Acoustical Measurement of Sound System Equipment according IEC 60268-21

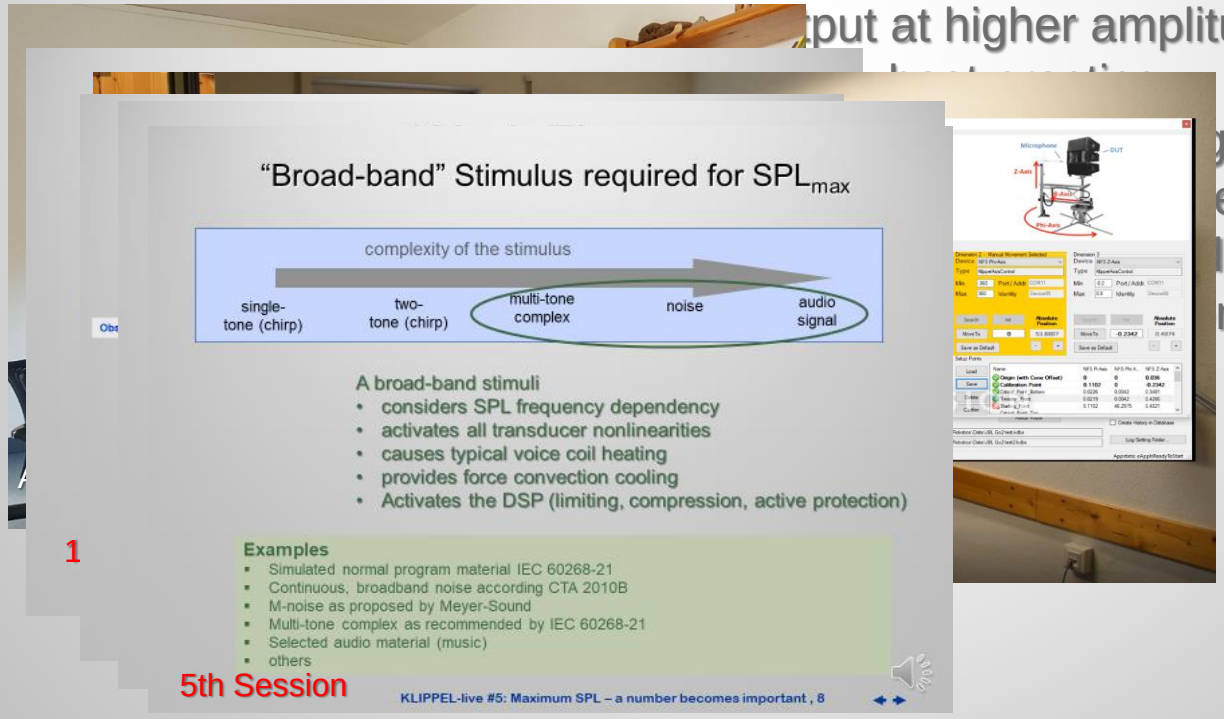
KLIPPEL- live

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



6th KLIPPEL live:

Selecting measurements with high diagnostic value

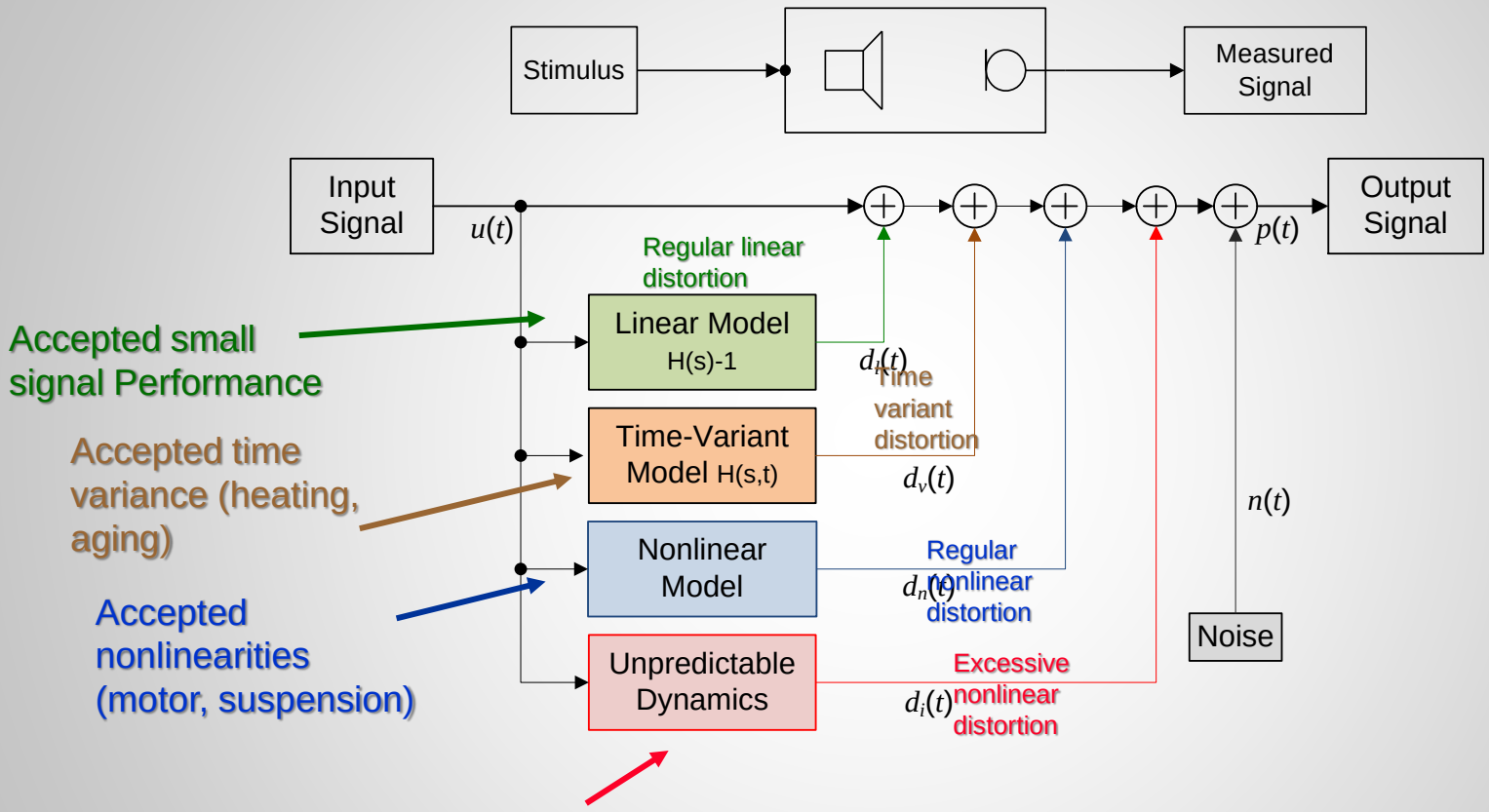
选择具有较高诊断意义的测量

Topics today:

今日话题：

1. Signal distortion – a useful concept for sound reproduction
   信号失真–声音再现的有用概念
2. Properties of linear, nonlinear and other distortion
   线性、非线性和其他失真的特性
3. Comprehensive evaluation of the large signal performance
   综合评估大信号性能
4. Interpretation of the measured symptoms and linking with the physical causes
   解读所测症状并与物理原因联系起来
5. Overview on new tests defined in IEC 60268-21
   IEC 60268-21中定义的新测试概述

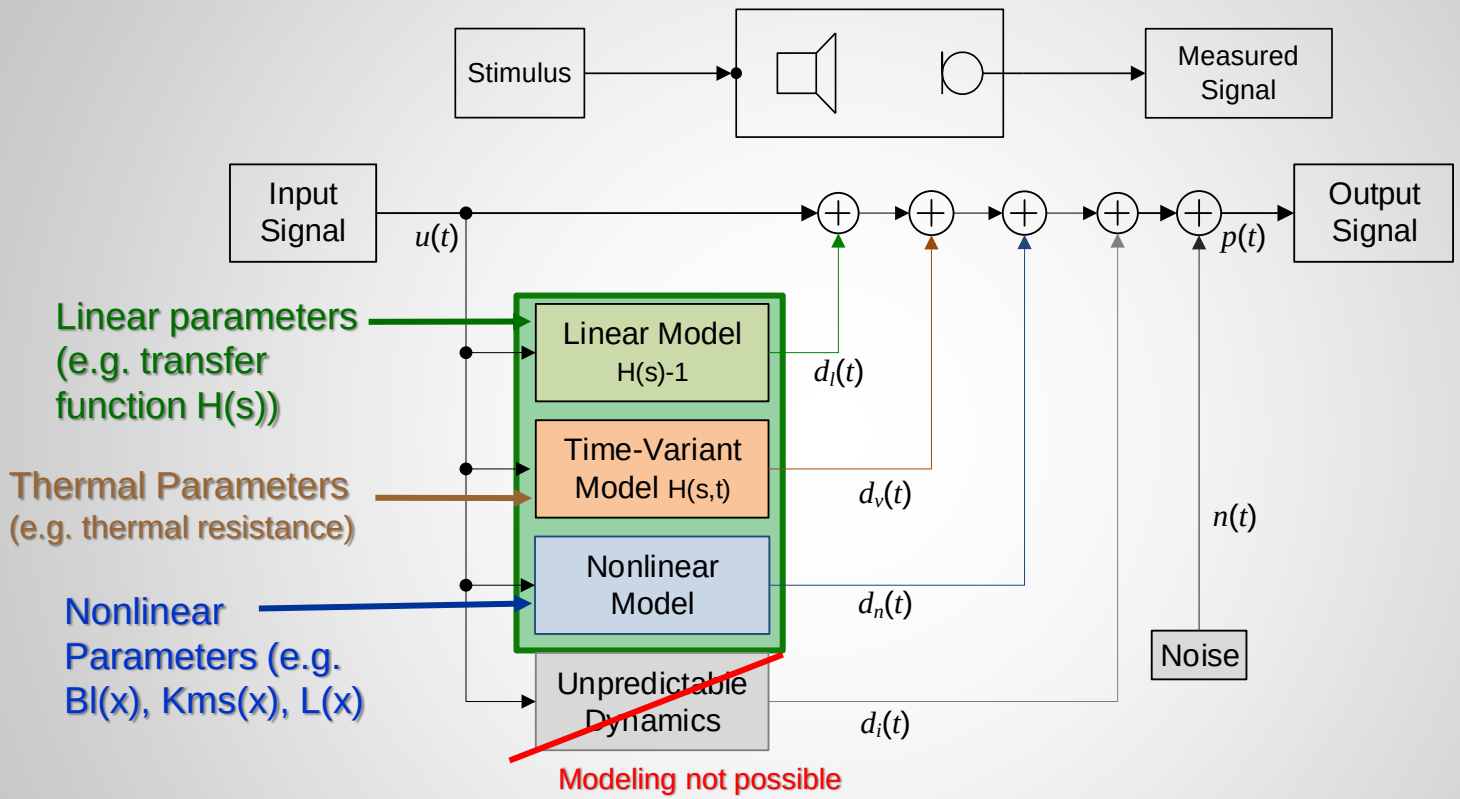
Generation of Signal Distortion in an Audio System
音频系统中信号失真的产生



