Sound Quality

of the Electroacoustic Signal Chain from Source to Ear

Part 6: Nonlinear, regular Distortion - Symptoms

Roadmap

Two day courses

第一天First Day

1. Introduction – definition of tools and terms & roadmap
2. Small-signal modeling & measurement
3. Cone vibration analysis
4. 3D Sound Radiation
5. Nonlinear modeling & measurement

第二天Second Day

1. Nonlinear distortion Symptoms, relationship to Large Signal Parameters
2. Abnormal sound - irregular behavior, defects
3. How to define maximum SPL?
4. Quality Control, full system assessment
5. Adaptive Nonlinear Control of speakers



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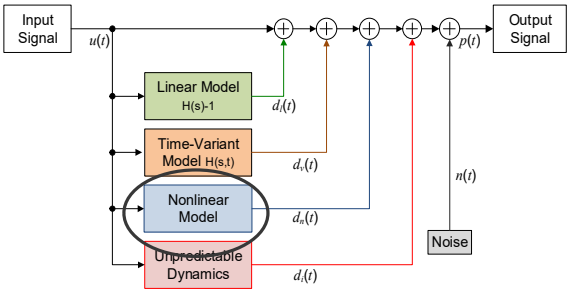
1. Nonlinear distortion and mechanism
2. One tone measurement (Harmonics, DC)
3. Two-tone measurement (Intermodulation)
4. Multi-tone measurement
5. How to measure in normal rooms?

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Regular nonlinear behavior

Distortion can be separated into:

- Linear transfer function: Desired small signal performance
- Time variant behaviour: Unavoidable time variance (e.g. heating, aging)
- Regular nonlinear distortion: Large signal performance (motor, suspension)
- Irregular distortion: Undesired defects



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HOW TO MEASURE

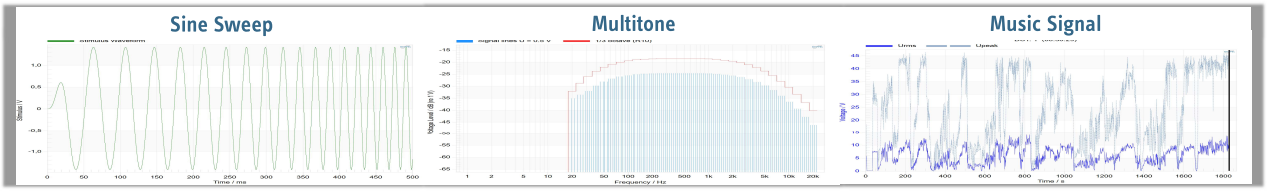
NONLINEAR SYMPTOMS?

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Which stimulus is useful?

→ Rising complexity of the stimulus →

Single-tone (TRF, DIS)	Two-tone (DIS)	Multi-tone (MTON)	Music (LAA)
Harmonic distortion (HD), DC	Intermodulation distortion (IMD), AMD	Multitone distortion (MTD)	Any signal



原型的評估
Evaluation of the Prototype

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1. 基於參數(模型要求) Parameter based (model required)
- 線性轉換函數 Linear transfer functions
- 小信號參數T/S Small signal parameter T/S
- 大信號參數(熱模型、非線性) Large signal parameters (thermal, nonlinear)



2. 基於性能(取決於信號) Performance-based (depend on stimulus)
- 非線性徵候 Nonlinear symptoms (THD, IMD, XDC)
- Rub & Buzz的表徵 Symptoms of Rub & Buzz
- 音圈溫度、壓縮、最大功率 Coil temperature, compression, Pmax

投票 Poll:

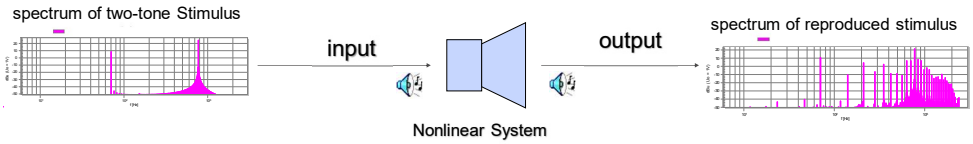
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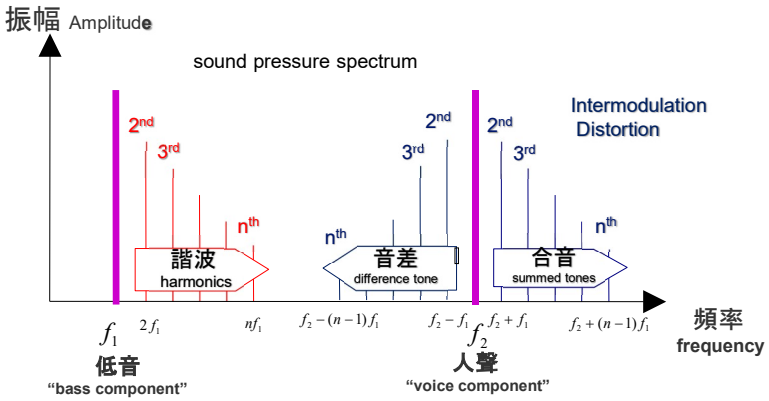
您如何評估常規非線性失真？
How do you assess the regular nonlinear distortion ?
(multiple responses are possible)

A. 我從來沒有這樣做過 I have never done this
B. 用聽的 Listening
C. 諧波失真測量 Harmonic distortion Measurement
D. 互調失真測試 Intermodulation distortion test
E. 直流位移測量 Measurement of DC-displacement
F. 其他 Others

特徵: 新的頻譜成分

Symptom: New Spectral Components



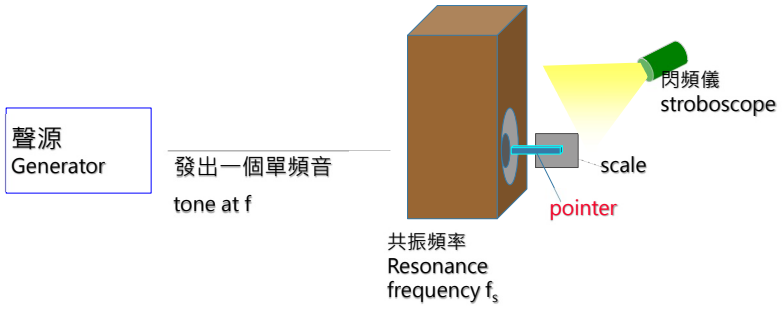


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由閃頻儀來觀察振動模式

Stroboscopic View on the Vibration Behavior

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觀察頻率小於共振頻率點

1. Experiment

f < fs

觀察頻率等於共振頻率點

2. Experiment

f≈ fs

觀察頻率大於共振頻率點

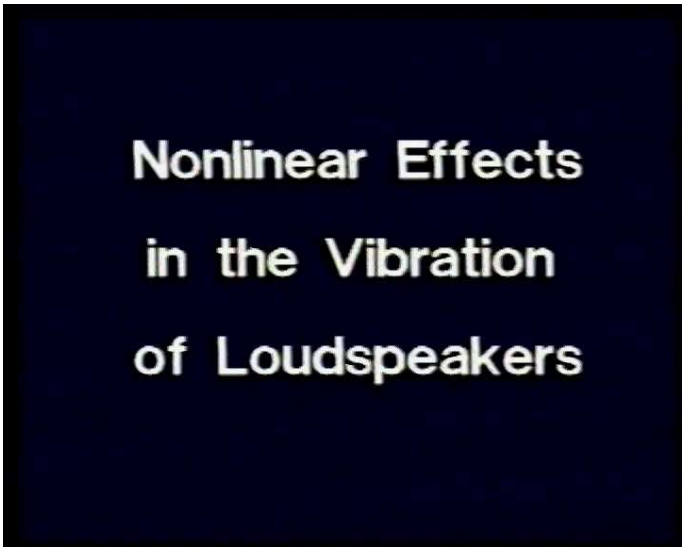
3. Experiment

f > fs

特徵：壓縮、直流位移

Symptom: Compression, DC Displacement

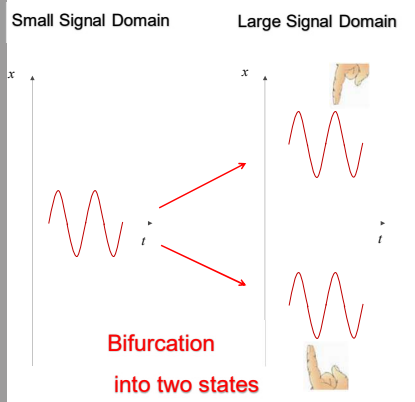
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非線性特徵：不穩定

Nonlinear Symptom: Instability

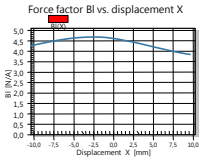
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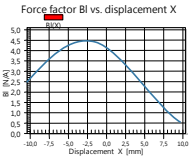


Stimulus: Single tone (f = 1.5fs) at high amplitude

弱非線性或強非線性?
Weak or Strong Nonlinearity ?



參數幾乎恒定
Parameter is almost constant



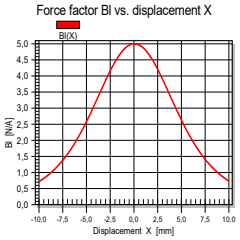
參數變化大
Parameter varies significantly

低訊號失真
LOW Signal Distortion (THD, IMD)

高訊號失真
HIGH Signal Distortion (THD, IMD)

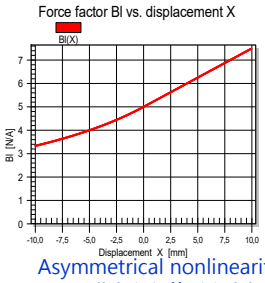
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對稱或非對稱
Symmetry or Asymmetry ?



Symmetrical nonlinearity
對稱非線性

與尺寸、重量、價格、
效率及最大輸出有關
related with size, weight, price,
efficiency, maximal output



Asymmetrical nonlinearity
不對稱非線性

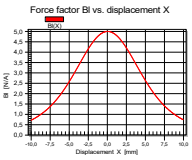
由幾何形狀的不對稱，音圈偏移所引起
Caused by asymmetry in geometry, voice coil offset, ...

有好有壞 Good and bad

通常不好 usually bad

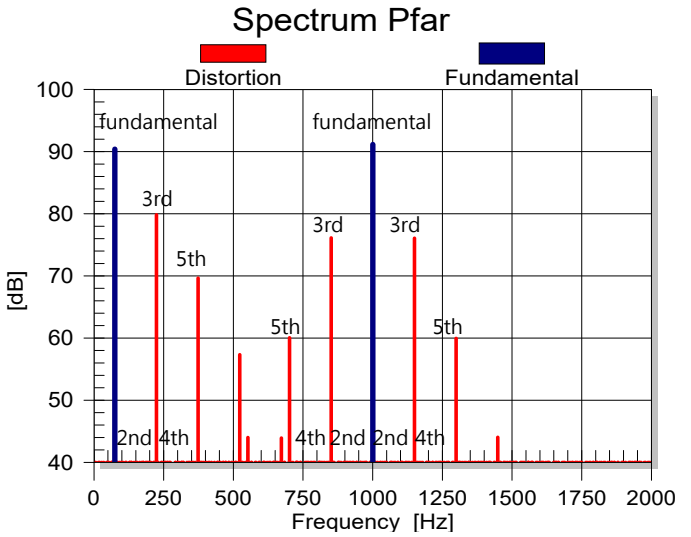
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對稱非線性失真
Distortion of a Symmetrical Nonlinearity



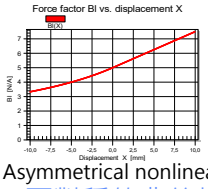
Symmetrical nonlinearity
對稱非線性

odd-order distortion
奇次諧波失真
3rd,5th,7th-order component



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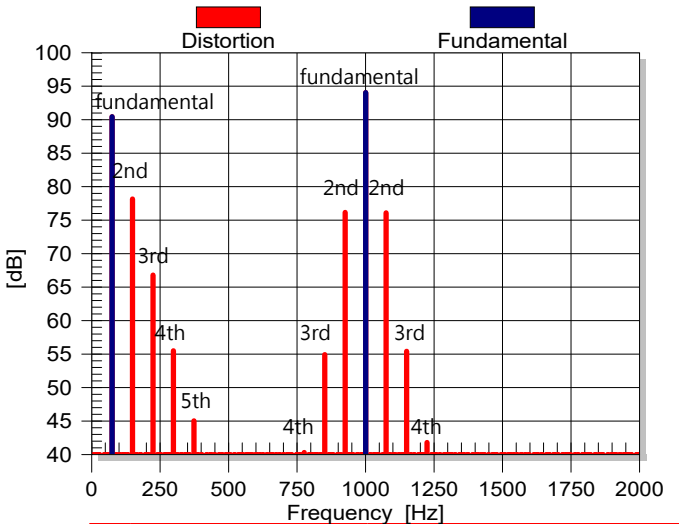
非對稱非線性失真
Distortion of a Asymmetrical Nonlinearity



Asymmetrical nonlinearity
不對稱的非線性

even-order distortion
偶次諧波失真
2nd,4th,6th-order component

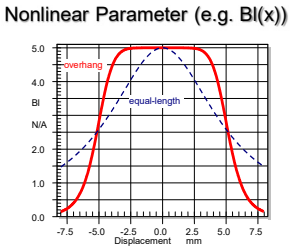
odd-order distortion
奇次諧波失真
3rd,5th,7th-order component



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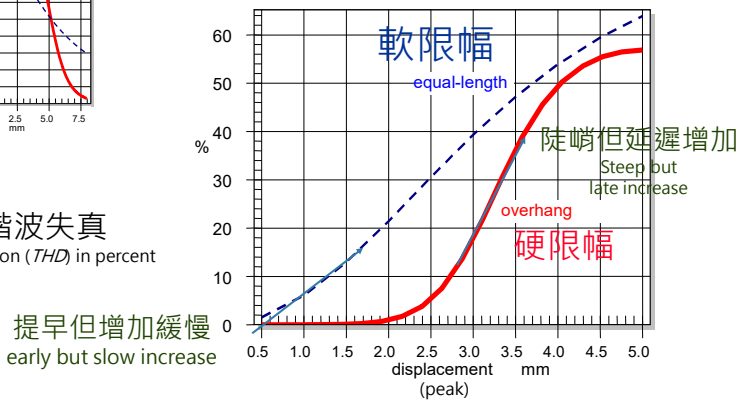
由軟或硬限幅所造成的總諧波失真

Total Distortion generated by hard or soft limiting nonlinearity



總諧波失真

Total harmonic distortion (*THD*) in percent



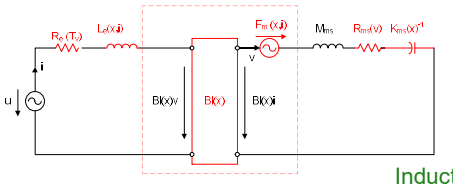
提早但增加緩慢

early but slow increase

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主導影響的非線性

Effects of the Dominant Nonlinearities



Stiffness
$K_{MS}(x)$

Mechanical Resistance
$R_{ms}(v)$

Force factor Bl(x)

Inductance
$L_e(x)$

Flux Modulation
$L_e(i)$

$$K_{ms}(x)x + \left(R_{ms}(v) + \frac{Bl(x)^2}{R_e}\right)v + M_{ms}\frac{dv}{dt} = \frac{Bl(x)}{R_e}\left(u(t) - \frac{d\left(L_e(i,x)i\right)}{dt}\right) + \frac{i^2}{2}\frac{dL_e(x)}{dx}$$

Nonlinear damping

非線性阻尼

Parametric excitation

Differentiated Flux

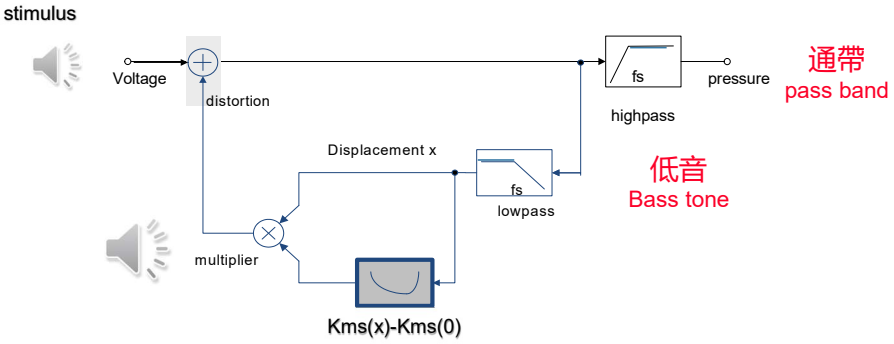
磁阻力

Reluctance Force

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問題:勁度係數Kms(X)引起的失真

Problem:Distortion due to Kms(x)

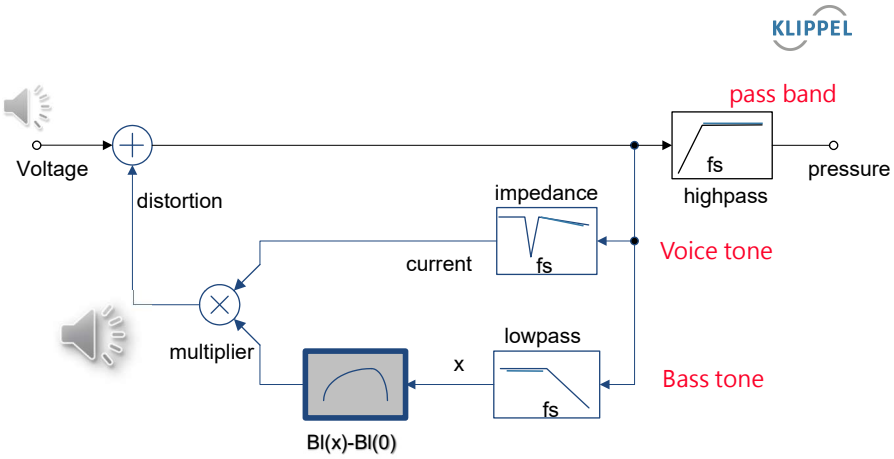


1. Generating displacement x by low-pass filtering
2. Multiplication of displacement x with nonlinear function of displacement x
3. Adding the nonlinear distortion to the input signal
4. High-pass filtering

→ harmonics ($f_1 \le f_s$) at lower frequencies

問題:BI(X)的失真

Problem: Distortion of BI(x)

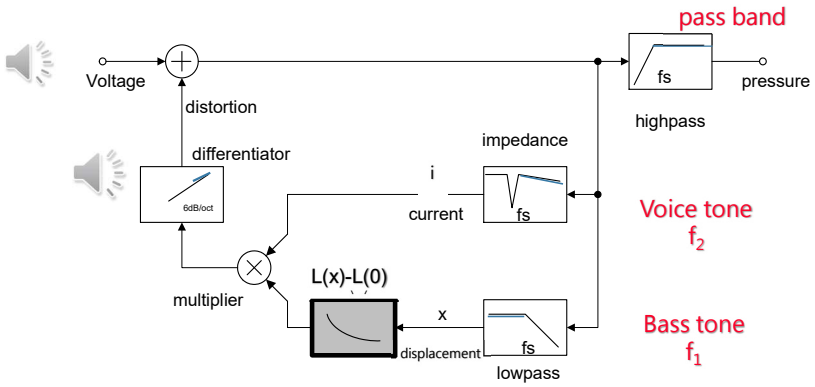


1. Generating displacement x and current i
2. multiplication of current i with a nonlinear function of displacement x
3. Adding the nonlinear distortion to the input signal
4. High pass filtering

→ harmonics ($f_1 \le f_s$) and intermodulation distortion at higher frequencies ($f_1 \le f_s$, $f_2 > f_s$)

電感Le(x)所引起的失真

Distortion caused by Le(x)

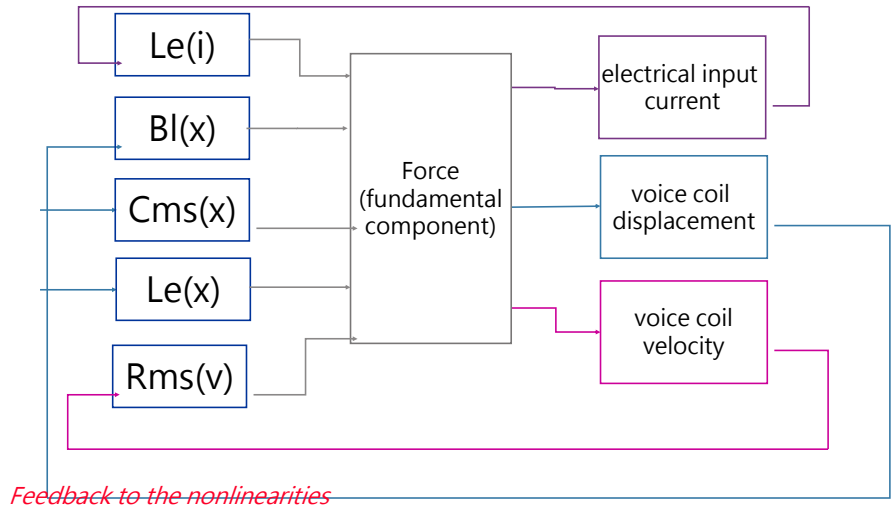


1. Generating displacement x and current i
2. Multiplication of current i(t) with a nonlinear function of displacement x(t)
3. Differentiation of distortion
4. Adding the nonlinear distortion to the input signal

→ High intermodulation distortion ($f_1 \leq f_s$, $f_2 > f_s$) at higher frequencies

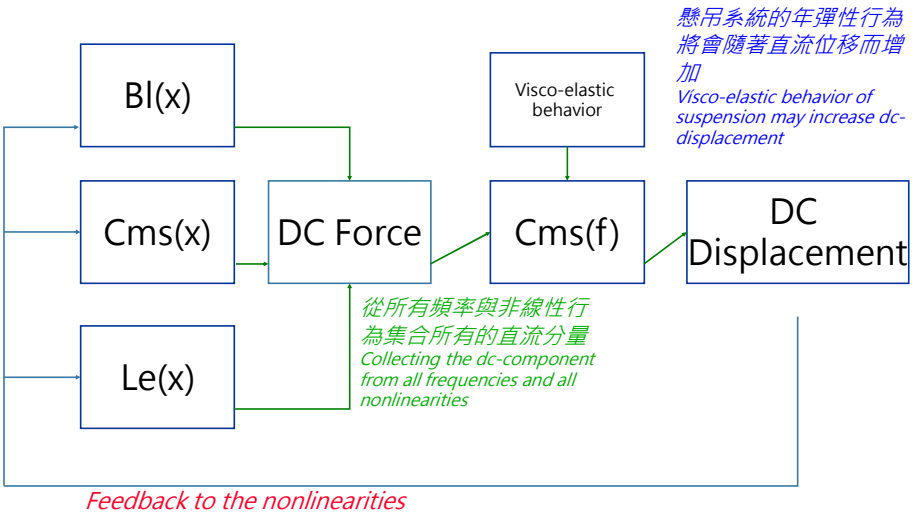
藉由基頻成份耦合各個非線性間的影響

Interaction between nonlinearities coupled via fundamental component



藉由直流位移耦合各個非線性間的影響

Interaction Between Nonlinearities coupling via DC displacement



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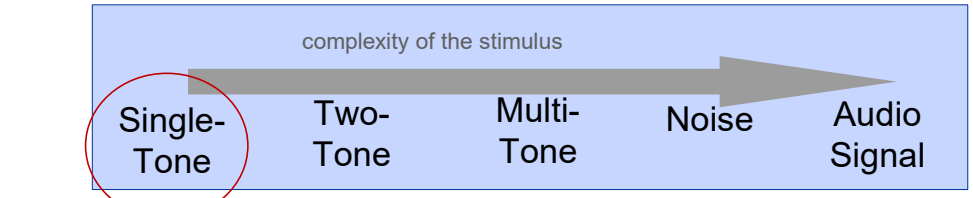


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1. Nonlinear distortion and mechanism
2. One tone measurement (Harmonics, DC)
3. Two-tone measurement (Intermodulation)
4. Multi-tone measurement
5. How to measure in normal rooms?

