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

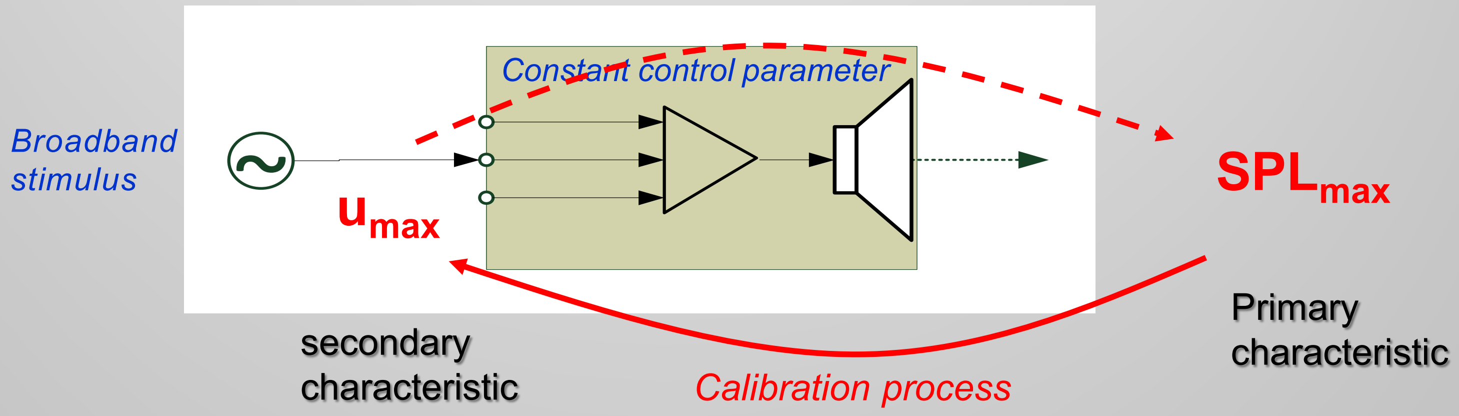
5th KLIPPEL LIVE:
Maximum SPL – giving this value meaning

Topics today:

1. Relationship between SPL_{max} and the rated stimulus
2. Characteristics describing the stimulus properties
3. Kurtosis – a powerful alternative for the crest factor
4. Calibration of the input channel in active audio devices
5. Practical demonstration

Maximum Input and Output Value

Discussed in 1st Webinar: click here!



Rated maximum input voltage u_{max}

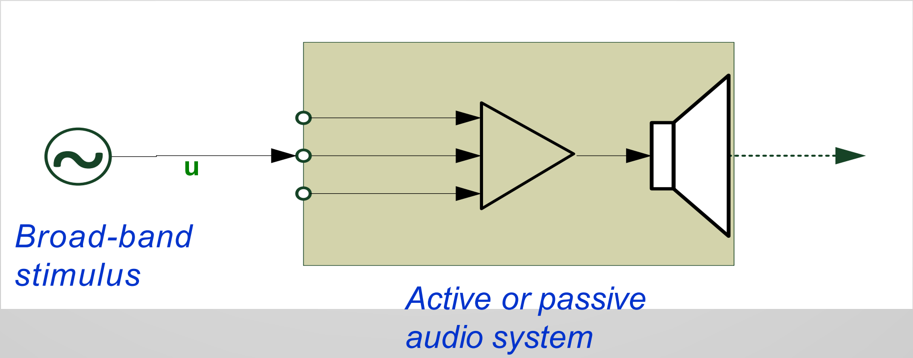
- Good for (passive) systems with a single input and constant transfer function between input and output
- Depends on the input channel
- Depends on the control parameter

Rated maximum (output) SPL_{max}

- Universal approach for passive and active systems
- Can be applied to any input channel
- Can cope with gain controllers, equalizers, limiters, protection systems, ect.

Who determines the maximum SPL value ?

Discussed in 1st Webinar: click here!



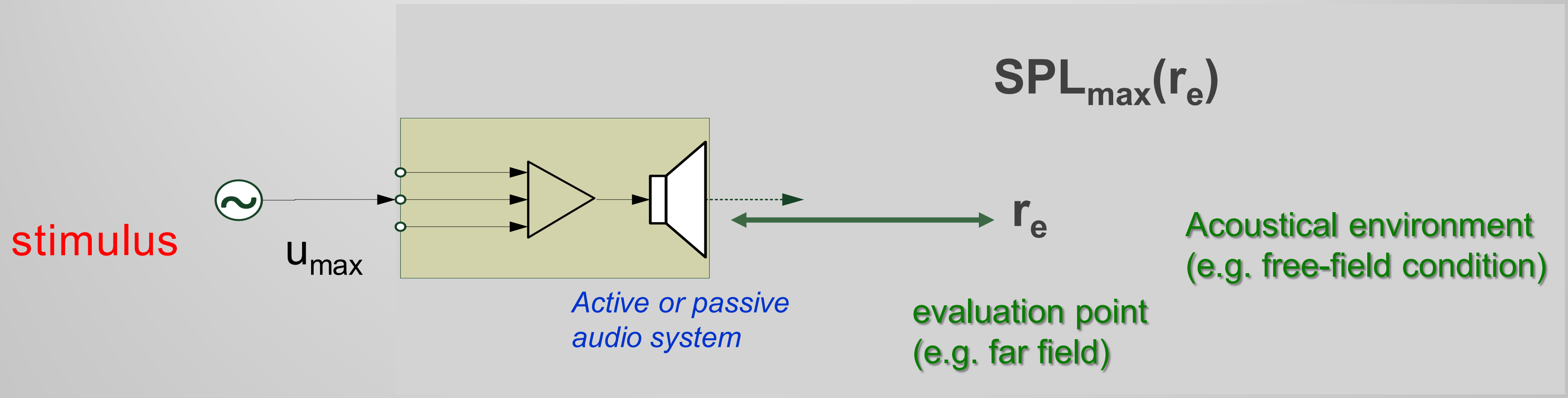
$SPL_{max}(r_e)$

Definition by IEC 60268-21
- Manufacturer rates the measurement condition (e.g. stimulus, position, environment)
- Manufacturer rates SPL_{max} based on information from design, practical measurements and the target application

Requirement
- DUT can reproduce a defined broadband stimulus at rated maximum SPL
- DUT will **not be damaged** by the stimulus during 100h power test

Benefit
- Maximum SPL value is meaningful for engineering, marketing, final user

Rated Conditions for SPLmax



Webinars 1-3 covered the conditions of the acoustical environment and positioning of the audio system and the microphone

Requirements for the stimulus used for rating SPLmax

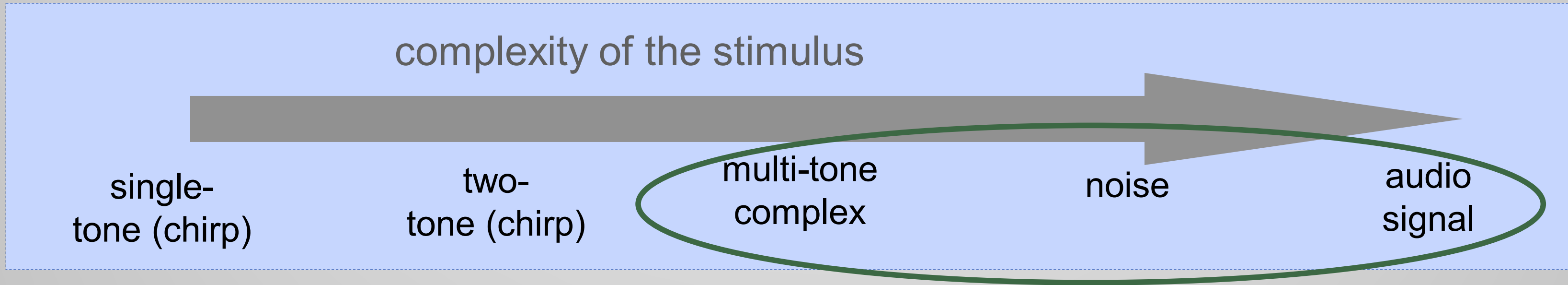
- The test signal represents typical program material in the final application
- The same test signal is used for calibrating the input channel and determining the maximum input voltage u_{max}
- Same test signal at maximum input voltage u_{max} is used in a 100 h long-term tests

Poll:

What kind of test signal do you use for your long-term testing (100h power test) ?

