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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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
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

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
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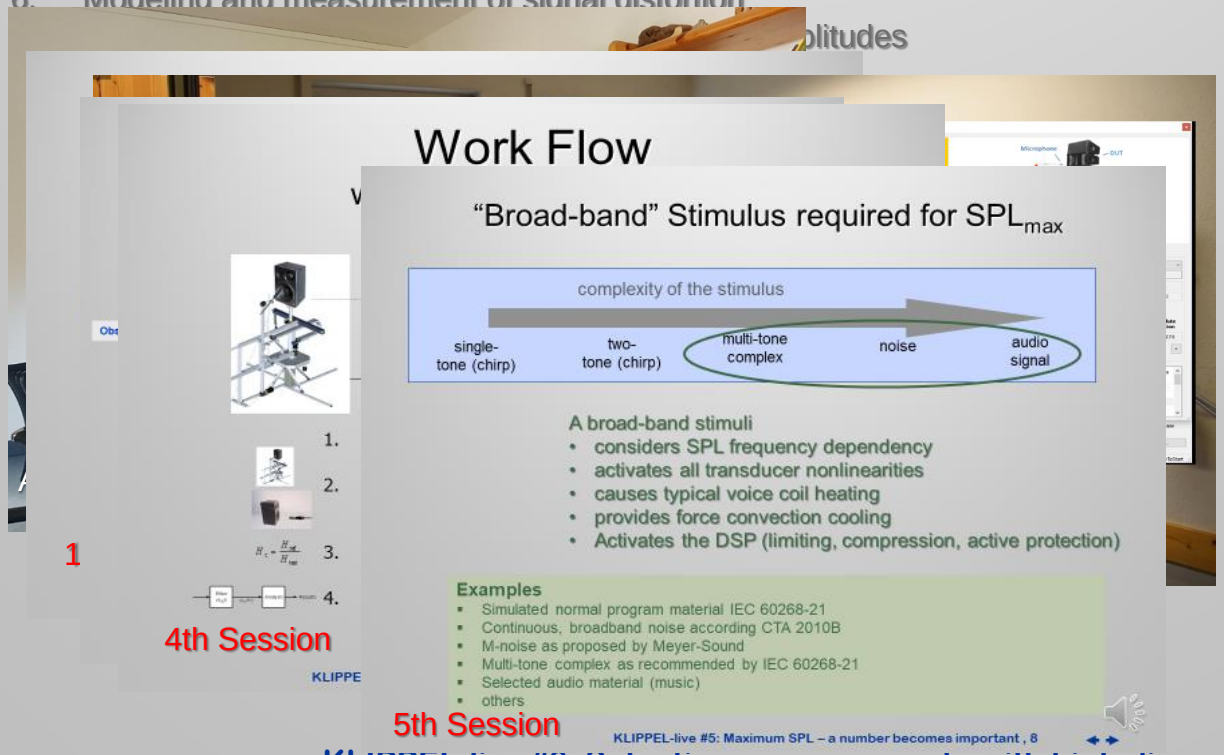
6. Modeling and measurement of signal distortion

Presented 2020



線上課程的目的
Targets of the Webinar

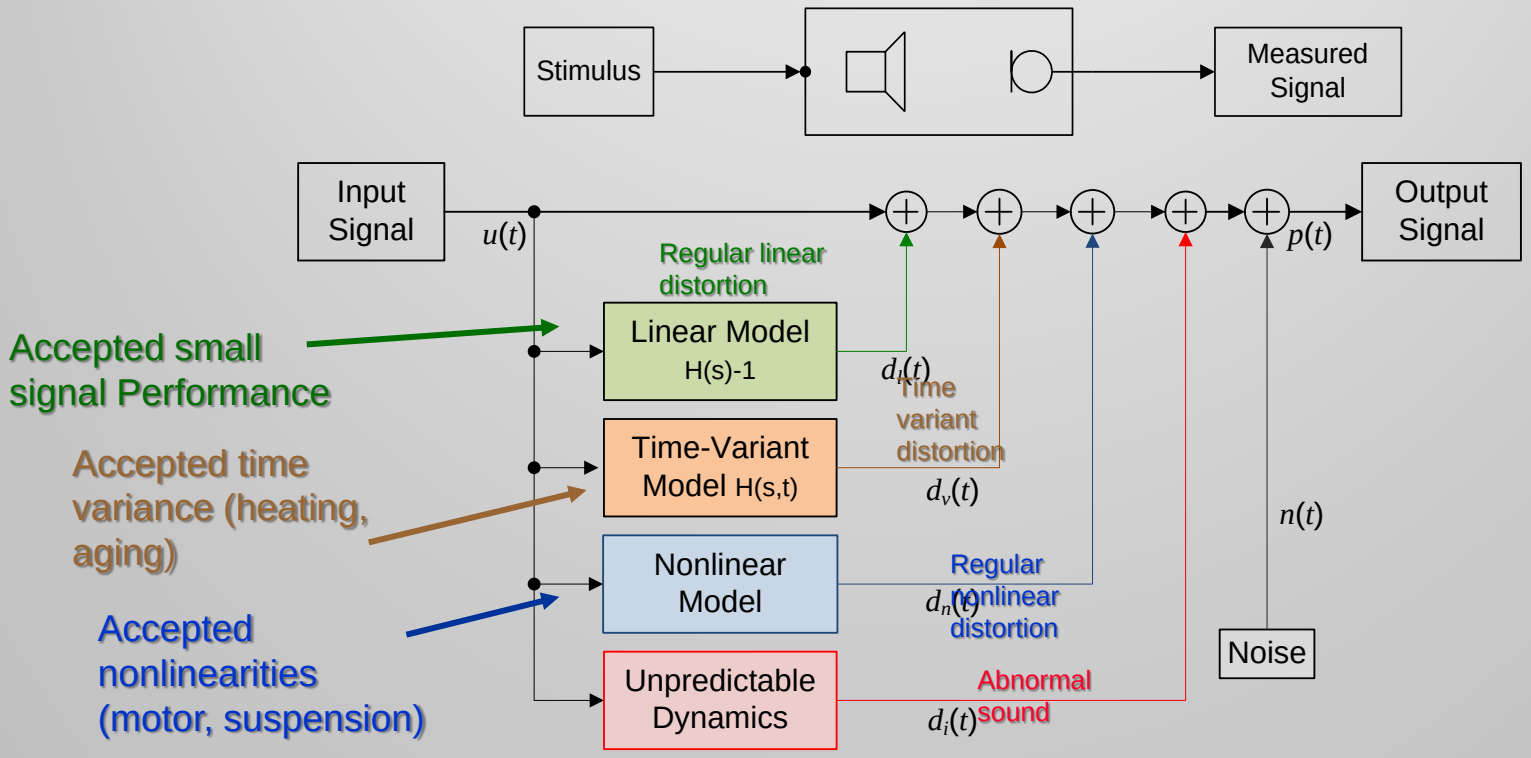
- 受益於國際標準 (IEC 60268-21) Benefit from international standards (IEC 60268-21)
- 連接音頻系統的物理和感知評估Link the physical and perceptual evaluation of audio systems
- 評價最大輸出（max SPL）Rate the maximum output (max SPL)
- 簡化描述和揚聲器診斷 Simplify interpretation and loudspeaker diagnostics
- 了解信號失真的原因 Understand the causes of signal distortion
- 應對異音、不規則振動和不良 Cope with abnormal sound, irregular vibration and defects
- 加速綜合測試 Speed up comprehensive testing
- 在普通房間進行模擬自由場測量 Perform simulated free field measurements in normal rooms
- 考慮現代音頻產品的特殊性 Consider particularities of modern audio products
- 討論未解決的問題，避免陷阱，獲得實用技巧 Discuss open question, avoid pitfalls, get practical tips

PART 6:信號失真–強大的揚聲器診斷概念
Signal distortion – a powerful concept for loudspeaker diagnostics

今日主題Topics today:

1. 什麼是信號失真？What are signal distortion ?
2. 線性、非線性和其他失真的特性Properties of linear, nonlinear and other distortion
3. 我們可以透過物理建模來預測信號失真嗎？Can we predict the signal distortion by physical modeling?
4. 解釋測量的不良並與物理原因連結起來Interpretation of the measured symptoms and linking with the physical causes
5. 音頻設備綜合評測Comprehensive evaluation of the audio device
6. IEC 60268-21 中定義的新測試概述Overview on new tests defined in IEC 60268-21

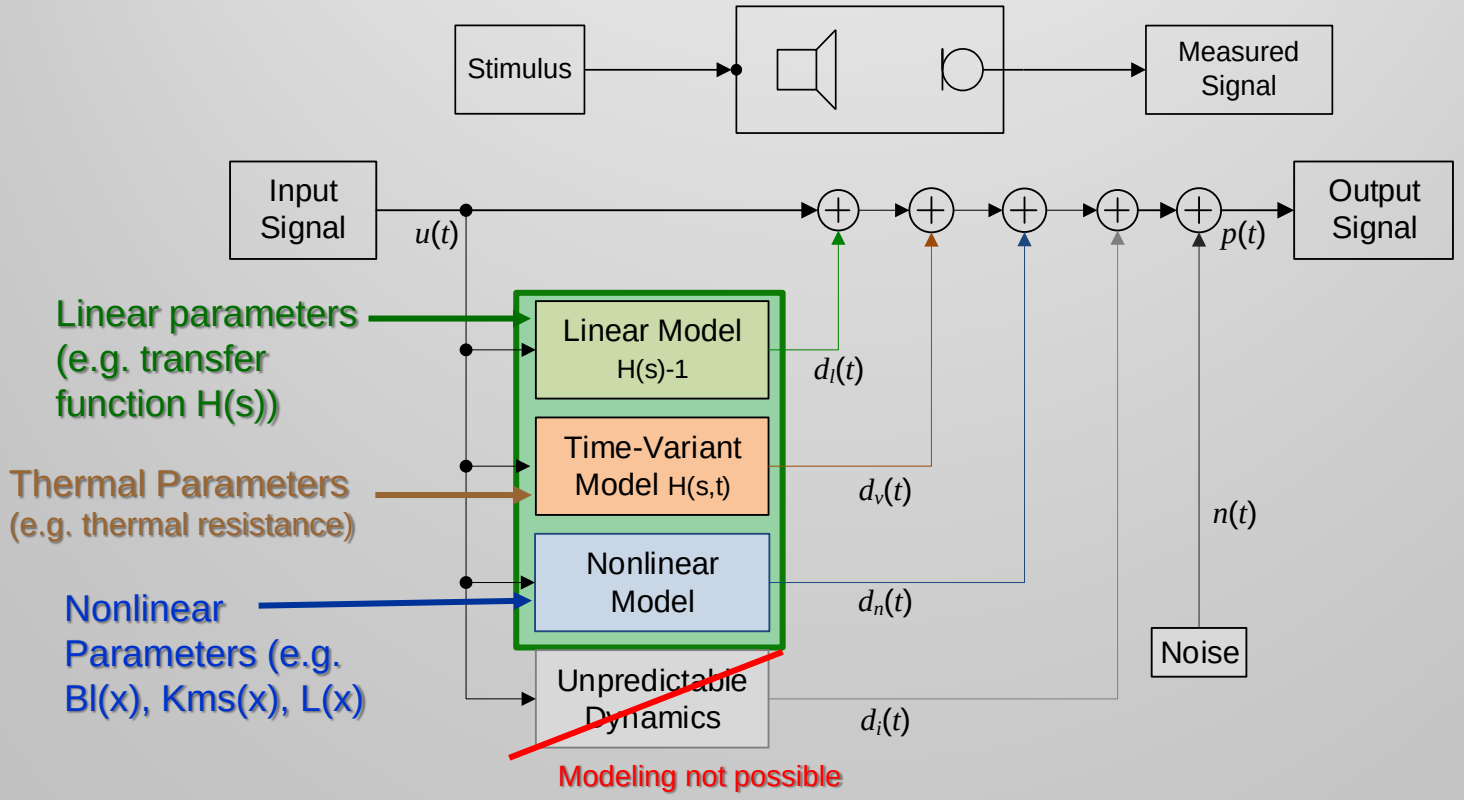
音頻系統中產生的信號失真
Generation of Signal Distortion in an Audio System



Undesired Defects

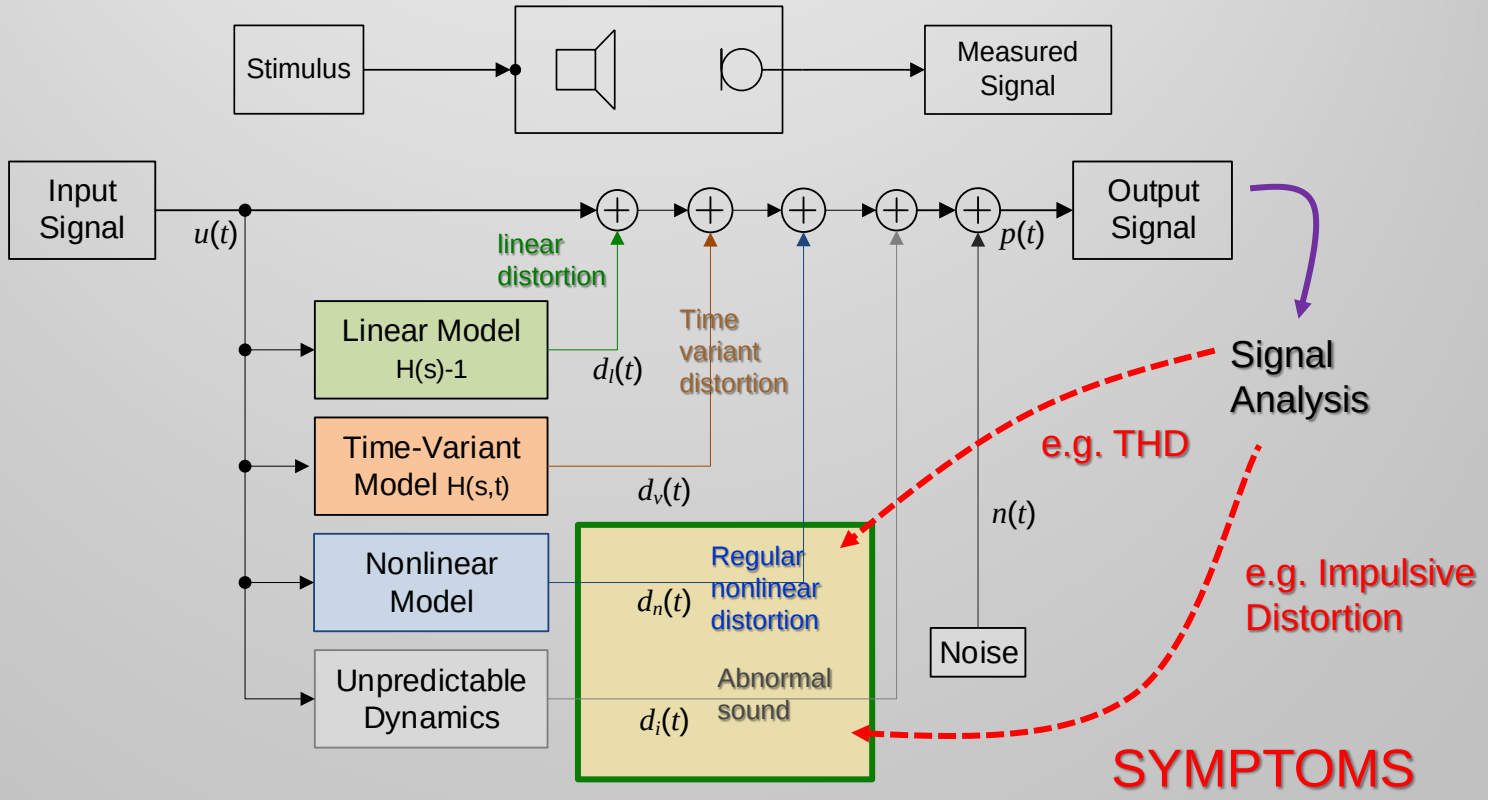
- Rubbing coils, buzzing parts
- Wire beat, coil bottoming
- Loose particles, air leak noise
- Parasitic vibration of other components

基於建模的診斷
Diagnostics based on Modeling



確定性失真分量可以通過具有識別參數的物理模型來預測。 此參數與激發無關
The deterministic distortion components can be prediced by a physical model with identified parameters. The parameters are independent of the stimulus!