單頻訊號是屬於一個好的激發訊號ㄇ?

Is a Single Tone a Good Stimulus ?



Spectral Analysis
(Fourier Transform,
High-pass and bandpass filter, ...)

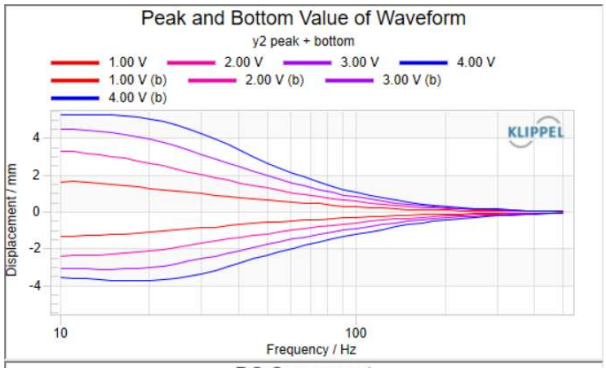
PRO:
- 生成上簡單 simple to generate
- 顯示諧波 reveals harmonics, dc component
- 顯示基頻壓縮的最大輸出 reveals maximal output of fundamental compression
- 快速 Ultra-fast sweep measurements are possible
- 對於R&B來說是好的 good for rub&buzz (see section D10)

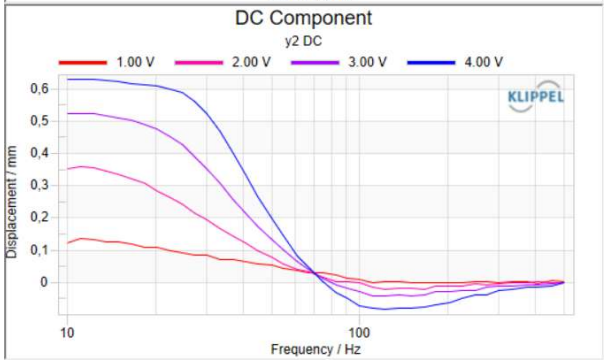
CONTRA:
- 沒有互調失真 no intermodulation components are generated
- 對於非線性無法完整的評估
  not a comprehensive assessment of the nonlinear behavior

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DIS: Harmonic distortion

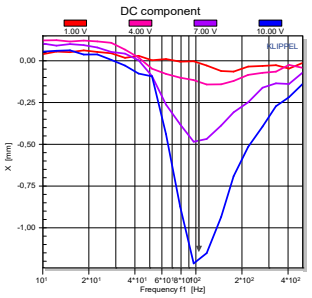
- Harmonic distortion
- Compression
- DC Component
- Motor stability





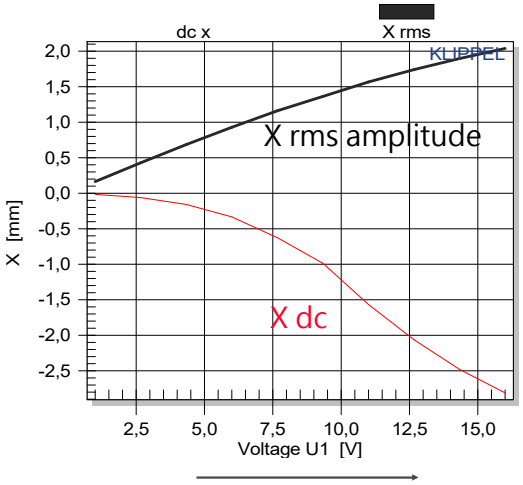
由於BI(x)不對稱性引起的直流位移

DC displacement due to BI(x) asymmetry



在臨界頻率處, ≈1.5 fs,進行測試

Test at critical frequency f≈1.5 fs

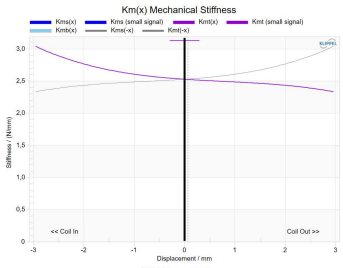


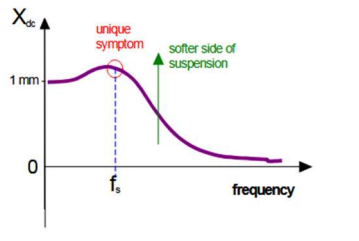
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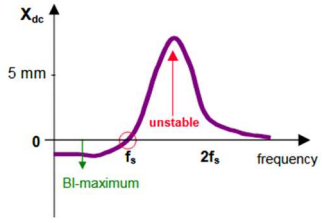
DIS: DC Component

- Nonlinearities produce DC component by rectifying the AC signal
- Different rectification processes cancel out each other
- More Information: AN13 Dynamic Generation of DC Displacement

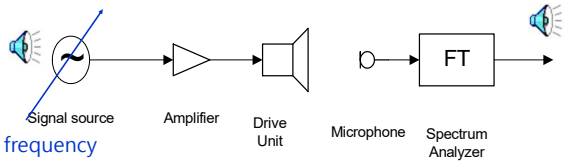
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聲壓中的諧波失真
Harmonic Distortion in Sound Pressure



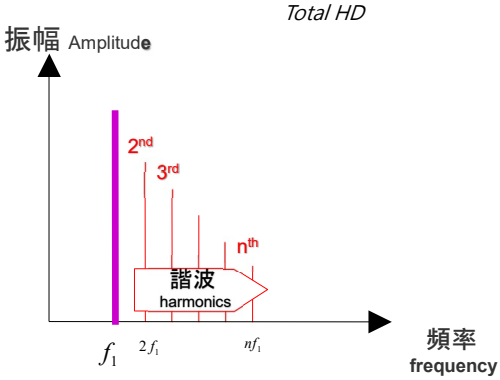
振幅反應
Amplitude response versus frequency:

2nd-order HD
3rd –order HD
Total HD

<u>最佳的激發訊號 Optimal Stimulus:</u>
隨頻率變化的單頻信號
Single Tone with varying frequency

Requirement:
ALMA Test CD, tone generator,
Real time analyzer

Defined by IEC standard 60268-5



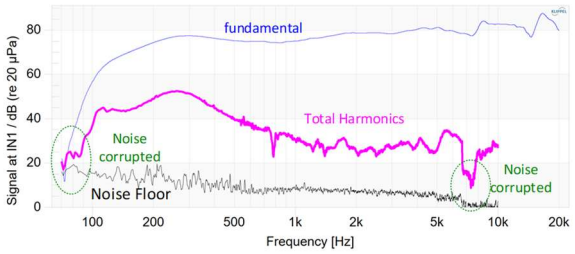
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Total Harmonic Distortion

Absolute SPL components in dB

$$L_{\mathrm{TH}}(f,\mathbf{r}_e)=10\lg\left(\frac{\sum_{n=2}^{N}\tilde{p}_{nf}^2(f,\mathbf{r}_e)}{p_0^2}\right)dB$$

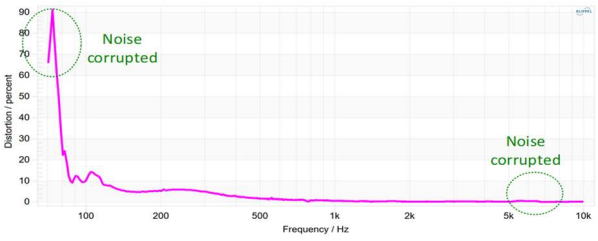
reference sound pressure p_0 = 20µPa



Relative Distortion Ratio in percent

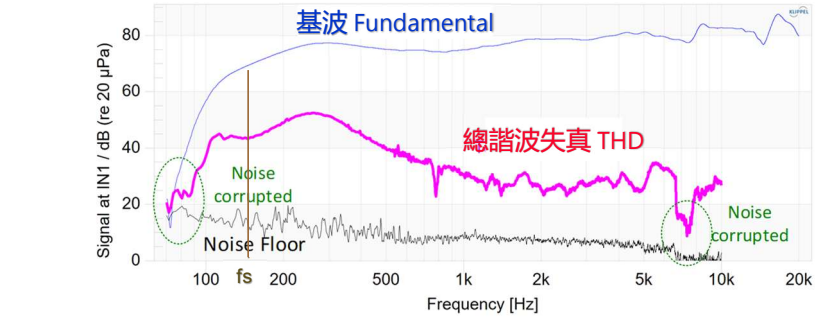
$$R_{\mathrm{THD}}(f,\mathbf{r}_e)=\frac{\sqrt{\sum_{n=2}^{N}\tilde{p}_{nf}^2(f,\mathbf{r}_e)}}{\tilde{p}_{ref}(f,\mathbf{r}_e)}\%$$

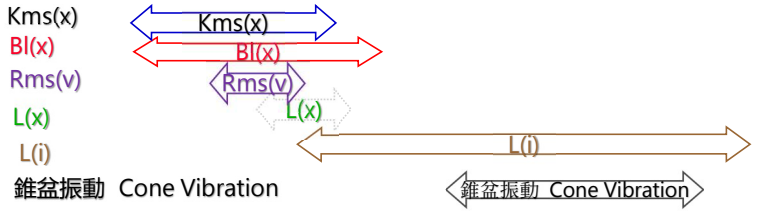
The reference signal can be
- the Fundament (IEC)
- the total signal (IEEE)



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諧波失真的原因
The causes of harmonic distortion





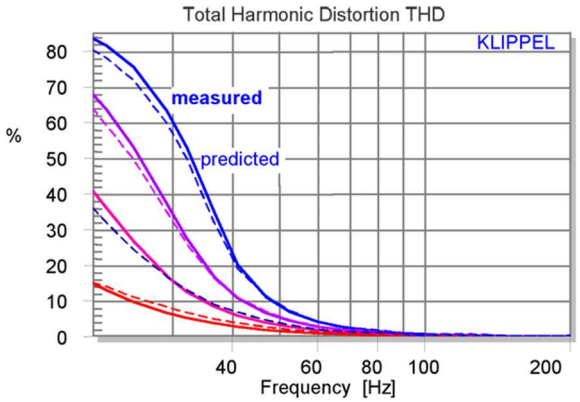
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How to verify measured nonlinearities?

Comparing measured distortions with simulated distortions based on nonlinear distortions

Measurement process:

1. Nonlinearities – FLSI/LSI3
2. Distortions – DIS
3. Simulation - SIM

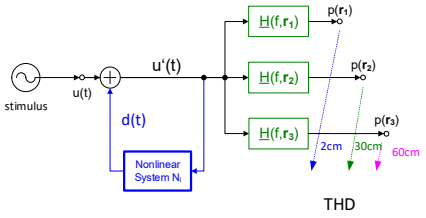


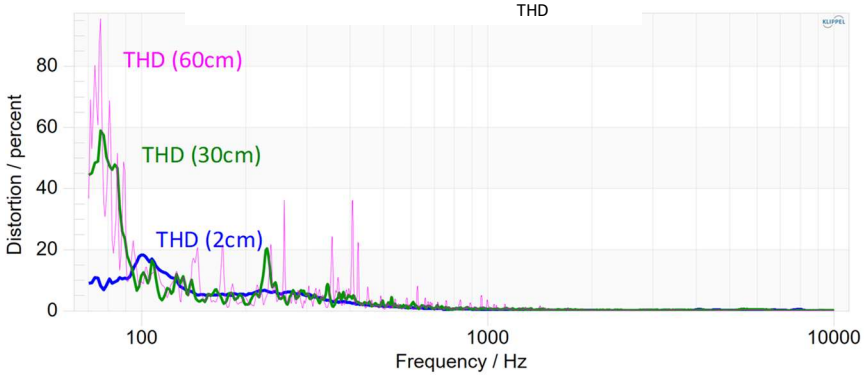
KLIPPEL

THD(f, r) versus distance

在非消聲環境中參考軸上三個距離處測量的總諧波失真 (THD) 與激勵頻率的百分比

Total harmonic distortion (THD) in percent versus excitation frequency measured at three distances on the reference axis in a non-anechoic environment





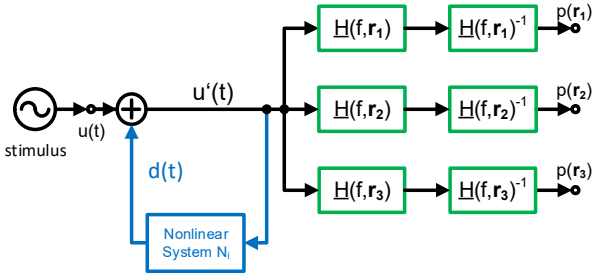
KLIPPEL

TRF: Equivalent input harmonic distortion (EIHD)

KLIPPEL

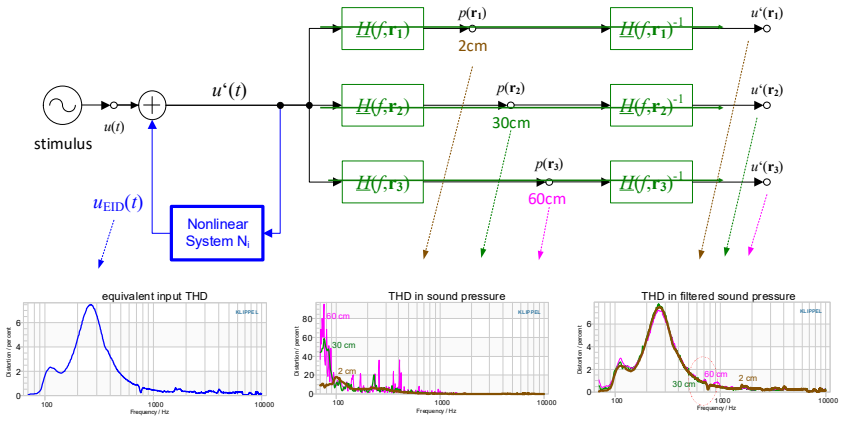
- Nonlinearities are independent of the measurement position
- One single point is sufficient (2-3 points are recommended)
- Near field measurement recommended (best SNR)
- Dependency on test point position
  = symptom of distributed nonlinear distortion and noise

Filtering with the inverse transfer function



Evaluate Distortion at the Source

equivalent input harmonic distortion IEC 60268-21



Distributed nonlinear distortion (negligible)

Advantages of Equivalent input distortion:

- explains the dominant loudspeaker nonlinearities
- is independent of the measurement position, room, microphone, etc.
- is the basis for generating relative voltage distortion ratio u_d/u (in percent)

KLIPPEL LIVE #8

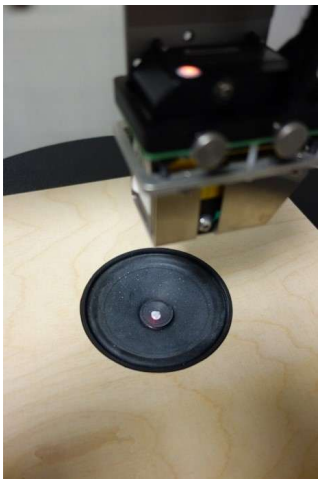
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非線性失真（單音）
Nonlinear Distortion (single tone)

Experiment

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- 只需最少的測試工作即可對以下症狀進行揚聲器診斷：
- Loudspeaker Diagnostic on following symptoms with minimum test effort:
- 基本非線性壓縮（最少溫升）
- Nonlinear Compression of the Fundamental (minimal heating)
- 使用三角測量雷射測量直流位移
- DC displacement measured with Triangulation Laser
- 諧波失真（線性調頻脈衝刺激）
- Harmonic Distortion (Chirp stimulus)





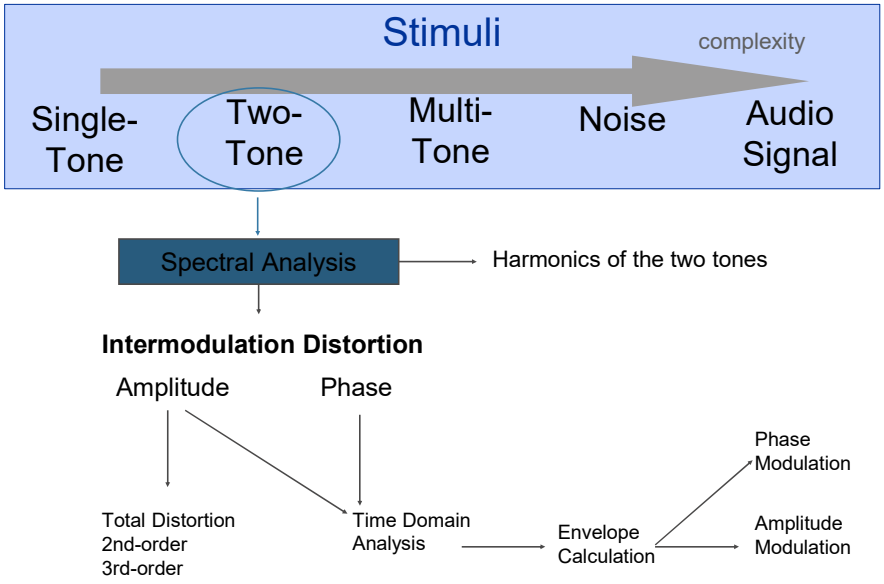
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Nonlinear distortion and mechanism
2. One tone measurement (Harmonics, DC)
3. Two-tone measurement (Intermodulation)
4. Multi-tone measurement
5. How to measure in normal rooms?