- A single tone
- A sinusoidal chirp signal covering a defined frequency band
- Random noise or a sparse multi-tone complex
- Music or other selected audio material

“Broad-band” Stimulus required for SPL_{max}



A broad-band stimuli

- considers SPL frequency dependency
- activates all transducer nonlinearities
- causes typical voice coil heating
- provides force convection cooling
- Activates the DSP (limiting, compression, active protection)

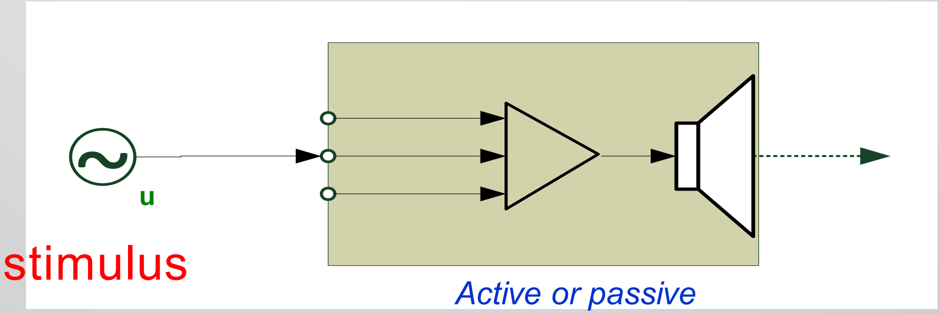
Examples

- Simulated normal program material IEC 60268-21
- Continuous, broadband noise according CTA 2010B
- M-noise as proposed by Meyer-Sound
- Multi-tone complex as recommended by IEC 60268-21
- Selected audio material (music)
- others

Rated Conditions: Test Stimulus

Discussed in 1st Webinar: click here!

f_l f_u



$SPL_{max}(r_e)$

Stimulus Properties (IEC 60268-21) stated by the manufacturer:

- Broadband (pink or white noise, dense or sparse multi-tone complex)
- Lower and upper limits f_l and f_u of the rated frequency band
- Shaping of the power spectrum (e.g. typical program material IEC 60268-1)
- Crest factor (Kurtosis)

There is a lot of freedom for modifying the stimulus!

Main Objective: The test stimulus shall represent the typical program material in the final application !

How to Describe the Stimulus ?

complexity of the stimulus

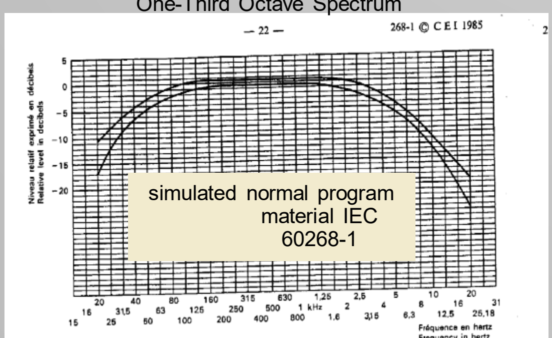
single-tone (chirp) → two-tone (chirp) → multi-tone complex → noise → audio signal

Spectral Distribution
- power spectrum
- one-third octave spectrum
- rated frequency range (bandpass)
- shaping function

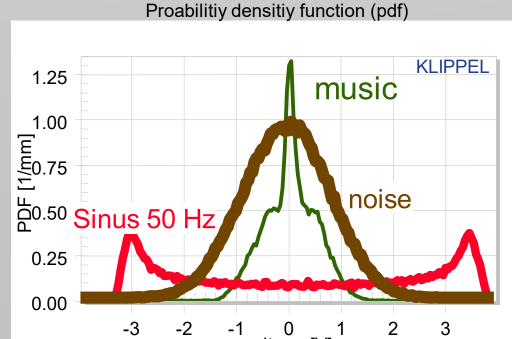
Amplitude Distribution
- probability density function (pdf)
- peak value
- rms value
- crest factor (peak/rms ratio)
- higher-order moments (kurtosis)

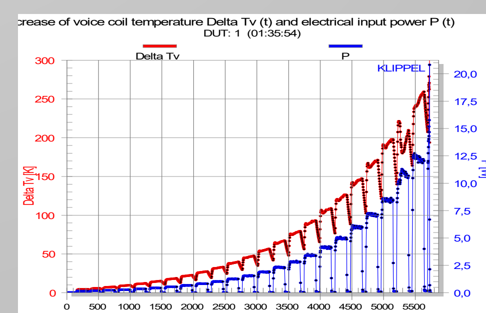
Temporal Properties
- stationarity
- autocorrelation
- periodicity
- modulation (on/off cycle, amplitude stepping)

One-Third Octave Spectrum



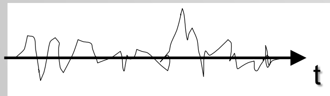
Proabilitiy densitiy function (pdf)



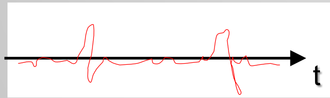


Basic Signal Characteristics

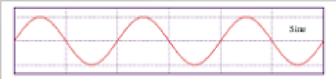
no DC component (zero mean value)



Gaussian noise



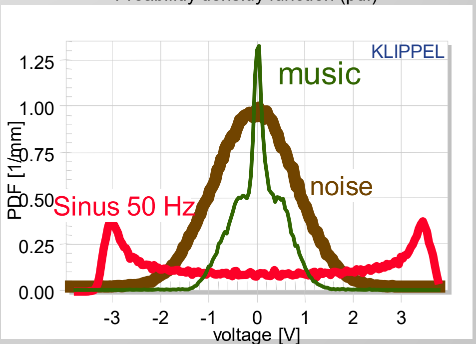
music



Sinusoidal wave

Amplitude Distribution

Proabilitiy densitiy function (pdf)



rms value (standard variation) :

$$x_{rms}^2 \approx \overline{x(t)^2} = \frac{1}{T}\int_{-T/2}^{T/2} x(t)^2\,dt \quad \longleftrightarrow \quad x_{rms}^2 = \int_{-\infty}^{\infty} x^2 p_{pdf}(x)\,dx$$

(2nd-order moment)

peak value:

$$x_{peak} = \underset{-T/2}{\overset{T/2}{Max}} |x(t)|$$

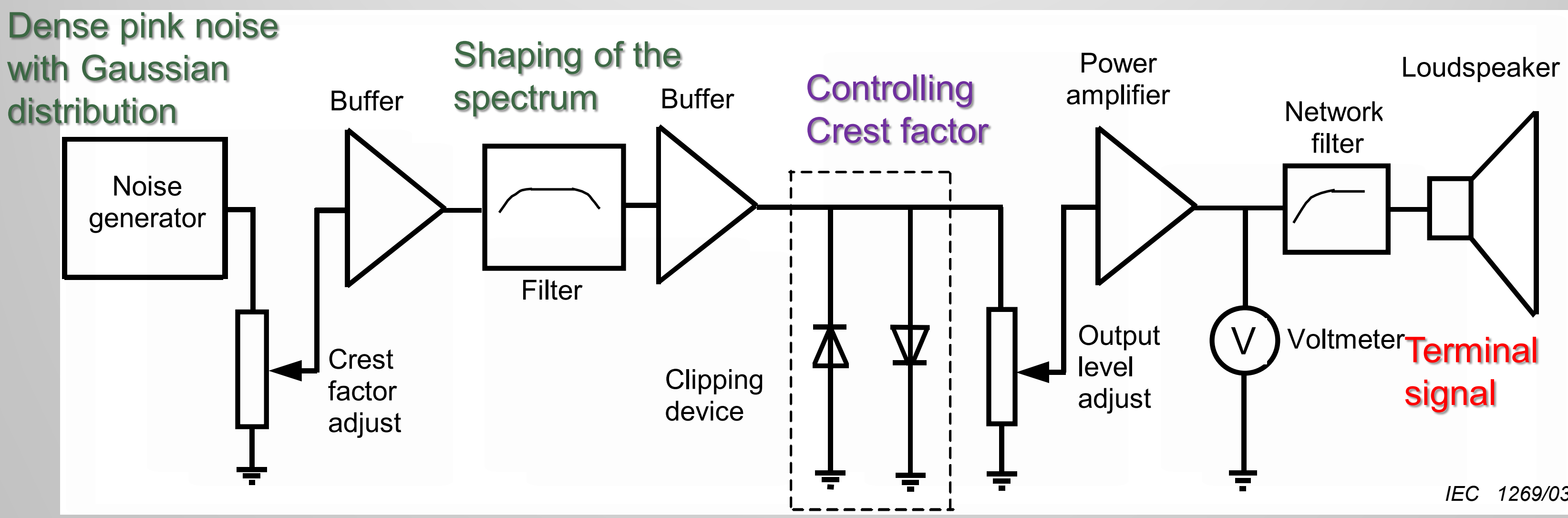
crest factor

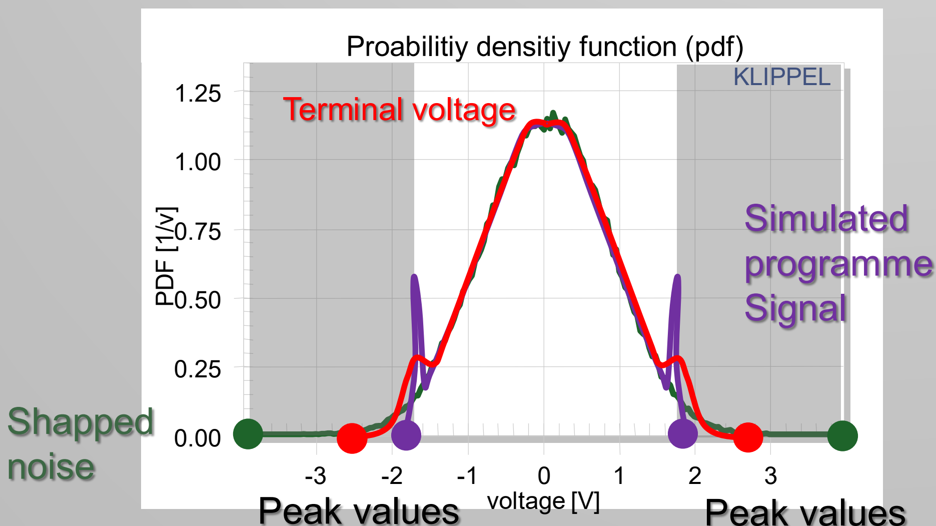
$$C_x = \frac{x_{peak}}{x_{rms}} \qquad C_{x,dB} = 20\lg\left(\frac{x_{peak}}{x_{rms}}\right) dB$$

Problem: Crest factor depends
on a (single) peak value !

Simulated Programme Signal

IEC 60268-21



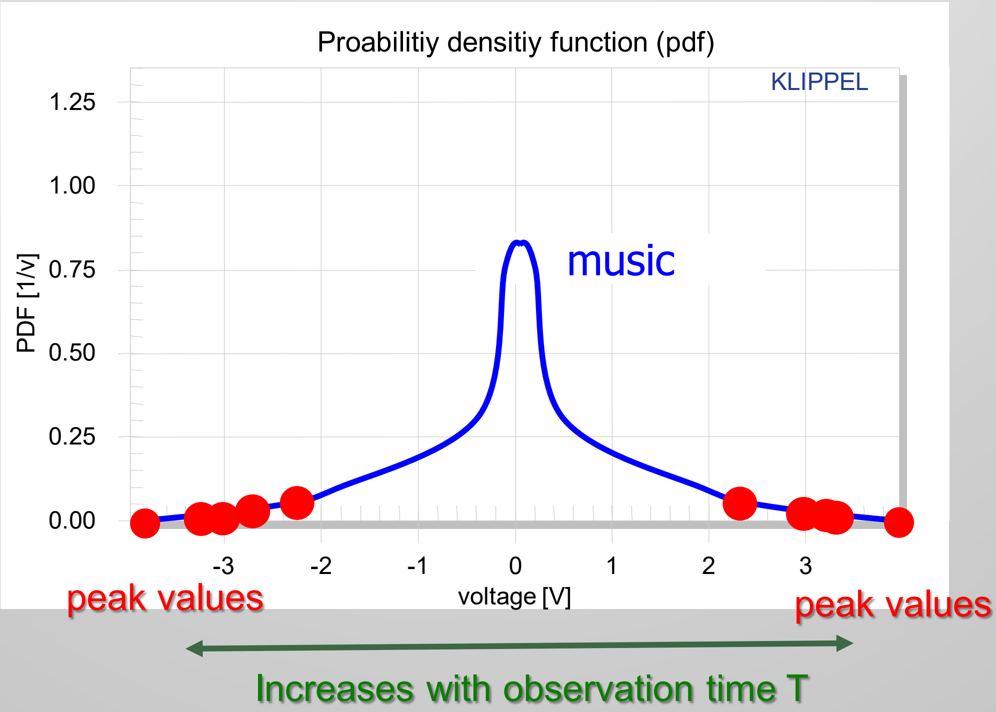


- Controlled Crest factor at amplifier input
- Amplifier clipping can be avoided
- Defined amplitude at amplifier output

Problem:

- Any following filter (crossover) will change the crest factor significantly

How meaningful is a Crest Factor ?



- Statistics depends on a single value (How to define a peak value ?)
- Crest factor value increases for longer observation time T
- High variance of measured crest factor for audio signals (music)
- Less suitable for assessing heating, mechanical load, fatigue, aging

Problem: We need a more robust statistical characteristic !

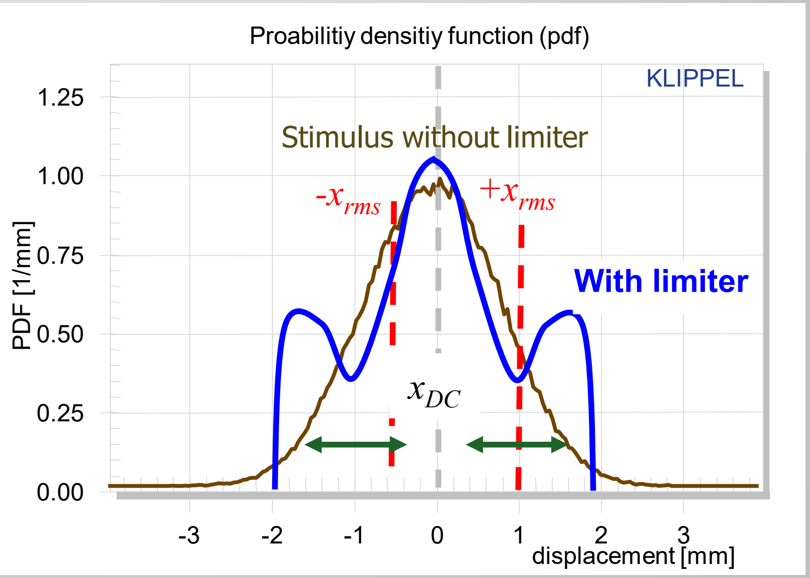
Solution: Evaluate the distribution mass (4th-order moment → **Kurtosis**) !

