

Acoustical Distortion Measurements

Parts 6-10 of the KLIPPEL- live webinar

**Acoustical Measurement of Sound System Equipment
according IEC 60268-21**

presented by
Wolfgang Klippel



Sessions of KLIPPEL- live Webinar

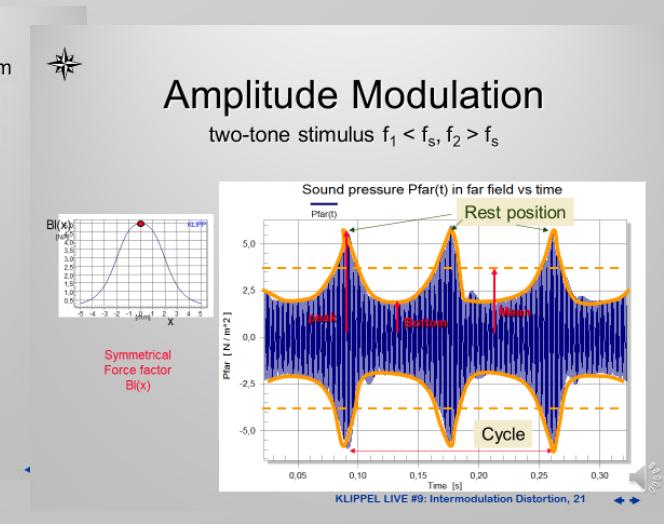
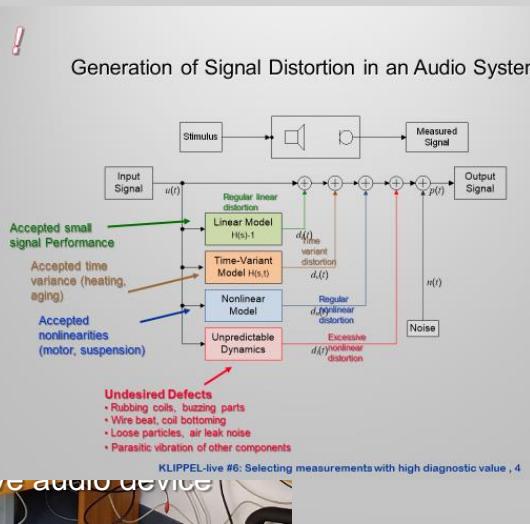
根據 IEC 60268-21 對音響系統設備進行聲學測量

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

Previous Sessions

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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
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
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10th KLIPPEL live: **Impulsive distortion - rub&buzz, abnormal behavior, defects**

今日主題 Topics today:

- 音頻設備不規則特性概述

Overview on irregular properties of audio devices

- 根據 IEC 標準 20268-21 進行測量

Measurements according to IEC Standard 20268-21

- 時域脈衝失真測量

Measurement of impulsive distortion in the time domain

- 結合物理測量和聽力

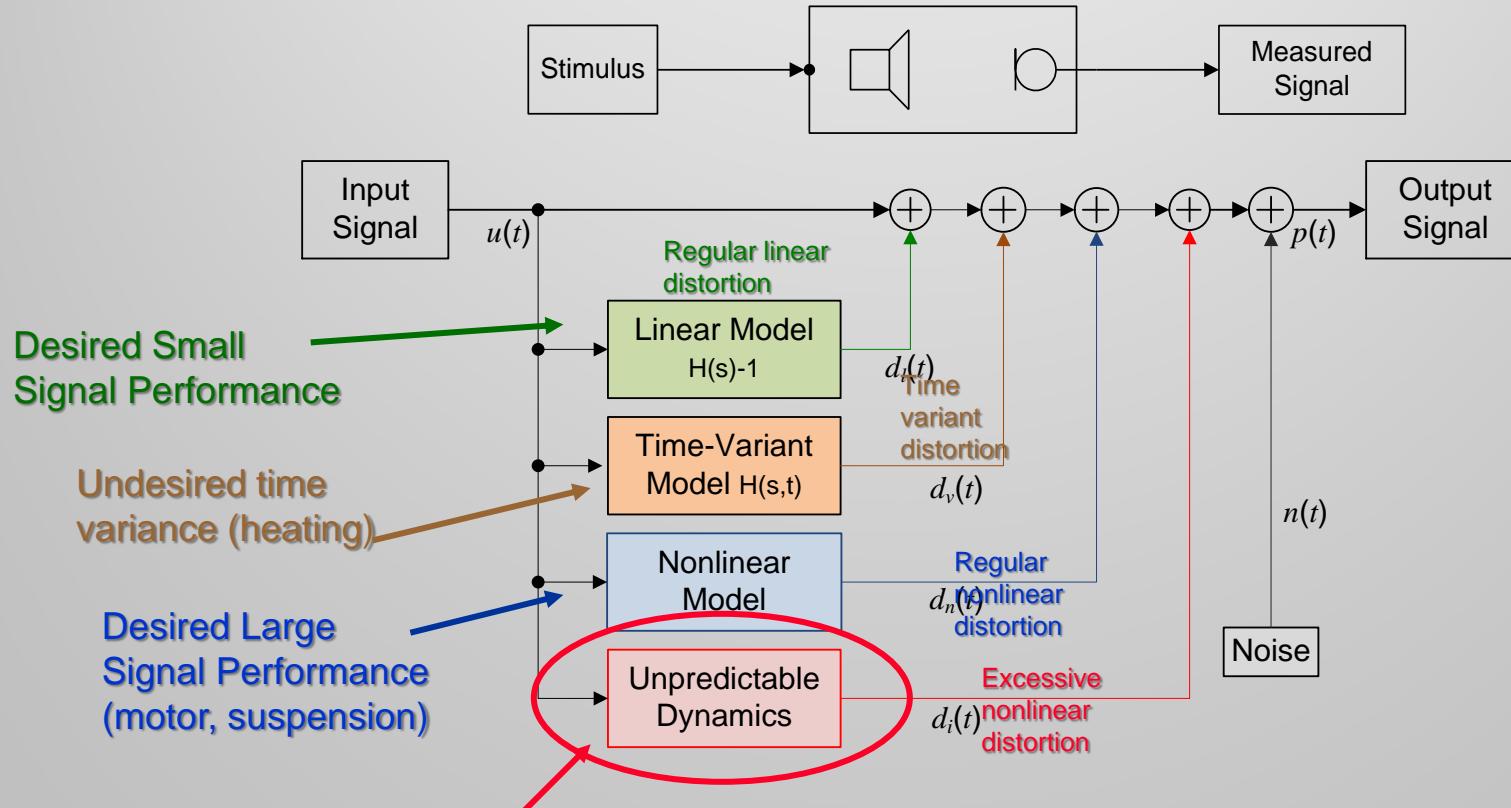
Combining physical measurements and listening





需要和不需要的組件？

Desired and Undesired Components ? 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

投票 Poll:

您如何發現和評估異音和其他不規則失真

How do you find and evaluate the rub&buzz and other irregular distortion ?

- A. 透過聽音樂 By listening with music
- B. 手動掃頻+聽 Manual sweep + listening
- C. 線性調頻 + 總諧波失真 (THD) Chirp + Total harmonic distortion (THD)
- D. 線性調頻 + 高次諧波 Chirp + Higher-order harmonics
- E. 線性調頻 + 時域分析（時頻分析、脈衝失真分析） Chirp + Time domain analysis (Time-Frequency Analysis, impulsive distortion analysis)

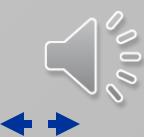


尋找關鍵激發
Searching for a Critical Stimulus
 Audibility of Voice Coil Rubbing

This Experiment investigates the influence of the stimuli and the input voltage

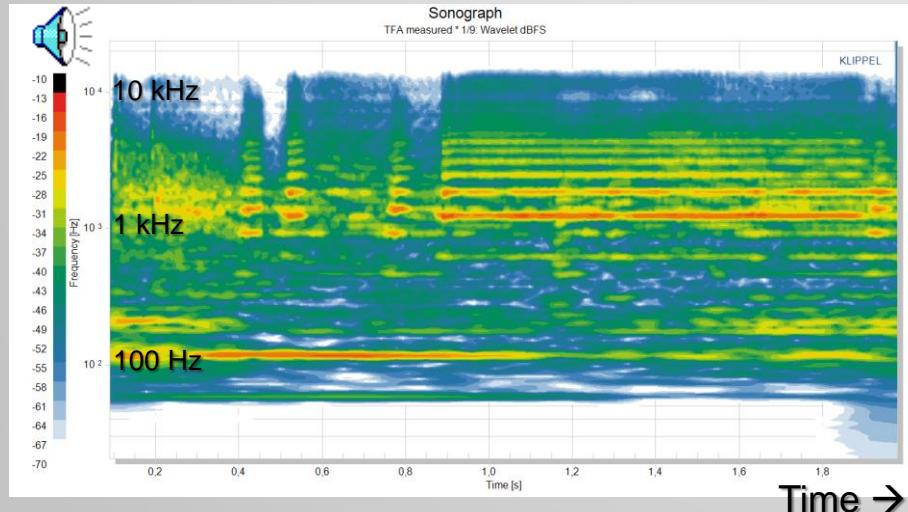
Signal	Stimulus	Output 1V	Output 2V	Output 3V
Music				
Multi-Tone 20 Hz – 20 kHz				
Multi-Tone 20 Hz – 1 kHz				 <i>clear audible</i>
Sinusoidal Sweep 1 s				

Most sensitive Stimulus

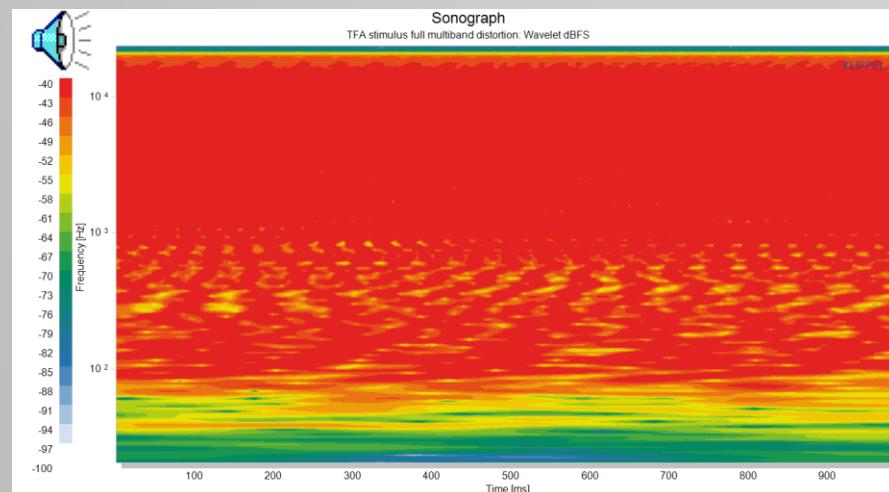


激發對異音不太重要 Stimuli less critical for Rub & Buzz

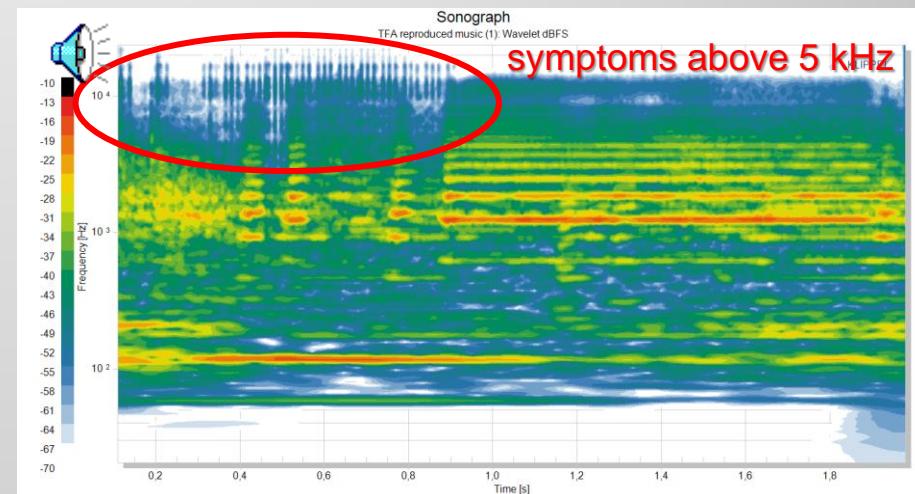
Frequency stimulus: music



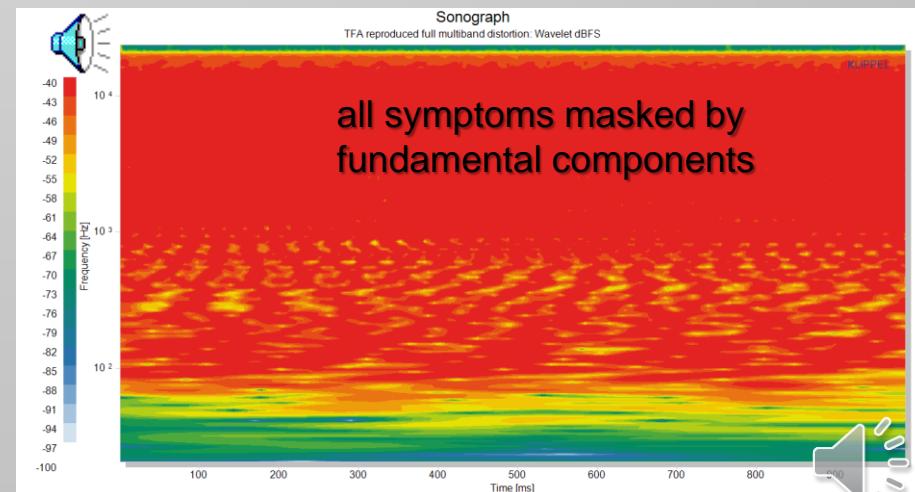
stimulus: Full Band Multi-tone complex



reproduced music at 3 V

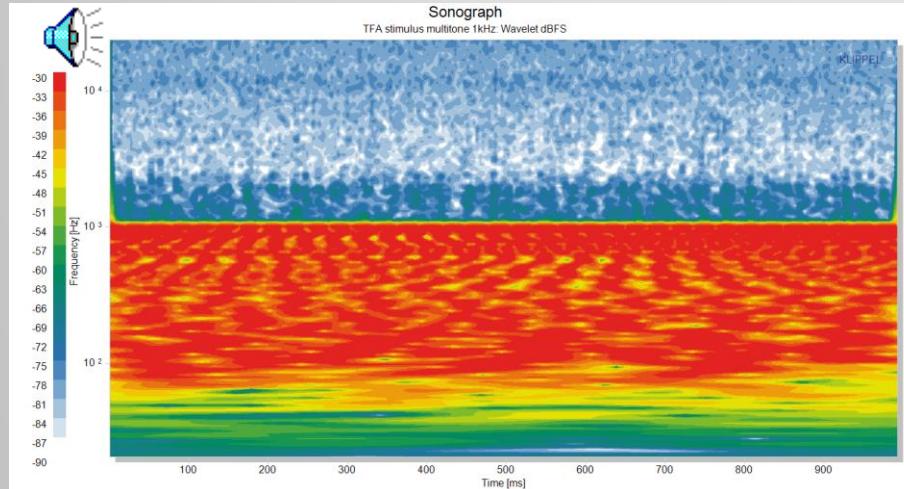


reproduced Full Band Multi-tone complex

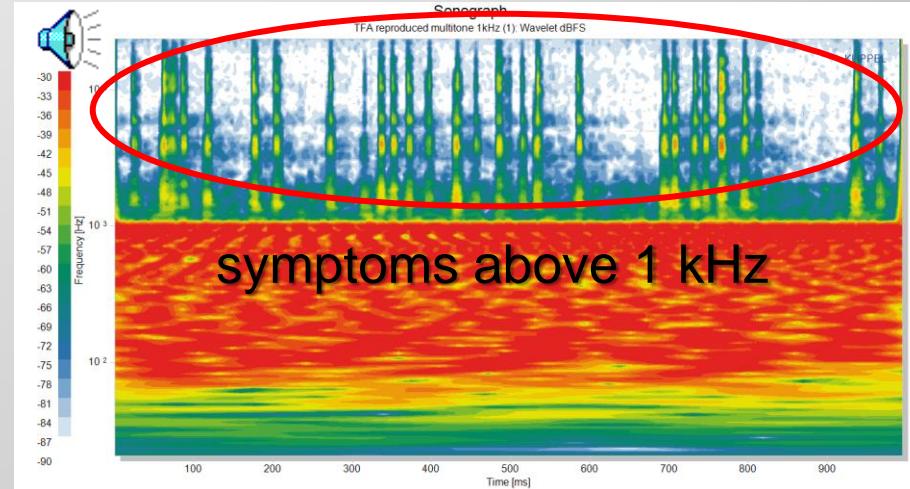


激發對異音至關重要 Stimuli critical for Rub & Buzz

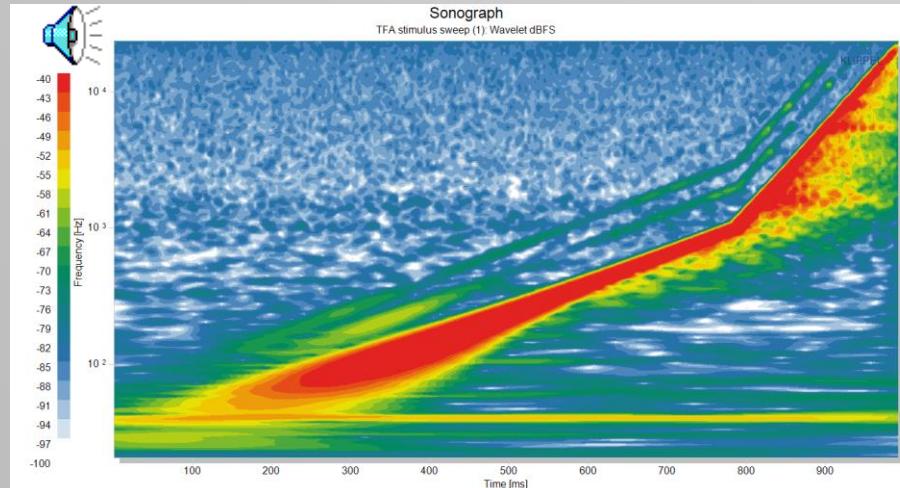
Stimulus: multi-tone distortion low pass 1 kHz



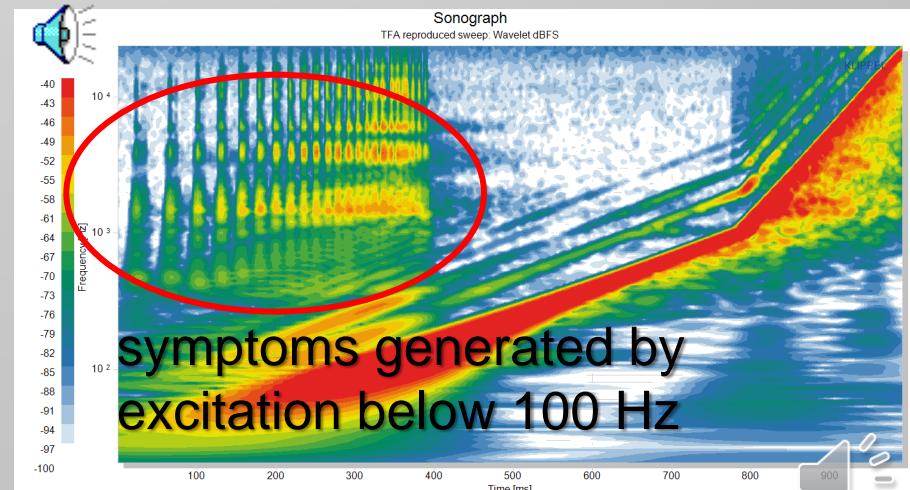
reproduced multi-tone distortion low pass 1 kHz at 3 V



Stimulus: sweep



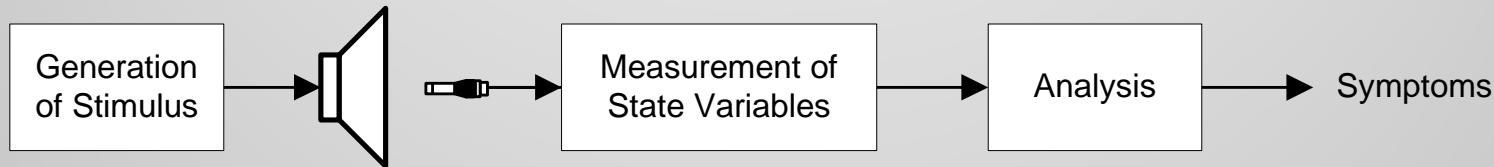
reproduced sweep at 3 V





檢測不規則揚聲器缺陷的基本要求

Basic Requirements to detect Irregular Loudspeaker Defects



- 需要高振幅（位移 x 和/或速度 v 和/或加速度 a ）→ 刺激應激發所有頻率
High amplitude is required (displacement x and/or velocity v and/or acceleration a) →
Stimulus shall excite all frequencies
- 大多數缺陷只會產生聲學症狀 → 需要靈敏的麥克風
Most defects only produce acoustical symptoms → **Sensitive microphone required**
- 缺陷產生高頻分量 → 低通濾波刺激和高通濾波麥克風信號
Defects produce high frequency components → **Low-pass filtered stimulus and high-pass filtered microphone signal**
- 缺陷類似於環境噪聲 → 麥克風位於靠近源的位置（近場測量）
Defects are similar to ambient noise → **Microphone is located close to the source (near-field measurement)**



異音、不良、不規則行為 Rub&Buzz, Defects, Irregular Behavior

症狀 Symptoms

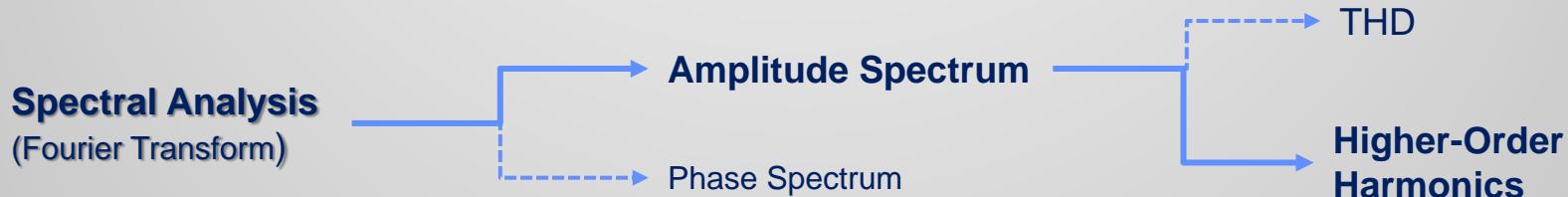
- 咔嗒聲、脈衝、音調突發、調製噪聲 Clicks, impulses, tone burst, modulated noise
- 低功率和小均方根值 Low power and small rms value
- 更高的峰值（脈衝） higher peak value (impulsive)
- 寬帶頻譜（不僅是諧波） Broad band spectrum (not only harmonics)

需要的特殊測量技術 Special measurement technique required:

- 時頻分析（幅度譜不夠） Time-frequency analysis (amplitude spectrum not sufficient)
- 精細結構的時域分析 Time domain analysis of the fine structure
- 新的失真指標（例如 IEC 60268-21 中定義的脈衝失真） New distortion metrics (e.g. Impulsive Distortion as defined in IEC 60268-21)