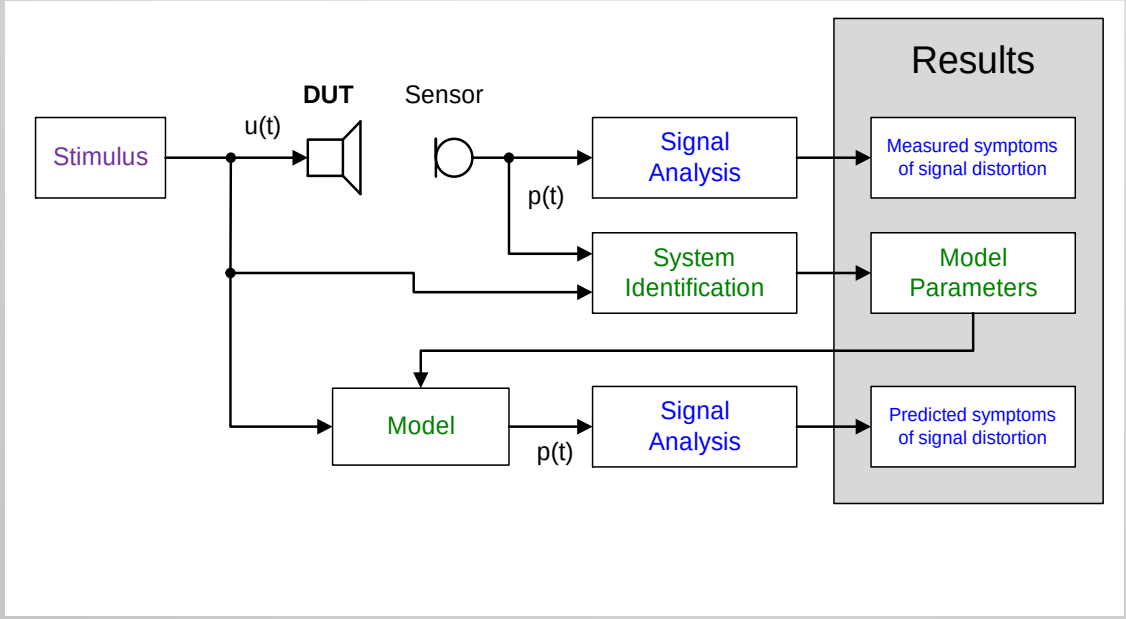
基於獨特症狀的診斷
Diagnostics based on Unique Symptoms



症狀的產生不需要模型 The generation of symptoms requires no model.

症狀取決於激發的特性The symptoms depend on the properties of the stimulus.

信號失真評估
Assessment of Signal Distortion



Depends on the stimulus

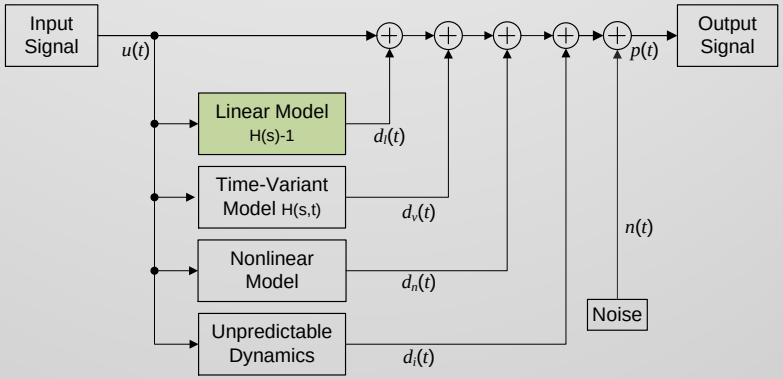
Should be independent of the stimulus

e.g. transfer function H(s)

Depends on the stimulus

- 待測物被特定刺激激發The **D**evice **U**nder **T**est is excited by a particular stimulus
- 使用傳感器（例如麥克風）觀察輸出信號Output signal is monitored by using sensors (e.g. microphone)
- 模型的自由參數可以通過系統識別技術來估計Free parameters of a model can be estimated by system identification techniques
- 將信號分析（例如傅立葉變換）應用於測量或預測的輸出信號，以推導出信號失真的症狀Signal analysis (e.g. Fourier Transform) is applied to the measured or predicted output signal to derive symptoms of the signal distortion

線性失真
Linear Distortion



特性Properties

- 確定的 Deterministic
- 因為使用線性模型激發所以可預測

Predictable based on the stimulus using a linear model

物理原因 Physical Causes:

- 換能器 + 外殼（共振）Transducer + Enclosure (resonances)
- 房間影響 Room influence
- DSP（對齊、均衡器、分頻器）DSP (Alignment, Equalizer, Crossover)

投票Poll:

您如何評估音頻設備的線性失真？（可多選）
How do you assess the linear distortion of an audio device ? (Multiple answers possible)

A. 自由場條件下的單點量測（遠場同軸）Single-point measurement (on-axis in the far field) under free field condition

B. 在無響室中使用轉盤或麥克風陣列在遠場中的多個測試點 Multiple points in the far field using turntables or microphone arrays in an anechoic room

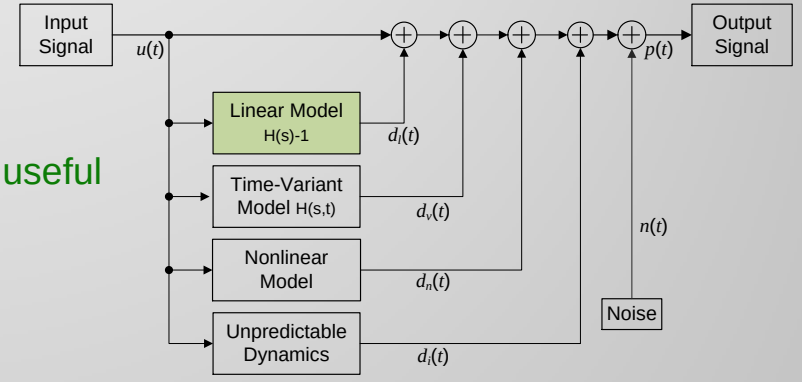
C. 在聲音裝置的近場量測 In the near field of the audio device

D. 透過將聲音裝置安裝到耦合器、測試箱、平面波管By mounting the audio device to a coupler, test box, plane wave tube

E. 在目標環境中（聆聽室、汽車中.....）In the target environment (listening room, car, ...)

F. 其他 Else

評估線性失真
Assessing Linear Distortion



測量技術 Measurement techniques

- 症狀的測量不太有用 Measurement of symptoms is less useful
- 線性參數的識別Identification of a linear parameters

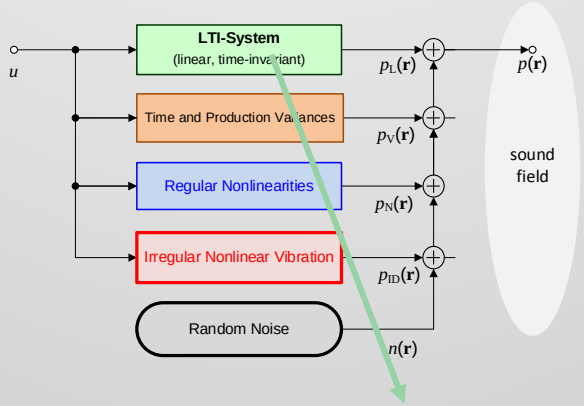
根據輸出測量來確定的參數：Parameters determined by output based measurements:

- 同軸 SPL 頻率響應 On-axis SPL frequency response
- 距離為 r（遠場）的球體上的 SPL 頻率響應 L(f, φ, θ) SPL frequence response L(f, φ, θ) on a sphere with distance r (far field)
- 聲功率頻率響應（指向性指數） Sound power frequency response (Directivity index)
- 3D 聲音輸出（近場和遠場中任意點 r 處的複雜傳遞函數 HL(f,r)） 3D Sound output (complex transfer function $H_L(f,r)$ at any point **r** in near and far field)
- 球面波擴展係數 C(f) Coefficients C(f) of the spherical wave expansion
- 集成在個人聆聽區的平均 SPL 響應 Mean SPL response integrated over personal listening zones
- 延遲（由 DSP 生成）Latency (generated by DSP)
- …

discussed in 3rd session of KLIPPEL live

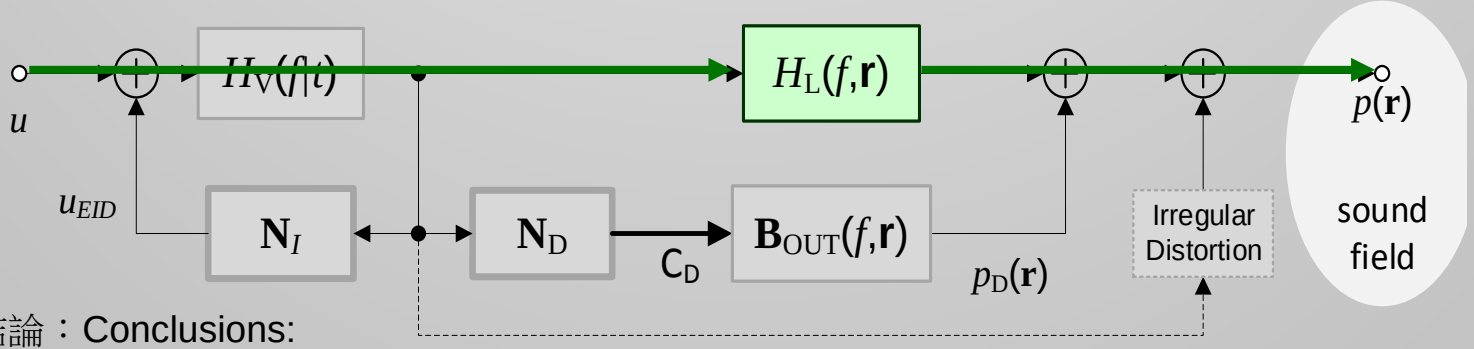
物理模型Physical Model
for Output-Based Measurements

Stimulus with small amplitude



ONLY Linear Distortion (Other distortion are negligible at small amplitudes)

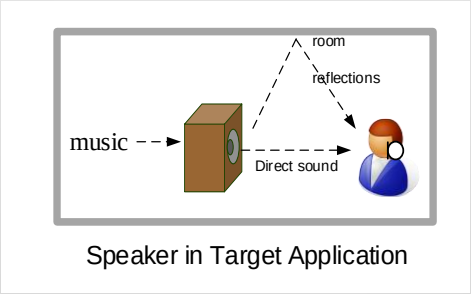
Spatial transfer function $H_L(f,r)$ based on wave expansion (IEC 60268-21)

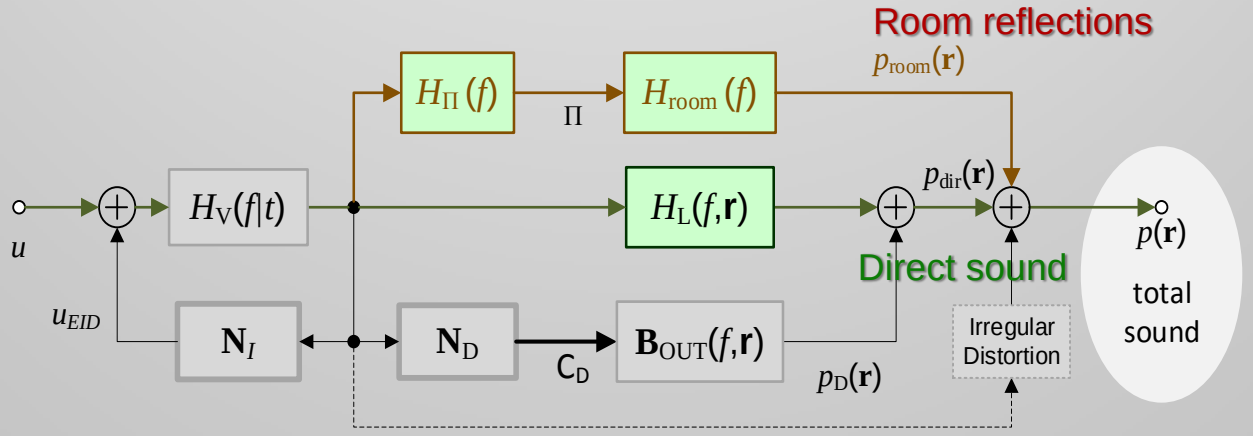


結論：Conclusions:

- 基於球面波展開的空間傳遞函數HL(f,r)可以描述自由場條件下3D聲場任意點的線性失真The spatial transfer function $H_L(f,r)$ based on spherical wave expansion can desribe the linear distortion at any point in the 3D sound field under free field condition
- 建議在小幅度下進行全息近場測量 Holographic near-field measurement at small amplitudes is recommended