Kurtosis – an important characteristic

Kurtosis (fourth standardized moment):

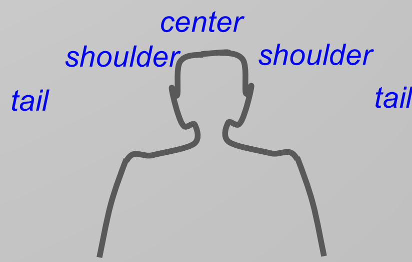
$$\kappa = \overline{\left(\frac{x(t)}{x_{rms}}\right)^4} = \frac{1}{T}\int_{-T/2}^{T/2}\left(\frac{x(t)}{x_{rms}}\right)^4 dt$$

$$\kappa = \int_{-\infty}^{\infty}\left(\frac{x}{x_{rms}}\right)^4 p_{pdf}(x)dx$$



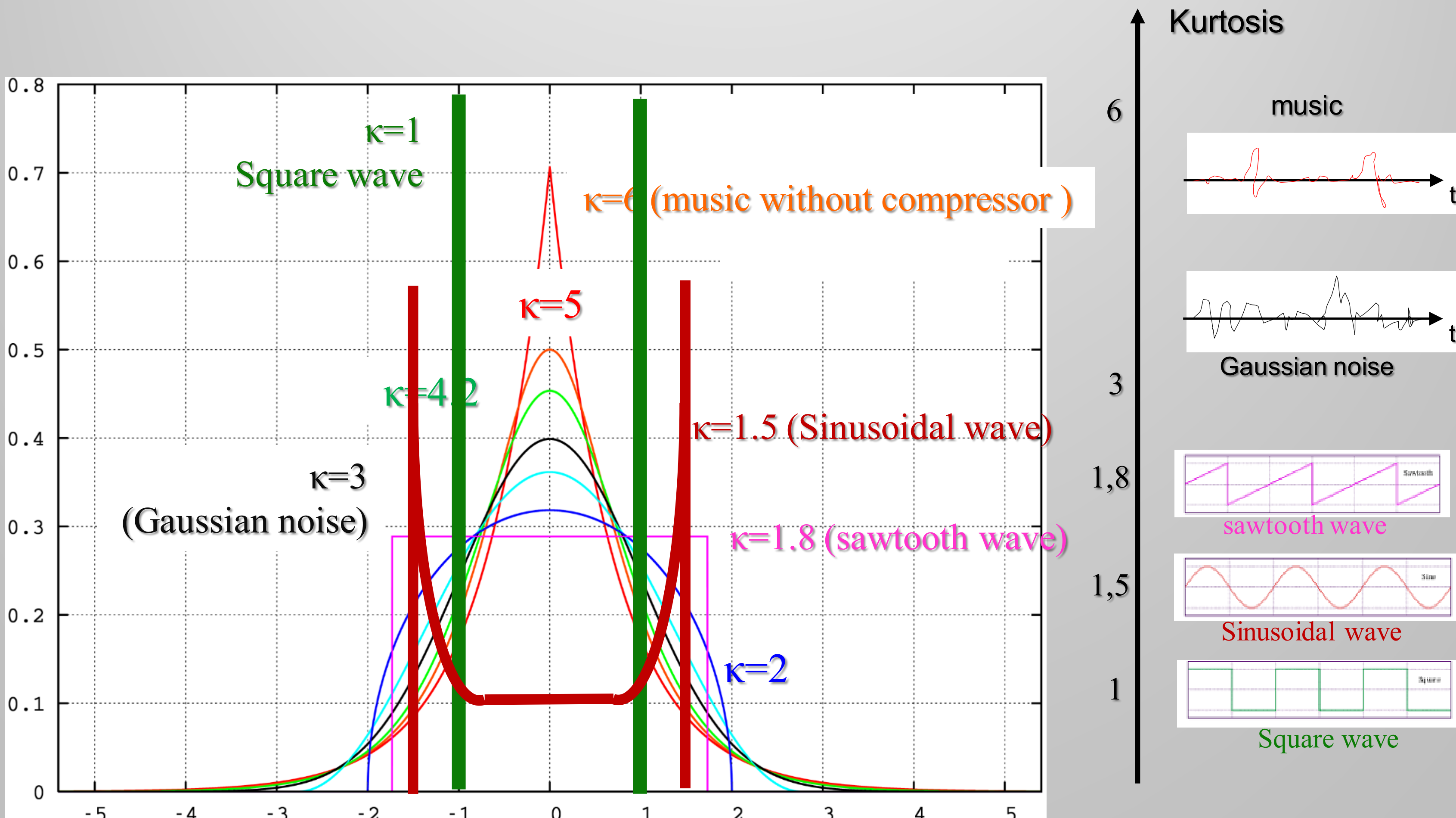
Interpretation:

- kurtosis is a measure of the dispersion of x around the rms value values x_{rms} (Moors 1986)
- kurtosis becomes higher if probability mass is moved from the shoulders of a distribution into its center and tails (Balanda and MacGillivray 1988)



Kurtosis of Common Signals

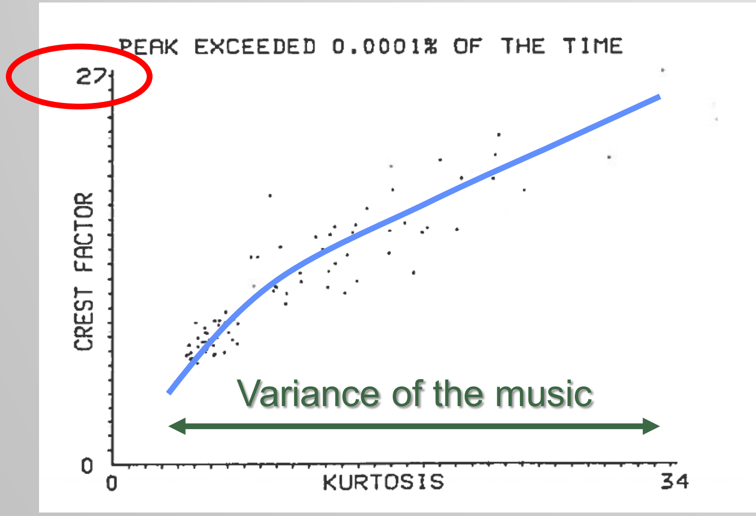
fourth standardized moment

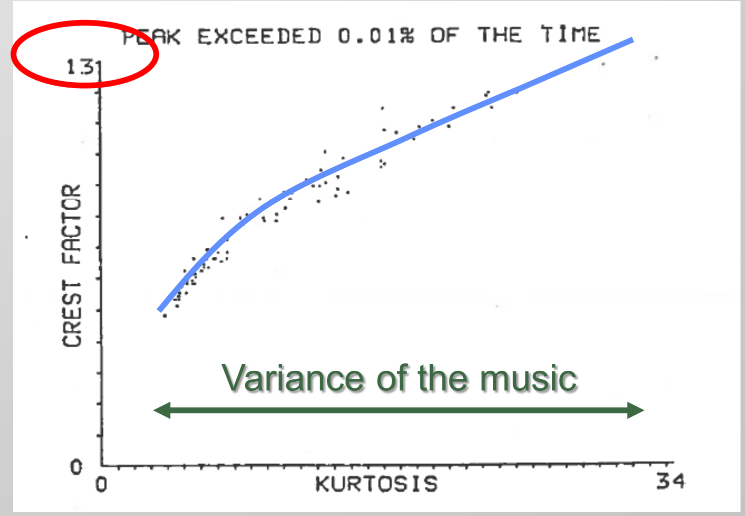


Probability density functions for selected distributions with mean 0, variance 1 and different kurtosis

Crest Factor contra Kurtosis

Same data but other peak value definition





Mark Steven Everett: The Temporal and Spectral Properties of Recorded Music, PhD thesis, Coventry, KEF, 1988

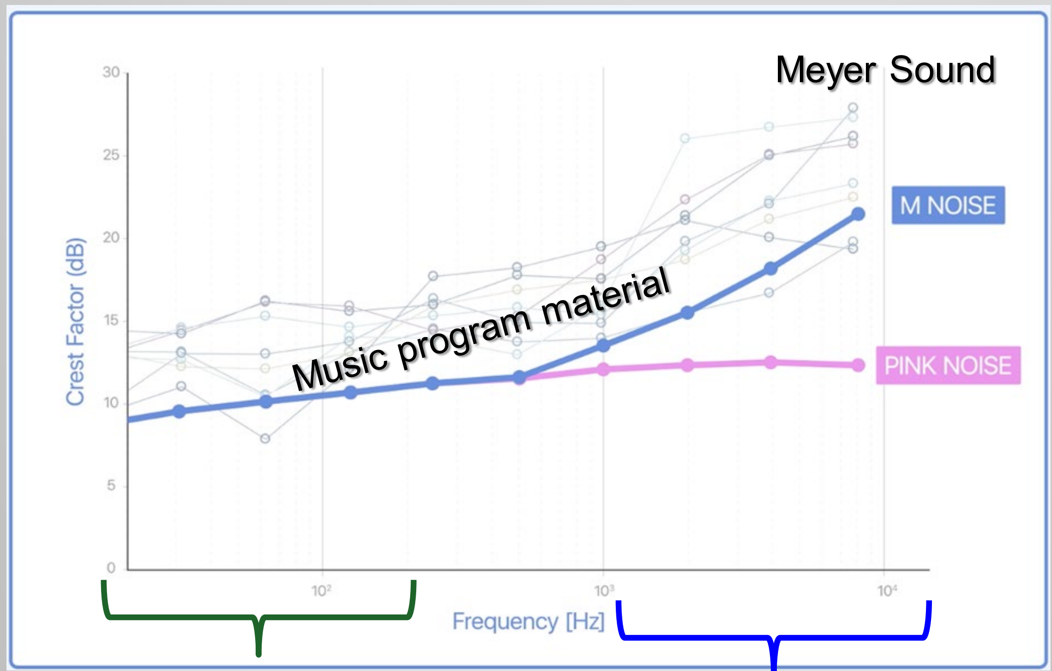
Analysis of more than 100 CD of popular and classic music recordings (pop, jazz, rock, vocalists, piano, orchestra, choral, chamber music)

Conclusion:

- Large variance found in crest factor and kurtosis
- Crest factor rises with kurtosis
- Crest factor values depend on observation time and peak value definition
- Kurtosis is a reliable and well defined characteristic (like rms-value)

Other Particularities of Music

The crest factor of bandpass filtered music material increases with frequency!