分析技術 Analysis Techniques for abnormal sound generated irregular behavior



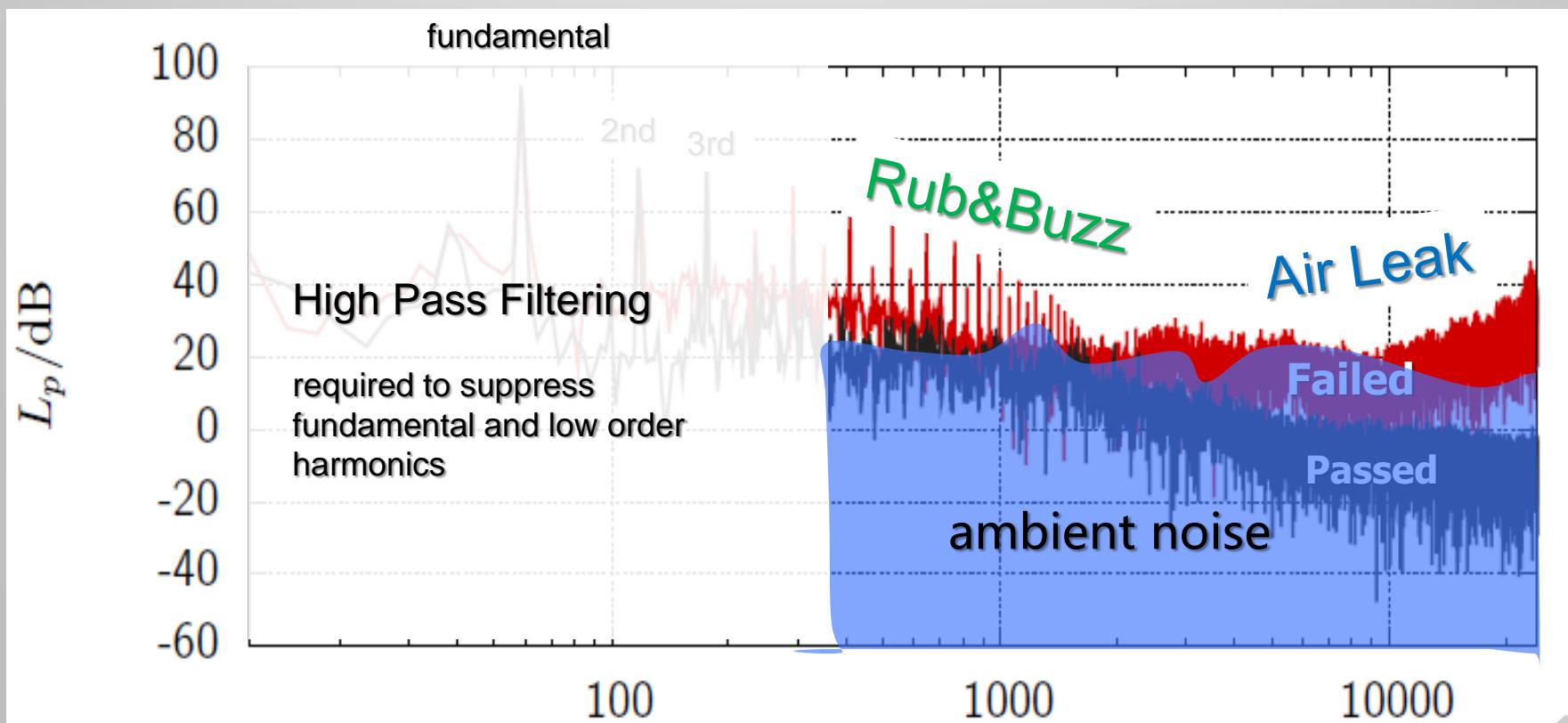
Time-Frequency Analysis
(Wavelet Transform)

Time-Domain Analysis
(Modeling, Highpass filtering)

頻域分析

Frequency Domain Analysis

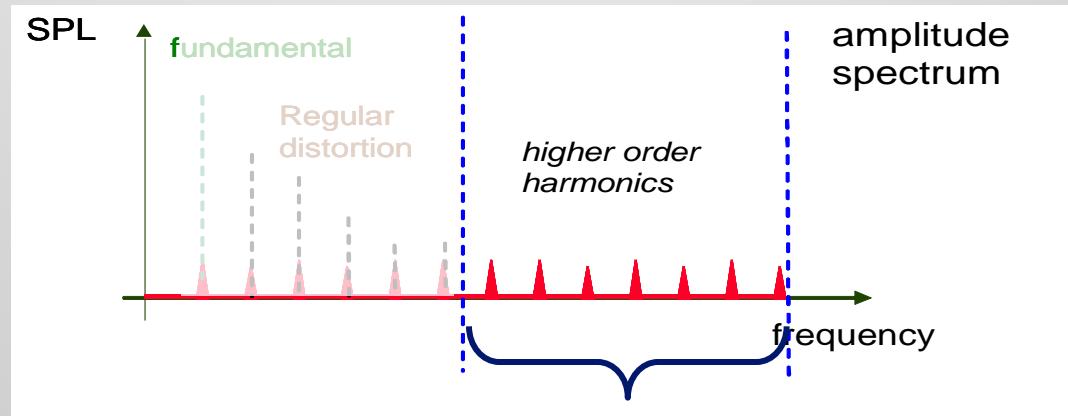
60 Hz Tone reproduced by a good and bad speaker





簡單的方法 Simple Approach

exploiting amplitude of higher-order harmonics only



Higher-order harmonic distortion
Are defined in IEC 60268-21

RMS value of
Higher-
harmonics

問題 PROBLEMS:

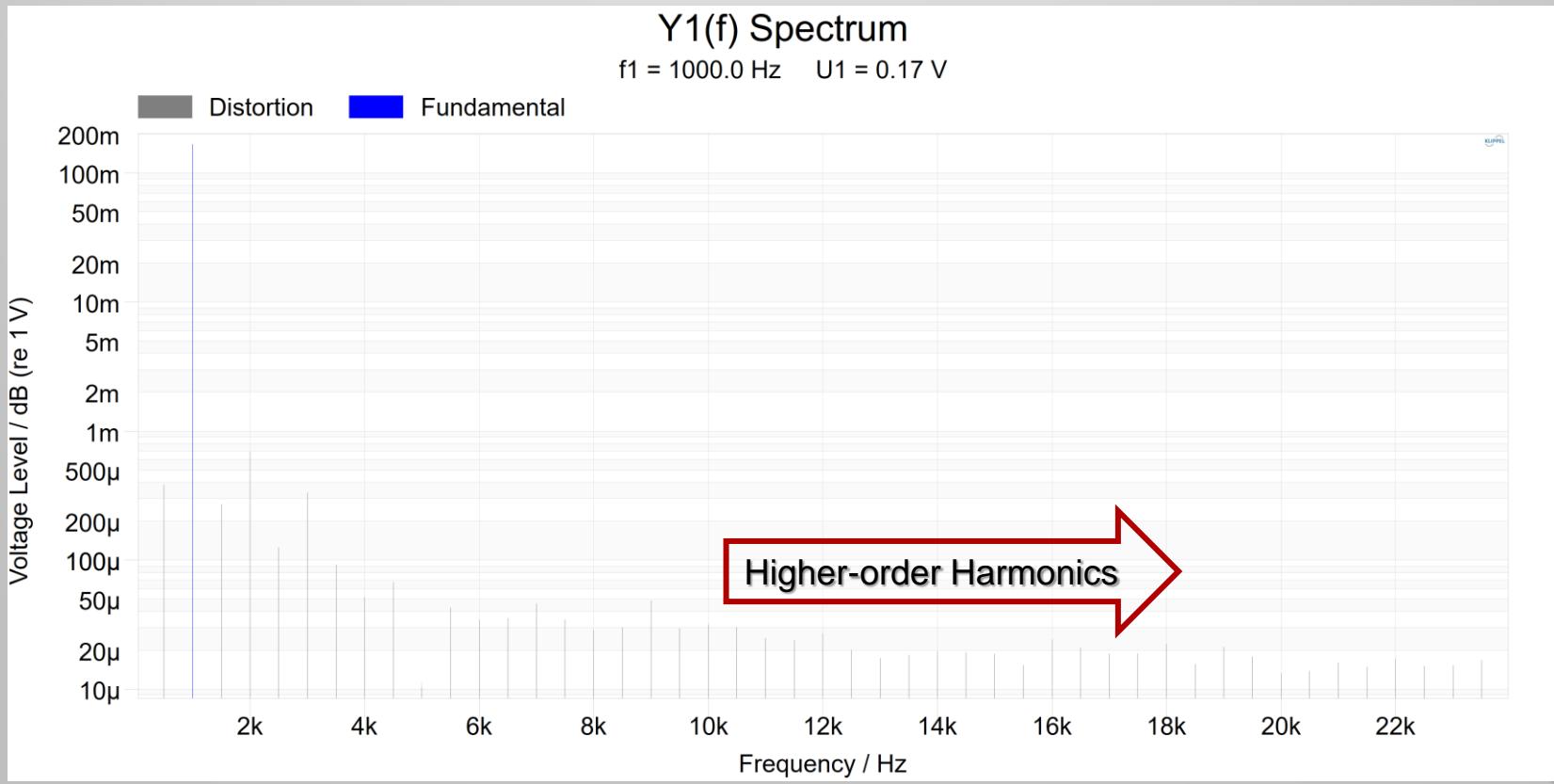
- 僅對確定性症狀敏感 Sensitive for deterministic symptoms only
- 每個諧波都接近噪音水平 each harmonic is close to the noise level
- 對鬆散顆粒和漏氣噪音不敏感 insensitive to loose particles and air leakage noise

示範

Demo: Higher-Order Distortion

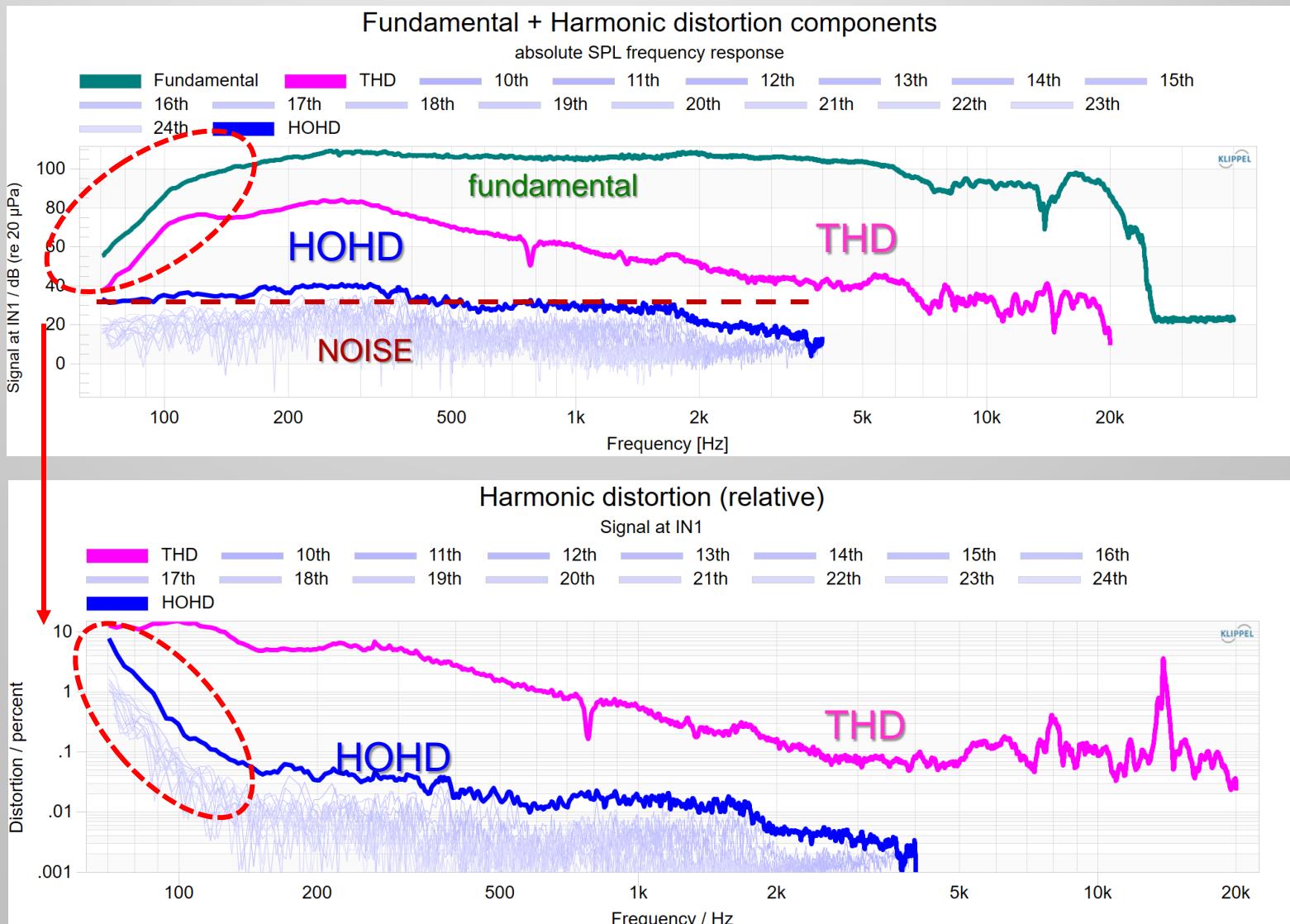
Tools: Using dedicated software modules of the KLIPPEL Analyzer

- DIS 3D Distortion
- TRF Transfer function Measurement

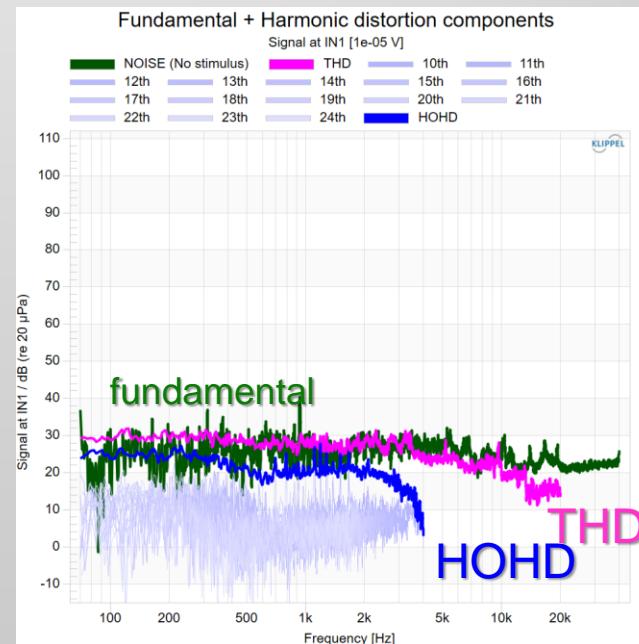
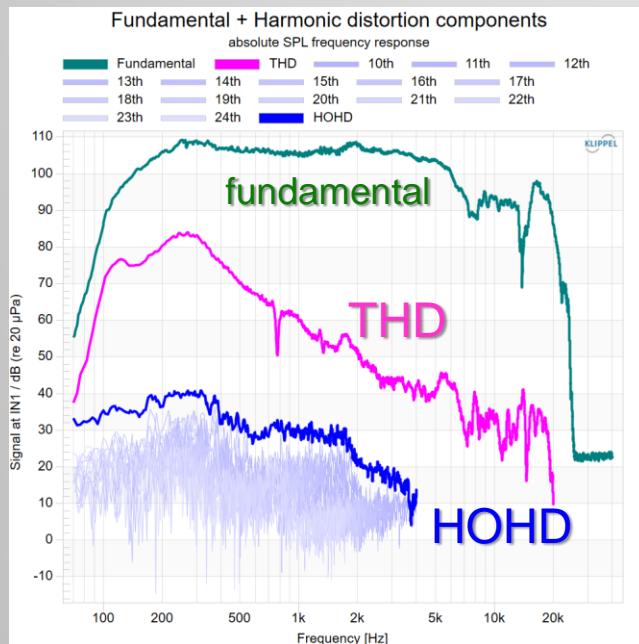


HOHD的噪音問題

Noise Problem of HOHD



處理 HOHD 中的噪音 Coping with Noise in HOHD



Distortion measurement (with stimulus)

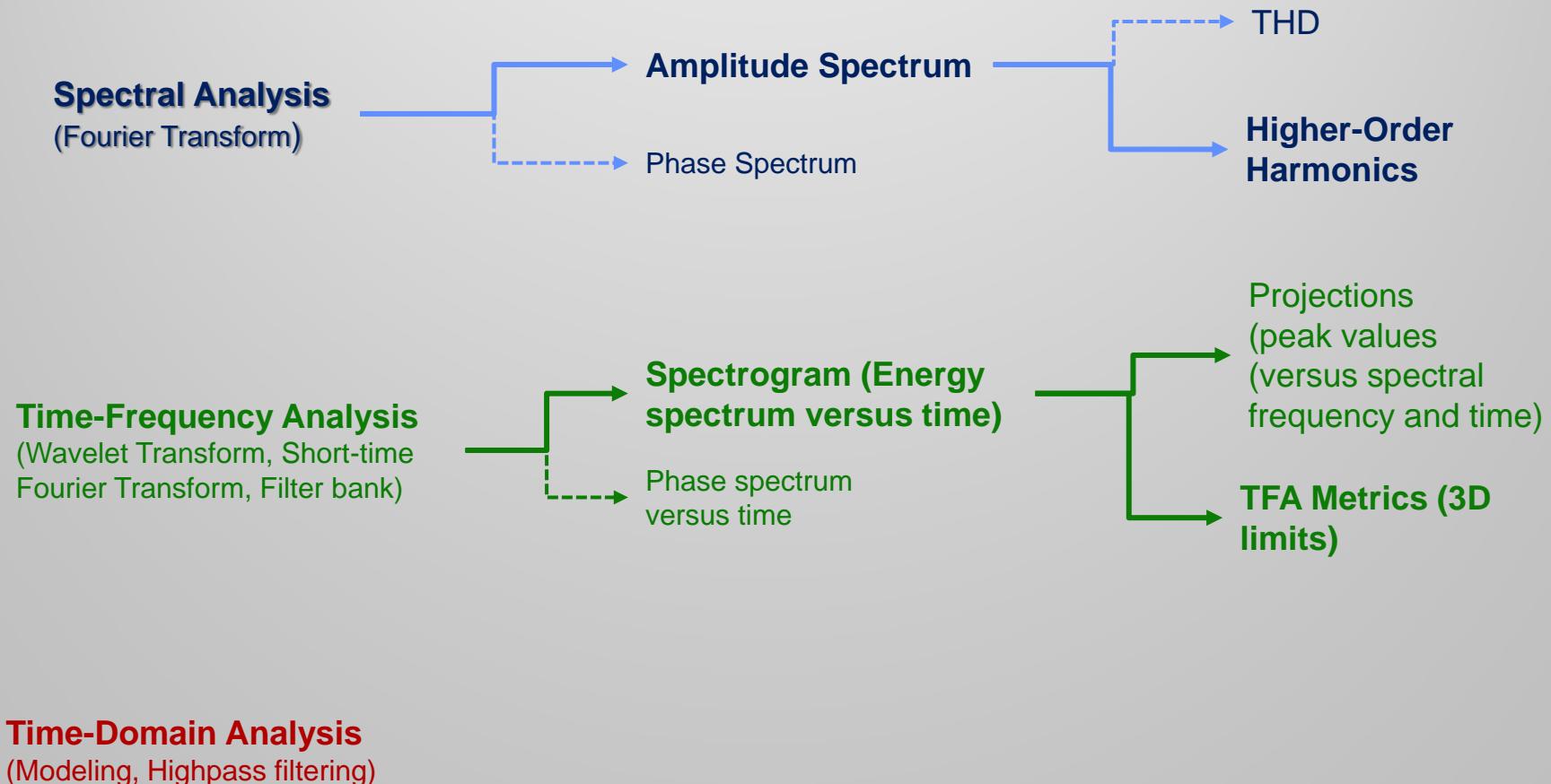
- 執行額外的噪音測量並比較絕對 HOHD 曲線
Perform additional noise measurement and compare absolute HOHD curves
- 使用第二個麥克風（遠場）進行並行環境噪音測量 → 環境噪音抗擾度
Parallel ambient noise measurement with 2nd microphone (in far field) → Ambient Noise Immunity

Noise measurement (without stimulus)

分析技術

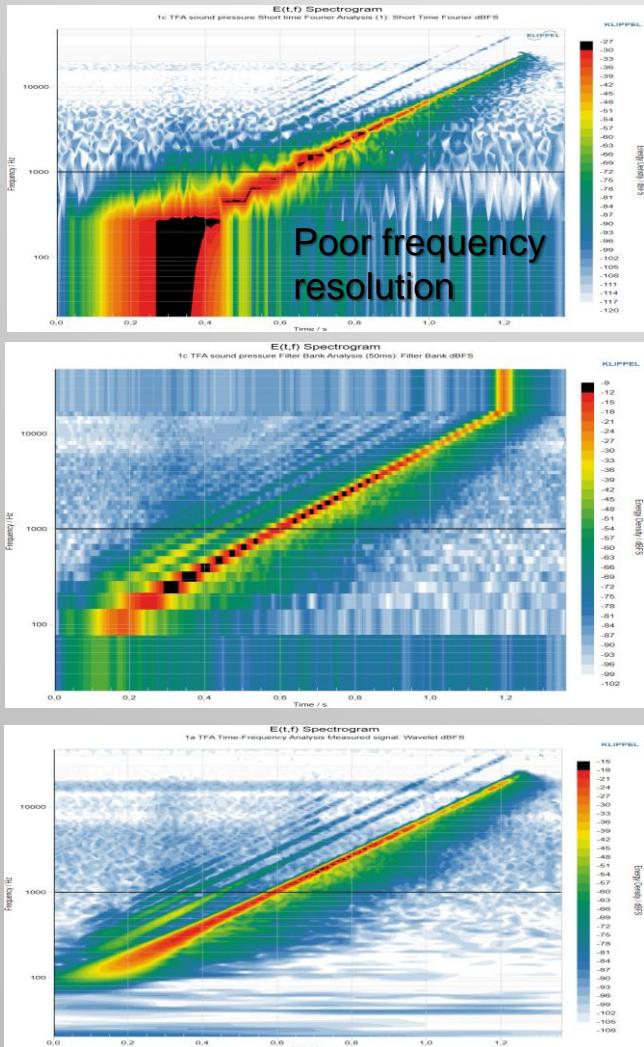
Analysis Techniques

for abnormal sound generated irregular behavior



TFA方法

TFA Methods



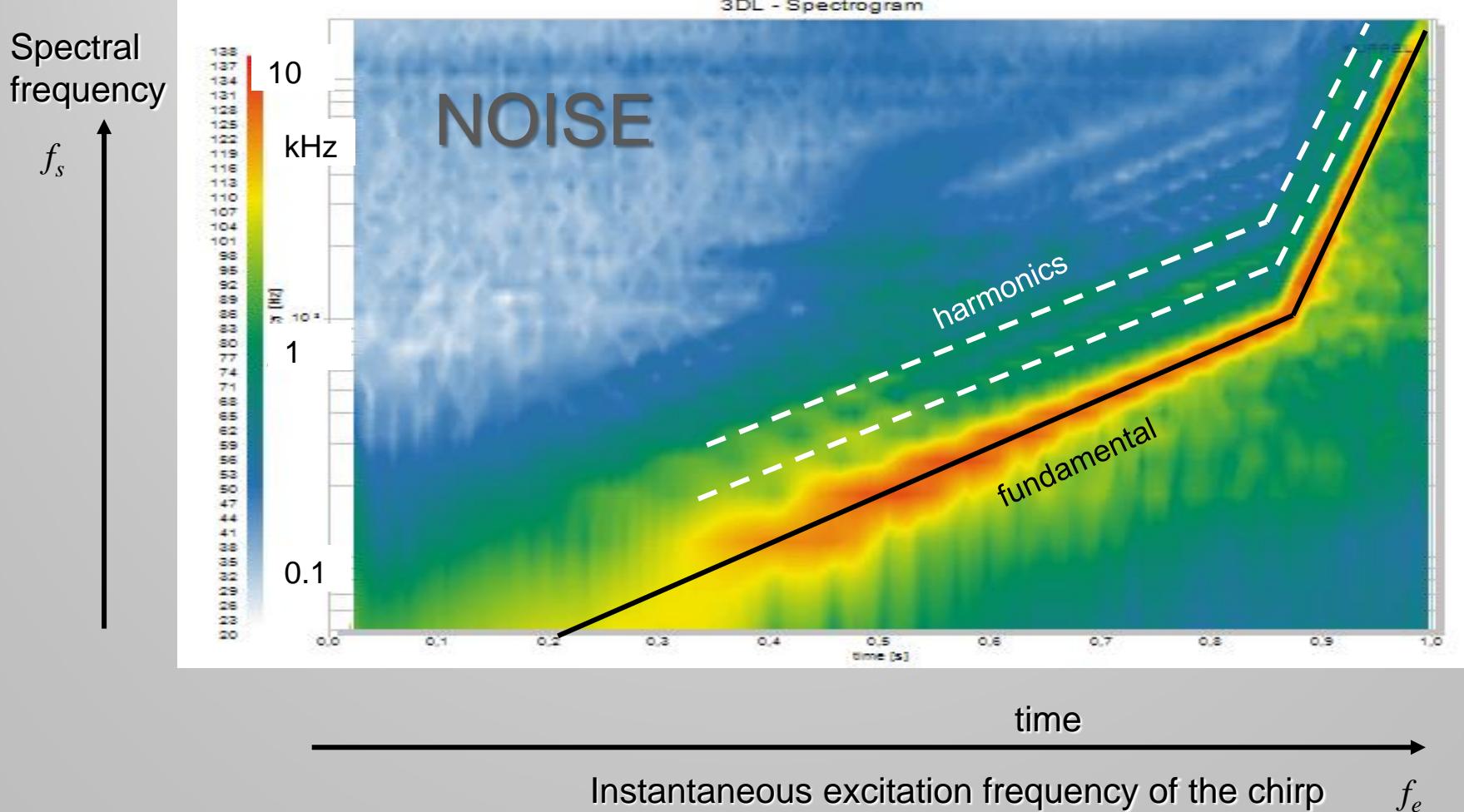
短時傅立葉變換Short-Time Fourier Transformation