激發訊號對於頻率而言是稀疏的分布，但卻是完整的

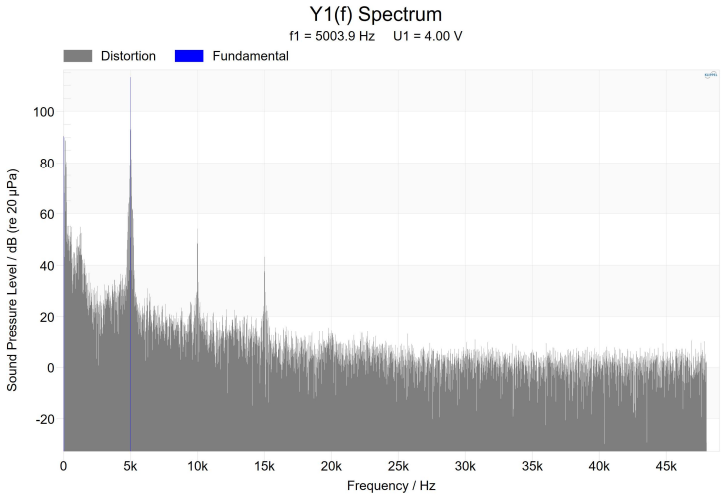
Sparse but Comprehensive Stimulus

KLIPPEL



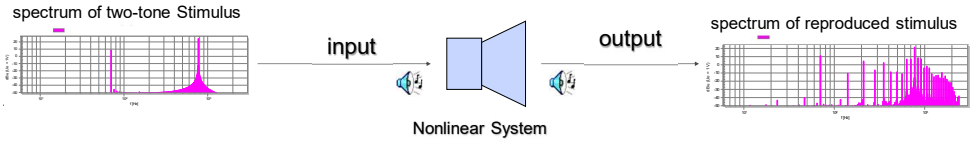
DIS: Intermodulation distortion

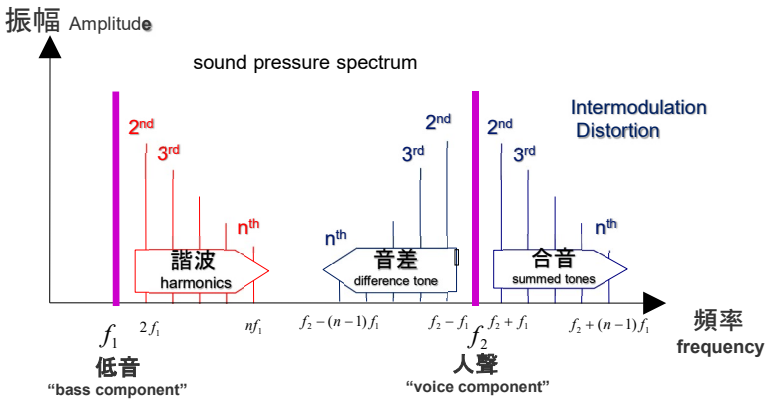
- Series of steady-state measurements
- Two-tone, different levels
- Intermodulation distortion



互調失真的測量 - 雙頻激發

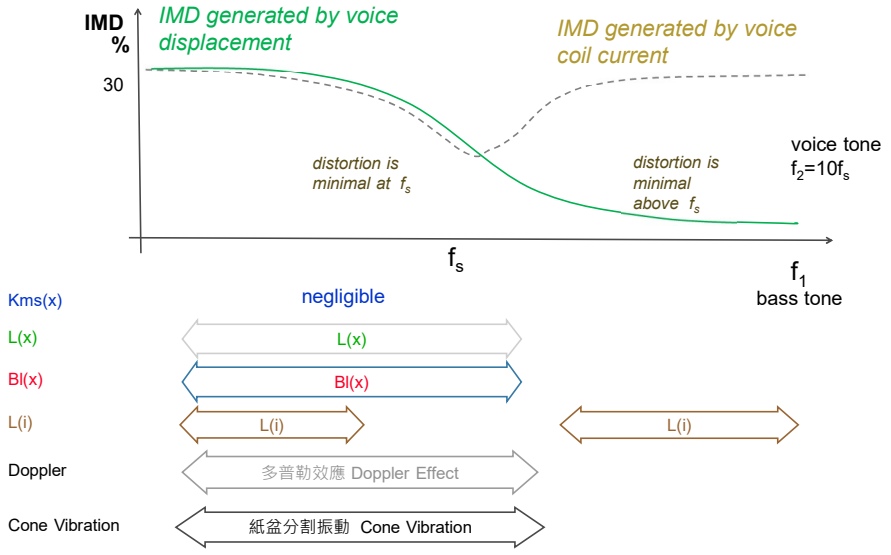
Measurement of Intermodulation - Two-tone Stimulus





互調失真的原因 - 低音掃頻技術

Causes of intermodulation distortion - bass sweep technique in sound pressure



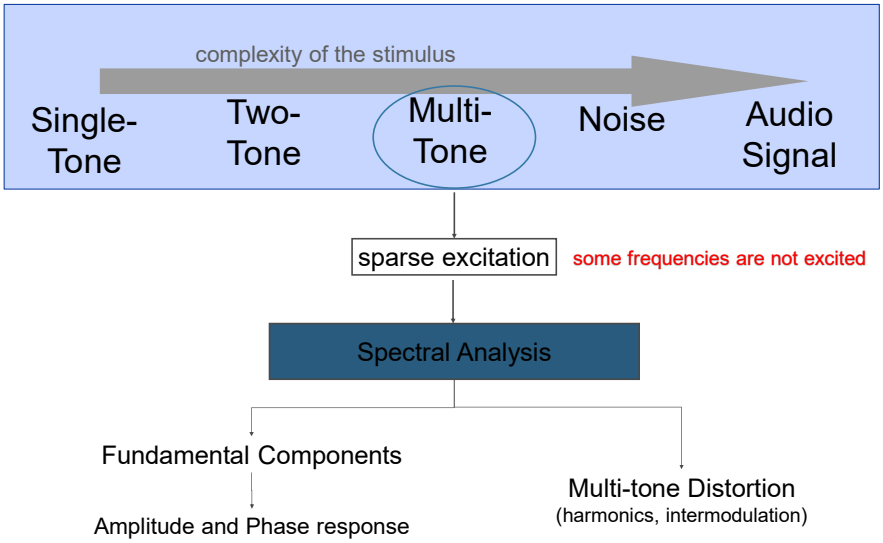
KLIPPEL



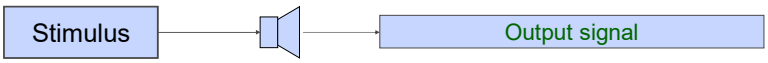
KLIPPEL

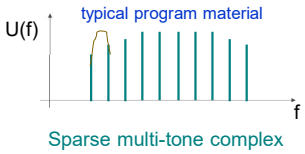
1. Nonlinear distortion and mechanism
2. One tone measurement (Harmonics, DC)
3. Two-tone measurement (Intermodulation)
4. Multi-tone measurement
5. How to measure in normal rooms?

普遍激發
Universal Stimulus
complex, steady-state, like an organ tone

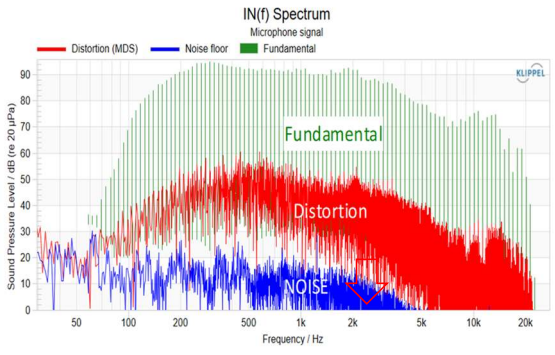


多音失真 (MTD)
Multi-Tone Distortion (MTD)





Sparse multi-tone complex

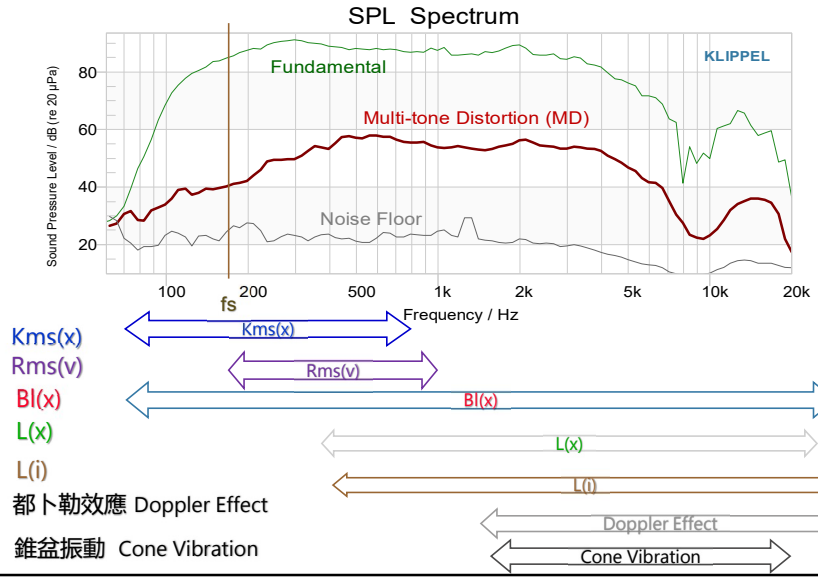


Unique „Fingerprint“ of the regular nonlinearities

MTD comprise
- harmonic components
- intermodulation components

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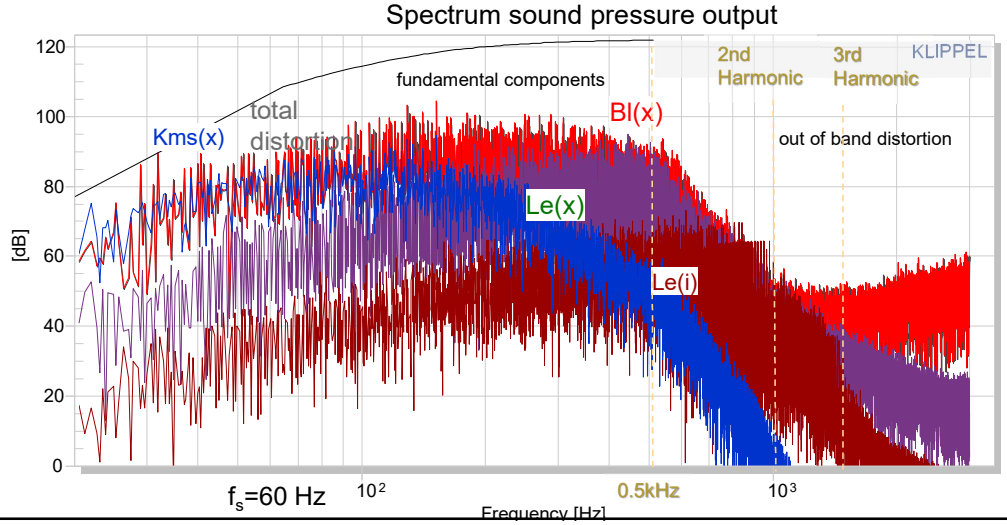
複頻失真原因
The causes of multi-tone distortion



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分析低音喇叭失真
Exercise: Woofer Analysis of Multi-tone Distortion (MD)

causes: Le(x) Kms(x) Bl(x) Le(i) Doppler Effect Cone Vibration

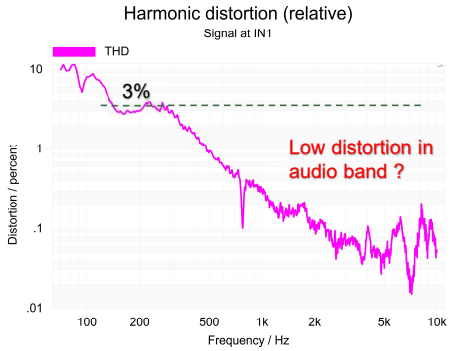


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THD 與 RMD（相對指標）

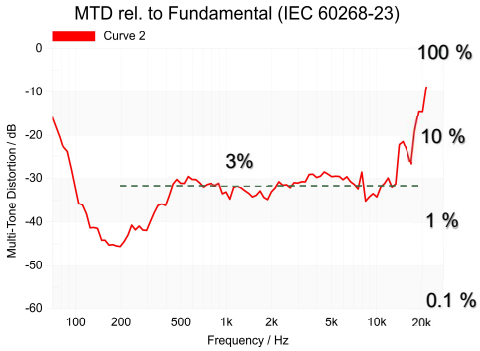
THD contra RMD (relative metrics)

Total Harmonic Distortion (THD)
(referred to fundamental)



excitation frequency f_i →

Relative multi-tone Distortion (RMD)



spectral frequency f →

How to interpret THD correctly ?

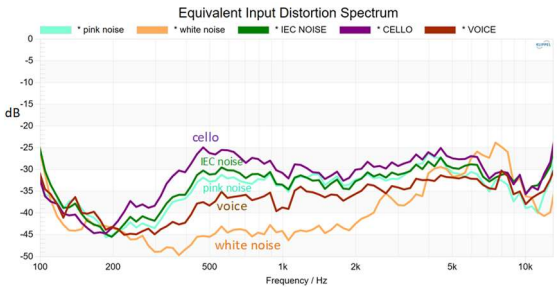
Harmonic distortion meausurement (THD) can not explain distortion generated by a normal audio signal (music)

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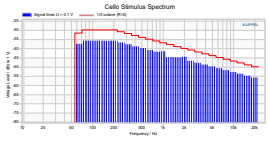
激發影響 Stimulus Influence

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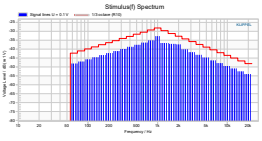
Relative Multi-tone Distortion (RMD)



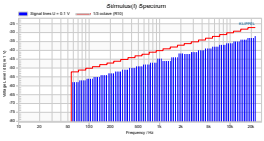
Simulated cello music



Simulated voice



White noise

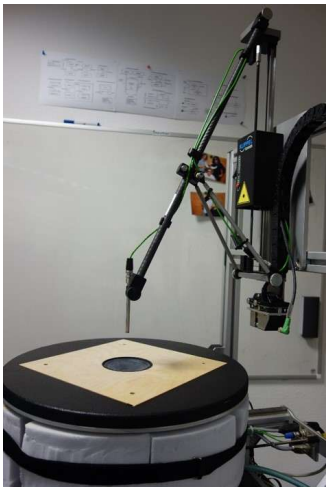


具有更多低頻功率的刺激會產生更多的音圈位移和失真
Stimuli with more low frequency power generates more voice coil displacement and distortion !

互調失真測量 (MTON) Intermodulation Distortion Measurement (MTON)
Experiment

KLIPPEL

- 只需最少的測試工作即可對以下症狀進行揚聲器診斷：
- Loudspeaker Diagnostic on following symptoms with minimum test effort:
-
- 雙音激發互調失真 (DIS)
- Intermodulation Distortion with Two-tone Stimulus (DIS)
- 由代表典型音訊訊號的稀疏多音刺激產生的失真頻譜 (MTON)
- Distortion Spectrum generated by sparse multi-tone stimulus representing typical audio signals (MTON)



如何妥善處理非線性
How to cope with nonlinearities

Summary

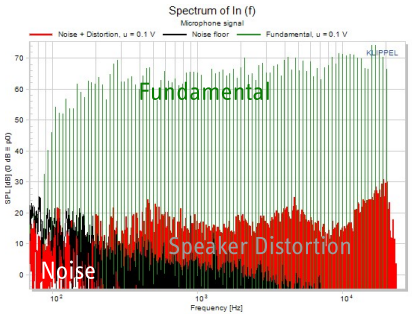
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- Measure harmonics and intermodulation
  → Use multi-tone stimulus
- 在近場測量非線性失真
  Measure nonlinear distortion in the near field
  →確保足夠的信噪比 ensure sufficient SNR
- 將失真轉換成揚聲器的輸入
  Transform distortion to the loudspeaker input
  →等效輸入失真的概念 concept of equivalent input distortion
- 注意非線性之間的相互作用
  Be aware of interactions between nonlinearities
  →不需要補償 no compensation of Kms(x), Bl(x), L(x)
- 檢測直流分量 Check for dc-displacement
  →不穩定性 instability
- 使用數值類比軟體 Use numerical simulation tool
  →看THD, X_{max}, SPL_{max}, IMD, P_{max} ,T的影響
  see impact on THD, X_{max}, SPL_{max}, IMD, P_{max} ,T

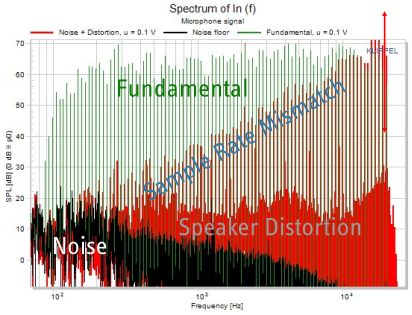
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EXCOURSE: Digital and Wireless Devices

Multi-tone distortion (analog input)



Multi-tone distortion (bluetooth input)



40 dB more distortion

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EXCOURSE: Digital and Wireless Devices

Tips: Avoid (if you can)

- Avoid long measurements (to get high frequency resolution)
- Avoid long averaging
- Use Clock Drift Tolerance (currently, only in MTON)

4. Regular nonlinear distortion (DIS, TRF, MTON)

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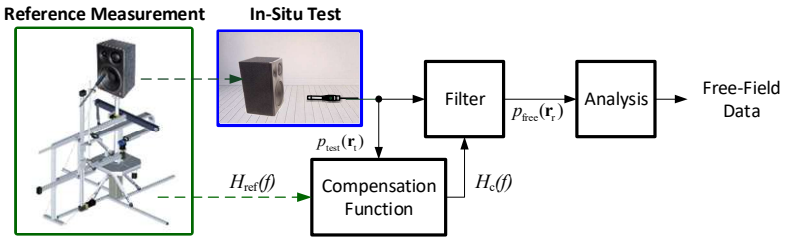
1. Nonlinear distortion and mechanism
2. One tone measurement (Harmonics, DC)
3. Two-tone measurement (Intermodulation)
4. Multi-tone measurement
5. How to measure in normal rooms?

How to compensate for the room influence?

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Measurements under simulated free-field conditions (IEC 60268-21)

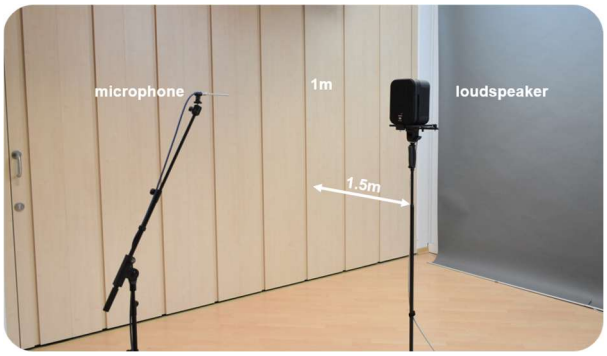
Target: Perform all measurements in a non-optimized environment
Problem: Reverberation, room modes, and other influences
Solution: Use a linear compensation function



ISC: Compensation with low frequency reference

- More Information: Fast Loudspeaker Measurement in Non-Anechoic Environment

KLIPPEL



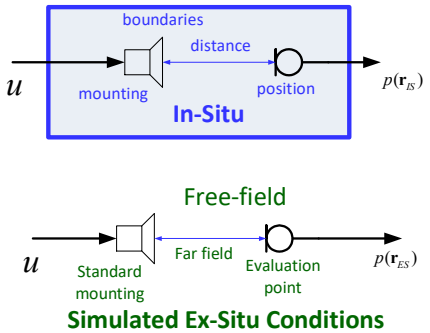
$$H_c(f) = \frac{H_{free}(f, \mathbf{r}_r)}{H_{room}(f, \mathbf{r}_r) H_{free}(f, \mathbf{r}_t)} = \frac{H_{ref}(f, \mathbf{r}_r)}{H_{test}(f, \mathbf{r}_t)}$$

Fast In-situ Measurement

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Targets:

- Single point in-situ measurement
- Accurate loudspeaker data under simulated ex-situ conditions
- Applicable to nonlinear distortion (THD, IMD, rub & buzz)



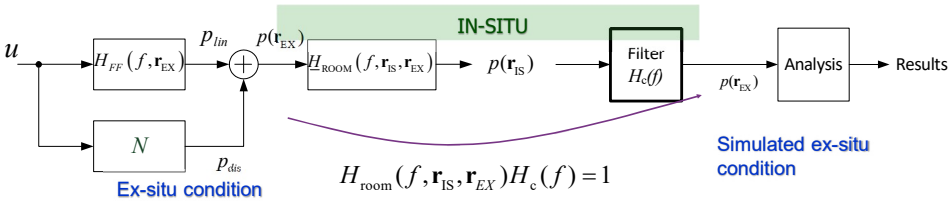
Measurement

compensation with reference information

Results

New Compensation Technique

Solution: Filtering the microphone signal ptest(rt) with compensation function



$$H_c(f)=\frac{1}{\underline{H}_{ROOM}(f,\mathbf{r}_{IS},\mathbf{r}_{EX})}=\frac{\underline{H}_{FF}(f,\mathbf{r}_{EX})}{\underline{H}_{IS}(f,\mathbf{r}_{IS})}$$

The same compensation function $H_C(f)$ can be applied to other speakers with similar geometry placed at the same position (→ fixed room compensation function)

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How to provide accurate reference response $\underline{H}_{EX}(f,r_{EX})$?