Undesired Defects

- Rubbing coils, buzzing parts
- Wire beat, coil bottoming
- Loose particles, air leak noise
- Parasitic vibration of other components

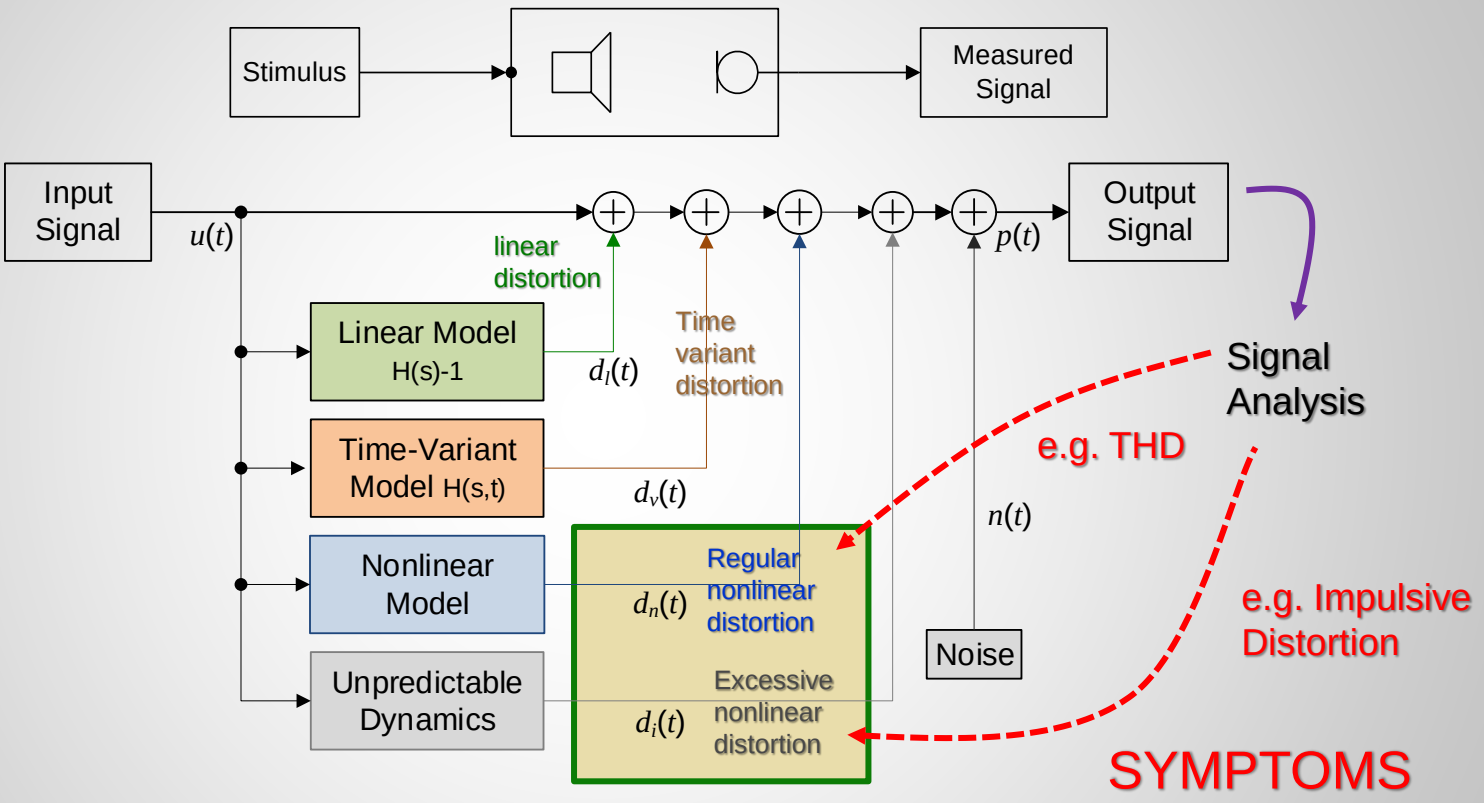
Diagnostics based on Modeling
基于建模的诊断



The deterministic distortion components can be prediced by a physical model with identified parameters. The parameters are independent of the stimulus!

确定性失真分量可以由具有已识别参数的物理模型进行预测。参数与激励无关！

Diagnostics based on Unique Symptoms
基于独特症状的诊断



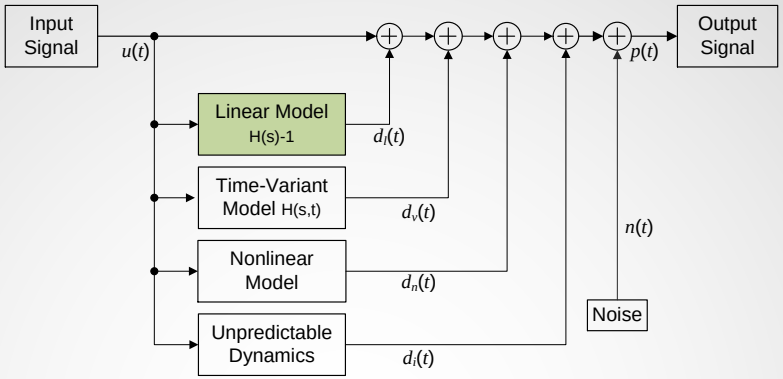
The generation of symptoms requires no model.

症状的产生不需要模型。

The symptoms depend on the properties of the stimulus.

症状取决于激励的性质。

Linear Distortion
线性失真



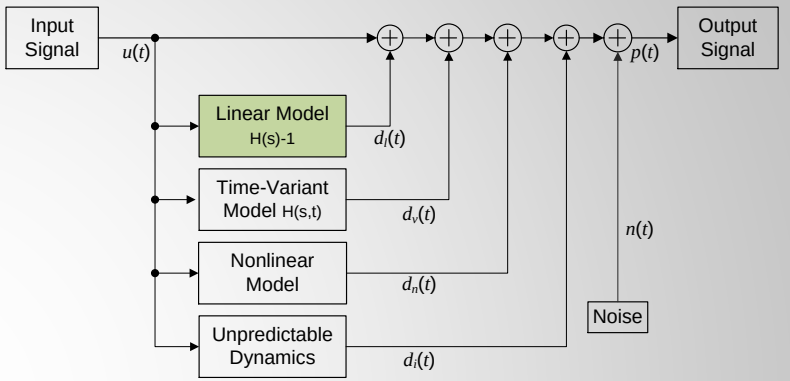
特性Properties

- Deterministic
  确定性的
- Predictable based on the stimulus using a linear model
  可使用线性模型基于激励进行预测

物理原因Physical Causes:

- Transducer + Enclosure (resonances)
  换能单元+箱体（谐振）
- Room influence
  房间影响
- DSP (Alignment, Equalizer, Crossover)
  DSP（对准、均衡器、分频器）

Assessing Linear Distortion
评估线性失真



测量技术Measurement techniques

- Measurement of symptoms is less useful
  症状测量不太有用
- Identification of a linear parameters
  线性参数的识别

Parameters determined by output based measurements:
由基于输出的测量确定的参数:

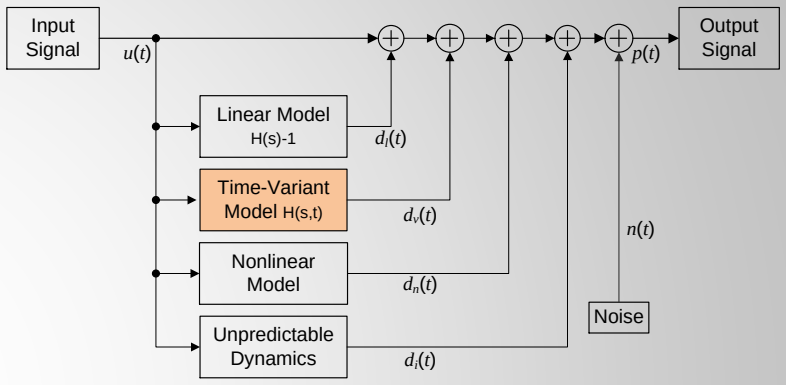
- On-axis SPL frequency response
  轴上SPL频率响应
- Sound power frequency response (Directivity index)
  声功率频率响应（指向性指数）
- 3D Sound output (complex sound pressure response an any point in near and far field)
  3D声音输出（近场和远场中任何一点的复声压响应）
- Coefficients C(f) of the spherical wave expansion
  球面波展开系数C(f)
- Mean SPL response integrated over personal listening zones
  积分到个人听音域的平均SPL响应
- Latency (generated by DSP)
  延迟（由DSP生成）
- ...

discussed in 3rd session of KLIPPEL live

Linear Time-Variant Distortion
线性时变失真

特性Properties:

- Generated by a deterministic process
  由确定性过程生成
- Slowly varying properties
  缓慢变化的属性
- Does not generate new spectral components
  不产生新的频谱成分
- Can be described by models
  可以用模型来描述
- Considered in the design
  设计中已考虑

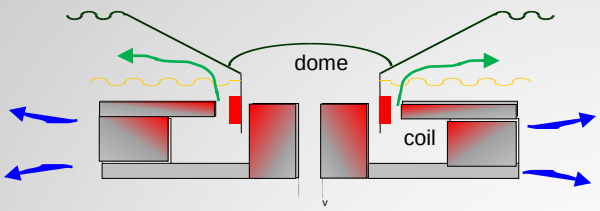


物理原因Physical Causes:

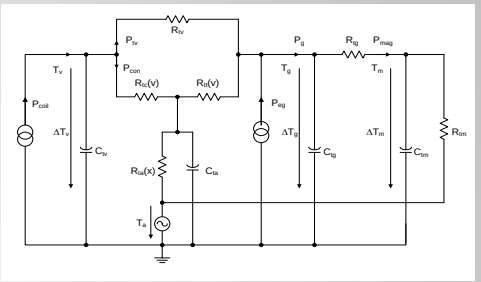
- Transducer (heating, aging, fatigue)
  换能单元（加热、老化、疲劳）
- Varying acoustical load, room and climate influence
  变化的声学负载、房间和气候影响
- Audio DSP Software (Compressor, Limiter, mechanical and thermal protection systems
  音频DSP软件（压缩器、限幅器、机械和热保护系统）

