

Acoustical Measurement of Sound System Equipment according IEC 60268-21

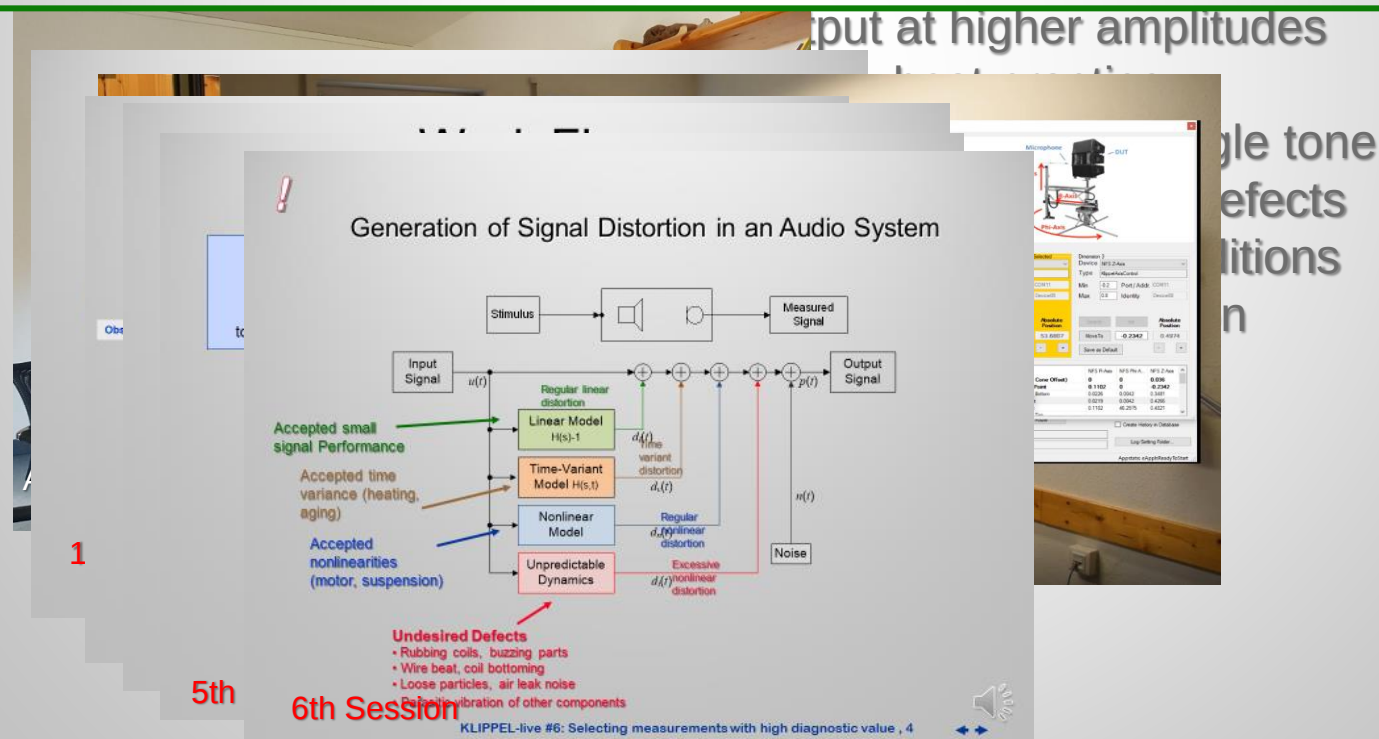
KLIPPEL- live

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



7th KLIPPEL live:
幅值压缩 – 高幅值时输出较少
Amplitude Compression – less output at higher amplitudes

今日话题 Topics today:

- 幅值压缩的物理原因 Physical causes for amplitude compression
- 测试的后果 Consequences for testing
- 符合IEC标准60268-21的测量 Measurement according IEC Standard 60268-21
- 其他有用测试方法概述 Overview of other useful test methods
- 结果解读 Interpretation of the results
- 实际演示 Practical demos



Poll:

您是否在最大输入电平 $u_{\max}$ 下测量传递函数（幅度响应）的变化？ Do you measure the change of the transfer function (amplitude response) at maximum input level $u_{\max}$?

- Yes
- No



Amplitude Compression

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

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

幅值压缩 $C(f, t_m)$ 是在 t_m 时间内测量的时变传递函数 $H(f, \mathbf{r}, u_{\max}, t_m)$ 的幅度频率响应与在 小信号域 (-20dB) 中相同条件 (位置、环境) 下测量的线性传递函数 $H_{lin}(f, \mathbf{r}, 0.1 u_{\max})$ 的幅度频率响应之间的 电平差。

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).

结果 Consequences:

- 不需要远场条件和消声环境 far field condition and anechoic environment are not required
- DUT和麦克风的位置不能改变! Position of DUT and microphone should not be changed !



How to do it

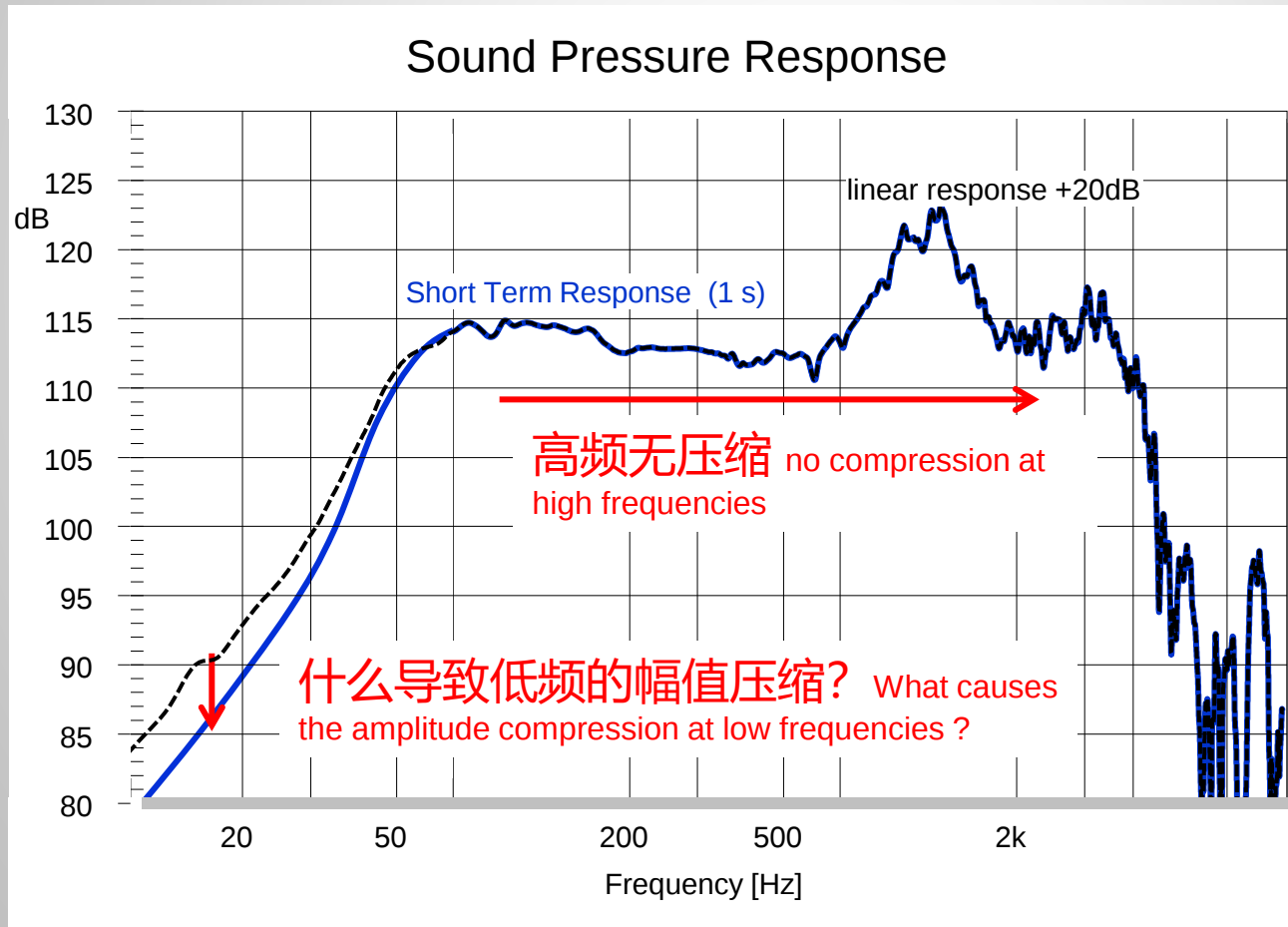
符合IEC60268-21简短测试 Testing according to IEC 60268-21 in short:

1. 定义宽带激励, 测量条件 (建议在近场)
Define the broadband stimulus, measurement condition (near field is recommended)
2. 确定最大输入电压 $u_{\max}$ Determine maximum input voltage $u_{\max}$
3. 测量线性传递函数 $H_{\text{lin}}(f, r, 0.1 u_{\max})$
Measure the linear transfer function $H_{\text{lin}}(f, r, 0.1 u_{\max})$
4. 在最大输入时测量时变传递函数 $H(f, r, t_m, u_{\max})$
Measure the time variant transfer function $H(f, r, t_m, u_{\max})$ at maximum input
5. 计算压缩 $\mathcal{A}(f, t_m)$ Calculate the compression $\mathcal{A}(f, t_m)$



SPL输出的压缩 Compression of SPL Output

最大输入电压 $U_{\max}$ 时的SPL输出 SPL output at maximum input voltage $U_{\max}$



通过小信号测量 (-20dB) 预测的线性响应 Linear response predicted from a small signal measurement (-20 dB)

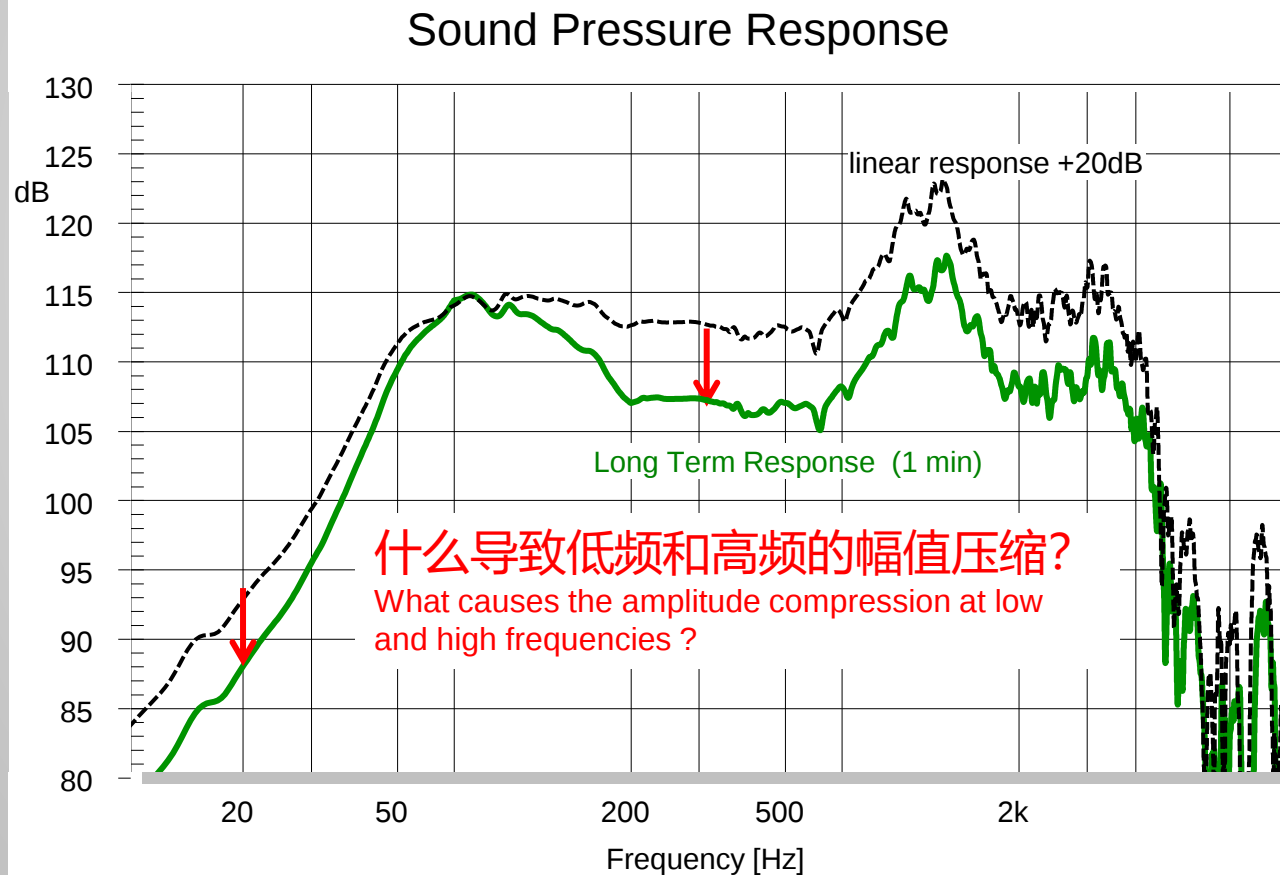
1s激励内测量的短时响应 Short term response measured within 1 s stimulus



SPL输出的压缩

Compression of SPL Output

最大输入电压 $U_{\max}$ 时的SPL输出 SPL output at maximum input voltage $U_{\max}$



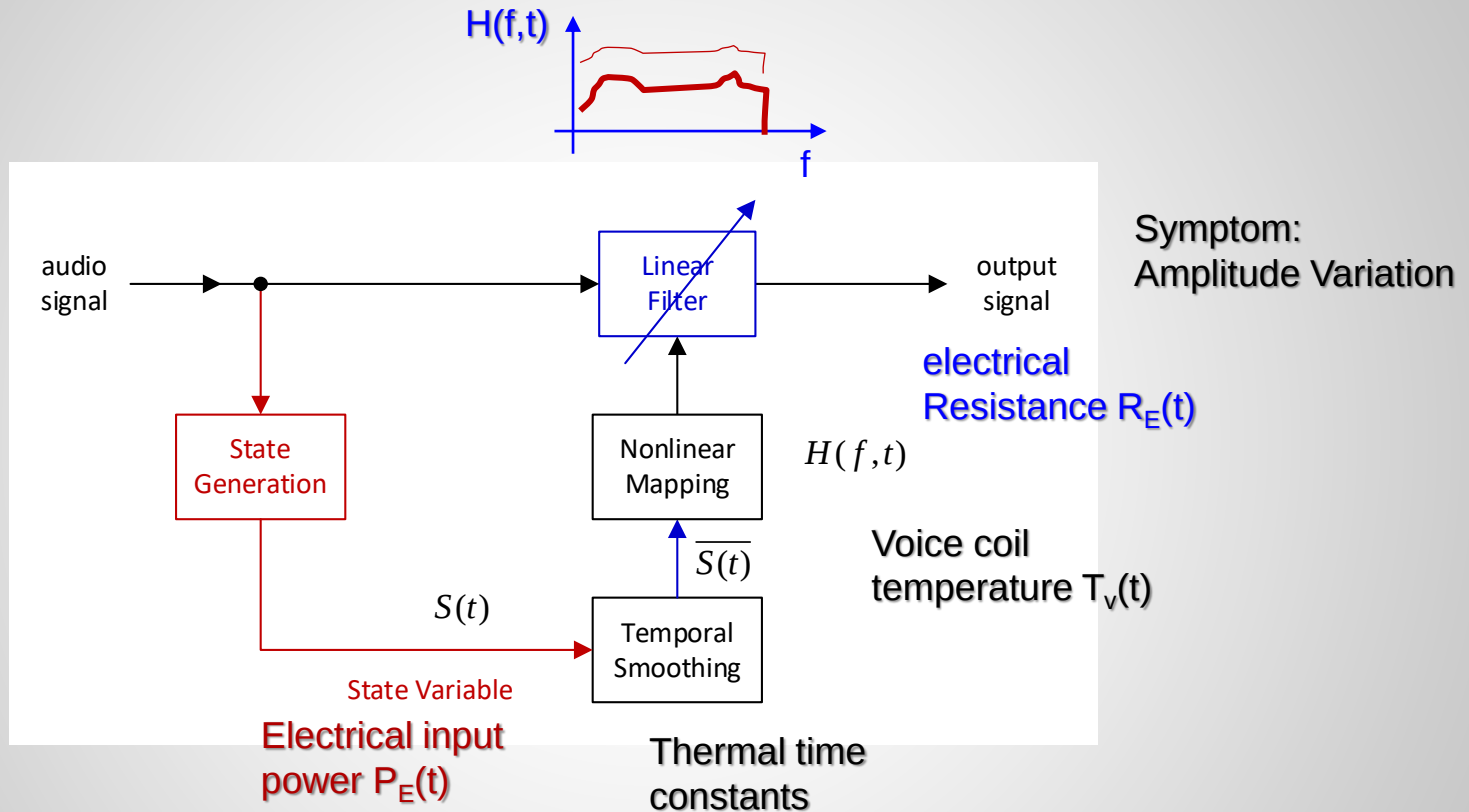
通过小信号测量 (-20dB) 预测的线性响应 Linear response predicted from a small signal measurement (-20 dB)