Low crest factor in voice coil displacement

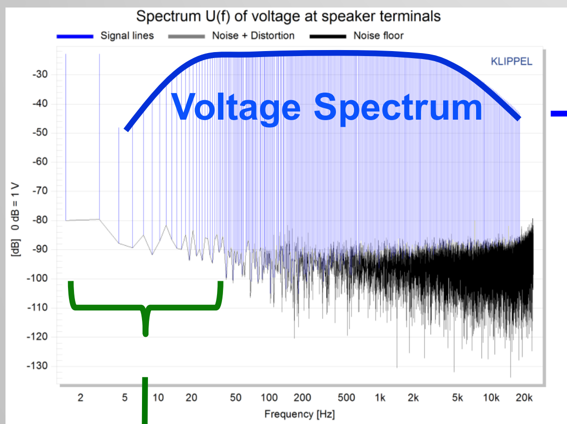
Increases peak voltage requirements for amplification

Possible Cause: percussion instruments generate impulsive components at higher frequencies!

To do: Measure the frequency dependency of the kurtosis

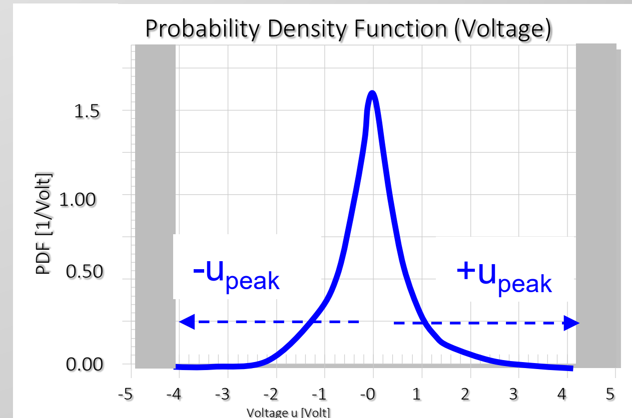
See test Stimulus m-noise https://meyersound.com/news/m-noise-test-signal/

Practical Consequences for Audio Devices



Amplifier limits peak voltage u_{peak}

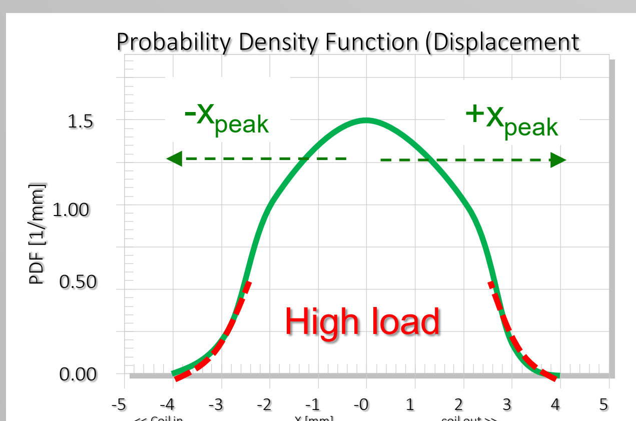
Voltage at Terminals



DISPLACEMENT (Low pass filtering by transducer)

peak u_{peak}, crest factor C_u, kurtosis κ_u

rms voltage u_{rms}, input powers P_{real},



peak displacement x_{peak}, crest factor C_x kurtosis κ_x,

power spectrum $S_X(f)$, rms displacement x_{rms}, apparent mechanical power P_{am}

nonlinearities, distortion

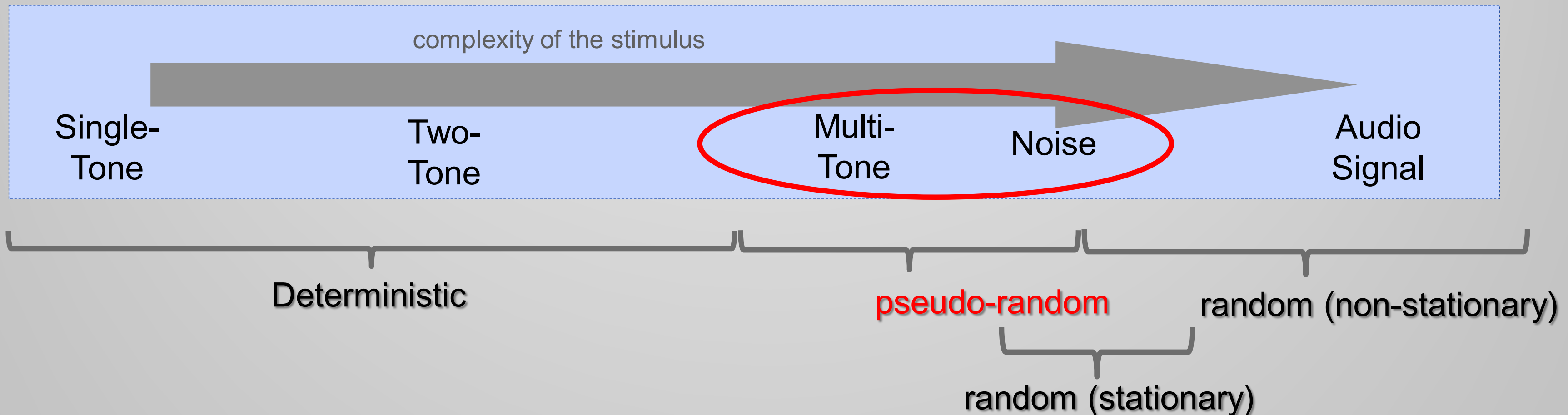
heating, thermal overload

mechanical overload, fatigue, aging,

Transducer

Need for a Standard Test Signal

representing relevant audio stimuli

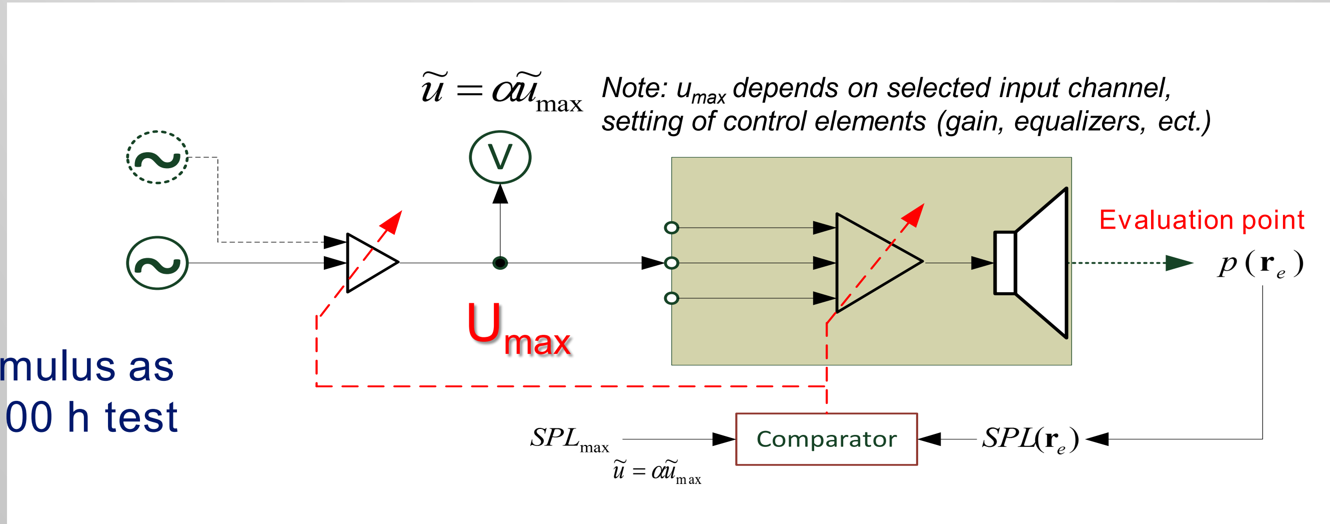


Requirements:

- Comparability, reproducibility and repeatability
- Generating a deterministic stimulus with pseudo-random properties
- Representing typical audio program material or aggressive program material (causing overload, aging, fatigue and defects of the DUT)
- Long-term testing (100h power test, endurance, reliability, climate influence)
- Fast calibration of the input channel using rated SPLmax
- On-line monitoring of output (distortion, compression) and internal states (displacement, temperature)

Calibration of the Input Signal

based on SPL_{max} rated by manufacturer (IEC 60268-21)



SPL_{max}

Same stimulus as used in 100 h test

Objectives of the calibration process

- Fast determination of the maximum input value u_{max} based on SPL_{max}
- Using u_{max} for the calibration of other test stimuli
- Full flexibility for using any input channel of the active system (analogue, digital, ect.)
- Simple technique giving high reproducible results

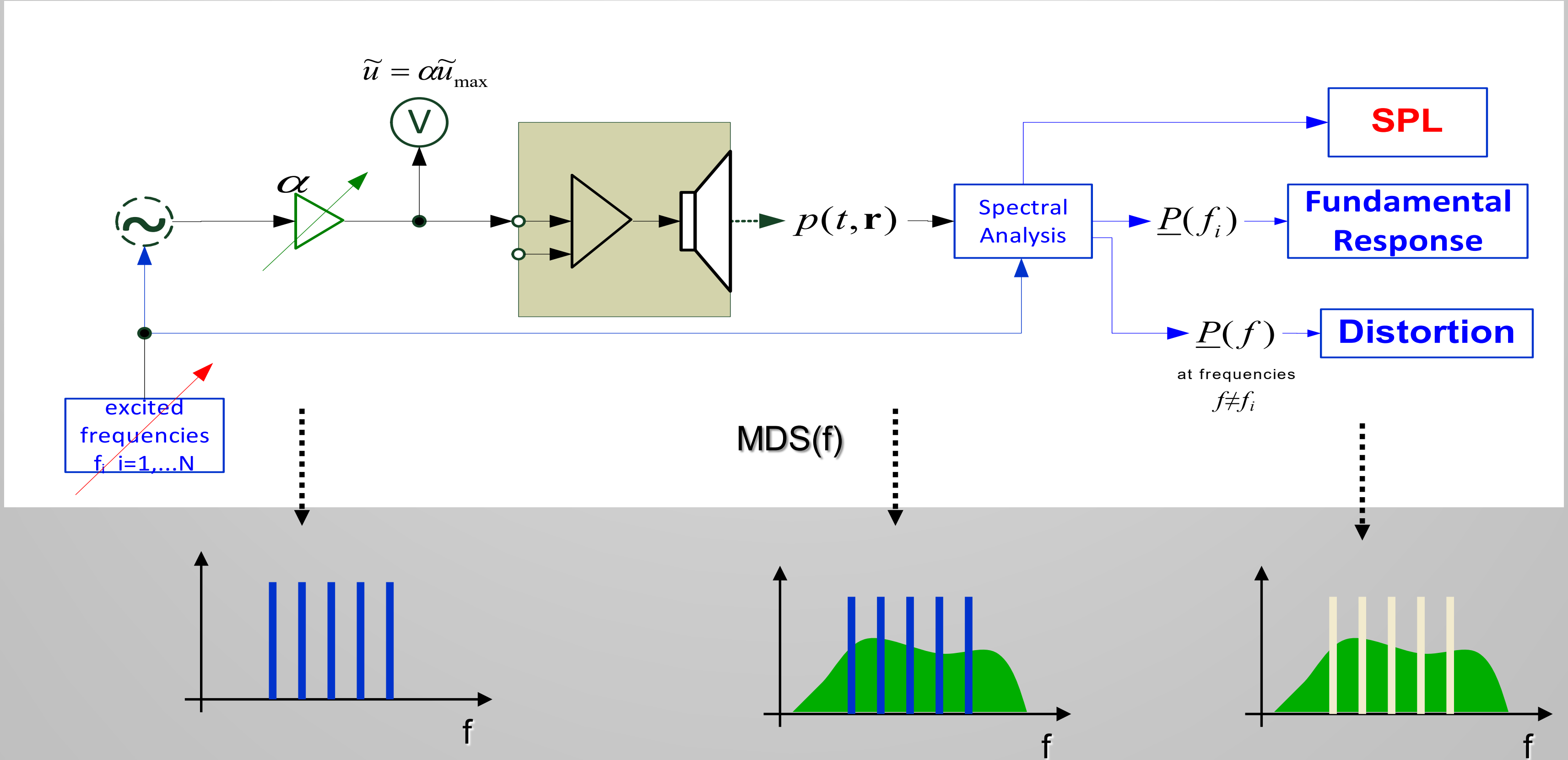
IEC 60268-21 recommends a multi-tone stimulus for calibration and long-term testing!

Sparse Multi-tone Stimulus
defined in IEC 60268-21

Advantages of MT Stimulus:

- Pseudo-random properties generated by a deterministic process (based on a few seed parameters)
- Fast testing (1 MT complex) to calibrate input channel, to measure distortion and thermal dynamics (time constant)
- Long-term testing (100 h) by looping one or more MT complexes
- Generating individual stimuli (interlaced tone complexes) for acoustical measurements of multiple DUTS in one room