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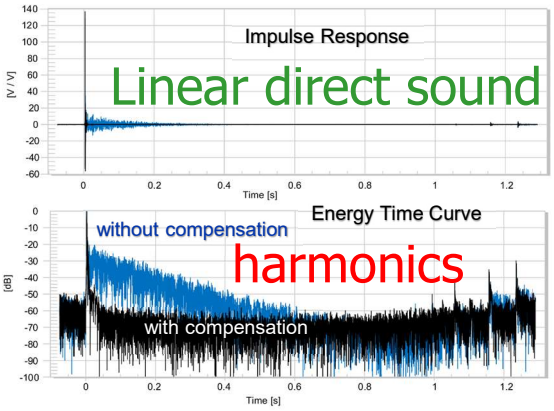
- Anechoic room (error caused at low frequencies)
- Outside free-field measurement (error caused by climate, wind, ambient noise)
- Holographic extrapolation provides accurate data at any evaluation point r_{EX} in 3D space

(recommended)

Chirp Analysis with Room Compensation



- The compensation filter compensates for the room influence
- reduces the ringing in the linear impulse response
- Reduces the ringing in harmonic impulse response
- Windowing can be applied to separate linear and distortion components (Farina technique)



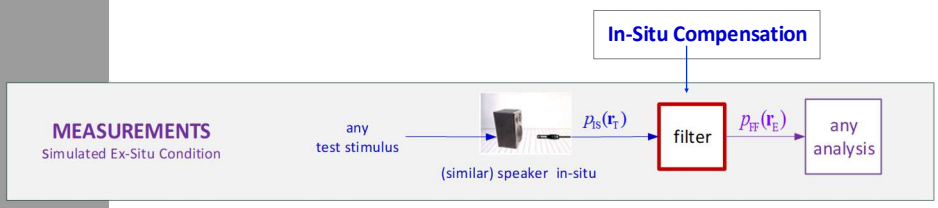
→ Nonlinear Distortion can be measured under non-anechoic conditions !

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In-Situ Room Compensation
Experiment

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- Topics:
- Target: Fast testing of units of the same or similar transducer type (without scanning) in the working bench
- Accurate Free-field Reference Data from NFS
- Generating simulated Ex-Situ standard conditions (according to IEC 60268-21/23)
- Measurement of the SPL frequency response and THD with In-Situ Compensation



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Important distortion measurements

according to IEC 60268-21

Total Harmonic Distortion:

$$L_{\mathrm{THD}} = 20\log_{10}\left(\frac{\sqrt{P(2f)^2 + P(3f)^2 + \cdots + P(Nf)^2}}{\sqrt{P(f)^2 + P(2f)^2 + \cdots + P(Nf)^2}}\right)$$

Intermodulation Distortion:

- Signal components due to modulation of different tones

Multitone Distortion:

- combines all distortion components, occurring during broadband excitation

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KEY TAKEAWAYS

- Most of all regular distortion components are caused by the nonlinear motor properties (e.g. $Bl(x)$, $K_{ms}(x)$).
- Regular distortion is independent of the mic position
- Measurements in the near field are highly recommended due to SNR.
- With a linear room correction curve, the room influence can be compensated

Sound Quality

of the Electroacoustic Signal Chain from Source to Ear

Part 7: Irregular Distortion (Defects)

Roadmap

Two day courses

第一天First Day

1. Introduction – definition of tools and terms & roadmap
2. Small-signal modeling & measurement
3. Cone vibration analysis
4. 3D Sound Radiation
5. Nonlinear modeling & measurement

第二天Second Day

1. Nonlinear distortion Symptoms, relationship to Large Signal Parameters
2. **Abnormal sound - irregular behavior, defects**
3. How to define maximum SPL?
4. Quality Control, full system assessment
5. Adaptive Nonlinear Control of speakers

6. Irregular nonlinear distortion

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1. Introduction
2. How to measure irregular distortion?
3. Defect Analysis
4. Experiments

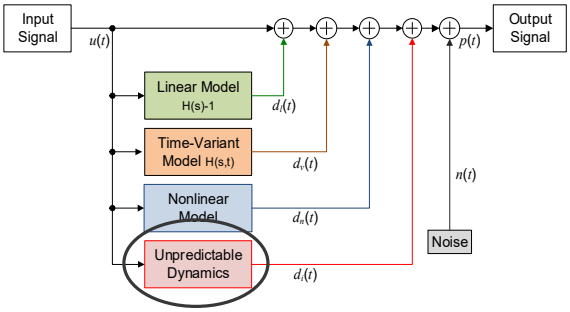
INTRODUCTION

What are irregular nonlinear effects?

Distortion can be separated into:

- Linear Transfer Function
- Time variant linear Behaviour
- Regular Nonlinear Distortion: Large signal performance (motor, suspension)
- Irregular Distortion: Undesired defects:

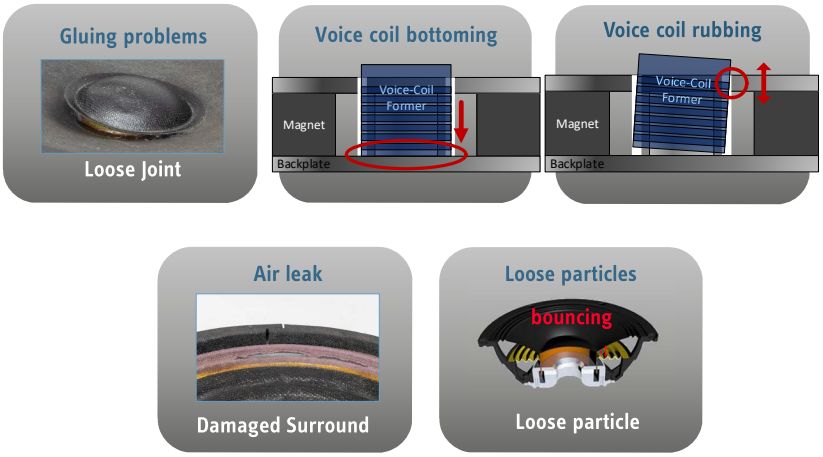
  Rubbing coils, Buzzing parts, Wire beat,
  Coil bottoming, Loose particles, Air leak noise,
  Parasitic vibration of other components



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INTRODUCTION

Typical physical causes of irregular distortion

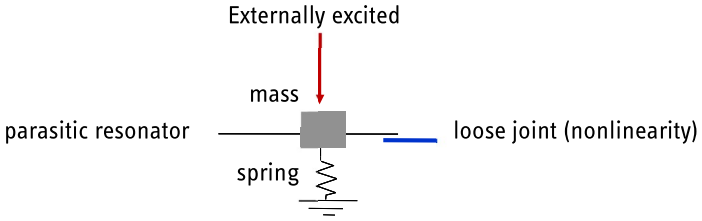


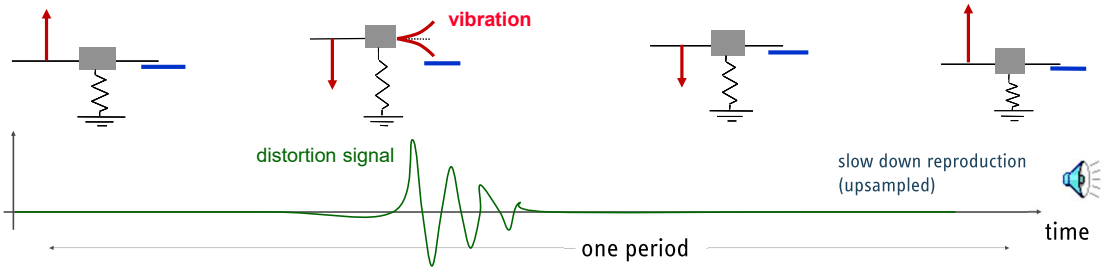
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Loudspeaker Defect: Buzz problem

Most defects behave as a nonlinear oscillator:

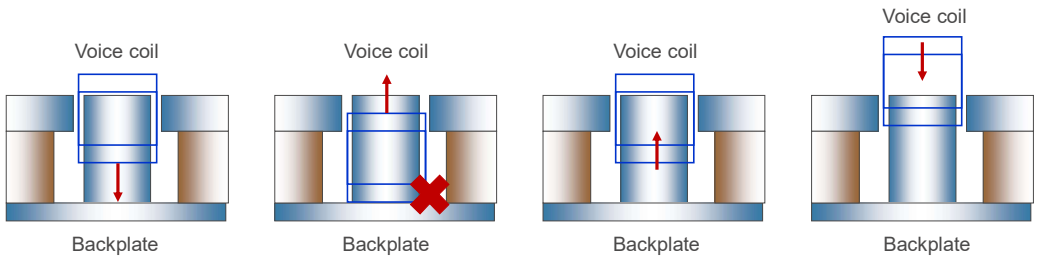
- active above a critical amplitude
- new mode of vibration
- powered and synchronized by stimulus
- constant output power

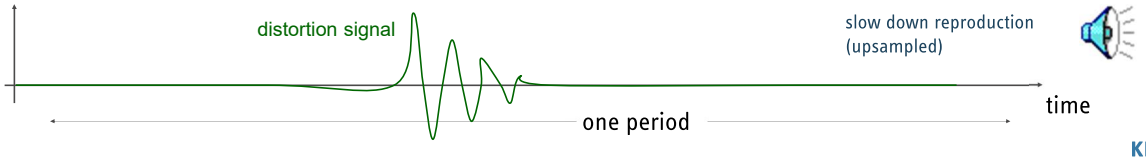




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Loudspeaker Defect: Voice coil bottoming

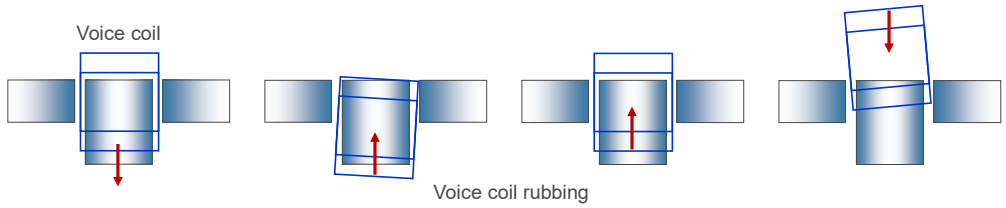


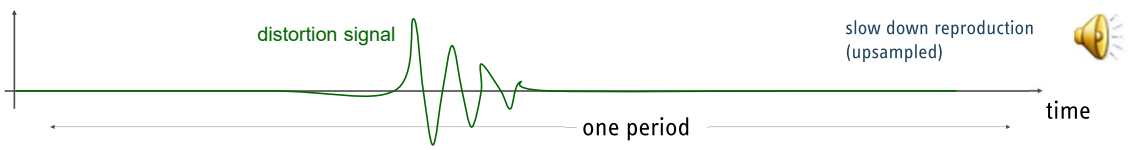


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Loudspeaker Defect: Voice coil rubbing

Signal contains reproduceable and stochastic components:

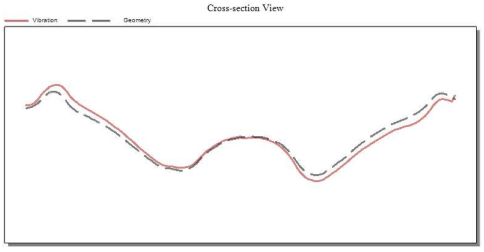


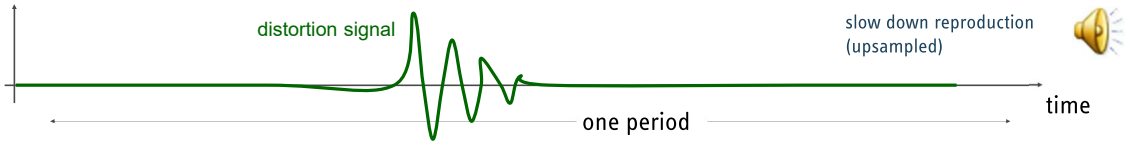


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Loudspeaker Defect: Voice coil rubbing

Cause: rocking mode at 328 Hz

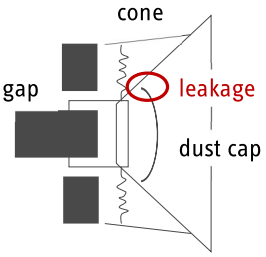


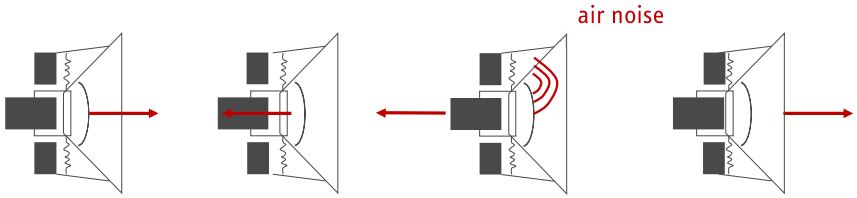


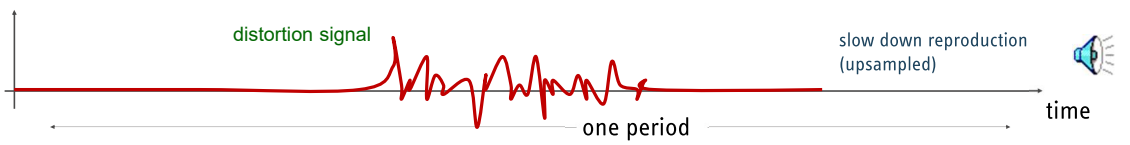
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Loudspeaker Defect: Air noise

- Stochastic signal
- Air pressure is changed by voice coil displacement
- Synchronized with stimulus – signal envelope



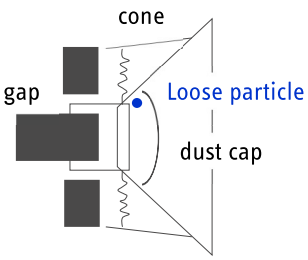


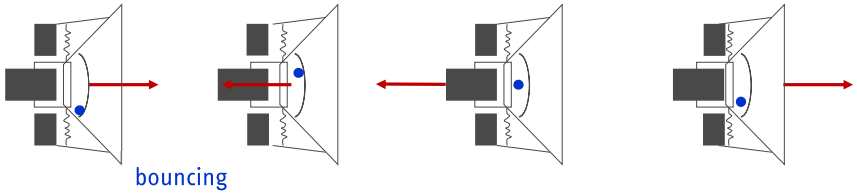


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Loudspeaker Defect: Loose particles

- Stochastic signal
- Air pressure is changed by voice coil displacement
- Synchronized with stimulus – signal envelope







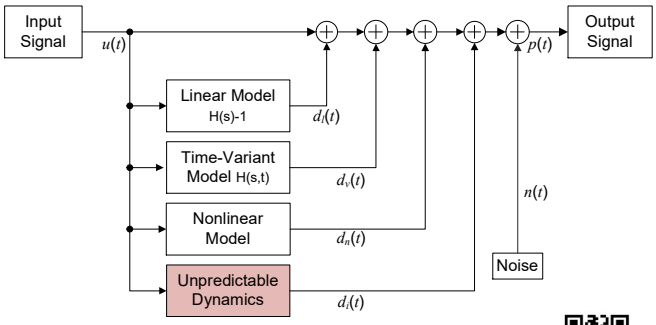
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不規則失真（異常聲音）

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)



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6. Irregular nonlinear distortion

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1. Introduction
2. How to measure irregular distortion?
3. Defect Analysis
4. Experiments

投票 Poll:

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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. 我從來沒有做過
I have never done it

B. 透過聽音樂
By listening with music

C. 掃描加聆聽
Manual sweep + listening

D. 線性調頻 + 總諧波失真
(THD)Chirp + Total harmonic distortion (THD)

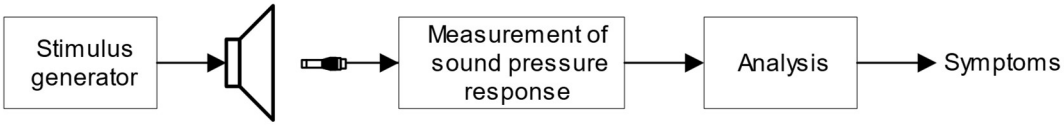
E. 線性調頻 + 高次諧波
Chirp + Higher-order harmonics

F. Chirp + 時域分析（時頻分析、脈衝失真分析）
Chirp + Time domain analysis (Time-Frequency Analysis, impulsive distortion analysis)

How to measure irregular distortion

Basic requirements

- High amplitude (displacement x, velocity v, acceleration a)
- Stimulus shall excite all frequencies
- Avoid masking by simple, tonal excitation (e.g. single-tone or chirp)
- Defects produce only acoustical symptoms which are similar to ambient noise:
  - Use a sensitive microphone
  - Place the microphone close to the source (near-field measurement)
- Defects produce high-frequency components:
  - Low-pass filtered stimulus and high-pass filtered microphone signal



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Searching for a critical stimulus

Audibility of voice coil rubbing

The 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				
Sinussoidal sweep 1s				

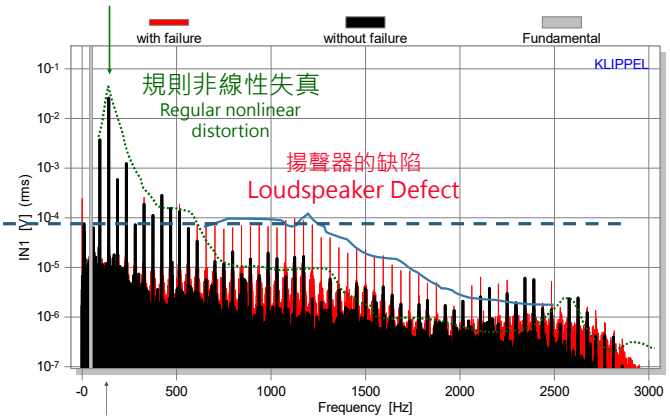
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揚聲器缺陷的症狀-揚聲器有無音圈摩擦

Symptoms of a Loudspeaker Defect- loudspeaker with and without rubbing coil

- 80 dB

被雜訊和常規失真所掩蔽
Masked by noise and regular distortion



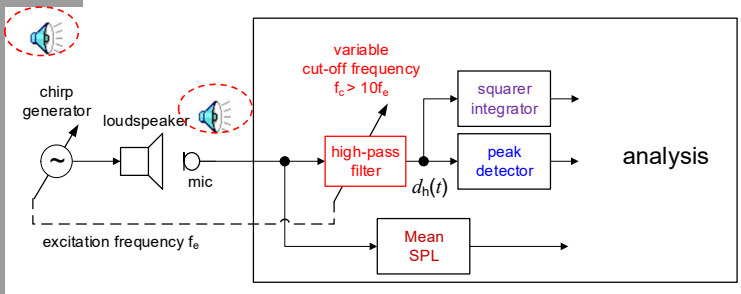
基頻50Hz Fundamental 50 Hz

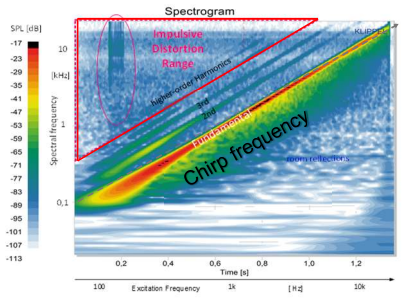
The abnormal sound (rub & buzz) generates not only harmonics but also energy at other frequencies !
How can we use those information for diagnostics ?

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脈衝失真量測 (1) Measurement of Impulsive Distortion (1)

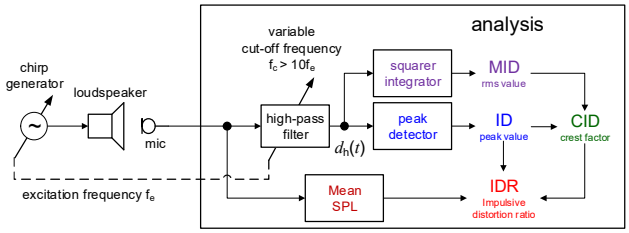
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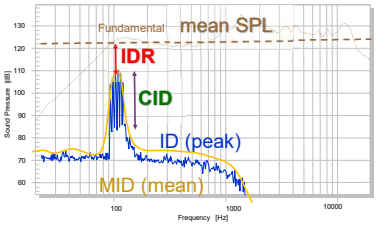




脈衝失真量測 (2)

Measurement of Impulsive Distortion (2)





Characteristics	Definition
Impulsive Distortion Level ID	Peak SPL of the high-pass filtered sound pressure signal determined within one period of a chirp signal
Mean Impulsive Distortion Level (MID)	RMS value of the high-pass filtered sound pressure signal within one period of the chirp.
Crest Factor Impulsive Distortion (CID)	Ratio (level difference) between ID and MID is an essential criterion for impulsive distortion (CID > 12 dB).
Maximum Impulsive Distortion Ratio (IDR)	Difference between maximum ID in the stated frequency range with CID > 12 dB and mean SPL of the fundamental

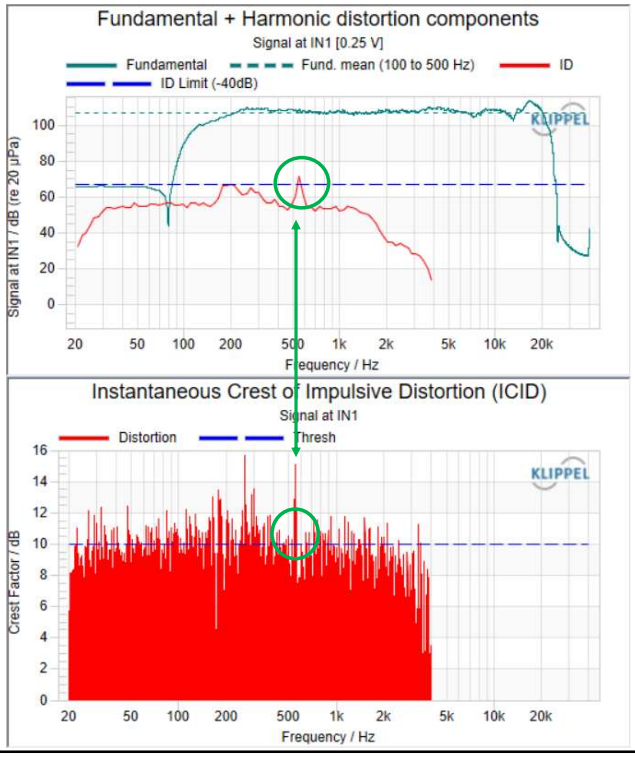
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HOW TO MEASURE Irregular Distortion?

