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

7th KLIPPEL LIVE:
Amplitude Compression – less output at higher amplitudes

Topics today:

- Physical causes for amplitude compression
- Consequences for testing
- Measurement according IEC Standard 20268-21
- Overview of other useful test methods
- Interpretation of the results
- Practical demos

Poll:

Do you measure the change of the transfer function (amplitude response) at maximum input level u_{max} ?

- Yes 75%
- No 25%

Amplitude Compression

Definition according to IEC 60268-21 (in short):

$$C(f,t_m) = 20\log\left(\left|\underline{H}_{lin}(f,\mathbf{r},\alpha u_{\max})\right|\right) - 20\log\left(\left|\underline{H}(f,\mathbf{r},u_{\max},t_m)\right|\right)$$

The amplitude compression $C(f,t_m)$ is the level difference between the magnitude frequency response of a time varying transfer function $H(f,\mathbf{r}, u_{max},t_m)$ measured at time t_m and the linear transfer function $H_{lin}(f,\mathbf{r}, 0.1\ u_{max})$ measured at the same conditions (position, environment) in the small signal domain (-20 dB).

Consequences:

- far field condition and anechoic environment are not required
- Position of DUT and microphone should not be changed !

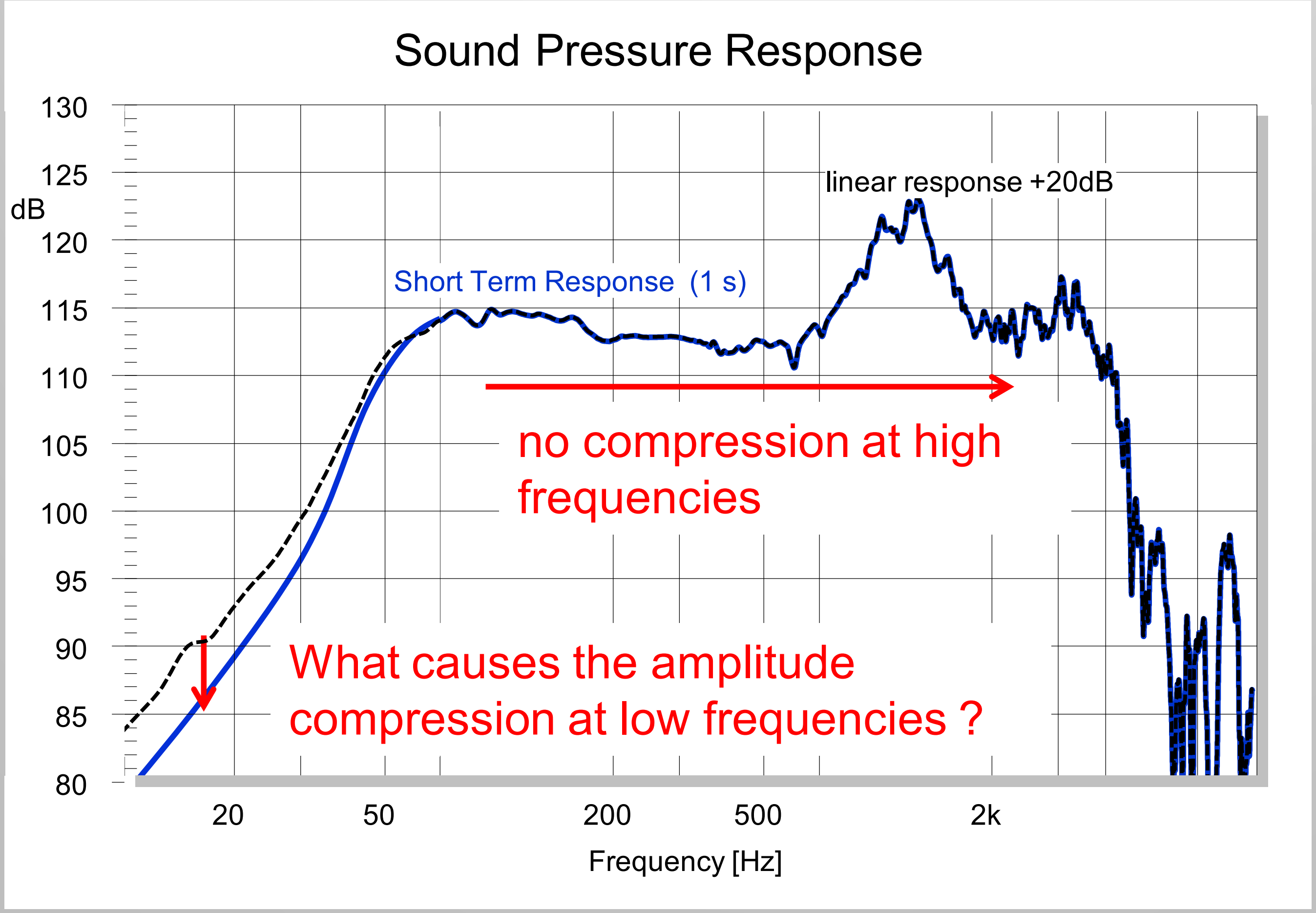
How to do it

Testing according to IEC 60268-21 in short:

1. Define the broadband stimulus, measurement condition (near field is recommended)
2. Determine maximum input voltage u_{max}
3. Measure the linear transfer function $H_{lin}(f,r, 0.1\ u_{max})$
4. Measure the time variant transfer function $H(f,r, t_m,u_{max})$ at maximum input
5. Calculate the compression $C(f,t_m)$