Testing with a Multi-tone Stimulus

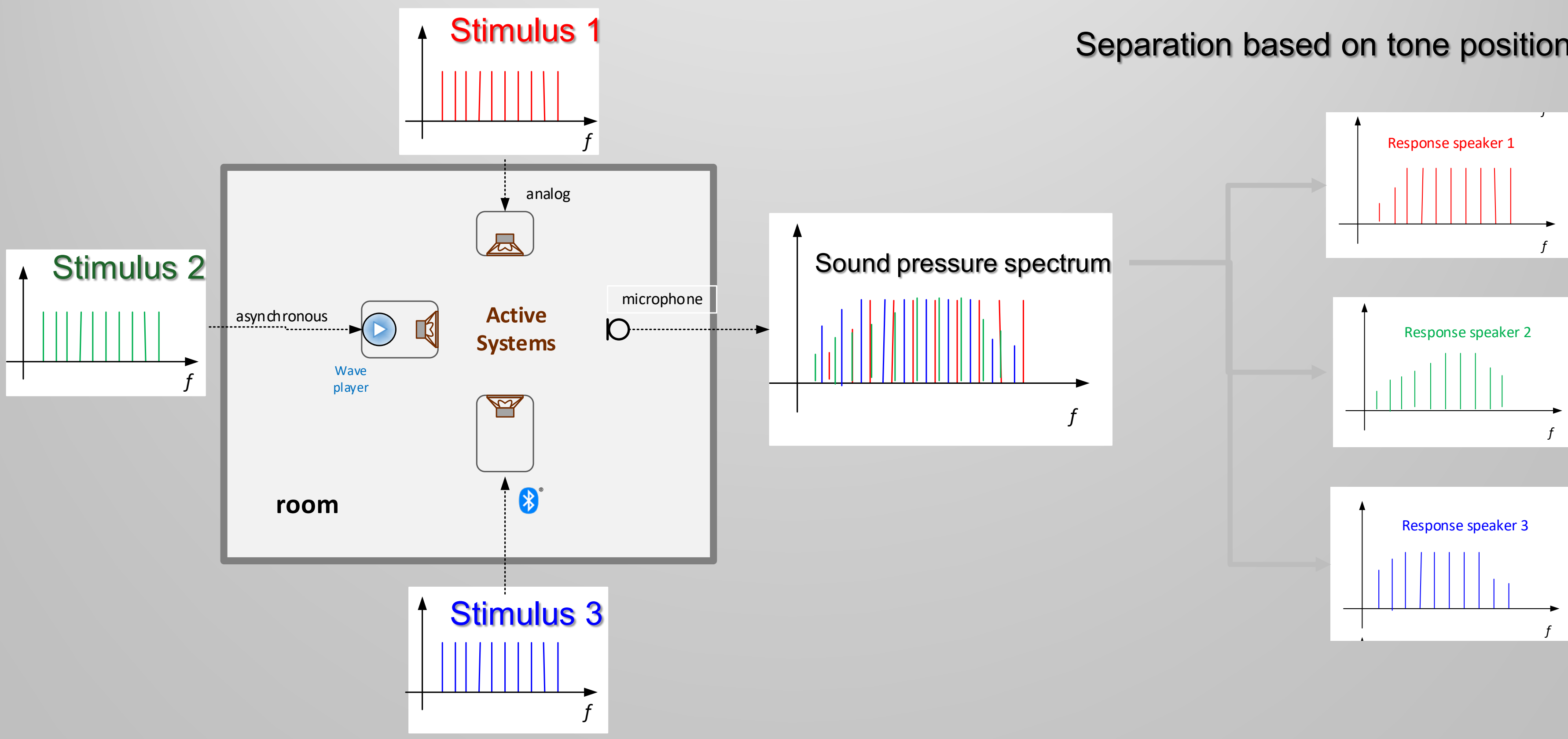


Sparse multi-tone complex

Spectrum of distortion

Standard IEC 60268-21 defines the measurement with multi-tone signals

Interlaced Multi-tone Testing

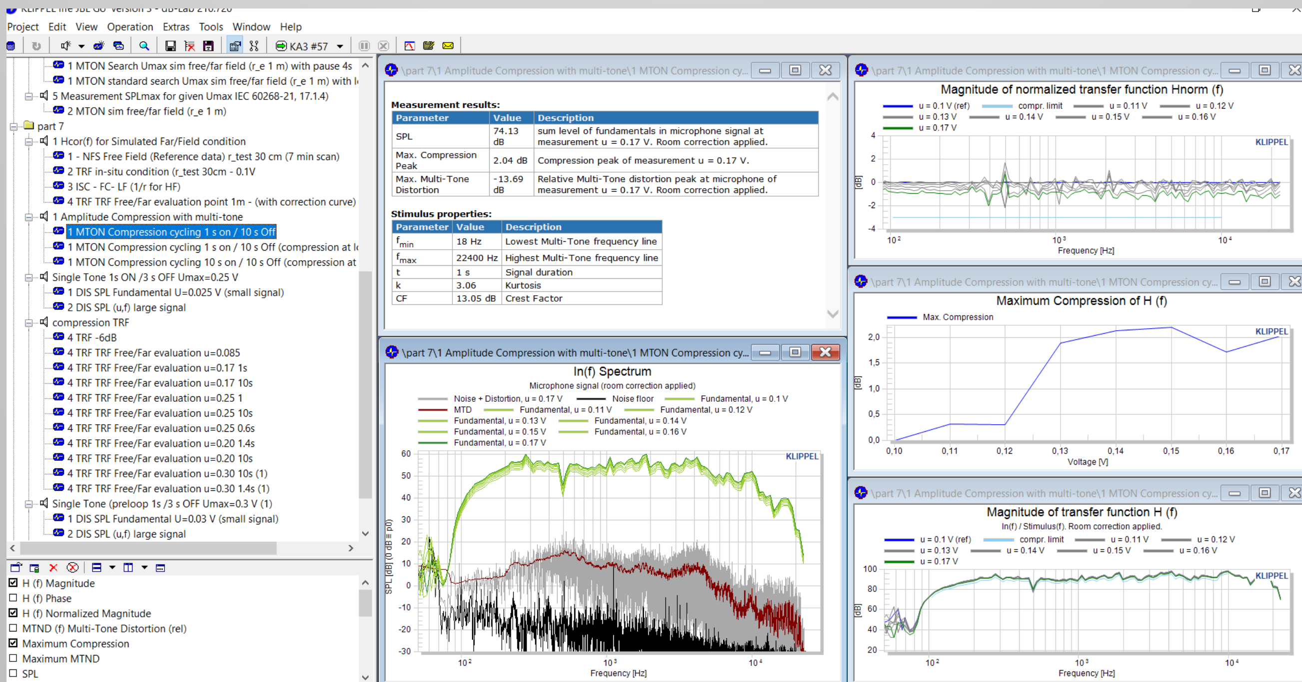


- Each stimulus uses different tones in the multi-tone spectrum
- Acoustical measurement applicable to multiple DUTs operated in one room
- Simultaneous measurement of nonlinear distortion generated by multiple DUTs is not possible

Demo: Multi-Tone Test

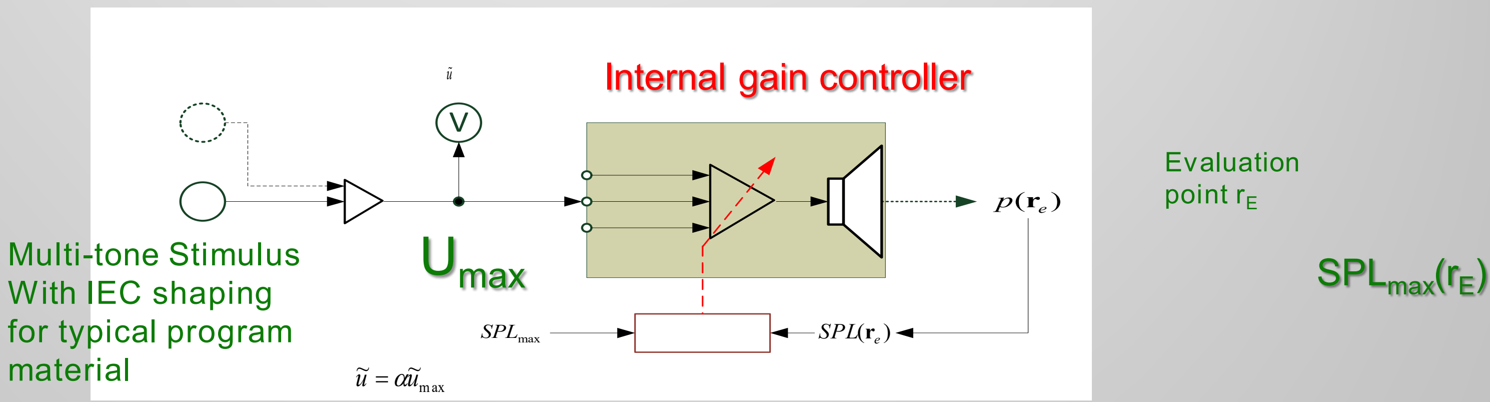
simulated Free/Far Field Condition

Tool: Using a dedicated software module Multi-Tone Measurement (MTON) of the KLIPPEL Analyzer



Calibration of the Input Channel

First Method: adjusting the internal gain controller



Characteristics stated by the manufacturer

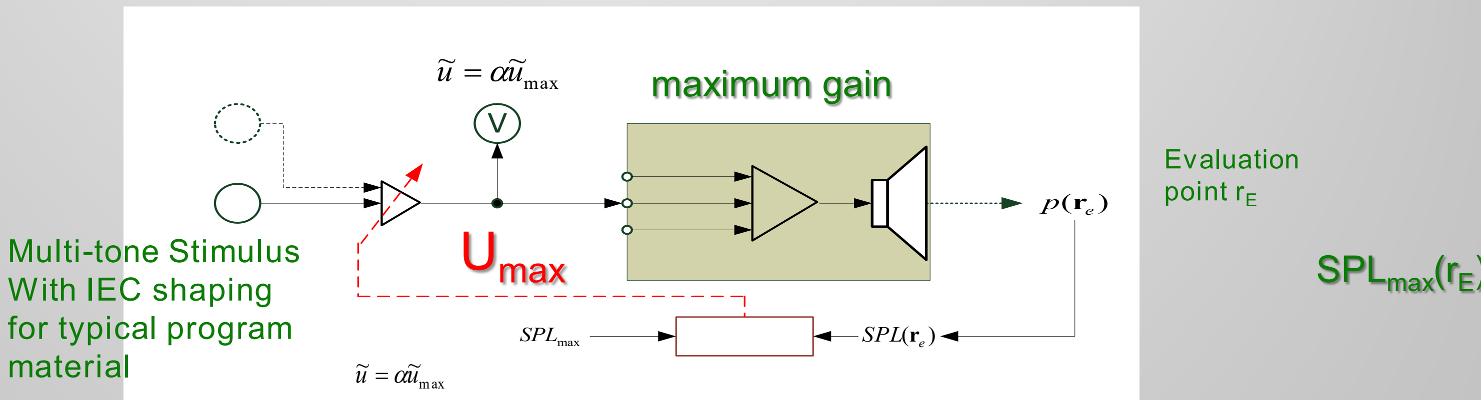
1. Properties of the broad-band stimulus (simulated program material)
2. Acoustical condition (simulated free-field and)
3. Evaluation point $\mathbf{r}_e$ = 1m (simulated far field condition)
4. Rated maximum sound pressure level SPL_{max} (rated in webinar 14)

