Acoustical Distortion Measurements

Parts 6-10 of the KLIPPEL- live webinar

Acoustical Measurement of Sound System Equipment

according IEC 60268-21

presented by

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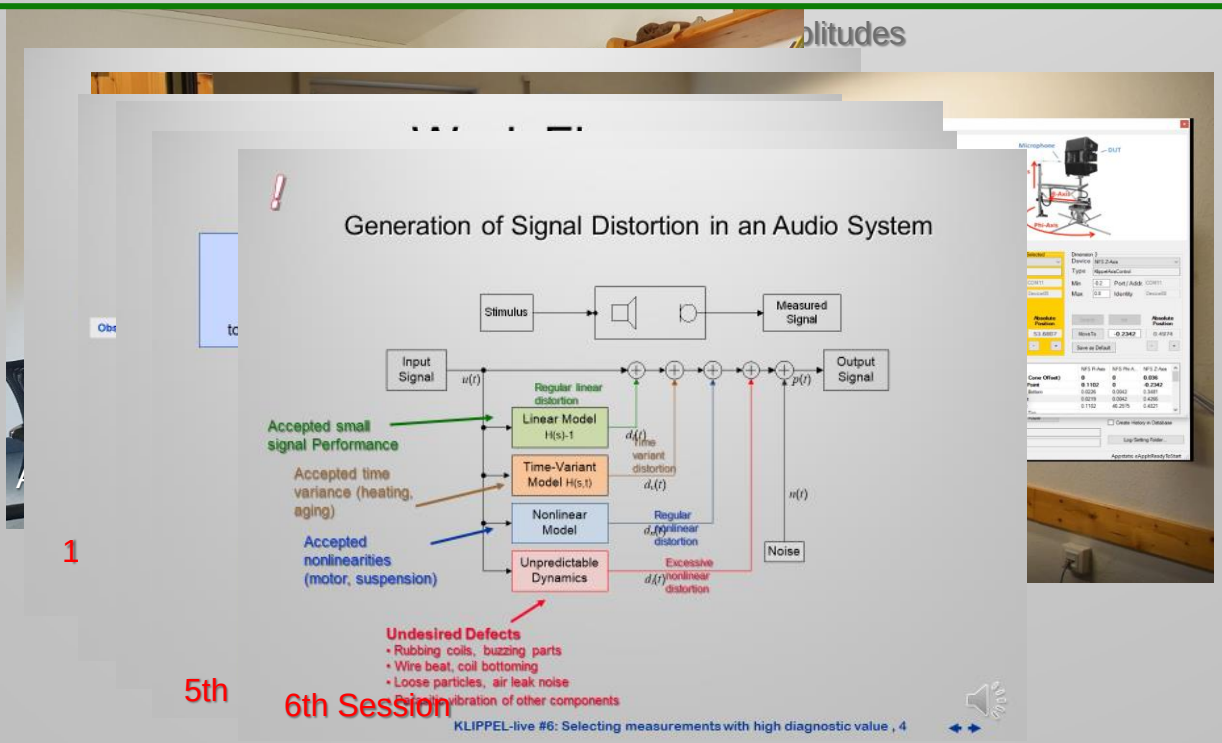
過去的課程 Previous Sessions

1. 現代音頻設備需要輸出基本的測試 Modern audio equipment needs output based testing
2. 在普通房間進行的聲學標準測試 Acoustical standard tests performed in normal rooms
3. 從 3D 輸出測量中得出有意義的結論 Drawing meaningful conclusions from 3D output measurement
4. 在單個評估點模擬標準條件 Simulated standard condition at a single evaluation point
5. 最大聲壓級– 數字變得很重要 Maximum SPL – a number becomes important
6. 選擇具有高診斷價值的測量 Selecting measurements with high diagnostic value



Sessions of KLIPPEL- live Webinar

根據 IEC 60268-21 對音響系統設備進行聲學測量

Acoustical Measurement of Sound System Equipment according IEC 60268-21

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6. 信號失真–強大的揚聲器診斷概念 Signal distortion – a powerful concept for loudspeaker diagnostics
7. 幅度壓縮–在較高幅度下輸出較少 Amplitude Compression – less output at higher amplitudes
8. 諧波失真測量 - 最佳實踐 Harmonic Distortion Measurements – best practice
9. 互調失真 - 音頻不僅僅是一個音調 Intermodulation Distortion – audio is more than a single tone
10. 脈衝失真 – 異音、異常行為、不良 Impulsive distortion - rub&buzz, abnormal behavior, defects
11. 具有無線音頻輸入的智能揚聲器測試 Smart speaker testing with wireless audio input
12. 在標準條件下對音頻產品進行基準測試 Benchmarking of audio products under standard conditions
13. 信號失真的可聽化——感知評估 Auralization of signal distortion – perceptual evaluation
14. 為信號失真設置有意義的容差 Setting meaningful tolerances for signal distortion
15. 評定產品的最大 SPL 值 Rating the maximum SPL value for product

7th KLIPPEL live:
幅度壓縮– 在較高震幅下有較少輸出
Amplitude Compression – less output at higher amplitudes

今日主題Topics today:

- 幅度壓縮的物理原因 Physical causes for amplitude compression
- 測試的後果 Consequences for testing
- 根據 IEC 標準 20268-21 進行測量 Measurement according IEC Standard 20268-21
- 其他有用的測試方法概述 Overview of other useful test methods
- 結果的解釋 Interpretation of the results
- 實際演示 Practical demos

投票 Poll:

您是否測量了最大輸入電壓 umax 傳遞函數（幅度響應）的變化？

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

- 有 Yes
- 沒有 No

幅度壓縮Amplitude Compression

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

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

幅度壓縮 C(f,tm) 是在時間 tm 測量的時變傳遞函數 H(f,r, umax,tm) 的幅度頻率響應與線性傳遞函數 Hlin(f,r, 0.1 umax) 在小信號域 (-20 dB) 的相同條件（位置、環境）下測得。

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).

結果 Consequences:

- 不需要遠場條件和消聲環境 far field condition and anechoic environment are not required
- 待測物和麥克風的位置不應改變！Position of DUT and microphone should not be changed !