Compression of SPL Output

SPL output at maximum input voltage U_{max}

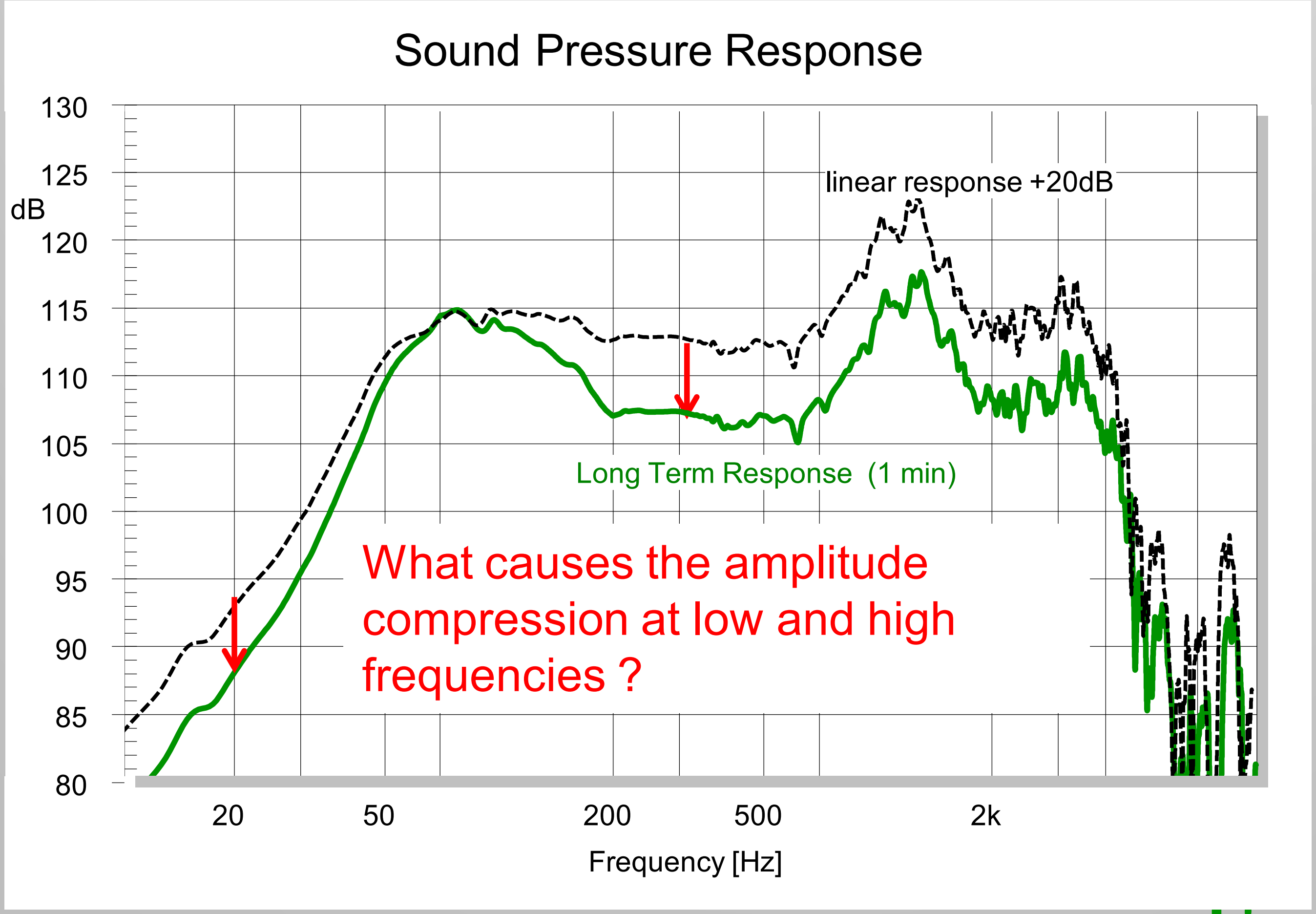


Linear response predicted from a small signal measurement (-20 dB)

Short term response measured within 1 s stimulus

Compression of SPL Output

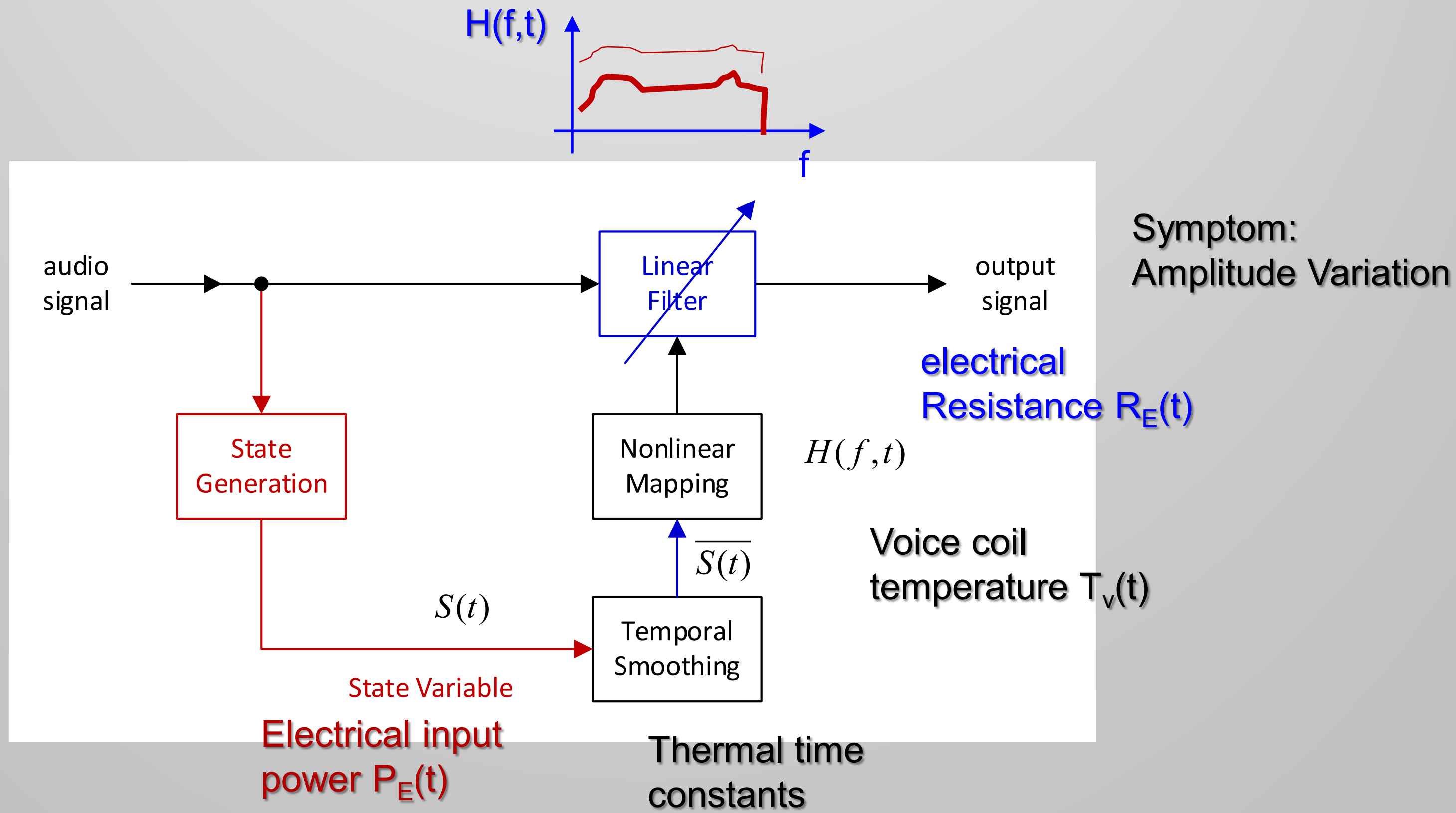
SPL output at maximum input voltage Umax



Linear response predicted from a small signal measurement (-20dB)