The thresholds for significant impulsive distortion are relevant if at the same frequencies:

- ICID is larger than 12 dB?
- Is ID above -40 dB (1%)?





Test Methods
Summary

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	Higher-order Harmonics	Spectrogram	Impulsive Distortion
Stimulus	Sinusoidal (chirp)	Any stimulus	Sinusoidal (chirp)
Distortion Separation	Spectral analysis	Time-Frequency Analysis	High-pass filtering, (residuum)
Characteristics	Total RMS value	Spectral power density	Time domain analysis
Fine-Structure	Limited information	Reveals envelope	Full temporal resolution
Sensitivity[1]	Low	Medium	High

Consequences for Testing:

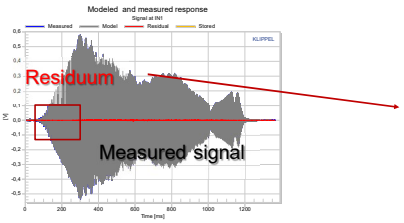
- Narrow band excitation (single tone or chirp at maximum amplitude)
- The fundamental and the low order harmonics have to be removed in analysis
- Time domain analysis provides maximum sensitivity and diagnostics value
- Near field measurement gives maximum signal-to-noise ratio
- Special methods and particular distortion metrics defined in IEC 60268-21

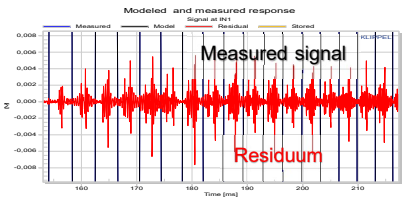
6. Irregular nonlinear distortion

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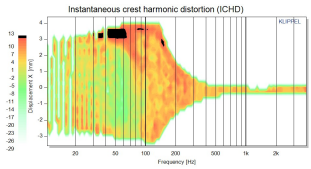
1. Introduction
2. How to measure irregular distortion?
3. Defect Analysis
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精細結構分析 Fine Structure Analysis

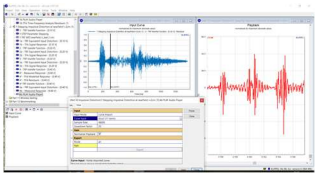




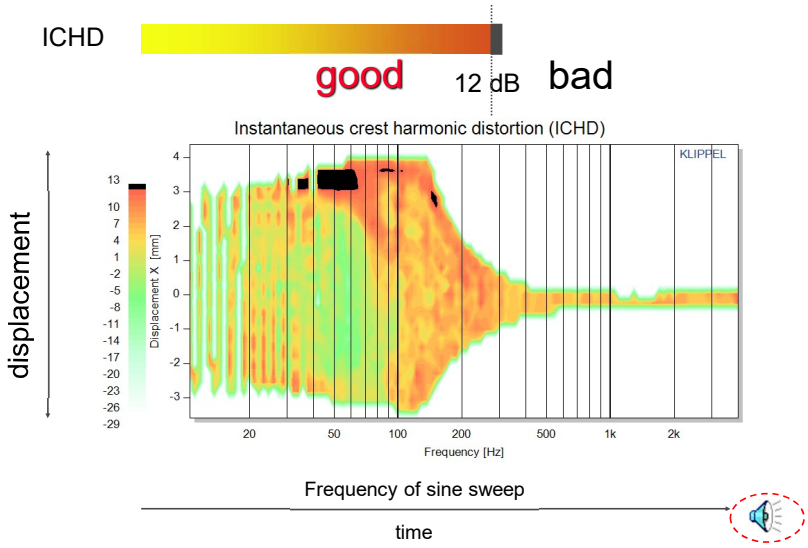
1) Mapping the residuum (instantaneous crest factor ICID) versus transducer state
- Voice coil displacement
- Sound pressure (acceleration)



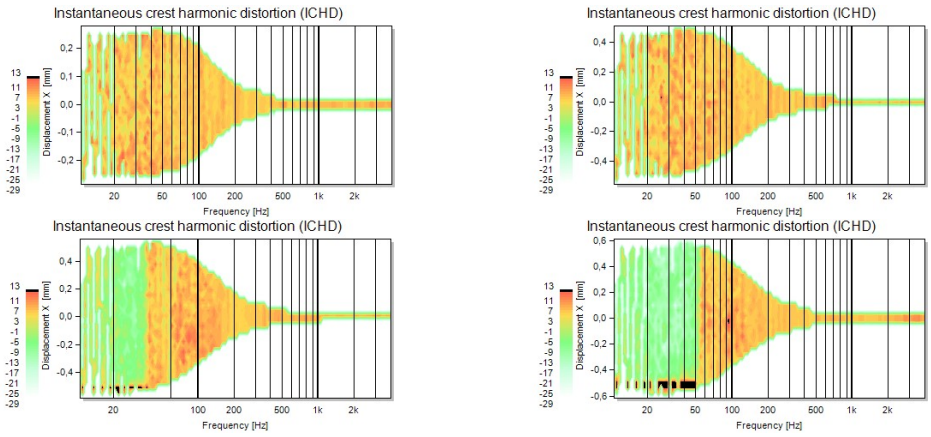
2) Human ear listening to the upsampled residuum (slowdown factor 10)



高通濾波失真ICHD(f,x)的瞬時峰值因數 Instantaneous crest factor of impulsive distortion ICHD(f,x)



診斷不規則缺陷(1st範例)
Diagnostics on Irregular Defect (1st example)

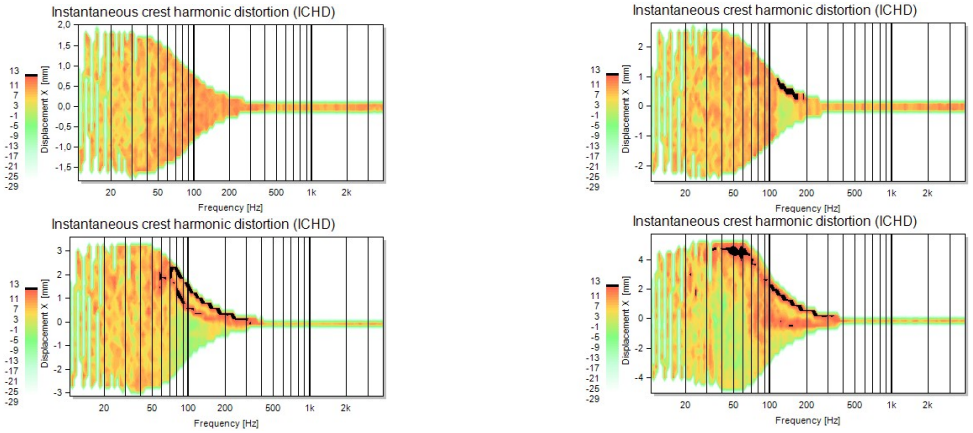


條件 Conditions:
- 低於共振頻率的正向的峰值位移為0.5mm
Positive peak displacement at 0.5 mm below f_s
- 大於端子電壓0.9V
above a terminal voltage of 0.9 V

問題來源：底部
Root Cause: Bottoming

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診斷不規則缺陷(2nd範例)
Diagnostics on Irregular Defect (2nd example)



Conditions:
- Negative turning point of voice coil excursion above f_s
- maximal acceleration → Tilting of voice coil former
- independent of displacement

根本原因：音圈磨擦
Root Cause: Voice coil Rubbing

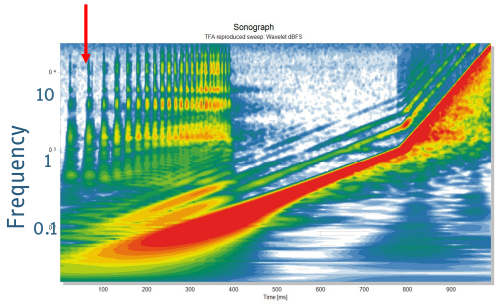
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Time-Frequency Analysis (TFA):

- Analyze spectral and temporal characteristics of defects causing irregular distortion
- Detect acoustical and mechanical resonators
- Visualize signal distortion

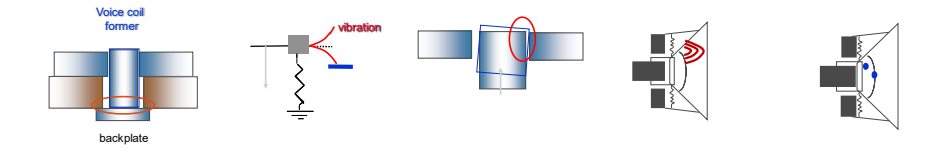
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Loose joint hitting the membrane



揚聲器缺陷的模型

Modeling of Loudspeaker Defects



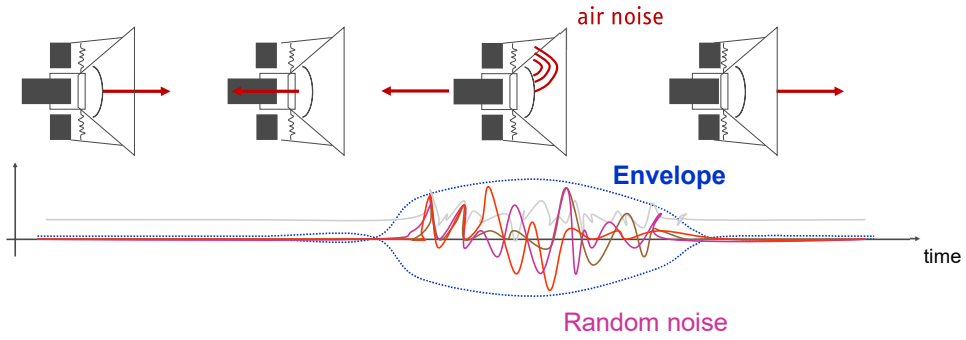
hitting backplate *撞擊背板*	*Buzzing* *摩擦*	*Coil rubbing* *線圈碰撞*	*Air leakage* *空氣洩漏*	*Loose particles* *鬆散元件*

確定的過程 Deterministic Process — **半隨機過程** Semi-Random Process — **隨機過程** Random Process

可重現的 reproducible	確定性和隨機過程的調製 Deterministic Modulation of a random process	不可預知的 Not predictable

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空氣洩漏產生信號的調變
Air Leakage generates a modulated signal

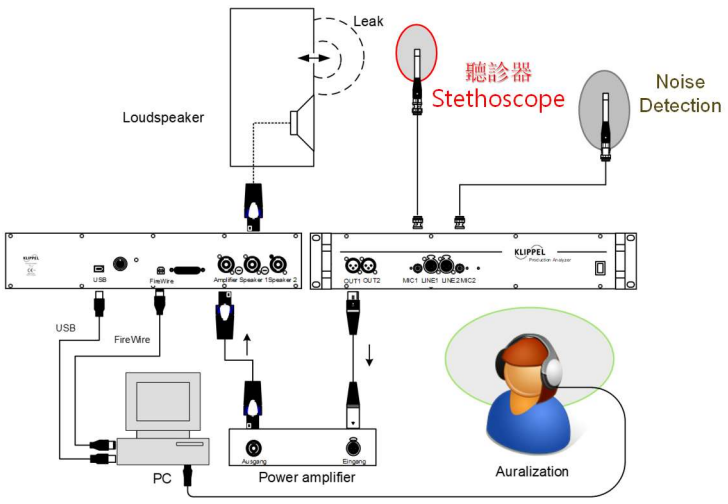


- 包絡是具有確定性的 Envelope is deterministic
- 包絡跟氣壓和音圈位置相一致 Envelope corresponds with air pressure and coil displacement
- 干擾產生隨機的雜訊信號 Turbulences generate a random noise signal

→空氣洩漏產生調變的雜訊信號 A air leakage generate a modulated noise signal

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主觀評價和客觀測量相結合
Combining Objective and Subjective Assesment



目標 Objectives:

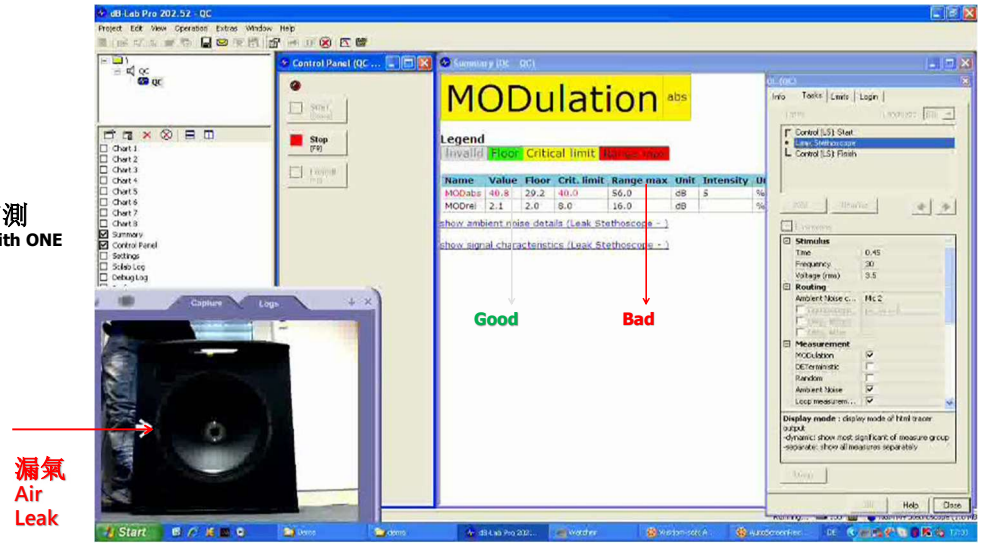
- 非常規失真的可聽化Auralization of Irregular Distortion
- 聽覺保護Ear Protection
- 信號轉化Signal Transformation
- 缺陷定位Defect Localization
- 診斷Diagnostics

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漏氣的定位

Localization of Air Leaks

用麥克風手動偵測
Manual inspection with ONE microphone



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6. Irregular nonlinear distortion (TRF, STEP, TFA, QC)

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1. Introduction
2. How to measure irregular distortion?
3. Defect Analysis
4. Experiments

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KEY TAKEAWAYS

- Testing for irregular nonlinear distortion is important to identify defects, design problems, and working range limitations
- For identifying irregular nonlinear distortion, the time (ICID) and frequency (IDR) signal needs to be analyzed
- Following IEC 60268-21 this is an essential part for rating max SPL

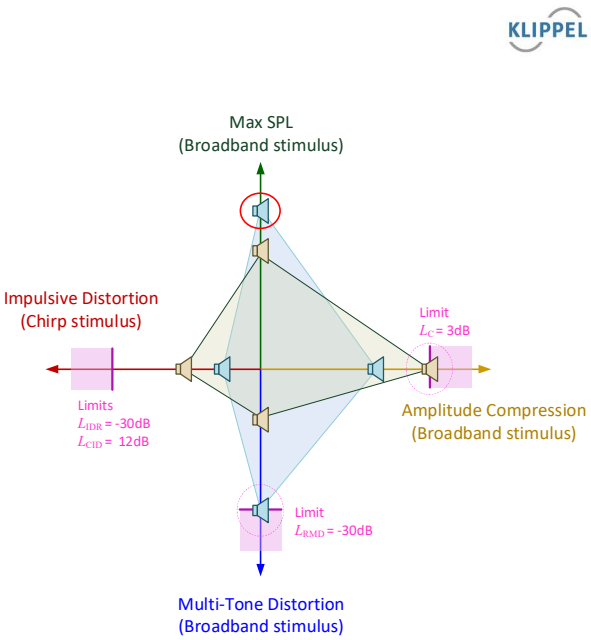
Sound Quality

of the electroacoustic Signal Chain from Source to Ear

8 – Max SPL by IEC 60268-21

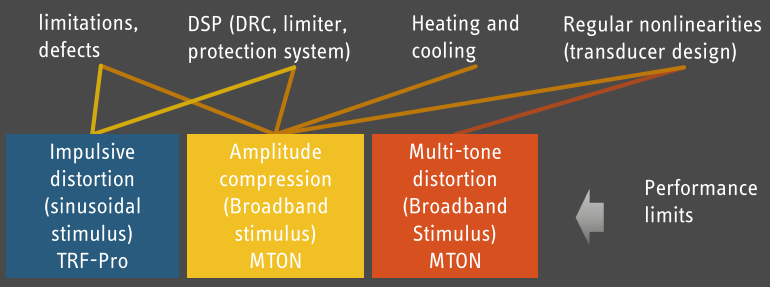
MOTIVATION

How to define maximum voltage for specific loudspeaker?



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PROPERTIES OF THE AUDIO DEVICE



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How can I define Umax following IEC 60268-21?

Rate limits for compression and MD:
- Compression shall be below 5 dB
- Multitone distortion shall be below -25 dB

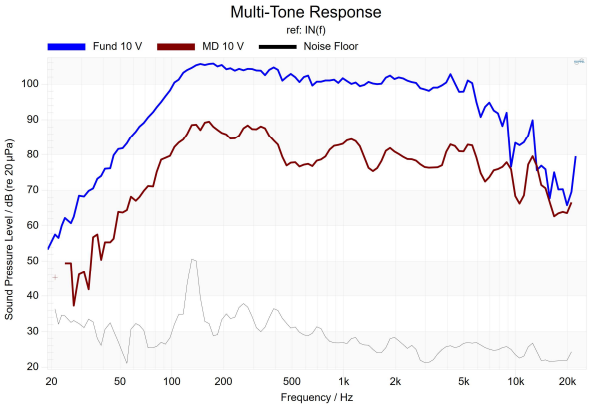
Rate limits for Rub&Buzz:
- Impulsive distortion ratio shall be below -40dB
- ICID shall be below 14 dB

Note: All limits are suggestions. They can be modified but must be stated.