如何執行 How to do it

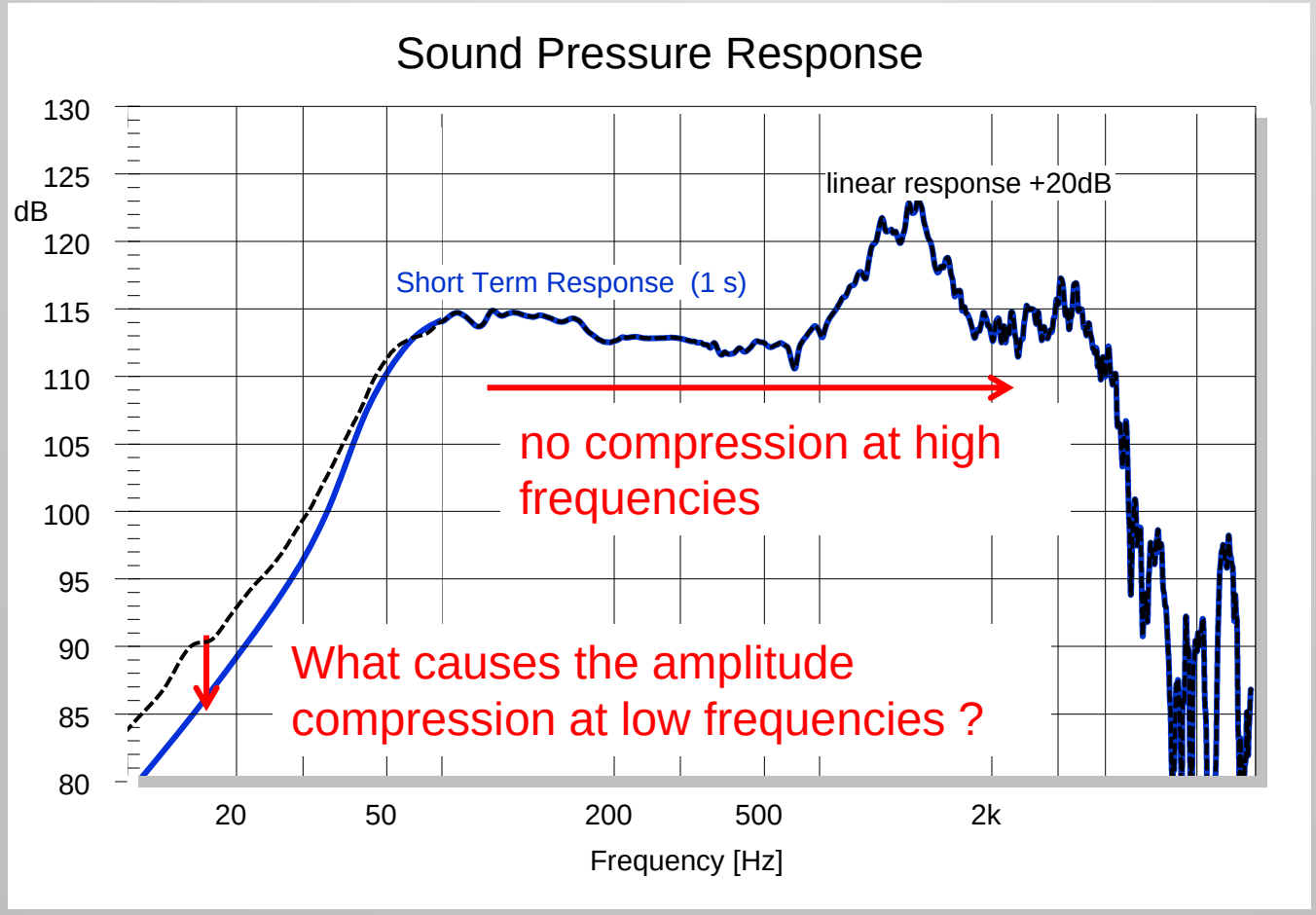
簡而言之，根據 IEC 60268-21 進行測試：

Testing according to IEC 60268-21 in short:

1. 定義寬帶激勵、測量條件（推薦近場）Define the broadband stimulus, measurement condition (near field is recommended)
2. 確定最大輸入電壓 umax Determine maximum input voltage u_{max}
3. 測量線性傳遞函數 Hlin(f,r, 0.1 umax) Measure the linear transfer function $H_{lin}(f,r, 0.1\ u_{max})$
4. 測量最大輸入時的時變傳遞函數 H(f,r, tm,umax) Measure the time variant transfer function $H(f,r, t_m,u_{max})$ at maximum input
5. 計算壓縮 C(f,tm) Calculate the compression $C(f,t_m)$

SPL 輸出的壓縮Compression of SPL Output

SPL output at maximum input voltage U_{max}

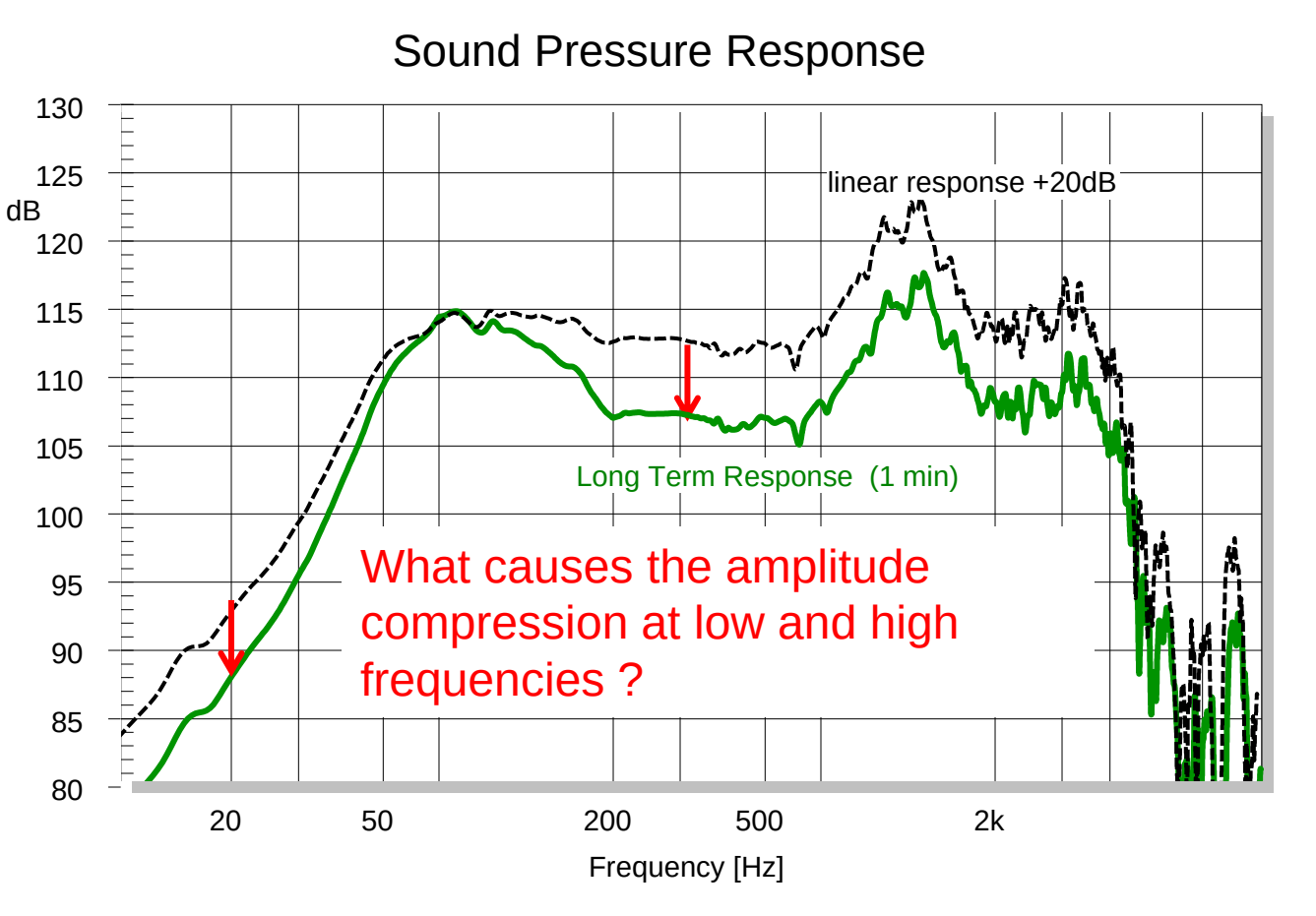


從小信號測量預測的線性響應
(-20 分貝)
Linear response predicted from a small signal measurement (-20 dB)