物理建模 Physical Modeling
Speaker – Room Interaction

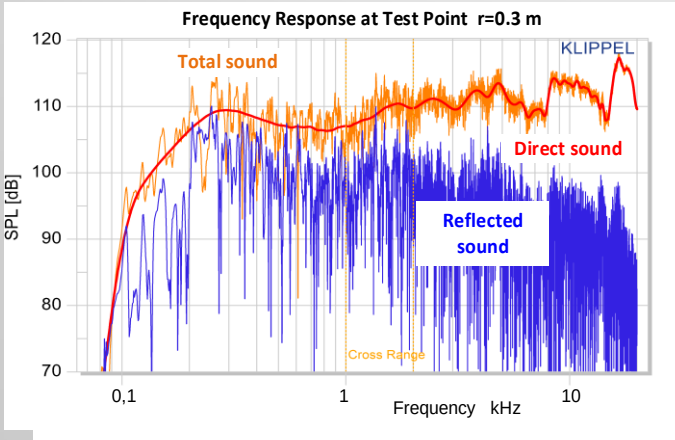


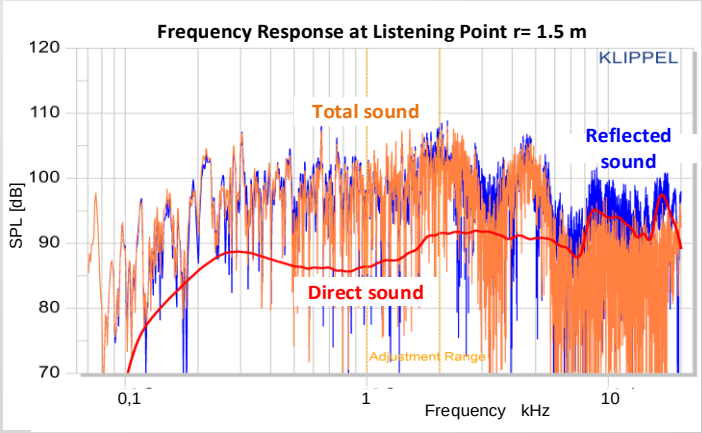


結論 Conclusions

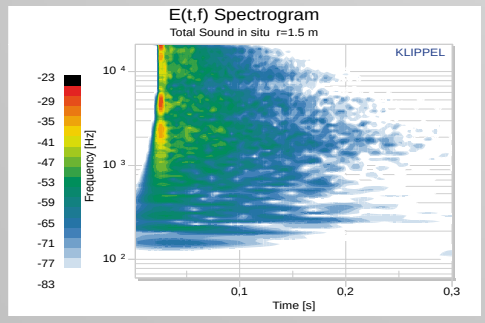
- 空間傳遞函數 HL(f,r) 僅代表直接音 The spatial transfer function $H_L(f,r)$ represents only the direct sound
- 聲功率響應 HΠ(f) 描述了激發房間模式的揚聲器特性 Sound power response $H_{\Pi}(f)$ describes the loudspeaker properties exciting the room modes
- 房間傳遞函數 Hroom(f,r) 表示房間屬性（大小、吸收）Room transfer function $H_{room}(f,\mathbf{r})$ represent room properties (size, absorption)

房間模式產生的線性失真
Linear Distortion generated by Room Modes





Total Sound



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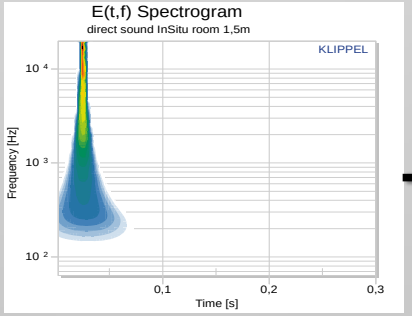
Direct Sound



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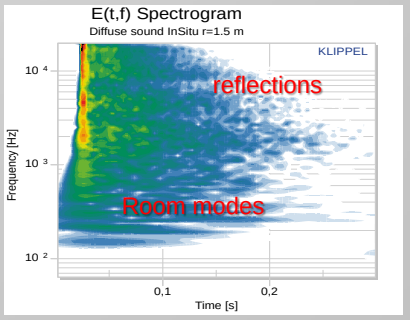
Reflected Sound



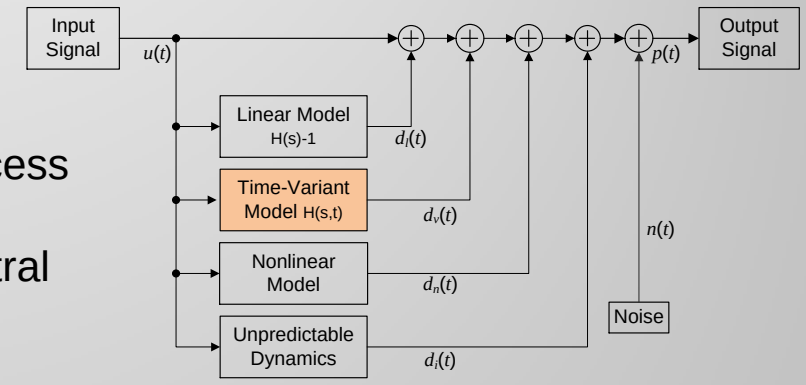
結論Conclusion:

- 房間模式會在目標環境中產生明顯的總聲音失真

Room modes generate significant distortion in the total sound in the target environment

- 房間模式以不同的頻率出現,隨時間平滑衰減 Room modes occur at distinct frequencies decaying smoothly with time
- 桌子和牆壁會引起反射 Table and wall can cause strong early reflections

線性時變失真
Linear Time-Variant Distortion



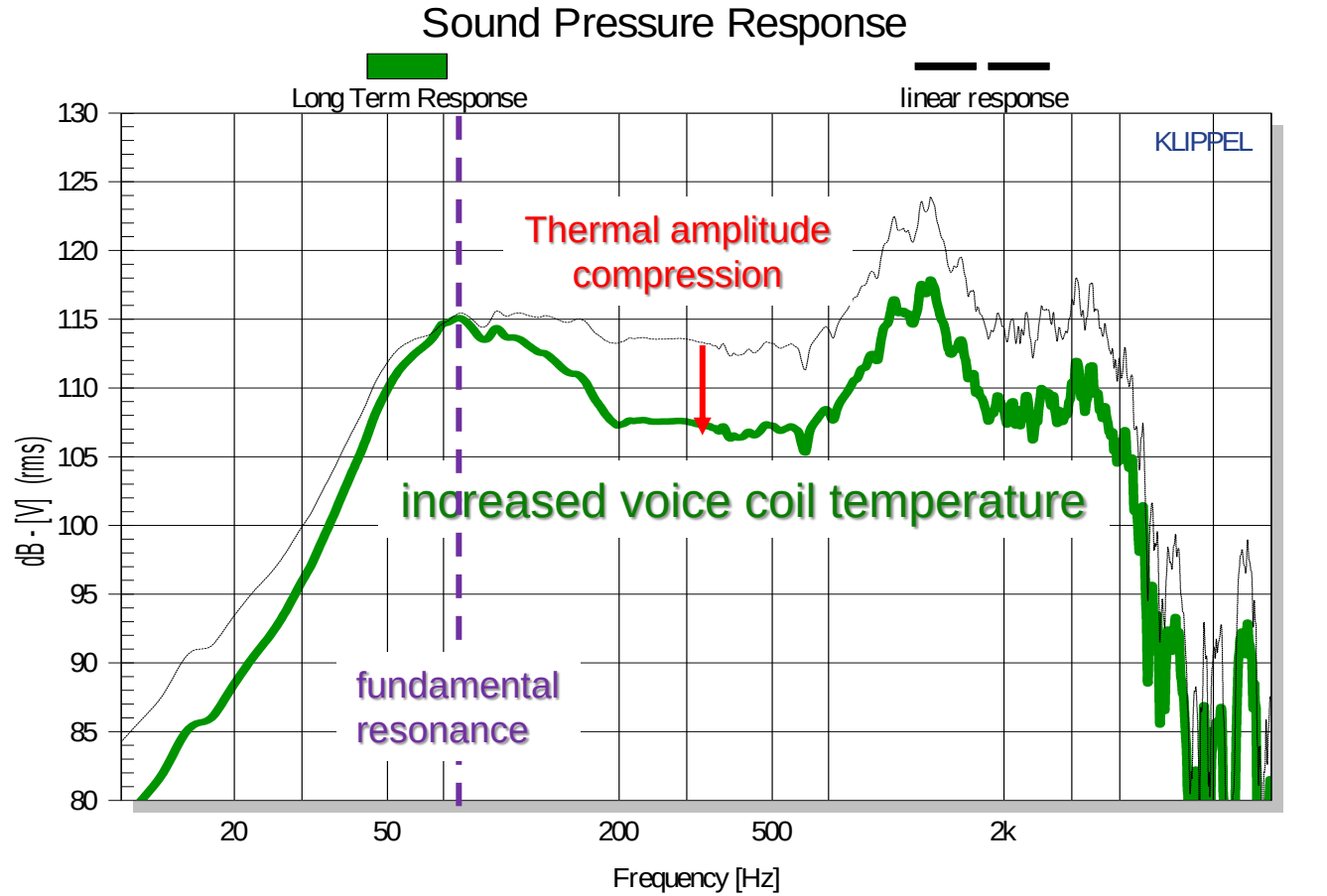
特性properties:

- 由特定過程生成Generated by a deterministic process
- 緩慢變化的屬性Slowly varying properties
- 不產生新的頻率成分Does not generate new spectral components
- 可以用模型來描述Can be described by models
- 設計中考慮Considered in the design

物理原因Physical Causes:

- 單體(溫度,老化,疲乏) Transducer (heating, aging, fatigue)
- 不同的聲學負載、房間和氣候影響 Varying acoustical load, room and climate influence
- 音頻 DSP 軟體（壓縮器、限制器、機械和熱保護系統 Audio DSP Software (Compressor, Limiter, mechanical and thermal protection systems

傳遞函數 H(f,t) 的時間方差
Time variance of the Transfer Function H(f,t)

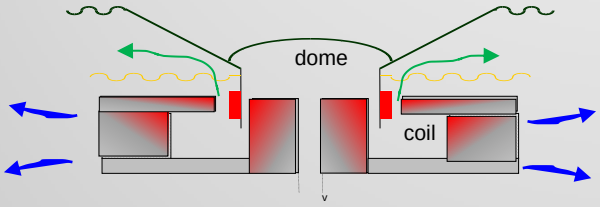


通過使用階梯式正弦波和循環 1 分鐘開/1 分鐘關來測量長時間響應
Long term response was measured by using a stepped sine wave and cycling 1 min on/1 min off

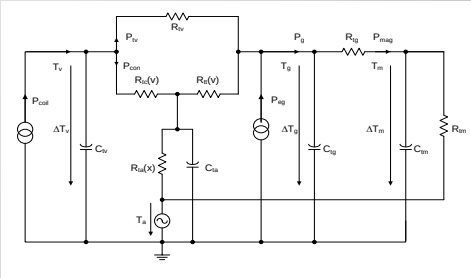
揚聲器的熱動態不會產生諧波和其他新的頻譜分量，因為音圈具有很高的熱時間常數
The thermal dynamics of the loudspeaker generates no harmonics and other new spectral components because the voice coil has a high thermal time constant (τ_V > 1s).