- 頻率和時間分辨率之間的折衷 poor compromise between frequency and time resolution
- 通過FFT簡單實現 Simple implementation by FFT
- 濾波器組 Filter Bank
- 離散數量的濾波器 (40...120) Discrete number of filters (40...120)
- 相對帶寬 (1 / 3 倍頻程) Relative bandwidth (1/3rd octave)
- 良好的時間分辨率 Good time resolution
- 並行處理 Parallel processing

小波變換Wavelet Transformation

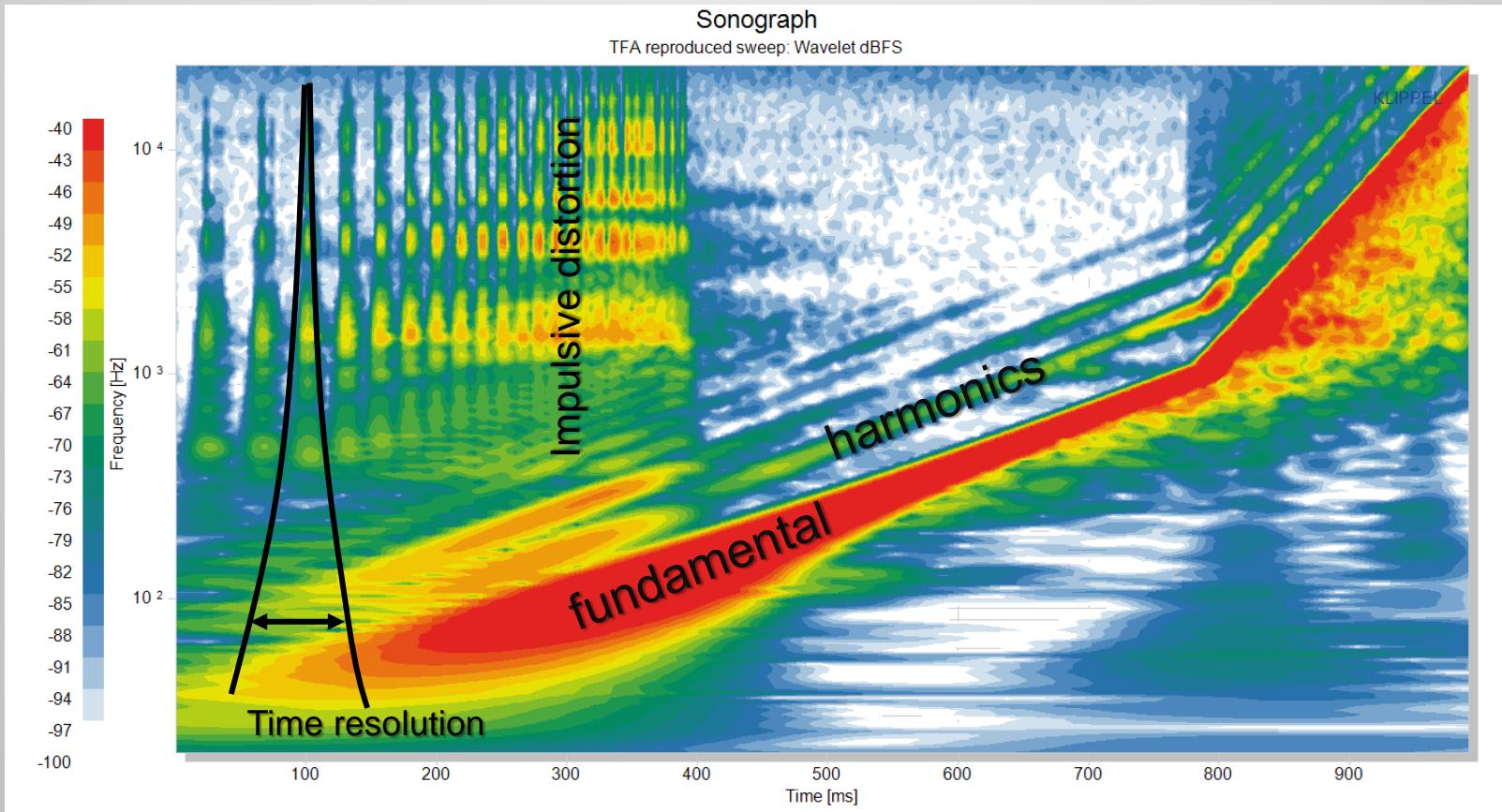
- 頻率和時間分辨率之間的良好折衷 Good compromise between frequency and time resolution
- 可用的快速算法 Fast algorithms available

頻譜圖 LREF (f_s, f_E)
Spectrogram L_{REF}(f_s, f_E)
generated by an wavelet transform



時頻分析

Time Frequency Analysis



時頻分析 (TFA) Time-Frequency Analysis (TFA)

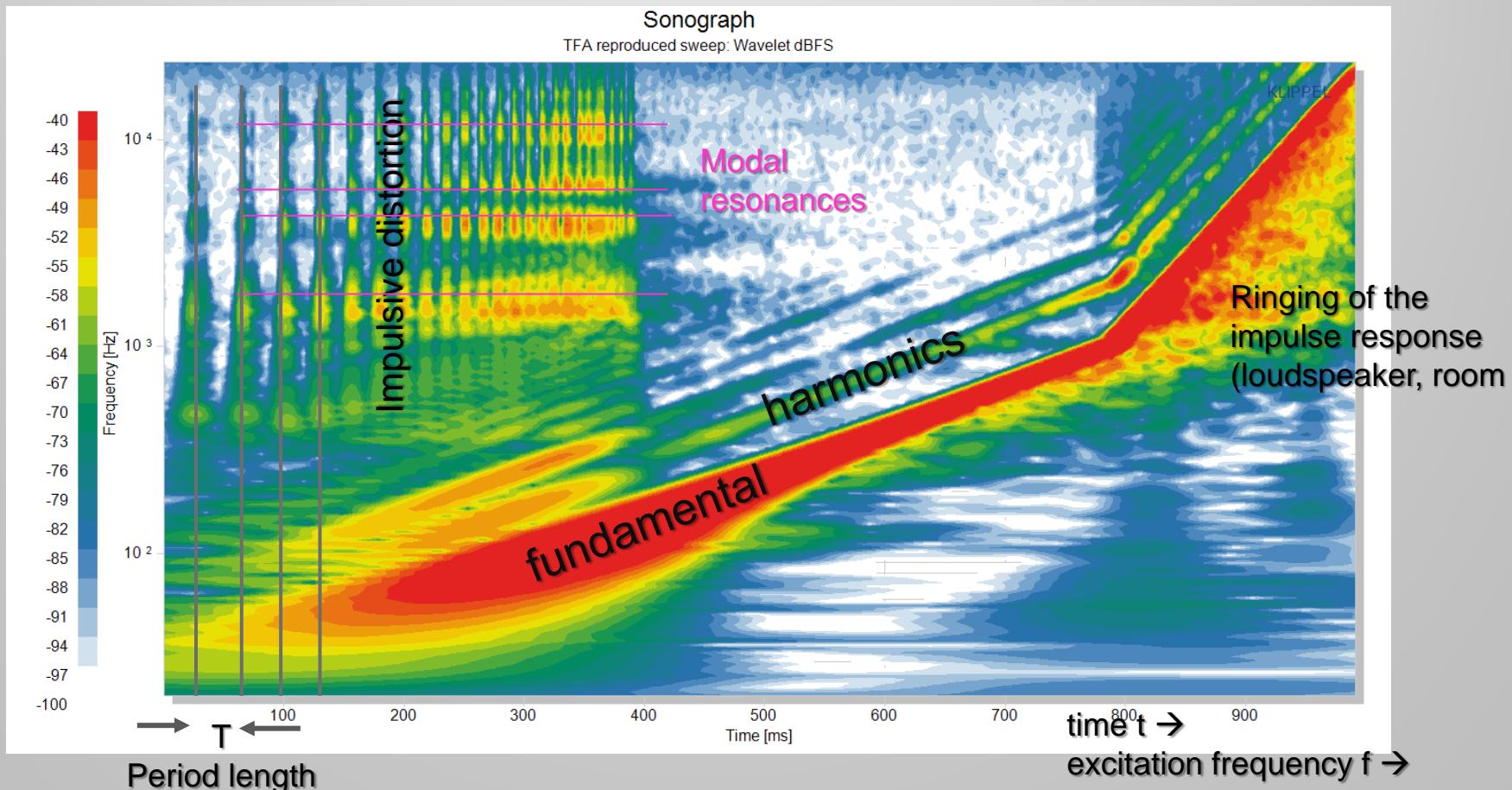
- 小波變換 Wavelet Transformation
- 頻率和時間分辨率之間的最佳折衷 Best compromise between frequency and time resolution
- 能量度量 (振幅信息) Energetic metric (amplitude information)
- 不使用相位信息 (時域中的大部分精細結構丟失) Phase information is not used (Most fine structure in the time domain is lost)



Chirp Stimulus 的 TFA 解釋

Interpretation of the TFA of Chirp Stimulus

Time-Frequency Analysis (TFA) applied to a reproduced sinusoidal stimulus (Chirp) with sweep speed profile



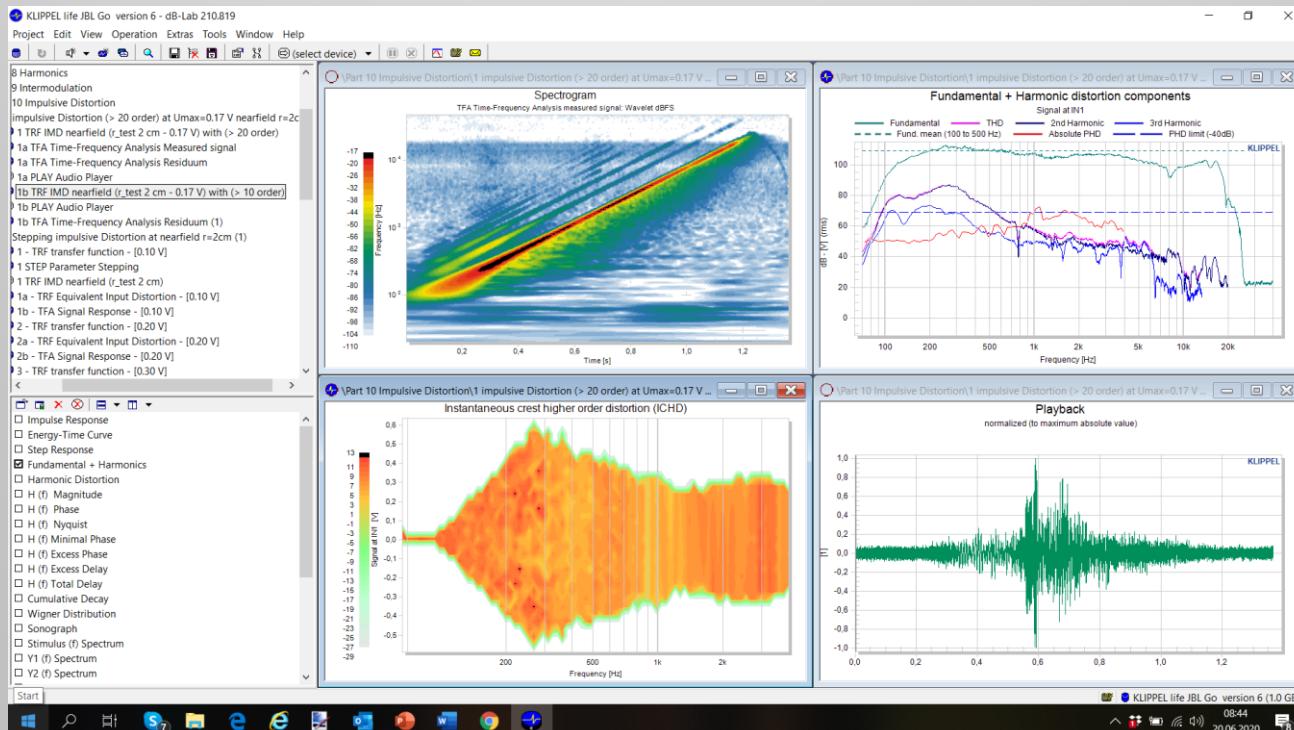
Abnormal sound occur as an impulsive fine structure within one period of the chirp
It covers a wide frequency range (not only at harmonics of the fundamental)



示範Demo: Time-Frequency Analysis

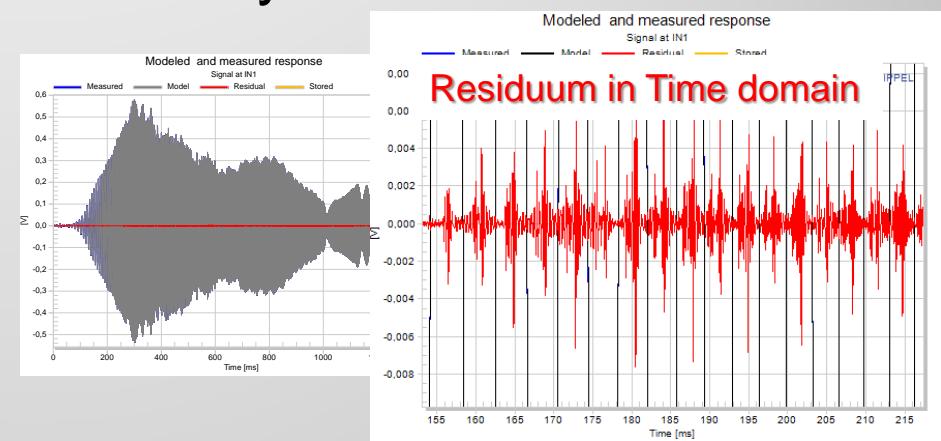
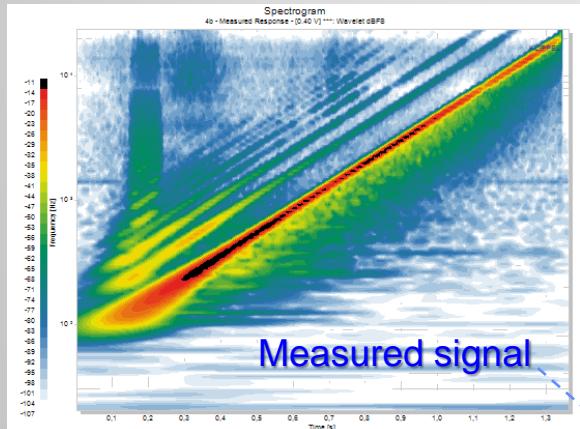
Tools: Using dedicated software modules of the KLIPPEL Analyzer

- TRF PRO (transfer function)
- TRF Stepping
- TFA (time frequency analysis)

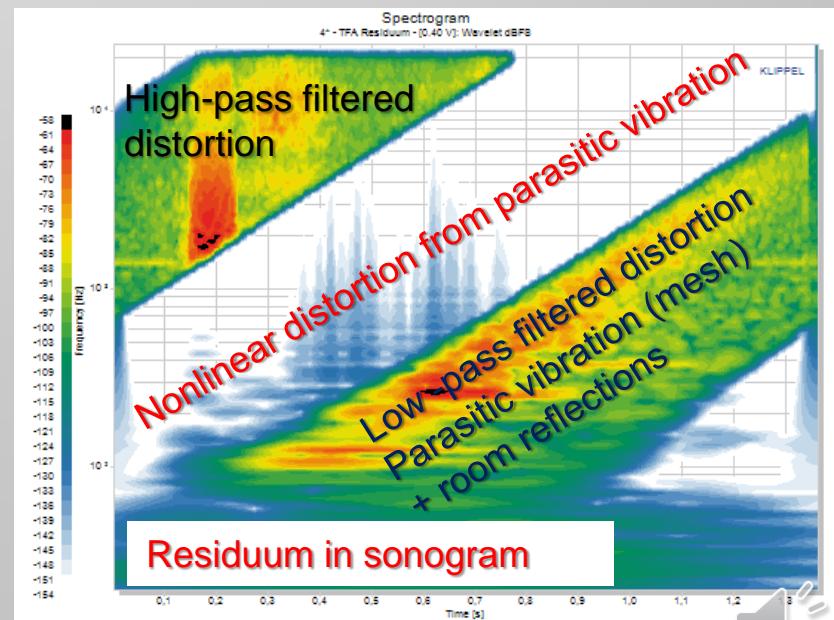
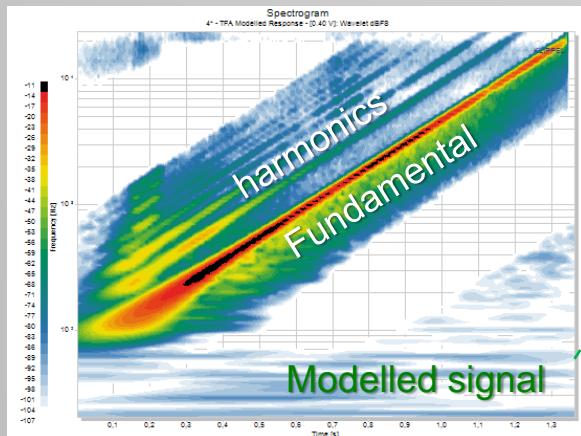


時域分析

Time Domain Analysis



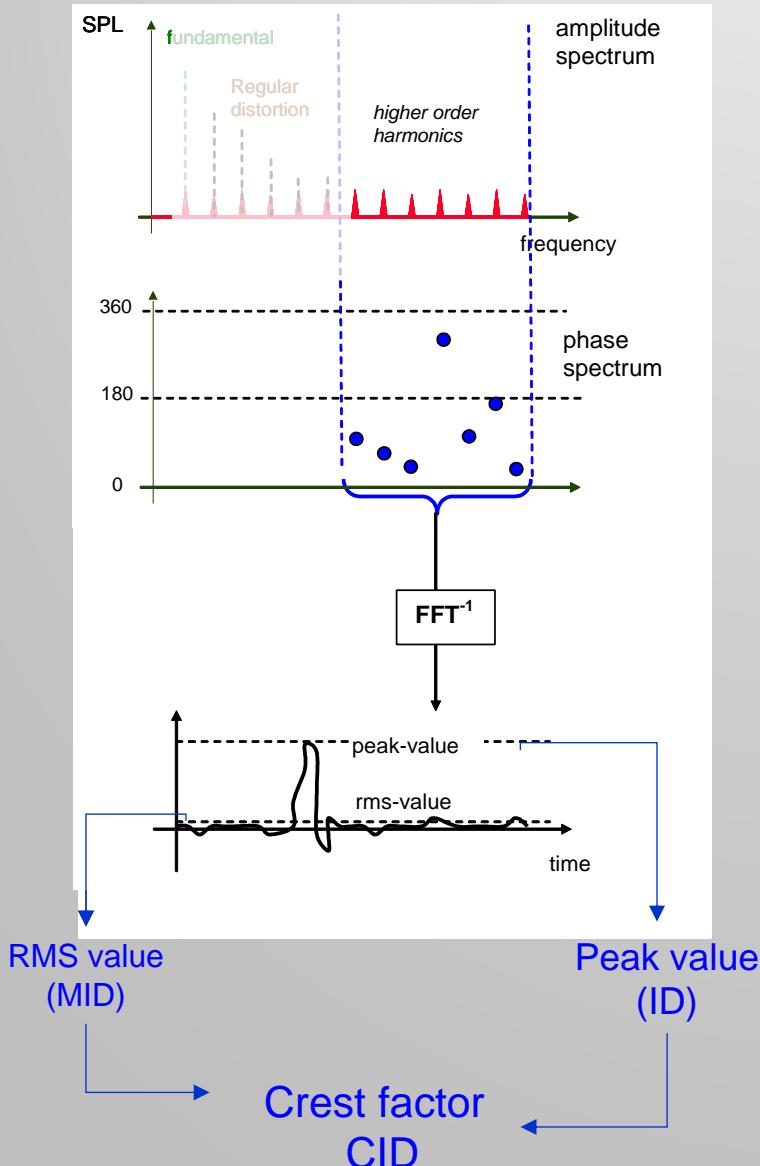
Residuum $p_{\text{res}}(t) = p_{\text{meas}}(t) - p_{\text{model}}(t)$





時域分析

Time Domain Analysis



分析技術 Analysis Techniques:

- 殘差（非線性建模） Residuum (nonlinear modeling)
- 高通濾波 High-pass filtering
- 根據 IEC 60268-21 According to IEC 60268-21

- 利用高次諧波和所有非諧波分量的幅度和相位 Exploiting amplitude and phase of higher-harmonics and all non-harmonic components
- 峰值顯示小的瞬變（咔嗒聲） Peak value reveals small transients (clicks)
- 對所有揚聲器缺陷敏感 Sensitive for all loudspeaker defects

大多數揚聲器缺陷會產生具有高波峰因數的脈衝失真 most loudspeaker defects generate impulsive distortion with high crest factor

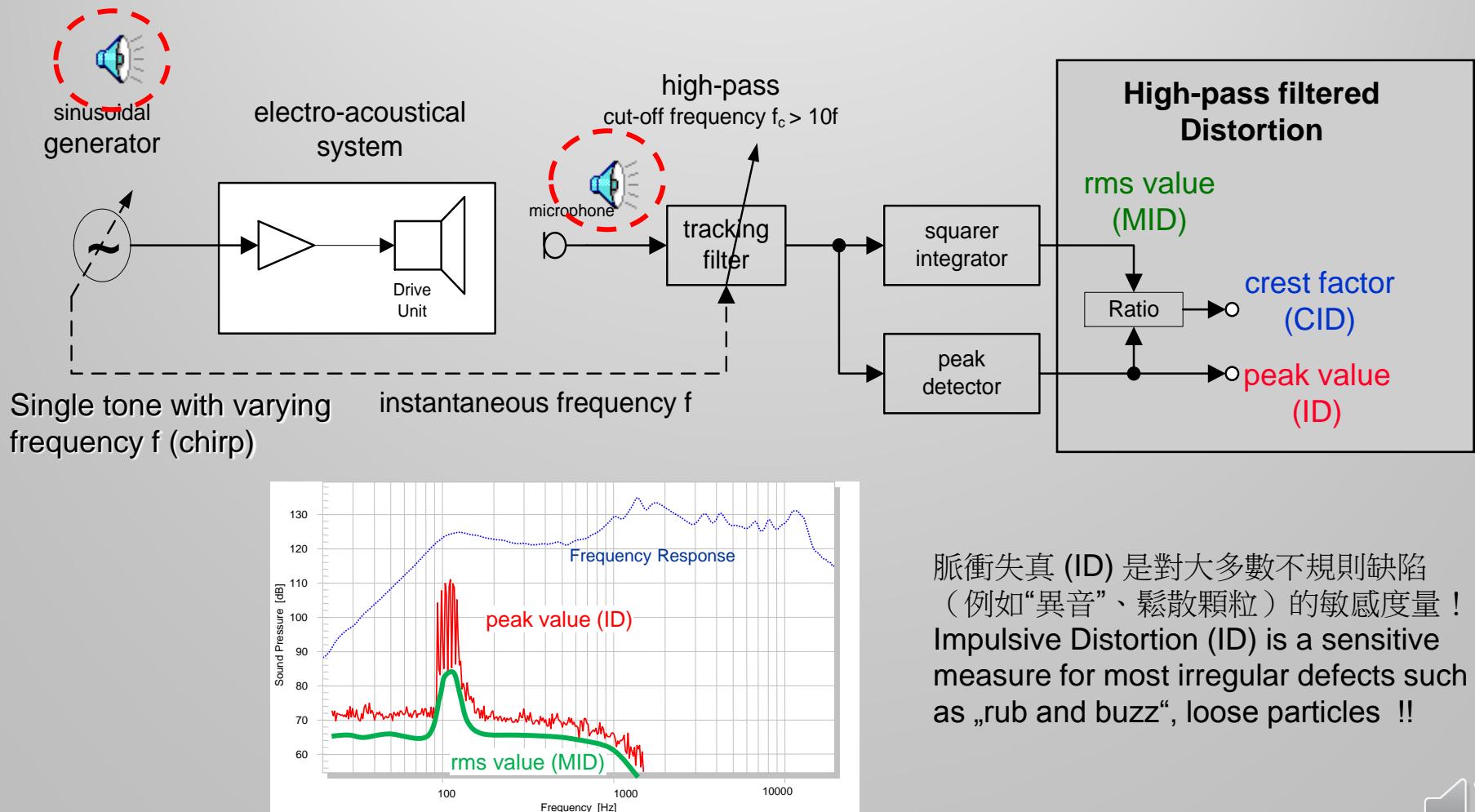
but

常規揚聲器失真、電氣和麥克風噪聲具有較低的波峰因數 regular loudspeaker distortions, electrical and microphone noise have lower crest factor