Define limit Umax with MTON

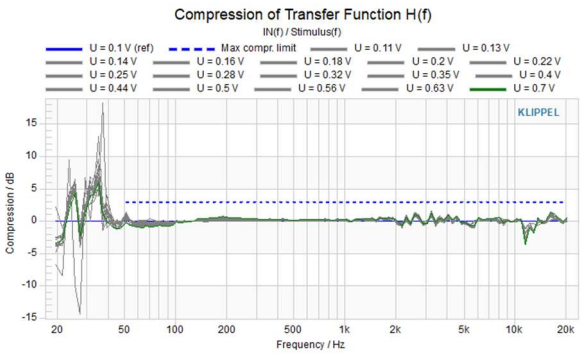
Rate limits for:

- Compression
- Multitone distortion



Compression limit

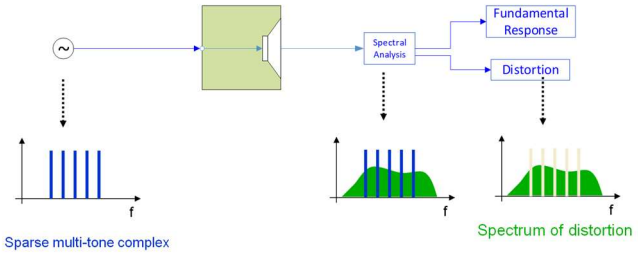
- **Compression collects transfer functions normalized to reference measurement**
- **Compression limit can be defined as a constant value for the full band or as a curve**



-> Compression shall be below 5 dB

Multitone distortion limit

- Multitone distortion is calculated as energy measured in frequency bins which are not excited by multi-tone stimulus
- Two different metrics are available:
  - Relative multi-tone distortion
  - Total multi-tone distortion ratio



-> Relative multi-tone distortion shall be below 25 dB

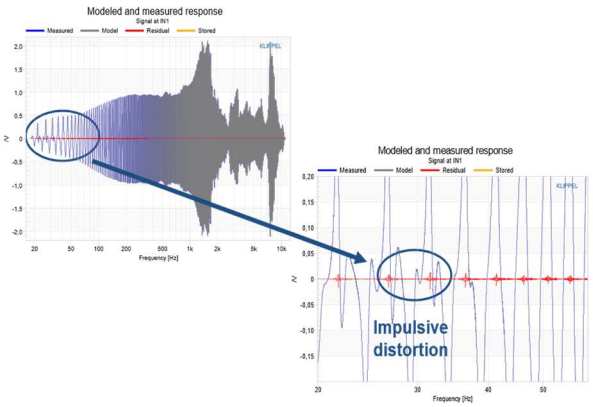
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Define limit Umax with TRF-STEP

Rate limits for:

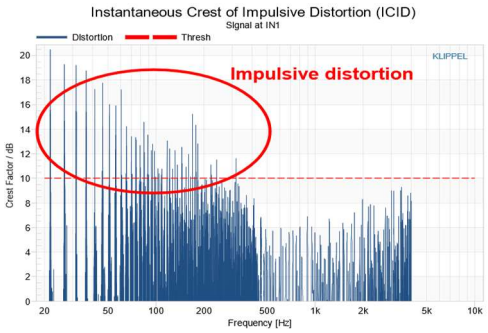
- Instantaneous crest of impulsive distortion (ICID)
- Impulsive distortion ratio

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ICID limit

- **ICID is calculated as ratio between instantaneous impulsive distortion (ID) and mean impulsive distortion (MID)**
- Typically, a crest factor higher than 12-14 dB indicates impulsive distortion

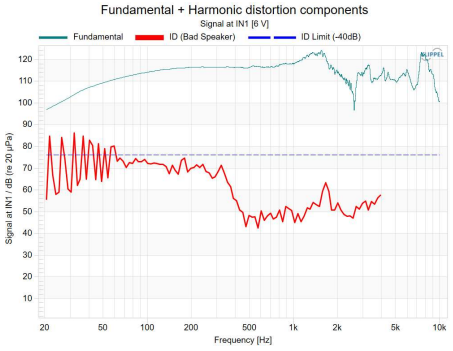


-> ICID shall be below 14 dB

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Impulsive distortion ratio limit

- **Impulsive distortion ratio (IDR) is calculated from distortion signal and RMS value of microphone signal**
- Typically, an IDR higher than -40 dB indicates impulsive distortion



-> IDR shall be below -40 dB

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Experiments

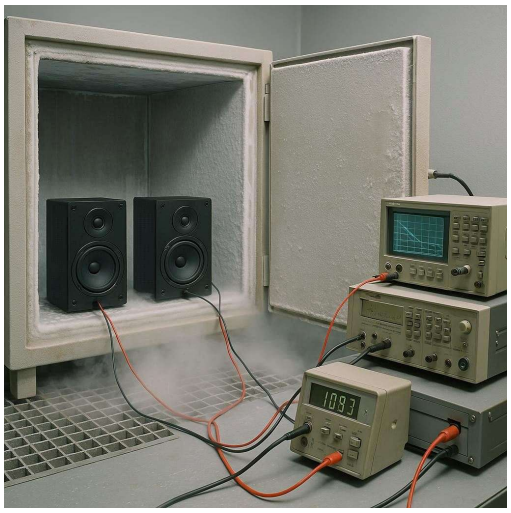
Performance Limits



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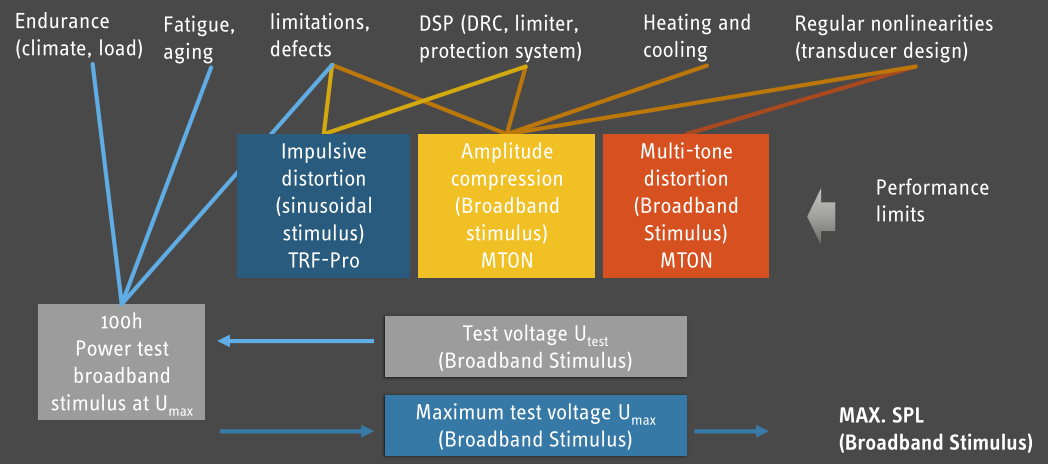
MOTIVATION

How to test maximum SPL for estimated maximum voltage?



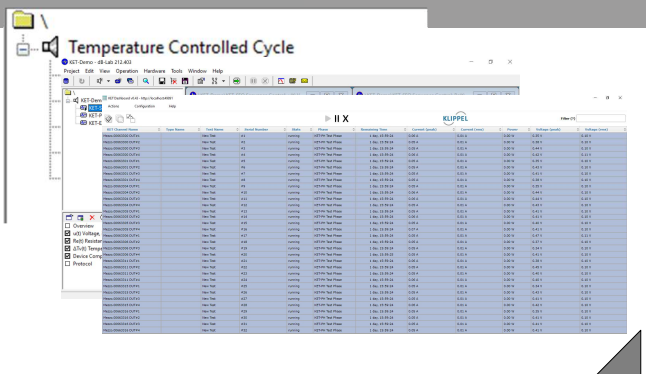
KLIPPEL

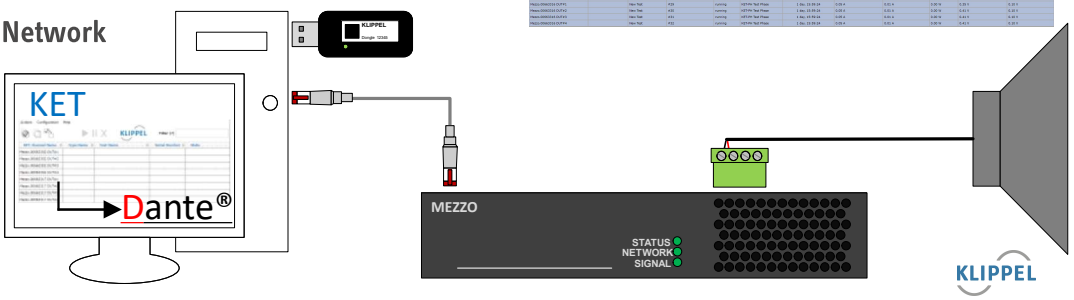
PROPERTIES OF THE AUDIO DEVICE



Klippel Endurance Test (KET)

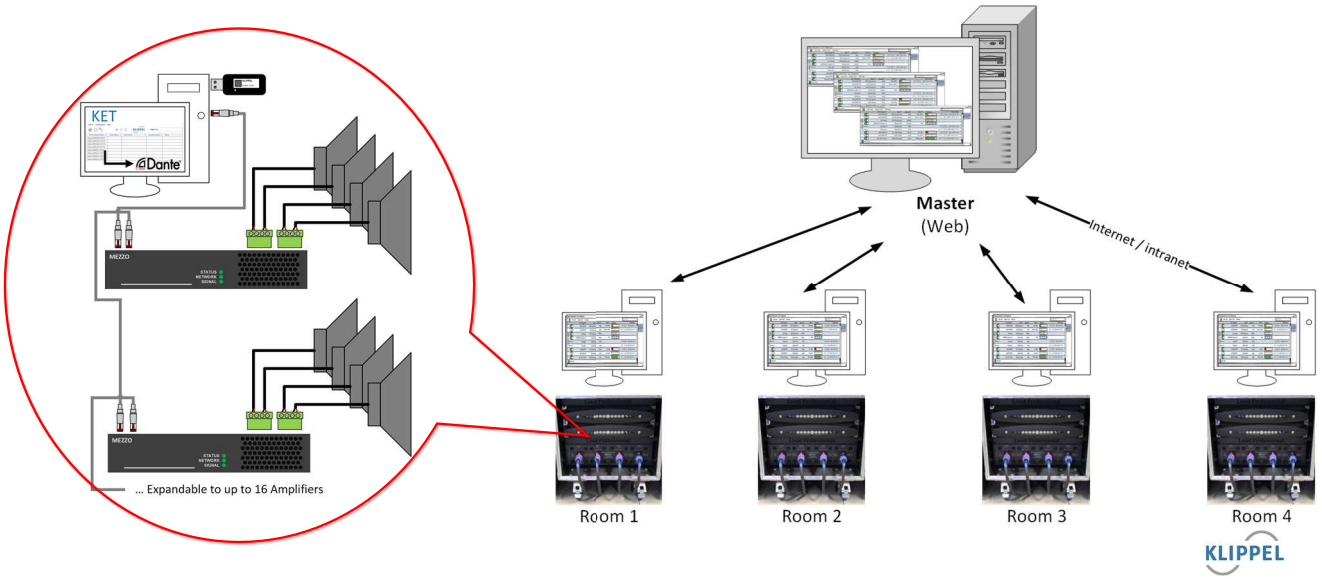
- KET Test in dB-Lab
  - KET SEQ → global settings
  - KET PH → individual settings
  - KET ExC → control external periphery
- dB-Lab – Framework software
- KET-Dashboard
- Dante® Network





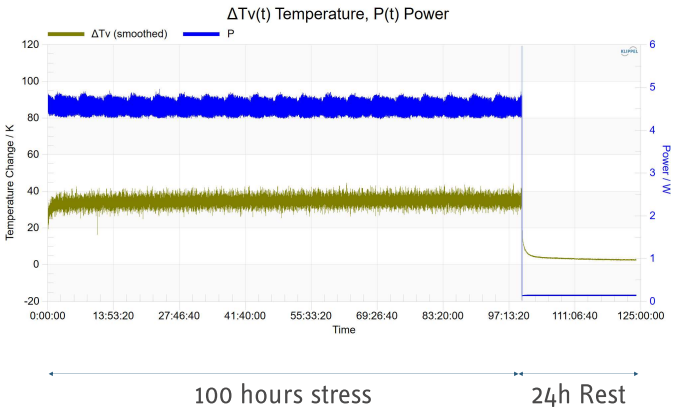
Fully Scalable Solution

With Remote Monitoring (Control)



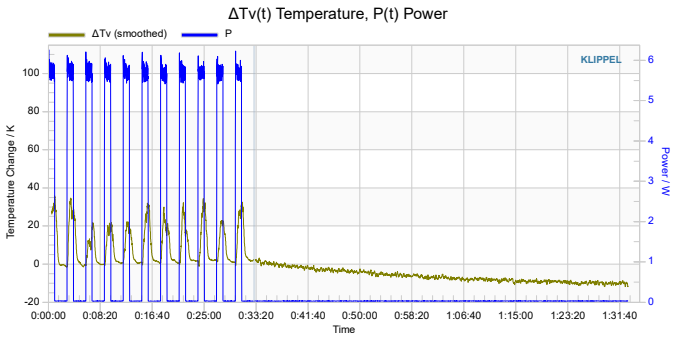
100h Long Term Test

- IEC 60268-21



Accelerated life test

- IEC 60268-21

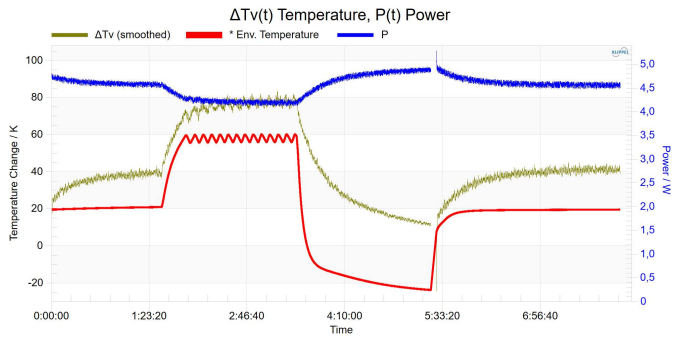


30 minutes stress
60s on, 120s off

1h Rest

Environmental stress test

- IEC 60268-21



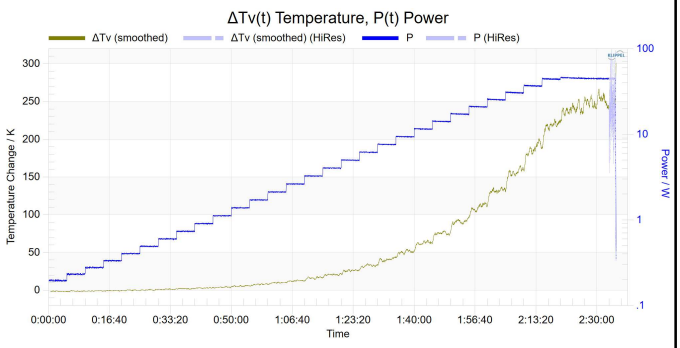
1.5h
Normal

2h
Heat

2h
Frost

3h
Normal

Destructive Test



Sound Quality

of the Electroacoustic Signal Chain from Source to Ear

Part 9: Quality Assurance

Roadmap

Two day courses

第一天First Day

1. Introduction – definition of tools and terms & roadmap
2. Small-signal modeling & measurement
3. Cone vibration analysis
4. 3D Sound Radiation
5. Nonlinear modeling & measurement

第二天Second Day

1. Nonlinear distortion Symptoms, relationship to Large Signal Parameters
2. Abnormal sound - irregular behavior, defects
3. How to define maximum SPL?
4. **Quality Control, full system assessment**
5. Adaptive Nonlinear Control of speakers

Particularities of Quality Control (QC)

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9. Quality Control (QC)

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1. Translating target performance to QC
2. High-Speed Testing
3. Noise Immunity
4. Experiments

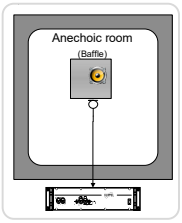
Interfacing Testing in R&D and QC

Example: Transducer

R&D Lab

- Measurement under (simulated) standard condition or defined lab conditions
- Define and verify specification



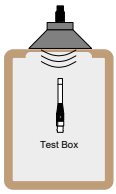


End-of-Line (Quality Control)

- Reproducible
- Fast, automatic mounting
- Sensitive, robust (suppresses production noise)

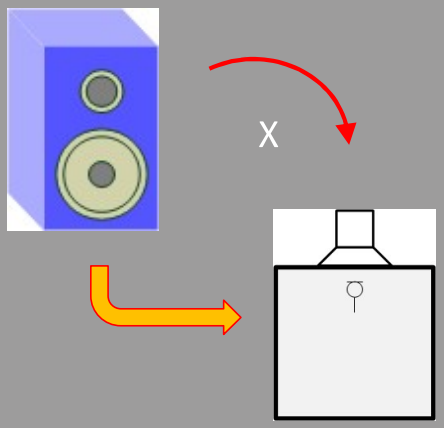


Golden Unit



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Transfer Settings from Final Application to QC



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Ensure similar conditions in QC as in final application

1. Use similar or higher displacement (Conditions for regular distortion, use stimulus shaping)
2. Use similar test volume (Conditions for potential defects)
3. Use tighter limits than in final application (Find defects as early as possible)

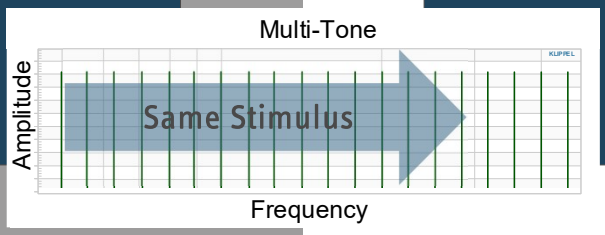
Linking Lab and Production Line Testing Through Stimulus

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R&D Applications: MTON

- Variable test and cooling intervals
- Stepping excitation
- Speaker protection:
  - Compression
  - Multi-tone distortion
  - Voice coil temperature
- Noise floor measurements
- Required for rating max SPL (IEC) and benchmarking

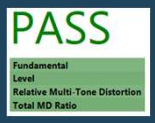




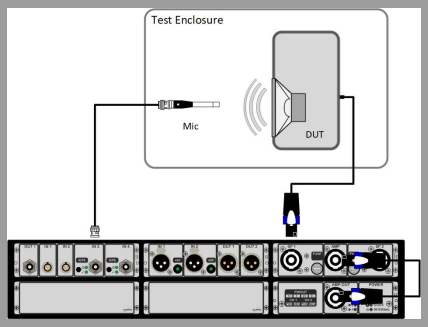
QC Applications: MTD



- Single test for max SPL capabilities
- Short cycle time + many DUTs
- Automated
- Clear verdicts (Pass/Fail)
- Reduced data (no spectra)
- Simple
- Traceable



Verifying Quality in Production



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Using Maximum Input Voltage U_{max}

- Apply the same stimuli
  - Sinusoidal Sweep (Sound Pressure Task - SPL)
  - Multi-tone Signal (Multi-tone Distortion Task - MTD)
  - Defined shaping
- Set excitation voltage U_{max}
- Test SPL_{max} key performance indicators (relative metrics)
  - Max. Impulsive Distortion Ratio (IDR)
  - Relative Multi-tone Distortion (RMD, TMDR)

Golden Units



Advantages

- Physical sample of (pilot) production
- Represents the target specification (closest match to mean of a pool)
- Reference object used for
  - Transferring limits from R&D and QC
  - Compensation of environmental changes
  - Communication and synchronization with customer/supplier
- Further “reference” units recommended
  - double check setup
  - Estimate process variation
  - “golden” defect samples – negative check

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Problems

- Wet DUTs at EOL
  - Systematic deviation from dried units due to condition and break-in effects
  - Define asymmetric limits (biased)
  - May be considered by limit calculation parameters (asymmetric limits)
- Ageing (glue, suspension parts ...)
  - Needs to be replaced regularly
  - Need for check, if production is statistically consistent (statistics)
- Consistency of Golden Units
  - Is frequency response a sufficient criterion?
  - How to cope with different Golden Units?

Using identical test box for R&D and QC



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Benefits

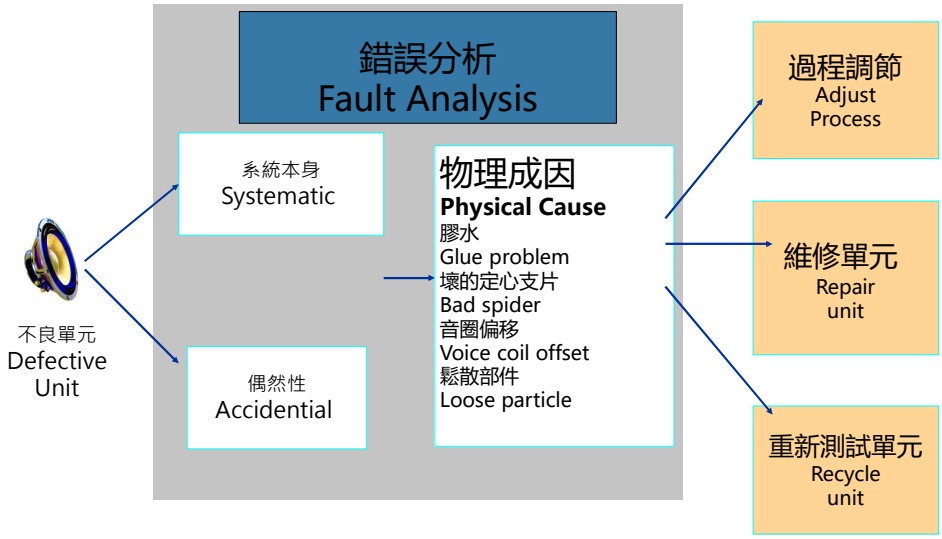
- Similar test condition for complete supply chain (transducer)
- Easy to build
- Use correction curves for simulated free field / far field (obtained from baffle measurement or holographic methods)

Drawback

- Not standardized yet (AES standard work in progress)
- No defined load conditions

目標: 降低不良率 --解決方案: 線上診斷

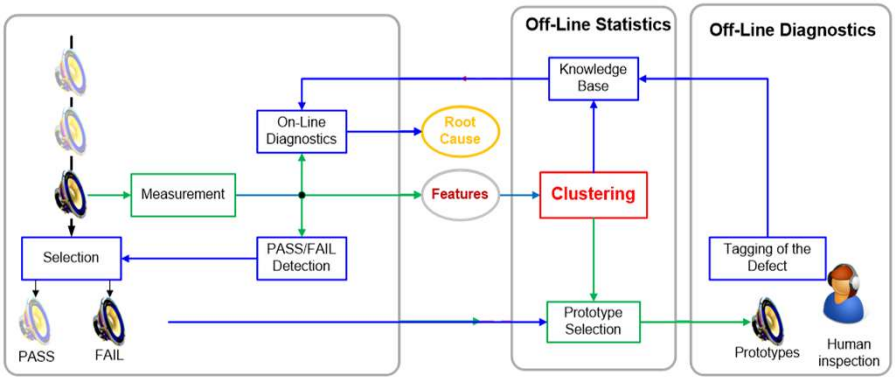
Target: Reduce Rate of Rejection -- Solution: On-line Diagnostics



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從製造端自動的學習

Automatic Learning from Manufacturing



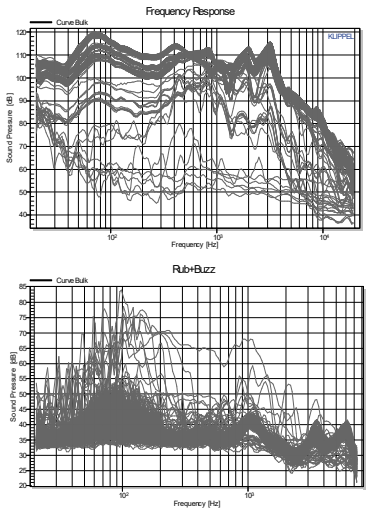
1st step:	自動收集數據	Automatic clustering of the raw data
2nd step:	雛形選擇（群組中最佳代表）	Prototype selection (best representative of the cluster)
3rd step:	由人檢測並且標籤缺陷	Human inspection and tagging of the defect
4th step:	對線上診斷更新知識	Updating the knowledge base for on-line diagnostics