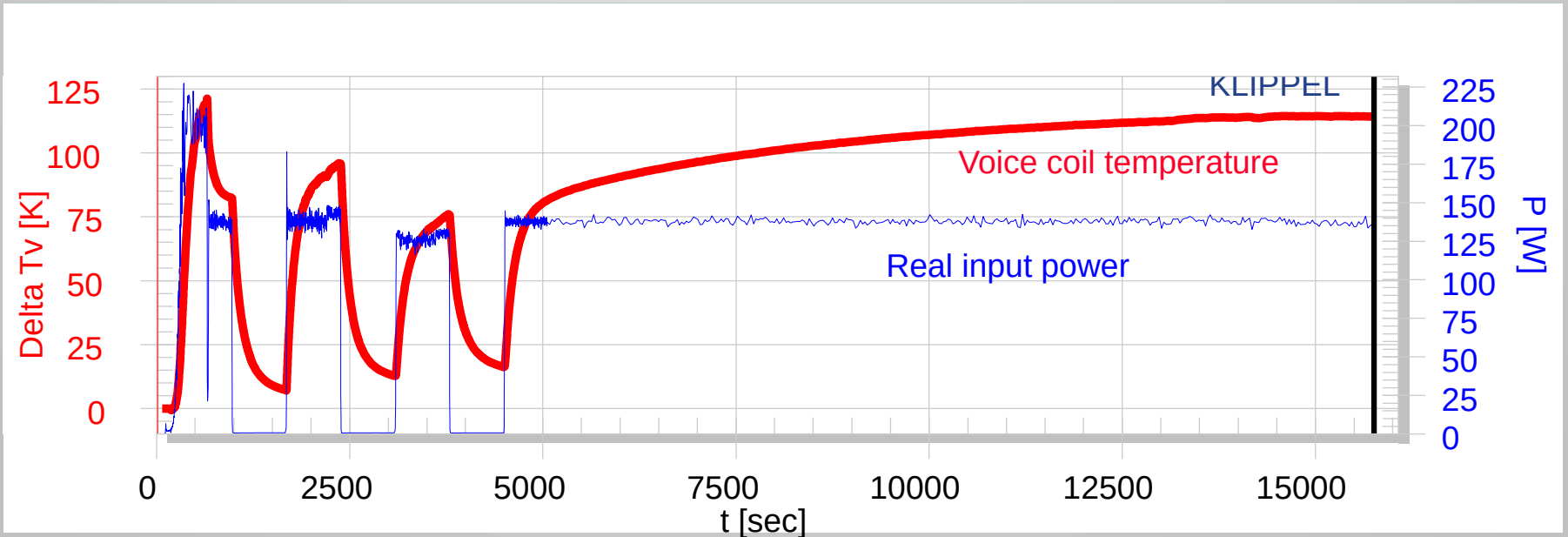
示範:熱動態
Example: Thermal Dynamics

Heat Flow



Thermal Model



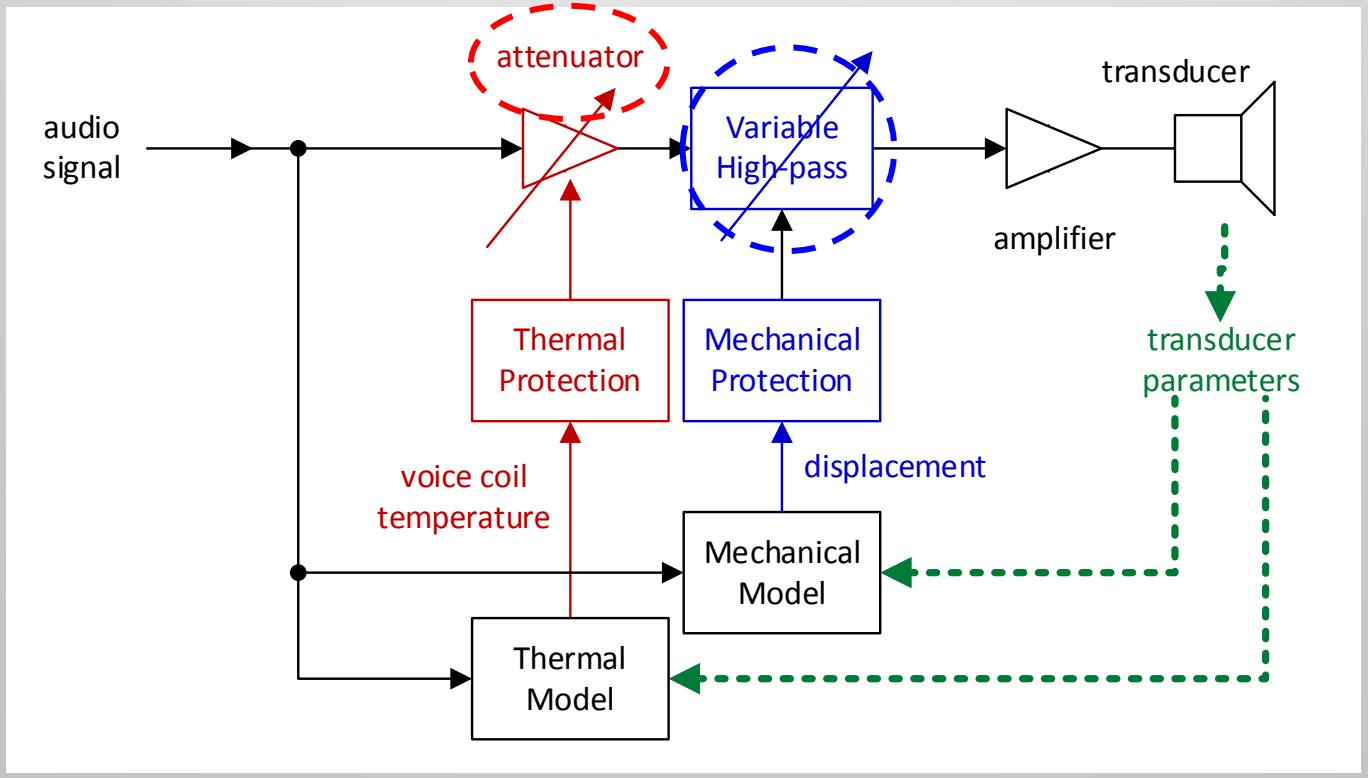


Time Constant of the voice coil
τ_V= 130 s

Time constant of the magnet
τ_M=67 min

主動喇叭保護
Active Transducer Protection

based on linear and thermal modeling and measured transducer parameters



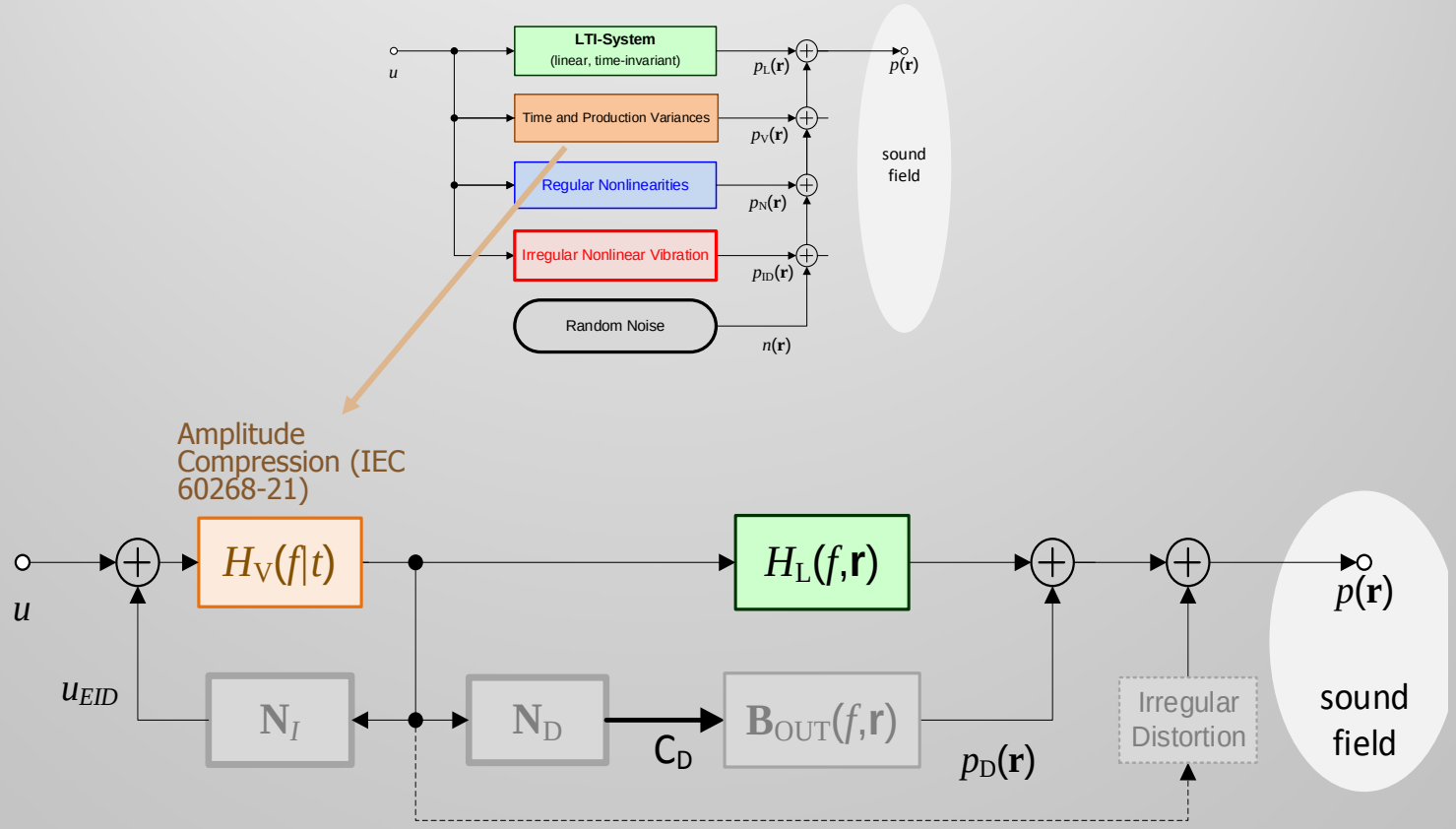
防止熱過載To prevent thermal overload

- 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

物理模型 Physical Model
for Output-Based Measurements



結論Conclusions:

- 時變系統 Hv(f|t) 與評估點 r 無關

Time variant system $H_V(f|t)$ is independent of the evaluation point r

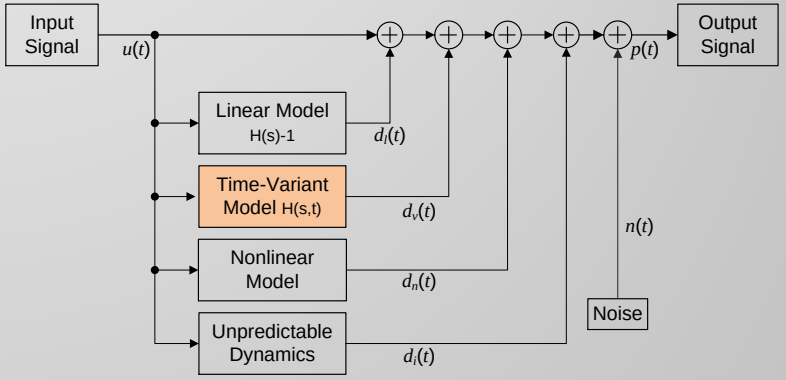
- 測量近場中的幅度壓縮 → 良好的信噪比

Measure amplitude compression in the near field → good signal-to-noise ratio

評估線性時變失真
Assessing Linear Time-Variant Distortion

測量技術：Measurement Techniques:

- 識別模型參數（例如熱參數）
  Identification of model parameters (e.g. thermal parameters)
- 測量特定激發產生的獨特症狀
  Measurement of unique symptoms generated by a particular stimulus



基於輸出的測量確定的症狀： Symptoms determined by output based measurements:

- 頻率響應的變化（幅度壓縮） Change of the frequency response (amplitude compression)

投票Poll:

你測量轉換函數的變化嗎？（可多選）

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

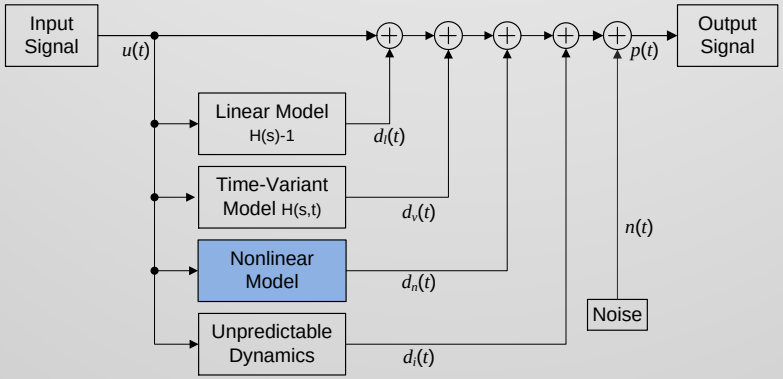
A. 沒有 No

B. 是的，通過改變輸入幅度來評估熱壓縮、保護系統和其他 DSP 功能 Yes, by changing the input amplitude to evaluate thermal compression, protection system and other DSP functionality

C. 是的，隨著時間的推移評估磨合、老化、疲勞 Yes, versus time to evaluate break-in, aging, fatigue

D. 是的，要評估氣候、負載變化的影響，..... Yes, to evaluate the influence of climate, load changes, ...

常規非線性失真
Regular Nonlinear Distortion



特性Properties:

- 取決於激發的幅度 Depend on amplitude of the stimulus
- 在小信號域中可忽略不計 Negligible in the small signal domain
- 確定性，可以建模 Deterministic, can be modeled
- 與設計相關，在批准的原型中接受 related to the design, accepted in an approved prototype

物理原因Physical Causes:

- 傳感器非線性 (Bl(x), Kms(x), L(x), L(i), ...)

Transducer nonlinearities (Bl(x), Kms(x), L(x), L(i), …)

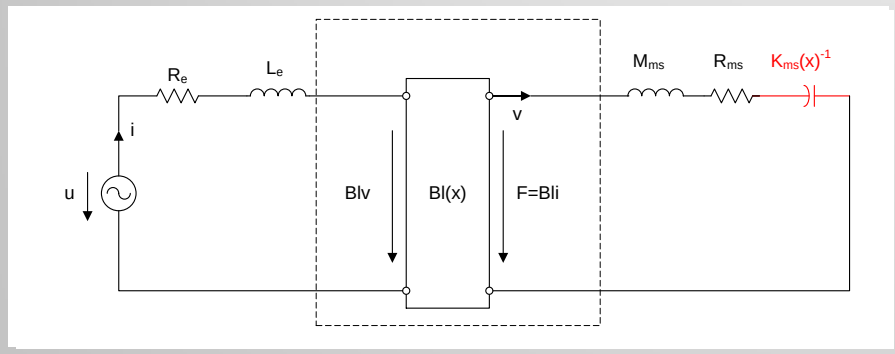
- 聲學端口非線性

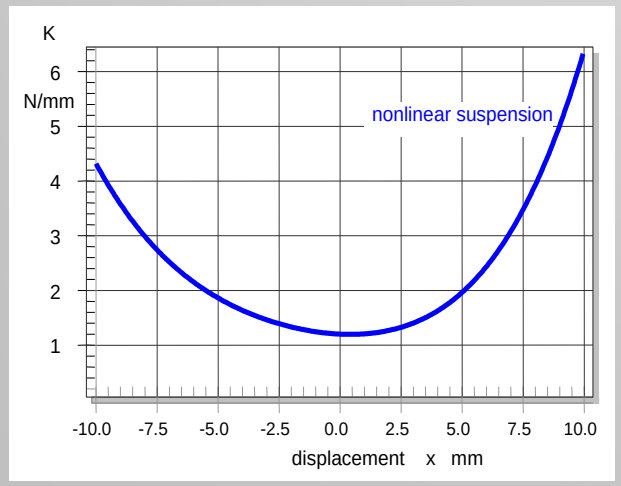
Acoustical port nonlinearity,

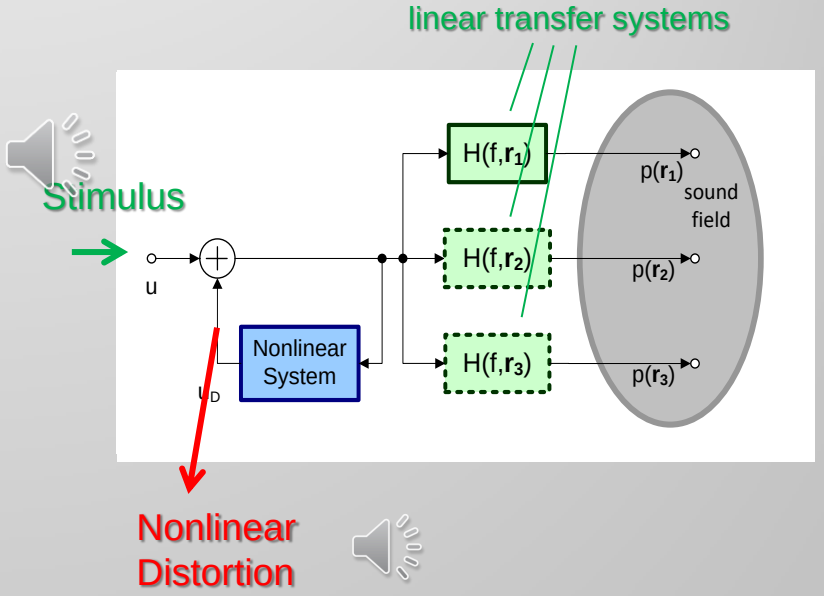
- DSP（硬峰值限制器）

DSP (hard peak limiter)