Long term response measured after applying the stimulus for 1 min

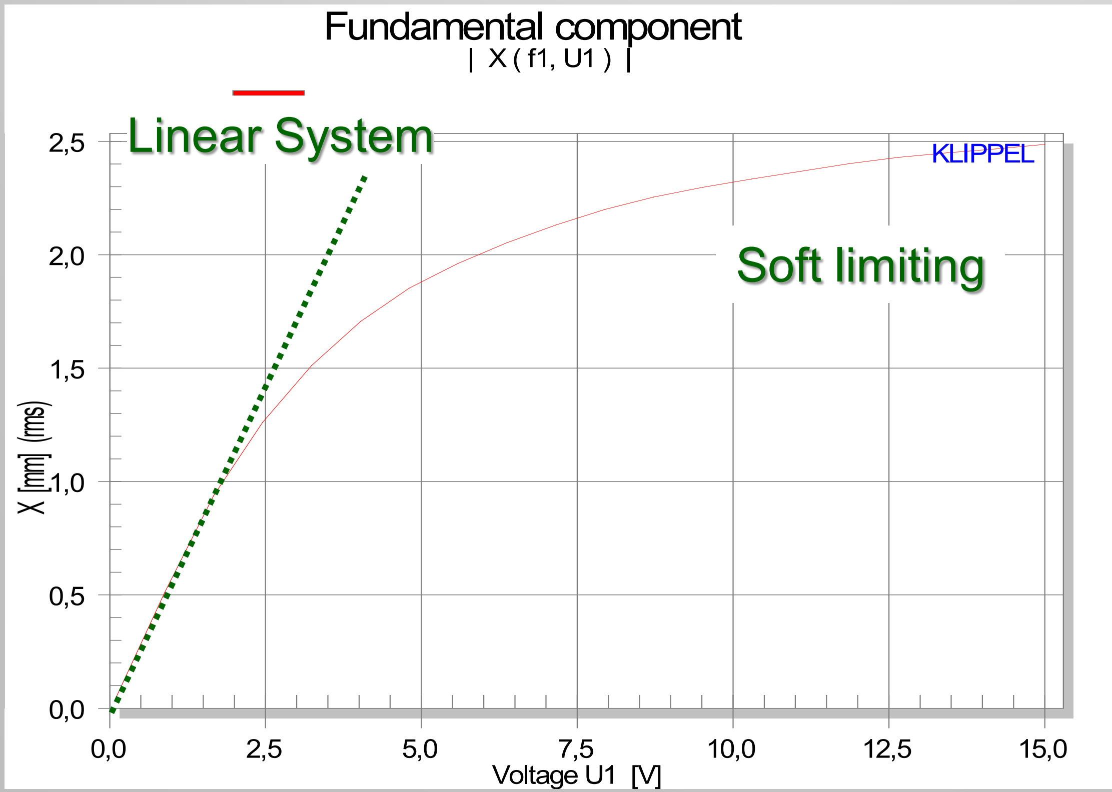
Simplified Modeling of Thermal Dynamics

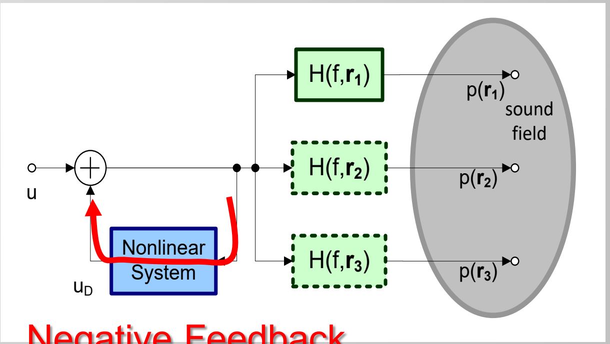


- The thermal time constants (voice coil τ_v > 1s , magnet τ_M < 1h) cause slow variations in the transfer function.
- New spectral components are not generated by the nonlinear mapping

Nonlinear Amplitude Compression

Voice coil displacement versus input voltage measured with a stepped sinusoidal stimulus (100 ms)



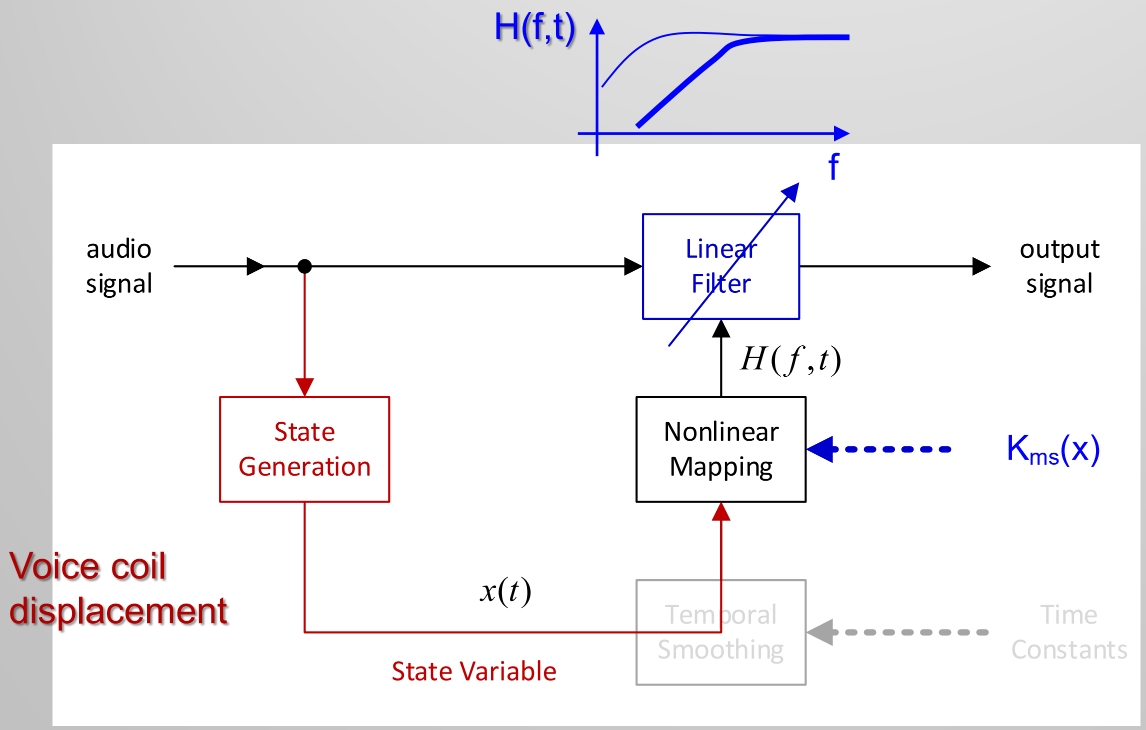


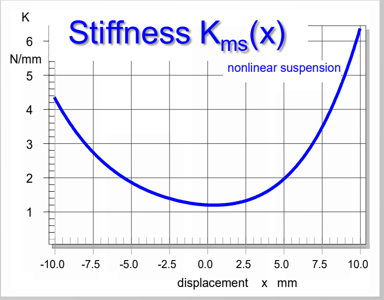
Negative Feedback

Symptoms:

- Needs high peak values displacement, current, …
- no time delay
- smooth compression characteristic