Peak value Contra rms-Value

Measurement technique defined in IEC 60268-21

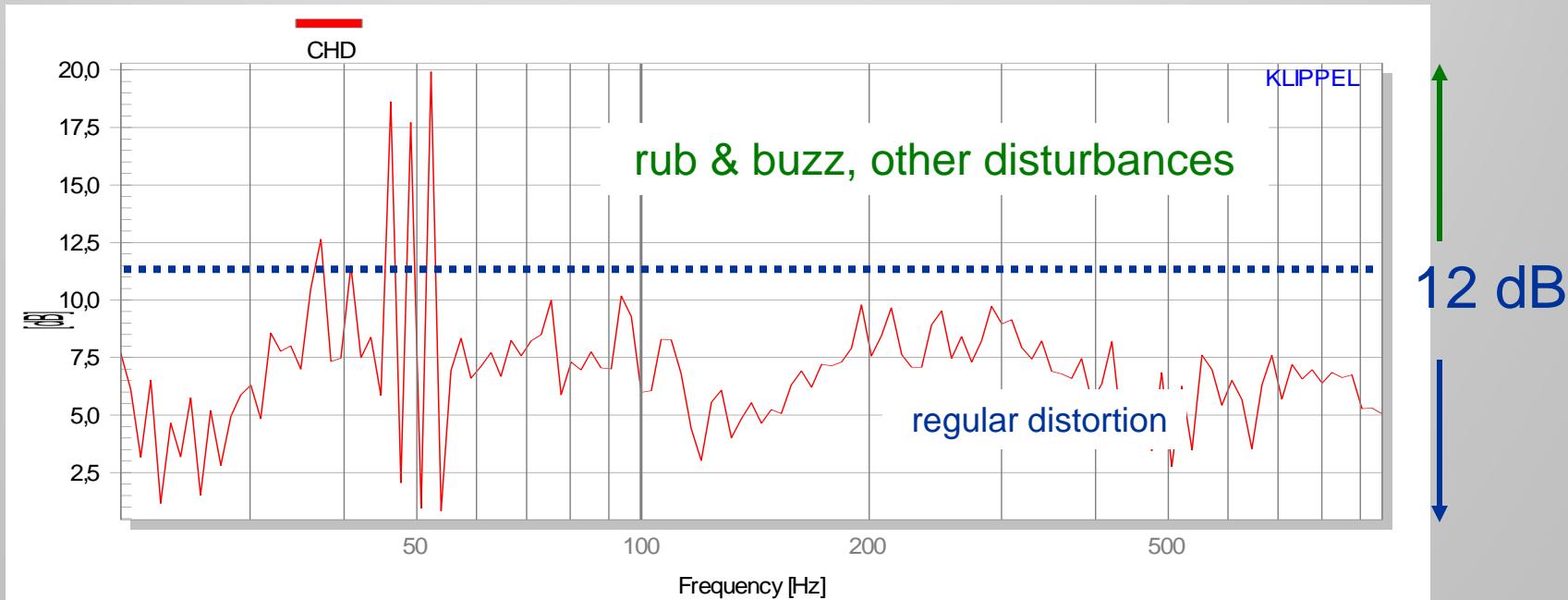


高通濾波失真的波峰因數 (CID) Crest factor of high-pass filtered distortion (CID)

Stimulus: Sinusoidal sweep

$$CID(f) = \frac{ID(f)}{MID(f)}$$

peak-value within one period
Rms-value averaged over one period



CID 可以在絕對尺度上解釋！CID can be interpreted on an absolute scale !

CID 利用所有高頻分量的相位信息 CID exploits the phase information of all high frequency components



脈衝失真映射與狀態信號

Impulsive Distortion mapped versus State Signal

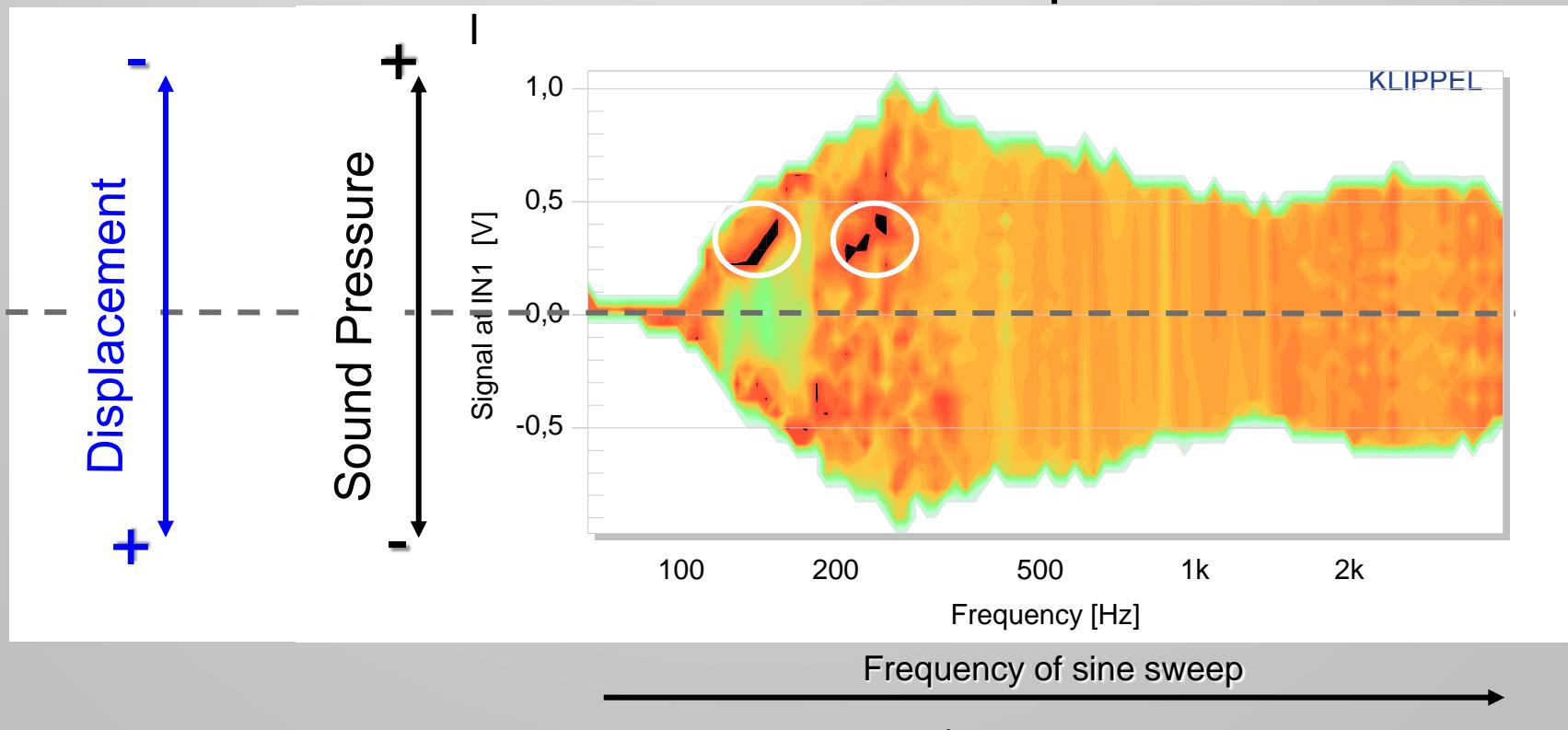
Instantaneous crest factor of impulsive distortion (ICID)



good

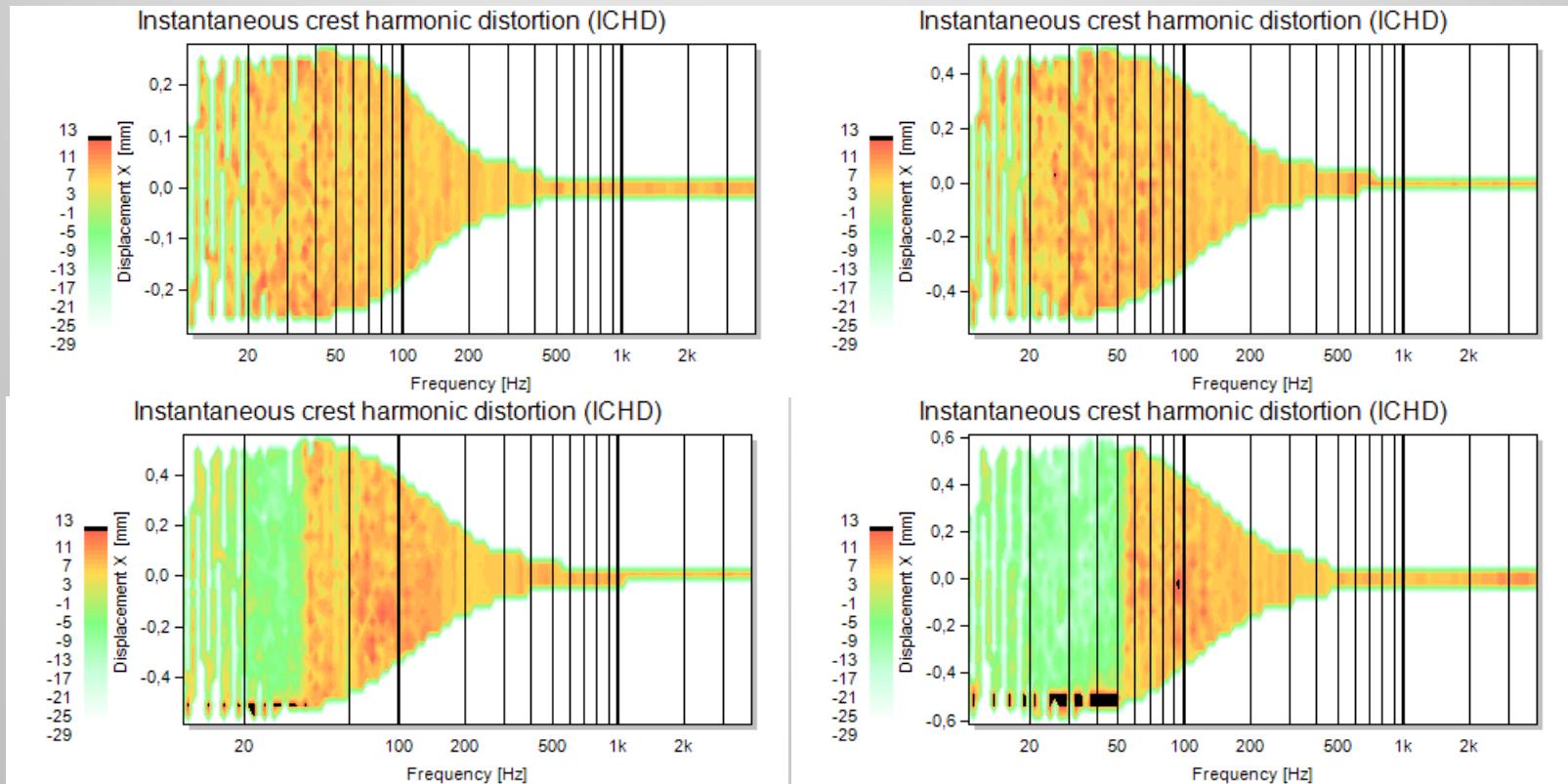
12dB

bad



不規則缺陷診斷（第一個例子）

Diagnostics on Irregular Defect (1st example)



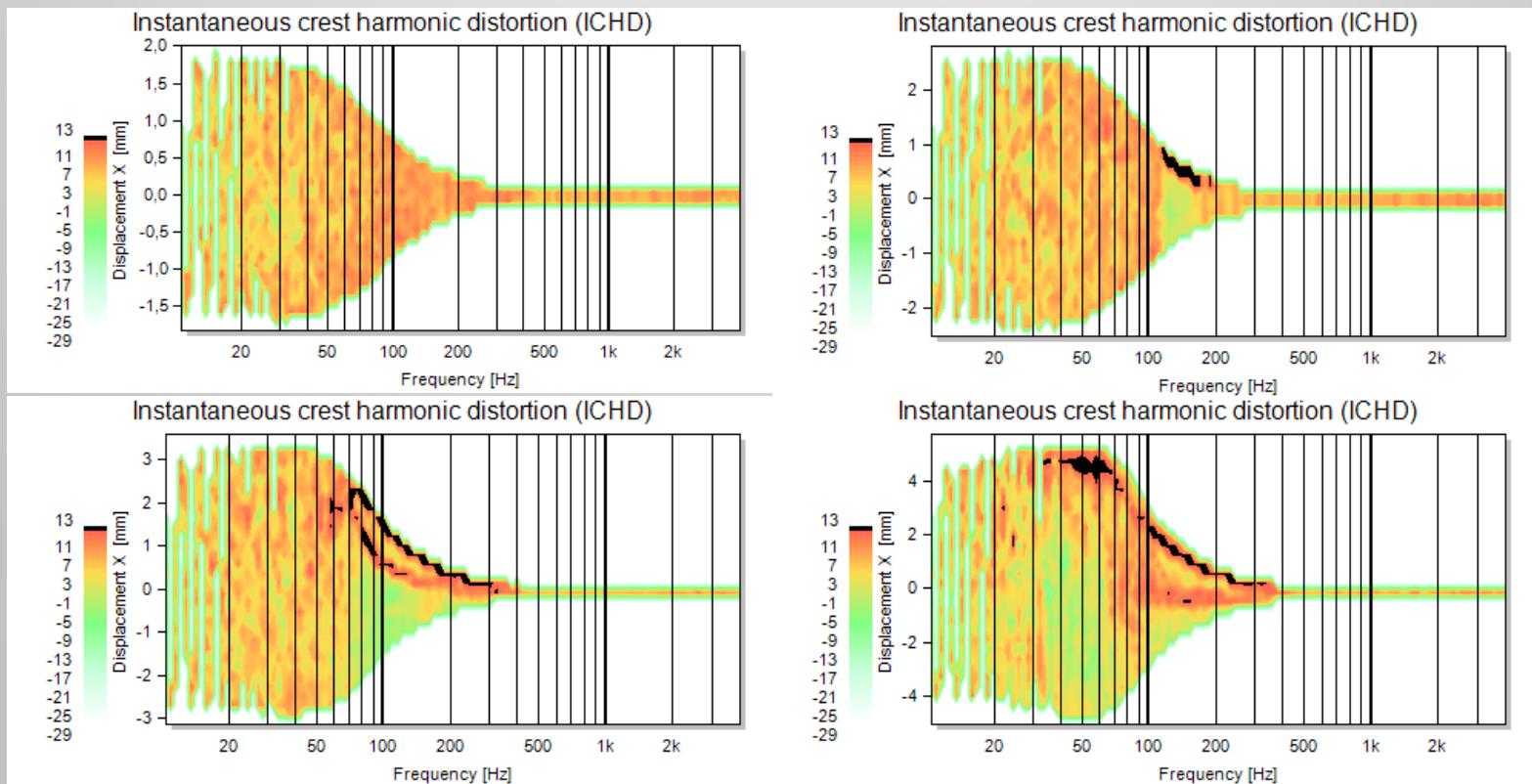
條件 Conditions:

- 峰值位移在 f_s 以下 -0.5 mm Peak displacement at -0.5 mm below f_s
- 高於 0.9 V 的端電壓 Above a terminal voltage of 0.9 V

Root Cause: Bottoming

不規則缺陷診斷（第二個例子）

Diagnostics on Irregular Defect (2nd example)



條件 Conditions:

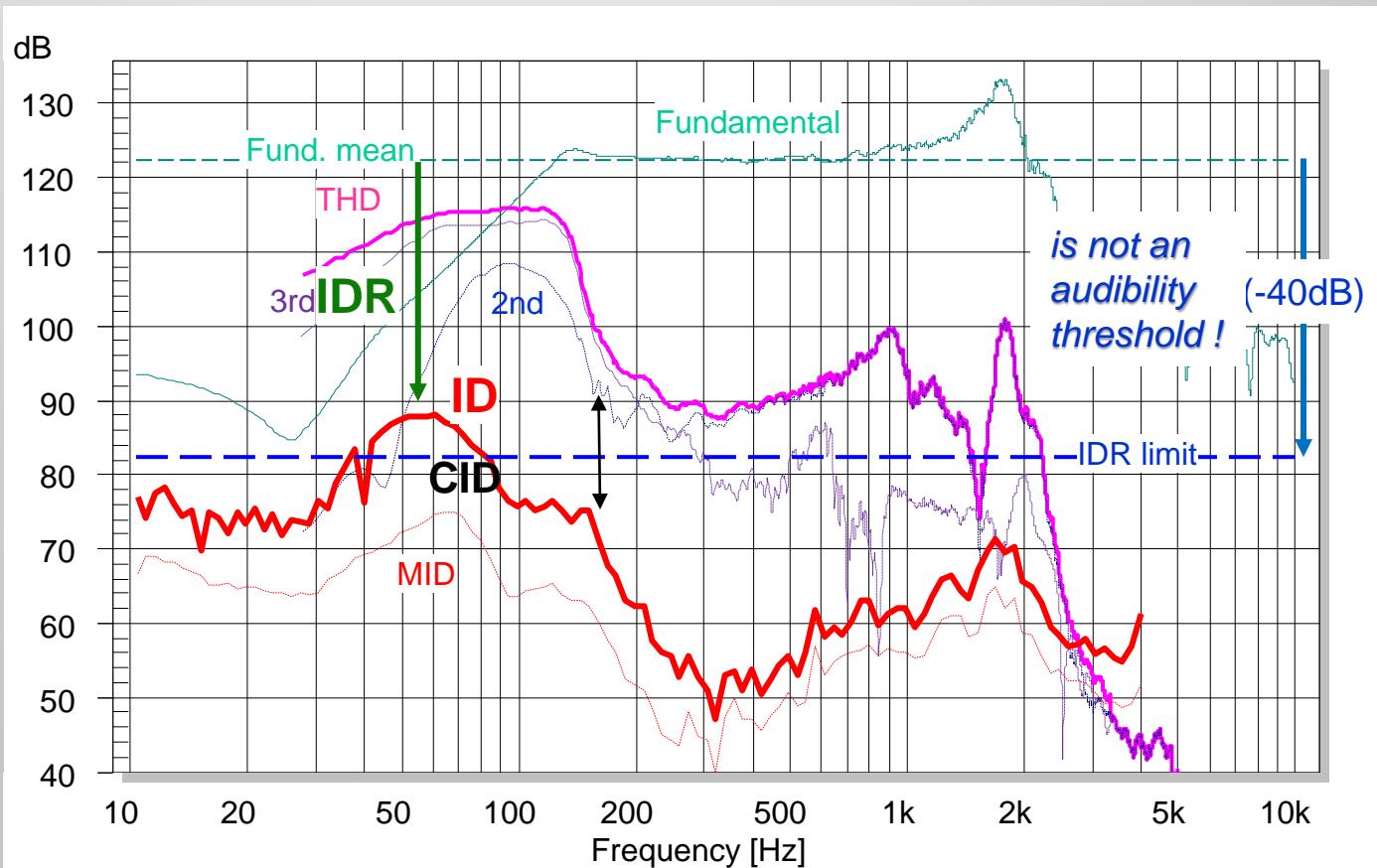
- 音圈偏移超過 f_s 的正轉折點
- Positive turning point of voice coil excursion above f_s
- 最大加速度 → 音圈傾斜
- maximal acceleration → Tilting of voice coil former
- 獨立於位移 independent of displacement



Root Cause: Voice coil Rubbing

揚聲器缺陷或噪音？ Loudspeaker Defect or Noise ?

Impulsive distortion ratio (IDR) is defined in IEC 60268-21



Symptoms of a significant defect:

1. Impulsive distortion ratio $IDR > -40dB$
2. Crest factor of impulsive distortion $CID > 12dB$

Check for coincidence !
(microphone noise is not impulsive)

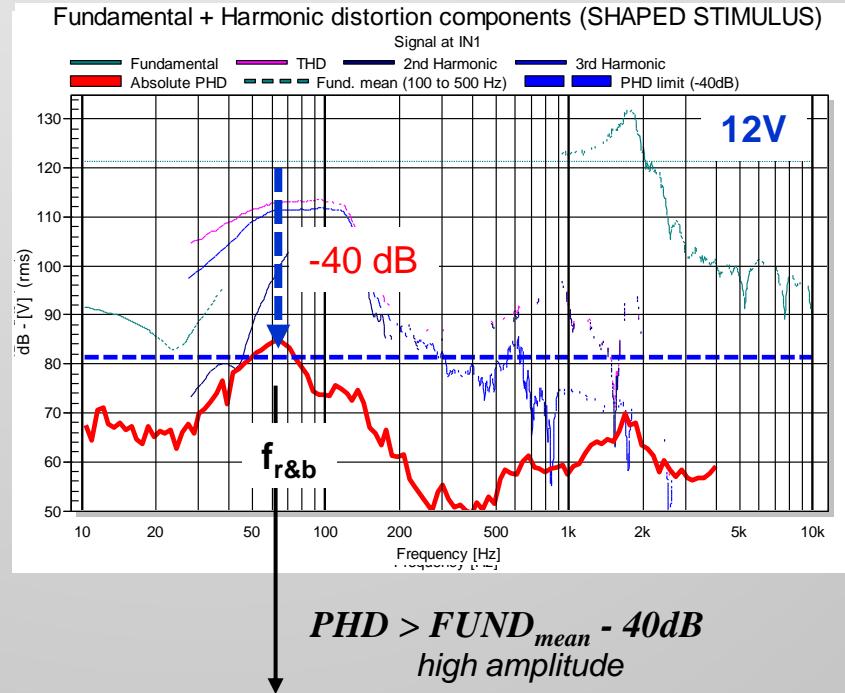
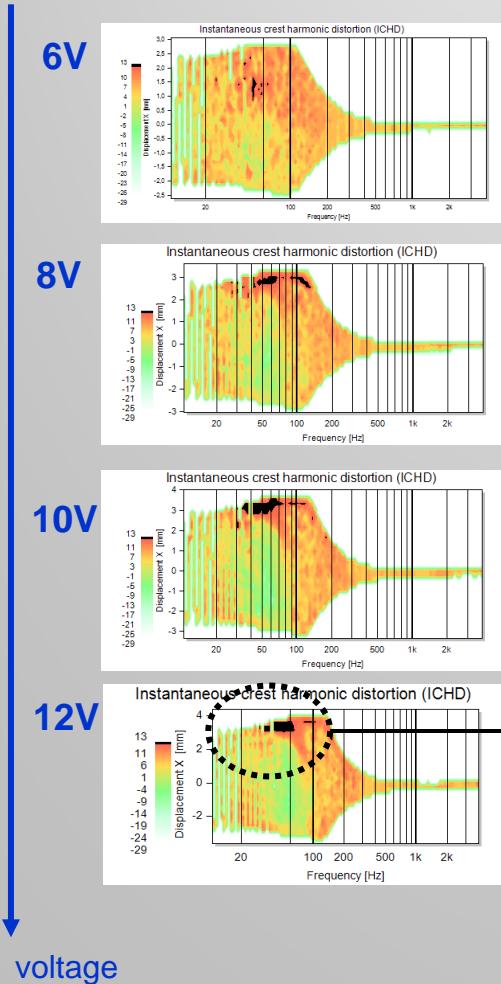