Short term response measured within 1 s stimulus

SPL 輸出的壓縮Compression of SPL Output

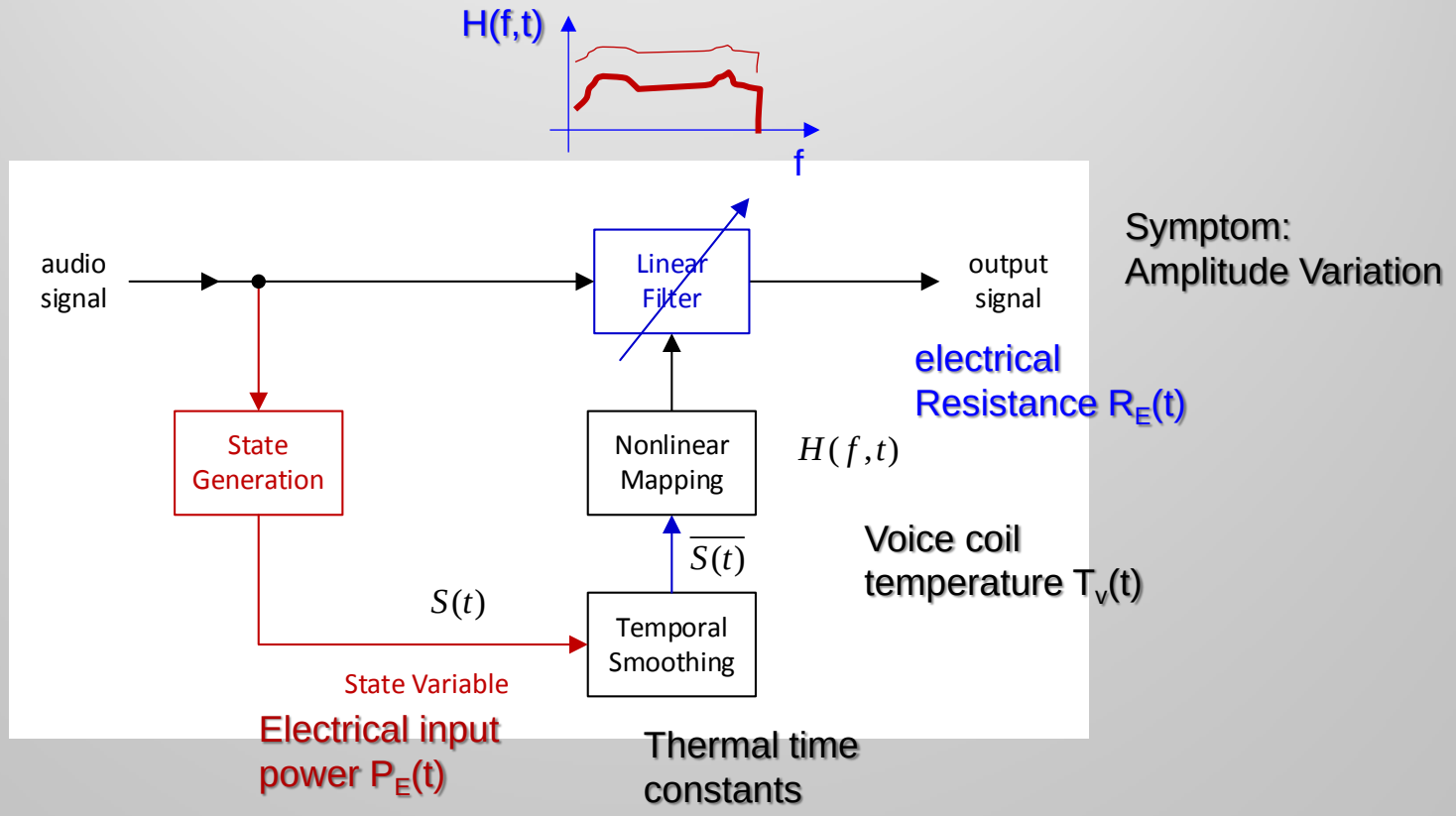
SPL output at maximum input voltage Umax



從小信號測量預測的線性響應
(-20dB)
Linear response predicted from a small signal measurement (-20dB)

Long term response measured after applying the stimulus for 1 min

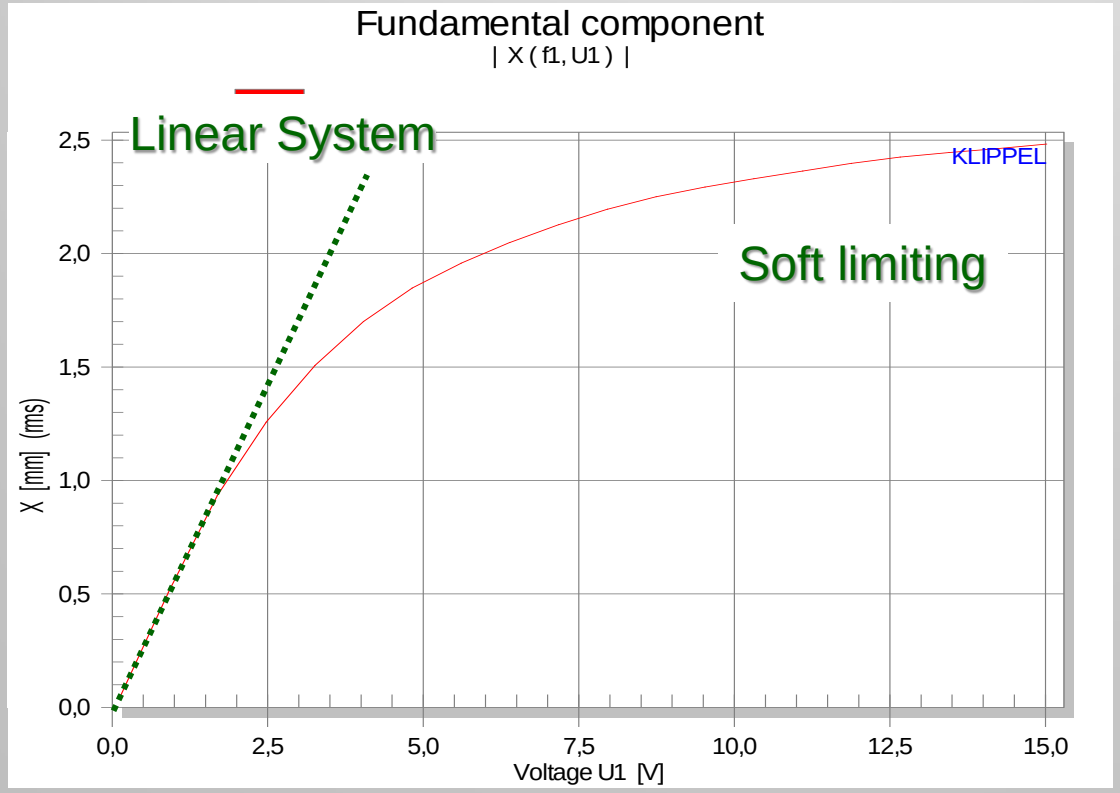
熱力學的簡化建模
Simplified Modeling of Thermal Dynamics

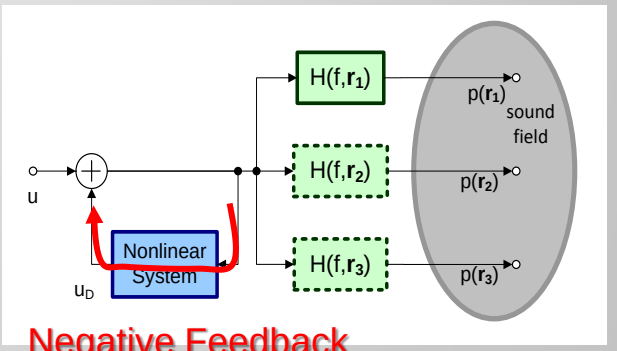


- 熱時間常數（音圈 τv > 1s ，磁鐵 τM < 1h ）導致傳遞函數的緩慢變化。 The thermal time constants (voice coil τ_v > 1s , magnet τ_M < 1h) cause slow variations in the transfer function.
- 非線性映射不會產生新的光譜分量 New spectral components are not generated by the nonlinear mapping

非線性幅度壓縮
Nonlinear Amplitude Compression

使用階梯式正弦刺激 (100 ms) 測量的音圈位移與輸入電壓的關係
Voice coil displacement versus input voltage measured with a stepped sinusoidal stimulus (100 ms)