Mechanical Suspension with nonlinear Stiffness $K_{ms}(x)$



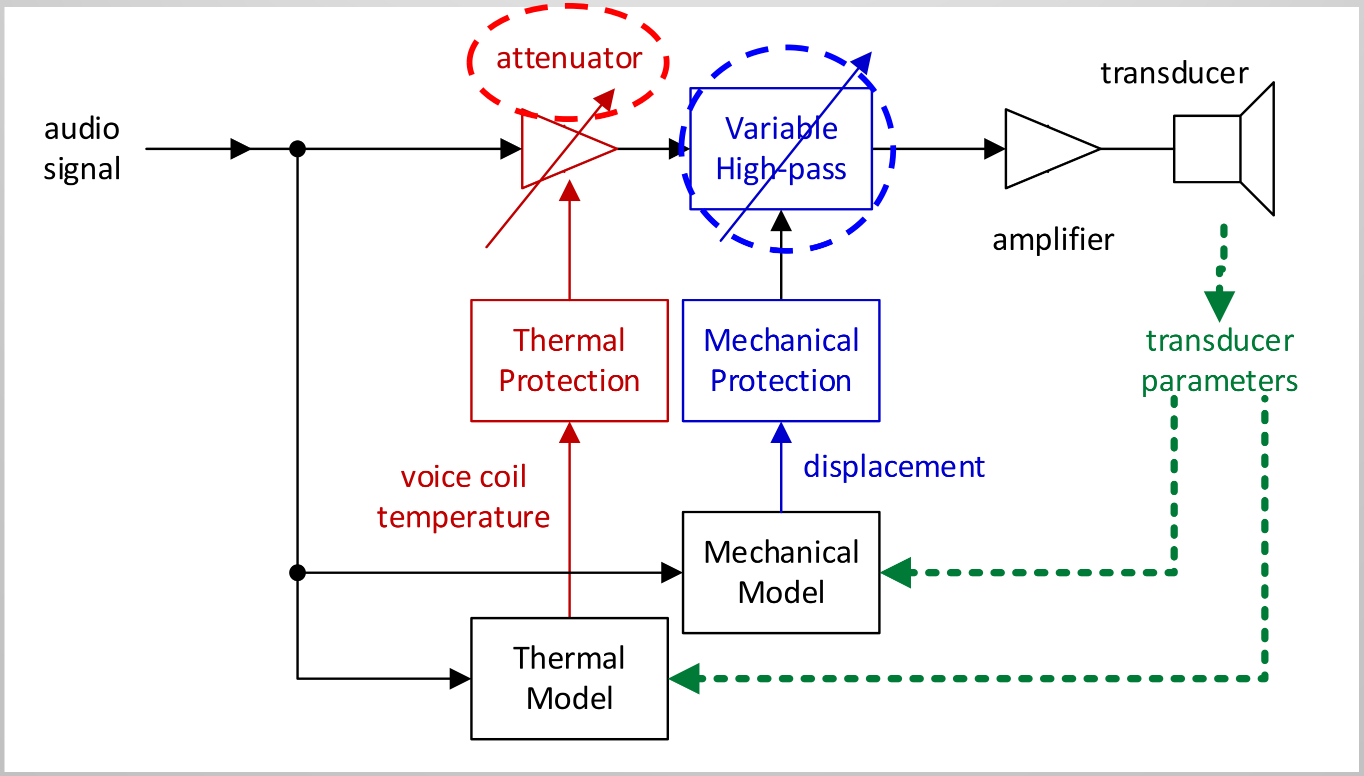


No integration or smoothing of the state variable !!

- The instantaneous displacement instantaneously increases the stiffness, which reduces the displacement and SPL at low frequencies
- A progressive stiffness characteristic makes the product more robust !
- Fast variation of the linear filter generates new spectral components (harmonics, intermodulation) in the output

Active Transducer Protection

based on linear and thermal modeling and measured transducer parameters



To prevent thermal overload

- slow attenuation of the input signal to keep the voice coil temperature below a permissible limit

To prevent a mechanical overload

- fast attenuation of the low frequency component to keep the voice coil peak displacement below a permissible limit

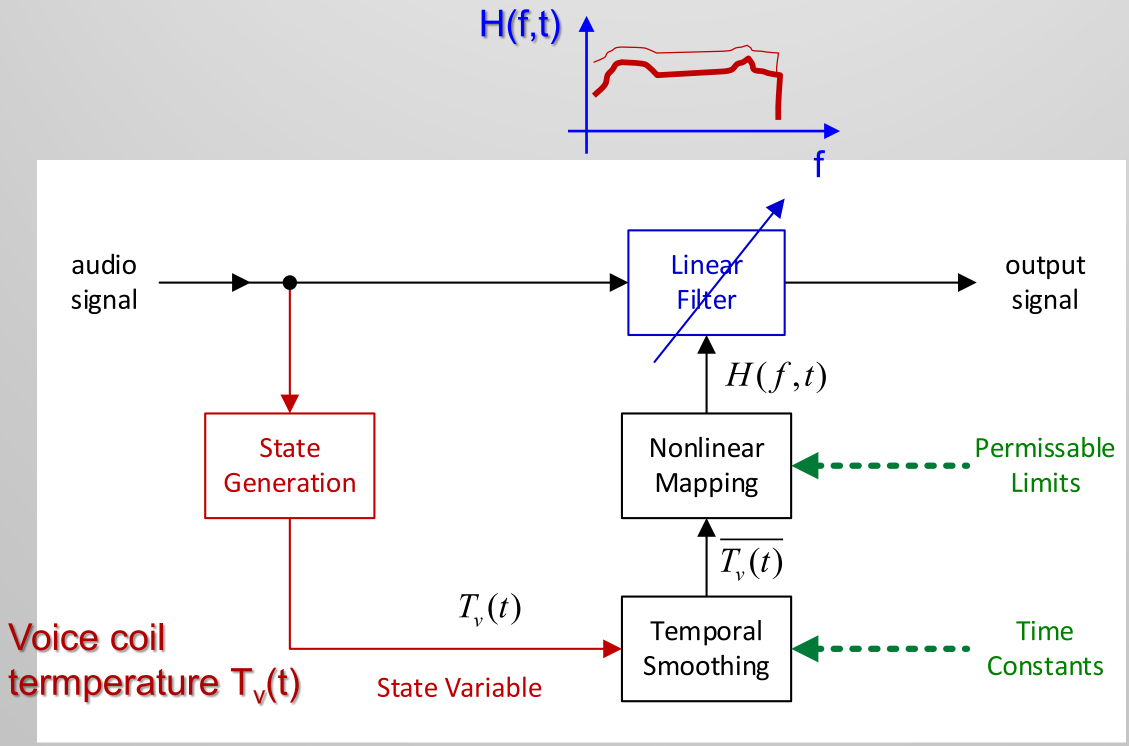
Poll:

How do you avoid an overload of your audio system ?

(multiple responses possible)

A. Limited amplifier output which can be handled by the transducer can 36%
B. Using electrical means (analogue) for realizing active protection of the hardware 28%
C. Using DSP software for limiting the maximum output and protecting the hardware 81%
D. Others 6%