Kms(x) 產生的失真
Distortion generated by $K_{ms}(x)$







Restoring force

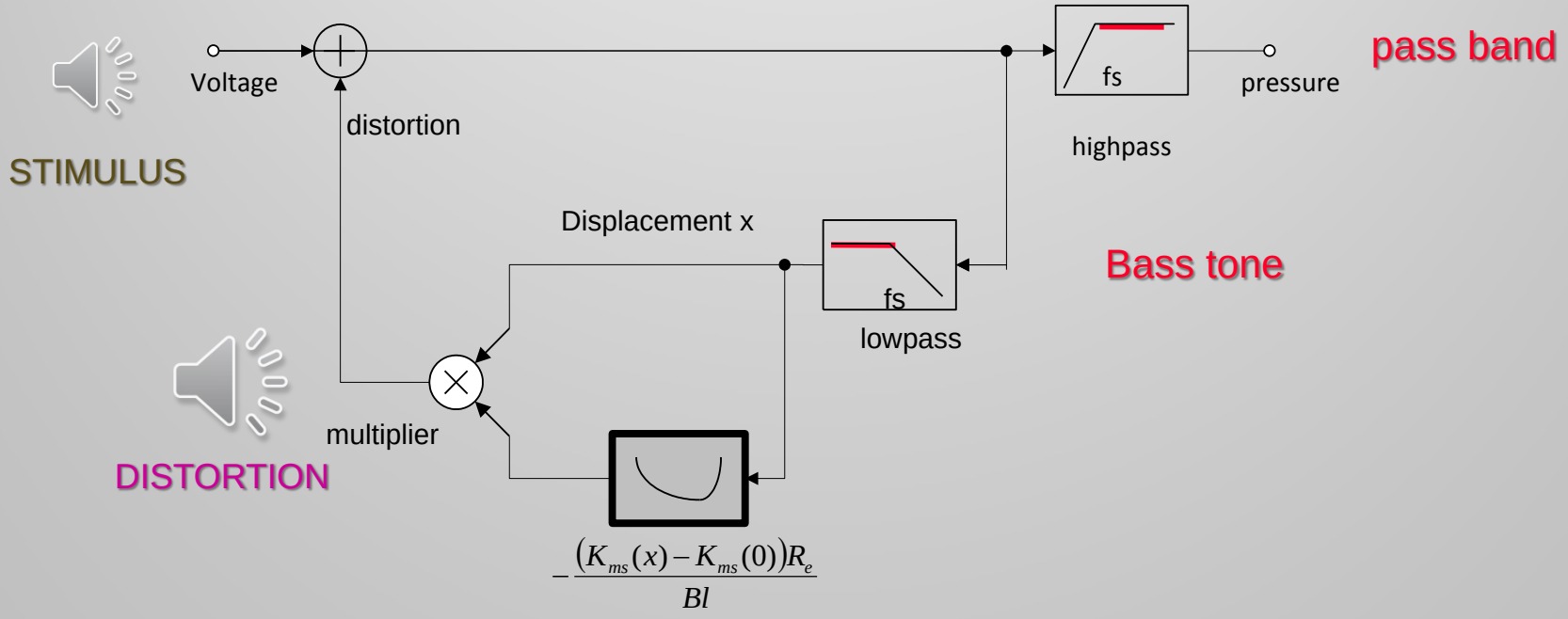
$$F = K_{ms}(x)x$$

Displacement

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

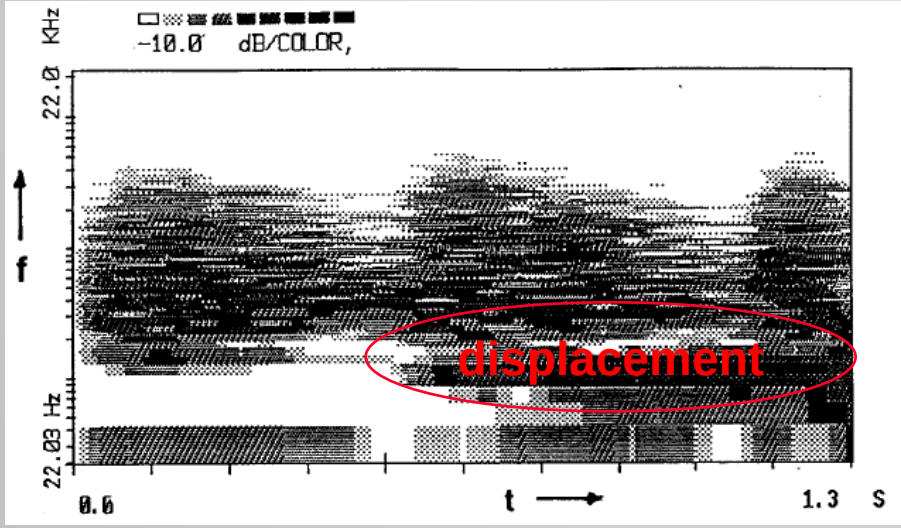
→ makes the reproduced bass signal „harder“ and more „aggressive“

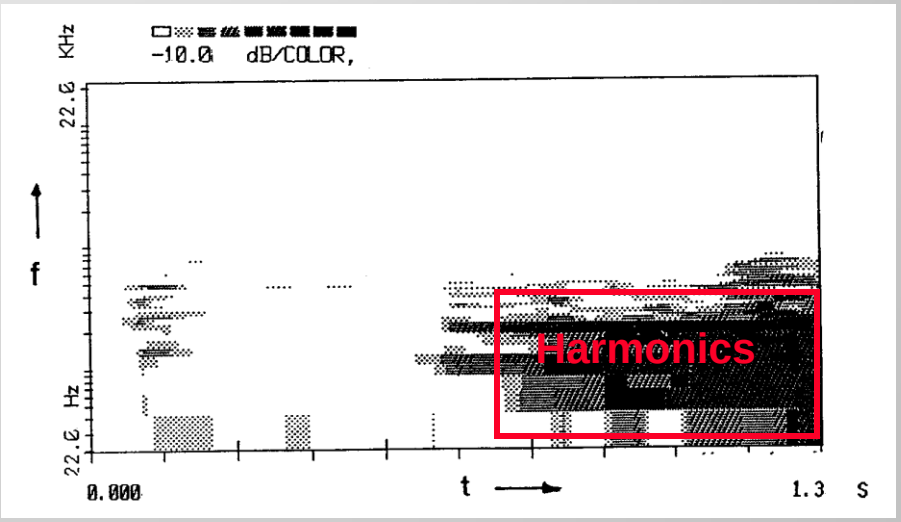
Kms(x) 產生的失真
Distortion Generated by $K_{ms}(x)$
simplified signal flow chart



→ Multiplication of displacement time signals x(t)*Kms(x(t))

Kms(x)-音樂失真
K_{ms}(x)-Distortion in Music





Undistorted music signal

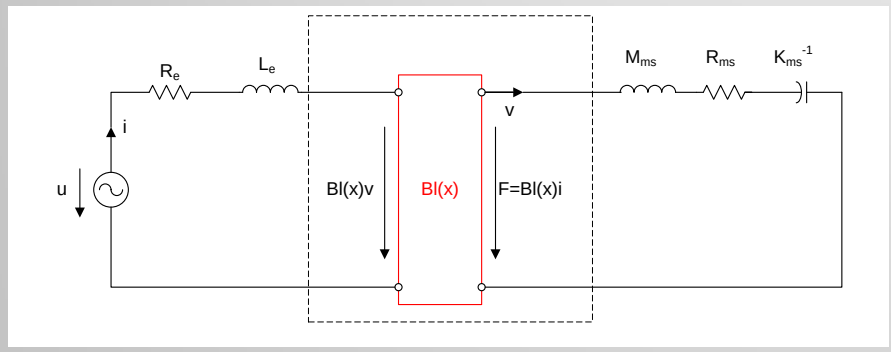
需要高位移 → 低於 fs 的信號 → 低音信號 High displacement required → signal below fs → bass signal

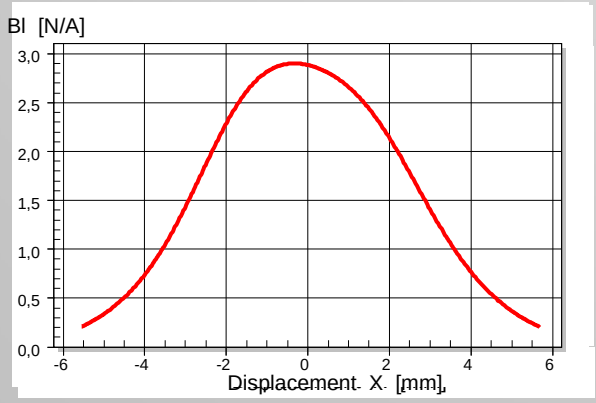
fs < 100 Hz 時的低頻失真 Low frequency distortion when fs < 100 Hz

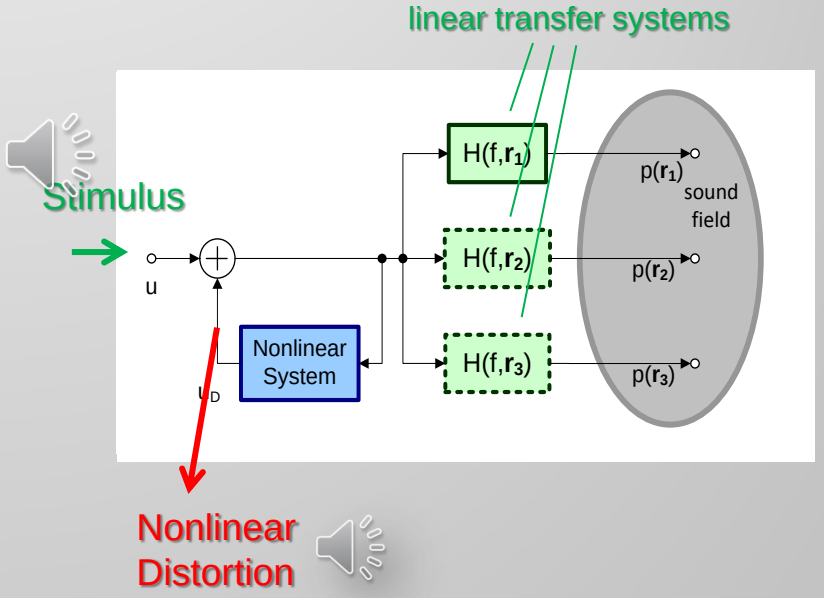
低音聽起來更有侵略性 Bass sounds more aggressive

對音質影響小 Low impact on sound quality

Bl(x) 產生的失真
Distortion generated by Bl(x)





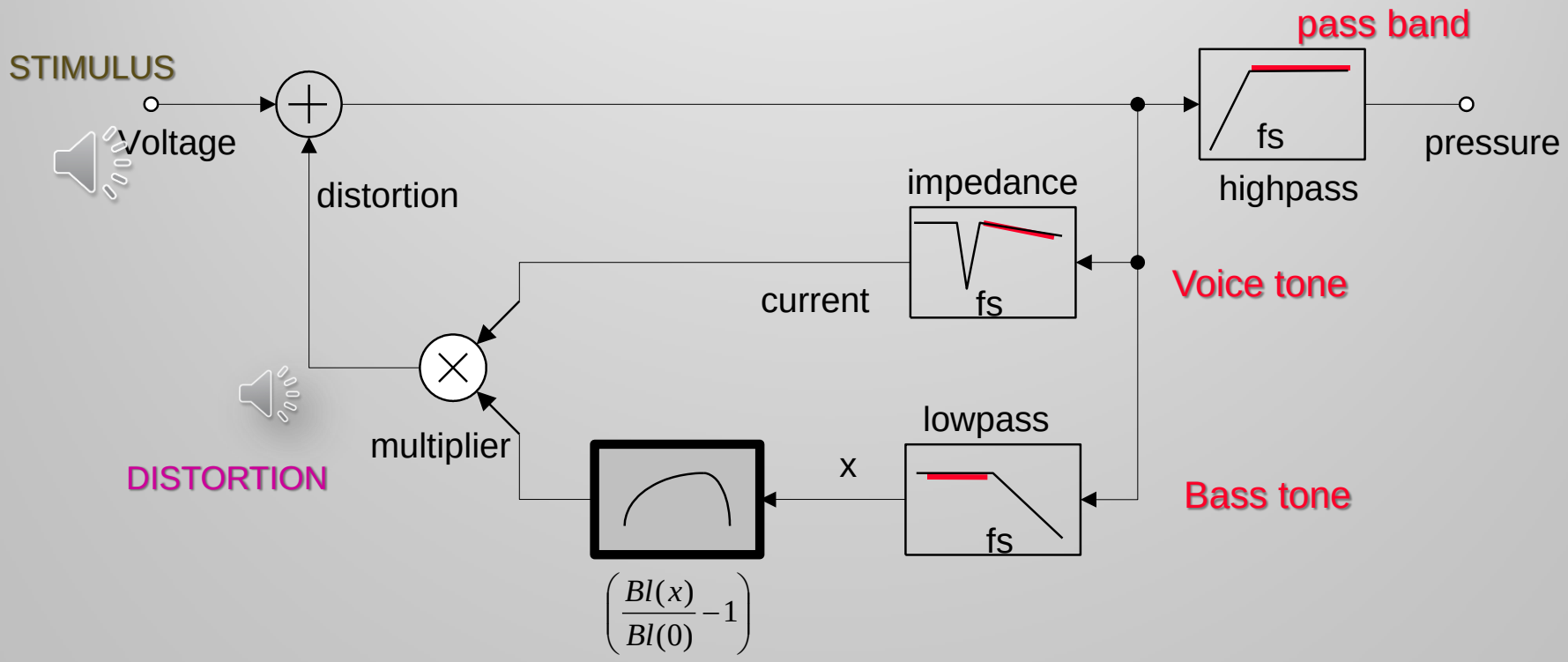


Electro-dynamical driving force $F = Bl(x)i$ Voice coil current

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

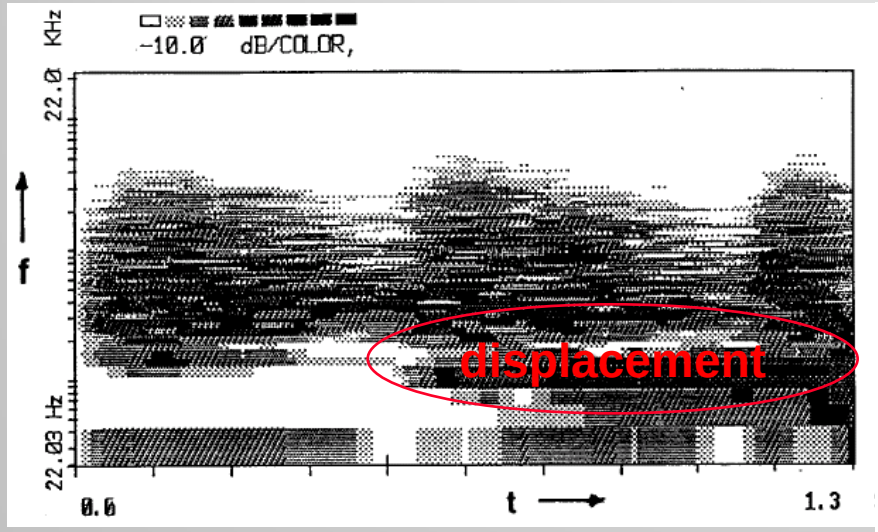
非線性 Bl(x) 導致位移 x 和電流 i 的乘積Nonlinear Bl(x) causes a multiplication of displacement x and current i
→在音頻頻段產生幅度互調失真generates amplitude intermodulation distortion in the audio band
→感覺聲音粗糙 perceived as roughness in the sound