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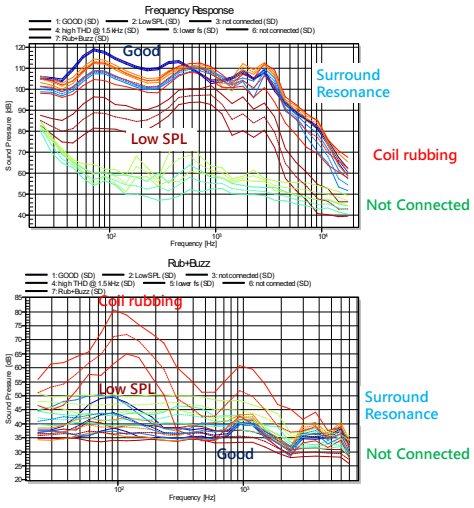
群組
Clustering

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Raw Measurement Data (300 DUTs)



Results of the Clustering



9. Quality Control (QC)

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1. Translating target performance to QC
2. High-Speed Testing
3. Noise Immunity
4. Experiments

目標:高速性能表現-解決方案:使用最佳的激發信號

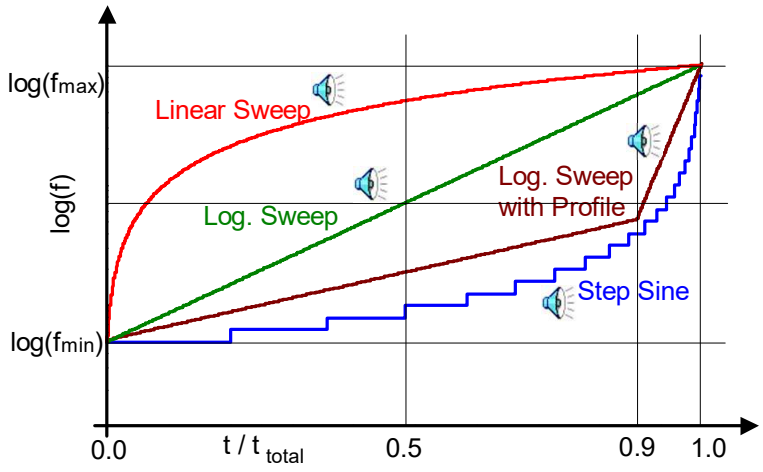
Target:High Speed Performance Solution: Using OptimalStimulus

激發Stimulus	敏感參數Sensitive for	優點Advantages	缺點 Disadvantages
連續正弦掃描 Continuous sine sweep	聲壓級,諧波,阻抗,異常聲 SPL fund, Harmonics, Impedance, Rub & Buzz	快速,測量異常聲最佳 Fast, best for Rub & buzz	沒有互調成分 no intermodulation
多音激發 Multi-tone complex	聲壓級,失真,阻抗.SPL fund, Distortion, Impedance	快速,測量阻抗,常規失真最佳 Fast, best for impedance, best for regular distortion	對異常聲不敏感 Insensitive for rub & buzz
音樂,語音,雜訊 Music, Speech, noise	聲壓級,失真. SPL fund, Distortion	音訊信號應用 any audio signal applicable	對異常聲不敏感,很慢 Insensitive for rub & buzz, slow

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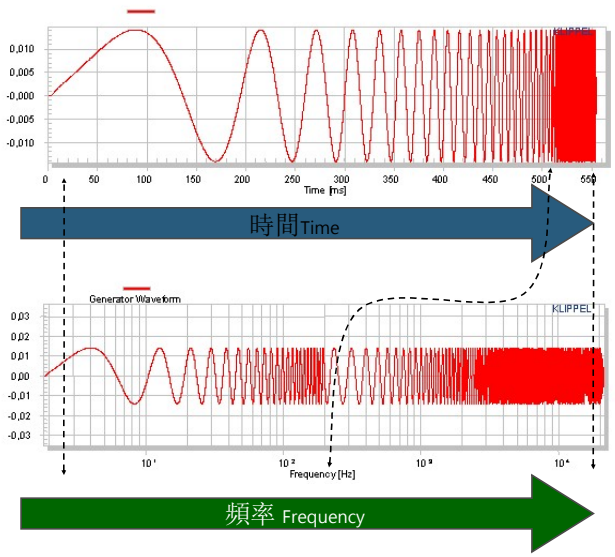
利用不同的時間頻率映射進行多種激發訊號方式產生諧波

Various Stimuli for Harmonics with different Time Frequency Mapping



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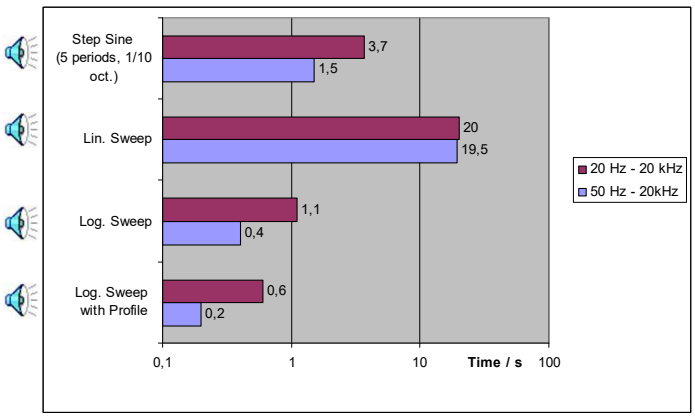
高速輪廓的對數掃頻
Log. Sweep with Speed Profile



測試信號的持續時間
Duration of Test Signals

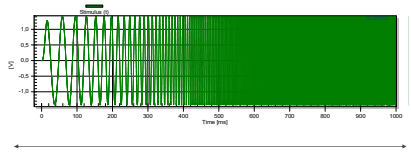
Requirements:
Fundamental: 20Hz - 20kHz
Harmonics: 20Hz - 20kHz
Rub&Buzz: 20Hz - 5kHz

Requirements:
Fundamental: 20Hz - 20kHz
Harmonics: 50Hz - 20kHz
Rub&Buzz: 20Hz - 5kHz



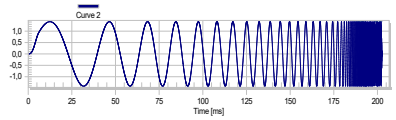
非常快速的Rub & Buzz測量

Ultra-fast testing of Rub & Buzz

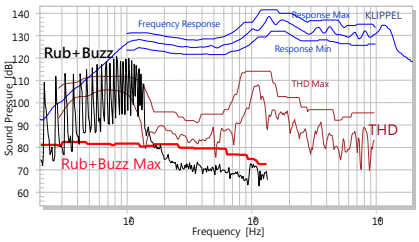


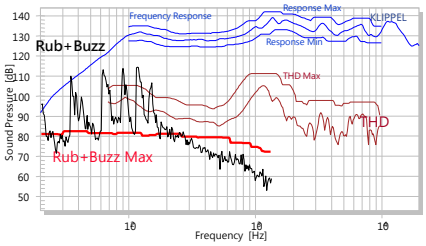
1 s





0.2 s

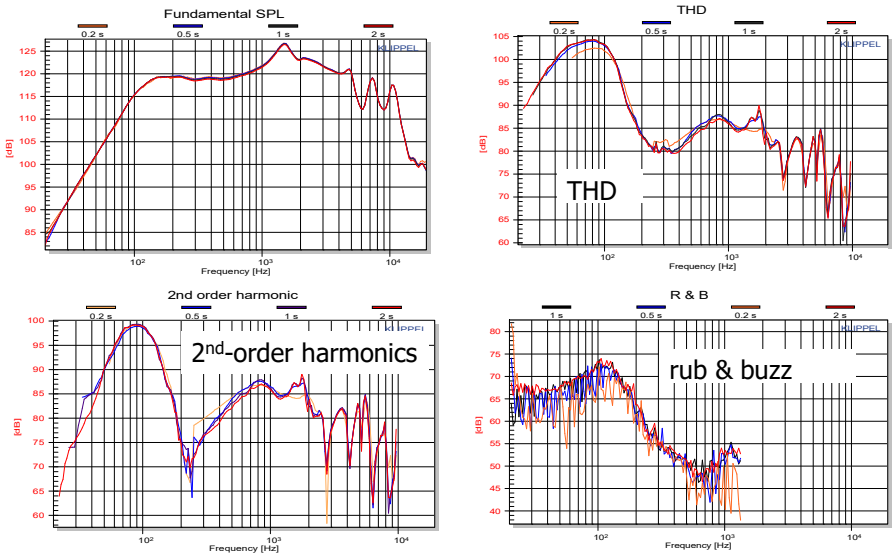




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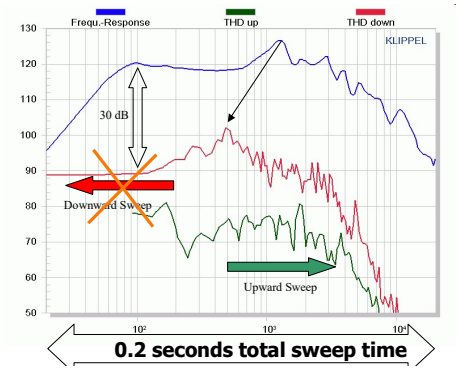
測量時間的影響-掃描時間

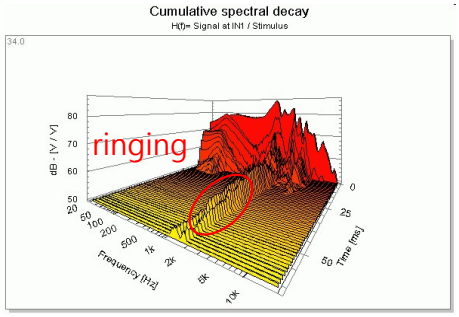
Influence of measurement time



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向上或向下掃描–非常短的測量< 0.5s





響聲的問題
Problems of ringing:

- 高品質因數需要衰減時間 >50 ms
  High Q resonances need decay time of >50ms
- 基頻成分被誤認為是諧波
  Fundamental interpreted as Harmonics

→使用向上掃描來達到非常快速的測量 Use UPWARDS SWEEP for extremely fast testing

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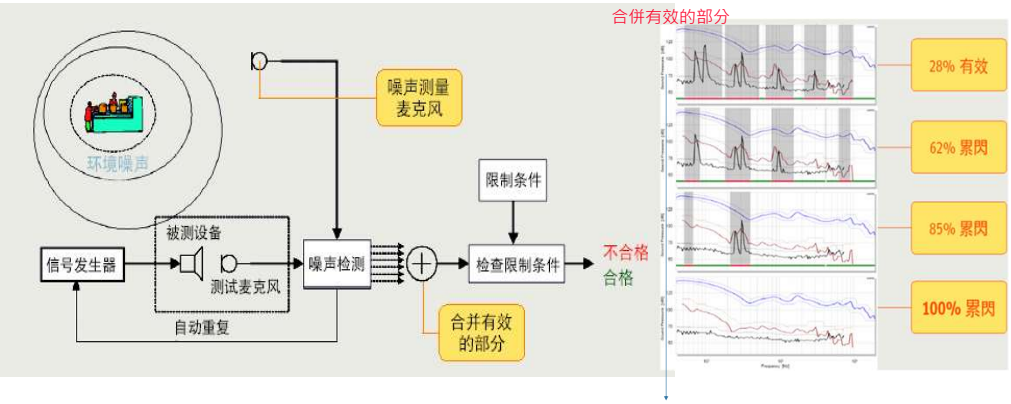
9. Quality Control (QC)

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1. Translating target performance to QC
2. High-Speed Testing
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環境雜訊免疫

Noise Immunity

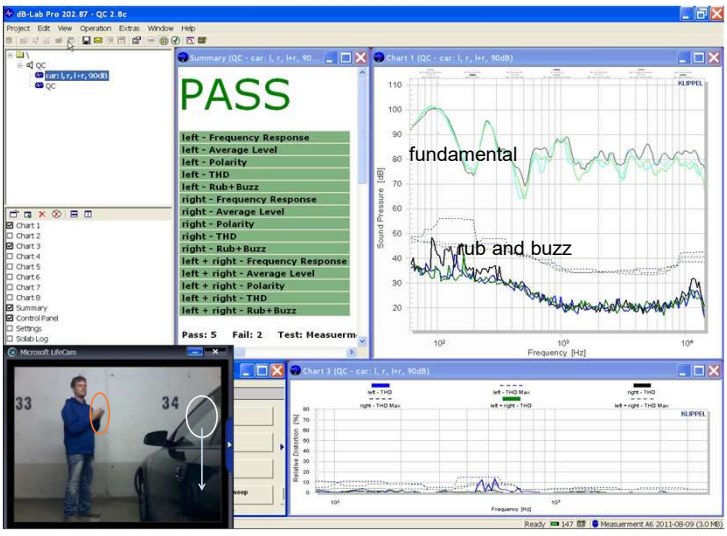


生產線上的環境雜訊可以由置於遠場的第二個麥克風來監測。被環境雜訊干擾的測量結果會自動重複測量，每個測量結果都會保存並整合，最後提供有效的測量結果。儘管每個單一的測量都被環境雜訊干擾，也確保了完全的生產線環境雜訊免疫

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汽車內部的聲音品質-汽車產線的雜訊免疫

Sound Quality in the Car Interior: Noise immunity at a car assembling line



ambient noise source

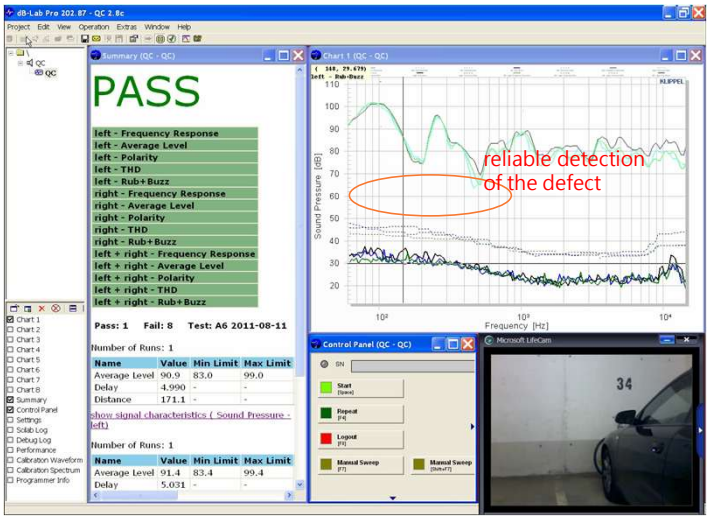
test microphone inside the car

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異音的模擬

Simulation of Door Buzzing





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9. Quality Control (QC)

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1. Translating target performance to QC
2. High-Speed Testing
3. Noise Immunity
4. Experiments

摘要
Summary Quality Control

測試儀器優於人耳聽力
An instrument is superior to the human ear

- 快速→非常快速地測試,更加全面的測量
  fast→ultra-fast testing, more comprehensive measurements
- 不會疲勞→可靠,可重複地測量
  no fatigue→ reliable, reproducible results over time
- 定量地評估→絕對限制條件
  quantitative assessment → absolute limits
- 穩健→環境雜訊免疫
  robust → ambient noise immunity
- 靈敏→平均,超聽力技術
  sensitive → averaging, meta-hearing

人耳測試優於儀器
An human tester is superior to the instrument because he has learning capabilities

- 學習能力→診斷,問題分析,程序控制
  →diagnostics, problem analysis, process control

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音頻系統的聲音品質
Sound Quality of Audio Systems

Part 10: 非線性自適應控制
Adaptive Nonlinear Control

Part 10: Adaptive Nonlinear Control

2026

Klippel GmbH

Roadmap
Two day courses

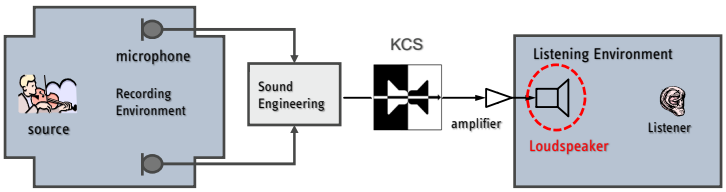
第一天First Day

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5. Nonlinear modeling & measurement

第二天Second Day

1. Nonlinear distortion Symptoms, relationship to Large Signal Parameters
2. Abnormal sound - irregular behavior, defects
3. How to define maximum SPL?
4. Quality Control, full system assessment
5. **Adaptive Nonlinear Control of speakers**

最弱的一個部件
The Weakest Part of the Audio Reproduction Chain



因為揚聲器 because the loudspeaker

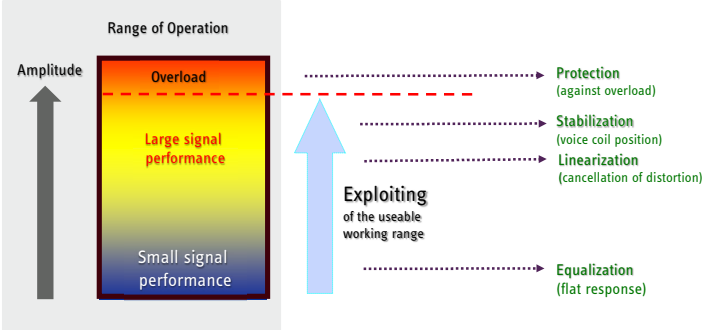
- **導致明顯的線性和非線性失真**
  causes significant linear and nonlinear distortion
- 由於生產差異，氣候，疲勞，老化而導致揚聲器特性發生變化
  varying loudspeaker properties due to production variances, climate, fatigue, ageing
- 限制聲音輸出
  limits the acoustical output
- 效率低並產生熱量
  has low efficiency and produces heat
- **有助於重量，尺寸和成本**
  contributes to weight, size and cost

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如何改善揚聲器
How to improve the Loudspeaker? (1/2)

目的 Targets:

- 降低成本 > Lower cost
- 較小的揚聲器輸出更多的聲壓 > More sound pressure output from smaller speakers
- 足夠的音質（無聲音失真） > Sufficient sound quality (no audible distortion)
- 可靠而強大的產品（沒有不良反應） > Reliable and robust product (no failures in the field)

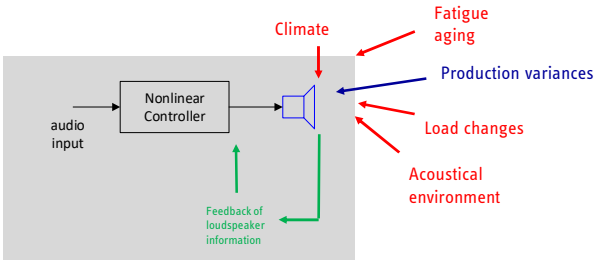


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如何改善揚聲器
How to improve the Loudspeaker? (2/2)

目的 Targets:

- 應對因生產差異而導致的揚聲器特性變化 > Coping with varying loudspeaker properties caused by production variance
- 應對隨時間變化的特性（老化）和外部影響（氣候） > Coping with changing properties over time (aging) and external influences (climate)
- 在產品生命週期內產生恆定的期望目標性能 > Generating constant desired target performance over product life



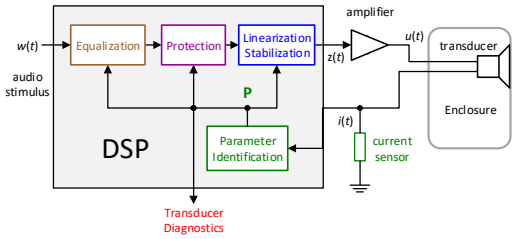
An adaptive, nonlinear control system is required !