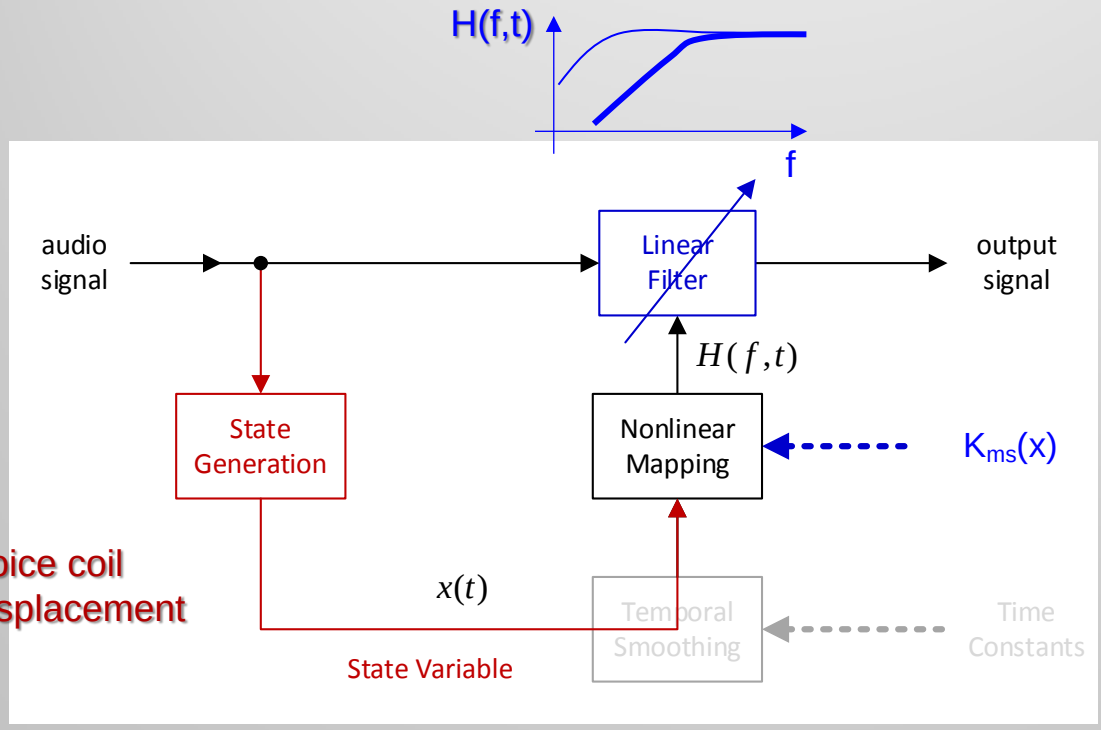


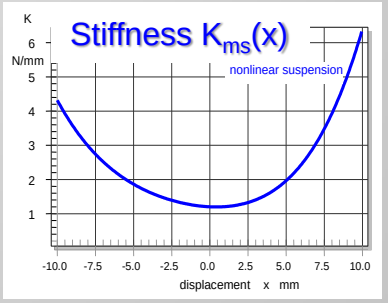


Symptoms:

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

具有非線性剛度 Kms(x) 的機械懸架
Mechanical Suspension with nonlinear Stiffness $K_{ms}(x)$





No integration or smoothing of the state variable !!

- 瞬時位移瞬間增加了剛度，從而降低了低頻下的位移和 SPL

The instantaneous displacement instantaneously increases the stiffness, which reduces the displacement and SPL at low frequencies

- 漸進的剛度特性使產品更加堅固！

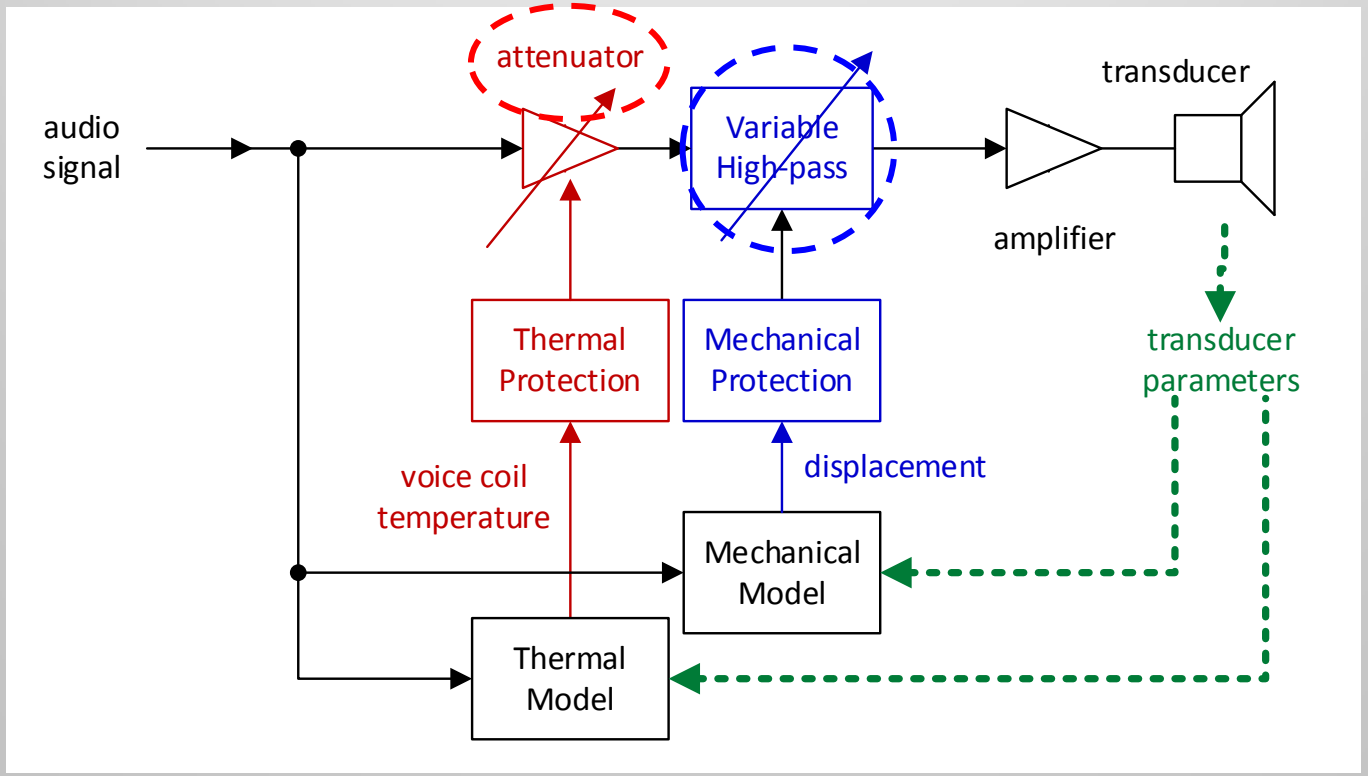
A progressive stiffness characteristic makes the product more robust !

- 線性濾波器的快速變化在輸出中產生新的頻譜分量（諧波、互調）

Fast variation of the linear filter generates new spectral components (harmonics, intermodulation) in the output

主動喇叭保護 Active Transducer Protection

based on linear and thermal modeling and measured transducer parameters



防止熱過載 To prevent thermal overload

- 緩慢衰減輸入信號，以將音圈溫度保持在允許的極限以下 slow attenuation of the input signal to keep the voice coil temperature below a permissible limit

防止機械過載 To prevent a mechanical overload

- 低頻分量的快速衰減，以將音圈峰值位移保持在允許的極限以下 fast attenuation of the low frequency component to keep the voice coil peak displacement below a permissible limit