診斷特性

Characteristics for Diagnostics

Single-valued parameter derived from PHD and CHD

Batch of TRF measurements



CHD > 12dB
impulsive

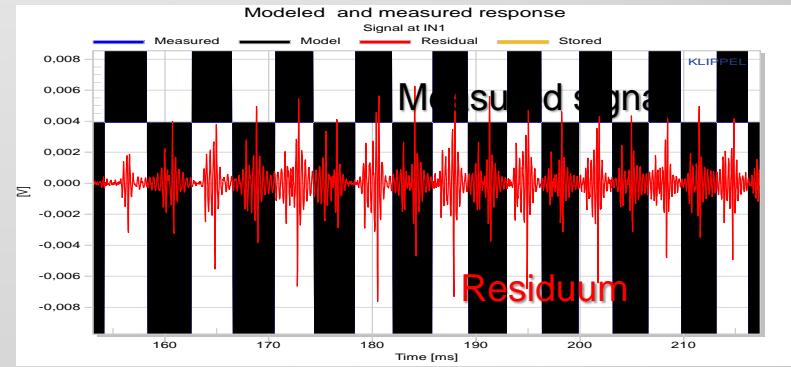
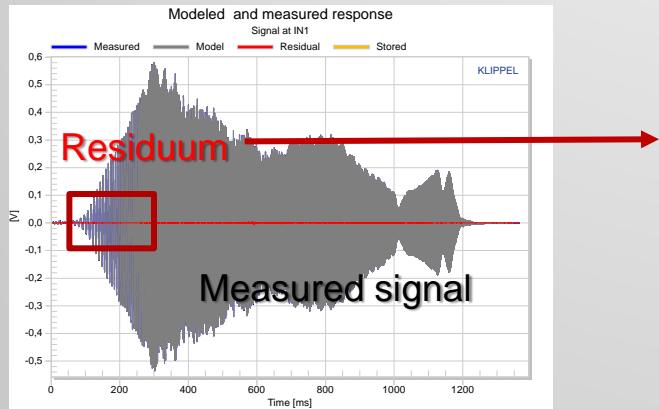
**Significant
defect (R&B)**

Conditions:
Rms Voltage $U_{r&b} = 12 \text{ V}$
Peak displacement $X_{r&b} = 4\text{mm}$
Frequency $f_{r&b} = 65 \text{ Hz}$
Inst. Displacement $x_{in, r&b} = 3.8 \text{ mm}$

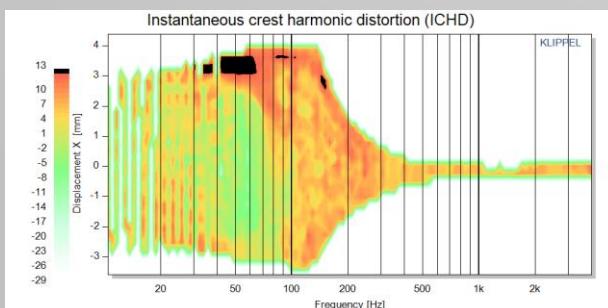


精細結構分析

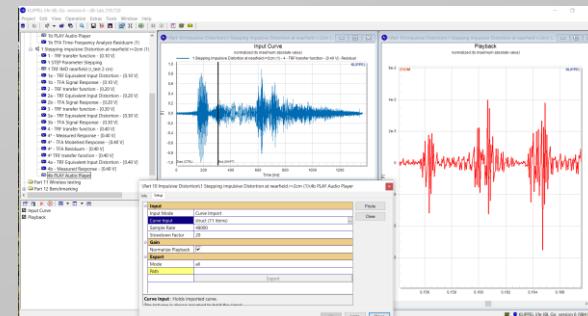
Fine Structure Analysis



- 1) Mapping the residuum (instantaneous crest factor ICID) versus transducer state
- Voice coil displacement
 - Sound pressure (acceleration)



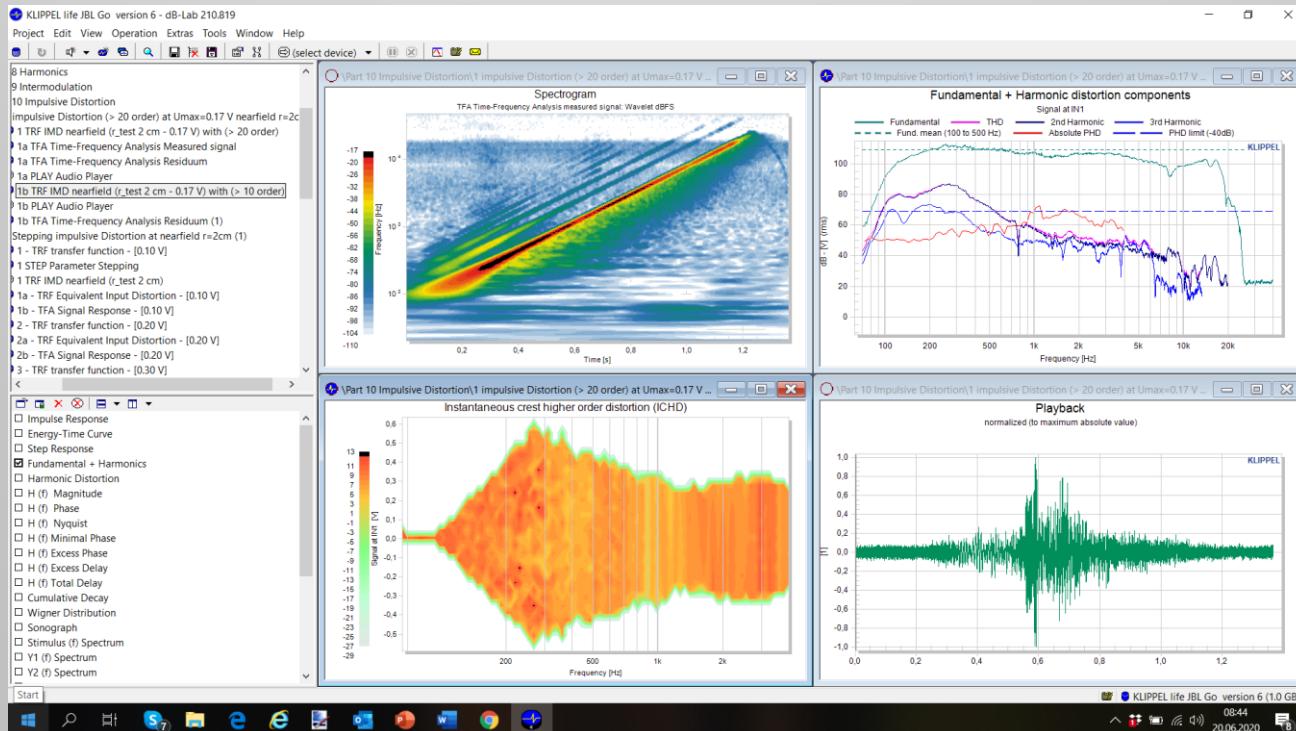
- 2) Human ear listening to the upsampled residuum (slowdown factor 10)



示範Demo

Tools: Using dedicated software modules of the KLIPPEL Analyzer

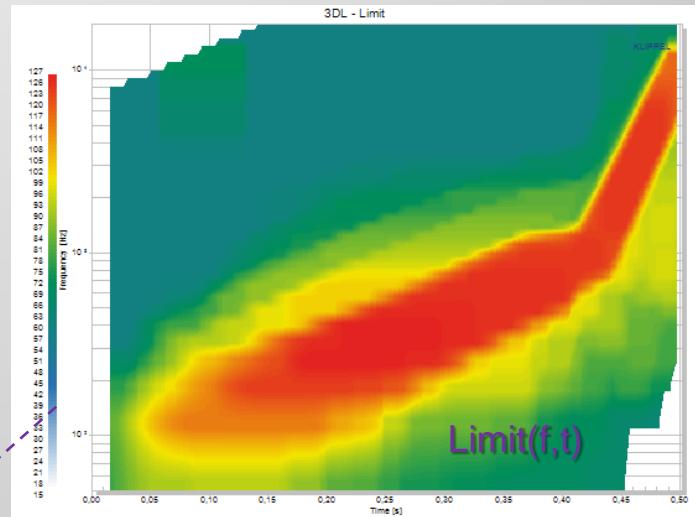
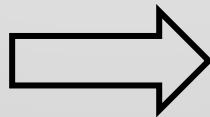
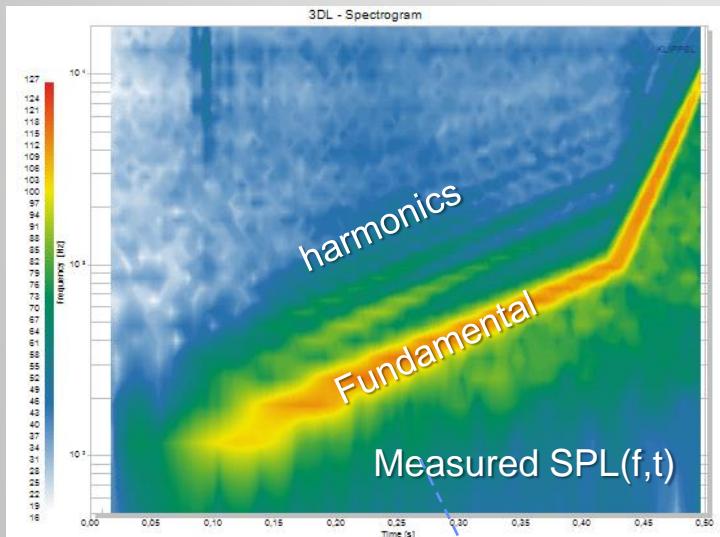
- TRF PRO (transfer function)
- TRF Stepping
- **TFA (time frequency analysis)**
- **PLAY (audio player for fine structure analysis)**



終端測試中的 3D 限制

3D Limits in End-of-Line Testing

LIMIT MODE (GOLDEN REFERENCE Device)

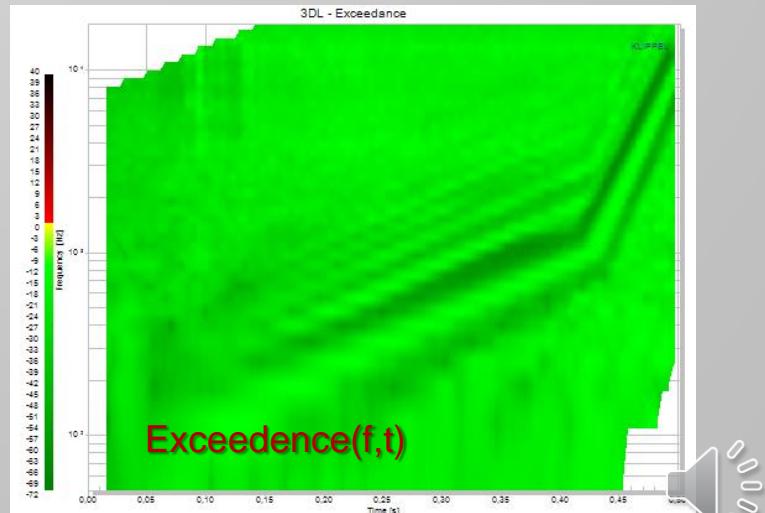


$$\text{Exceedence}(f, t) = \text{SPL}_{\text{meas}}(f, t) - \text{Limit}(f, t)$$

Classification:

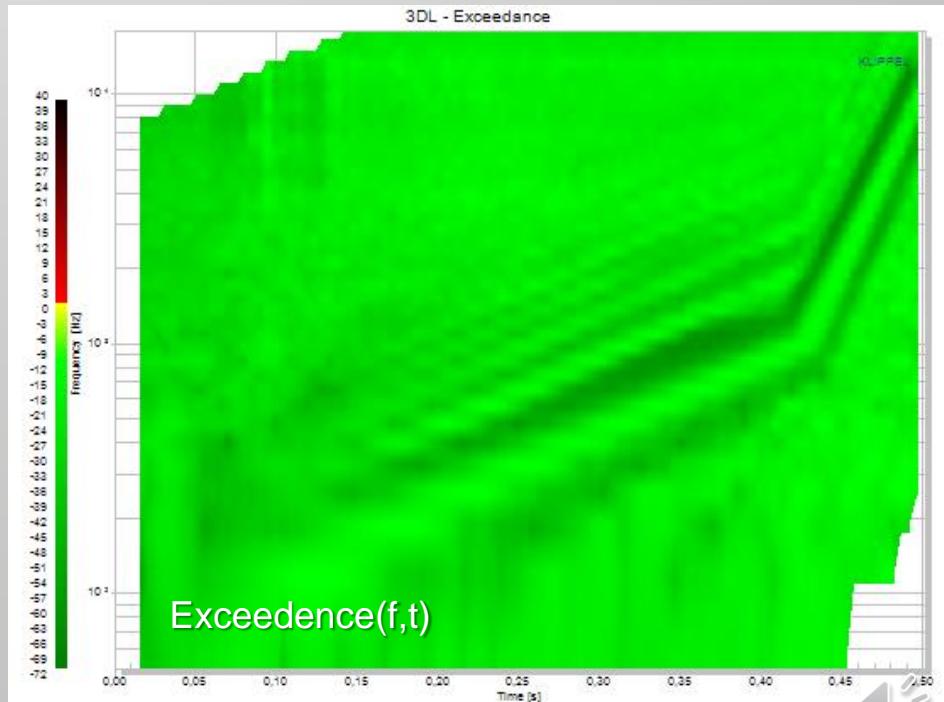
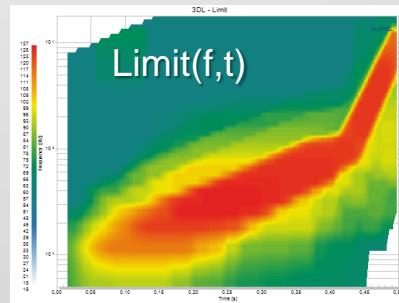
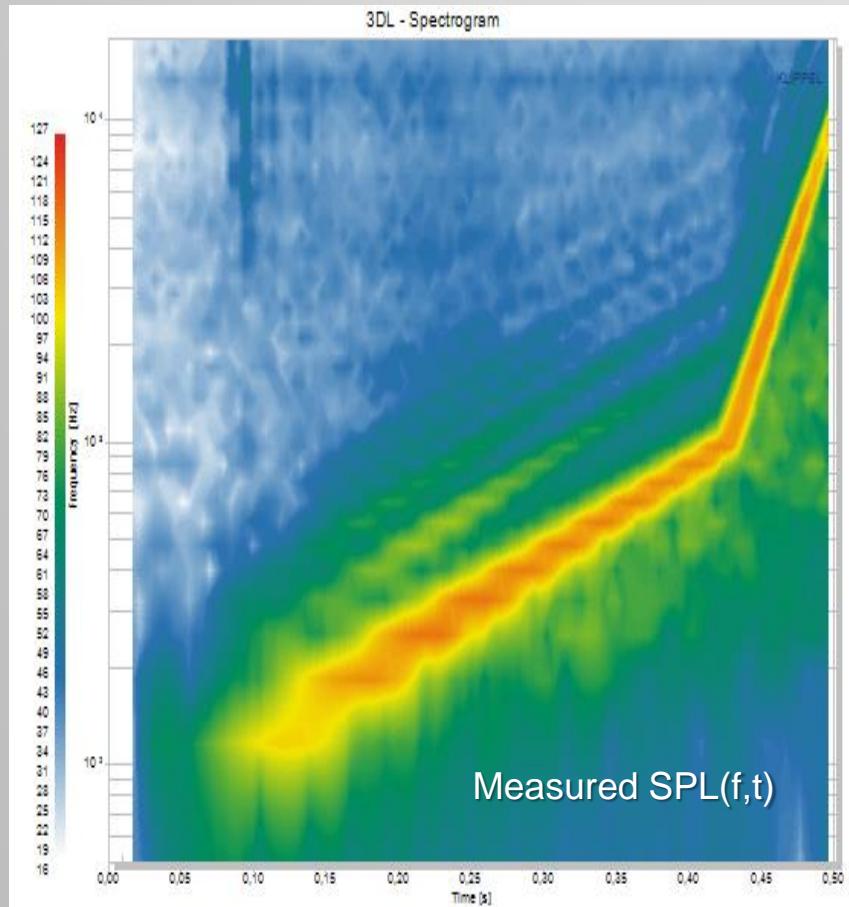
PASS: negative exceedence value (green)

FAIL: positive Exceedence value (red)



終端測試中的 3D 限制 3D Limits in End-of-Line Testing

On-Line MODE
(DUT without defect)

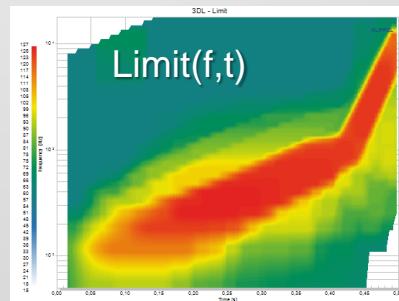
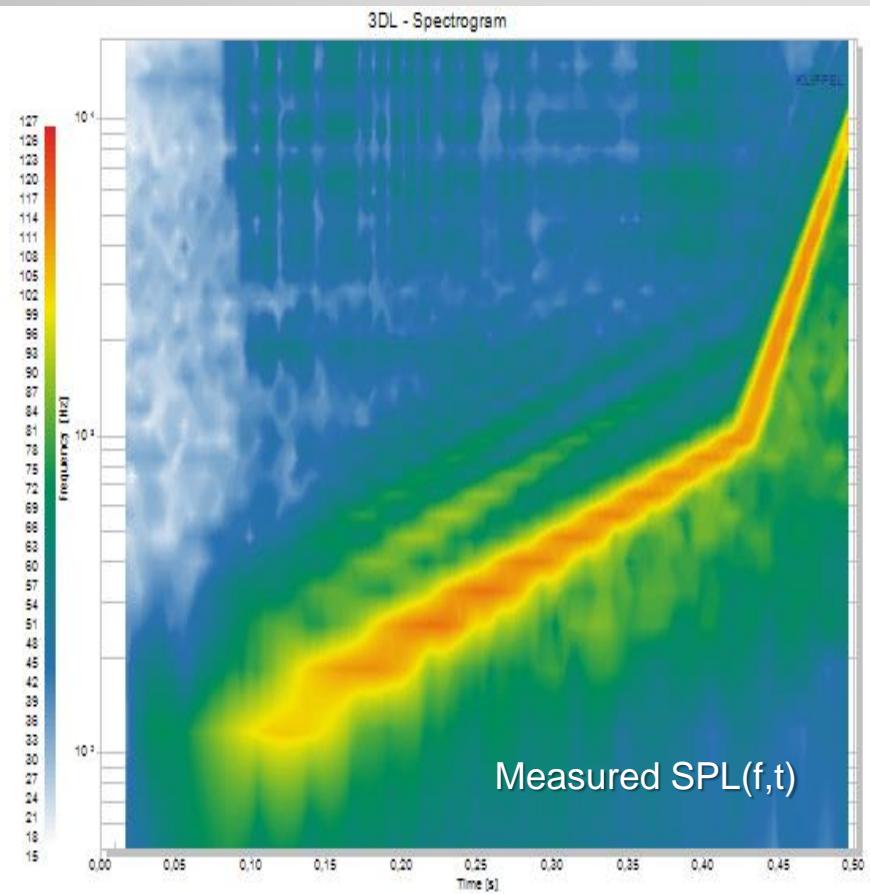


PASS

Frequency Response
Average Level
Polarity
THD
2nd Harmonic
3rd Harmonic
Rub+Buzz
3DL - Spectrogram

終端測試中的 3D 限制 3D Limits in End-of-Line Testing

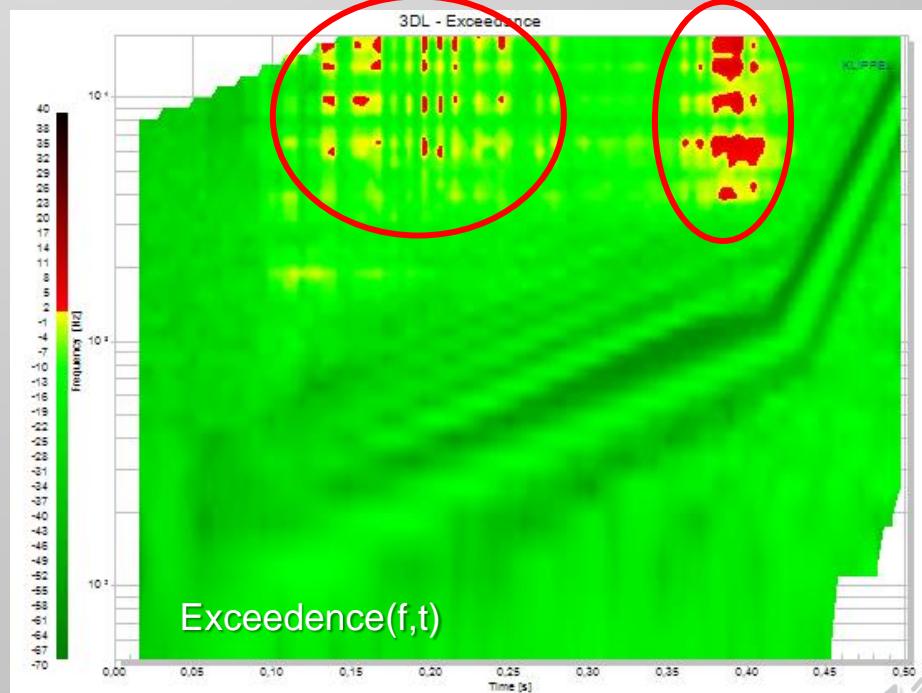
On-Line MODE
(DUT with defect)



FAIL

Frequency Response
Average Level
Polarity
THD
2nd Harmonic
3rd Harmonic
Rub+Buzz
3DL - Spectrogram

Statistics:

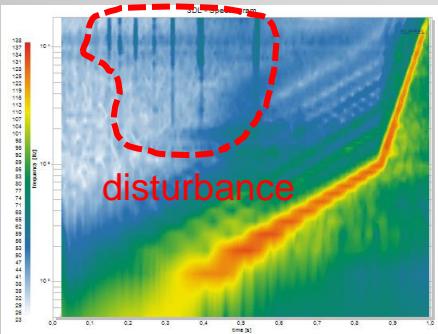


示範：對有缺陷揚聲器的物理評估

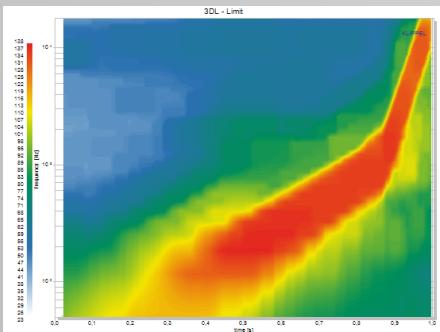
Example: Physical Evaluation of a Defective Speaker Loose Particles (one grain of salt)