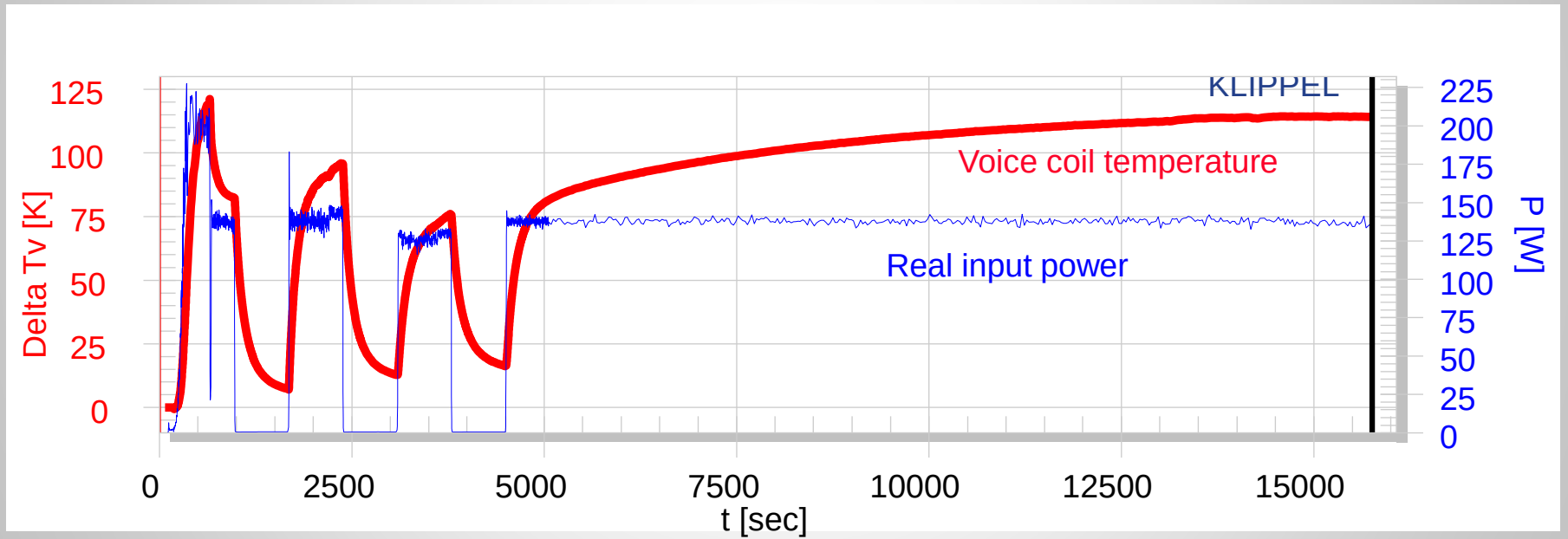
Example: Thermal Dynamics

Heat Flow



Thermal Model

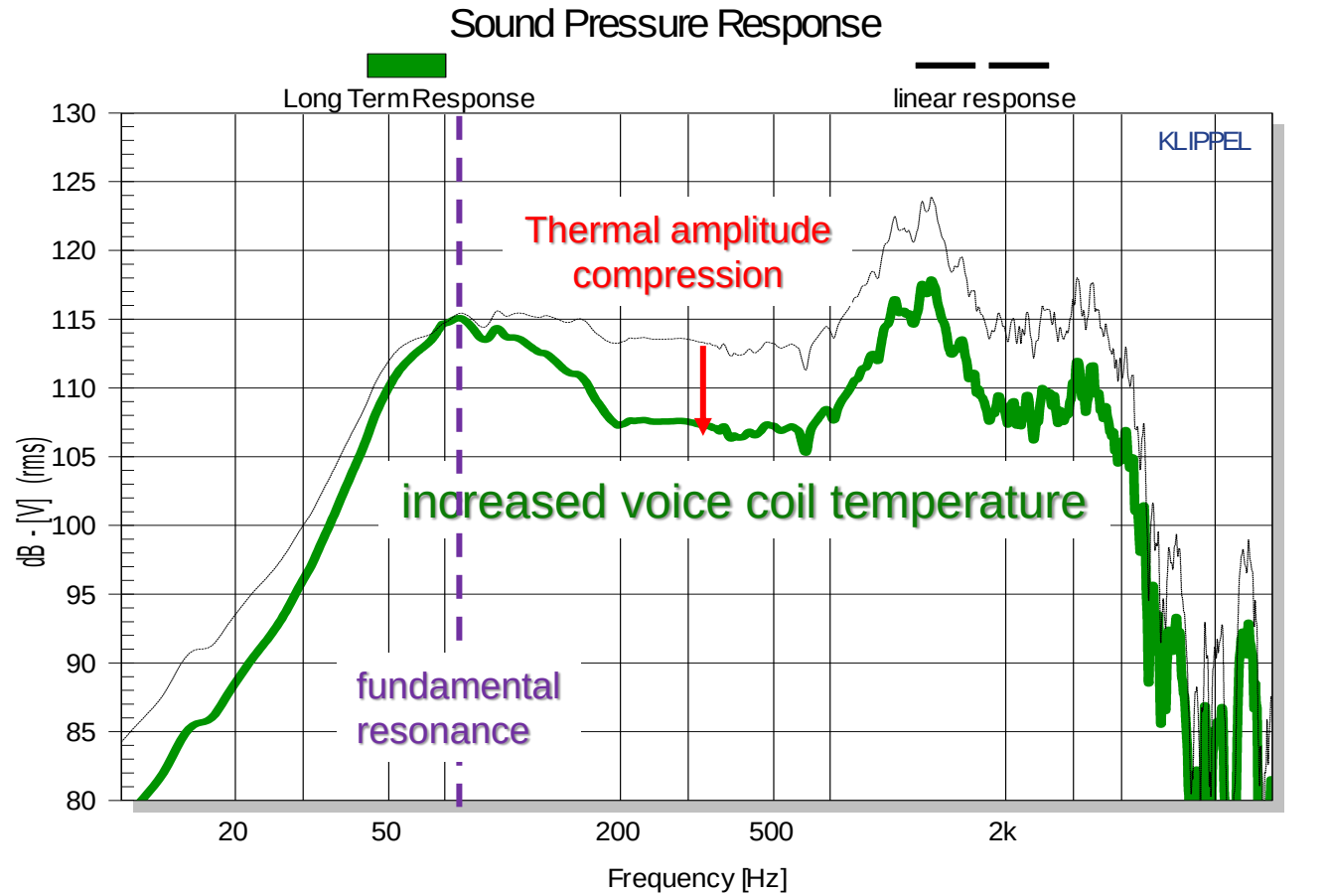




Time Constant of the voice coil
τ_V= 130 s

Time constant of the magnet
τ_M=67 min

Time variance of the Transfer Function H(f,t)



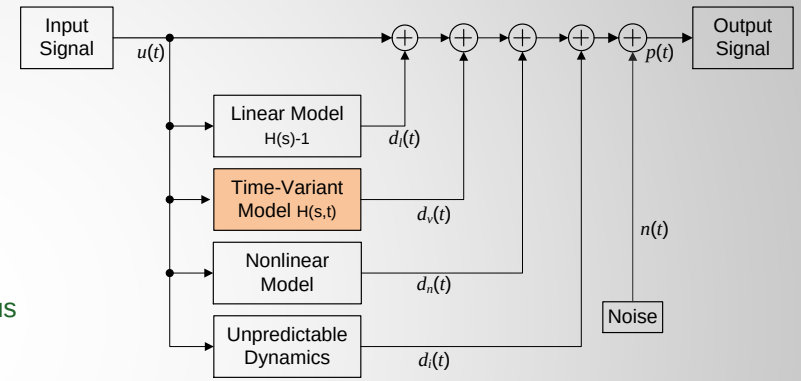
Long term response was measured by using a stepped sine wave and cycling 1 min on/1 min off

通过使用步进正弦波并使用1分钟开启/1分钟关闭循环，来测量长时响应

The thermal dynamics of the loudspeaker generates no harmonics and other new spectral components because the voice coil has a high thermal time constant (τ_V > 1s).

扬声器的热动力不会产生谐波和其他新的频谱成分，因为音圈具有较高的热时间常数（ τ_V > 1s ）。

Assessing Linear Time-Variant Distortion
评估线性时变失真



测量技术Measurement Techniques:

- Identification of model parameters (e.g. thermal parameters)
  识别模型参数（例如热参数）
- Measurement of unique symptoms generated by a particular stimulus
  测量特定激励产生的独特症状

由基于输出的测量确定的参数： Symptoms determined by output based measurements:

- Change of the frequency response (amplitude compression)
  频率响应的变化（幅值压缩）

Poll:

Do you measure the change of the transfer function? (Multiple answers possible)

您是否测量传递函数的变化？ (可多选)

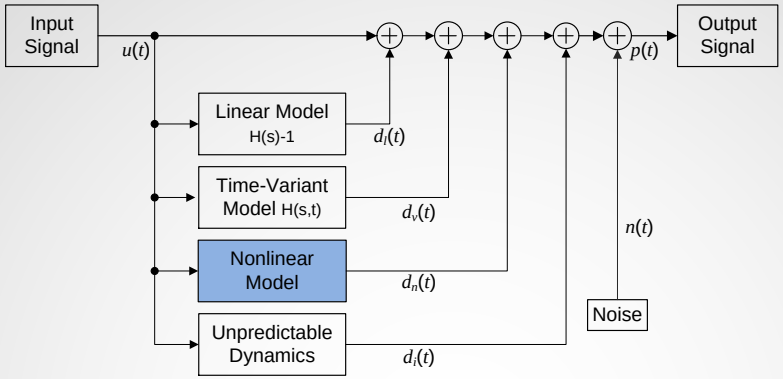
A. 否 No

B. 是，通过更改输入幅度来评估热压缩、保护系统和其他DSP功能 Yes, by changing the input amplitude to evaluate thermal compression, protection system and other DSP functionality

C. 是，根据时间评估磨合、老化疲劳 Yes, versus time to evaluate break-in, aging, fatigue

D. 是，评估气候、负荷变化的影响…… Yes, to evaluate the influence of climate, load changes, …

常规非线性失真
Regular Nonlinear Distortion



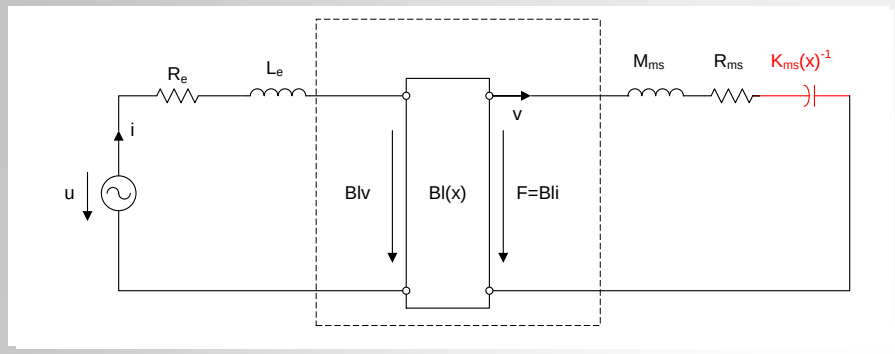
特性Properties:

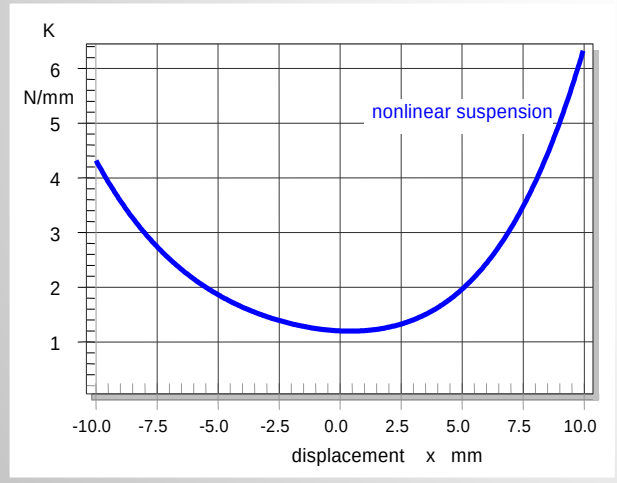
- 取决于激励的幅值 Depend on amplitude of the stimulus
- 在小信号域可忽略不计 Negligible in the small signal domain
- 确定性的，可以建模 Deterministic, can be modeled
- 与设计有关的，在批准的原型中接受 related to the design, accepted in an approved prototype

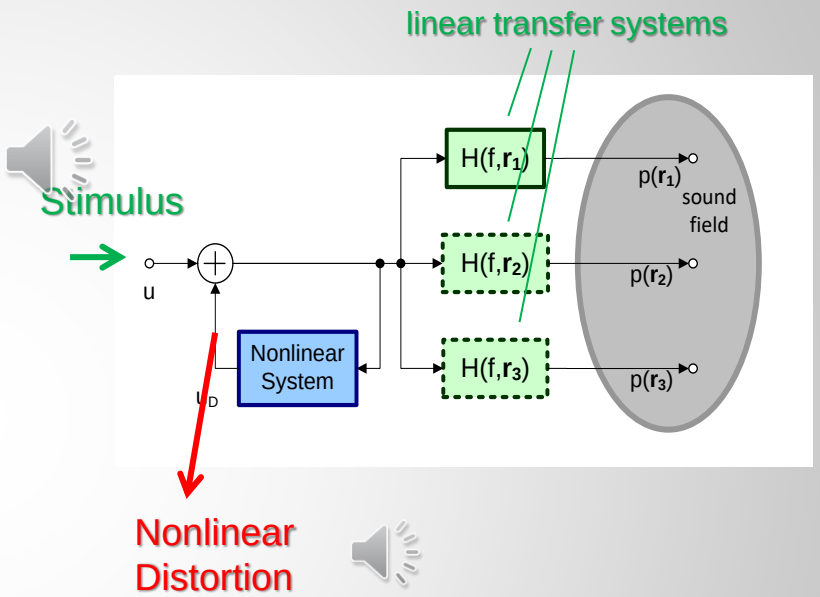
物理原因Physical Causes:

- 换能单元非线性(Bl(x), Kms(x), L(x), L(i), …) Transducer nonlinearities (Bl(x), Kms(x), L(x), L(i), …)
- 声学端口非线性 Acoustical port nonlinearity,
- DSP(硬峰值限制器) DSP (hard peak limiter)

Distortion generated by $K_{ms}(x)$







Restoring force $F = K_{ms}(x)x$ Displacement

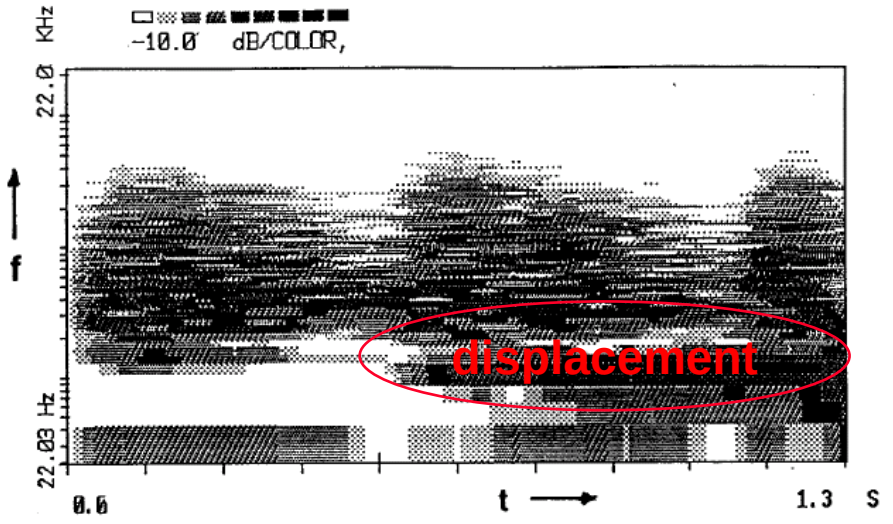
Variation of stiffness $K_{ms}(x)x$ versus displacement x generates nonlinear distortion at low frequencies

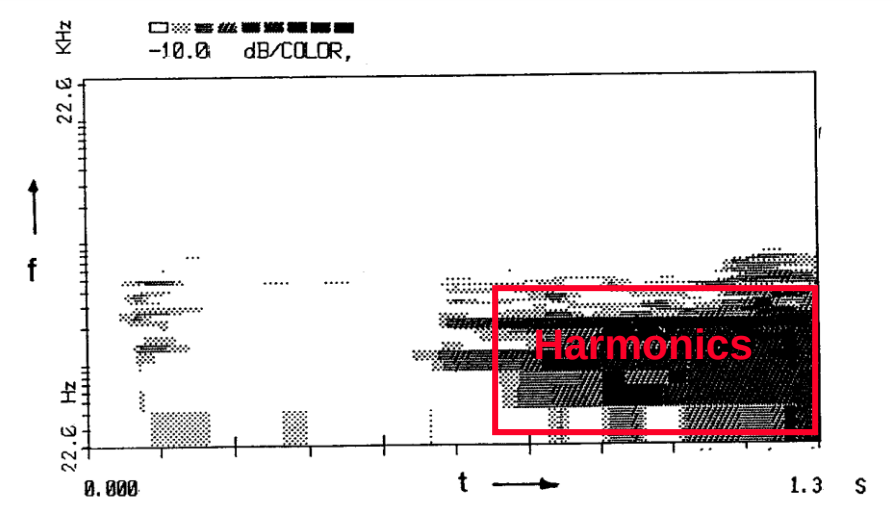
刚度$K_{ms}(x)x$与位移x的变化会在低频产生非线性失真

→使再现的低音信号“更硬”，更“激进”

makes the reproduced bass signal „harder“ and more „aggressive“

$K_{ms}(x)$-Distortion in Music

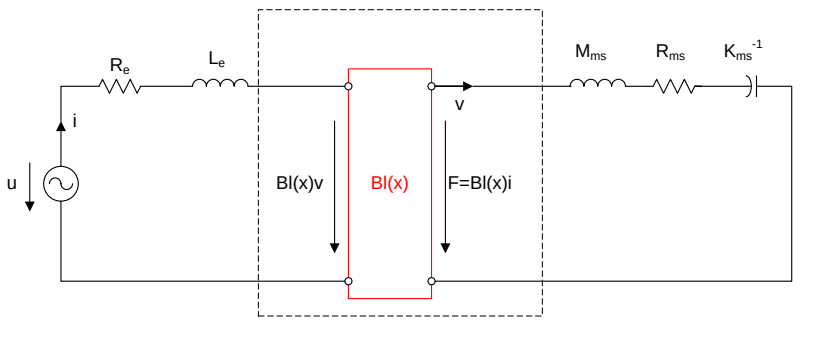


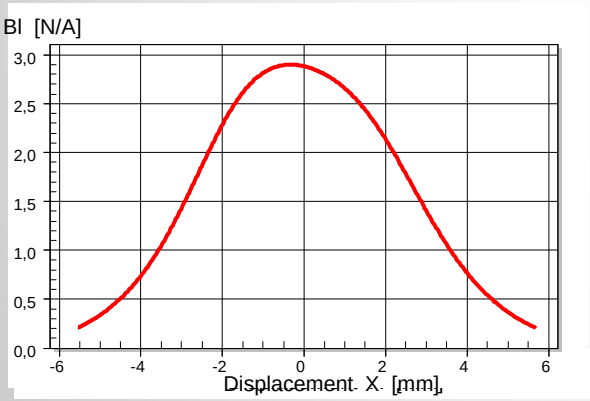


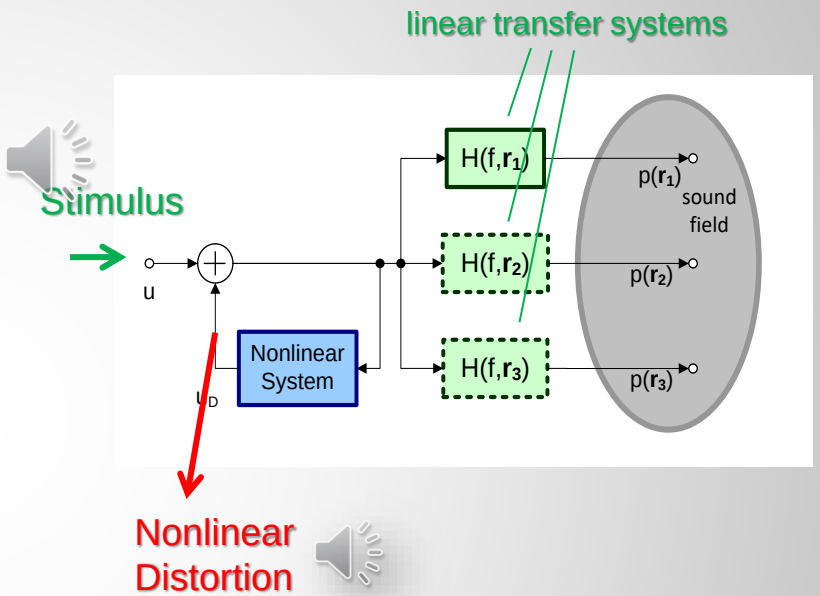
未失真音乐信号 Undistorted music signal

需要大位移 → 信号低于fs → 低音信号 High displacement required → signal below fs → bass signal
Fs <100 Hz时低频失真 Low frequency distortion when fs < 100 Hz
低音听起来更激进 Bass sounds more aggressive
对音质影响小 Low impact on sound quality

Distortion generated by Bl(x)