施加1分钟激励的长时响应 Long term response measured after applying the stimulus for 1 min



热动力简化模型

Simplified Modeling of Thermal Dynamics

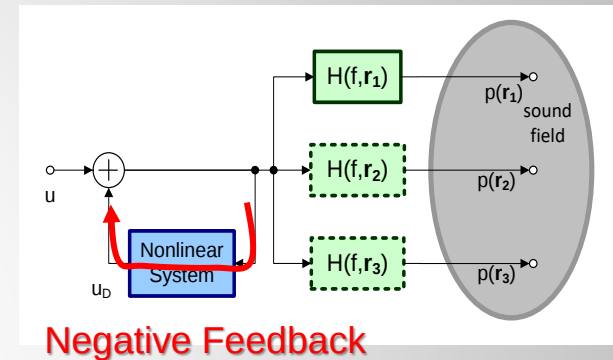
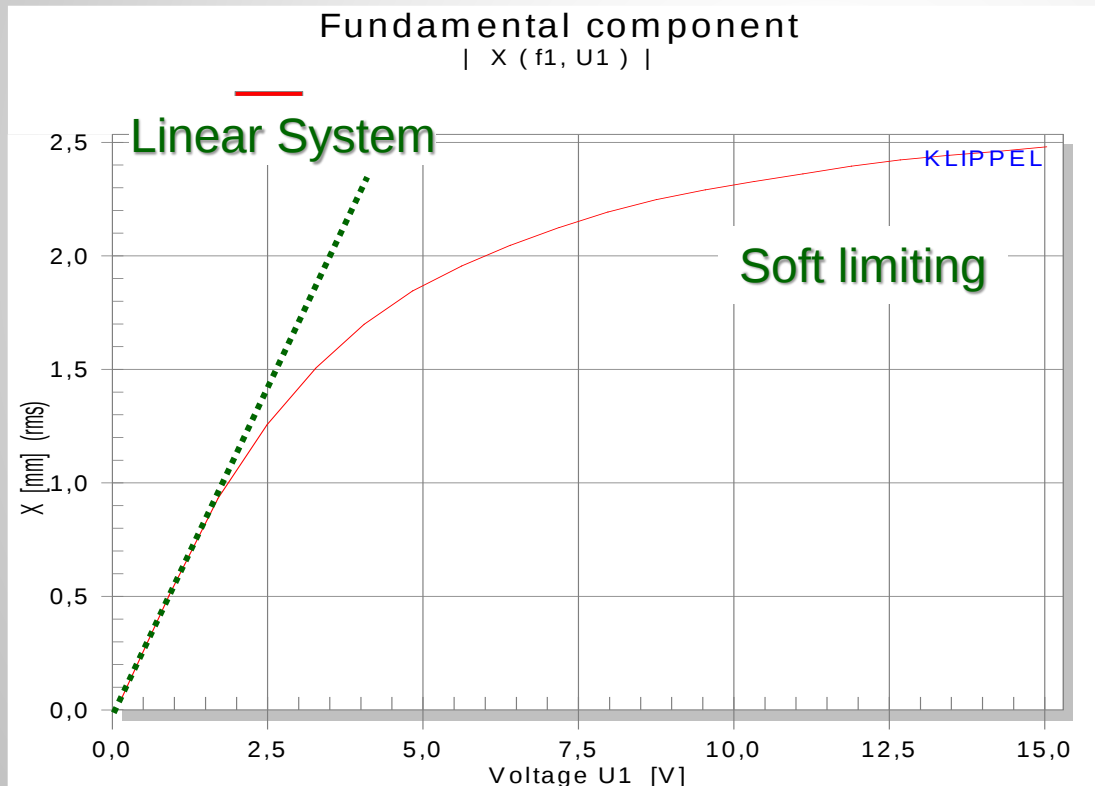


- 热时间常数（音圈 $\tau_v > 1s$ 、磁铁 $\tau_M < 1h$ ）导致传递函数缓慢变化。 The thermal time constants (voice coil $\tau_v > 1s$, magnet $\tau_M < 1h$) cause slow variations in the transfer function.
- 非线性映射不会生成新的频谱成分 New spectral components are not generated by the nonlinear mapping



Nonlinear Amplitude Compression

音圈位移与输入电压的关系，使用步进正弦激励(100ms)
Voice coil displacement versus input voltage measured with a stepped
sinusoidal stimulus (100 ms)



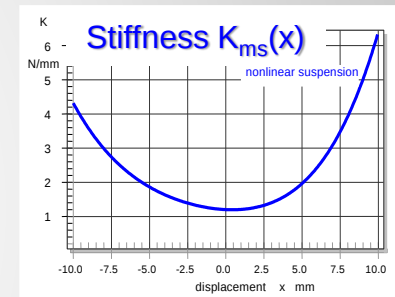
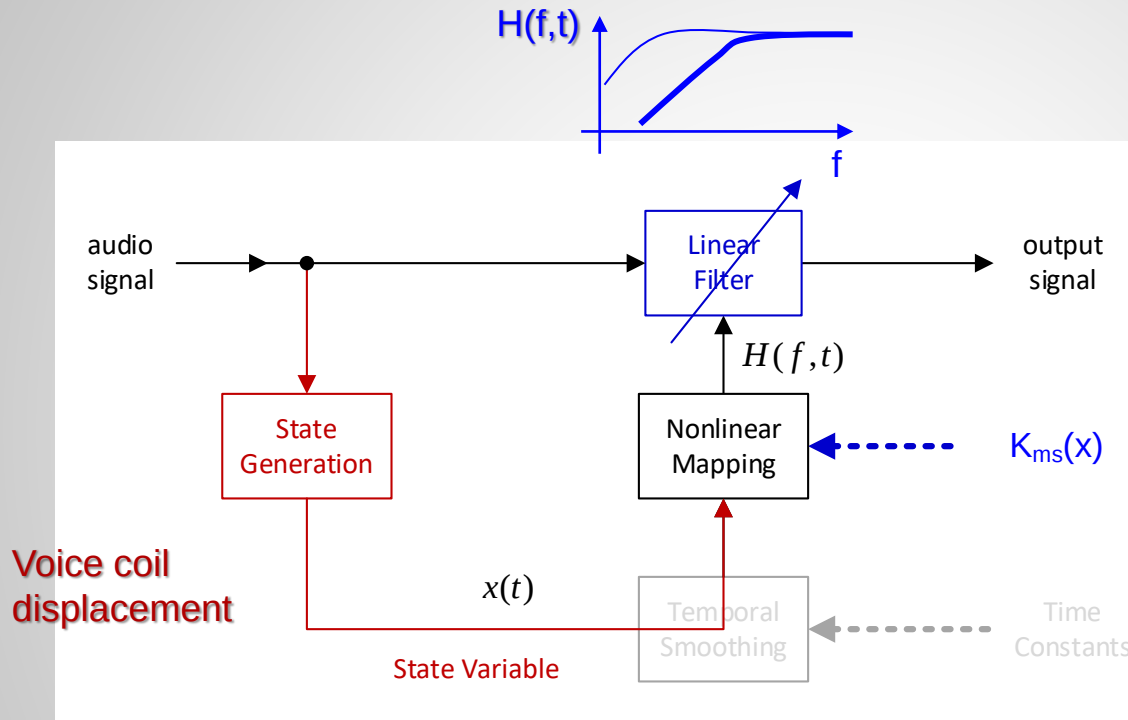
Symptoms:

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



具有非线性刚性 $K_{ms}(x)$ 的机械悬挂

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



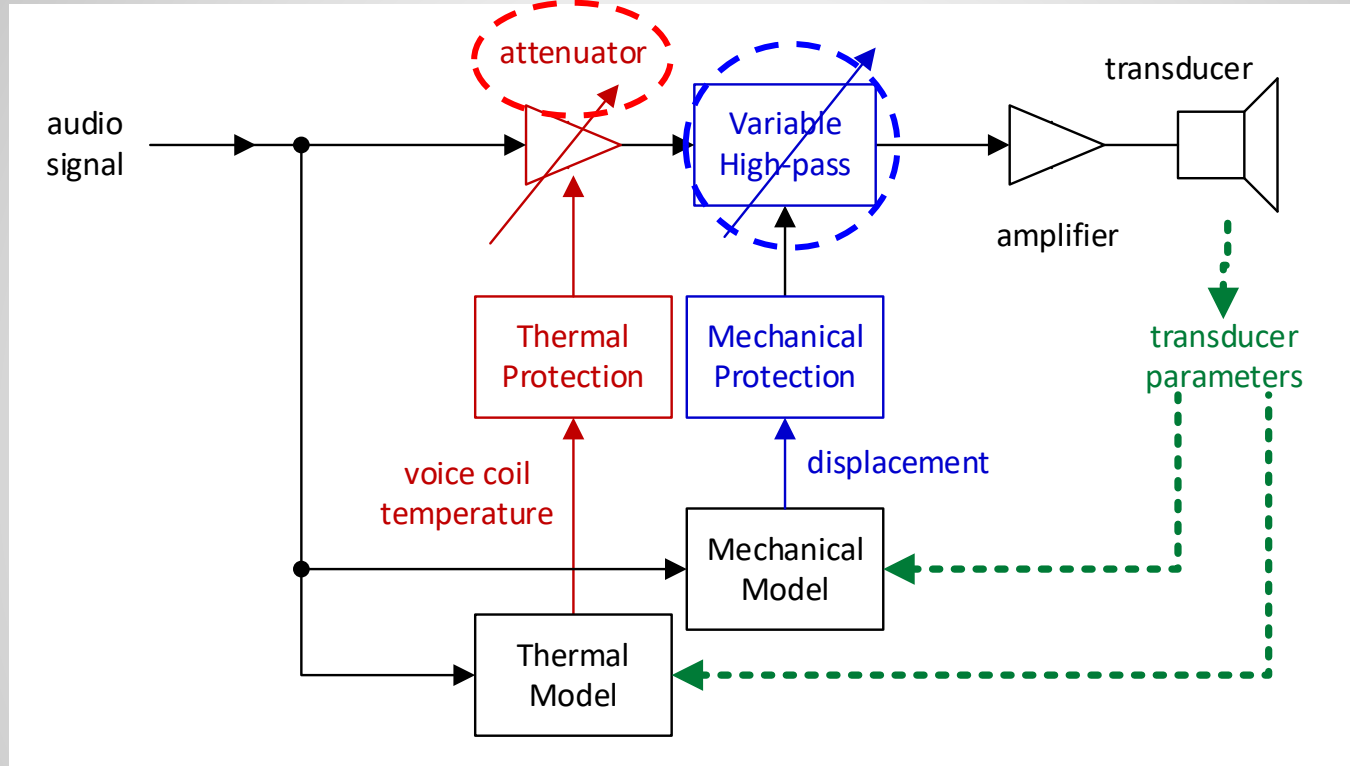
No integration or smoothing of the state variable !!

- 瞬时位移会立即增加刚性，从而降低低频处的位移和SPL The instantaneous displacement instantaneously increases the stiffness, which reduces the displacement and SPL at low frequencies
- 渐进的刚性特性使产品更坚固 A progressive stiffness characteristic makes the product more robust !
- 线性滤波器的快速变化会在输出中产生新的频谱分量（谐波、互调） Fast variation of the linear filter generates new spectral components (harmonics, intermodulation) in the output



主动换能器保护 Active Transducer Protection

基于线性和热模型以及测得的换能器参数 based on linear and thermal modeling and measured transducer parameters



防止热过载 To prevent thermal overload

- 缓慢衰减输入信号，使音圈温度保持在允许的极限之下

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

防止机械过载 To prevent a mechanical overload

- 快速衰减低频分量，使音圈峰值位移在允许的极限之下

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



Poll:

如何避免音频系统过载？（可多选）

How do you avoid an overload of your audio system ? (multiple responses possible)

A. 通过换能器可处理的放大器受限输出

Limited amplifier output which can be handled by the transducer can

B. 使用电气方式（模拟）实现对硬件的主动保护

Using electrical means (analogue) for realizing active protection of the hardware

