

Acoustical Measurement of Sound System Equipment according IEC 60268-21

符合IEC 60268-21的音響系統聲學測量設備

KLIPPEL- live

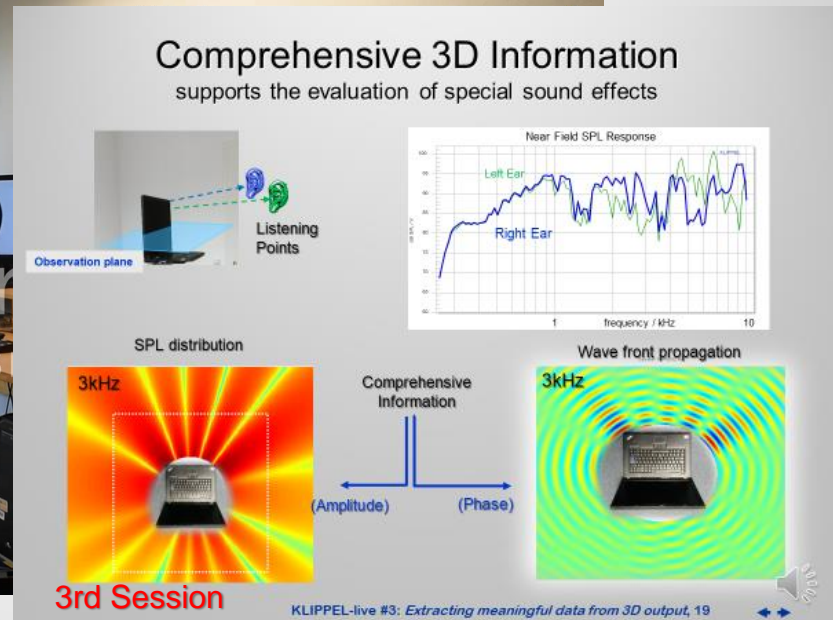
a series of webinars presented by

Wolfgang Klippel



Previous Sessions

1. Modern audio equipment needs output based testing
2. Standard acoustical tests performed in normal rooms
3. Drawing meaningful conclusions from 3D output measurement



Ask Klippel

First Question:

實施近場掃描是否有缺點，如何克服？

Is there disadvantage to implement near field scanning and how to overcome it?

Response WK:

缺點Disadvantages :

- 準確定位麥克風需要機電一體化 (Robotics) → 尋找輕便，經濟高效的掃描硬體
Mechatronic (Robotics) required for accurate microphone positioning → searching for light, cost-efficient scanning hardware
- 掃描過程限制了測量時間→減少測量點的數量（利用對稱校正功能，利用複雜的校正功能）（今天的主題）

Scanning process limits the measurement time → Reducing the number of measurement point (exploiting symmetry, using a complex correction function (our topic today))



Ask Klippel

Second Question:

您能提出一種在產線質量控制中實施方向性測量的好方法嗎？

Can you suggest a good way to implement directivity measurement for production QC on line?

Response WK:

1) 問題PROBLEM:

- 大多數製造商都假定方向性是恆定的，不會受到製造過程的影響（對於單個傳感器幾乎是正確的） → 不需要此測試

Most manufacturer assume that the directivity is constant and will not be affected by manufacturing process (almost true for a single transducer) → this test is not required

- 但是，在具有多個單體的音頻系統中（例如具有主動波束控制的線性陣列），一個單體中的缺陷會嚴重影響方向性

However, in audio systems with multiple transducers (e.g. linear arrays with active beam steering) a defect in one transducer can significantly affect the directivity

→ 需要在終端產線進行測試！ Testing at EoL is required !