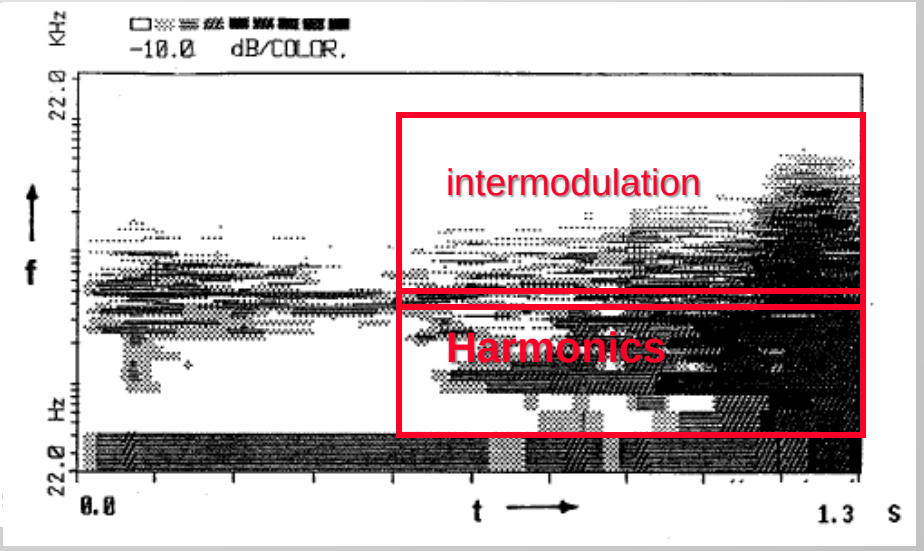
Bl(x) 的症狀
Symptoms of Bl(x)
1st nonlinear effect: Parametrical Excitation



1. Motor force F=Bl(x)*i
2. Multiplication of displacement x(t) and current i(t)
3. High distortion ($f_1 \leq f_s$, $f_2 > f_s$)

音樂中的BI失真
BI-Distortion in Music



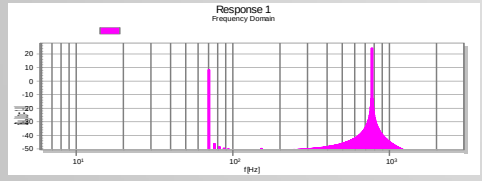


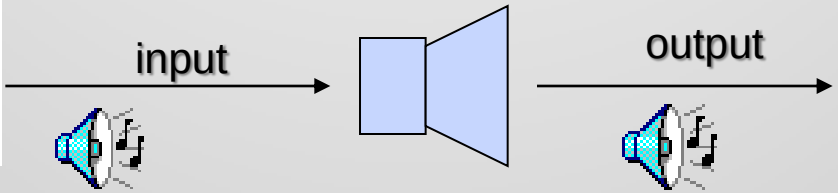
Undistorted music signal

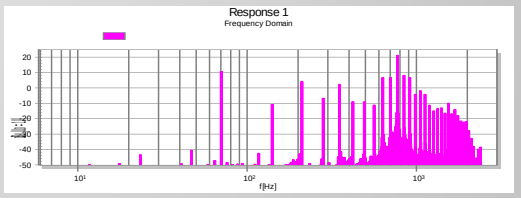
Distortion generated by Bl(x) only

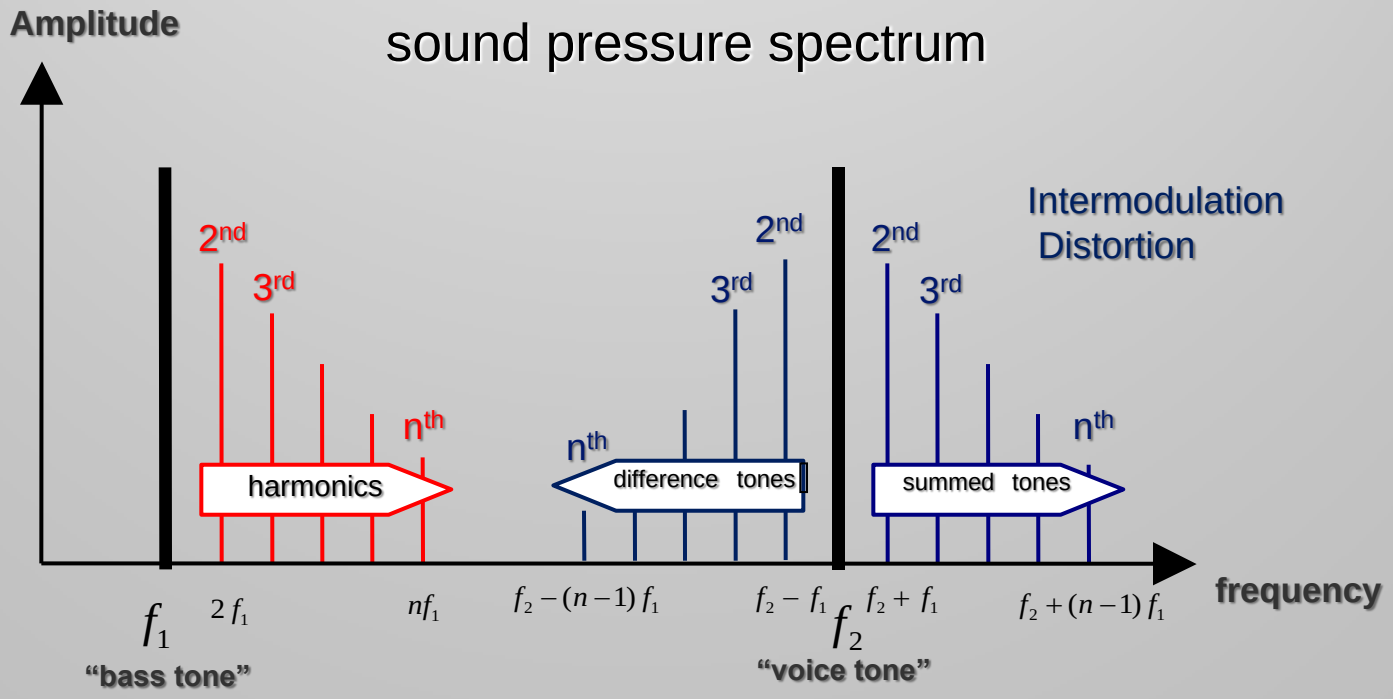
High displacement required → signal below fs → bass signal
Intermodulation with signal in audioband generate roughness when fs < 100 Hz
High impact on sound quality

非線性症狀：新的音頻成分
Nonlinear Symptom: New Spectral Components
generated by Two-tone Stimulus

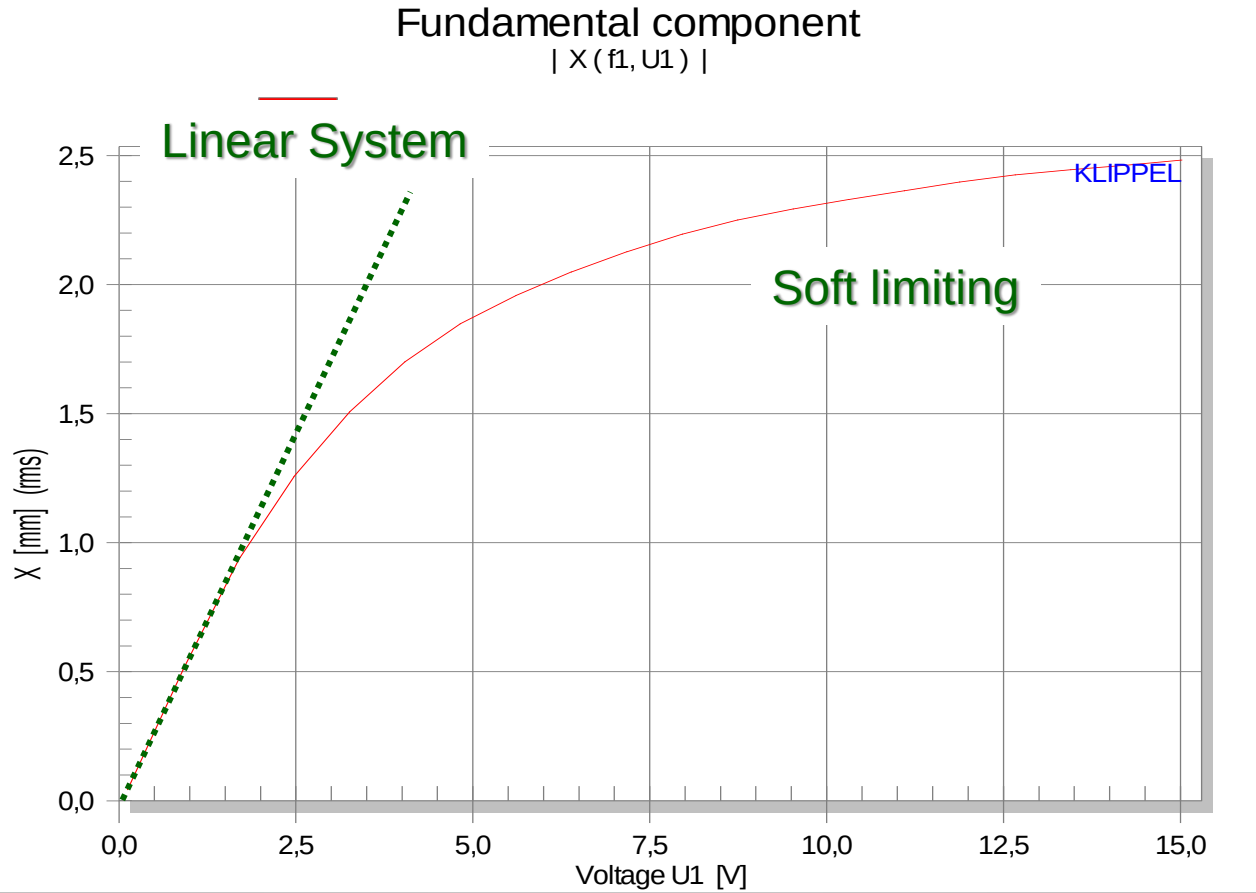








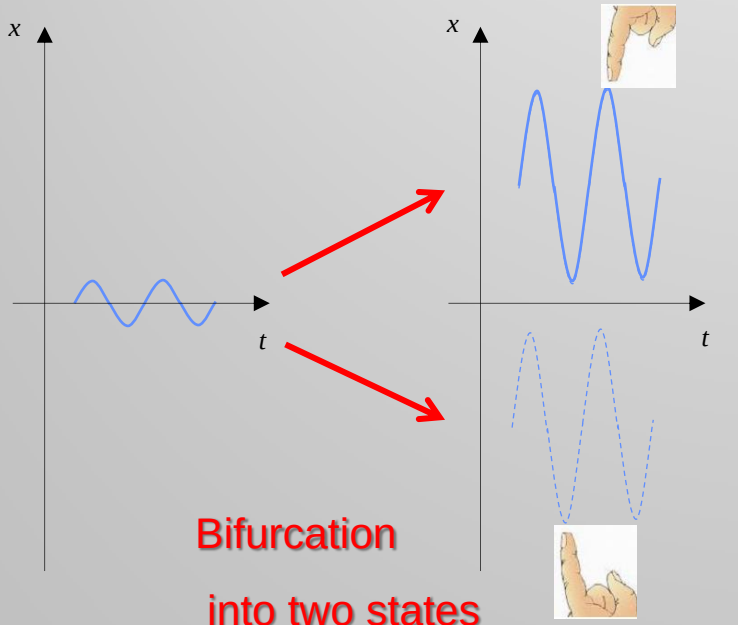
非線性症狀：幅度壓縮
Nonlinear Symptom: Amplitude Compression



非線性症狀：不穩定
Nonlinear Symptom: Instability

Small Signal Domain

Large Signal Domain



Bifurcation

into two states

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

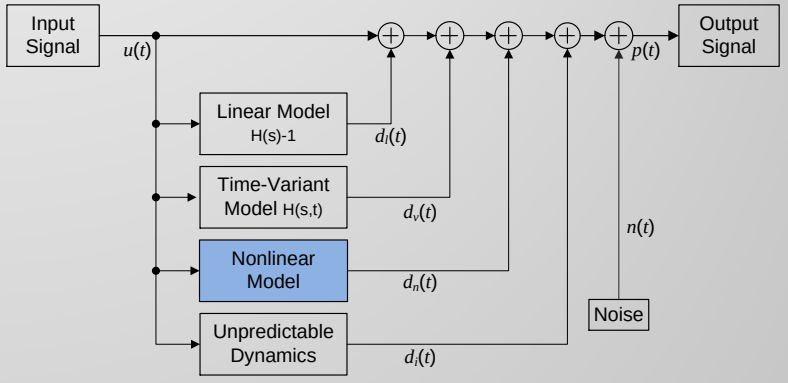
投票 Poll:

您使用常規非線性的哪些症狀？（可多選）

Which symptoms of the regular nonlinearities do you use? (Multiple answers possible)

A. 沒有任何 None
B. 諧波失真（第 2、第 3、THD、...） Harmonic Distortion (2^{nd}, 3^{rd}, THD, ...)
C. 互調失真（由 2 個或多個音調產生） Intermodulation Distortion (generated by 2 or multiple tones)
D. 基本分量的非線性壓縮 Nonlinear compression of the fundamental component
E. DC-位移、跳躍效果、其他不穩定性 DC-displacement, jumping effects, other instabilities

評估常規的非線性失真
Assessing Regular Nonlinear Distortion



測量技術Measurement Techniques:

- 非線性模型參數的識別Identification of nonlinear model parameters
- 尋找非線性的獨特症狀Searching for unique symptoms of the nonlinearities

基於輸出的測量確定的症狀：Symptoms determined by output based measurements:

- 不同人工刺激產生的非線性失真（諧波、互調分量）

Nonlinear distortion generated by different artificial stimuli (**Harmonic**, **intermodulation** components)

- 頻率響應的變化（非線性幅度壓縮）

Change of the frequency response (nonlinear amplitude **compression**)

- **使用靜態噪聲刺激的輸入和輸出之間的非相干性**

Non-coherence between input and output using stationary noise stimulus

- 系統建模的非線性殘差（對於任何音頻刺激）

Nonlinear **residuum** of system modeling (for any audio stimulus)

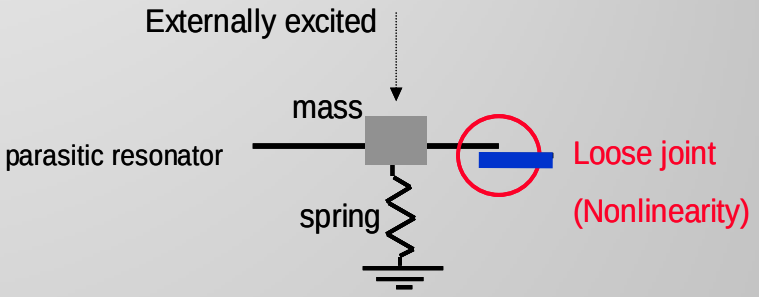
不規則失真Irregular Distortion

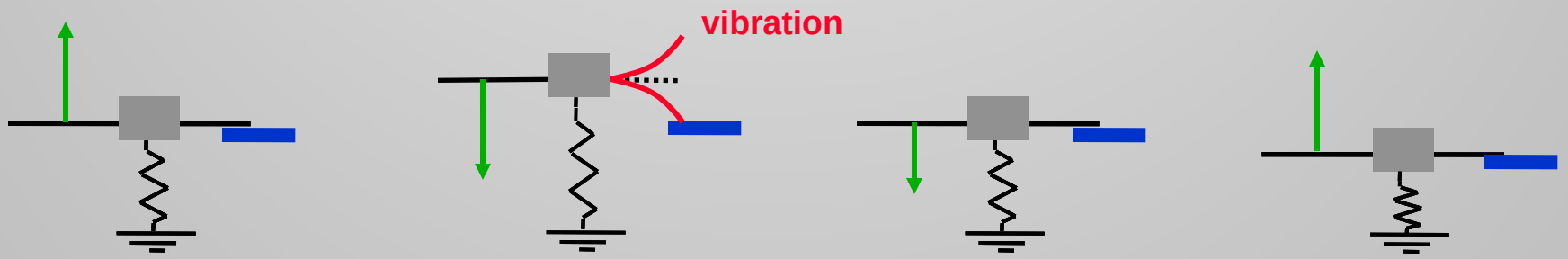
loose joint in a defective transducer generates a buzzing sound