KLIPPEL Controlled Sound (KCS)

KLIPPEL

Adaptive Nonlinear Control

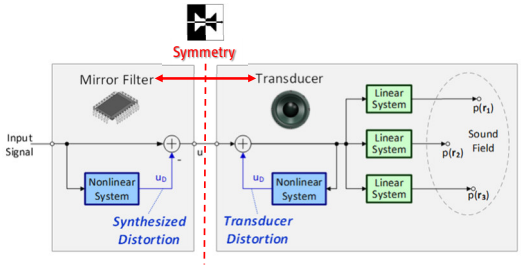
e.g. KLIPPEL Controlled Sound (KCS)



- Accurate modeling of the loudspeaker over the full working range
- Adaptive identification of the transducer parameters P by current monitoring
- Mirror Filter cancels DC displacement, harmonics and other nonlinear speaker distortion
- Active stabilization of the voice coil rest position
- Reliable protection against thermal and mechanical overload
- Automatic equalization to a target alignment (virtual shift of f_s, Q_{TS}, ...)
- On-line diagnostic of the system

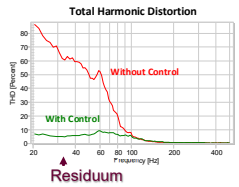
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減少非線性失真
Nonlinear Distortion Reduction



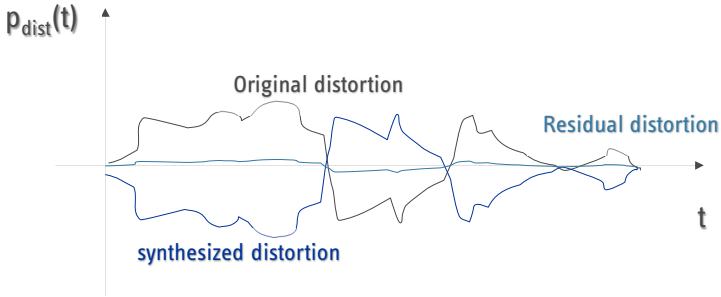
完美消除建模中考慮的非線性失真
Perfect cancellation of the nonlinear distortion components that are included in the modeling
殘留（剩餘失真）包括：Residuum (remaining distortion) comprise:

- 異音，不確定的失真 > Noise, non-deterministic distortion (rub&/buzz)
- 控制參數和瞬時傳感器參數不匹配 > Mismatch between control parameters and instantaneous transducer parameters
- 與其他被忽略的非線性失真 > Distortion from neglected other nonlinearities



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減少失真的要求
Distortion Reduction

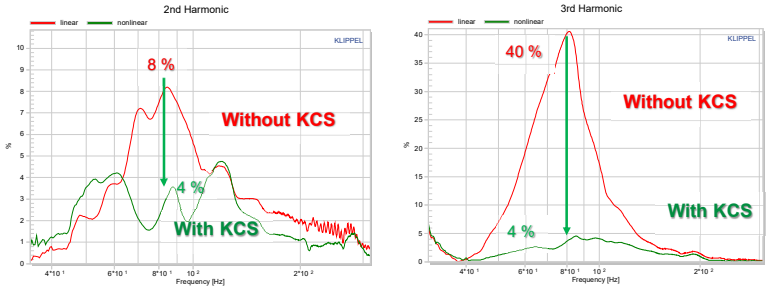


- Equal amplitude
- Inverted Signal

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消除諧波失真
Cancellation of Harmonic Distortion

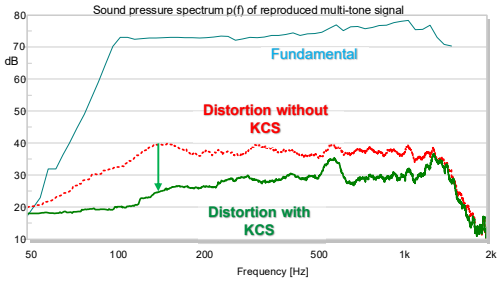
- optimized driver with and without KCS
- 2nd- and 3rd-order harmonic distortion measured with a sine chirp



KCS reduces harmonic distortion significantly

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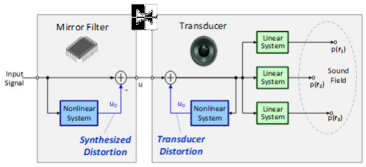
消除非線性失真
Cancellation of Nonlinear Distortion

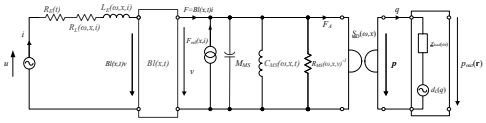


KCS reduces all nonlinear distortion components (harmonics, IMD) in the audio band significantly

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KCS Mirror Filter





優點 Benefits:

- 結構，參數和狀態信號具有物理意義
  Parameters and state signal have a physical meaning
- 減少線性和非線性失真 L
  Linear and nonlinear distortions are reduced
- 可以針對主要的非線性量身定制
  Can be tailored to the dominant nonlinearities
- 最少的處理工作（RAM，MIPS）
  Minimum processing effort (RAM, MIPS)
- 低延遲（<1個樣本），但可以添加時間延遲
  Low latency (< 1 sample), but time delay can be added
- 始終穩定 Always stable

要求 Requirements:

- 揚聲器失真的物理建模
  Physical modeling of the speaker distortion
- 需要每個揚聲器單元的最佳控制參數
  Requires optimum control parameters for each speaker unit
- 需要保護系統以限制非線性工作範圍
  Requires protection system to limit the nonlinear working range

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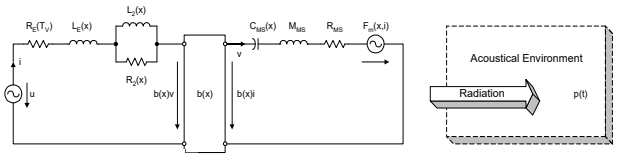
控制參數調整
Control Parameter Adjustment

自適應方法 ADAPTIVE APPROACH:

- 補償揚聲器參數（產量，時間）的變化
  Compensates for variations of the loudspeaker parameters (production, time)
- 主動在線再現音頻信號（音樂）
  Active on-line reproducing an audio signal (music)
- 確保控制器的最佳性能
  Guarantees optimal performance of the controller
- 簡化處理
  Simplifies the handling
- 導致自我學習系統
  Leads to a self-learning system

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Which State Variables Should be Measured ?



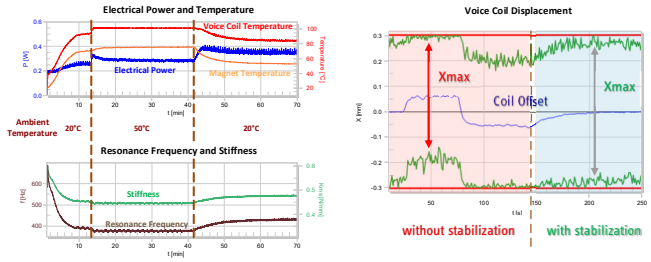
Electrical domain | Mechanical domain | Acoustical domain

Sensor Type	Current & voltage sensor	Optical Laser Sensor	Microphone
Advantages	Robust, reliable, inexpensive sensor	Absolute measurement of mechanical quantities	Sensitive to acoustical problems
Disadvantages	Reflects mechanical and acoustical system indirectly	Price, Resolution, Sensor Linearity, Handling	Acoustical disturbances Time delay

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透過音樂現場診斷（KCS）

In-Situ Diagnostics with Music (KCS)

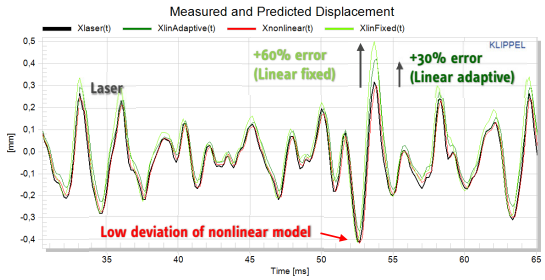


優點 Benefits:

- 任意音頻信號進行測 — Measurement while reproducing arbitrary audio signals
- 即時監測老化，疲勞，氣候影響 — In-situ monitoring of aging, fatigue, climate influence
- 收集全面信息 — Comprehensive information collected over lifetime
- 揚聲器缺陷的根本原因分析 — Root cause analysis of loudspeaker defects
- 對設計過程的反饋 — Feedback to the design process

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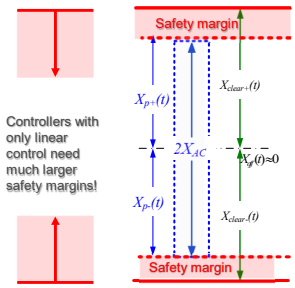
非線性模型與線性模型
Nonlinear Model vs Linear Model



- 線性預測位移明顯超過測量位移
  linear predicted displacements exceed the measured displacement significantly
- 線性模型不能考慮非線性機械壓縮和DC位移。
  linear model cannot describe **nonlinear mechanical compression and DC displacements.**
- 自適應$fs_{eff}(t)$和$Qts_{eff}(t)$更新可提高預測信號的準確性
  adaptive $fs_{eff}(t)$ and $Qts_{eff}(t)$ update increases the accuracy of the predicted signal
- 非線性預測位移非常接近實際
  nonlinear predicted displacement is very close to reality

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保護系統
KCS – Protection System – Adaptive Nonlinear Control



自適應非線性建模和控制可補償
Adaptive nonlinear control in KCS compensates:

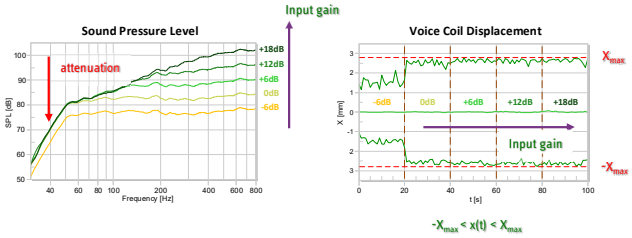
- 時間變化（年齡，氣候） Time variance (aging, climate)
- 生產傳播 Production spread
- 直流位移X_{DC} DC Displacement X_{DC}
- 音圈靜止位置$X_{off}(t)$的偏移 Offset in voice coil rest position $X_{off}(t)$

Small safety margin M required to cope with
- Modeling error
- Attenuation control

優點 Benefits:
- 最大交流排量
  Maximum AC displacement
- 最大聲音輸出
  Maximum acoustical output

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可靠的換能器保護
Reliable Transducer Protection (KCS)

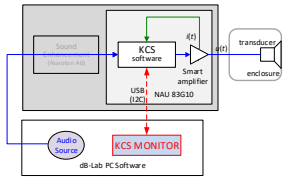


優點 Benefits:

➢ 可靠的機械和熱保護	> Reliable mechanical and thermal protection
➢ 最大低音表現（受Xmax限制）	> Maximum bass performance (limited by X_{max})
➢ 增加最大SPL輸出	> Increased maximum SPL output
➢ 利用整個音圈擺幅	> Exploiting the entire voice coil swing
➢ 最少的零件	> Minimum artifacts
➢ 零延遲	> Zero delay possible

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KCS Monitor

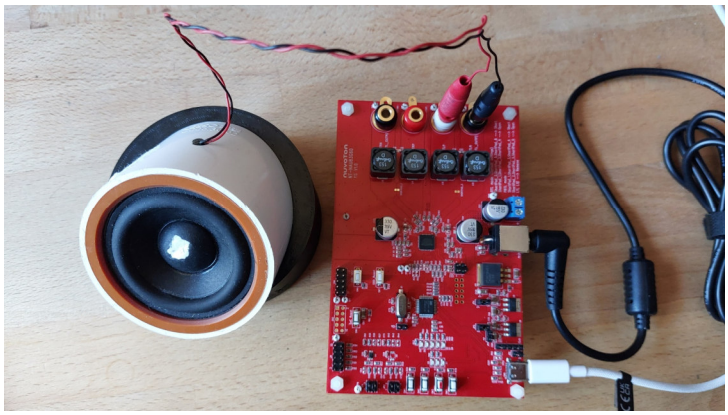


目標和功能 Objectives and Functionality

- 工程師與KCS之間的通訊（例如NAU 83G10 / G20 / G60）
  Communication between engineer and KCS (e.g. NAU 83G10 / G20 / G60)
- 用於修改設置控制參數（例如保護參數）的用戶界面
  User interface for modifying setup control parameters (e.g. protection parameters)
- 選擇KCS操作模式（ON，OFF，僅均衡，…）
  Selection of KCS operation mode (ON, OFF, Equalization only, …)
- 監看KSC，放大器，傳感器中的狀態變量（例如電壓與時間的關係）
  Monitoring state variables in KSC, amplifier, transducer (e.g. voltage vs time)
- KCS操作的長期歷史（例如耐力測試）
  Long-term history of KCS operation (e.g. endurance testing)

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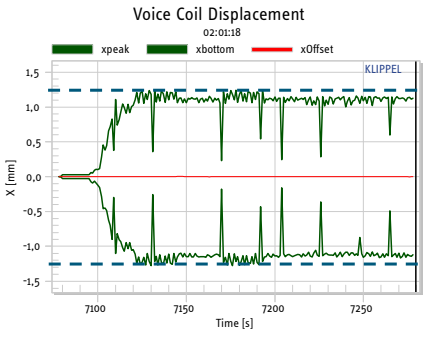
Evaluation Board NAU83G60



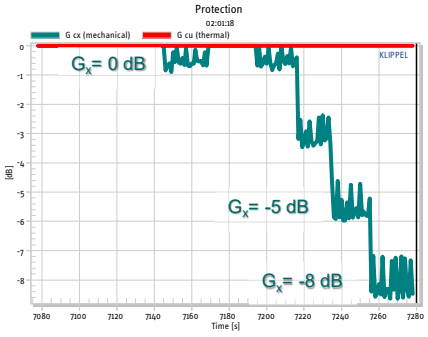
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檢查保護系統

Inspect Protection System – using KCS Monitor



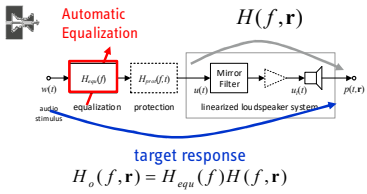
Thermal protection not active G_T= 0 dB

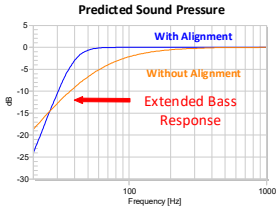


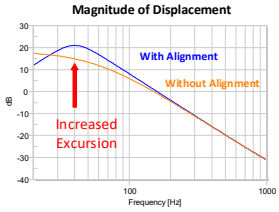
Mechanical Protection system active G_x< 0

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Desired Linear Transfer Response





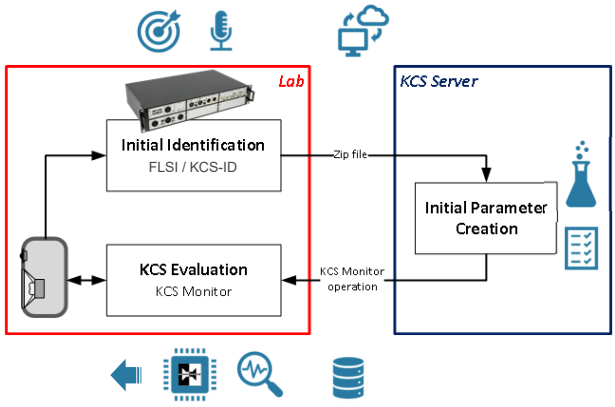


- Adaptive, nonlinear control generates a **virtual loudspeaker** with linear, time-invariant properties
- **Compensation** of production variances, aging, fatigue and climate
- **Automatic** transducer-enclosure alignment to desired target response $H_o(f,r)$
- Extended bass response
- Decoupled enclosure and transducer design
- Simplified sound **tuning**

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參數識別過程

Initial Parameter Identification Process

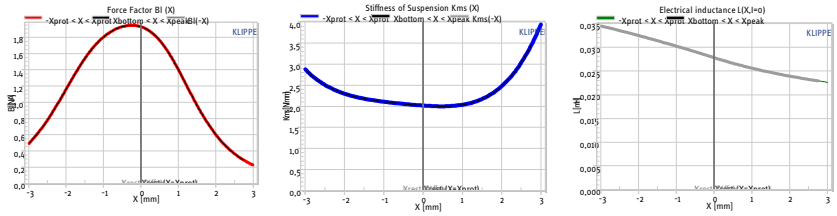


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初始參數
KCS – KCS Initial Parameters

Linear Parameters: Re, Mms, Bl, Kms, Rms, Qts, fs

Nonlinear Parameters:



Thermal Parameters: Thermal resistance Rtv, Thermal capacity Ctv, ….

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揚聲器設計的新典範
New Paradigm in Loudspeaker Design

綠色揚聲器設計
Green Speaker Design

- 使用非線性電機拓撲和較軟的懸架
  using nonlinear motor topologies and softer suspensions
- 利用模態振動（共振）
  exploiting modal vibrations (resonances)

更有效率
More Efficiency

提升SPL輸出
Increasing the SPL output

減少尺寸,重量,花費Reducing size, weight and cost

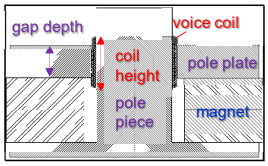
更多失真
More Distortion
f_s, Q_{TS}, Bl(x), L(x), K_{ms}(x)

透過KCS來降低
reduced by KCS

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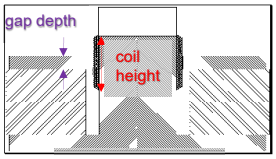
Optimum Gap-Coil Topology

Efficiency versus Linearity

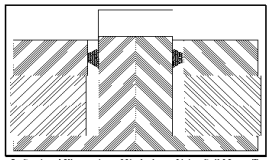


optimum-length configuration

Highest efficiency
(exploiting fringe field)



over-hung coil



under-hung coil

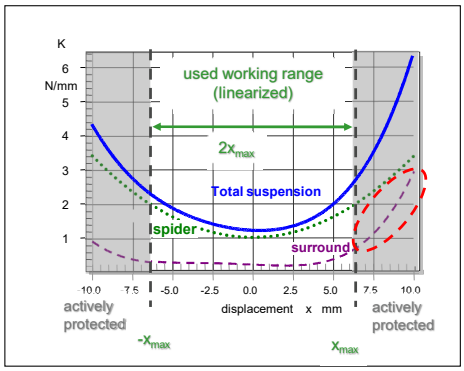
Topology	Optimum length	Over-hang	Under-hang
Efficiency	high	low	low
Moving mass M_{MS}	medium	high	low
Bl(x)-nonlinearity	strong	weak	weak
L(x)-nonlinearity	medium	strong	weak
DC-Stability	critical	robust	robust
Weight, size cost	low	medium	high

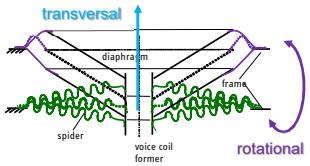
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最佳非線性之剛性

Optimal Stiffness Nonlinearity

Guidelines for maximum reliability and efficiency:



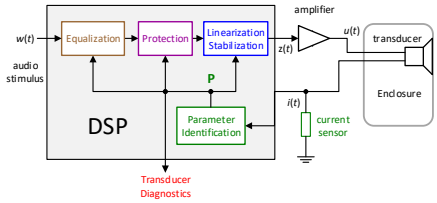


- Similar stiffness of spider and surround
  - → high rotational stiffness
  - → defeat rocking modes → coil rubbing
- Low increase of transversal stiffness in working range $|x|<x_{max}$
- Strong progressive increase of the transversal stiffness outside working range $|x|>x_{max}$

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總結自適應非線性控制
Summary Adaptive Nonlinear Control

KLIPPEL Controlled Sound (KCS)



- 在整個工作範圍內對揚聲器進行精確建模
  Accurate modeling of the loudspeaker over the full working range
- 通過電流監控自適應識別傳感器參數P
  Adaptive identification of the transducer parameters P by current monitoring
- 鏡面濾波器可消除直流位移，諧波和其他非線性揚聲器失真
  Mirror Filter cancels DC displacement, harmonics and other nonlinear speaker distortion
- 主動穩定音圈的靜止位置 Active stabilization of the voice coil rest position
- 可靠的保護，防止熱過載和機械過載。零延遲可能
  Reliable protection against thermal and mechanical overload. Zero latency possible
- 自動均衡到目標對準（fs，QTS等的虛擬位移）
  Automatic equalization to a target alignment (virtual shift of f_s, Q_{TS}, ...)
- 系統在線診斷 On-line diagnostics of the system

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揚聲器控制技術
Loudspeaker Control Technologies

線性控制 Linear Control

- 揚聲器由線性系統建模，該線性系統在小振幅下有效，而忽略了限制最大輸出的所有揚聲器為非線性 Loudspeaker is modeled by a linear system valid at small amplitudes while neglecting all loudspeaker nonlinearities that limit maximum output
- 沒有減少非線性失真（THD，IMD，DC位移，壓縮等）No reduction of nonlinear distortion (THD, IMD, DC displacement, compression,...)
- 小幅度的揚聲器診斷有限 Limited loudspeaker diagnostics at small amplitudes
- 困難的參數調整（需要由專家進行調整）
  Difficult parameter adjustment (tuning by human expert required)
- 不監視音圈靜止位置
  No monitoring of voice coil rest position
- 預測音圈位移時出現重大錯誤（無壓縮，無直流分量）Significant error in predicting voice coil displacement (no compression, no dc identification)
- 保護揚聲器需要很大的安全餘量→輸出降低
  Large safety margin required to protect loudspeaker → reduced output
- 需要線性揚聲器→更高的成本，重量，尺寸，更低的效率，更少的輸出
  Requires linear loudspeakers → higher cost, weight, size, lower efficiency, less output

自適應非線性控制 Adaptive Nonlinear

- 揚聲器由在整個工作範圍內有效的非線性系統建模
  Loudspeaker is modeled by a nonlinear system valid over the full working range
- 主動補償揚聲器的非線性（線性化）並產生所需的線性整體傳遞特性 Compensates actively for loudspeaker nonlinearities (linearization) and generates desired linear overall transfer behavior
- 揚聲器診斷顯示物理限制和缺陷 Loudspeaker diagnostics showing physical limits and defects
- 具有簡單自動調整程序的自學習控制系統（類似於LSI）
  Self-learning control system with simple automatic adjustment procedure (similar to LSI)
- 簡單監控整個產品壽命中的絕對音圈靜止位置
  Simple monitoring of absolute voice coil rest position over product life
- 準確識別小振幅和高振幅的音圈位移
  Accurate identification of voice coil displacement at small and high amplitudes
- 可靠保護揚聲器所需的最小安全範圍→最大輸出
  Minimum safety margin required to protect loudspeaker reliably → maximum output
- 允許使用高效換能器（綠色揚聲器設計）
  Allows to use highly efficient transducers (green speaker design)

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