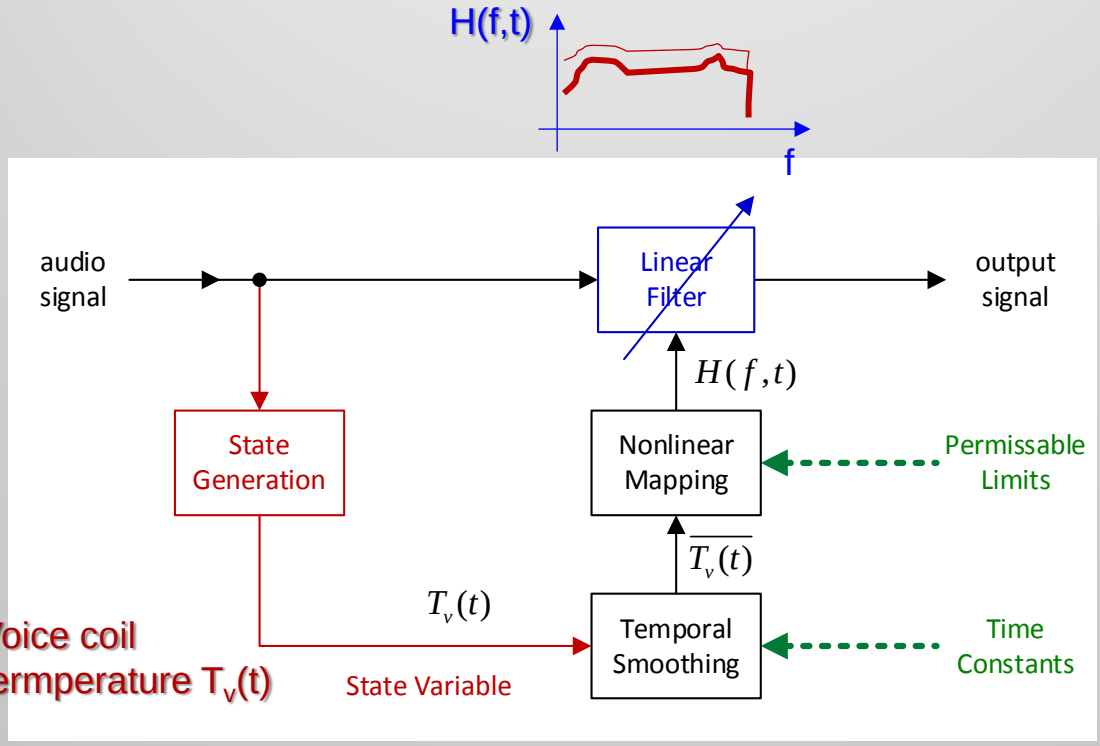
投票 Poll:

您如何避免音頻系統過載？（可複選）

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

A. 傳感器可以處理的有限放大器輸出可以 Limited amplifier output which can be handled by the transducer can
B. 利用電氣方式（模擬）達成硬體的主動保護 Using electrical means (analogue) for realizing active protection of the hardware
C. 使用DSP限制最大輸出和保護硬體 Using DSP software for limiting the maximum output and protecting the hardware
D. 其他 others

主動熱保護 Active Thermal Protection



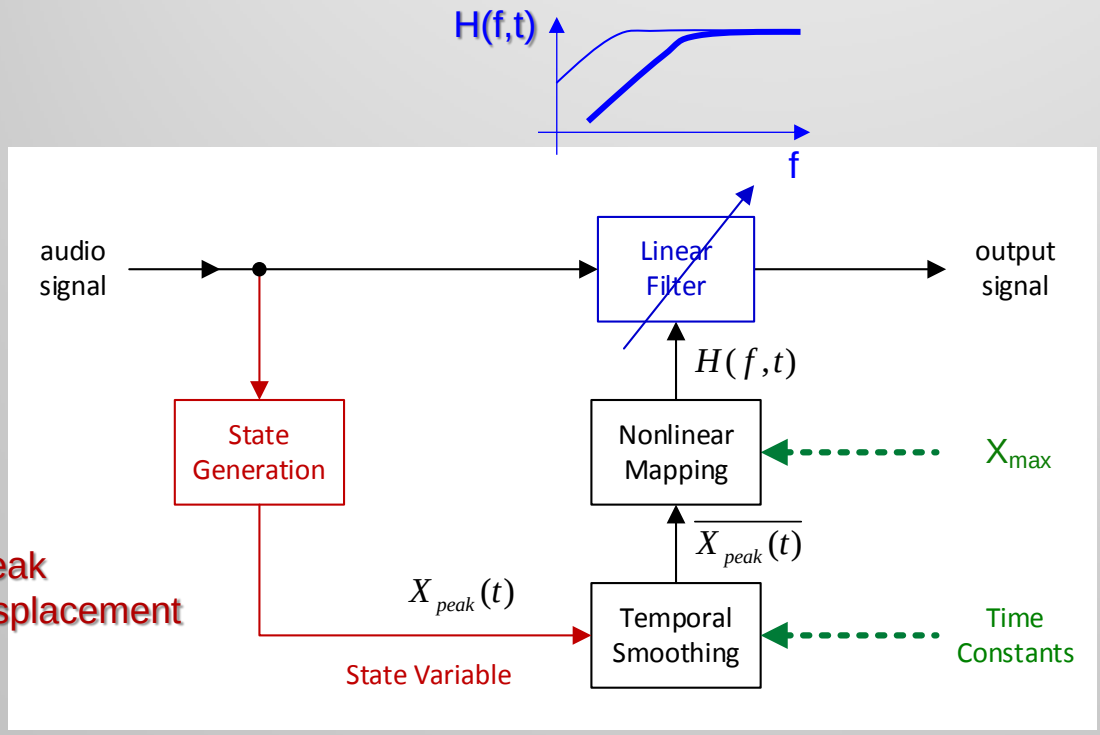
Symptom: Amplitude Variation

Maximum voice coil temperature T_{max}

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

- 熱時間常數導致傳遞函數的緩慢變化 The thermal time constants cause slow variations in the transfer function.
- 保護系統衰減輸入信號以保持 Tv(t) < Tmax The protection system attenuates the input signal to keep $T_v(t) < T_{max}$
- 保護系統不會產生新的頻譜分量 New spectral components are not generated by the protection system

機械保護系統 Mechanical Protection System

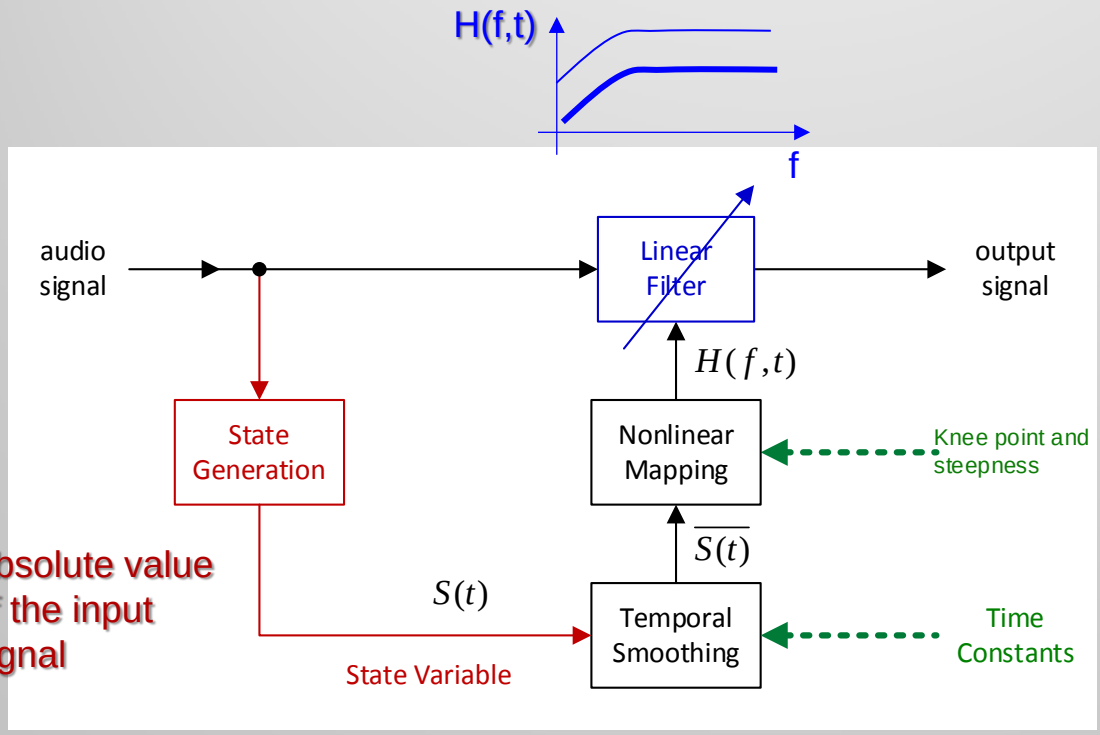


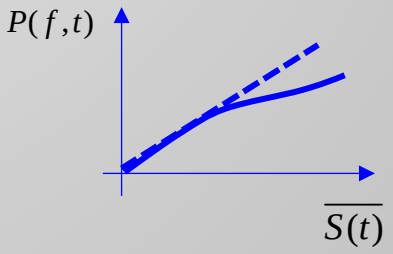
Maximum permissable displacement X_{max}