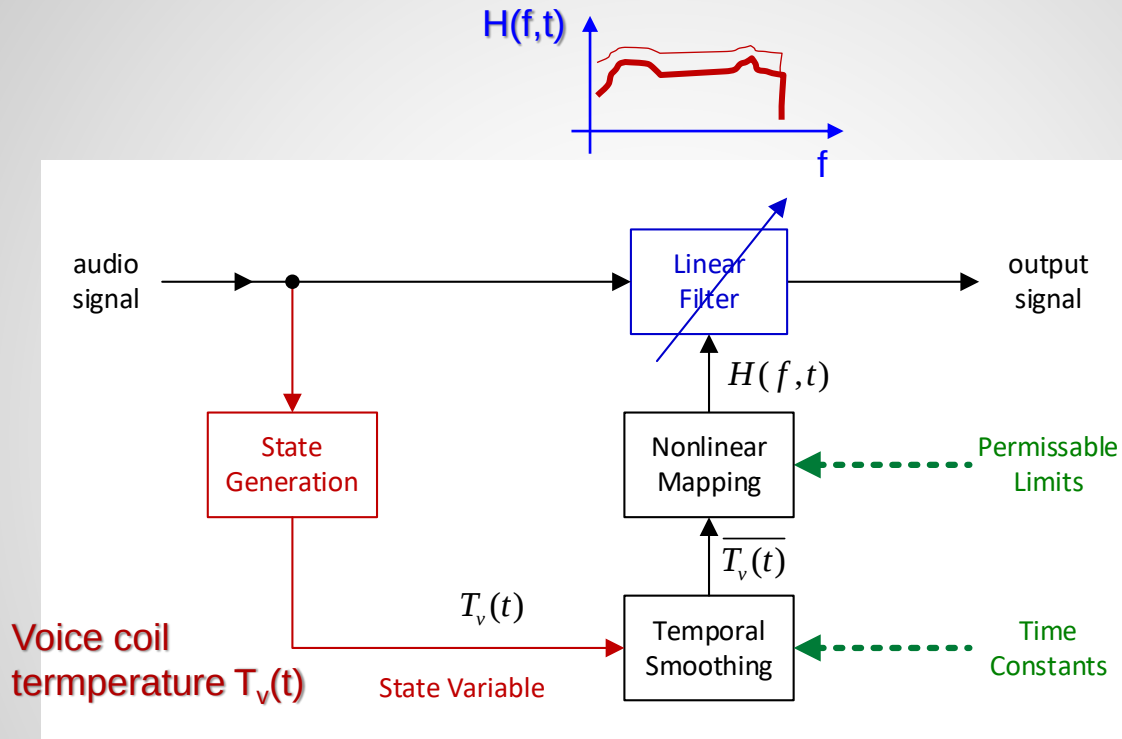
C. 使用DSP软件限制最大输出并保护硬件

Using DSP software for limiting the maximum output and protecting the hardware

D. 其他 others



Active Thermal Protection



Symptom:
Amplitude Variation

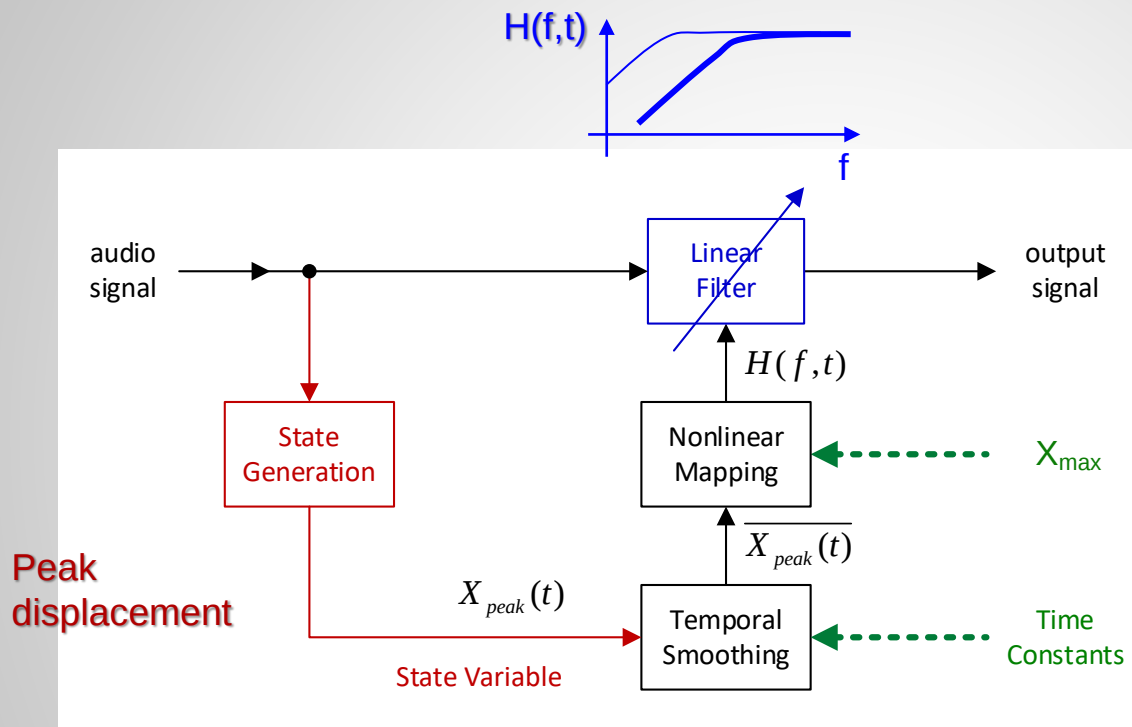
Maximum voice coil temperature $T_{\max}$

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

- 热时间常数导致传递函数缓慢变化 The thermal time constants cause slow variations in the transfer function.
- 保护系统衰减输入信号以保持 $T_v(t) < T_{\max}$ The protection system attenuates the input signal to keep $T_v(t) < T_{\max}$
- 保护系统不会产生新的频谱成分 New spectral components are not generated by the protection system



Mechanical Protection System



Maximum permissible displacement X_{max}

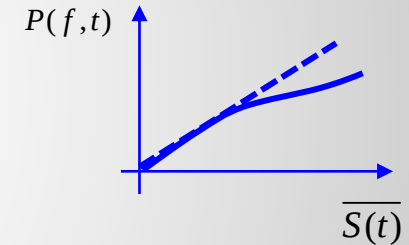
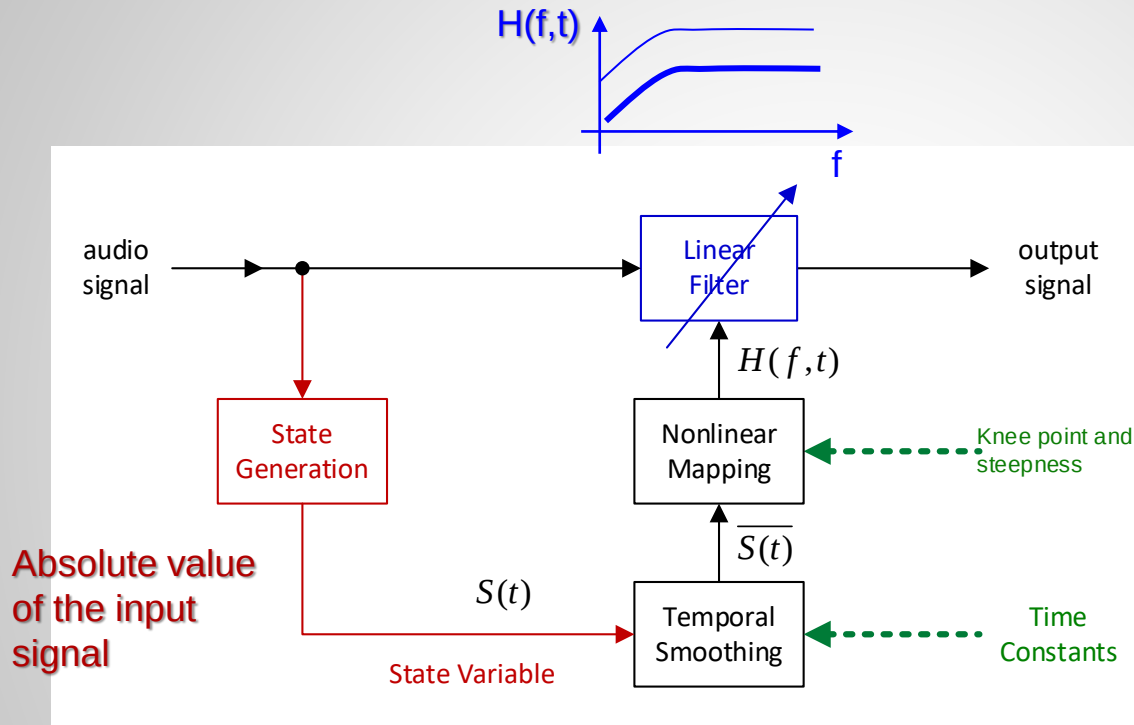
- Short Attack time (1 ms)
- Long release time (> 100 ms)

- 状态发生器产生音圈位移的峰值 The state generator generates the peak value of the voice coil displacement
- 低频范围将被衰减以使峰值位移 x_{peak} 保持在极限值 x_{max} 以下 The low frequency range will be attenuated to keep the peak displacement x_{peak} below the limit value x_{max}
- 较长的释放时间可减少非线性失真和其他不良现象（泵浦效应），但也会降低声学输出
 出 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



