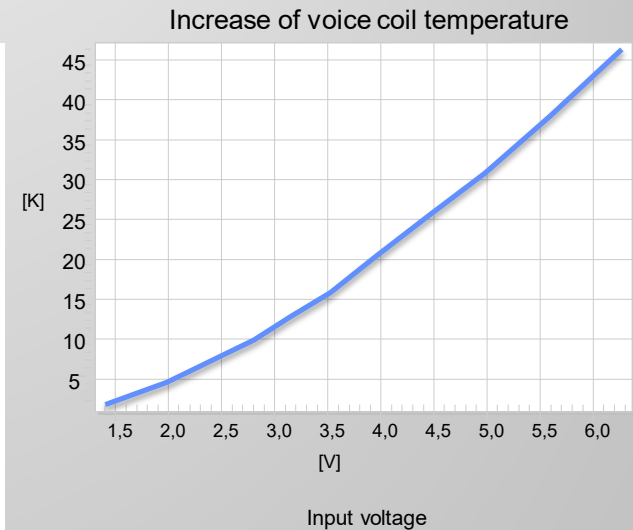
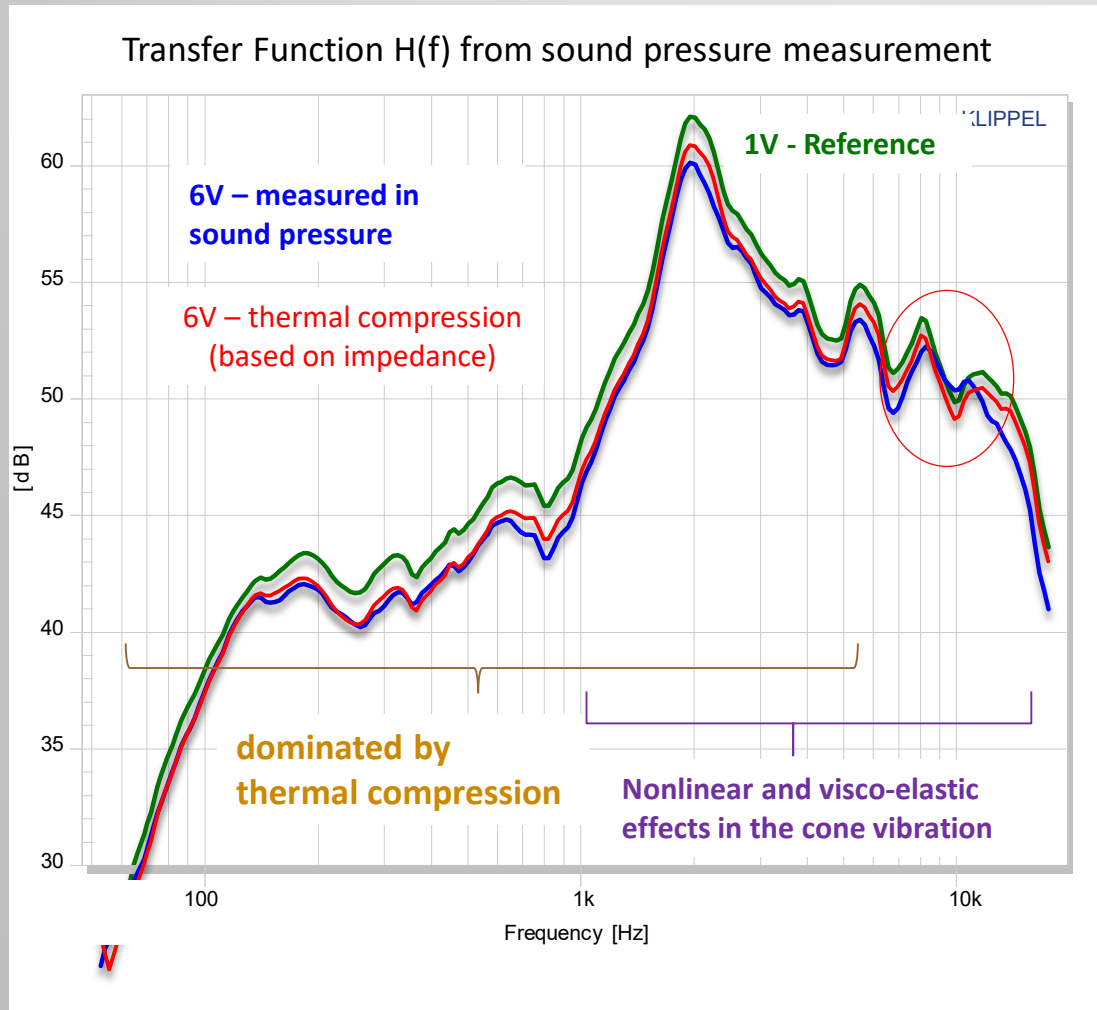
Other factors:

- Temperature distribution and heat flow
- Thermal dynamics (time constants)
- Forced convection cooling
- Thermal properties of other components
- Safety margin

Component	Critical application	Critical local temperature in the component	Corresponding thermal compression in passband	Useful limit (mean value)
Voice coil	Pro woofer with long coils	150 - 400°C	3 - 8dB	2 - 5dB
Diaphragm	Headphone, microspeaker	100 - 200°C	3 - 4dB	2 - 3dB
magnet	Small neodymium magnet	100 - 250°C	3 - 5dB	2 - 3dB
Spider	Pro woofer	150 - 300°C	5dB	2 - 4dB

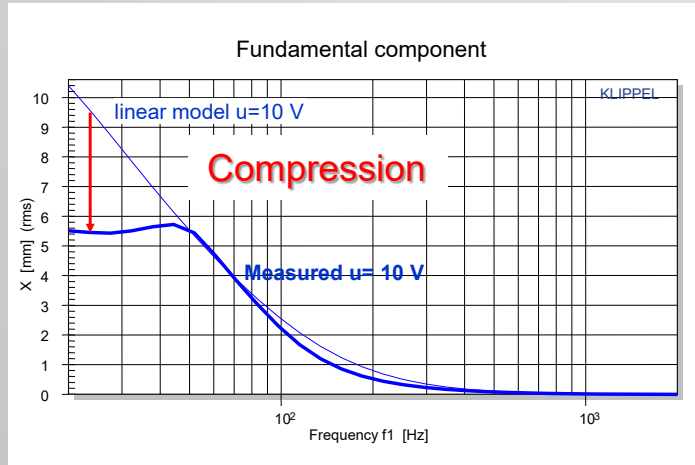
The limits are applied to the mean compression averaged in the passband below cone break up !

Separating Thermal and Mechanical Compression



Limits for Compression

caused by regular nonlinearities in transducer and enclosure



Nonlinear Compression

- Occurs in a particular frequency band
- Comes along with other nonlinear distortion
- Can indicate mechanical overload of the suspension (→ impulsive distortion and fatigue)
- In a port, also generates modulated noise

Nonlinearity	Critical frequency Band	Maximum compression in this band	Useful limit L_c (mean value in this band)
Stiffness of suspension $K_{ms}(x)$	$f < f_s$	< 7dB	2 - 4dB
Force factor $Bl(x)$	$f < f_s$ $f > f_s$ multitone	< 6dB < 2dB	2 - 3dB 1dB
Port resistance $R_p(v)$	$f = f_p$	< 10 dB	2 - 5dB