- 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

動態範圍壓縮器Dynamic Range Compressor
applied to the input signal

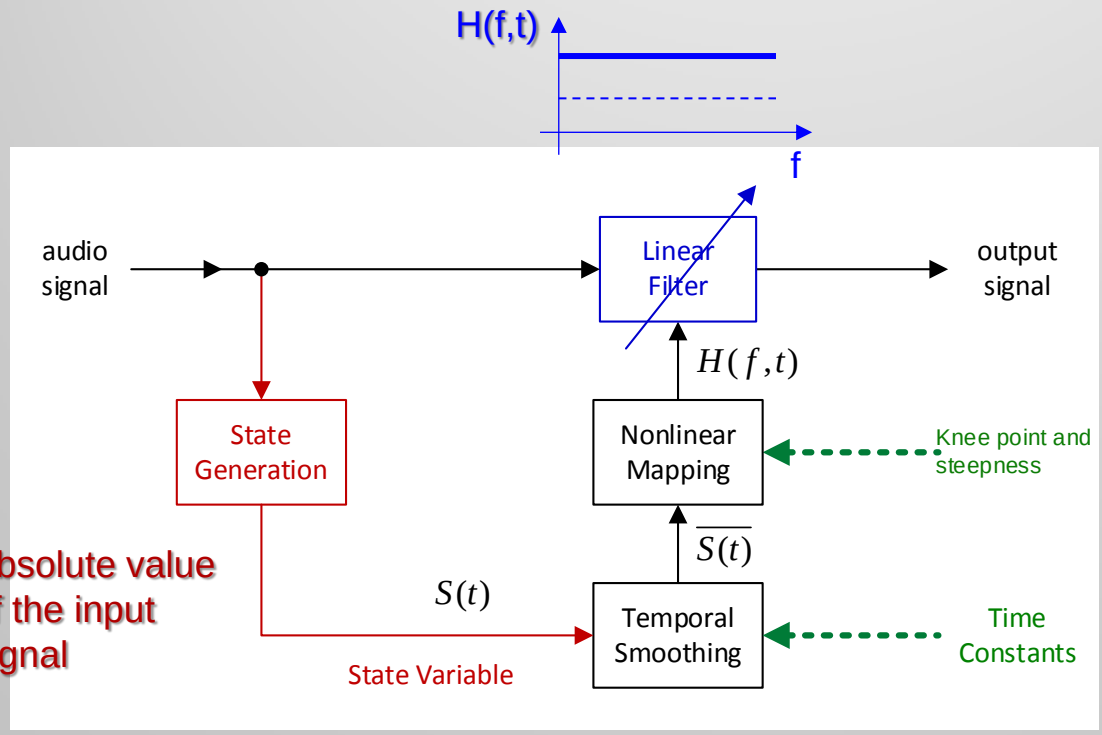


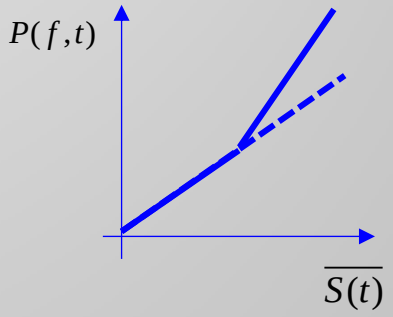


- Short Attack time (0.5 ms)
- Long release time (50 ms)

- 目標：降低放大器的峰值電壓要求，同時增加 SPL 輸出 Target: Reduction of the peak voltage requirements of the amplifier while increasing the SPL output
- 起始階段產生非線性和脈衝失真 Nonlinear and impulsive distortion are generated during attack phase
- 較長的釋放時間常數會降低非線性失真，但會降低長期 SPL A longer release time constant reduces the nonlinear distortion but reduces the long-term SPL

噪聲控制 Noise Gating
applied to the input signal



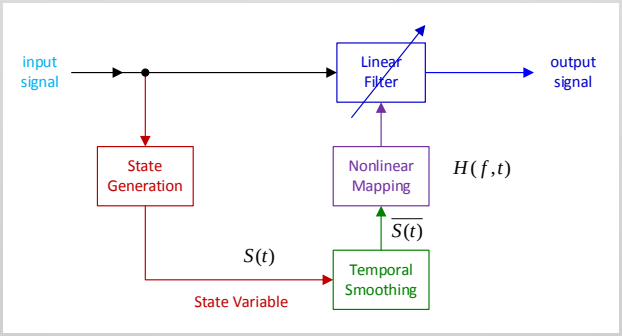


- Short Attack time (0.1 ms)
- Long release time (200 ms)

- 目標：在沒有應用音頻信號時減少電子噪音 Target: Reduction of electronic noise when no audio signal is applied
- 在攻擊階段（增益切換）產生非線性和脈衝失真 Nonlinear and impulsive distortion are generated during attack phase (gain switching)
- 更長的釋放時間常數減少了反射 A longer release time constant reduces the artifacts

測試的結果
Consequences for Testing

寬帶測試激勵代表典型的音頻信號
Broadband test stimuli represent typical audio signals



快速分析以测量瞬態行为
Fast analysis to measure transient behavior

增加激發幅度（線性步進）以測量特性（軟、硬限制）
Increasing stimulus amplitude (linear stepping) to measure the characteristic (soft, hard limiting)

需要帶限測試激勵來找到激發幅度壓縮的狀態信號 Band limited test stimulus is required to find the state signal that activates the amplitude compression

低頻 (f < fs) 位移 x
low frequencies ($f < f_s$)
→ displacement x

需要短時間激發來評估非線性壓縮、DSP 和音圈加熱 Short Stimuli are required to evaluate the nonlinear compression, DSP and voice coil heating

長時間激發考慮熱壓縮（磁鐵）Long Stimuli to consider the thermal compression (magnet)

測試方法概述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

實踐中的多音測試Multi-Tone Testing in Practice

狀況 Conditions:

用於測試最大輸出 SPLmax 的稀疏多音刺激（典型方案素材）Sparse multi-tone stimulus (typical program material) as used for testing maximum output SPLmax (session 5)

根據 IEC 60268-21 第 16.4 章進行測量 Measurements according to IEC 60268-21 chapter 16.4

1a)在最大輸入 Umax=0.17 V 下的短期壓縮在預循環中播放相同刺激後使用刺激長度 T=1s

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

1b)在最大輸入 Umax=0.17V 和相同的刺激 T=1s 下測量的長期壓縮在預循環中播放刺激 1 分鐘 + 1 分鐘冷卻休息（無休息）

Long-term compression measured at maximum input 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)搜索輸入電壓 u 產生短期壓縮 C = 3dB