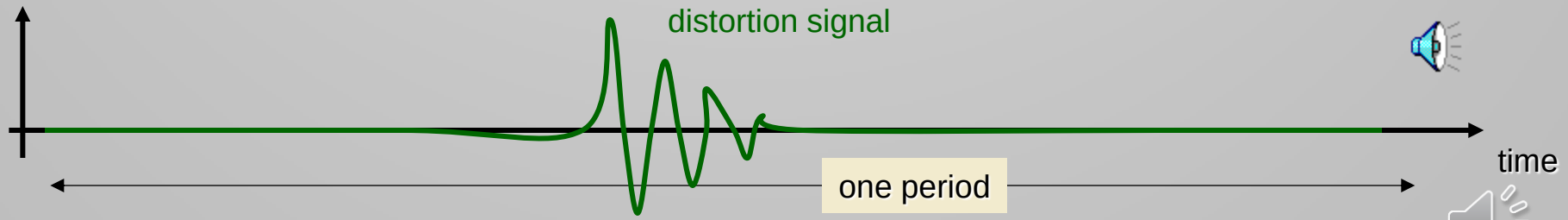
大多數缺陷表現為非線性振盪器

Most defects behave as a **nonlinear oscillator**

- 在臨界幅度以上活躍active above a critical amplitude
- 新的振動模式new mode of vibration
- 由激發提供動力和同步powered and synchronized by stimulus
- 恆定輸出功率constant output power



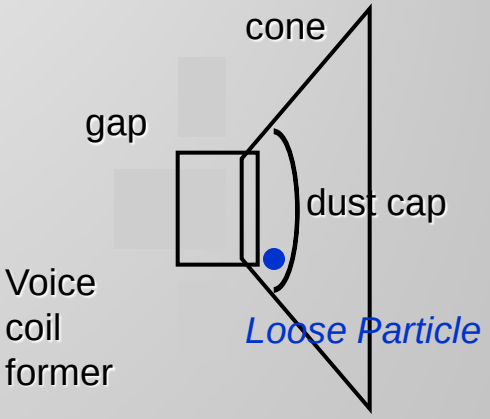


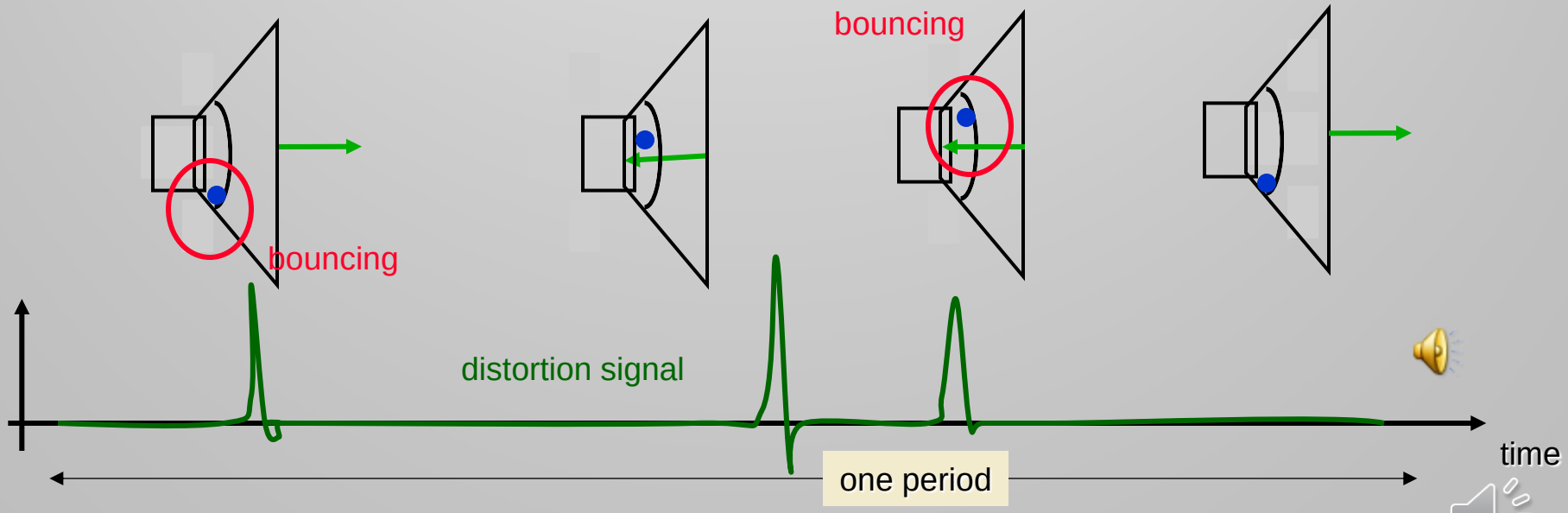


2nd Example: 不規則失真Irregular Distortion

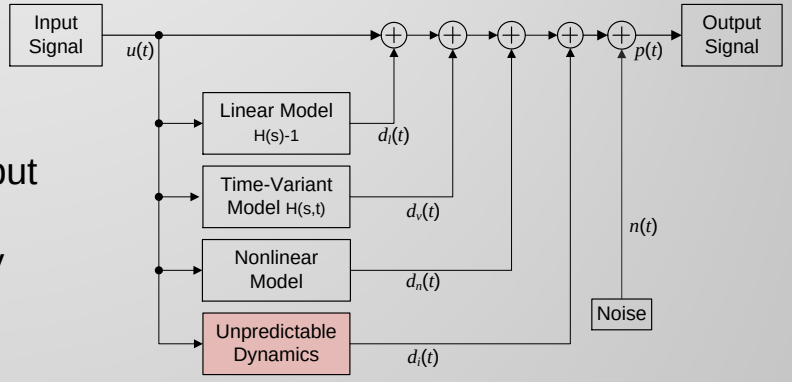
generated by a loose particles in a defective transducer

- 過程中完全隨機completely random process
- 脈衝失真波形impulsive distortion waveform
- 粒子通過錐體位移加速particles are accelerated by cone displacement
- 與激發不同步not synchronized with stimulus
- 恆定輸出功率constant output power





不規則失真（異音）
Irregular Distortion (Abnormal Sound)



特性Properties:

- 脈衝（低能量但高峰值）Impulsive (low energy but high peak values)
- 產生新的高頻成分 Generate new high-frequency components
- 隨機屬性 Random properties
- 難以建模和預測 Difficult to model and to predict
- 隨時間變化（通常變得更糟）Time varying (usually getting worse)

原因Causes:

- 設計中的缺陷Imperfections in the design (e.g. modulated port noise due to high air velocity)
- 製造中的問題Problems in the manufacturing (e.g. glue problem)
- 最終應用中過載導致的缺陷Defect caused by an overload in final application
- 設備的橡膠耐久性不足Insufficient robustness, endurance of the device

投票Poll:

不規則振動產生的異音如何處理？

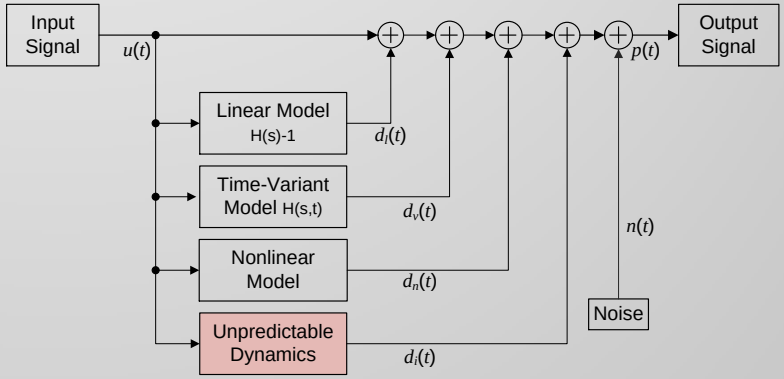
How do you cope with abnormal sound generated by irregular vibration ?

A. 我不在乎 I don’t care
B. 小心聆聽 Careful listening
C. 總諧波失真測量 (THD) Total harmonic distortion measurement (THD)
D. 高次諧波失真（高頻能量）Higher-order harmonic distortion (energy at high frequencies)
E. 時域分析（脈衝失真、時頻分析）Time-domain analysis (impulsive distortion, Time-frequency analysis)
F. 其他技術 Residuum, other techniques

評估不規則失真
Assessing Irregular Distortion

測量技術Measurement Techniques:

- 建模困難 - 參數測量不適用Modeling difficult - parameter measurement not applicable
- 利用獨特的症狀（衝動）Exploting unique symptoms (impulsivity)



Characteristics determined by output based measurements:

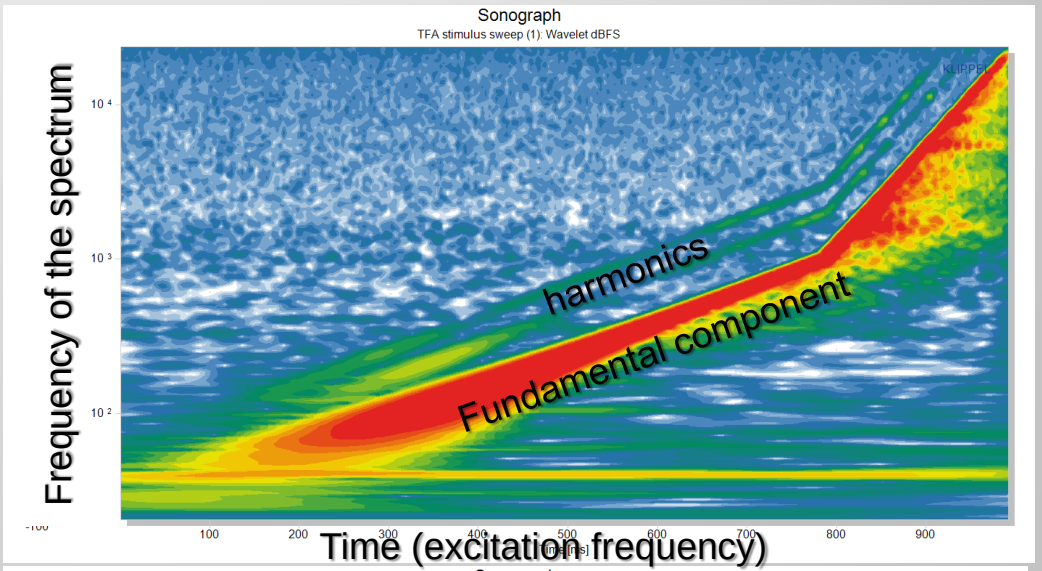
- Impulsive distortion measured in the time domain (IEC 60268-21)
- Higher-order harmonic distortion (IEC 60268-21)
- Nonlinear residuum of system modeling (any audio stimulus)
- New characteristics calculated from the sonagram

音圈摩擦的症狀
Symptom of Coil Rubbing

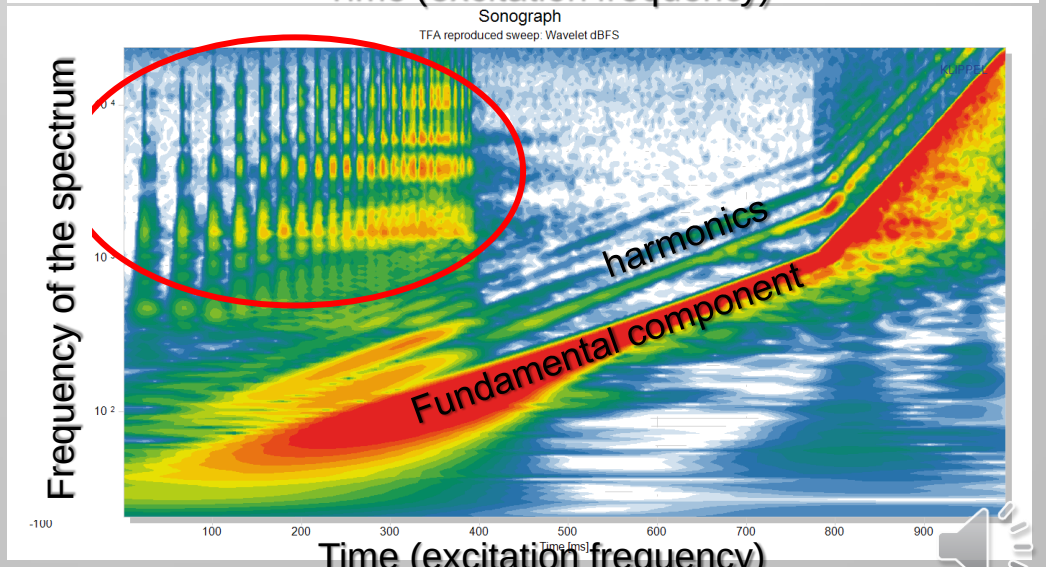
Stimulus:
Sinusoidal chirp with variable sweep sweed (length 1s)

reproduced sweep at 1 V

Analysis:
Time-Frquency Analysis (Wavelet)