Compression is a useful indicator in vented and bandpass systems

Limits for Compression

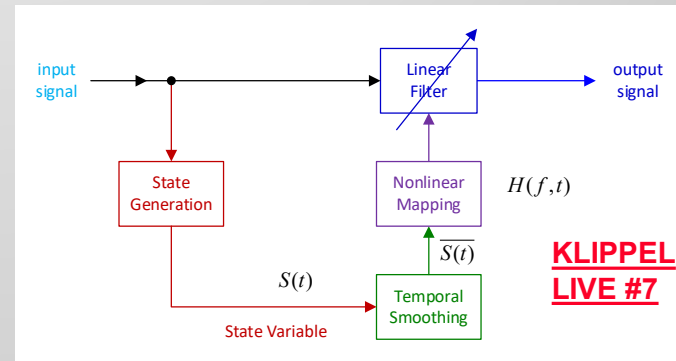
caused by electrical means and DSP

DSP Algorithms

- Can provide more output (maxSPL)
- Can protect the audio device reliably

BUT

- Increase the latency
- Generate impulsive distortion during attack phase



Control System	Critical frequency Band	Typical compression in this band	Useful limit L_c (mean value in this band)	Consequences on audio quality
Dynamic Range Compressor (DRC)	Full (or selected) band	<15 dB	2... 8dB	impairs natural dynamics of audio input
Mechanical transducer protection	Low pass ($f < f_s$)	<12 dB	2 - 7dB	Impairs bass performance
Thermal protection	Full band	<8 dB	2 - 5dB	Minor impact
Power saving (noise suppression)	Full band, low pass	12 ...20 dB	0dB	Should be deactivated in time (look ahead)

Limits depend on expected audio quality !

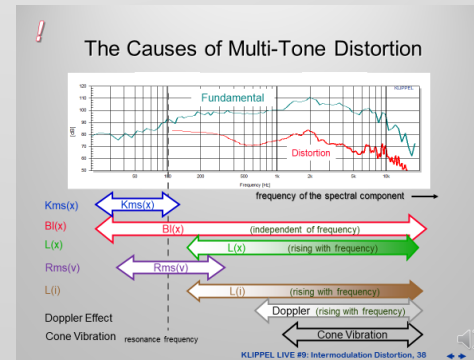
Limits for Multi-Tone Distortion

Setup

- Stimulus (typical program material)
- Smoothed distortion response (Voishvillo)
- Searching for maximum value

Multi-tone Distortion reveals

- HD and IMD form regular nonlinearities (transducer)
- Fast varying time variant behavior



**KLIPPEL
LIVE #9**



Control System	Critical frequency Band	Typical distortion this band	Useful limit L_{MTD} (max. value in this band)	Consequences on audio quality
Suspension Stiffness $K_{MS}(x)$	Low frequencies ($f < 3f_s$)	< -15 dB	-30 ... -20 dB	Bass performance
Force Factor $Bl(x)$,	Full band	< -20 dB	-40 ... -25 dB	roughness
Inductance $L(x)$	Higher frequencies ($f > 5f_s$)	< -25 dB	-40 ... -25 dB	Roughness, sharpness
Dynamic Range Compressor (DRC)	Full band, low pass	< -25 dB	-40 ... -25 dB	Fluctuation, „Pumping“

Limits depend on expected audio quality !

Limits for Impulsive Distortion

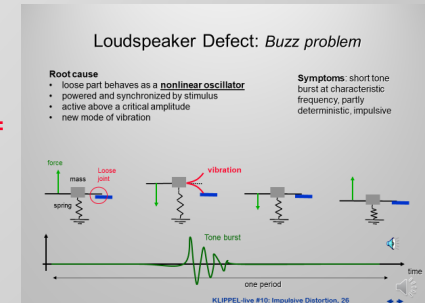
Setup (according IEC 60268-21)

- Stimulus (chirp)
- Impulsive distortion ratio IDR
- Crest factor impulsive distortion CID

Impulsive Distortion reveal

- Irregular behavior of transducer (overload, defects)
- Artifacts of DSP (attack phase)

See KLIPPEL
LIVE #10



Cause	Critical excitation frequencies	Typical impulsive distortion ratio (IDR)	Useful limits (max. value in this band)	Consequences on audio quality
Defect in Woofer ($f_s \approx 50$ Hz)	20 Hz – 200 Hz	-60 ... - 20 dB	$-50 < L_{IDR} < -30$ dB $12 < L_{CID}$	low masking of impulsive distortion in worst case
Defect in Microspeaker ($f_s \approx 500$ Hz)	200Hz – 2kHz	-50 ... - 20 dB	$-40 < L_{IDR} < -30$ dB $12 < L_{CID}$	Some masking by fundamental, regular distortion and hearing threshold
Mechanical Protection System for woofer with low latency	20 Hz – 200 Hz	-60 ... - 30 dB	$-40 < L_{IDR} < -30$ dB $12 < L_{CID}$	low masking of impulsive distortion in worst case
Dynamic Range Compressor (DRC) or Limiter with low latency	Full band	-60 ... - 30 dB	$-50 < L_{IDR} < -30$ dB $12 < L_{CID}$	low masking of impulsive distortion in worst case

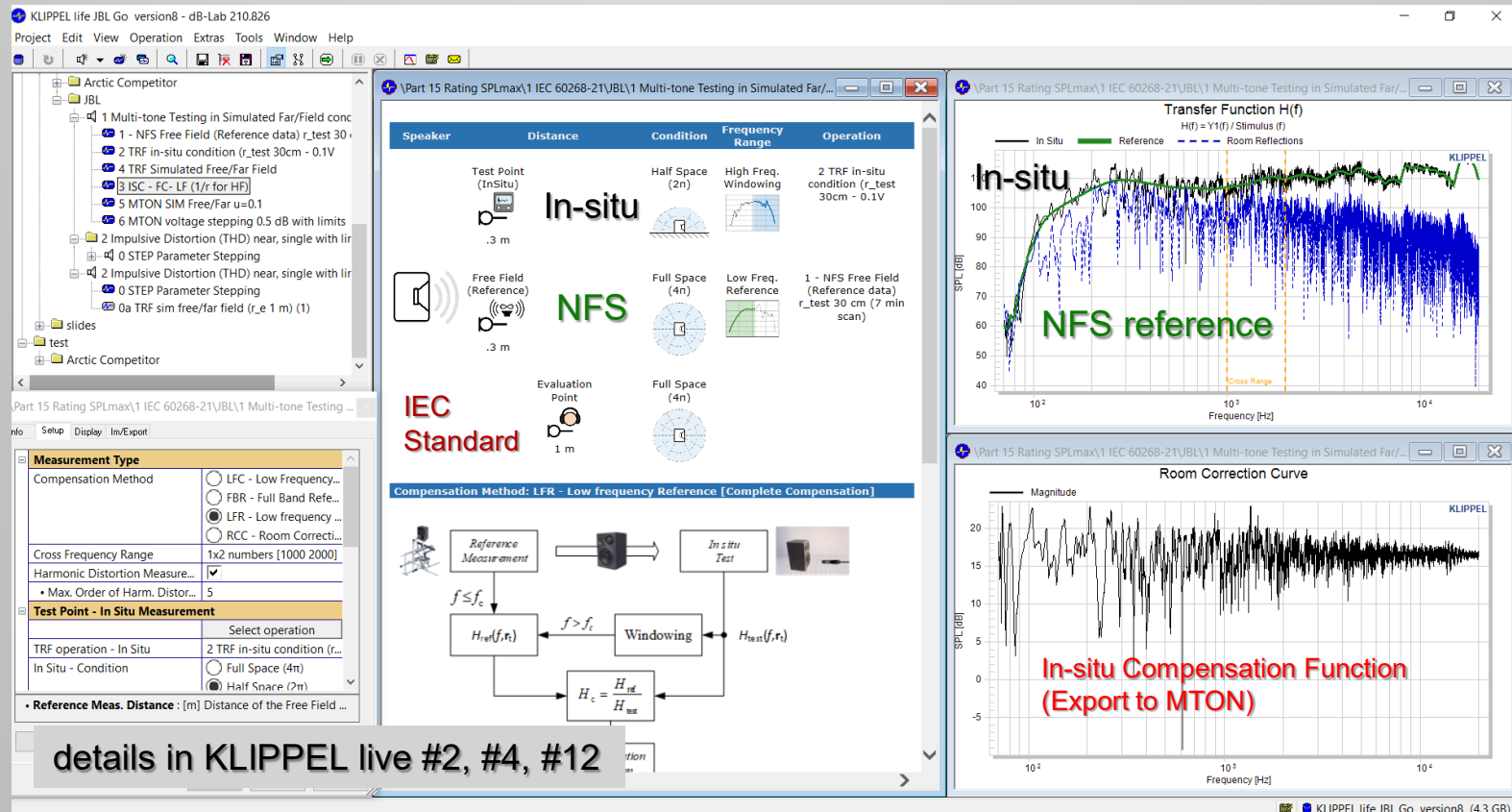
Limits depend on target application (positioning) and expected audio quality !