Active Thermal Protection



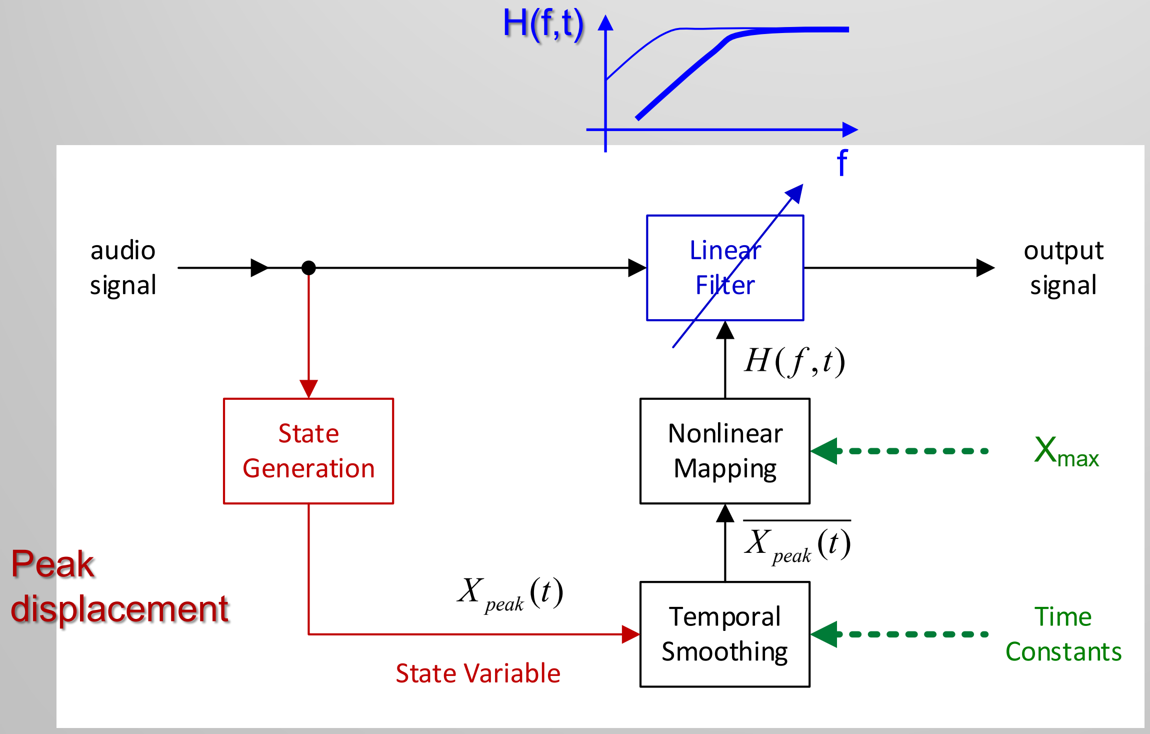
Symptom:
Amplitude Variation

Maximum voice coil temperature T_{max}

Attack and release constants are related to thermal time of the voice coil (1…. 60 s)

- The thermal time constants cause slow variations in the transfer function.
- The protection system attenuates the input signal to keep $T_v(t) < T_{max}$
- New spectral components are not generated by the protection system

Mechanical Protection System



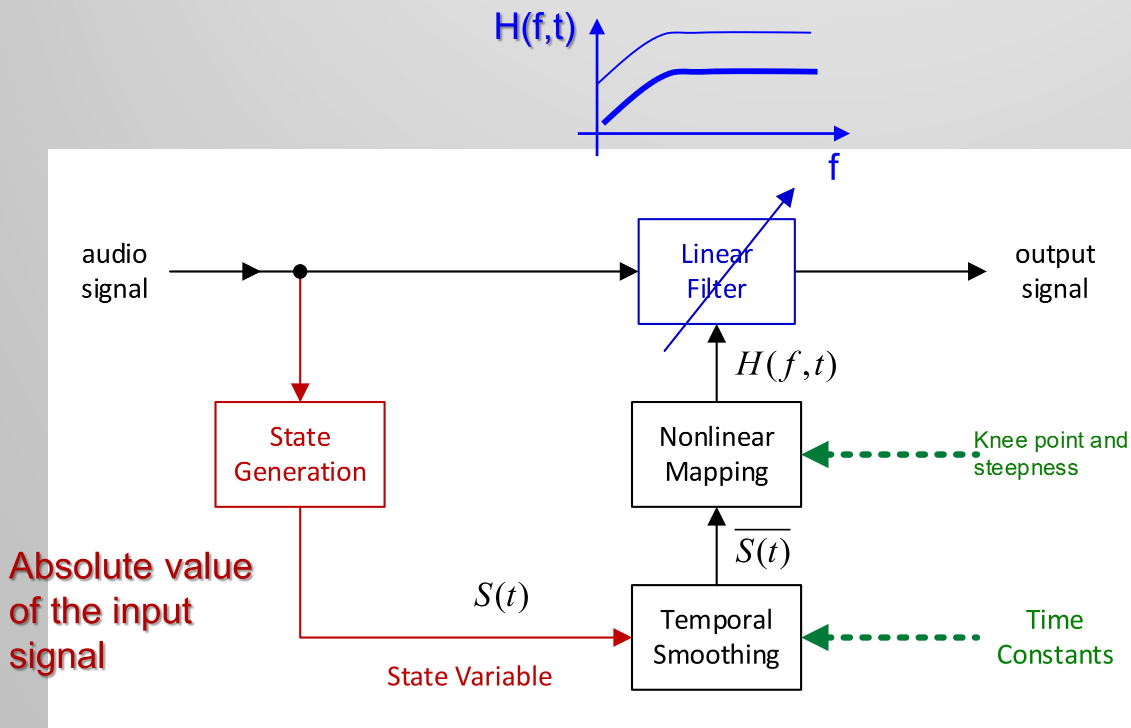
Maximum permissable displacement X_{max}

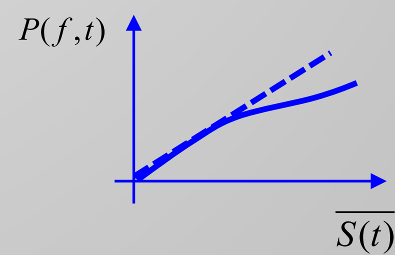
- Short Attack time (1 ms)
- Long release time (> 100 ms)

- The state generator generates the peak value of the voice coil displacement
- The low frequency range will be attenuated to keep the peak displacement x_{peak} below the limit value x_{max}
- A longer release time reduces the nonlinear distortion and other undesired artifacts (pumping effect) but also reduces the acoustical output