Calibration

Setting of the internal gain that the U_{max} = -20 dBV at the analog input generates the maximum SPL value SPLmax

Calibration of the Input Channel

Second Method: Measuring U_{max} at maximum internal gain



Characteristics stated by the manufacturer

1. Stimulus is simulated program material according IEC
2. Internal gain is adjusted to maximum
3. Acoustical condition (simulated free-field and)
4. Evaluation point $\mathbf{r}_e$ = 1m (simulated far field condition)
5. Rated maximum sound pressure level (SPL_{max} rated in webinar 14)

Calibration

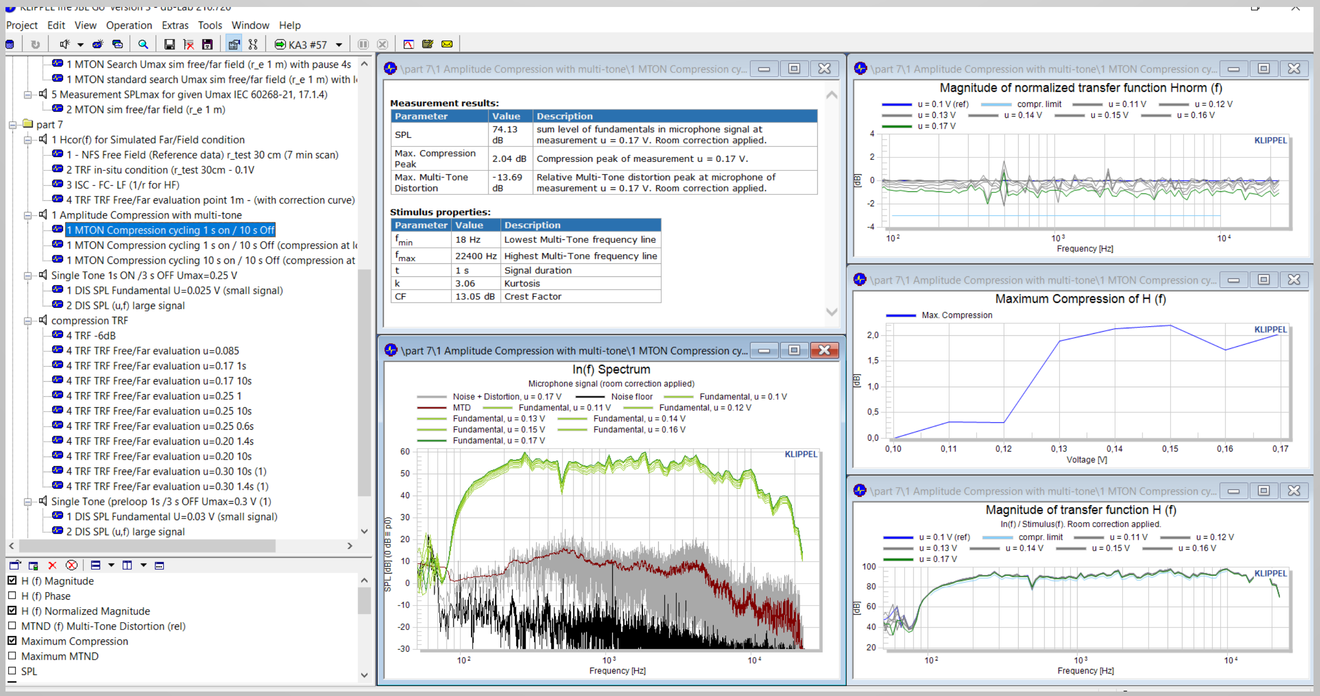
Searching for U_{max} at the analog input that generates SPLmax

We are ready for a practical demonstration!

Demo: InputCalibration

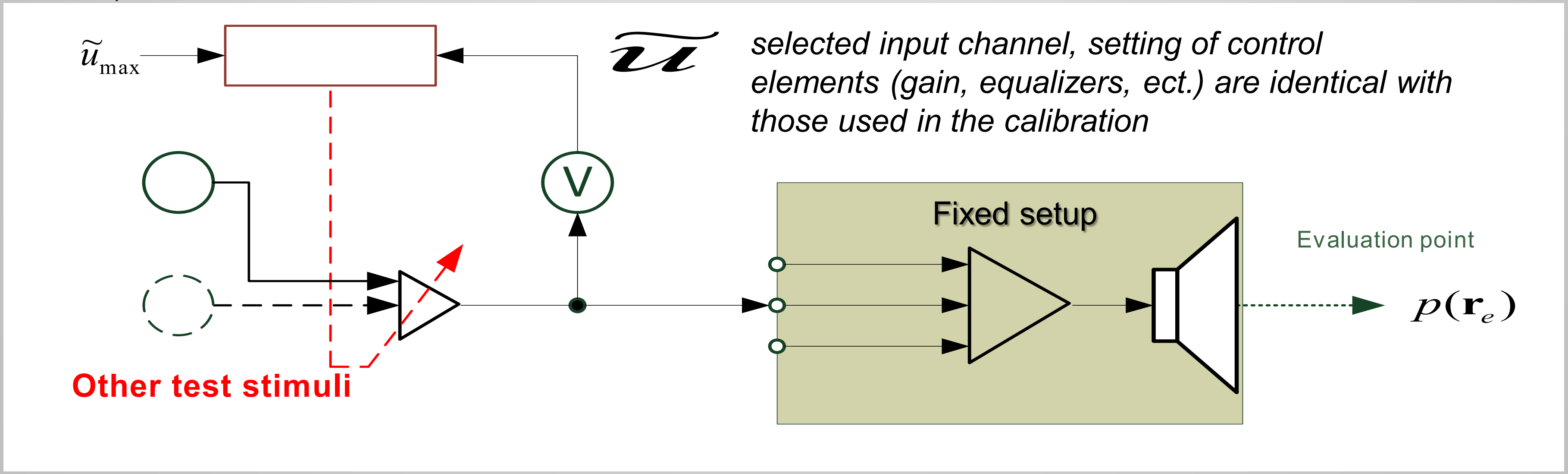
Method 2: Searching for U_{max}

Tool: Using a dedicated software module Multi-Tone Measurement (MTON) of the KLIPPEL Analyzer



How to Calibrate Other Test Stimuli
based on maximum input u_{max} (IEC 60268-21)?

Maximum input value



Benefits:

- Amplitude adjustment of other test stimuli
- Simplifies automatic testing
- Clear definition of small signal domain $u_{max} < 0.1\ u_{max}$
- Avoiding unintended overload of the DUT

Summary

- The rated value SPLmax depends on the properties of the selected broad-band stimulus
- Kurtosis describes is an important characteristic for describing the properties of the stimulus
- The same stimulus is used in the calibration process and in the 100h long term test
- Multi-tone stimulus is an interesting stimulus for evaluating SPLmax
- The input calibration of active audio systems can be accomplished in a few seconds

Open Questions

Now we are ready for evaluating the large signal performance!

The next 6th KLIPPEL LIVE webinar titled
Selecting measurements with high diagnostic value
will address

- What is signal distortion?
- What limits the maximum output and SPL_{max}?
- How to get sufficient information with a minimum of testing?
- How to find the physical causes for the measured symptoms?

Next Section

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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
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