Integral Test Solution for max. SPL

IEC 60268-21

Step 0: Preparation (if acoustical conditions are not sufficient)

- Ensure fixed room correction curve is valid for the audio device (→ **ISC module**) **KLIPPEL Analyzer**
- Generate simulated far/free field condition by creating an in-situ compensation function for microphone position $r > 0.3\text{m}$ (→ **TRF**, **NFS**, **ISC modules**)



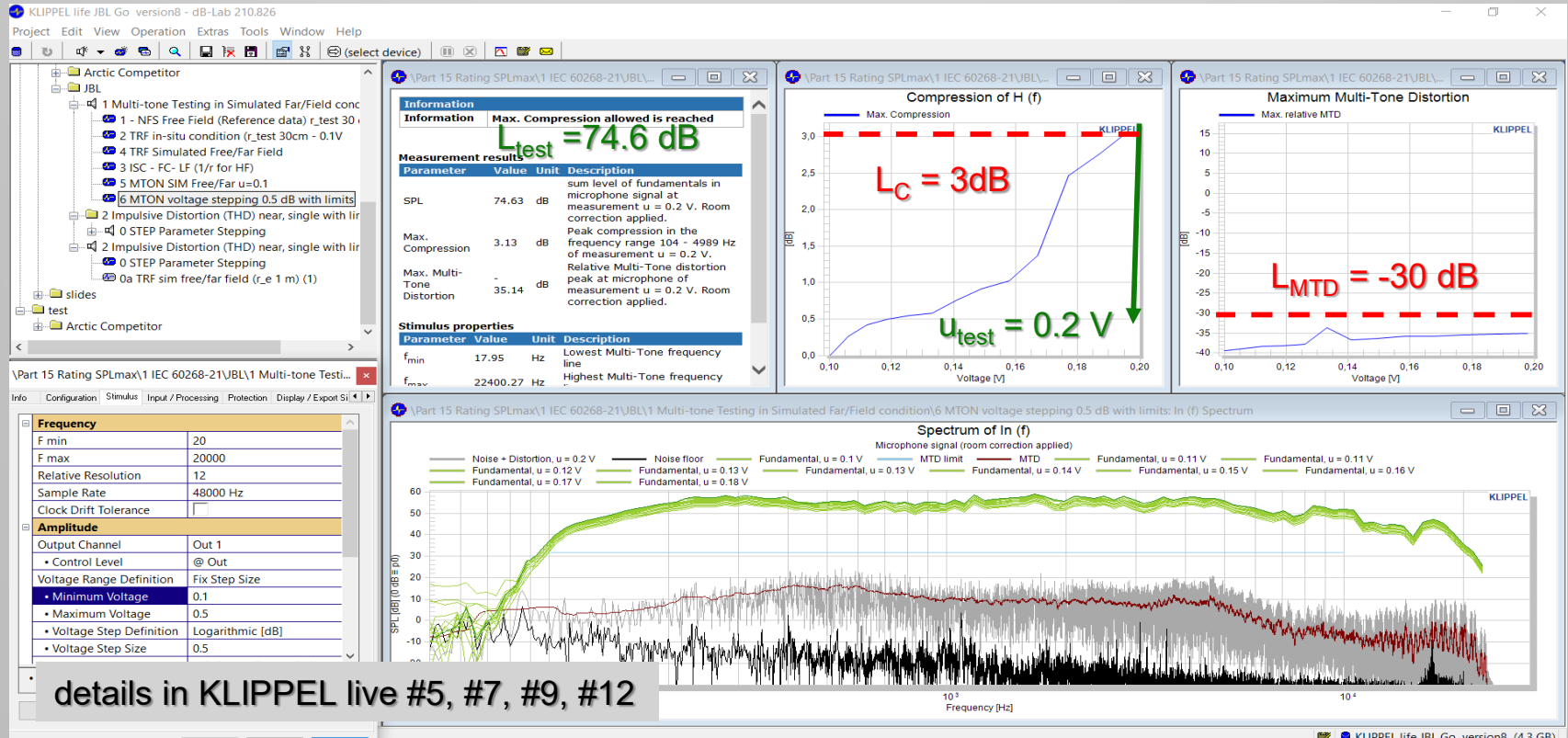
details in KLIPPEL live #2, #4, #12

KLIPPEL Test Solution for max. SPL

IEC 60268-21

Step 1: Far/Free Field Measurement (multi-tone)

- Place microphone at evaluation distance ($r=1\text{m}$) or in-situ test position ($r=0.3\text{m}$)
- shaped multi-tone stimulus with increasing voltage
- Automatic search for maximum input voltage u_{test} and L_{test} where either compression or distortion hit the limits ($\rightarrow$ new MTON module) **KLIPPEL Analyzer**