Spectrogramm

$L_{DUT}(f_s, f_E)$ of the DUT

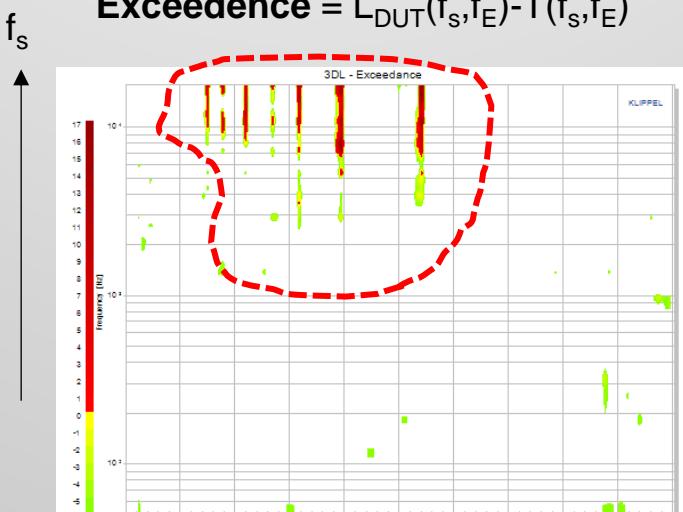


3D-Limit $T(f_s, f_E)$

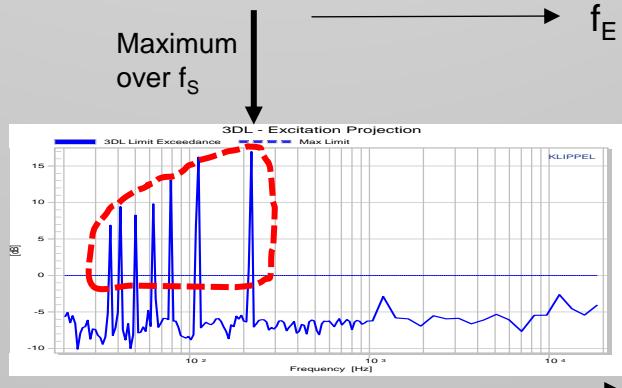


spectrogram of the golden reference unit + 10 dB

$$\text{Exceedence} = L_{DUT}(f_s, f_E) - T(f_s, f_E)$$

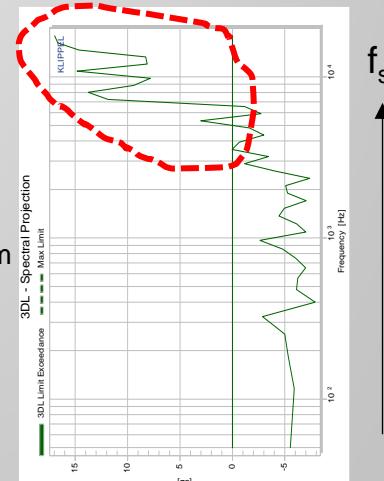


Maximum
over f_S



Excitation Projection to 2D-plot versus excitation frequency f_E

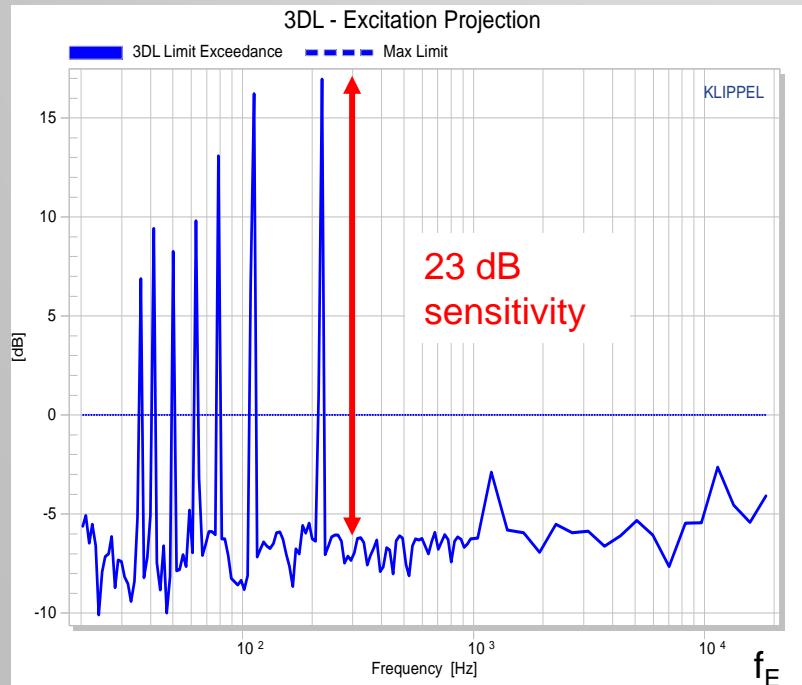
Spectral Projection
to 2D-plot versus
spectral frequency f_s



示例：對有缺陷揚聲器的物理評估
Example: Physical Evaluation of a Defective Speaker
Loose Particles (one grain of salt)

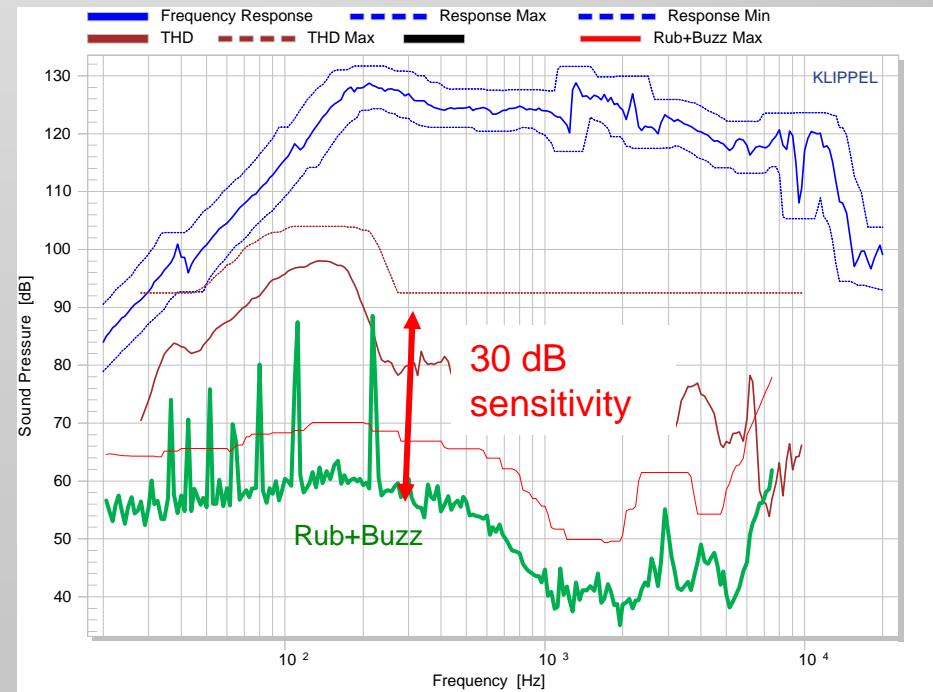
Maximum of Exceedence

in the spectrogram generated by
auditory filterband projected versus
excitation frequency



Impulsive Distortion (Rub+Buzz)

Measurement in time domain by using a
high-pass filter according IEC 60268-21

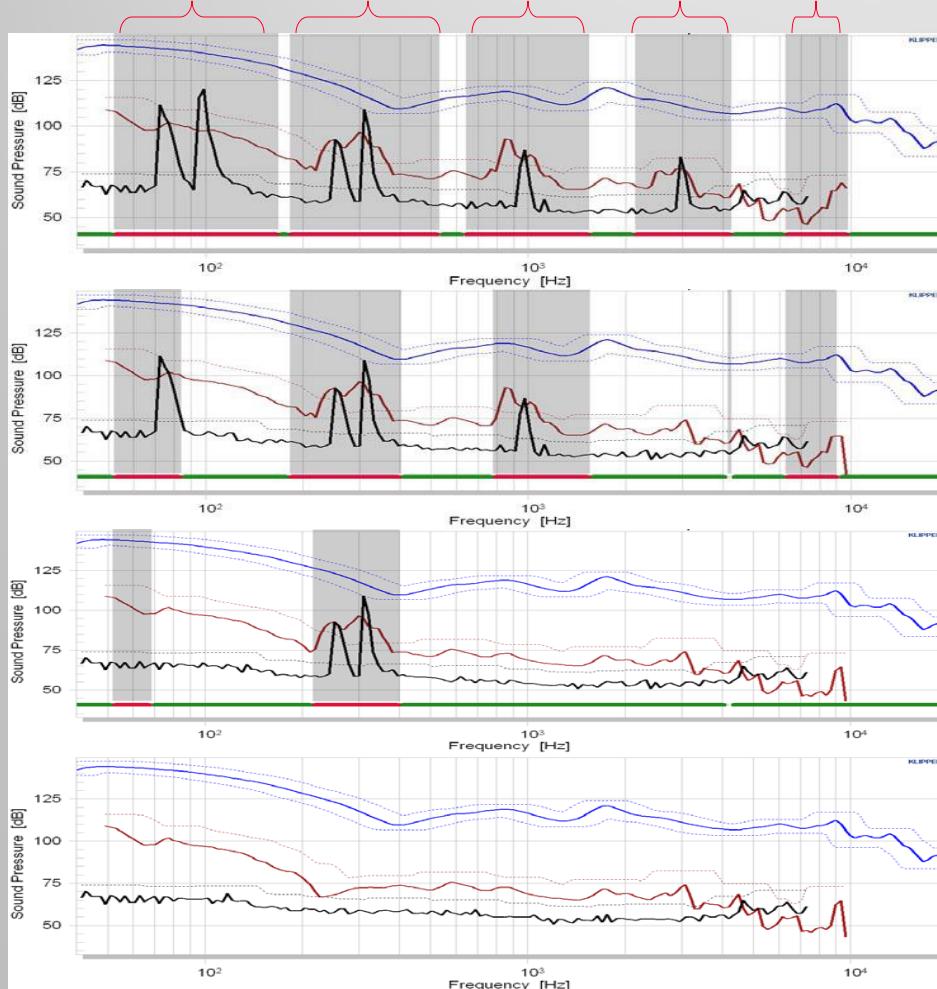




合併技術 Merging Technique

repeating measurement automatically and accumulating valid parts

Ambient noise generated by permanent hand clapping



→ 28 % valid

→ 62% accumulated

→ 85% accumulated

→ 100% valid →

PASS

Frequency Response
Average Level

Full immunity against random noise

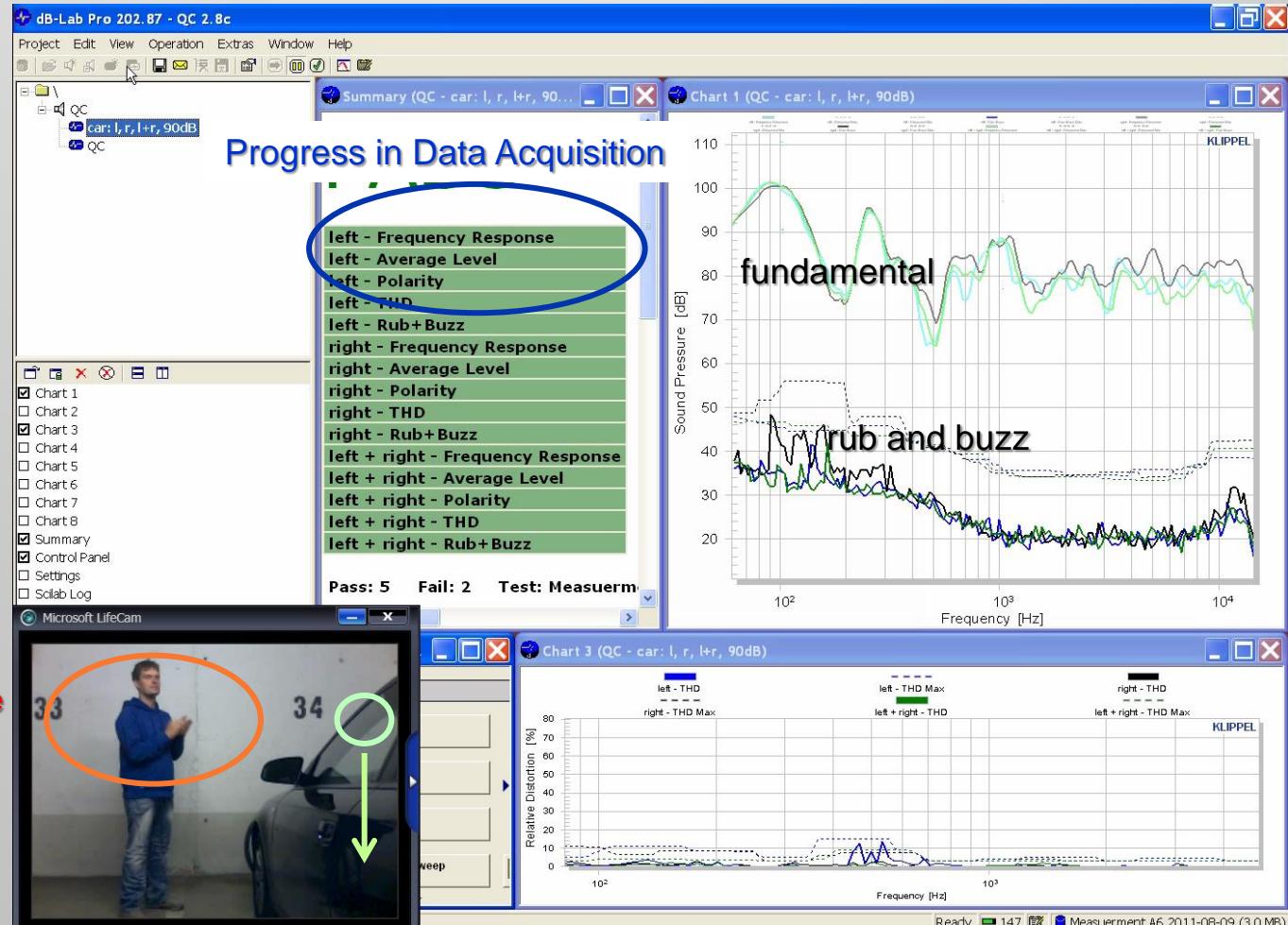




汽車內部的聲音品質

Sound Quality in the Car Interior

Noise immunity at a car assembling line

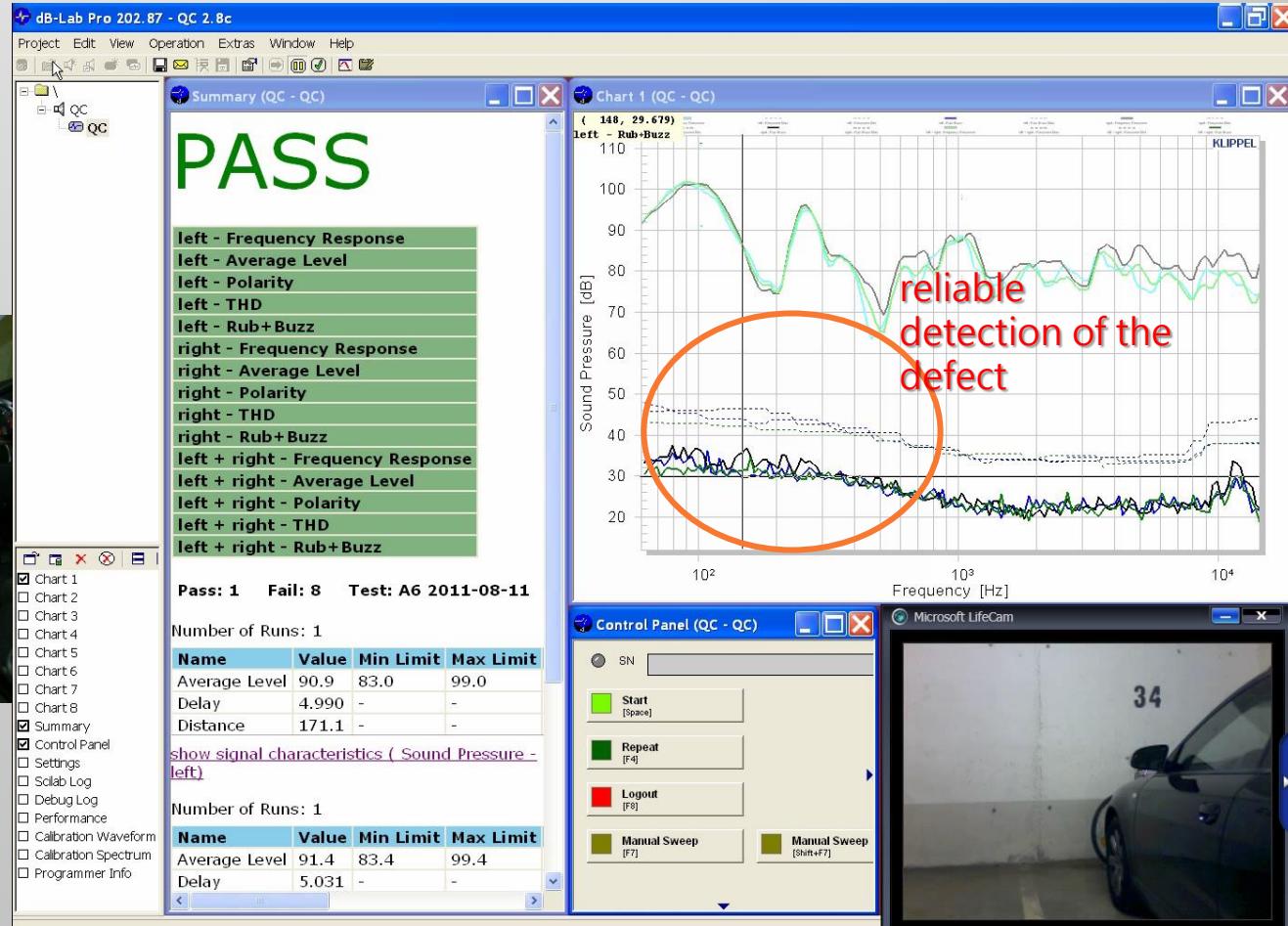


test microphone inside the car





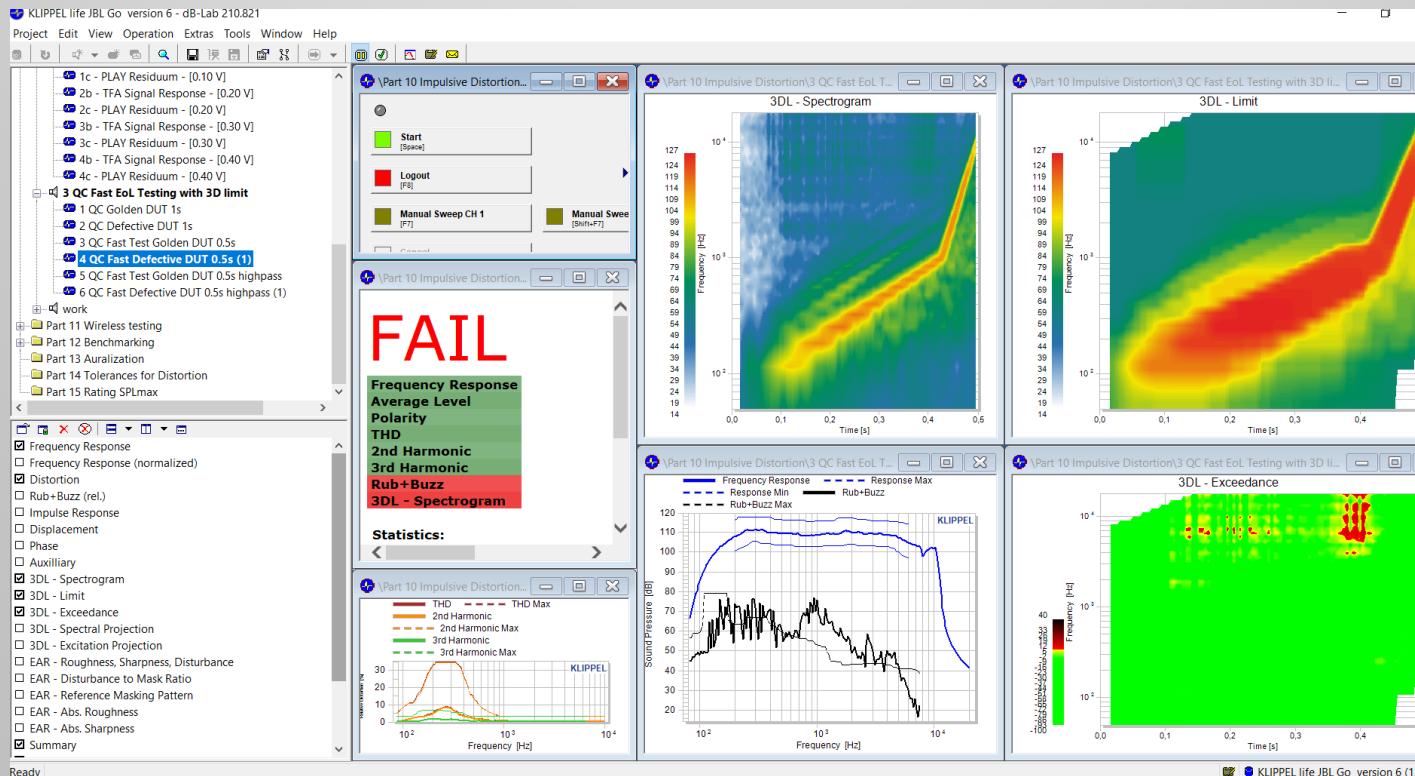
門噪聲模擬 Simulation of Door Buzzing



示範Demo

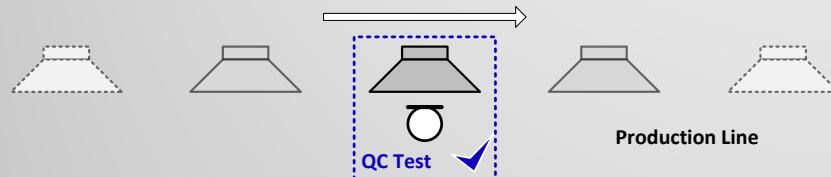
Tools: Using dedicated software modules of the KLIPPEL Analyzer

- QC Software (SPL Task with 3D limits)

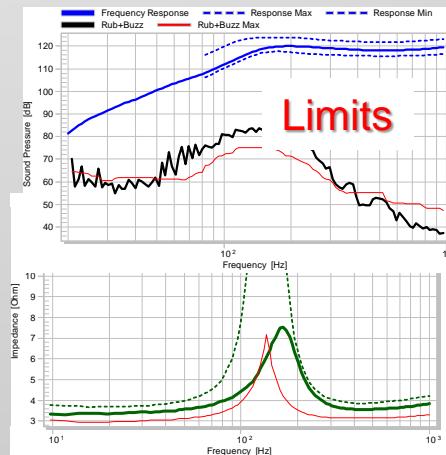
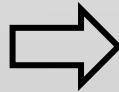


如何最大化產量？

How to maximize the Production Yield ?



Root Cause ?



Symptoms

Verdict

FAIL	
Impedance	
Re	
Le	
Cmes	
Lces	
Res	
fs	
Qts	
Qms	
Qes	
Frequency Response	
Average Level	
Polarity	
THD	
2nd Harmonic	
3rd Harmonic	
4th Harmonic	
5th Harmonic	
Rub+Buzz	
MODulation (abs,rel)	
DETerministic (abs,rel)	
Random	

- 判定是否表示設備有故障（或導致不良的拒絕）？ Does the verdict indicate a faulty device (or causing a false reject)?
- 如何解釋指標和限制？ How to interpret the metrics and the limits?
- 如何將症狀與不良聯繫起來？ How to link the symptoms with the defect?
- 如何找到根本原因並解決問題？ How to find the root cause and to fix the problem?
- 如何打造揚聲器診斷方面的專業知識？ How to create expertise in loudspeaker diagnostics?



投票Poll:

您如何修復缺陷或其他不規則行為，例如異音？

How do you fix defects or other irregular behavior such as rub&buzz ?