Electro-dynamical driving force $F = Bl(x)i$ Voice coil current

Back EMF $U_{EMF} = Bl(x)v$ Voice coil velocity

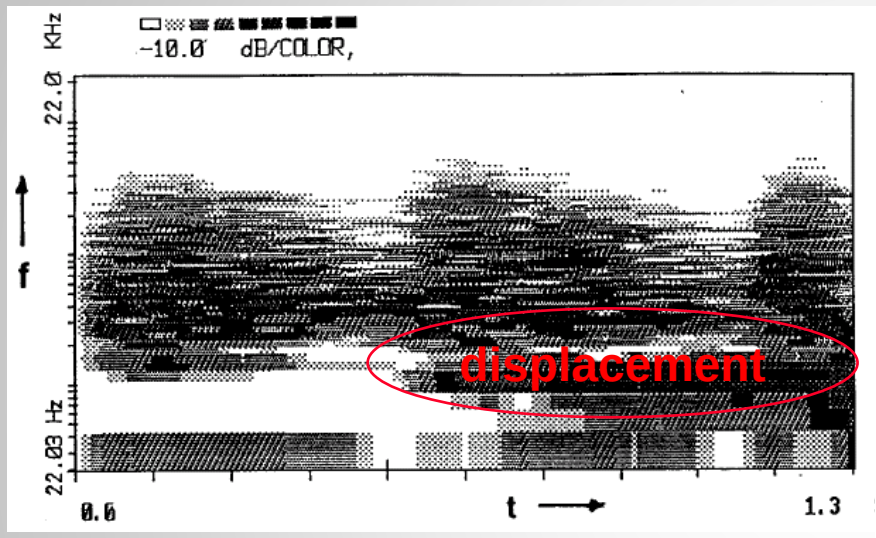
Nonlinear Bl(x) causes a multiplication of displacement x and current i

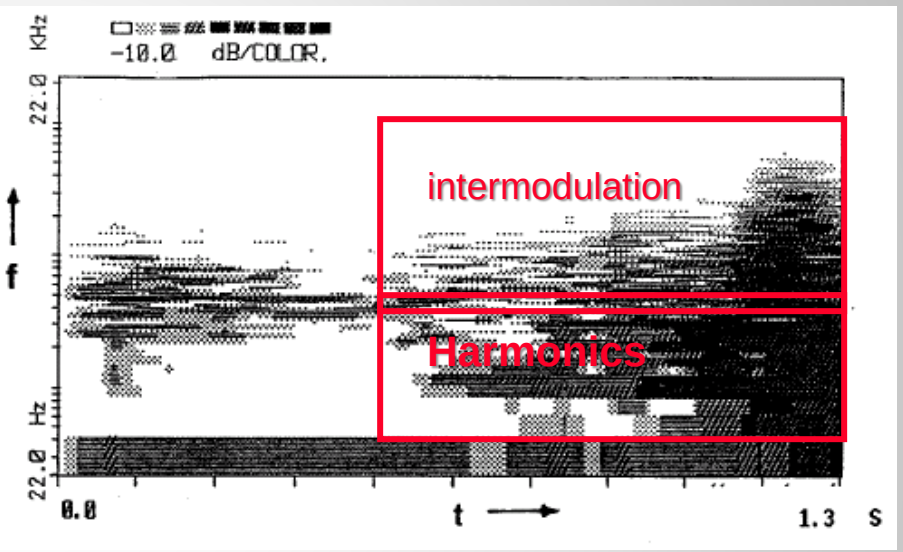
非线性Bl(x)导致位移x与电流i相乘

→在音频频带中产生幅度互调失真 generates amplitude intermodulation distortion in the audio band

→感知为声音的粗糙度 perceived as roughness in the sound

Bl-Distortion in Music





Undistorted music signal

Distortion generated by Bl(x) only

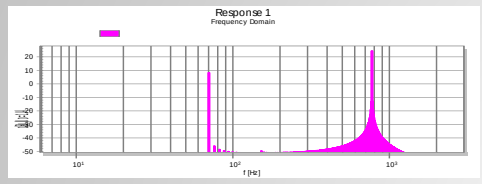
需要大位移 → 信号低于fs → 低音信号 High displacement required → signal below fs → bass signal

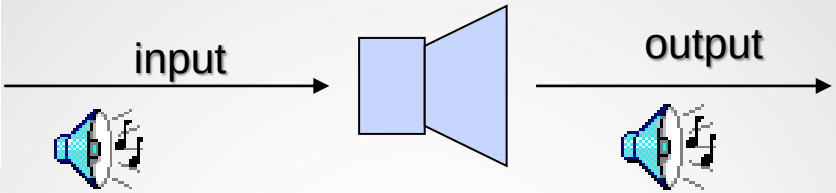
当fs <100 Hz时，音频带中信号的互调会产生粗糙度 Intermodulation with signal in audioband generate roughness when fs < 100 Hz