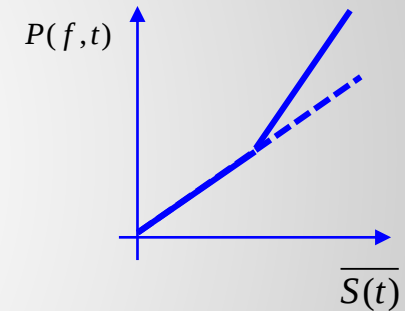
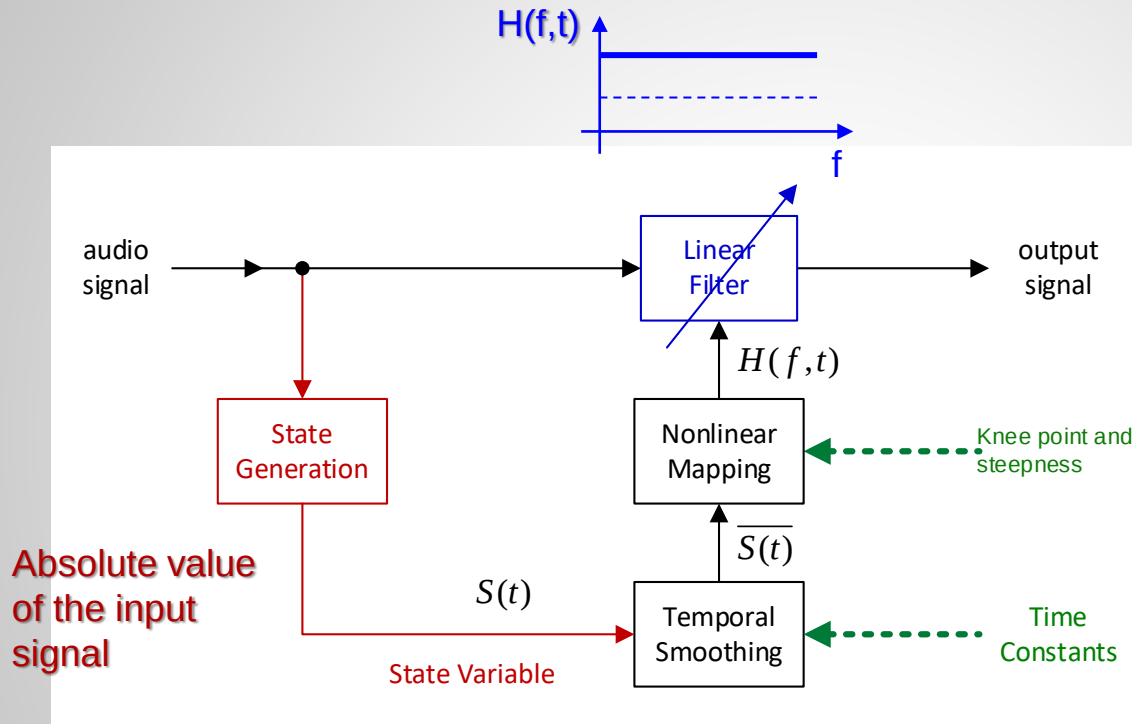
- Short Attack time (0.5 ms)
- Long release time (50 ms)

- **目标：降低放大器的峰值电压要求，同时增加SPL输出**
Target: Reduction of the peak voltage requirements of the amplifier while increasing the SPL output
- **在攻击阶段会产生非线性和脉冲失真** Nonlinear and impulsive distortion are generated during attack phase
- **较长的释放时间常数会减少非线性失真，但会降低长时SPL**
A longer release time constant reduces the nonlinear distortion but reduces the long-term SPL



Noise Gating

applied to the input signal



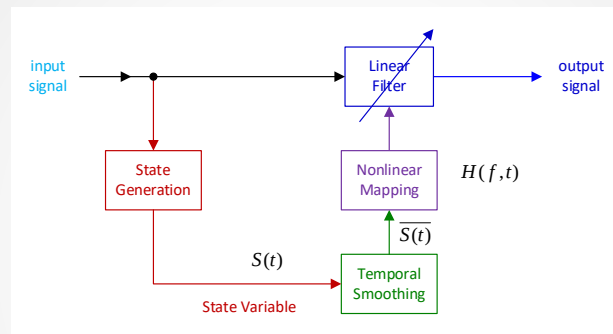
- Short Attack time (0.1 ms)
- Long release time (200 ms)

- 目标：未施加音频信号时减少电子噪声 Target: Reduction of electronic noise when no audio signal is applied
- 攻击阶段（增益切换）会产生非线性和脉冲失真
Nonlinear and impulsive distortion are generated during attack phase (gain switching)
- 较长的释放时间常数可减少伪值 A longer release time constant reduces the artifacts



Consequences for Testing

宽带测试激励代表典型
音频信号 Broadband test
stimuli represent typical audio
signals



快速分析以测量瞬态行为
Fast analysis to measure
transient behavior

增加激励幅值（线性步
进）来测量特性（软、
硬限制） Increasing
stimulus amplitude (linear
stepping) to measure the
characteristic (soft, hard
limiting)

需要带限测试激励来找到激活幅
度压缩的状态信号 Band limited test
stimulus is required to find the state signal
that activates the amplitude compression

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

需要短激励来评估非线性压缩、
DSP和音圈加热 Short Stimuli are
required to evaluate the nonlinear
compression, DSP and voice coil heating

长激励来考虑热压缩（磁铁）
Long Stimuli to consider the thermal
compression (magnet)



Overview on Test Methods

Noise Generator + Spectrum Analyzer + Cross correlation

- 常规技术, 适用于缓慢热压缩 Conventional technique, good for slow thermal compression
- 需要平均来提高SNR (费时) Averaging required to improve SNR (time consuming)
- 时间分辨率差 (DSP、非线性) Poor temporal resolution (DSP, nonlinearities)

Multi-tone testing (sparse pseudo-random noise)

- 类似于密集噪声的稀疏频谱但SNR高 Sparse spectrum similar to dense noise but higher SNR
- 如果采样率不匹配需要特殊分析 (第15期) Special analysis required if there is a sample rate mismatch (session 15)

Sinusoidal chirp testing (logarithmic frequency-time mapping)

- 频谱密集、高SNR、快速分析 Dense spectrum, good SNR, fast analysis
- 换能器非线性高度激活 High activation of the transducer nonlinearities

IEC 60268-21

Single Tone, Burst at selected frequencies

- 测试瞬态行为的最佳时间分辨率 Best temporal resolution for testing transient behavior
- 耗时 Time consuming



Multi-Tone Testing in Practice

Conditions:

用于测试最大输出SPLmax的稀疏多音激励（典型素材）（第5期） Sparse multi-tone stimulus (typical program material) as used for testing maximum output SPLmax (session 5)

根据IEC 60268-21第16.4章节进行测量 Measurements according to IEC 60268-21 chapter 16.4

1a) **短时压缩**，在最大输入 $U_{\max}=0.17\text{V}$ 时，在预循环中播放相同的激励后使用激励长度 $T=1\text{s}$

Short-term compression at maximum input $U_{\max}=0.17\text{ V}$ using a stimulus length $T=1\text{s}$ after playing the same stimulus in a preloop

1b) **长时压缩**，在最大输入 $U_{\max}=0.17\text{V}$ 时，在预循环中播放激励1分钟+冷却中断1分钟（无中断）后使用激励长度 $T=1\text{s}$ 测量 **Long-term compression** measured at maximum input $U_{\max}=0.17\text{V}$ with the same stimulus $T=1\text{s}$ after the playing the stimulus 1 min in a preloop + 1 min cooling break (without break)

2) 搜索输入电压 u 产生短时压缩 $C = 3\text{dB}$ Search for input voltage u generating a short-term compression $C = 3\text{dB}$