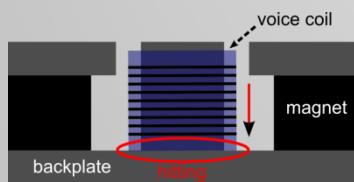
- A. 不斷嘗試來發現錯誤 Trial and error
- B. 目視檢查（拆解設備） Visual inspection (dissembling the device)
- C. 使用修改後的激發（幅度變化）進行進一步測試 Further testing with modified stimuli (amplitude variation)
- D. 與其他物理特性的相關性 Correlation with other physical characteristics
- E. 其他方式 Other ways



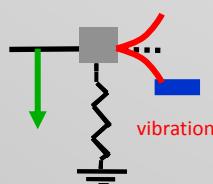
揚聲器缺陷的特徵

Characteristic Features of Loudspeaker Defects

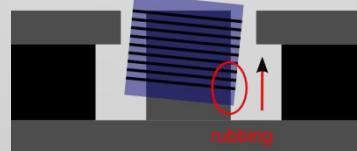
Coil hitting backplate



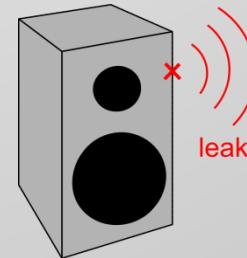
Buzzing loose joint



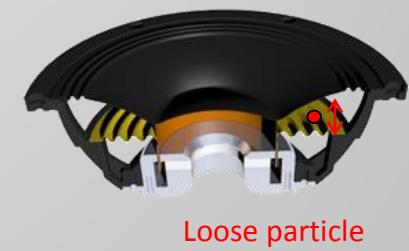
Rubbing voice coil



Flow noise at air leak



Loose particle hitting membrane



Deterministic

Semi-random
(mixed characteristic)

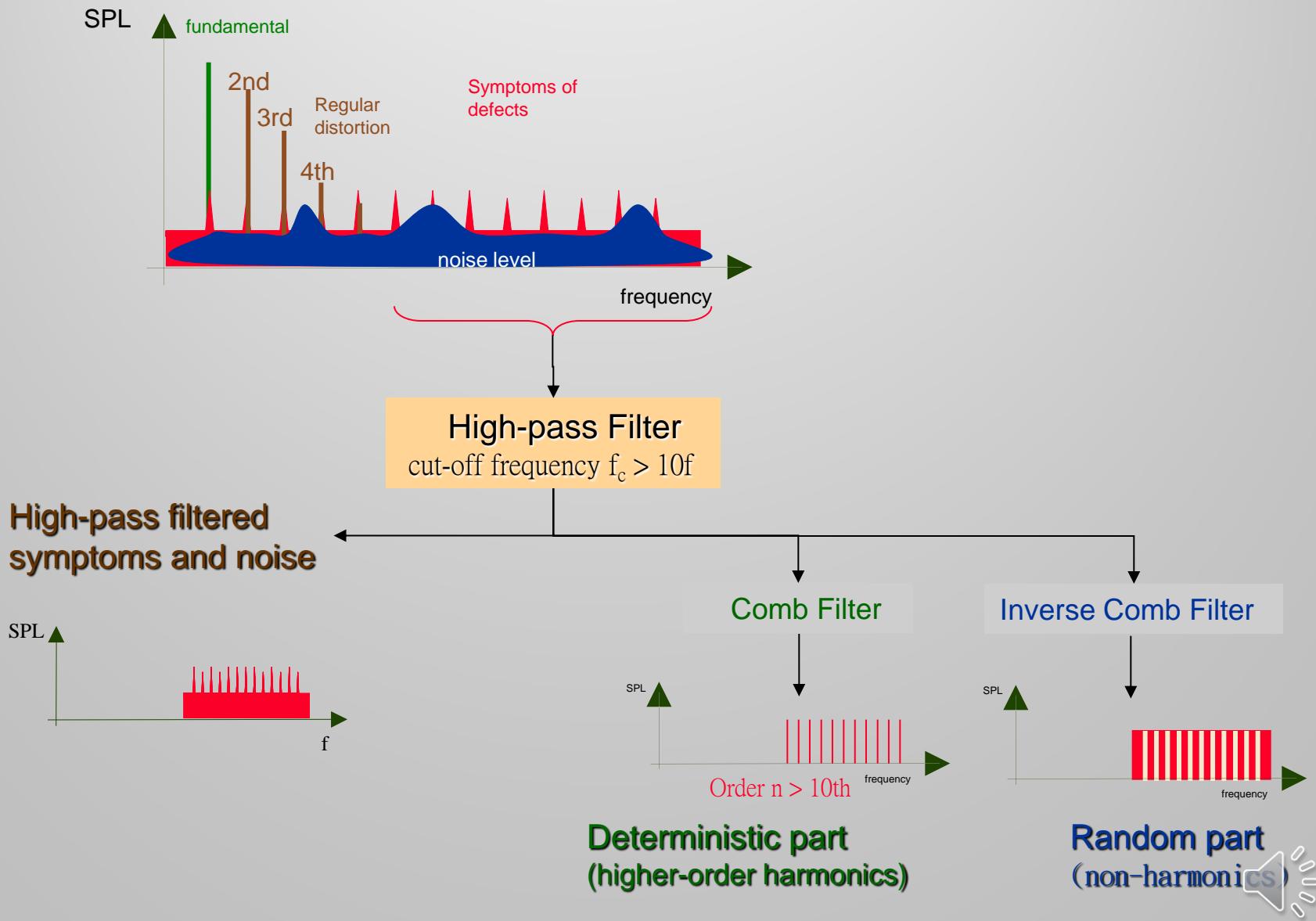
Random

Waveform is completely reproducible

Envelope is reproducible
(Waveform is not)

Waveform is not reproducible

分離缺陷的症狀 Separating Symptoms of a Defect

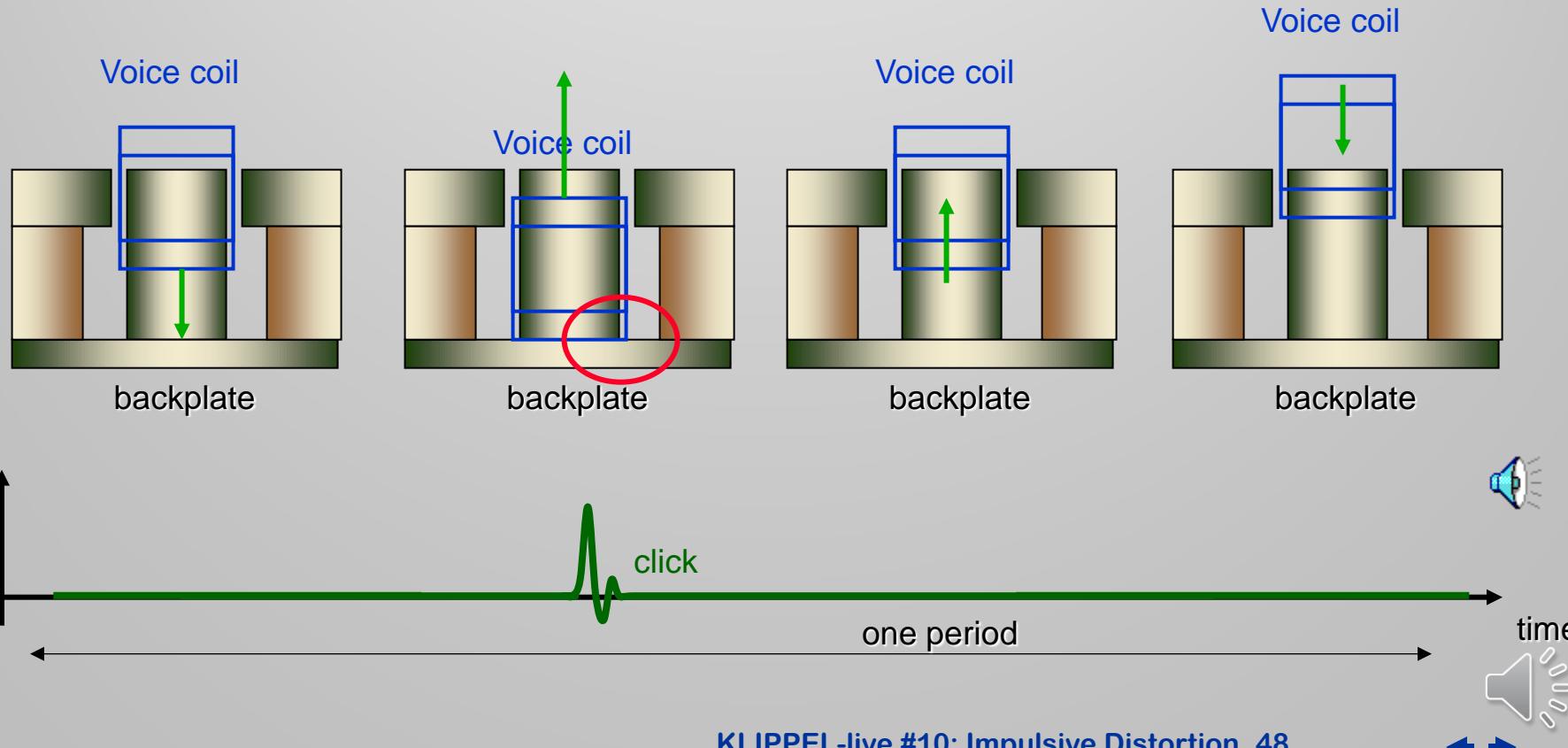


揚聲器缺陷：音圈底部 Loudspeaker Defect: Voice Coil Bottoming

根本原因 Root causes:

- 靜止位置偏移，直流位移 offset in rest position, DC displacement
- 高音圈偏移 high voice coil excursion
- 音圈位移的限制 hard limiting of the voice coil displacement

Symptoms: impulsive, deterministic, click at peak excursion



確定性失真 Deterministic Distortion

例如 Example:

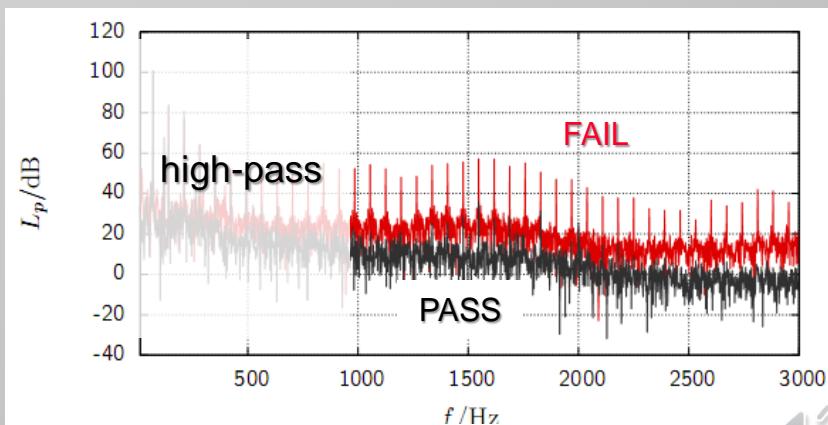
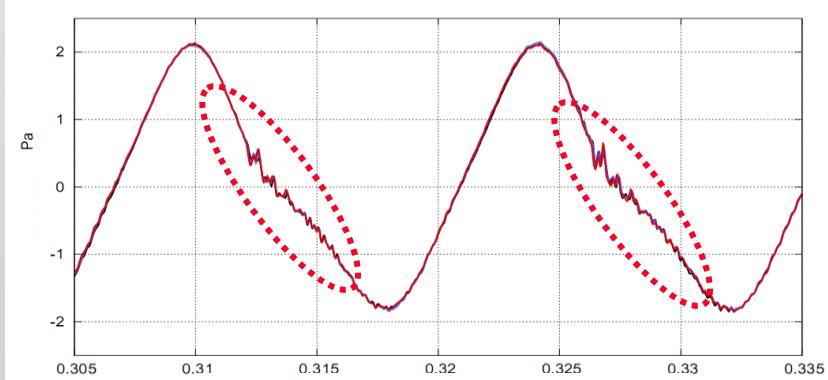
tensile slap, bottoming



特徵 Symptoms:

- Reproducible, repeatable
- Related with stimulus
- impulsive distortion
- Deterministic amplitude and phase of higher-order ha

Results of three measurements



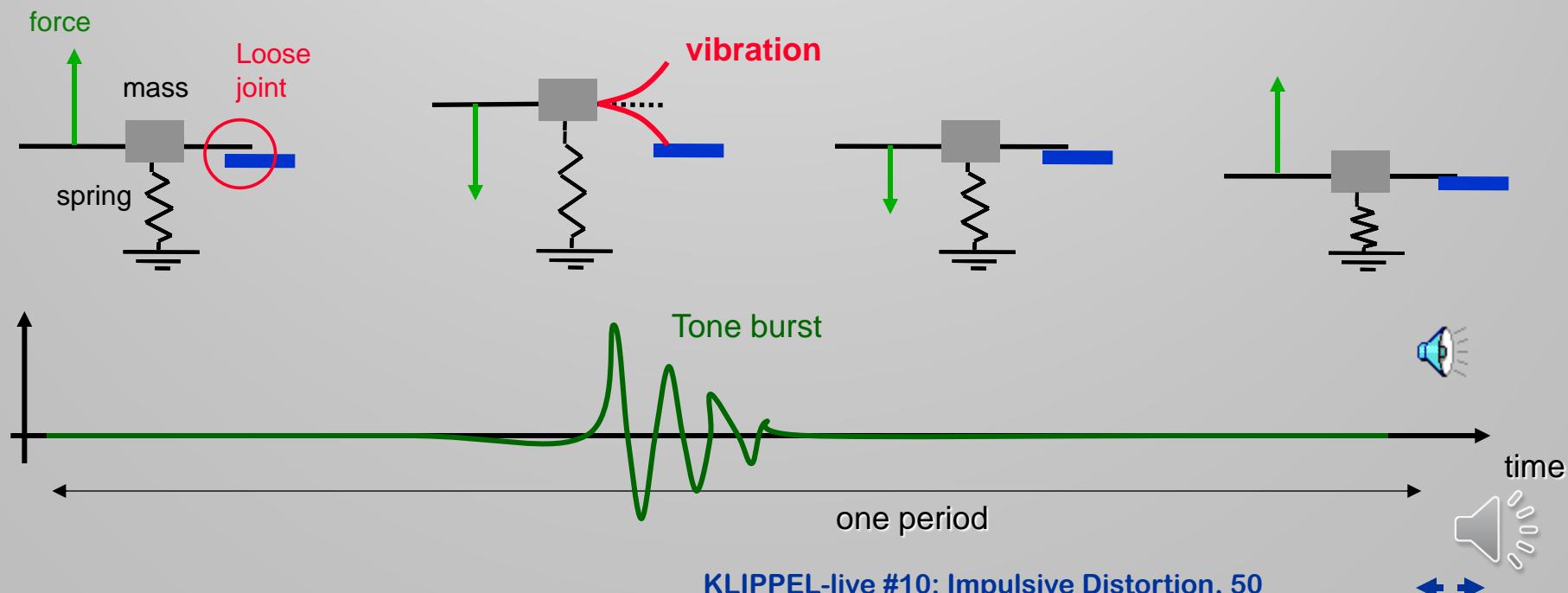
揚聲器缺陷：嗡嗡聲問題

Loudspeaker Defect: Buzz problem

根本原因 Root cause

- 鬆散部分表現為非線性振盪器 loose part behaves as a nonlinear oscillator
- 由激發提供動力和同步 powered and synchronized by stimulus
- 高於臨界幅度時活躍 active above a critical amplitude
- 新的振動模式 new mode of vibration

Symptoms: short tone burst at characteristic frequency, partly deterministic, impulsive



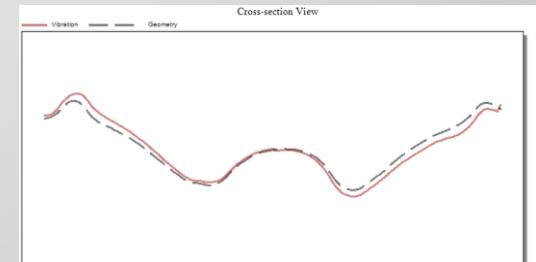
揚聲器缺陷：音圈摩擦

Loudspeaker Defect: Voice Coil Rubbing

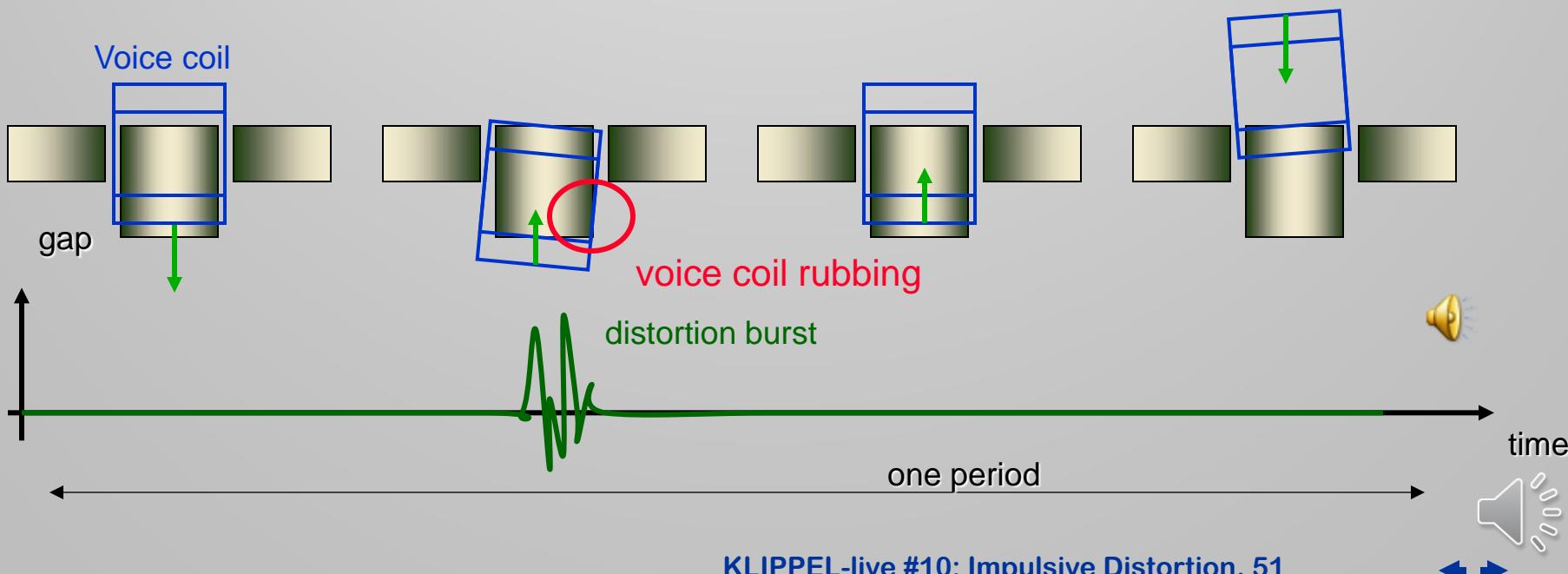
Cause: rocking mode at 328 Hz

根本原因 Root causes:

- 質量、剛度、BI 分佈不平衡 imbalances in mass, stiffness, BI distribution
- 高線圈位移激發搖擺模式 high coil displacement excites rocking mode
- 線圈在某個線圈位置摩擦 coil rubbing at a certain coil position



特徵 Symptoms: stochastic signal, modulated by the stimulus, impulsive burst

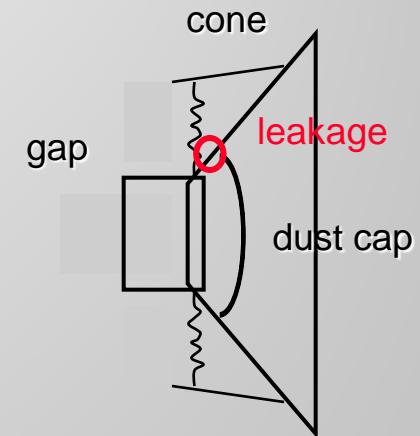


揚聲器缺陷：空氣噪聲

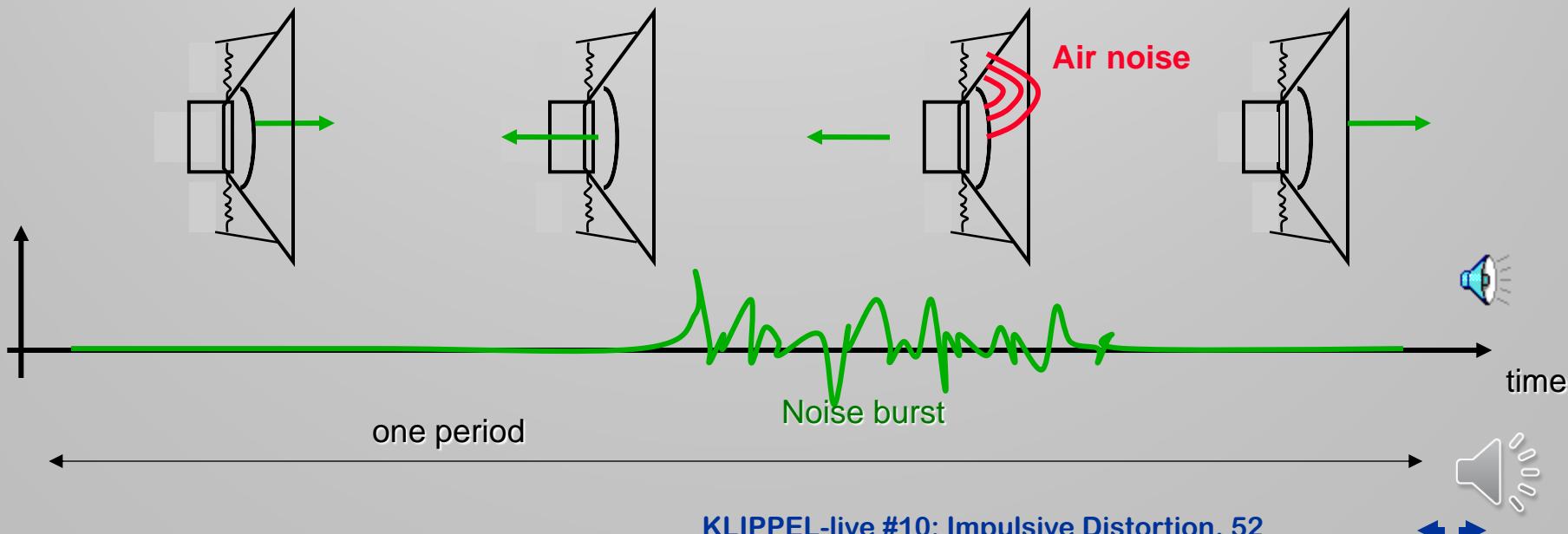
Loudspeaker Defect: Air Noise

根本原因 Root cause:

- 防塵帽、音箱、...leakage in dust cap, box, ...
- 線圈位移產生氣壓coil displacement generates air pressure
- 高壓導致洩漏處的高風速High pressure causes high air velocity at the leakage
- 湍流在此期間產生噪音爆發Turbulences generate a noise burst in the period



特徵 Symptoms: stochastic signal, noise is modulated by the stimulus, impulsive noise burst



隨機失真

Random Distortion



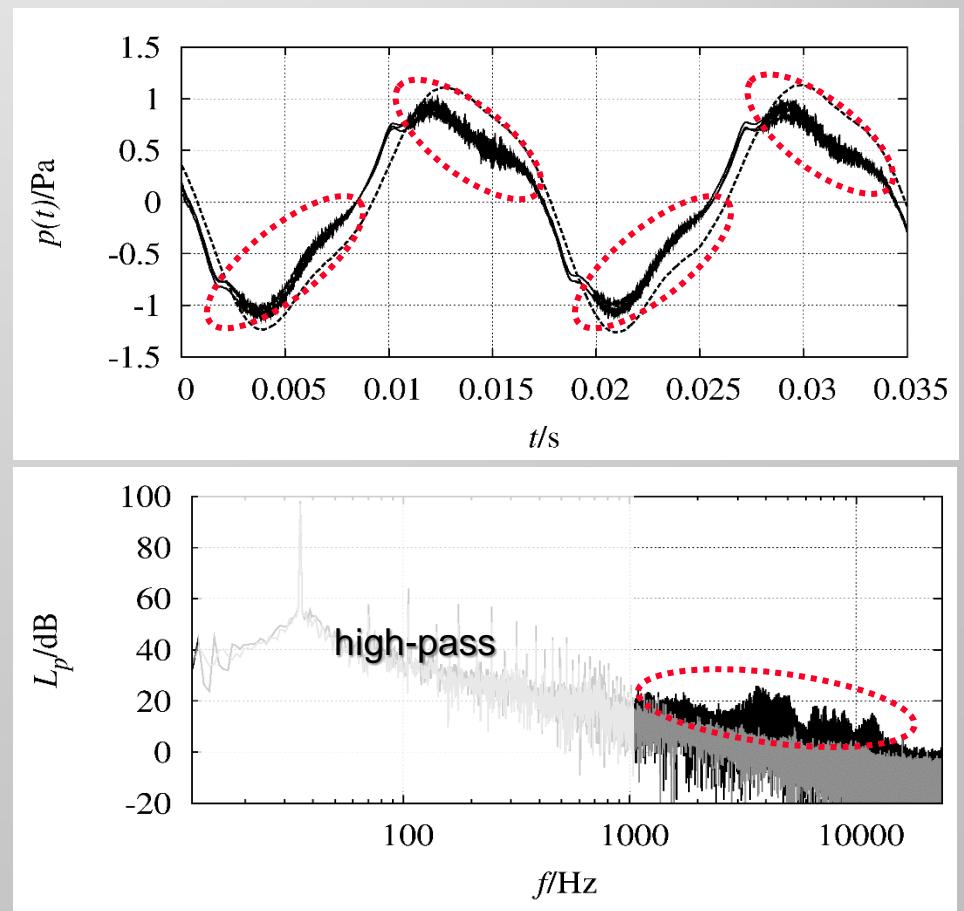
例如 Example:

洩漏處產生湍流空氣噪音，線圈摩擦

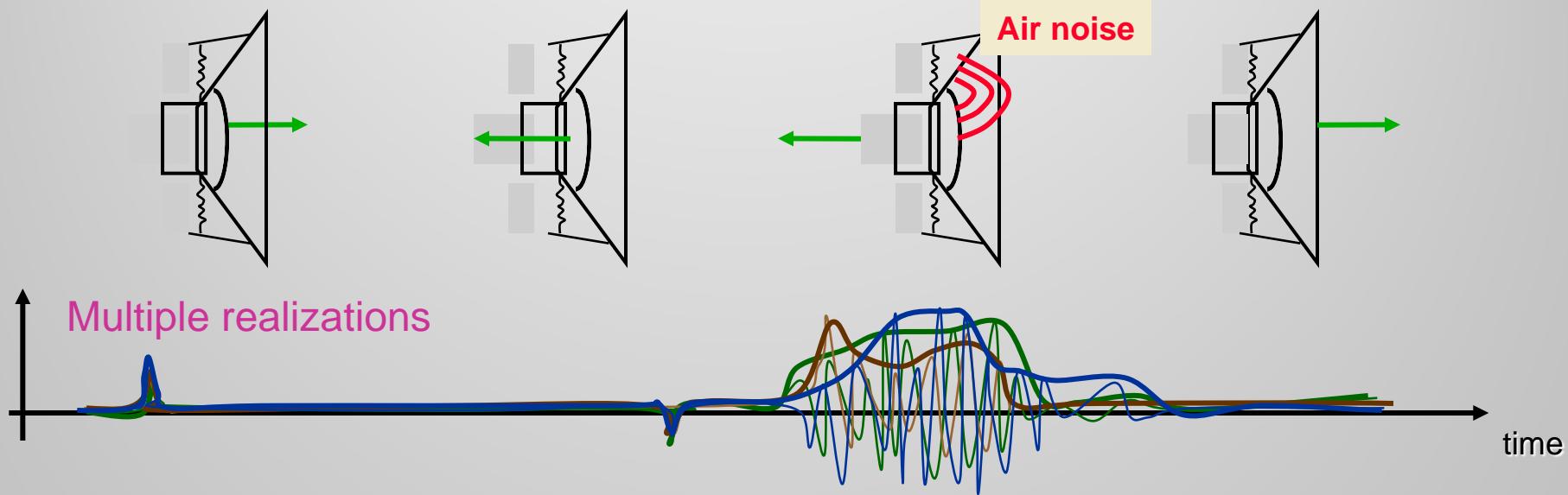
Turbulent air noise generated at leaks, coil rubbing

特徵 Symptoms:

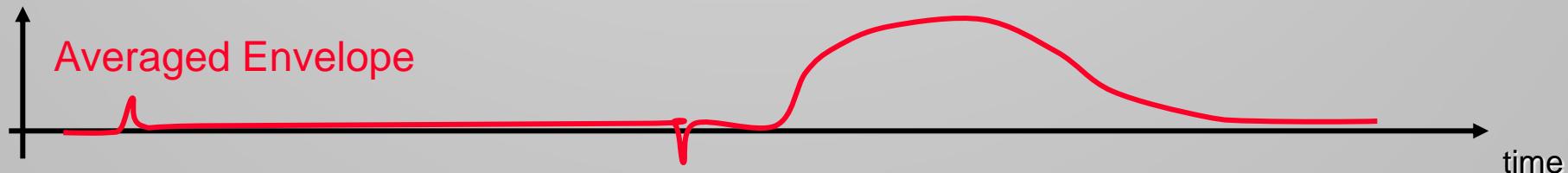
- 失真不可重現 Distortion are NOT reproducible
- 失真發生在特定時間 Distortion occur at particular times
- 密集頻譜（涵蓋音頻頻段及以上） Dense spectrum (cover audio band and beyond)



調製噪聲的封包 Envelope of the Modulated Noise



- Envelope of the modulated noise is deterministic
- Averaging of the envelope increases signal to noise ratio

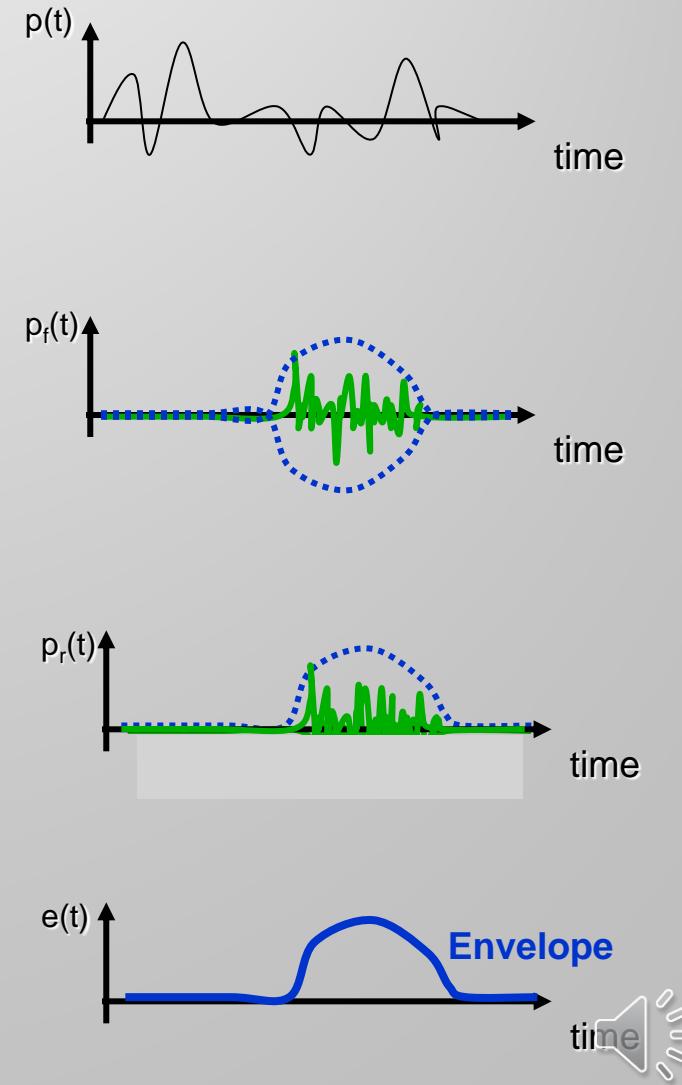
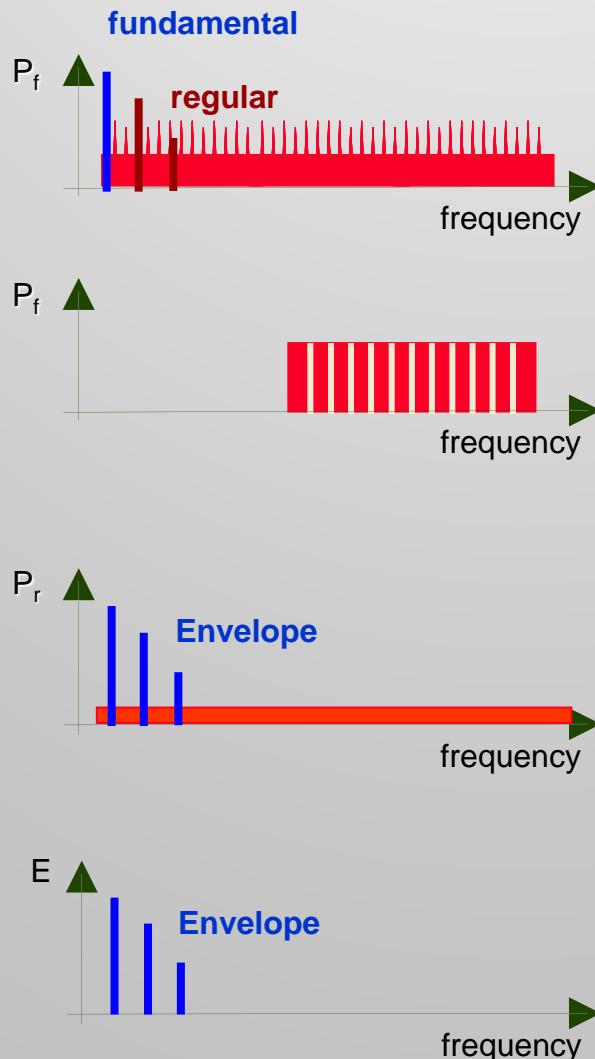
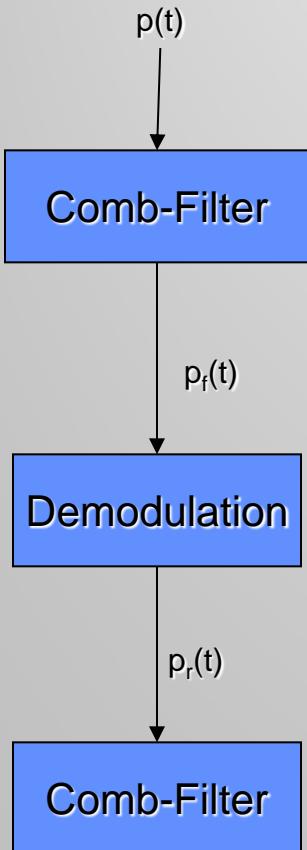




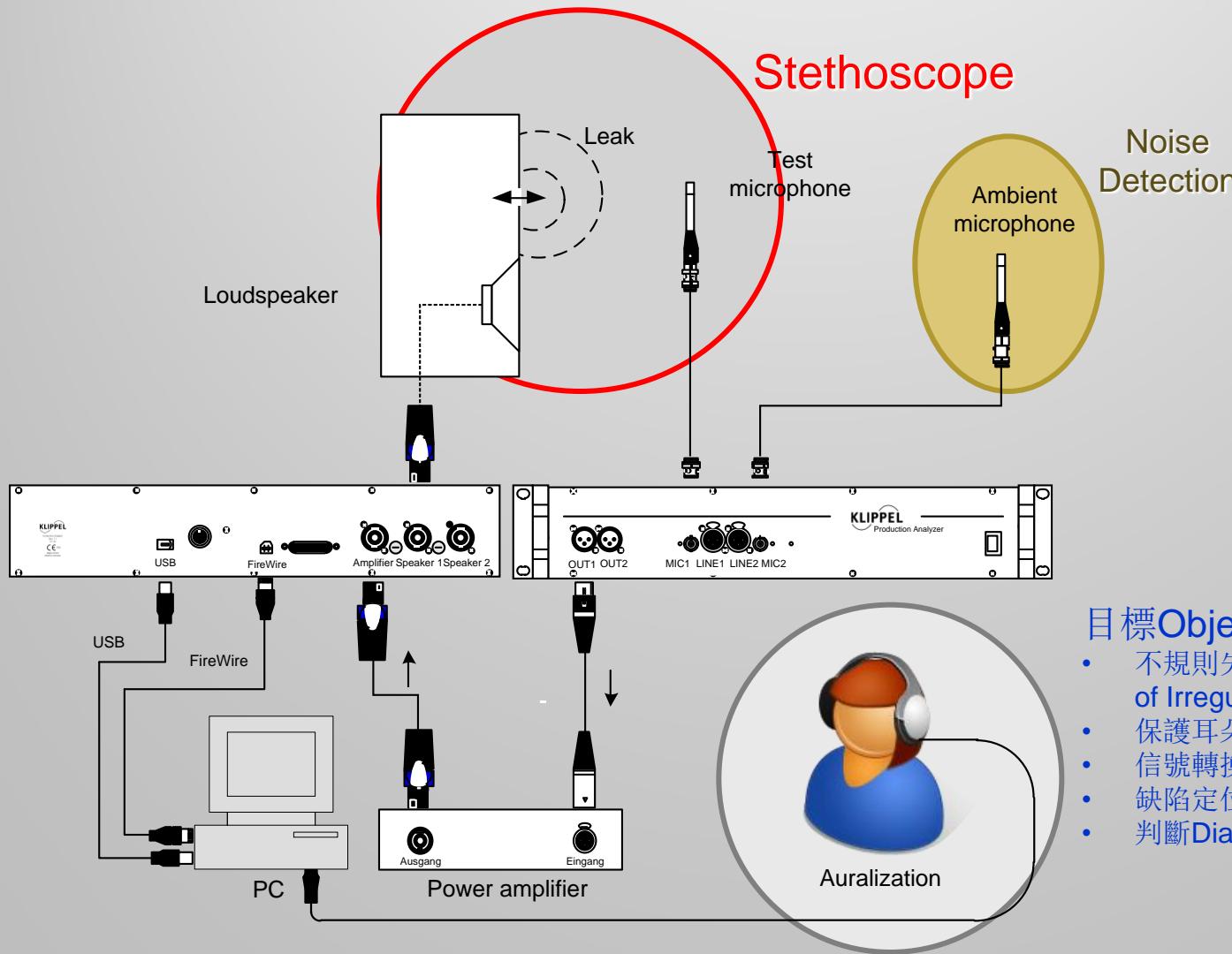
如何計算封包

How to Calculate the Envelope

Single tone



結合主觀和客觀評估 Combining Subjective and Objective Assessment

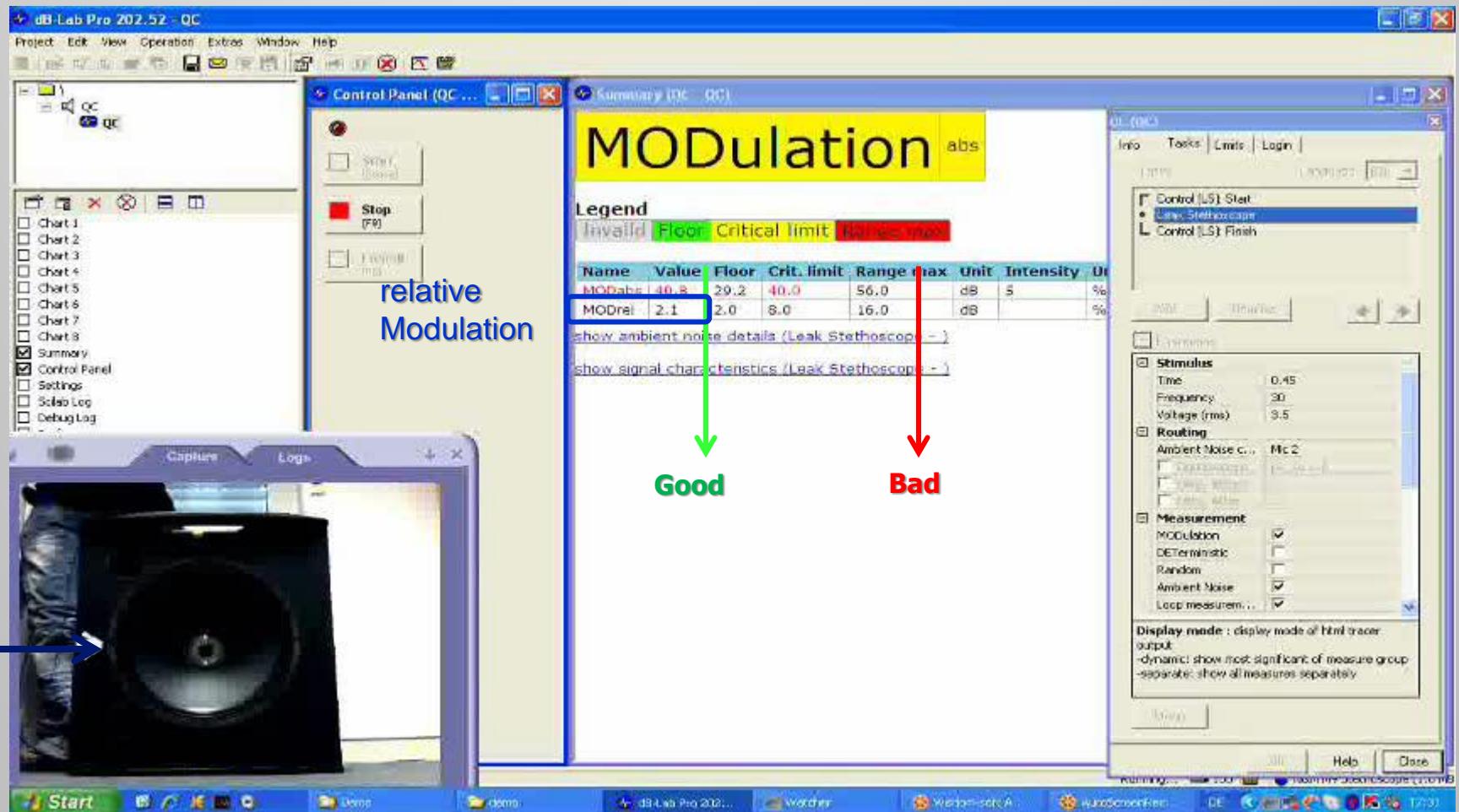


目標 Objectives:

- 不規則失真的可聽化 Auralization of Irregular Distortion
- 保護耳朵 Ear Protection
- 信號轉換 Signal Transformation
- 缺陷定位 Defect Localization
- 判斷 Diagnostics

揚聲器缺陷的定位

Localization of Loudspeaker Defects



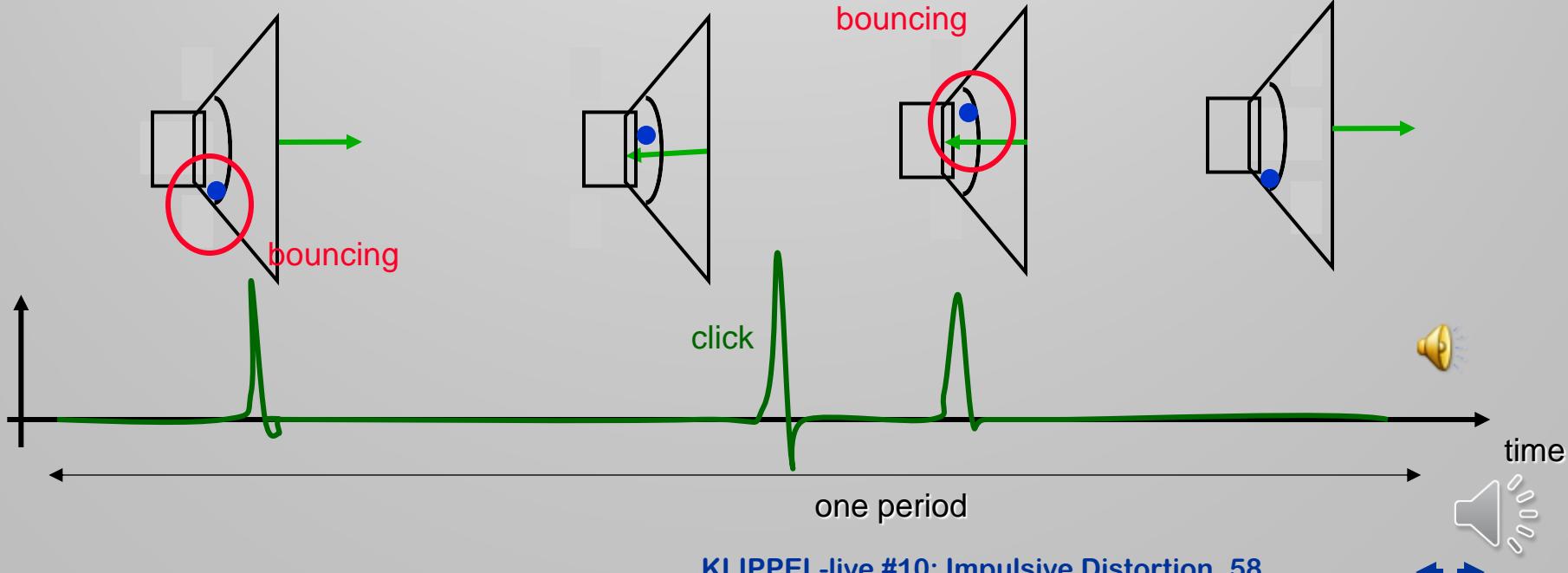
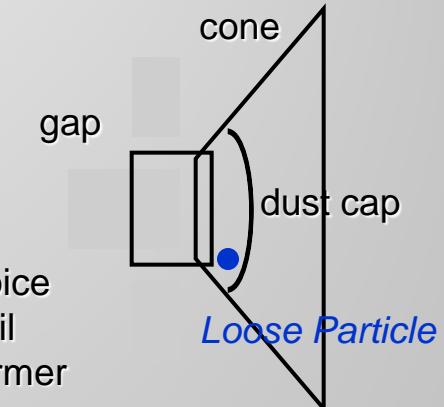
揚聲器缺陷：鬆散顆粒 Loudspeaker Defect: Loose Particles

根本原因 Root Cause

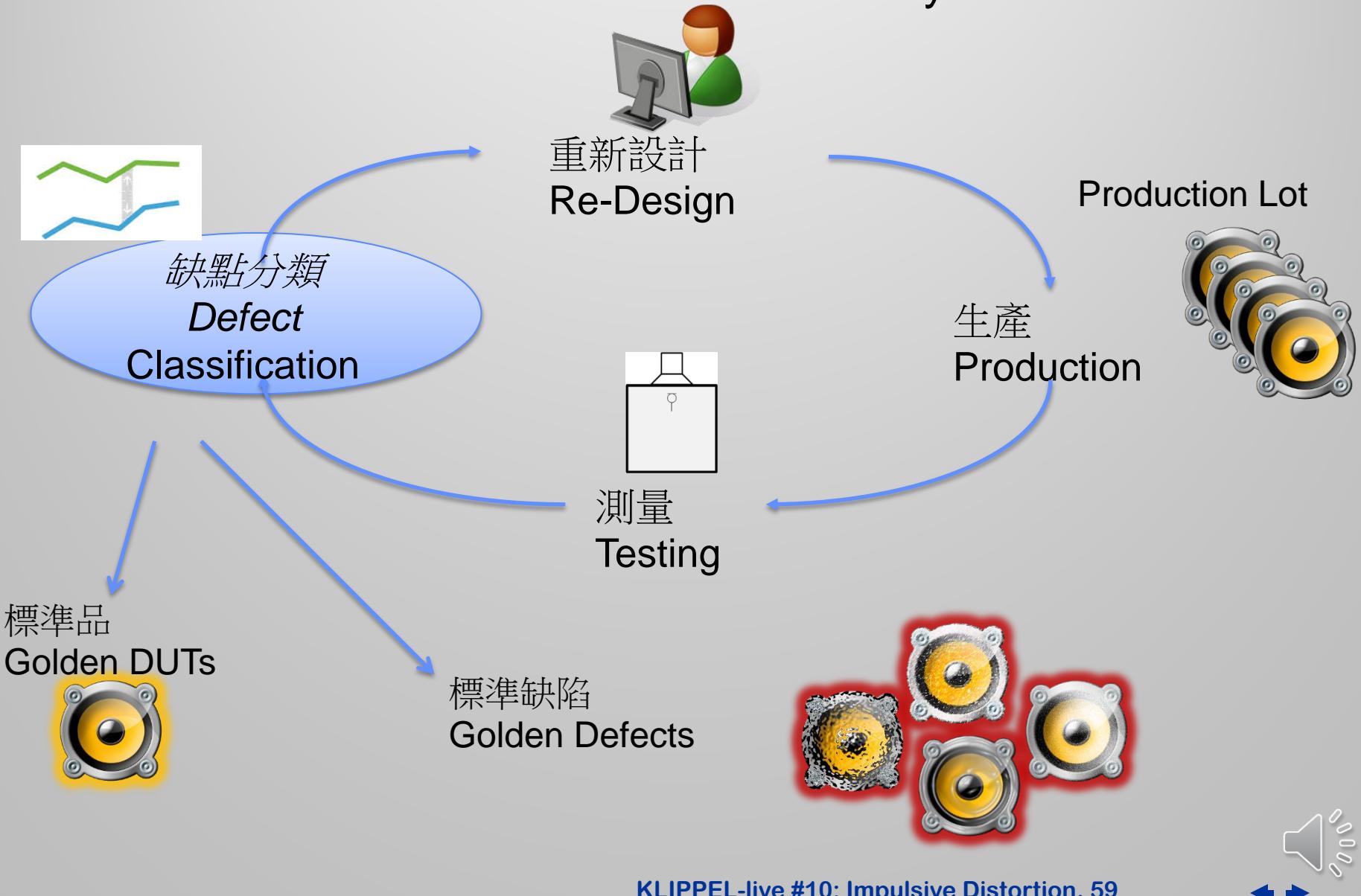
- 粒子通過錐體位移加速 particles are accelerated by cone displacement
- 彈跳隨時會產生短暫的點擊 bouncing generates a short click any time

特徵 Symptoms:

隨機，與激發不同步，峰值 SPL 高但輸出功率低，脈衝 random, not synchronized with stimulus, high peak SPL but low output power, impulsive



根本原因分析結果 Results of Root Cause Analysis



討論 Discussion



結論 Summary

- 正弦信號是對不規則失真非常敏感的刺激

A sinusoidal signal (chirp) is a very sensitive stimulus for irregular distortion

- 在近場使用靈敏的麥克風位置

Use a sensitive microphone place in the near field

- 檢查時域中的失真（殘差）

Inspect the distortion (residuum) in the time domain

- 尋找根本原因並修復它

Search for the root cause and fix it

- 聆聽上採樣失真信號以檢查精細結構

Listen to the up-sampled distortion signal to inspect the fine structure

- 不要將有缺陷的設備運送給客戶（大多數不規則的失真會隨著時間的推移而變得更糟）！

Do not ship a defective unit to a customer (most irregular distortion become worse over time) !