Dynamic Range Compressor

applied to the input signal



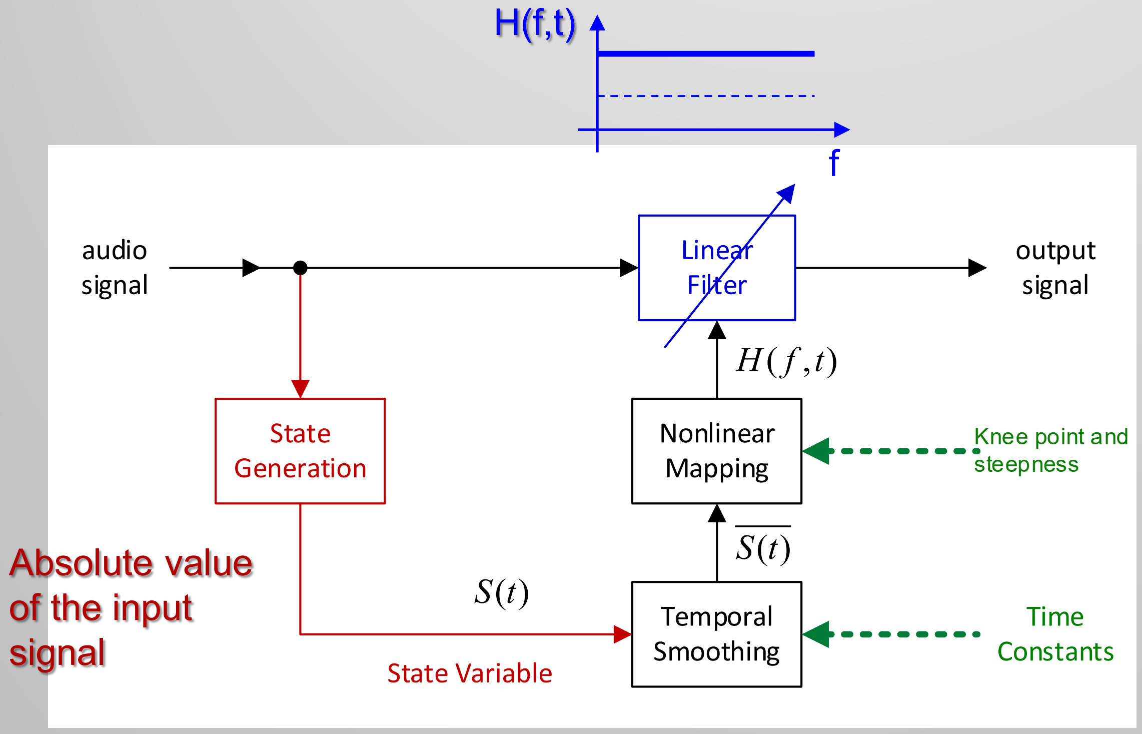


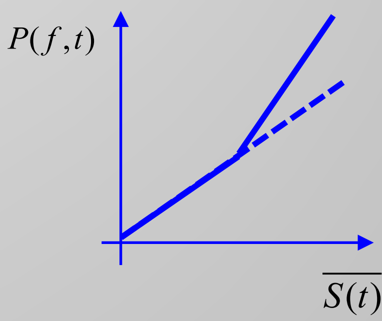
- Short Attack time (0.5 ms)
- Long release time (50 ms)

- Target: Reduction of the peak voltage requirements of the amplifier while increasing the SPL output
- Nonlinear and impulsive distortion are generated during attack phase
- A longer release time constant reduces the nonlinear distortion but reduces the long-term SPL

Noise Gating

applied to the input signal



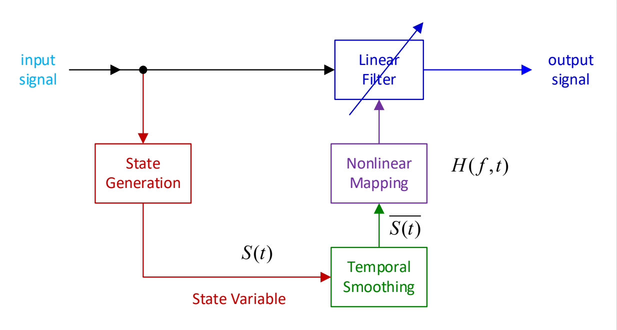


- Short Attack time (0.1 ms)
- Long release time (200 ms)

- Target: Reduction of electronic noise when no audio signal is applied
- Nonlinear and impulsive distortion are generated during attack phase (gain switching)
- A longer release time constant reduces the artifacts

Consequences for Testing

Broadband test stimuli represent typical audio signals



Fast analysis to measure transient behavior

Increasing stimulus amplitude (linear stepping) to measure the characteristic (soft, hard limiting)

Band limited test stimulus is required to find the state signal that activates the amplitude compression

low frequencies ($f < f_s$)
→ displacement x

Short Stimuli are required to evaluate the nonlinear compression, DSP and voice coil heating

Long Stimuli to consider the thermal compression (magnet)

Overview on Test Methods

Noise Generator + Spectrum Analyzer + Cross correlation
- Conventional technique, good for slow thermal compression
- Averaging required to improve SNR (time consuming)
- Poor temporal resolution (DSP, nonlinearities)

Multi-tone testing (sparse pseudo-random noise)
- Sparse spectrum similar to dense noise but higher SNR
- Special analysis required if there is a sample rate mismatch (session 15)

Sinusoidal chirp testing (logarithmic frequency-time mapping)
- Dense spectrum, good SNR, fast analysis
- High activation of the transducer nonlinearities

IEC 60268-21

Single Tone, Burst at selected frequencies
- Best temporal resolution for testing transient behavior
- Time consuming

Multi-Tone Testing in Practice

Conditions:

Sparse multi-tone stimulus (typical program material) as used for testing maximum output SPLmax (session 5)

Measurements according to IEC 60268-21 chapter 16.4

1a) **Short-term compression** at <u>maximum input</u> U_{max}=0.17 Vusing a stimulus length T=1s after playing the same stimulus in a preloop

1b) **Long-term compression** measured at <u>maximum input</u> U_{max}=0.17V with the same stimulus T=1s after the playing the stimulus 1 min in a preloop + 1 min cooling break (without break)

2) Search for input voltage u generating a short-term compression C = 3dB

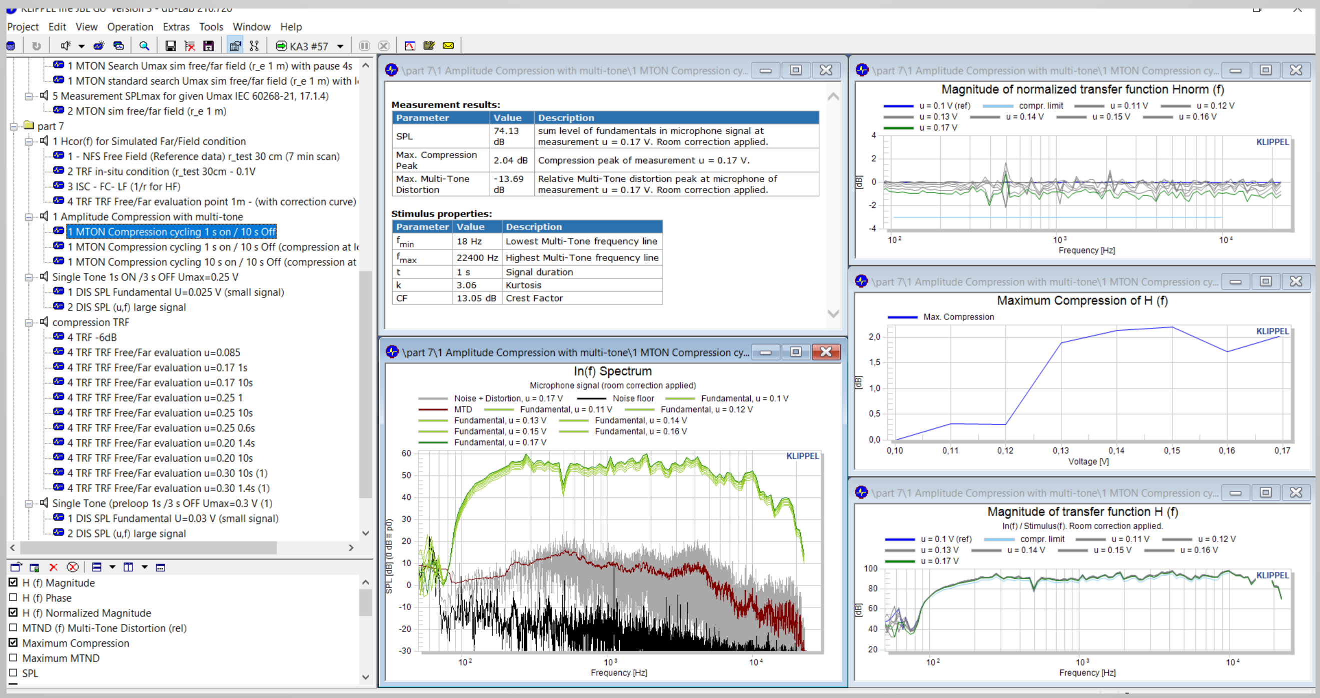
Tip: Perform measurement in near field to improve SNR