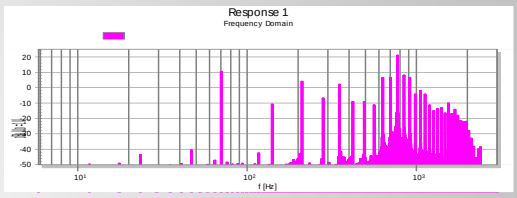
对音质影响很大 High impact on sound quality

Nonlinear Symptom: New Spectral Components

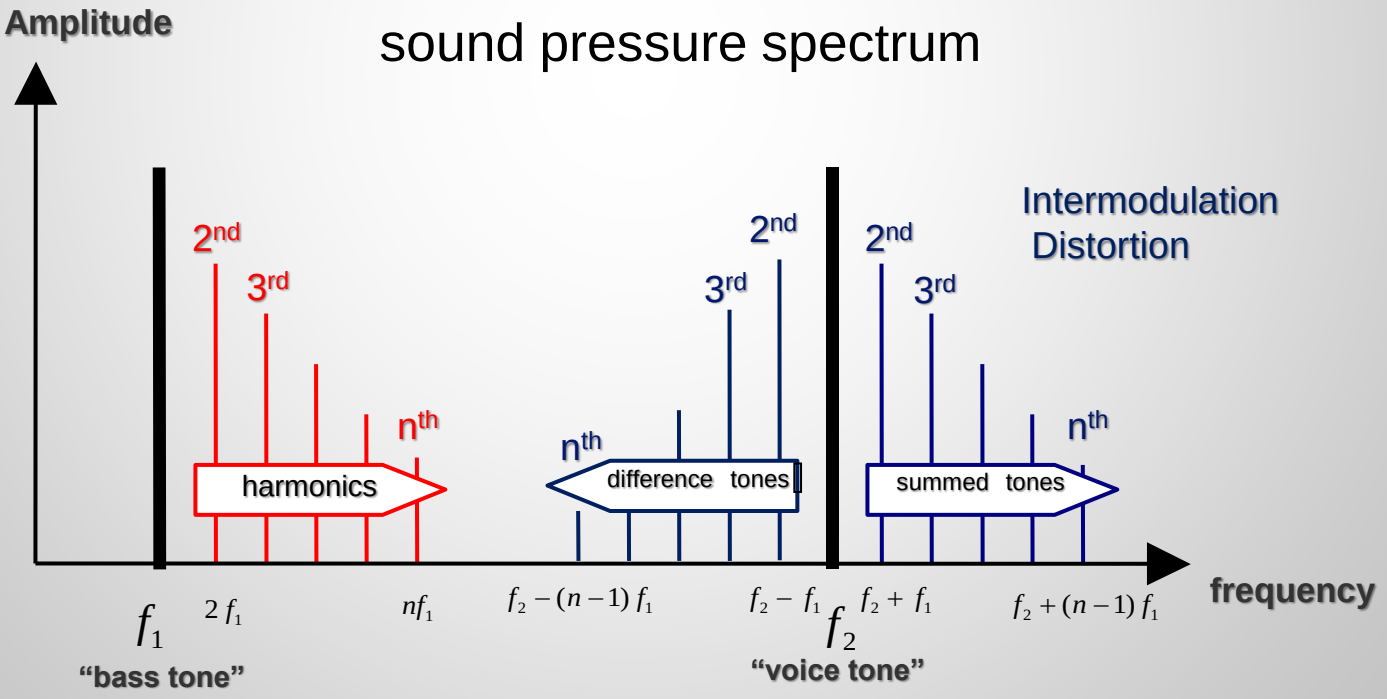
generated by Two-tone Stimulus



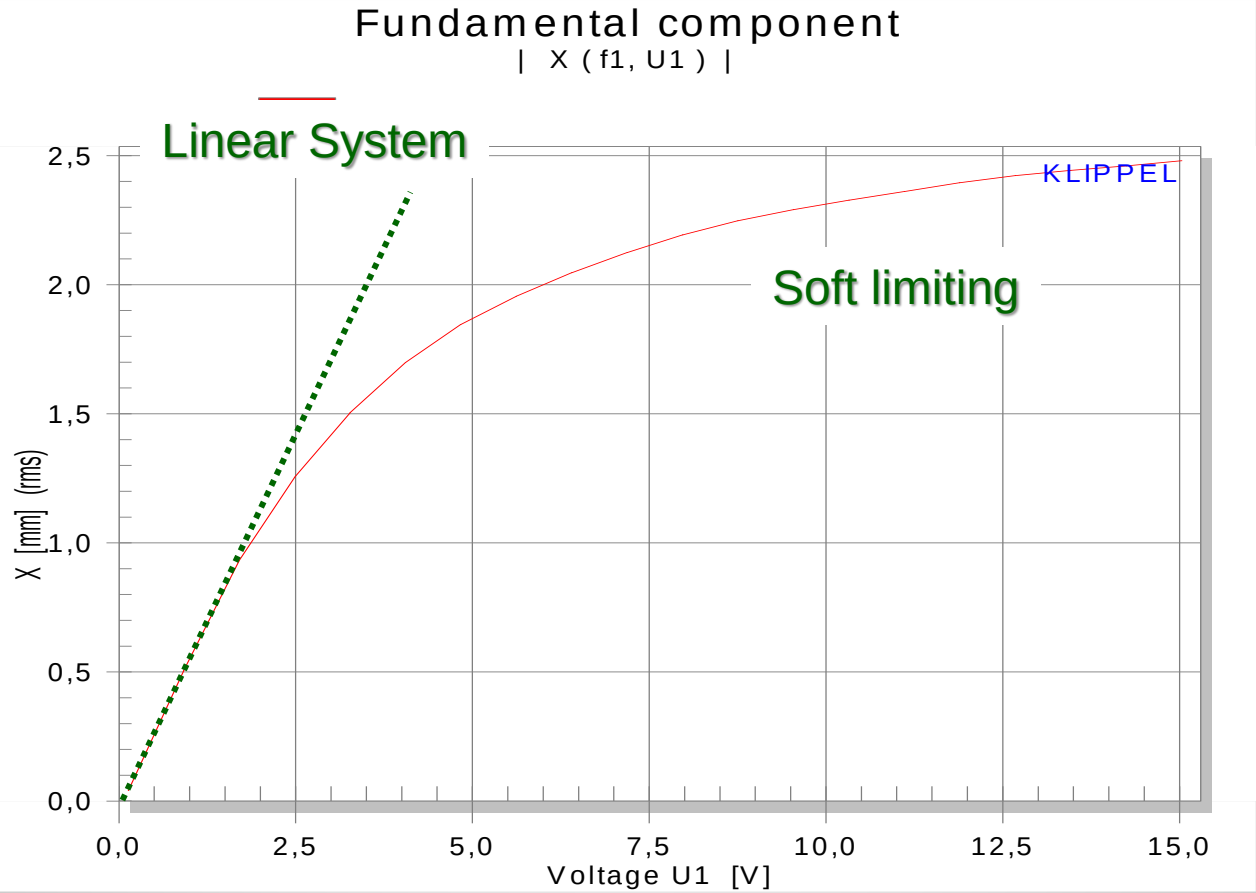




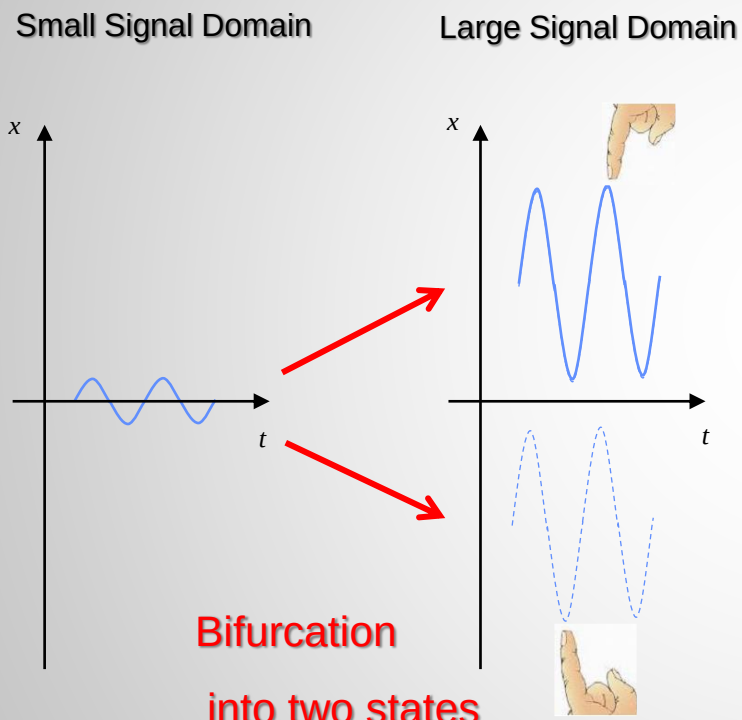
sound pressure spectrum



Nonlinear Symptom: Amplitude Compression



Nonlinear Symptom: Instability



Stimulus: Single tone (f = 1.5fs) at high amplitude

Poll:

Which symptoms of the regular nonlinearities do you use? (Multiple answers possible)
您使用常规非线性的哪些症状？ (可多选)

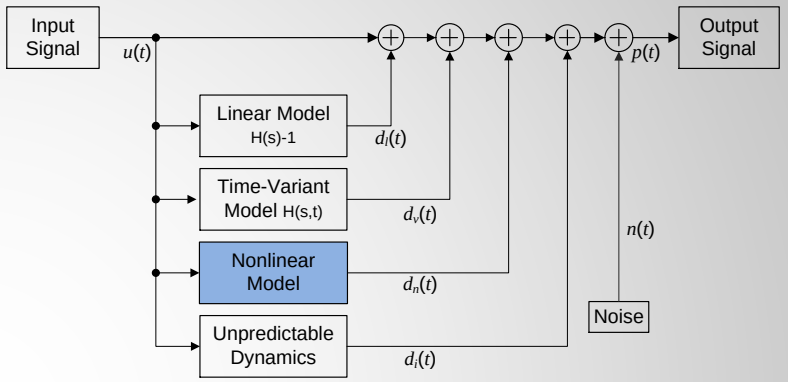
A. None
B. Harmonic Distortion (2^{nd}, 3^{rd}, THD, …)
C. Intermodulation Distortion (generated by 2 or multiple tones)
D. Nonlinear compression of the fundamental component
E. DC-displacement, jumping effects, other instabilities

Assessing Regular Nonlinear Distortion

评估常规非线性失真

测量技术Measurement Techniques:

- 非线性模型参数的识别 Identification of nonlinear model parameters
- 寻找非线性的独特症状 Searching for unique symptoms of the nonlinearities



由基于输出的测量确定的参数 Symptoms determined by output based measurements:

- 由不同的人工激励产生的非线性失真 （**谐波、互调**分量） Nonlinear distortion generated by different artificial stimuli (**Harmonic**, **intermodulation** components)
- 频率响应的变化（非线性幅值**压缩**） Change of the frequency response (nonlinear amplitude **compression**)
- 使用平稳噪声激励的输入和输出之间的**非相关性** **Non-coherence** between input and output using stationary noise stimulus
- 系统建模的非线性残余部分（用于任何音频激励） Nonlinear **residuum** of system modeling (for any audio stimulus)

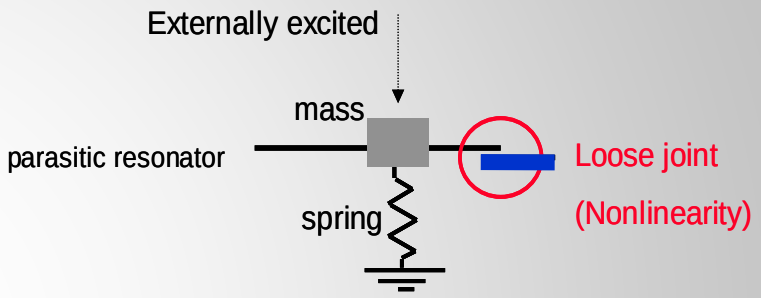
非常规失真 Irregular Distortion

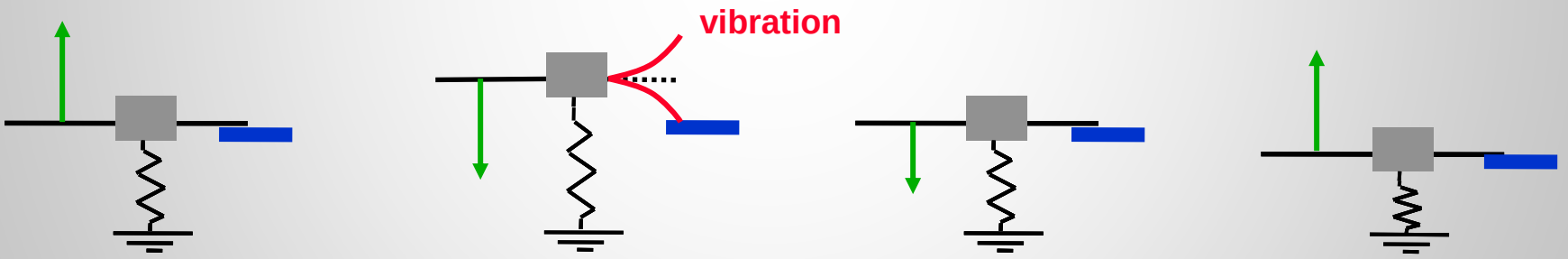
loose joint in a defective transducer generates a buzzing sound

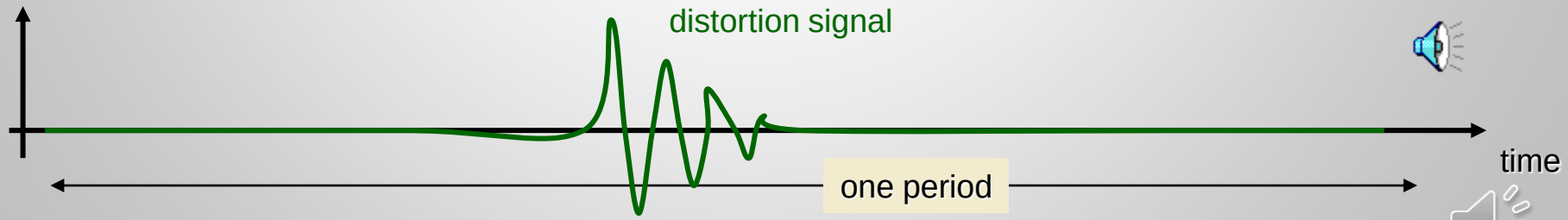
有缺陷换能器的接头松动会产生嗡嗡声

Most defects behave as a **nonlinear oscillator**

- active above a critical amplitude
- new mode of vibration
- powered and synchronized by stimulus
- constant output power





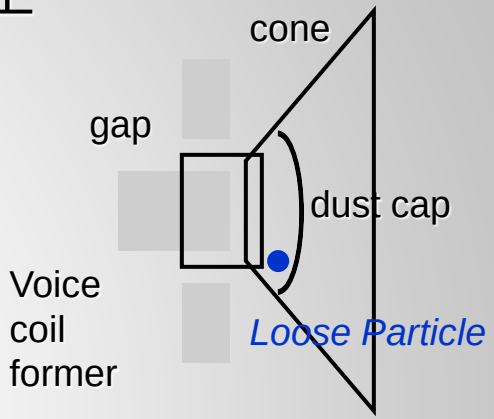


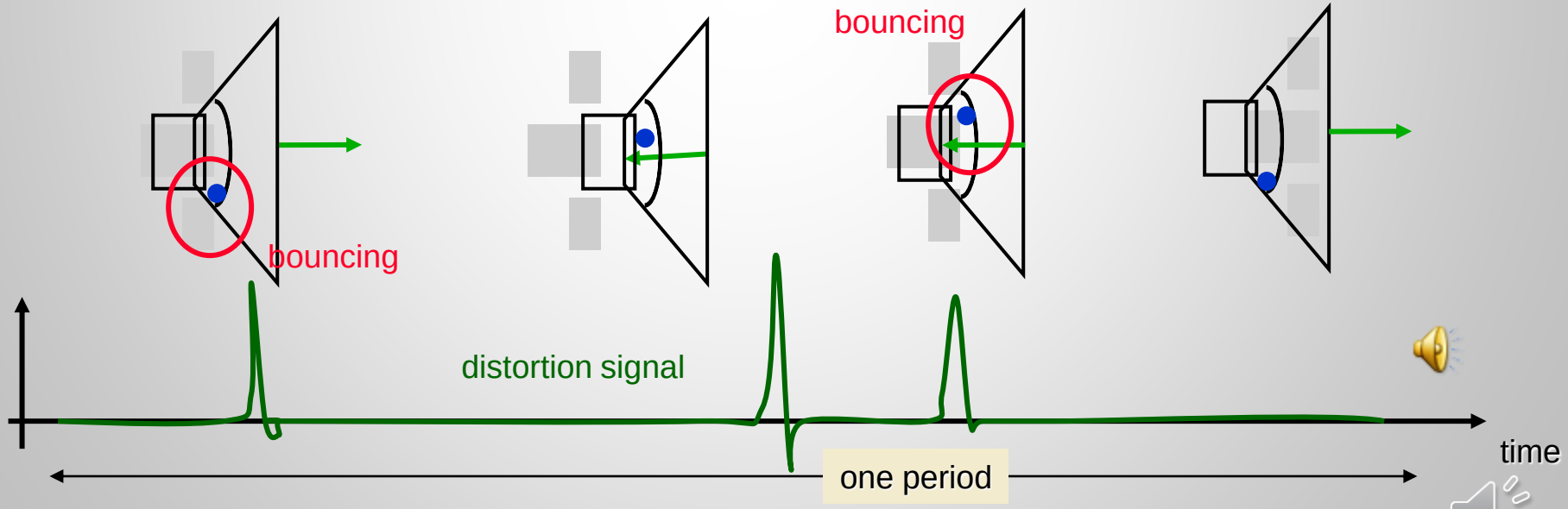
2nd Example: Irregular Distortion

generated by a loose particles in a defective transducer

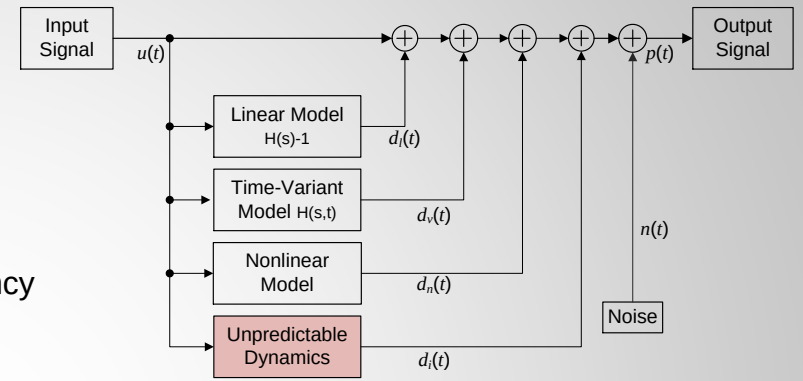
由有缺陷的换能器中的松散颗粒产生

- completely random process
- impulsive distortion waveform
- particles are accelerated by cone displacement
- not synchronized with stimulus
- constant output power