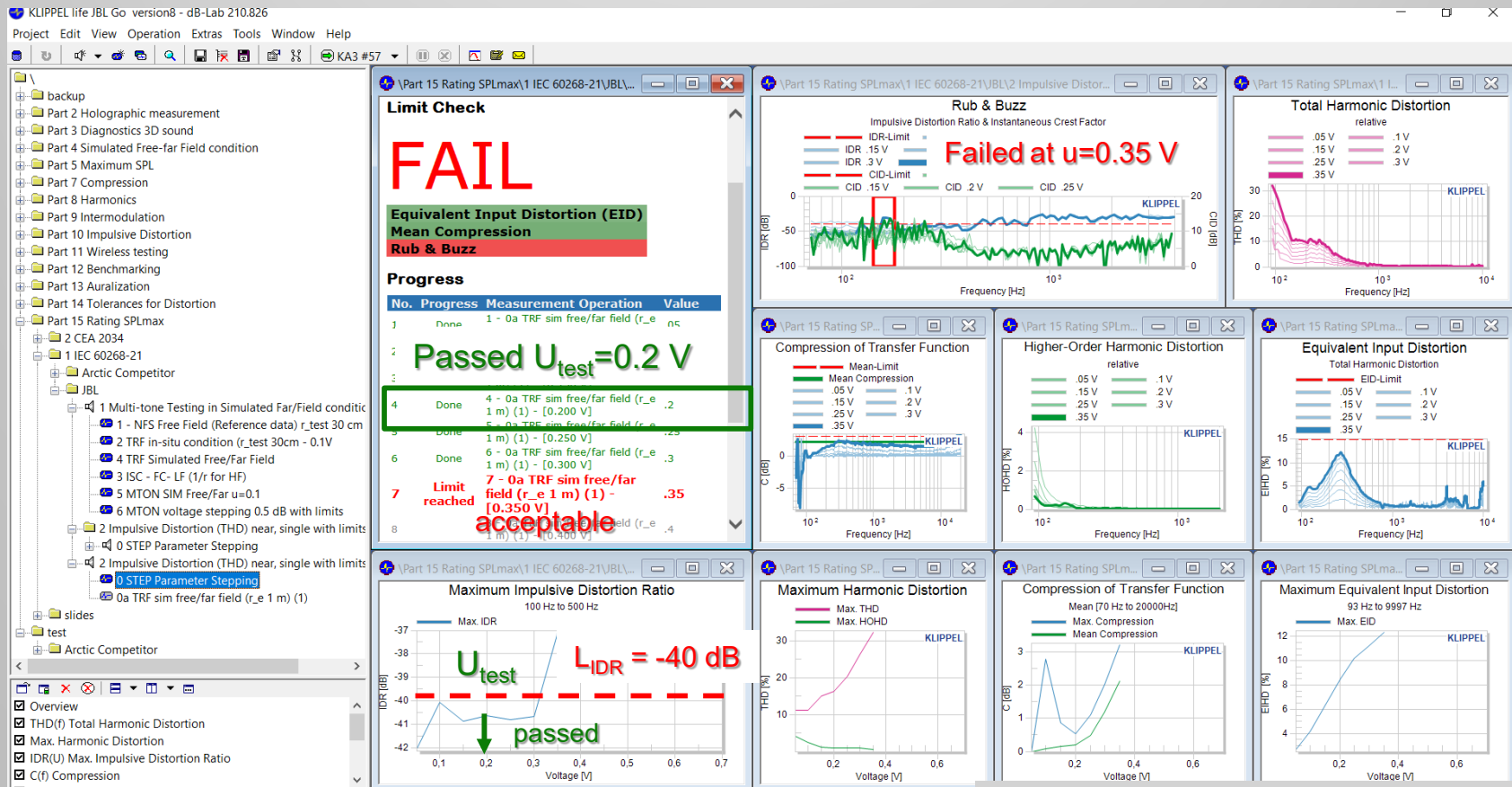
Integral Test Solution for max. SPL

IEC 60268-21

STEP 2: Near Field Measurement (chirp)

- Place microphone close to the diaphragm $r < 5$ cm (best SNR)
- Measure **Impulsive Distortion** (IDR and CID) and harmonic distortion (optional) with increasing voltage u with $0.1u_{\text{test}} < u < u_{\text{test}}$ while checking the limits ($\rightarrow$ new TRF STEP Module)
- IF IDR and CID exceeds the limits create a lower value for u_{test}

KLIPPEL Analyzer



Details in KLIPPEL LIVE #10, #12

KLIPPEL LIVE #15: Rating the maximum SPL , 20



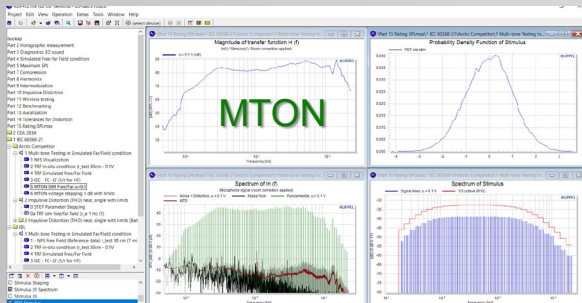
Integral Test Solution for max. SPL

IEC 60268-21

3 Long-term test 100 h (multi-tone)

- Operate the DUT for 100h with the multi-tone signal at u_{test} (**MTON** → Wave Player)
- Check the performance of the DUT and assign $u_{\text{max}} = u_{\text{test}}$ and $\text{maxSPL} = L_{\text{test}}$

KLIPPEL Analyzer



Broadband Stimulus

Wave Player
(new KET module
optimized for endurance
testing coming soon)

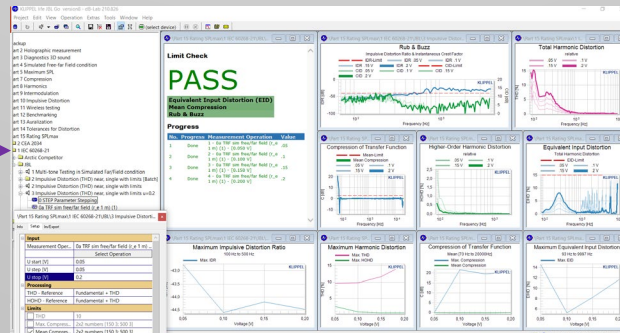


TRF
Stepping



Check Performance

Rate
maximum SPL
74.6 dB



Details in KLIPPEL LIVE **#5**, **#12**

KLIPPEL LIVE **#15**: Rating the maximum SPL , 21



Additional Tests

for defining the test voltage u_{test}

Testing audio quality

KLIPPEL LIVE series

- Harmonic distortion (THD, EHID, chirp stimulus, IEC 60268-21) → [#8](#)
- Harmonic distortion without heating (burst stimulus CTA 2010) → [#15](#)
- Intermodulation distortion (two-tone signal, IEC 60268-21) → [#13](#)
- In-coherence (white or pink noise stimulus) → [#13](#)
- Residuum (audio signal) & auralization signal distortion → [#13](#)

Testing reliability and robustness of the product

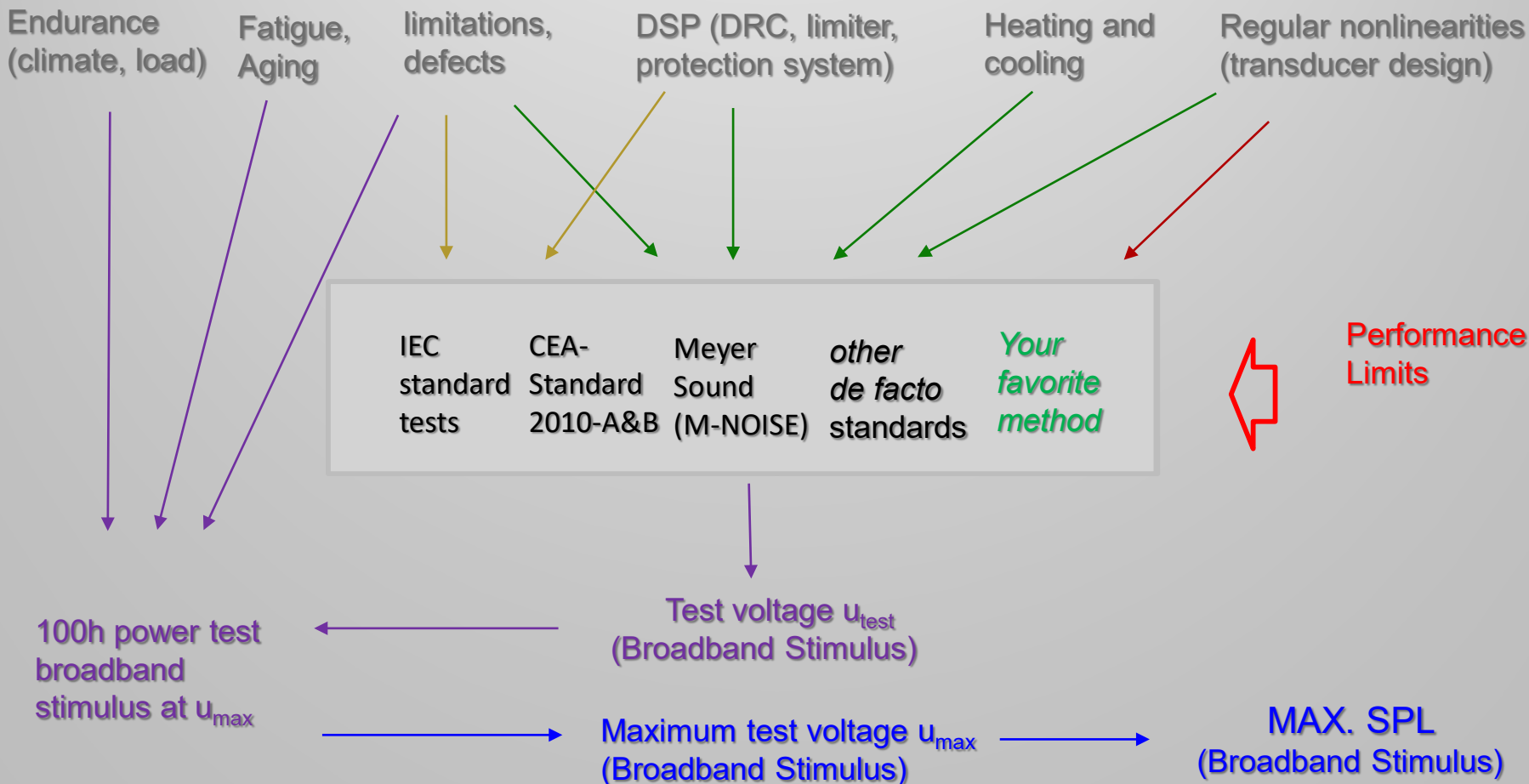
- Destructive testing (short-term and long-term maximum SPL, IEC 60268-21)
- Accelerated life test (critical multi-tone stimulus) → [#5](#)
- Environmental testing (IEC 60268-22)