Interpretation:

Compare with Short-Term and Long-Term Measurement

Demo

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



Chirp Testing in Practice

Conditions:

Sinusoidal chirp with logarithmic frequency-time mapping at SPLmax (session 5)

Measurements of the compression

3a) Short-term compression using a stimulus length T=0.6s after playing the same stimulus in a preloop at maximum input u_{max}=0.17

3b) Long-term compression (slow sweep speed) with T=20s) after playing the same stimulus in a preloop at maximum input u_{max}=0.17

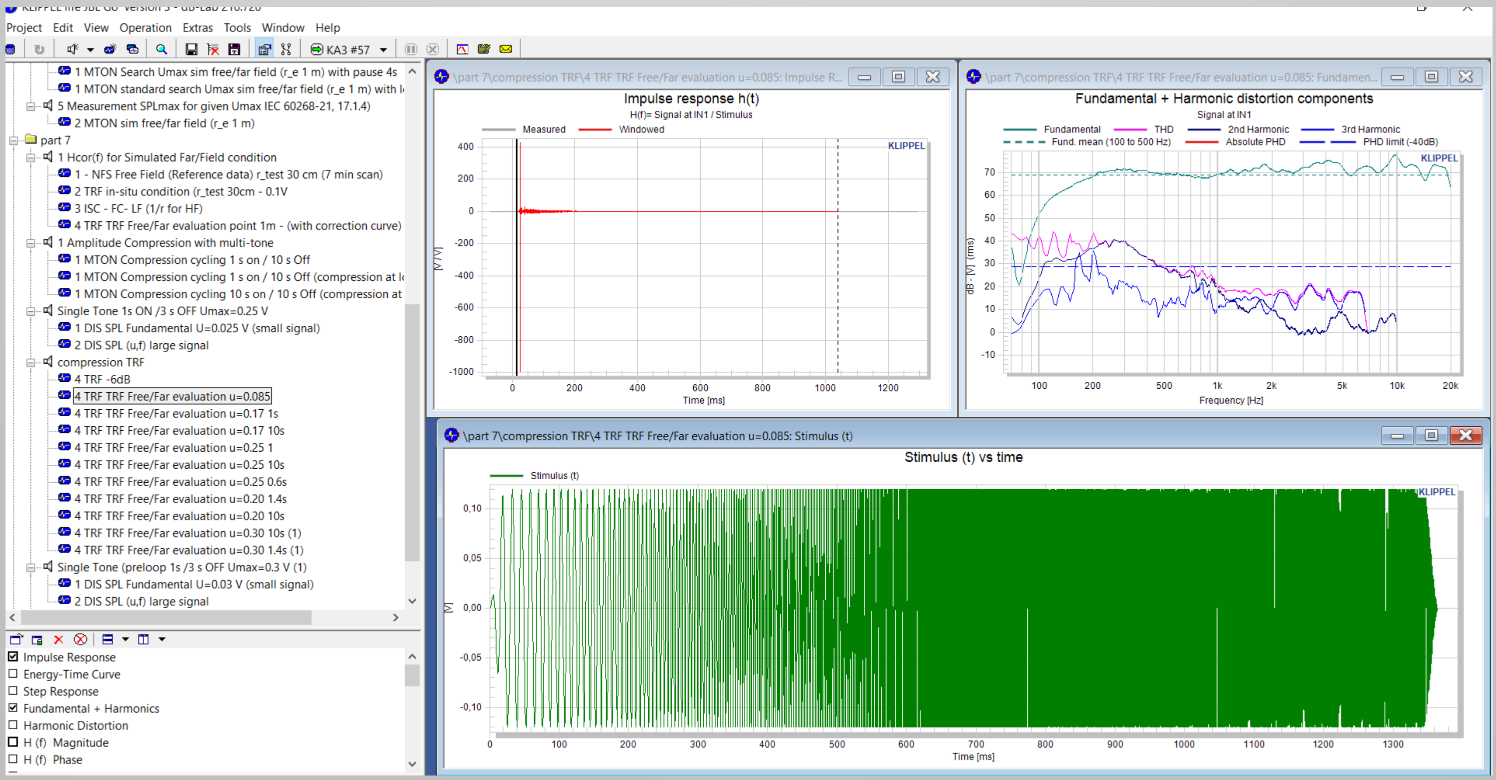
3c) Searching for voltage giving amplitude compression C=3dB

Interpretation:

- Compare Short-term multi-tone test with short-term chirp test
- Compare amplitude compression from chirp and multi-tone

Demo

Tool: Using a dedicated software module Transfer Function Measurement (TRF) and TRF Stepping of the KLIPPEL Analyzer



Single Tone Testing in Practice

Conditions:

- Stepped tone excitation versus frequency and voltage with preloop and pause between the steps (off)
- Negligible heating of the transducer

Tests:

4) Searching for steady-state test condition (preloop, pause)

5) Influence of preloop on the compression

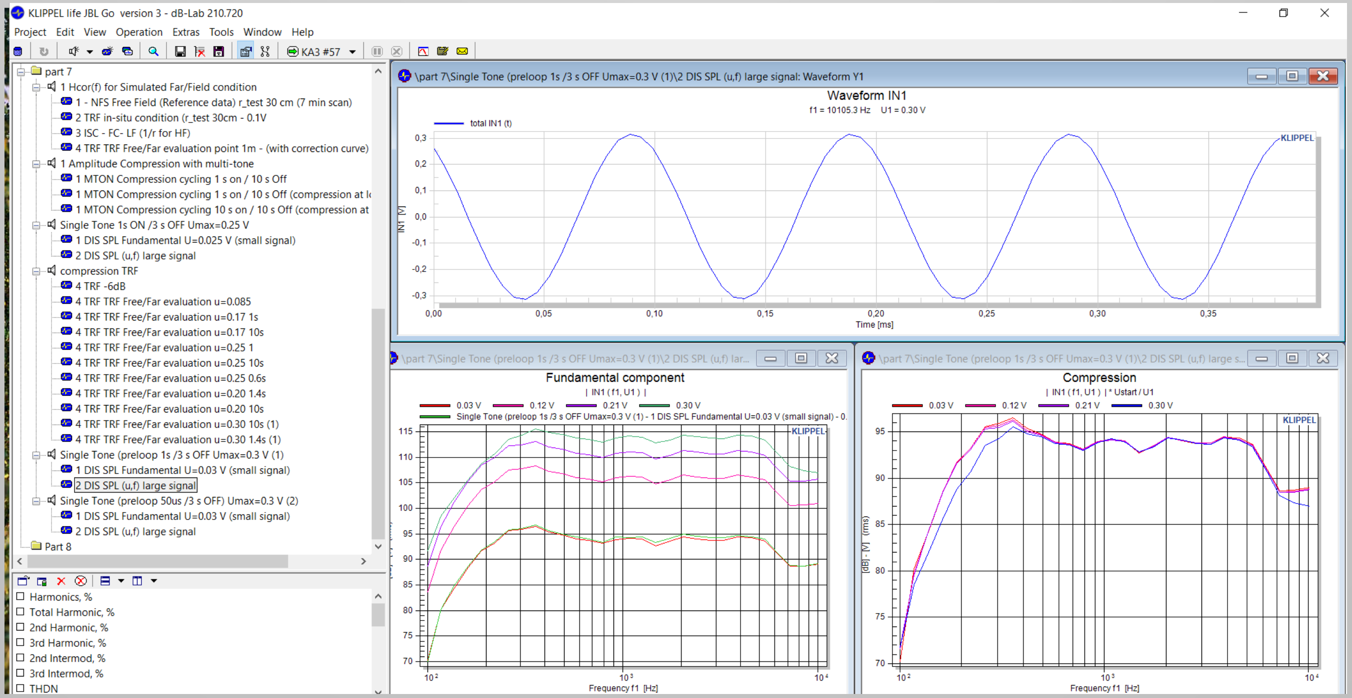
Interpretation:

Compare with m with Ultra-Fast

Demo: Compression (Stepped Sine)

Tools of the KLIPPEL Analyzer:

- 3D Distortion measurement (DIS)



Burst Testing in Practice

Conditions:

- Transient ultra-fast testing
- Tone burst with preloop, pause stepped at increasing voltages
- Negligible heating of the transducer

Measurements of the compression

- 1st Short-Term Test: Preloop 1s
- 2nd Ultra-Fast Test: Preloop 50 us

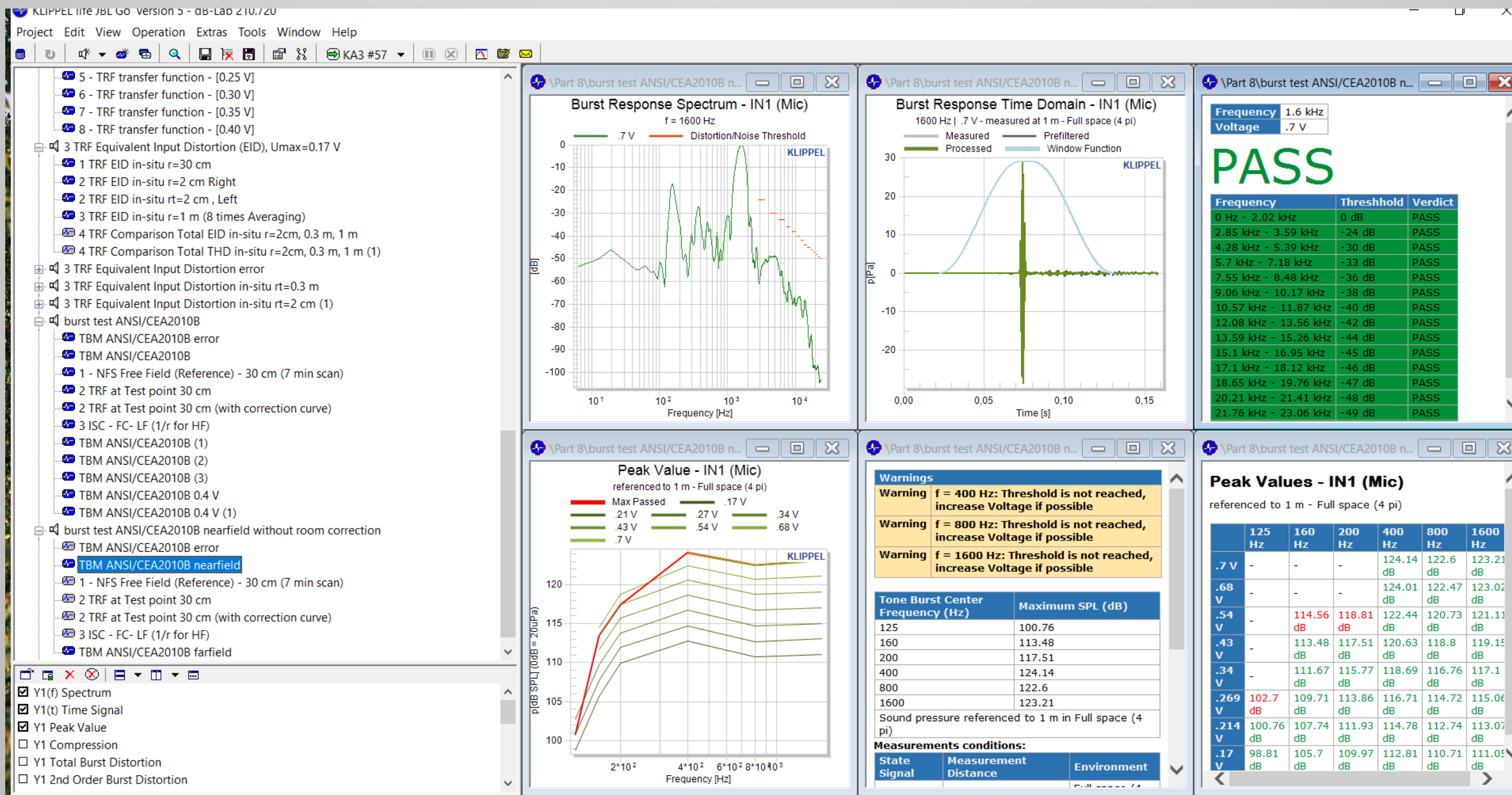
Interpretation:

Compare with with Ultra-Fast

Demo: Amplitude Compression (Burst)

Tools of the KLIPPEL Analyzer:

- Tone Burst Measurement Module (TBM)
- Time Frequency Analysis (TFA)



!

Interpretation of the Test Results

full-band audio processing (limiter, DRC)

Multi-Tone
(short-Term test T=1s)

compare

Sinusoidal Chirp
(sweep time T=1s)

reveals transducer nonlinearities and band-limited DSP (mechanical protection)

compare

Compression depends on the stimulus !

compare

Multi-Tone
long-term test with preloop, T=1min

Single Tone/Burst
(few periods, T < 50 ms)

Heating of the voice coil, active thermal protection

Transducer nonlinearities + transient behavior DSP (DRC, limiter, mechanical protection)

Discussion

Summary

Amplitude Compression

- Is an important characteristic for rating the maximum acoustical output
- Depends on the particular stimulus
- Is a natural effect of transducers (close to overload)
- Is intentionally generated in active systems with limiters, protection systems and other DSP software (Trading Compression for THD !!)
- Can be measured in the near field of the transducer without correction curve

Open Questions

Now it is time to consider spectral components which are not in the stimulus!

The next 8th KLIPPEL LIVE webinar entitled
Harmonic Distortion Measurements – best practice
will address the points:

- Traditional and new ways for testing (IEC 60268-21)
- Can we simplify the interpretation of THD response ?
- What reveals the 2nd and 3rd harmonics ?
- Reducing the influence of positioning, distance, room, sensor, ….
- How to link QC end-of-line testing with standard measurements ?

Next Section

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