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

提示：在近場進行測量以提高 SNR

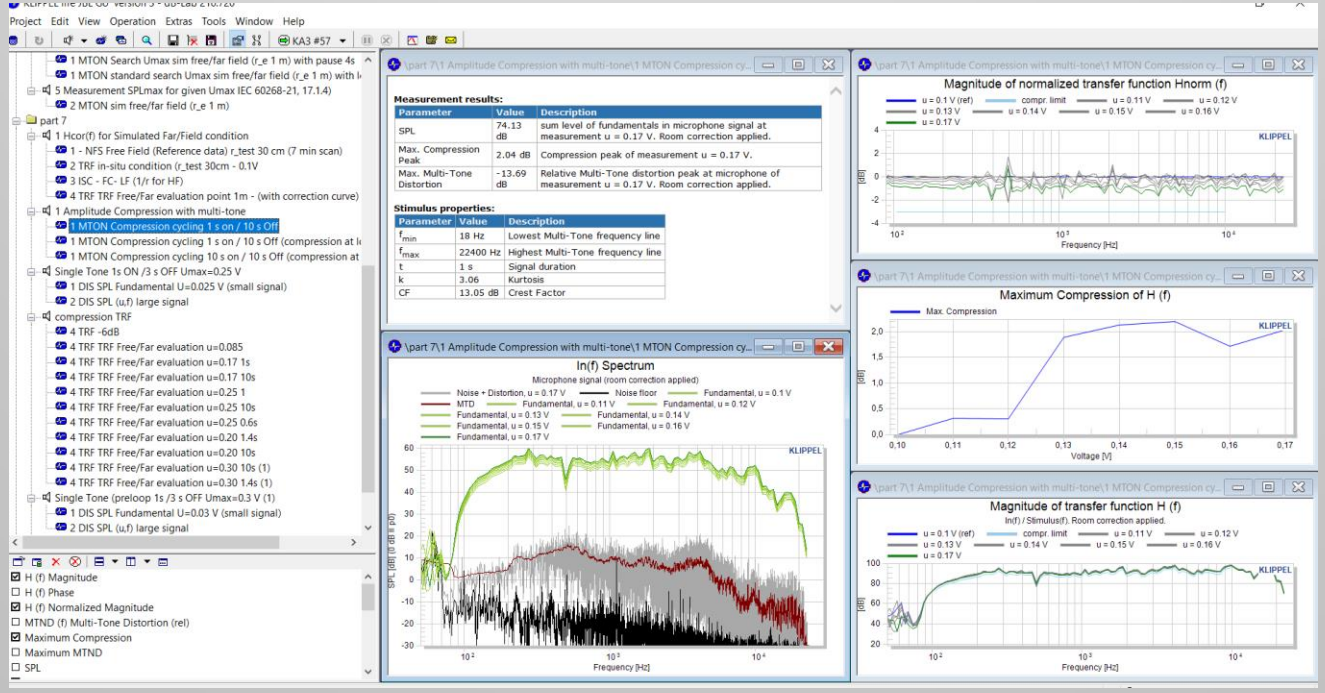
Tip: Perform measurement in near field to improve SNR

解釋 Interpretation:

與短期和長期測量比較 Compare with Short-Term and Long-Term Measurement

示範 Demo

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



線性調頻測試 Chirp Testing in Practice

狀況Conditions:

在 SPLmax 處具有對數頻率-時間映射的正弦波

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

壓縮測量 Measurements of the compression

3a)在最大輸入 umax=0.17 的預循環中播放相同刺激後，使用刺激長度 T=0.6s 的短期壓縮

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)在最大輸入 umax=0.17 的預循環中播放相同刺激後的長期壓縮（低掃描速度），T=20s）

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)搜索電壓給出幅度壓縮 C=3dB

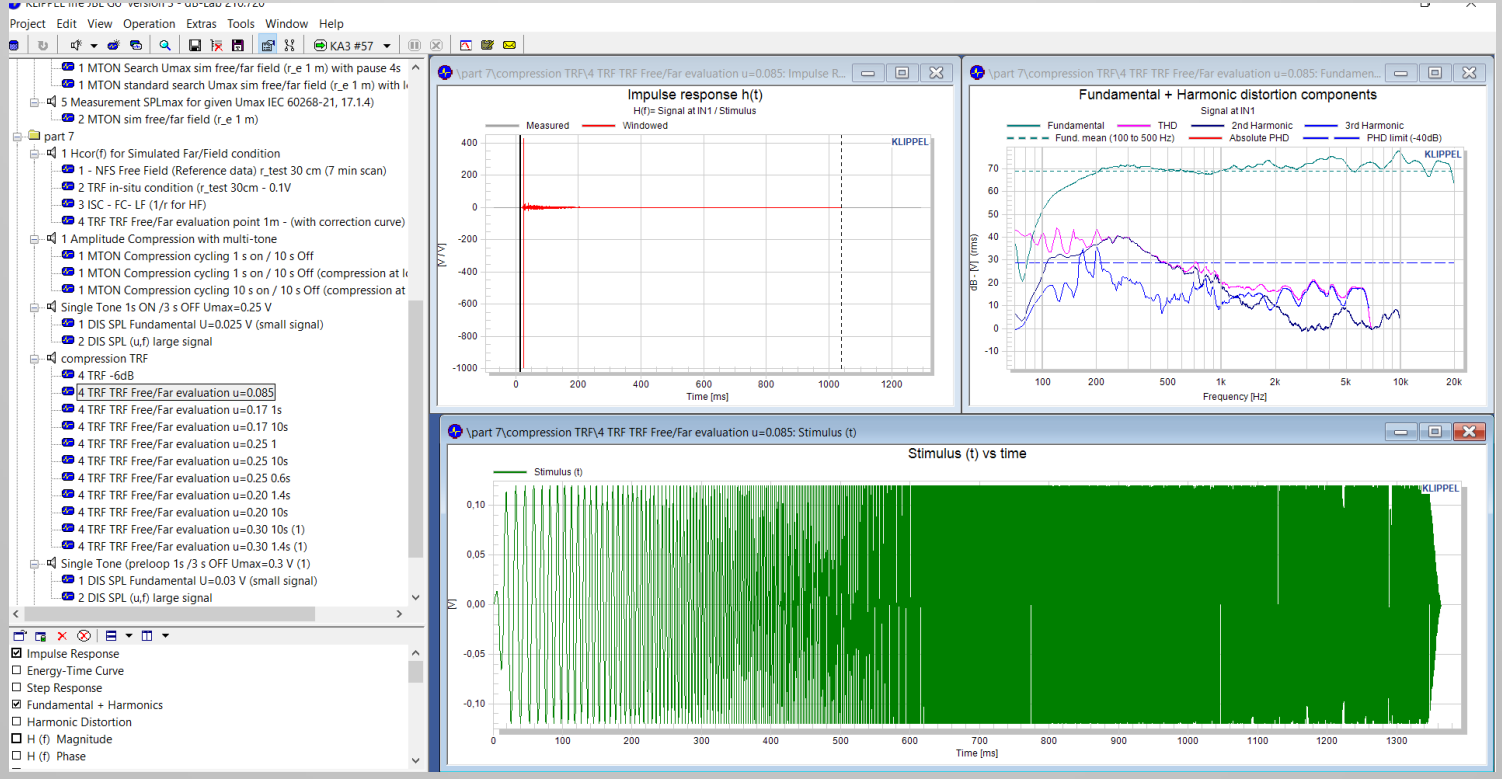
Searching for voltage giving amplitude compression C=3dB

解釋 Interpretation:

- 比較短期多音測試及短期線性調頻 Compare Short-term multi-tone test with short-term chirp test
- 比較線性調頻和多音的幅度壓縮 Compare amplitude compression from chirp and multi-tone

示範 Demo

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



單音測試 Single Tone Testing in Practice

狀況Conditions:

- 步進音激勵與頻率和電壓的關係，帶有預循環和步進之間的暫停（關閉） Stepped tone excitation versus frequency and voltage with preloop and pause between the steps (off)
- 傳感器發熱可忽略不計 Negligible heating of the transducer

測試 Tests:

4)尋找穩態測試條件（預循環、暫停）Searching for steady-state test condition (preloop, pause)