Comparison with Other Approaches

	IEC STANDARD 60268-21	CEA-Standard 2010-A&B + 2034	Meyer Sound (M-NOISE)
Max. SPL value	Rated value according to particular application	Calculated value based on two tests with fixed limits	Measured value in a single test
Requirements	DUT generates max. SPL and handles maximum input level (100h test required)	DUT generates max. SPL at fixed limits in long-term compression (3 dB) and in harmonic distortion	DUT generates max. SPL at fixed limits in long-term compression (2 dB)
Stimulus	User defined broadband signal (shaped multitone)	- Shaped pink noise (preheating 1min) - Burst Signal	Special M-NOISE signal (dense full band) with preheating (5 min)
Audio quality	not defined (depends on target application)	not completely defined (important physical and perceptual aspects are missing)	not completely defined (important physical and perceptual aspects are missing)

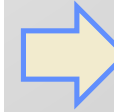
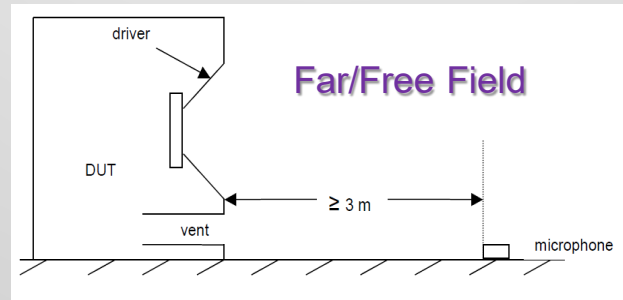
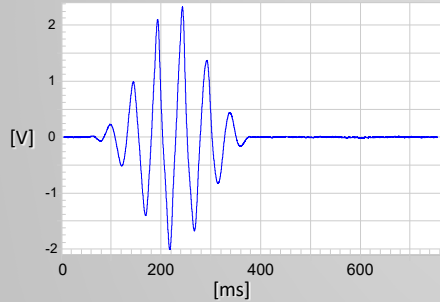
Harmonizing other Standards or Practices with IEC 60268-21

PROPERTIES OF THE AUDIO DEVICE

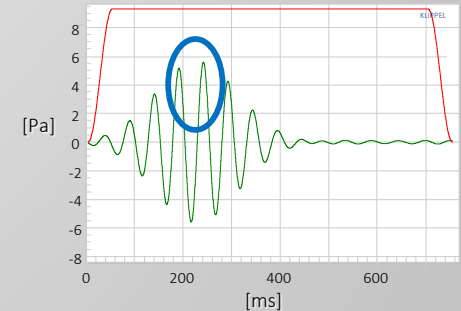


Burst Test (CEA-2010-A)

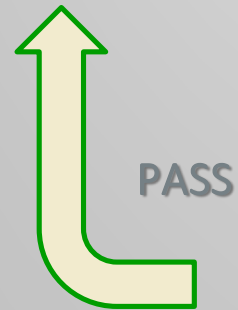
Stimulus



Microphone Signal



Increase
Voltage

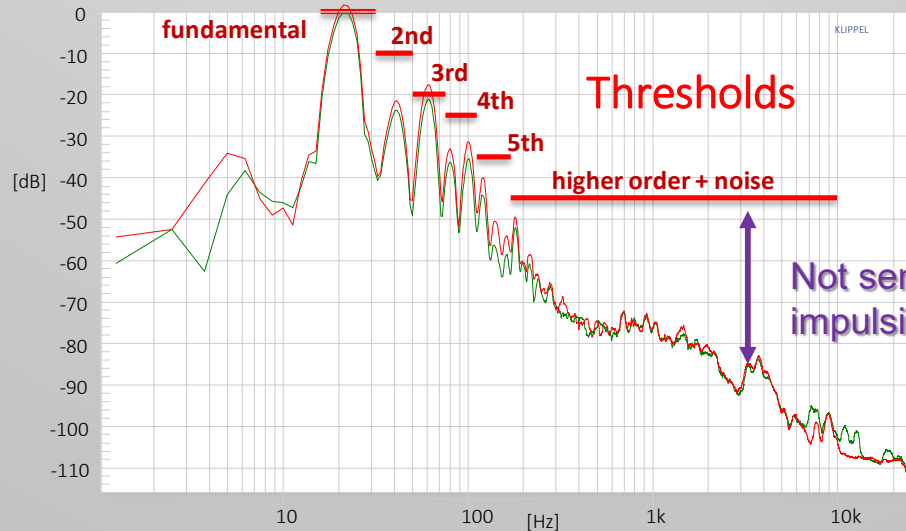


PASS

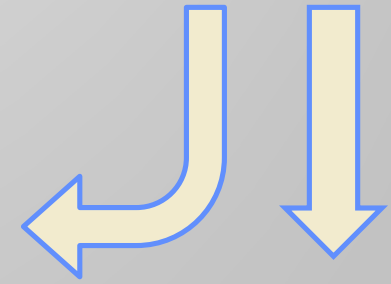


FAIL

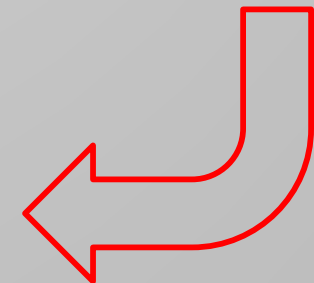
Limit Check



Maximum SPL_{burst}
(last passed peak value)



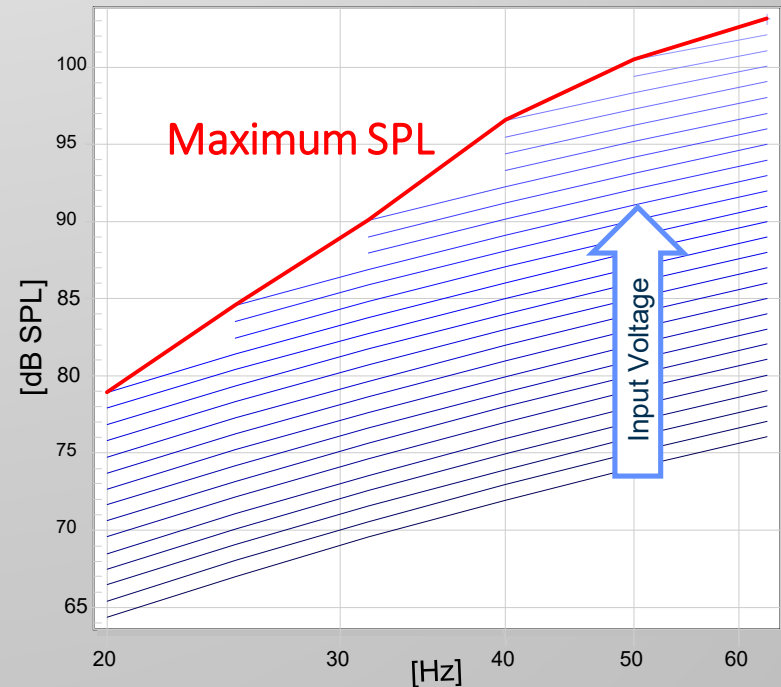
Peak Value



Burst Test Results

SPL_{MAX} referenced to 1m and 2.83V

Tone Burst Center Frequency (Hz)	Maximum SPL	CEA-2010 Rating
20	79	84
25	85	
31.5	89	
40	96	100
50	101	
63	104	