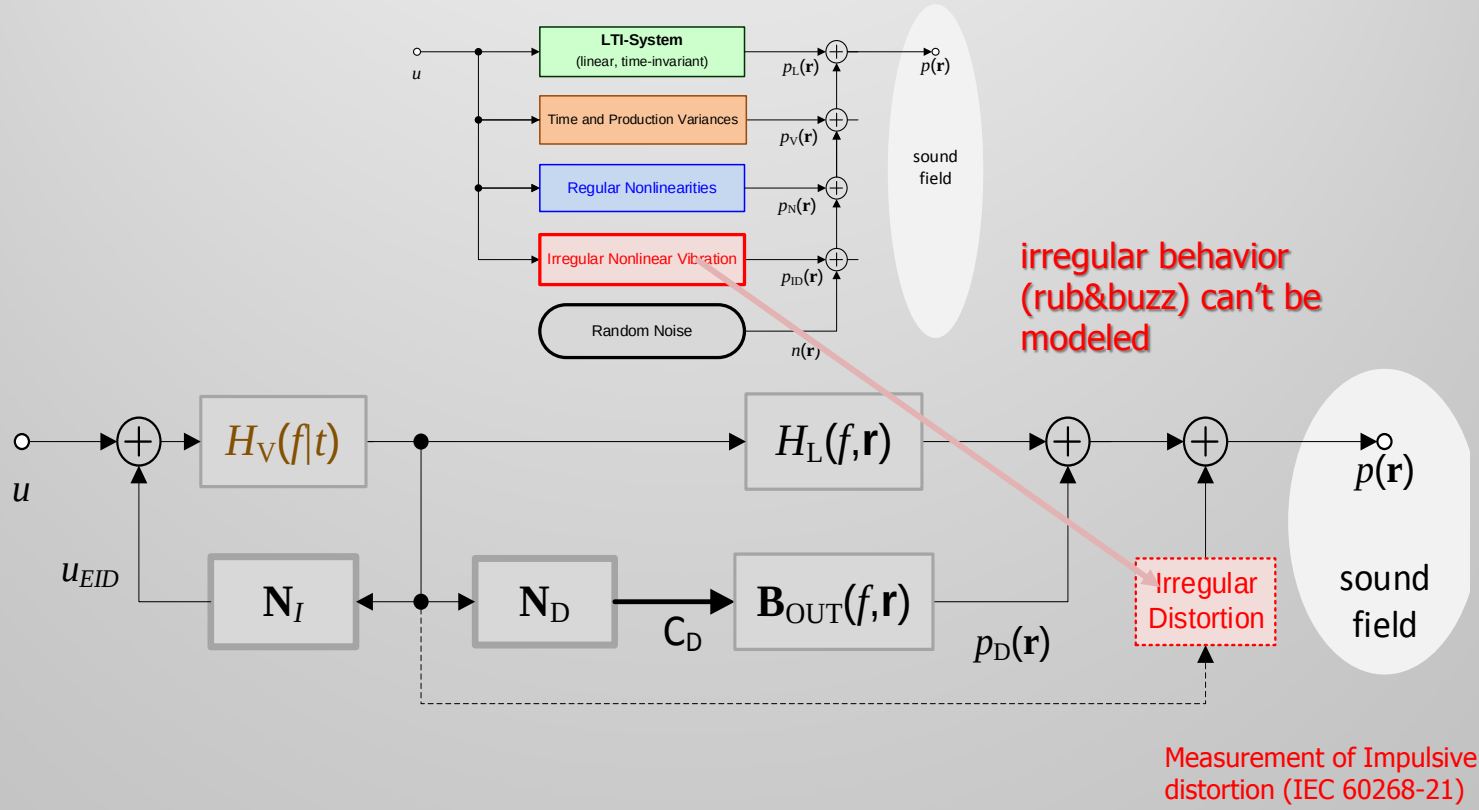


reproduced sweep at 3 V



Impulsive distortion generated frequencies below 100 Hz

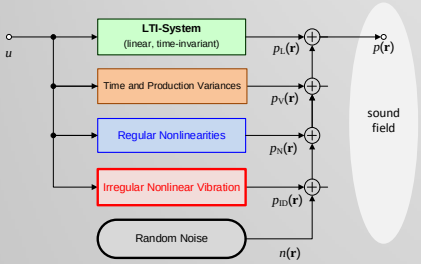
物理模型 Physical Model
for Output-Based Measurements



結論 Conclusions:

- 測量顯示不規則振動的獨特症狀的脈衝失真 Measure the impulsive distortion which reveals unique symptoms of irrregular vibrations
- 執行近場測量以獲得最佳信噪比 Perform a near field measurement to have the best signal-to-noise ratio!

基於輸出的測量 Output-Based Measurements
based on physical modeling



Neglecting distributed nonlinearities
(e.g. nonlinear break-up modes)

Sound Power
$H_{\Pi}(f,r)$ response
(IEC 60268-21)

Room Transfer Function
$H_{room}(f, r)$ (IEC 60268-23
in progress)

Amplitude Compression
C(f) (IEC 60268-21)

$H_{\Pi}(f)$ → Π → $H_{room}(f,\mathbf{r})$ → $p_{room}(\mathbf{r})$

$H_V(f\,|t)$

$H_L(f,\mathbf{r})$ → $p_{dir}(\mathbf{r})$

u

u_{EID}

$\mathbf{N}_I$

Spatial transfer
function $H_L(f,r)$
(IEC 60268-21)

Irregular
Distortion

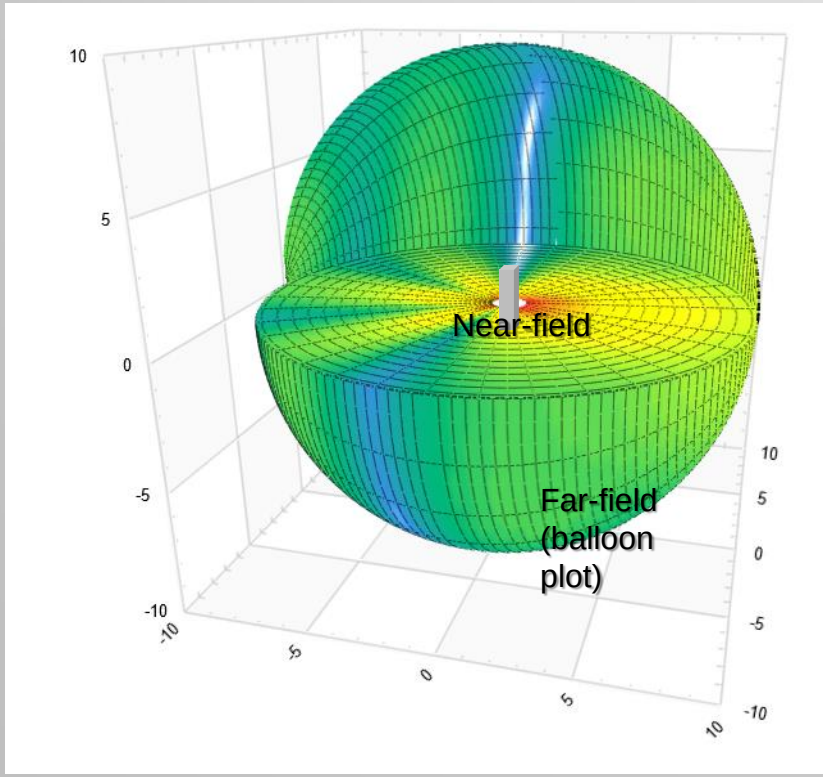
$p(\mathbf{r})$

sound
field

Equivalent input distortion
for multi-tone stimulus (IEC
60268-21)

impulsive distortion
measurement with chirp
stimulus (IEC 60268-21)

小信號測量的結果
Consequences for Small Signal Measurement

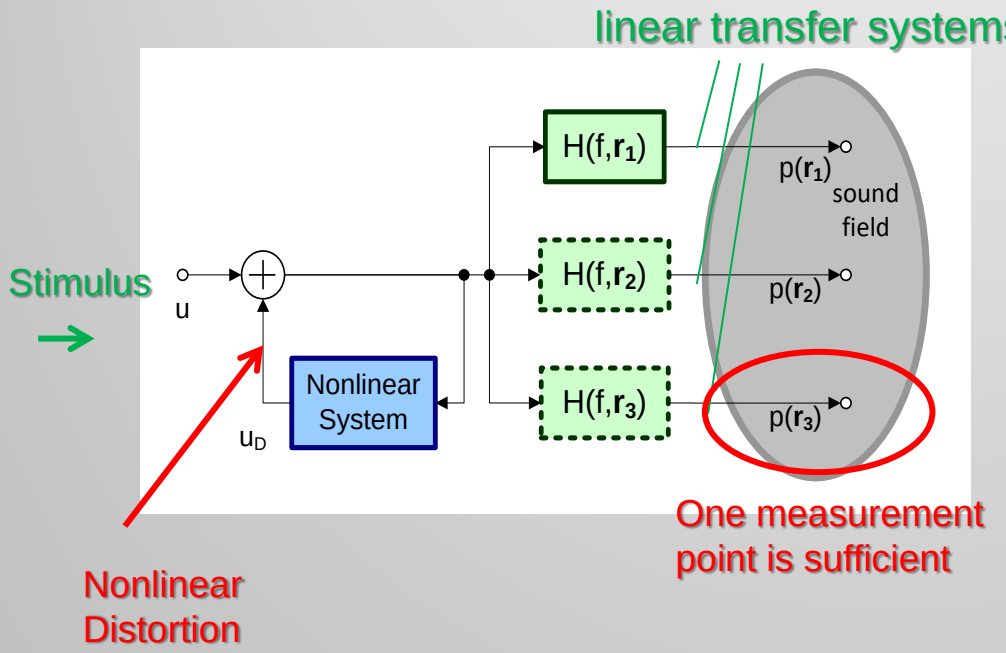


全息測量Holographic Measurement

- 基於近場掃描擬合的球面波模型 Based on spherical wave model fitted by near field scanning
- 波擴展係數 C(f) 以所需的精度描述直接音 Coefficients **C**(f) of wave expansion describe the direct sound with required accuracy
- 給出近場和遠場中任意點 r 的空間傳遞函數 HL(f,r) gives spacial transfer function $H_L(f,r)$ at any point r in near and far field
- 給出預測房間相互作用所需的聲功率傳遞函數 HΠ(f,r)Gives sound power transfer function $H_\Pi(f,r)$ required for predicting room interaction
- 不需要無響室 no anechoic room required
- 快速測量 Fast measurements
- 對於 3D 聲音應用很重要 Important for 3D sound application

See webinar Klippel live

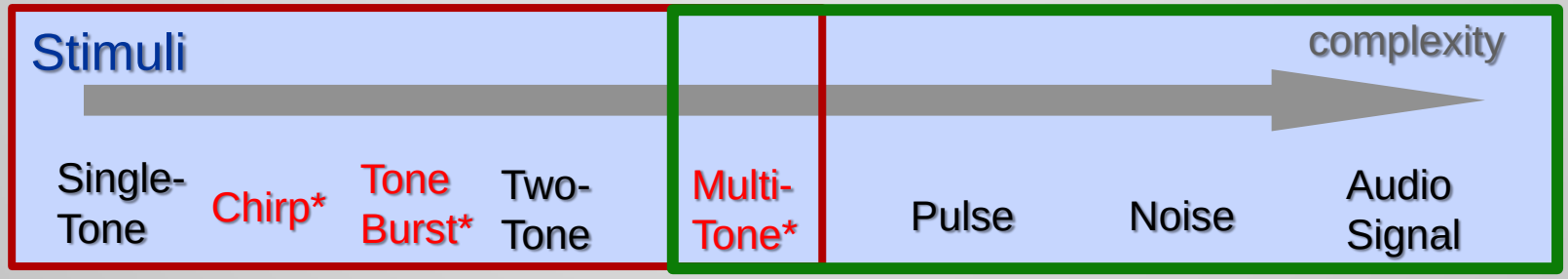
大信號測量的結果
Consequences for Large Signal Measurements



- 主要非線性的失真被添加到輸入中 Distortion of dominant nonlinearities are added to the input !
- 線性傳遞函數 H(f,r) 為非線性失真提供後處理Linear transfer function H(f,r) provides a post-shaping to the nonlinear distortion
- 方向性對於評估非線性和不規則失真不太重要 The directivity is less important for evaluating nonlinear and irregular distortion
- 建議在近場的某一點進行測量The measurement at one point in the near field is recommend!

失真測量的最佳激發
Optimum Stimulus for Distortion Measurements

* New test stimuli defined in IEC 60268-21



簡化非線性失真與其他信號分量的分離
Simplifies the separation of the nonlinear distortion from other signal components

簡化結果的解釋（基音的諧波）
Simplifies the interpretation of the results (harmonics of a fundamental tone)

確保被測設備的充分（持續）激勵（例如幅度譜、幅度分佈）Ensure sufficient (persistent) excitation of the device under test (e.g. amplitude spectrum, amplitude distribution)

產生各種非線性失真（諧波、互調、直流分量）
Generates all kinds of nonlinear distortion (harmonics, intermodulation, DC components)

基於不良的判斷
Diagnostic based on Symptoms
found in the aoustical output signal

1. 基本分量的幅度壓縮 Amplitude Compression of the Fundamental Component
   - 長期（音圈發熱）Long term (voice coil heating)
   - 短期（非線性）Short term (nonlinearities)
2. 聲壓輸出中的諧波失真（單音刺激）Harmonic Distortion in Sound Pressure Output (single-tone stimulus)
   - 總諧波失真 Total harmonic distortion
   - N次諧波失真分量 Nth-order harmonic distortion component
   - 定義的 THD 限制的最大 SPL Maximum SPL for defined THD limit
   - 等效諧波輸入失真（新） Equivalent harmonic input distortion (New)
   - 高階失真（新） Higher-order Distortion (New)
3. 互調失真（雙音刺激） Intermodulation Distortion (two-tone stimulus)
   - 二階和三階互調分量 2nd and 3rd-order intermodulation component
   - 調幅失真 Amplitude modulation distortion
4. 多頻失真（新）Multi-tone Distortion (New)
   - 典型製造材料產生的失真Distortion generated by typical program material
5. 脈衝失真（新）Impulsive Distortion (new)
   - 脈衝失真等級Impulsive distortion level
   - 最大脈衝失真比 Maximum impulsive distortion ratio
   - 脈衝失真與位移的波峰因數 Crest factor of impulsive distortion versus displacement
6. 互相關技術（噪聲） Cross-correlation technique (noise)
   - 不相關的 Incoherence
7. 通過建模進行失真分離（音樂） Distortion Separation by Modeling (music)
   - 非線性殘差 Nonlinear residuum

Defined in IEC 60268-21

討論 Discussion

總結 Summary

- 不同類型的信號失真需要不同的測量技術

The different kinds of signal distortion require different measurement techniques

- 測量技術基於物理建模

Measurement techniques are based on physical modeling

- 模型的參數應該獨立於輸入信號

Parameters of the model should be independent of the input signal

- 徵兆產生信號分析

Symptoms are generated signal analysis

- 症狀取決於輸入信號和傳感器的內部狀態（例如位移、線圈溫度）

Symptoms depend on the input signal and the internal state of the transducer (e.g. displacement, coil temperature)

- IEC 標準 60268-21 提供了新的激發和新的測量技術

IEC standard 60268-21 provides new stimuli (multi-tone, chirp, burst) and new measurement techniques

開放問題 Open Questions

症狀反映了信號失真的原因！
Symptoms reveal the causes of signal distortions !

讓我們詳細討論最重要的症狀。
Let's discuss the most important symptoms in detail.

The next 7th KLIPPEL live webinar entitled
Amplitude Compression – less output at higher amplitudes
will address the following points

- 是什麼導致幅度壓縮？What causes amplitude compression?
- 換能器是否還提供更高幅度的更多輸出（"擴展"）？ Does the transducer also provide more output at higher amplitudes ("expansion") ?
- 如何根據 IEC 60268-21 測量基波響應的變化 How to measure the variation of fundamental response according IEC 60268-21
- 如何解釋結果How to interpret the results
- 如何使用這些信息來改進硬件和 DSP 軟件 How to use this information for improving hardware and DSP software

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 (Next session)
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