非常规失真
Irregular Distortion



特性 Properties:

- 脉冲性（低能量但高峰值） Impulsive (low energy but high peak values)
- 产生新的高频分量 Generate new high-frequency components
- 随机属性 Random properties
- 难以建模和预测 Difficult to model and to predict
- 时变（通常变得更糟糕） Time varying (usually getting worse)

原因 Causes:

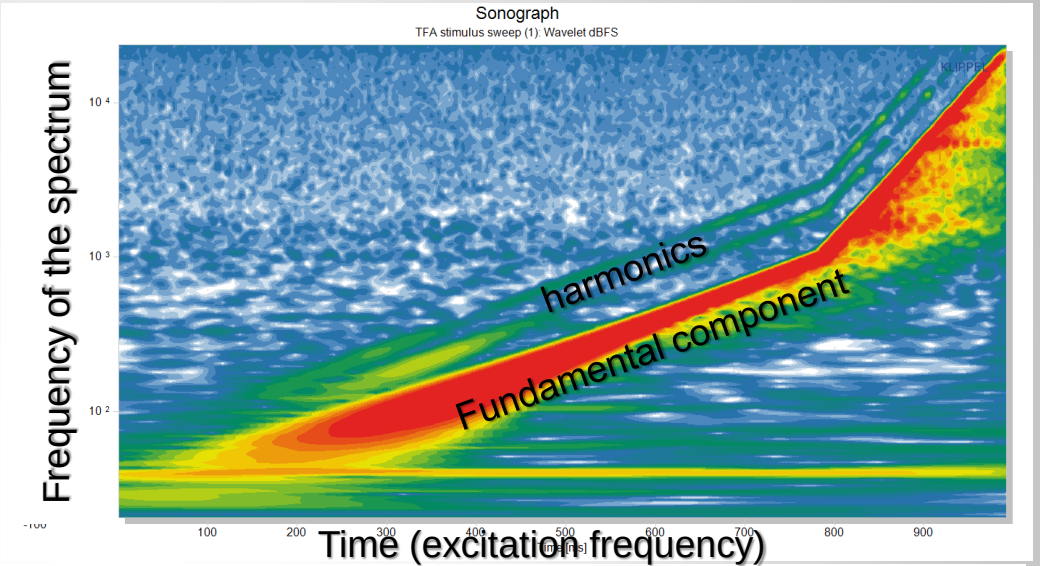
- 设计中的缺陷（例如由于高空气速度引起的调制端口噪声） Imperfections in the design (e.g. modulated port noise due to high air velocity)
- 生产中的问题（例如胶水问题） Problems in the manufacturing (e.g. glue problem)
- 最终应用中过载导致的缺陷 Defect caused by an overload in final application
- 设备的稳固性、耐用性不足 Insufficient robustness, endurance of the device

Symptom of Coil Rubbing

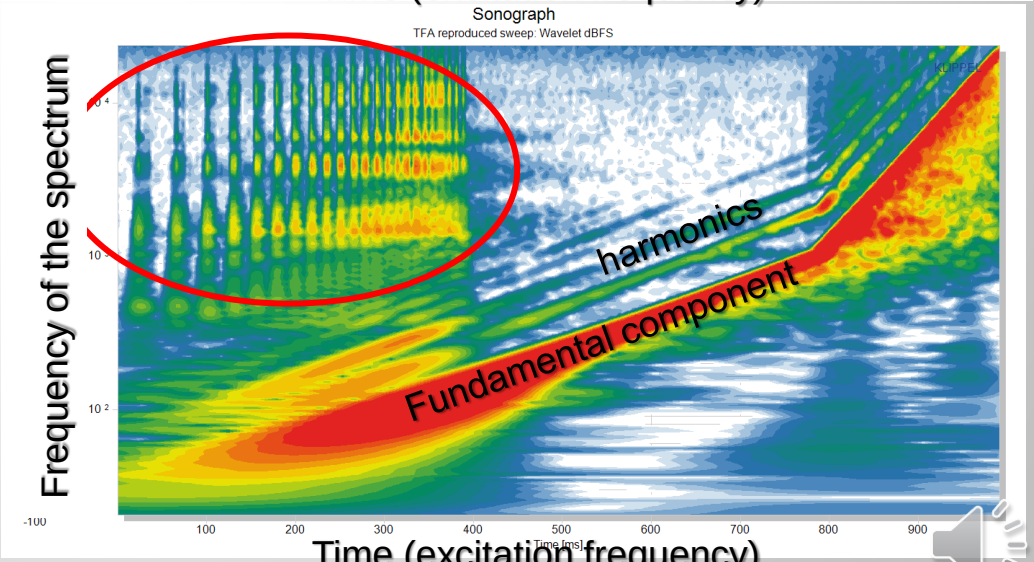
Stimulus:
Sinusoidal chirp with variable sweep sweed (length 1s)

reproduced sweep at 1 V

Analysis:
Time-Frquency Analysis (Wavelet)



reproduced sweep at 3 V

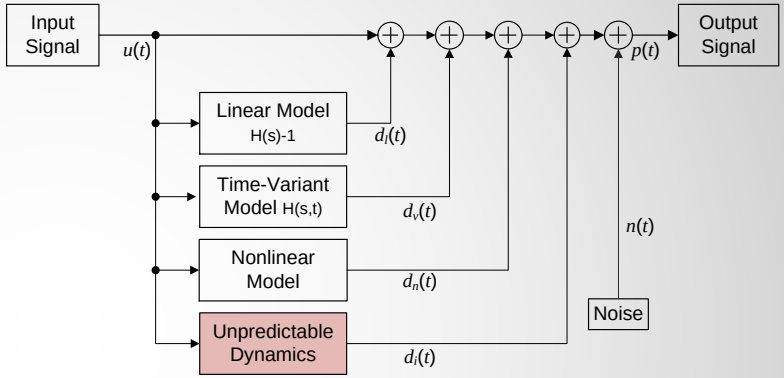


Impulsive distortion generated frequencies below 100 Hz

评估非常规失真
Assessing Irregular Distortion

测量技术 Measurement Techniques:

- 建模困难-参数测量不适用 Modeling difficult - parameter measurement not applicable
- 利用独特症状（脉冲性） Exploting unique symptoms (impulsivity)



由基于输出的测量确定的特性 Characteristics determined by output based measurements:

- 在时域中测量的脉冲失真（IEC 60268-21 ） Impulsive distortion measured in the time domain (IEC 60268-21)
- 高次谐波失真（IEC 60268-21） Higher-order harmonic distortion (IEC 60268-21)
- 系统建模的非线性残余部分（任何音频激励） Nonlinear residuum of system modeling (any audio stimulus)

Poll:

您是怎么处理非常规失真的? How do you cope with irregular distortion ?

A. 不关心 I don't care

B. 仔细听 Careful listening

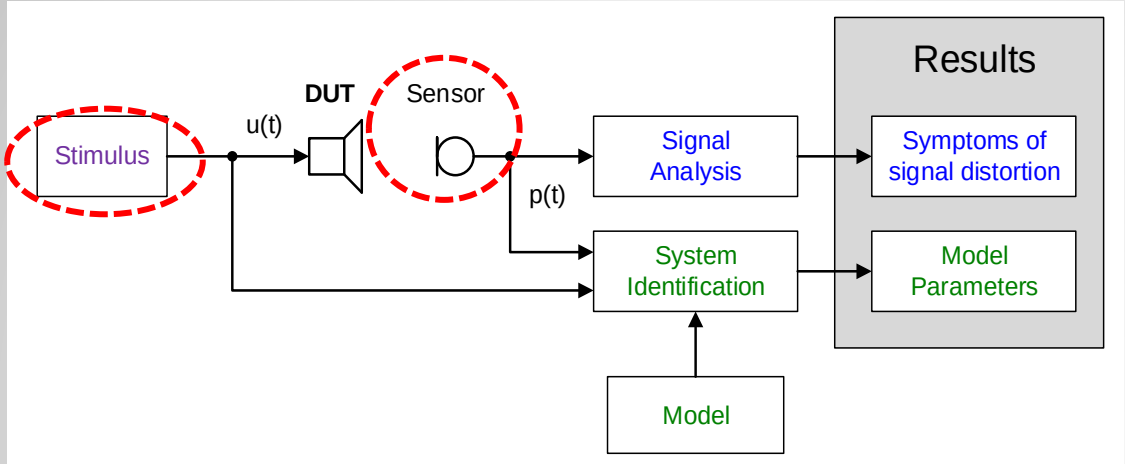
C. 总谐波失真测量THD Total harmonic distortion measurement (THD)

D. 高次谐波失真（高频能量） Higher-order harmonic distortion (energy at high frequencies)

E. 时域分析（脉冲失真、时频分析） Time-domain analysis (impulsive distortion, Time-frequency analysis)

F. 残余、其他技术 Residuum, other techniques

Measurement of Signal Distortion



Depends on the stimulus

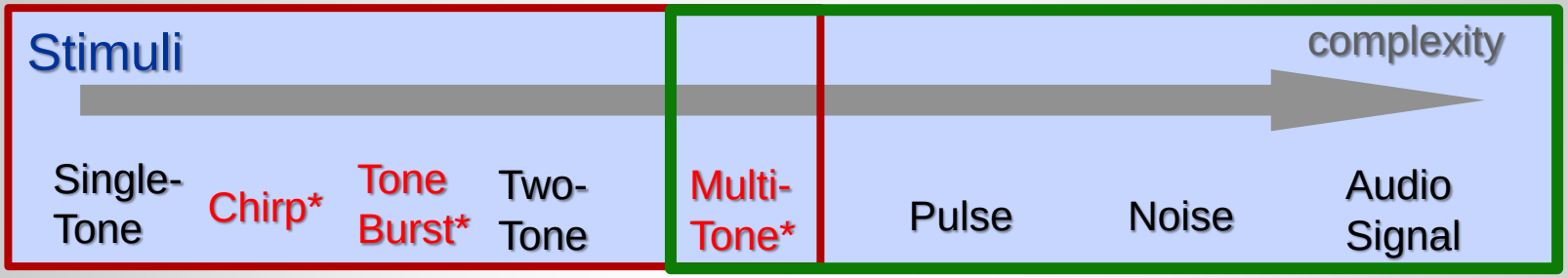
Should be independent of the stimulus

e.g. transfer function H(s)