Room effects must be compensated for low frequencies

Burst Test in CEA 2010 A

Benefit:

Human ear is very sensitive for harmonic distortion, impulsive distortion and (modulated) noise for low frequency bursts $f < 200$ Hz

Problems:

- Far/free field condition required (room modes can generate a significant error !!)
- Test is not sensitive for impulsive distortion (energy based)
- Poor SNR (ambient noise) reduces max SPL!

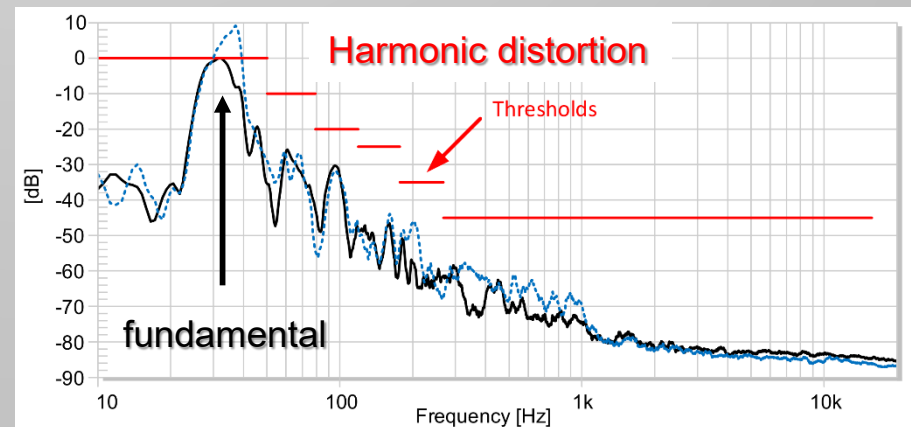
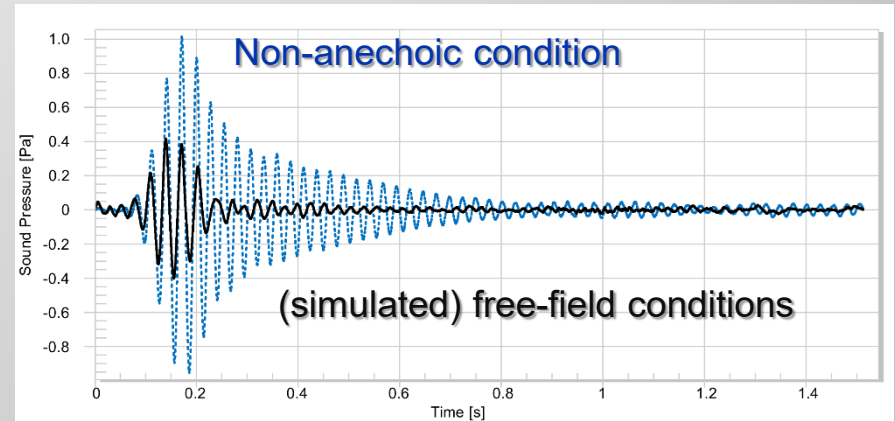
Problem: Room Modes

Problems:

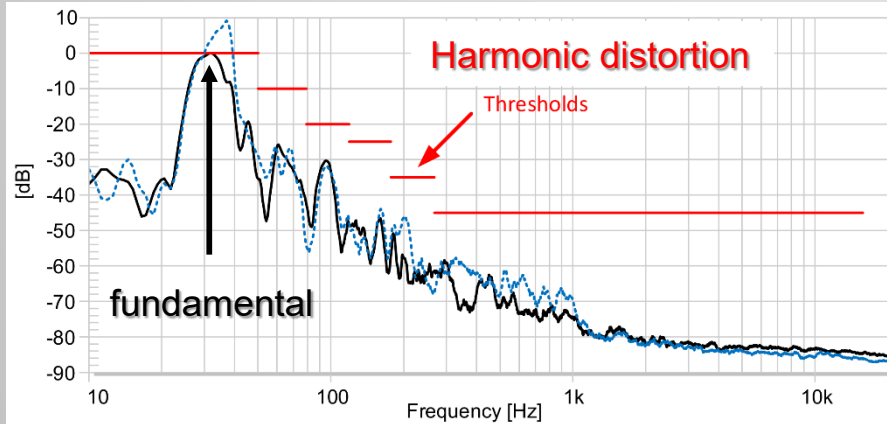
- CEA 2010 requires (simulated) far/free field conditions
- Room modes are narrow band resonances which affect the measured sound pressure in the far field

Symptoms:

- Asymmetrical envelope of the reproduced burst signal (ringing)
- Harmonics distortion affected
- Larger sound pressure SPL peak value (10 dB)

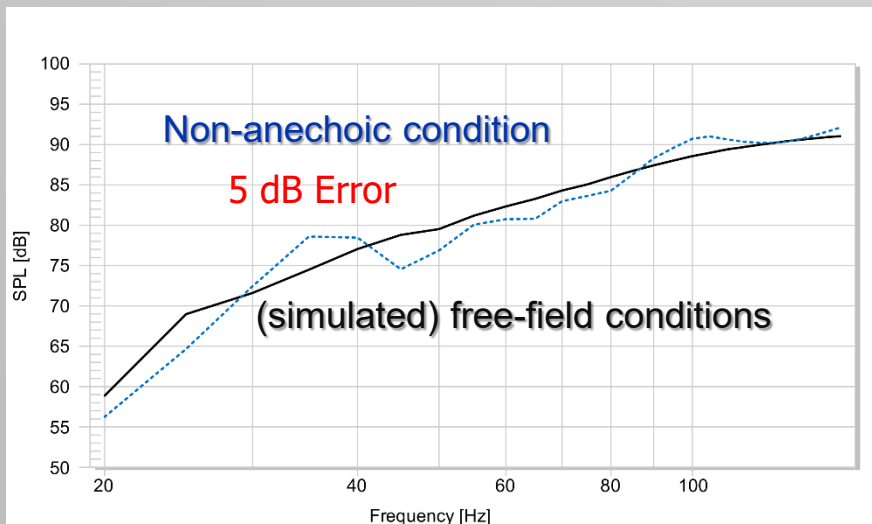


Room Modes (2)



Problem:

The room modes generate a significant error in the maximum SPL value



a complex compensation filter for simulated far/free field can solve this problem