提示：在近场中进行测量以提高SNR Tip: Perform measurement in near field to improve SNR

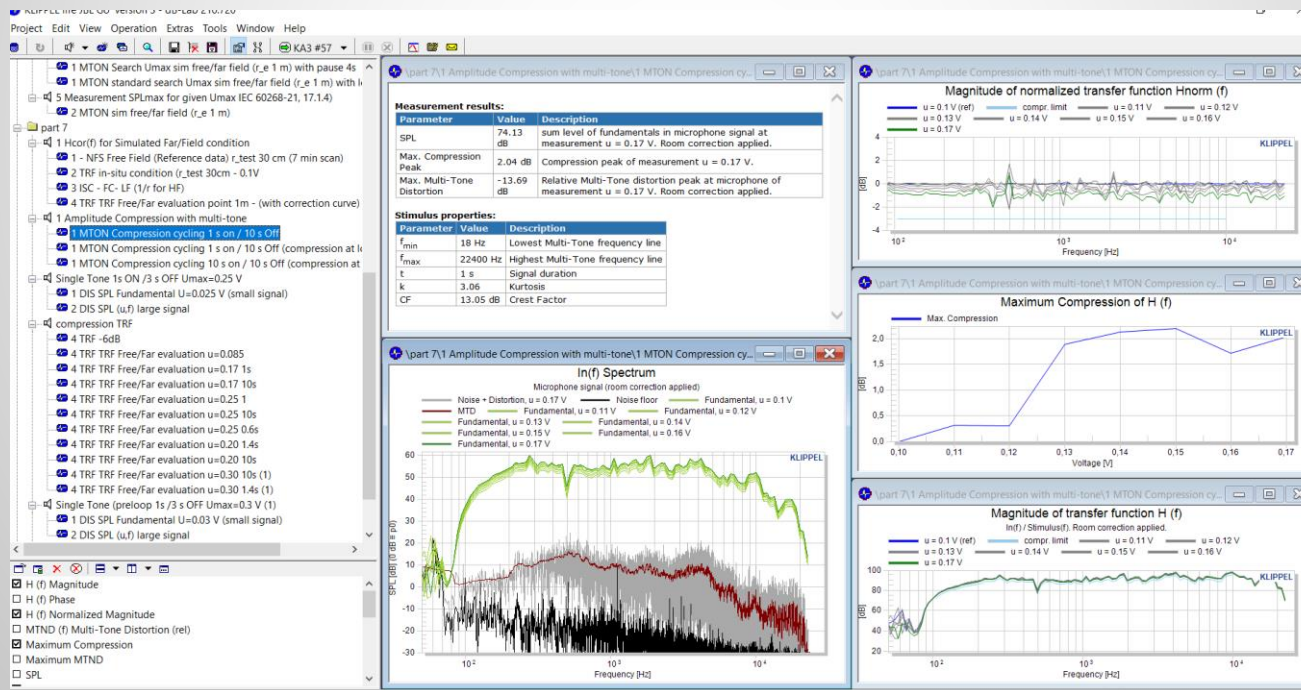
解读： Interpretation:

与短时和长时测量进行比较 Compare with Short-Term and Long-Term Measurement



Demo

Tool: Using a dedicated software module MTON (multi-tone) of the KLIPPEL Analyzer



Chirp Testing in Practice

Conditions:

SPLmax时使用对数频率-时间映射的正弦chirp信号 (第5期)

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

Measurements of the compression

3a)短时压缩, 在最大输入 $U_{\max}=0.17\text{V}$ 时, 在预循环中播放相同的激励后使用激励长度 $T=0.6\text{s}$

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

3b)长时压缩 (缓慢扫频速度), 在最大输入 $U_{\max}=0.17\text{V}$ 时, 在预循环中播放相同的激励后使用激励长度 $T=20\text{s}$

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

3c)搜索提供幅值压缩 $C=3\text{dB}$ 的电压 Searching for voltage giving amplitude compression $C=3\text{dB}$

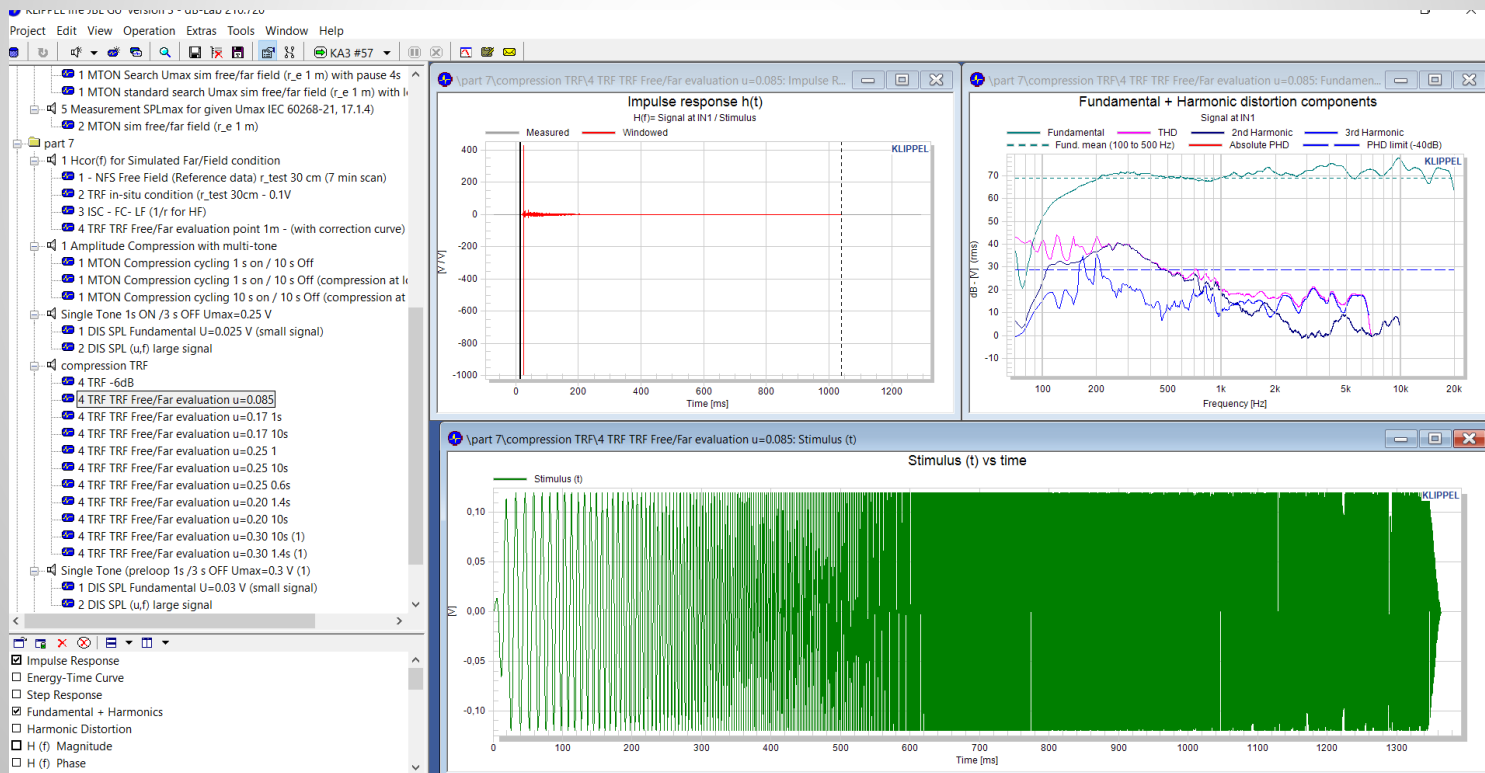
解读 Interpretation:

- 比较短时多音测试和短时chirp测试 Compare Short-term multi-tone test with short-term chirp test
- 比较chirp和多音测试的幅值压缩 Compare amplitude compression from chirp and multi-tone



Demo

Tool: Using a dedicated software modules TRF (transfer function) and TRF Stepping of the KLIPPEL Analyzer



Single Tone Testing in Practice

Conditions:

- 与频率电压相关的步进音激励，含预循环，步长之间有停顿（关闭）
Stepped tone excitation versus frequency and voltage with preloop and pause between the steps (off)
- 换能器的加热可忽略 Negligible heating of the transducer

Tests:

- 4) 搜索稳态测试条件（预循环、停顿） Searching for steady-state test condition (preloop, pause)
- 5) 预循环对压缩的影响 Influence of preloop on the compression

解读 Interpretation:

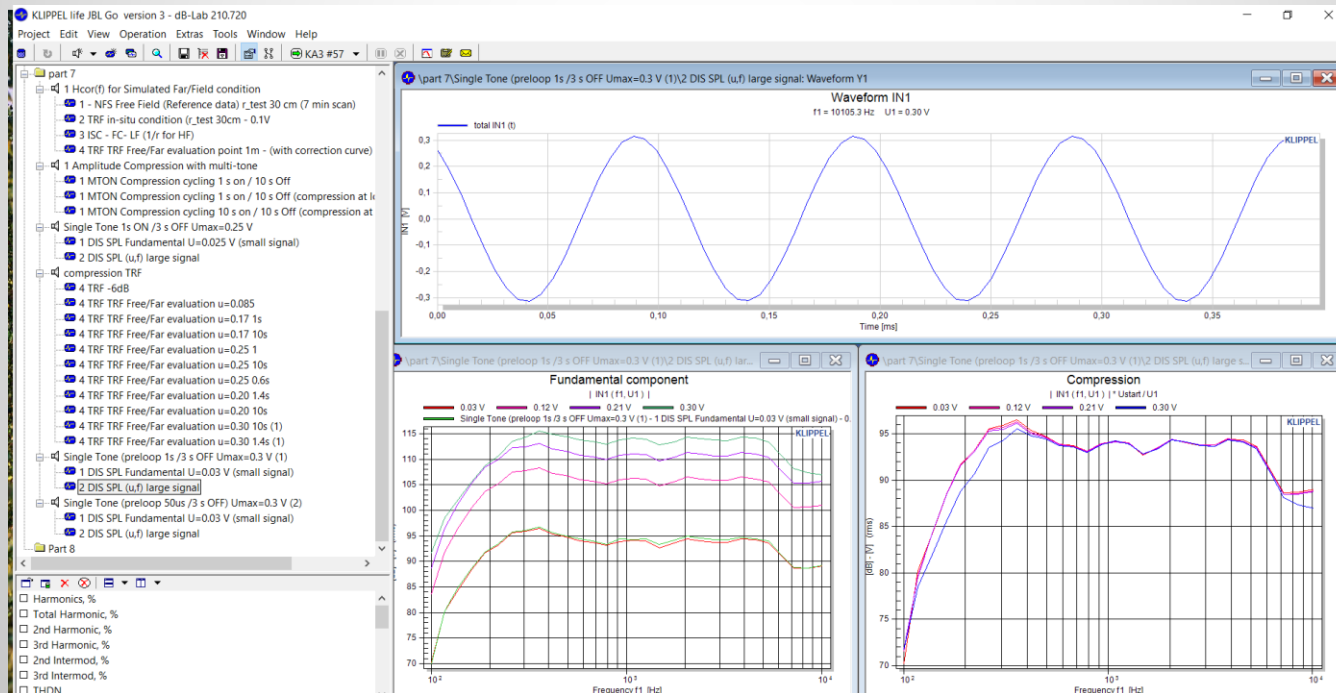
和超快速测试比较 Compare with m with Ultra-Fast



Demo: Compression (Stepped Sine)

Tools of the KLIPPEL Analyzer:

- 3D distortion measurement (DIS)



Burst Testing in Practice

Conditions:

- 瞬态超快速测量 Transient ultra-fast testing
- 猝发音有预循环、电压步进增长有停顿 Tone burst with preloop, pause stepped at increasing voltages
- 换能器加热可忽略 Negligible heating of the transducer

压缩测量 Measurements of the compression

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

Interpretation:

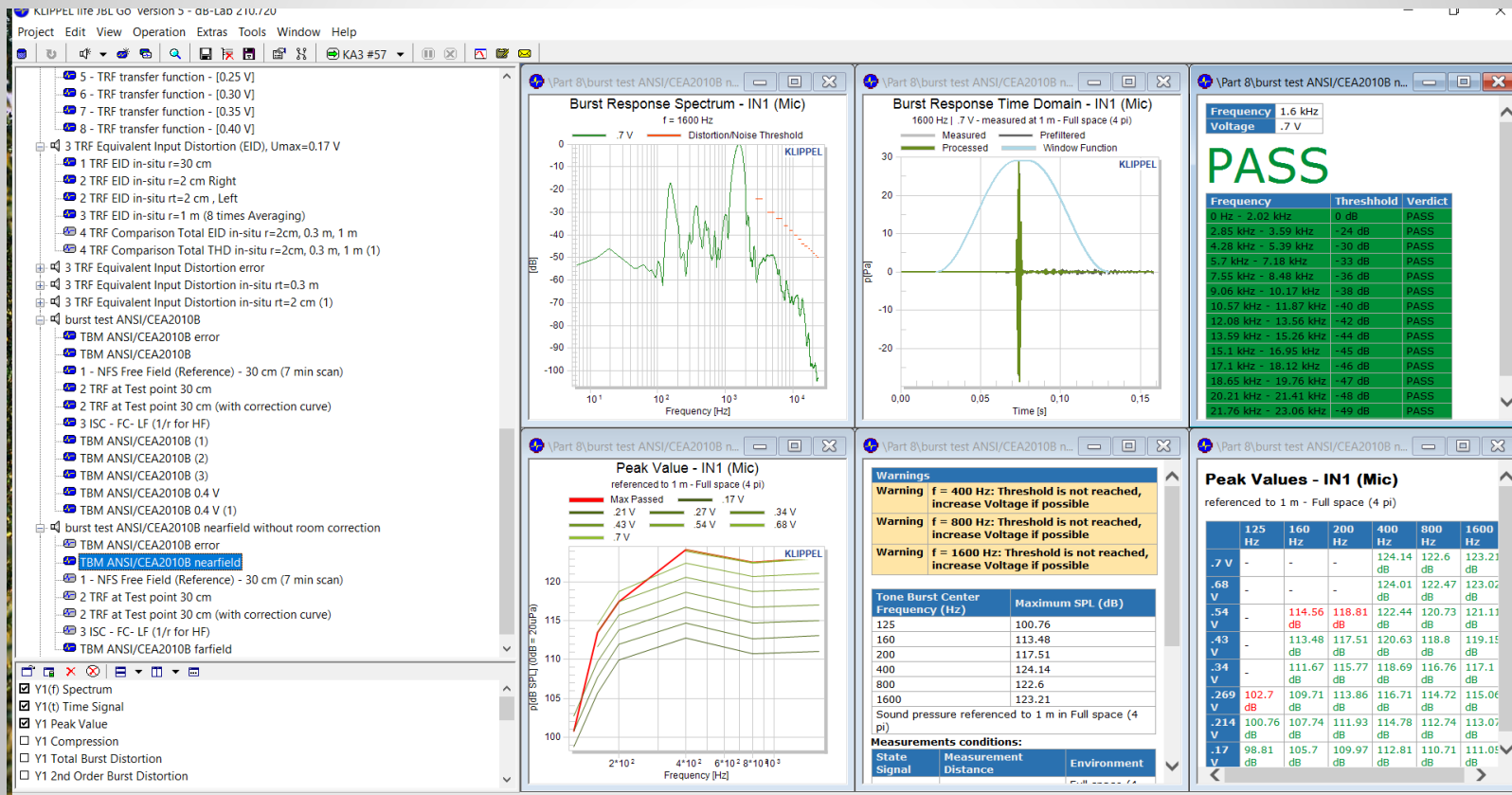
Compare with with Ultra-Fast



Demo: Amplitude Compression (Burst)

Tools of the KLIPPEL Analyzer:

- Tone Burst Measurement Module (TBM)
- Time frequency Analysis





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

幅值压缩 Amplitude Compression

- 是评定最大声学输出的重要特性
Is an important characteristic for rating the maximum acoustical output
- 取决于特定激励 Depends on the particular stimulus
- 是换能器的自然作用（接近过载）
Is a natural effect of transducers (close to overload)
- 在带有限制器、保护系统和其他DSP软件的有源系统中有意生成（用幅度压缩代替THD!!）
Is intentionally generated in active systems with limiters, protection systems and other DSP software (Trading amplitude compression for THD !!)
- 可在换能器近场测量，无需房间校正曲线
Can be measured in the near field of the transducer without using a room correction curve



Open Questions

现在是时候考虑激励中不含有的频谱成分了！

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

第八期网络研讨会主题 The next 8th KLIPPEL live webinar entitled
谐波失真测量 – 最佳实践 Harmonic Distortion Measurements – best practice
将讨论 will address the points:

- 传统和新的测试方法(IEC 60268-21) Traditional and new ways for testing (IEC 60268-21)
- 可以简化THD响应的解读吗？ Can we simplify the interpretation of THD response ?
- 什么揭示了2阶和3阶谐波？ What reveals the 2nd and 3rd harmonics ?
- 减少位置、距离、房间、传感器等的影响
Reducing the influence of positioning, distance, room, sensor,
- 如何将QC终端测试和标准测量联系起来？
How to link QC end-of-line testing with standard measurements ?



Next Section

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
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 product
15. Smart speaker testing with wireless audio input