- 通过系统识别技术估算模型的参数 Parameters of a model are estimated by system identification techniques
- 信号分析（如傅立叶变换）应用于输出信号以得出信号失真的症状 Signal analysis (e.g. Fourier Transform) is applied to the output signal to derive symptoms of the signal distortion
- 用特定激励激发DUT The **D**evice **U**nder **T**est is excited by a particular stimulus
- 通过使用传感器（如麦克风）监测输出信号 Output signal is monitored by using sensors (e.g. microphone)

Optimum Stimulus for Distortion Measurements
失真测量的最佳激励

* New test stimuli defined in IEC 60268-21



Sparse spectrum

Simplifies the separation of the nonlinear distortion from other signal components
简化非线性失真与其他信号分量的分离

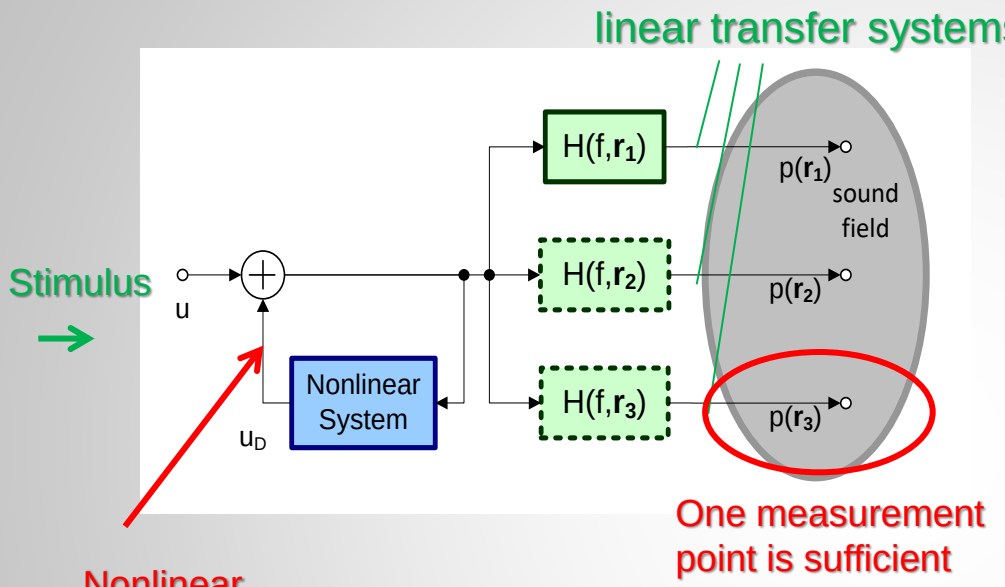
Simplifies the interpretation of the results (harmonics of a fundamental tone)
简化结果解读（基音的谐波）

Dense spectrum

Ensure sufficient (persistent) excitation of the device under test (e.g. amplitude spectrum, amplitude distribution)
确保DUT进行充分（持续）激励（例如幅度谱，幅值分布）

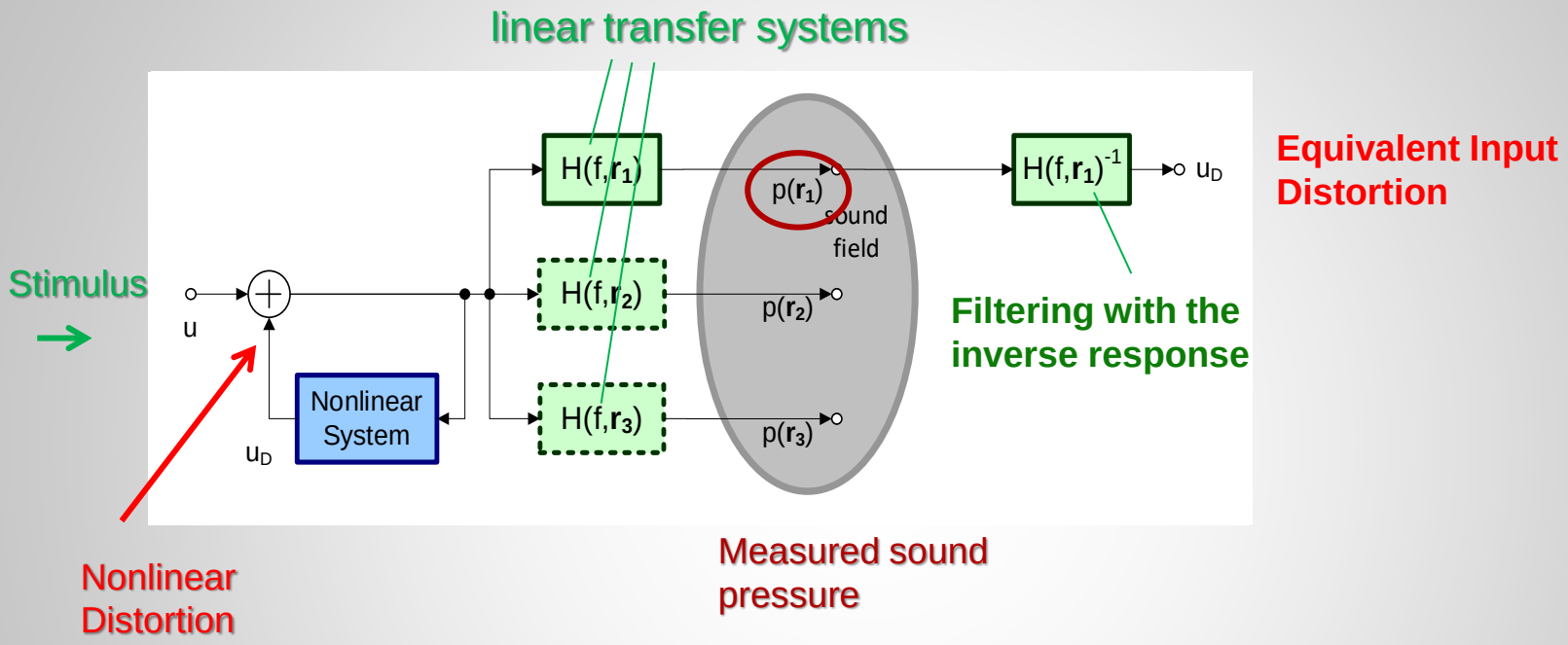
Generates all kinds of nonlinear distortion (harmonics, intermodulation, DC components)
产生各种非线性失真（谐波、互调、直流分量）

Where to place the Microphone



- 主要非线性失真添加到输入中！ Distortion of dominant nonlinearities are added to the input !
- 线性传递函数H(f,r)为非线性失真提供后期整形 Linear transfer function H(f,r) provides a post-shaping to the nonlinear distortion
- 方向性对于评估非线性和非常规失真不太重要 The directivity is less important for evaluating nonlinear and irregular distortion
- 建议在近场中的一点进行测量！ The measurement at one point in the near field is recommend!

Measure Distortion at the Source



等效输入失真 Equivalent input distortions

- 利用扬声器建模的结果（主要是非线性） exploit the results of loudspeaker modeling (dominant nonlinearities)
- 独立于测量点、房间影响 are independent of the measurement point, room influence
- 是生成相对失真比u_D/u的基础 （以%表示） are a basis for generating relative distortion ratio (in percent)
- 在IEC 60268-21中定义 are defined in IEC 60268-21

Diagnostic based on Symptoms

found in the aoustical output signal

1. Amplitude Compression of the Fundamental Component
   - Long term (voice coil heating)
   - Short term (nonlinearities)
2. Harmonic Distortion in Sound Pressure Output (single-tone stimulus)
   - Total harmonic distortion
   - Nth-order harmonic distortion component
   - Maximum SPL for defined THD limit
   - Equivalent harmonic input distortion (New)
   - Higher-order Distortion (New)
3. Intermodulation Distortion (two-tone stimulus)
   - 2nd and 3rd-order intermodulation component
   - Amplitude modulation distortion
4. Multi-tone Distortion (New)
   - Distortion generated by typical program material
5. Impulsive Distortion (new)
   - Impulsive distortion level
   - Maximum impulsive distortion ratio
   - Crest factor of impulsive distortion versus displacement
6. Cross-correlation technique (noise)
   - Incoherence
7. Distortion Separation by Modeling (music)
   - Nonlinear residuum

Defined in IEC 60268-21

Discussion

总结Summary

- 信号失真可以通过参数（基于建模）和症状（生成的信号分析）来描述
  Signal distortion can be described by parameters (based on modeling) and symptoms (generated signal analysis)
- 参数应独立于输入信号
  Parameters should be independent of the input signal
- 症状取决于输入信号和换能器的内部状态（例如位移、线圈温度）
  Symptoms depend on the input signal and the internal state of the transducer (e.g. displacement, coil temperature)
- IEC标准60268-21提供了稀疏频谱的新激励（多音、chirp、猝发音）
  IEC standard 60268-21 provides new stimuli (multi-tone, chirp, burst) with sparse spectrum
- 对换能器建模的深入了解可简化对症状的解读（例如THD）
  Insight in transducer modeling simplifies interpretation of the symptoms (e.g. THD)

Open Questions

症状揭示信号失真的原因！ Symptoms reveal the causes of signal distortions !
让我们来详细讨论最重要的症状。 Let's discuss the most important symptoms in detail.

第七次网络研讨会题目 The next 7th KLIPPEL live webinar entitled
幅值压缩 – 幅值更高但输出更少
Amplitude Compression – less output at higher amplitudes
将讨论一下几点 will address the following points

- 什么导致幅值压缩 What causes amplitude compression?
- 换能器在幅值更高时是否提供更多输出（“扩展”） Does the transducer also provide more output at higher amplitudes (“expansion”) ?
- 如何根据IEC 60268-21测量基波响应的变化 How to measure the variation of fundamental response according IEC 60268-21
- 如何解读结果 How to interpret the results
- 如何使用该信息改进硬件和DSP软件 How to use this information for improving hardware and DSP software

Next Section

1. Modern audio equipment needs output based testing
2. Acoustical standard 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 – a number becomes important
6. Selecting measurements with high diagnostic value
7. Amplitude Compression – less output at higher amplitudes
8. Harmonic Distortion Measurements – best practice
9. Intermodulation Distortion – audio 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