KLIPPEL LIVE #4



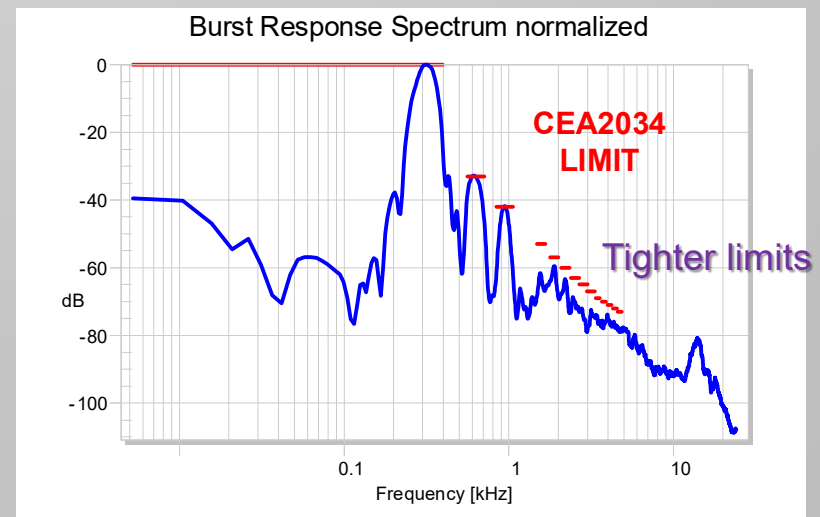
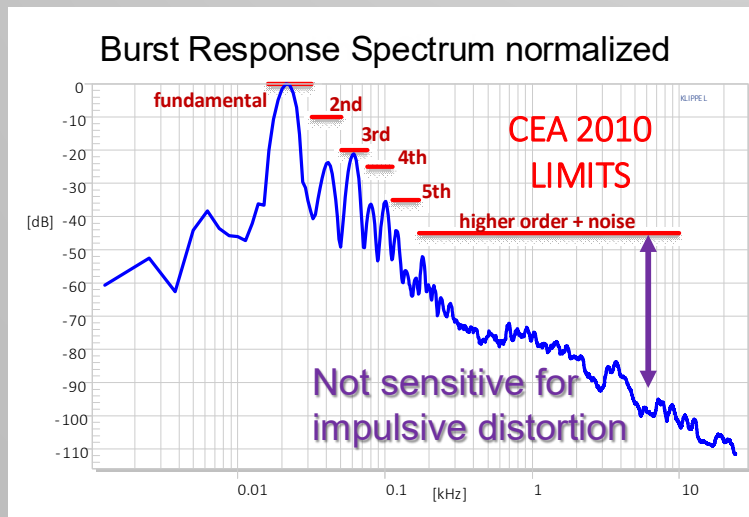
Burst Test in CEA 2034

Intention:

- Applying burst test to other (full-band) consumer products
- Improving sensitivity for irregular distortion, rub&buzz, defects

Solution:

Sensitive limits for harmonic distortion and noise

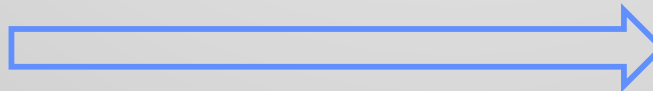


Broadband Peak SPL Data

calculated in CEA 2034

Results from
Burst Measurement

Frequency [Hz]	Peak SPL [dB]
20	119.95
25	120
32	120.03
40	120.04
50	120.07
63	120.07
80	120.07
100	120.07
125	120.07
160	120.07
200	120.08
250	120.08
315	120.08
400	120.08
500	120.08
630	102.68
800	120.08
1000	120.07
1250	120.08
1600	120.06
2000	120.07
2500	120.01
3150	120.04
4000	120.03
5000	119.75



Data Post-processing

- Limiting the weighted SPL values using an average value
- Summing the squared pressure

6.2.3 Max Peak SPL Data Post-Processing

- The recorded peak SPL at each 1/3 octave band shall be weighted by the power spectrum given in Table 1 (6.1.1).
- The Average Weighted SPL shall be calculated by averaging the weighted SPL values from 100 Hz to 5 kHz, inclusive.
- The weighted SPL for any 1/3 octave band exceeding the Average Weighted SPL by 2 dB shall be reduced to a value of the Average Weighted SPL plus 2 dB.
- The weighted & limited SPL in each 1/3 octave band shall be converted to its squared-pressure value ($p^2 = 10^{(SPL/10)}$)
- The sum of all of the squared-pressure values for each 1/3 octave band shall be calculated.
- The SPL of the summed squared-pressure shall be calculated ($SPL = 10\log(\sum(p^2))$).
- The Broadband Peak SPL shall be the SPL of the summed squared-pressure minus 14 dB.

Frequency [Hz]	Weighted & limited Maximum SPL [dB]	CEA2034 - Broadband Peak SPL [dB]
20	117	119.00
25	119	
32	119	
40	120	
50	120	
63	120	
80	120	
100	120	
125	120	
160	120	
200	120	
250	120	
315	120	
400	120	
500	120	
630	103	
800	120	
1000	120	
1250	120	
1600	119	
2000	119	
2500	119	
3150	118	
4000	117	
5000	115	

Maximum SPL Calculation

according CEA 2034

Broadband Peak SPL L_{peak}
(measured with burst stimulus)

Maximum Usable Continuous Output SPL L_{con}
(measured with noise stimulus)