5)預循環對壓縮的影響Influence of preloop on the compression

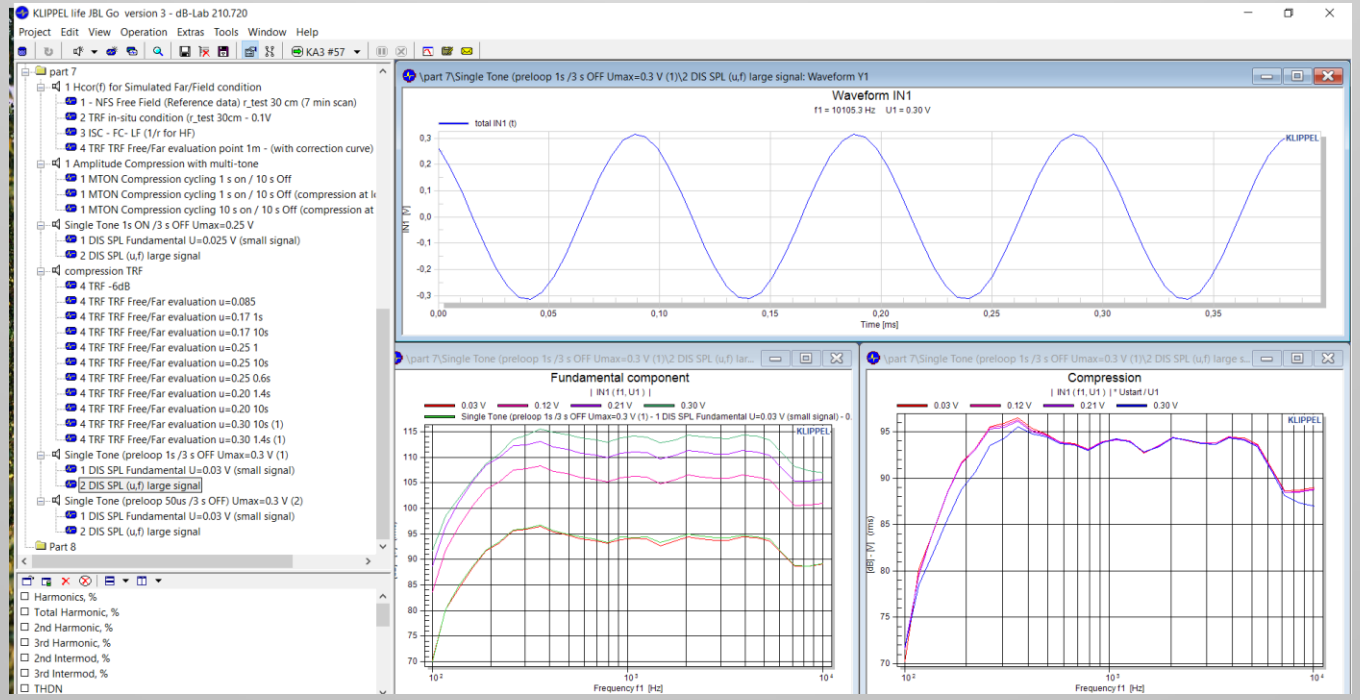
解釋 Interpretation:

與 m 與 Ultra-Fast 比較 Compare with m with Ultra-Fast

示範 Demo: Compression (Stepped Sine)

Tools of the KLIPPEL Analyzer:

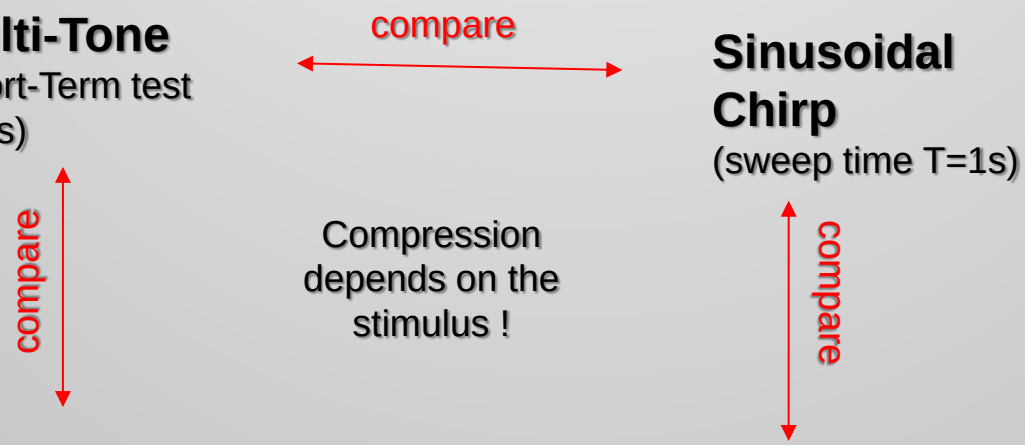
- 3D distortion measurement (DIS)



測試結果的解釋 Interpretation of the Test Results

全頻段音頻處理（限制器，DRC）
full-band audio processing
(limiter, DRC)

揭示傳感器非線性和帶限 DSP（機械保護）
reveals transducer nonlinearities and band-limited DSP (mechanical protection)



音圈加熱，主動熱保護
Heating of the voice coil, active thermal protection

傳感器非線性 + 瞬態行為 DSP（DRC、限制器、機械保護）
Transducer nonlinearities + transient behavior DSP (DRC, limiter, mechanical protection)

討論 Discussion

總結 Summary

幅度壓縮 Amplitude Compression

- 是評定最大聲輸出的一個重要特性 Is an important characteristic for rating the maximum acoustical output
- 取決於特定的激發Depends on the particular stimulus
- 是換能器的自然效應（接近過載）Is a natural effect of transducers (close to overload)
- 意在帶有限制器、保護系統和其他 DSP 軟件的有源系統中生成（為 THD 交易幅度壓縮！！）Is intentionally generated in active systems with limiters, protection systems and other DSP software (Trading amplitude compression for THD !!)
- 可以在換能器的近場測量，無需使用房間校正曲線Can be measured in the near field of the transducer without using a room correction curve

提問 Open Questions

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

接下來的KLIPPEL 直播網絡研討會名為諧波失真測量 - 最佳實踐
The next 8th KLIPPEL live webinar entitled
Harmonic Distortion Measurements – best practice

將解決以下幾點 will address the points:

- 傳統和新的測試方法 (IEC 60268-21) Traditional and new ways for testing (IEC 60268-21)
- 我們可以簡化對 THD 響應的解釋嗎？Can we simplify the interpretation of THD response ?
- 什麼揭示了二次和三次諧波？What reveals the 2nd and 3rd harmonics ?
- 減少定位、距離、房間、傳感器等的影響。Reducing the influence of positioning, distance, room, sensor, ….
- 如何將 QC 線下測試與標準測量聯繫起來？How to link QC end-of-line testing with standard measurements ?

Sessions of KLIPPEL- live Webinar

根據 IEC 60268-21 對音響系統設備進行聲學測量

Acoustical Measurement of Sound System Equipment according IEC 60268-21

1. 現代音頻設備需要輸出基本的測試 Modern audio equipment needs output based testing
2. 在普通房間進行的聲學標準測試 Acoustical standard tests performed in normal rooms
3. 從 3D 輸出測量中得出有意義的結論 Drawing meaningful conclusions from 3D output measurement
4. 在單個評估點模擬標準條件 Simulated standard condition at a single evaluation point
5. 最大聲壓級– 數字變得很重要 Maximum SPL – a number becomes important
6. 信號失真–強大的揚聲器診斷概念 Signal distortion – a powerful concept for loudspeaker diagnostics
7. 幅度壓縮–在較高幅度下輸出較少 Amplitude Compression – less output at higher amplitudes
8. 諧波失真測量 - 最佳實踐 Harmonic Distortion Measurements – best practice (Next session)
9. 互調失真 - 音頻不僅僅是一個音調 Intermodulation Distortion – audio is more than a single tone
10. 脈衝失真 – 異音、異常行為、不良 Impulsive distortion - rub&buzz, abnormal behavior, defects
11. 具有無線音頻輸入的智能揚聲器測試 Smart speaker testing with wireless audio input
12. 在標準條件下對音頻產品進行基準測試 Benchmarking of audio products under standard conditions
13. 信號失真的可聽化——感知評估 Auralization of signal distortion – perceptual evaluation
14. 為信號失真設置有意義的容差 Setting meaningful tolerances for signal distortion
15. 評定產品的最大 SPL 值 Rating the maximum SPL value for product