$$L_{\text{peak}} - L_{\text{con}} < 9\text{dB}$$

$$L_{\text{peak}} - L_{\text{con}} \geq 9\text{dB}$$

Maximum SPL
 $L_{\text{max}} = L_{\text{peak}} - 9\text{dB}$

*Harmonics + Noise
limits Maximum SPL*

Maximum SPL
 $L_{\text{max}} = L_{\text{con}}$

*Long-term usable
continuous (heating) limits
Maximum SPL*

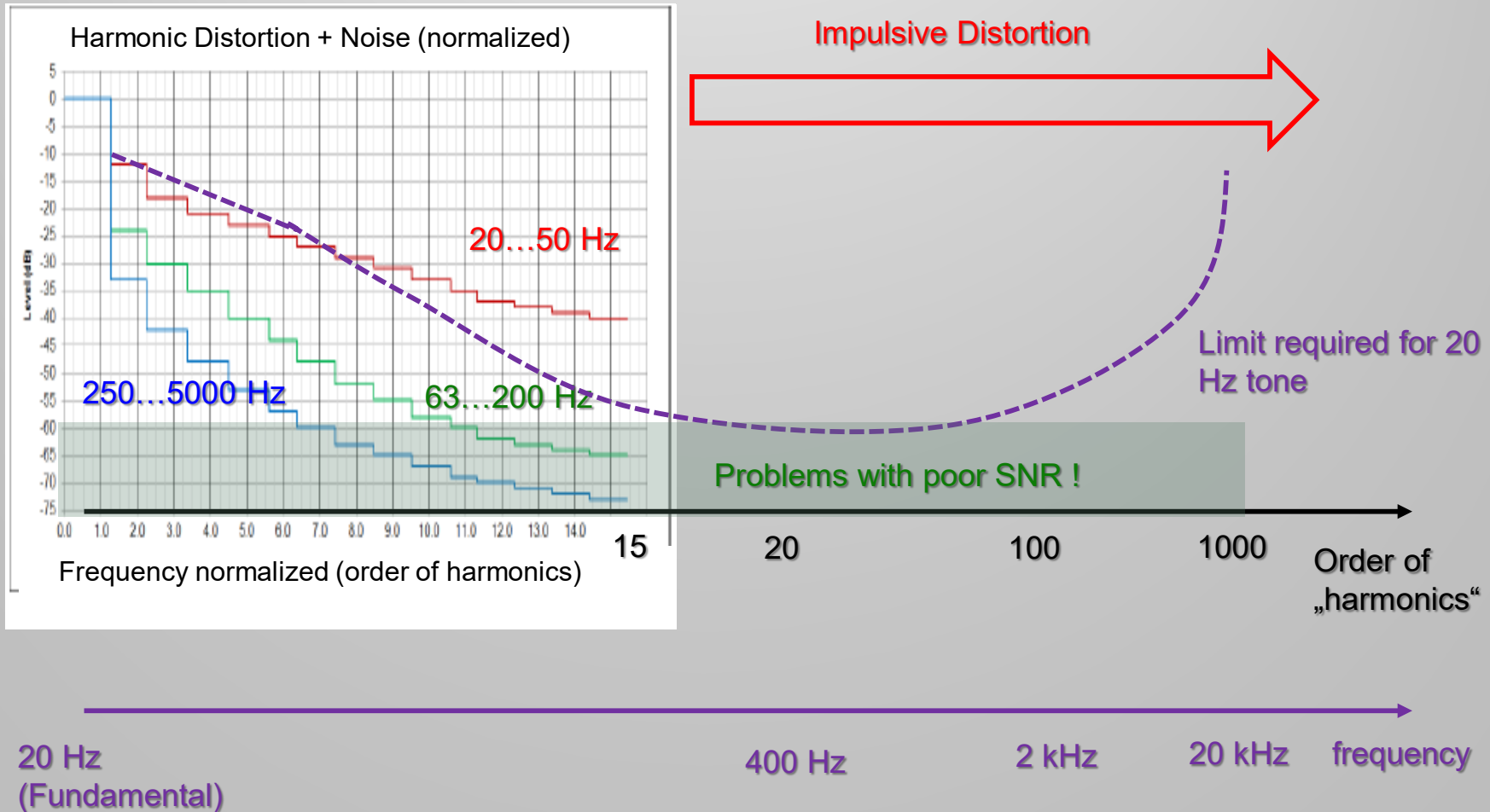
Problems in CEA 2034

KLIPPEL LIVE series

- Intermodulation distortion is not considered (fluctuation and roughness sensation → KLIPPEL live [#14](#))
- Listening becomes less meaningful at higher burst frequencies $f > 500$ Hz (burst too short < 100 ms) → [#14](#)
- Burst stimulus is too short to wake up power saving mode in modern audio devices → [#7](#)
- Poor sensitivity for impulsive distortion (rub&buzz and other defects) → [#10](#)
- Ambient noise (poor SNR) reduces max. SPL in small speakers
- Averaging proposed by CEA 2034 reduces sensitivity for all regular distortion (random properties) → [#10](#)
- (simulated) far/free field condition required → [#4](#)

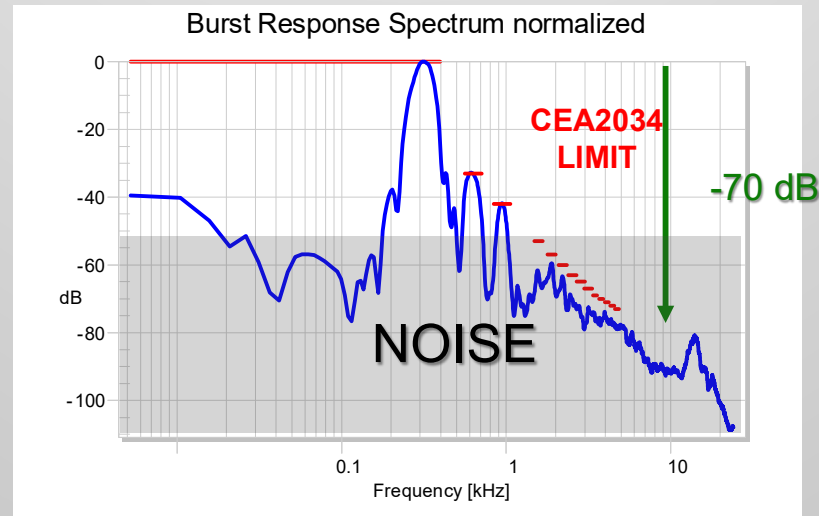
Poor Sensitivity for Impulsive Distortion

a problem in CEA 2034



Ambient Noise Immunity in Burst Test

Problem in CEA 2010 & 2034



Problems:

- Ambient noise reduces max. SPL
- CEA 2034 recommends averaging to improve SNR which reduces sensitivity for irregular distortion with random properties

Solution for SNR problem:

1. determine $u_{\max, \text{burst}}(f)$ based on distortion limits in near field (5cm) (**20dB more SNR !**)
2. Measure maximum peak $\text{SPL}_{\text{burst}}(f)$ in (simulated) far field using $u_{\max, \text{burst}}(f)$

KLIPPEL Test Solution for maxSPL

according to CEA 2010A and CEA 2034

0 Preparation (if acoustical conditions are not sufficient)

KLIPPEL Analyzer

- a) Ensure fixed room correction curve is valid for the audio device (→ ISC module)
- b) Generate simulated far/free field condition by creating an in-situ compensation function for microphone position $r > 0.3\text{m}$ (→ TRF, NFS, ISC modules)

1 Far/Free Field Measurement (continuous, multi-tone)

- a) Place microphone at evaluation distance ($r = 1\text{m}$) or in-situ test position ($r = 0.3\text{m}$)
- b) shaped multi-tone stimulus with increasing voltage
- c) Automatic search for maximum test voltage u_{con} and SPL_{con} where either compression or distortion hit the limits (→ new MTON module)

2 Near Field Measurement (burst)

- a) Place microphone close to the diaphragm $r < 5\text{ cm}$ (best SNR)
- b) Automatic search for maximum test voltage $u_{\text{burst}}(f)$ where **normalized** harmonic distortion exceeds the limits (→ new TBM module)

3 Far/Free Field Measurement (burst)

- a) Place microphone at evaluation distance ($r = 1\text{m}$) or in-situ test position ($r = 0.3\text{m}$)
- b) Measure maximum SPL at maximum test voltage $u_{\text{burst}}(f)$ where **normalized** harmonic distortion exceeds the limits (→ new TBM module)

4 Assignment of maxSPL

- a) Calculate maxSPL based on SPL_{con} and $\text{SPL}_{\text{burst}}$
- b) Perform **100h test** to comply with IEC 60268-21 (optional but strongly recommended)

At the end: What is important ?

Message of IEC 60268-21:

- Use the **freedom** provided by IEC 60268-21
- Clearly define and document the **test conditions**
- Consider **reliability** and **endurance** and check it with a 100 h power test at $u_{\max}$
- Provide maxSPL value together with **documented** measurement conditions to your coworkers, suppliers and customers (standard simplifies the effort !)

THEN

MaxSPL becomes a **meaningful** number for

- Calibrating the input of active systems → #5 KLIPPEL LIVE series
- Benchmarking of audio products → #12
- Making better products as seen by the end user → #14

Discussion

Conclusions

- OUTPUT based measurements can provide a comprehensive evaluation of audio system
- DSP algorithms, wireless transmission, smart amplifiers need modern measurement techniques
- IEC Standard 60268-21 is a good basis and is ready for your application
- Provide any feedback (errors, new ideas) to IEC or AES standard committees
- Perceptual modeling and auralization techniques can further reduce the gap between listening and measurement (future standard project ?)

Share and Use the Material

KLIPPEL LIVE “Acoustical Measurement of Sound System Equipment according IEC 60268-21” ?

1. Free access to the recorded webinars on www.klippel.de
2. Contact rnd-support@klippel.de if you
 - need more detailed information,
 - found errors, have some suggestions or new ideas,
 - need software and templates for practical evaluation with free demo license,
 - other things



OUTLOOK

A new KLIPPEL Live webinar series entitled
“Electrical and Mechanical Measurement of Transducers and Systems according IEC 60268-22”

will address the points:

- Considering fundamental physical relationships
- Exploiting the power of loudspeaker modeling (lumped, modal, finite element, system oriented...)
- Identification of free model parameters
- Optimal design and product development
- Consequences for DSP development
- And much more