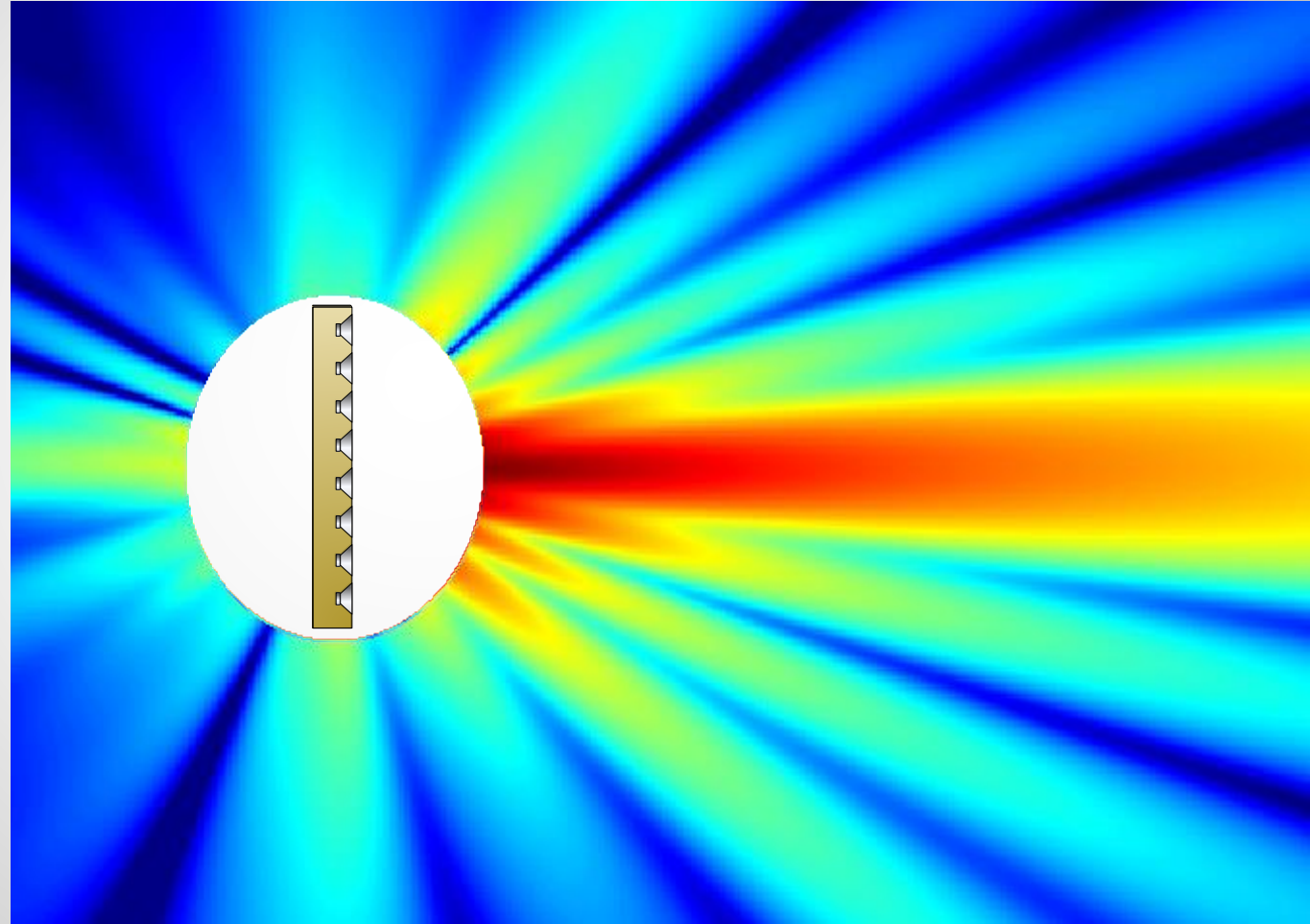
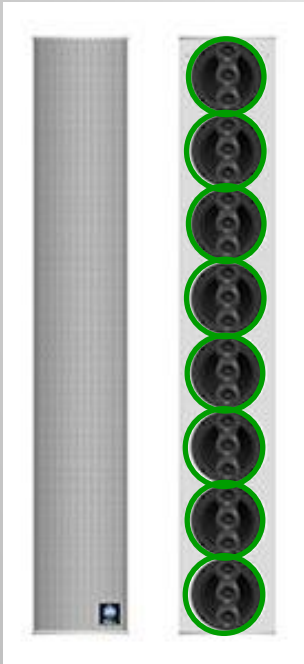
線源の量測 Measurement of line sources (2)

Super positioning of the multiple measurements

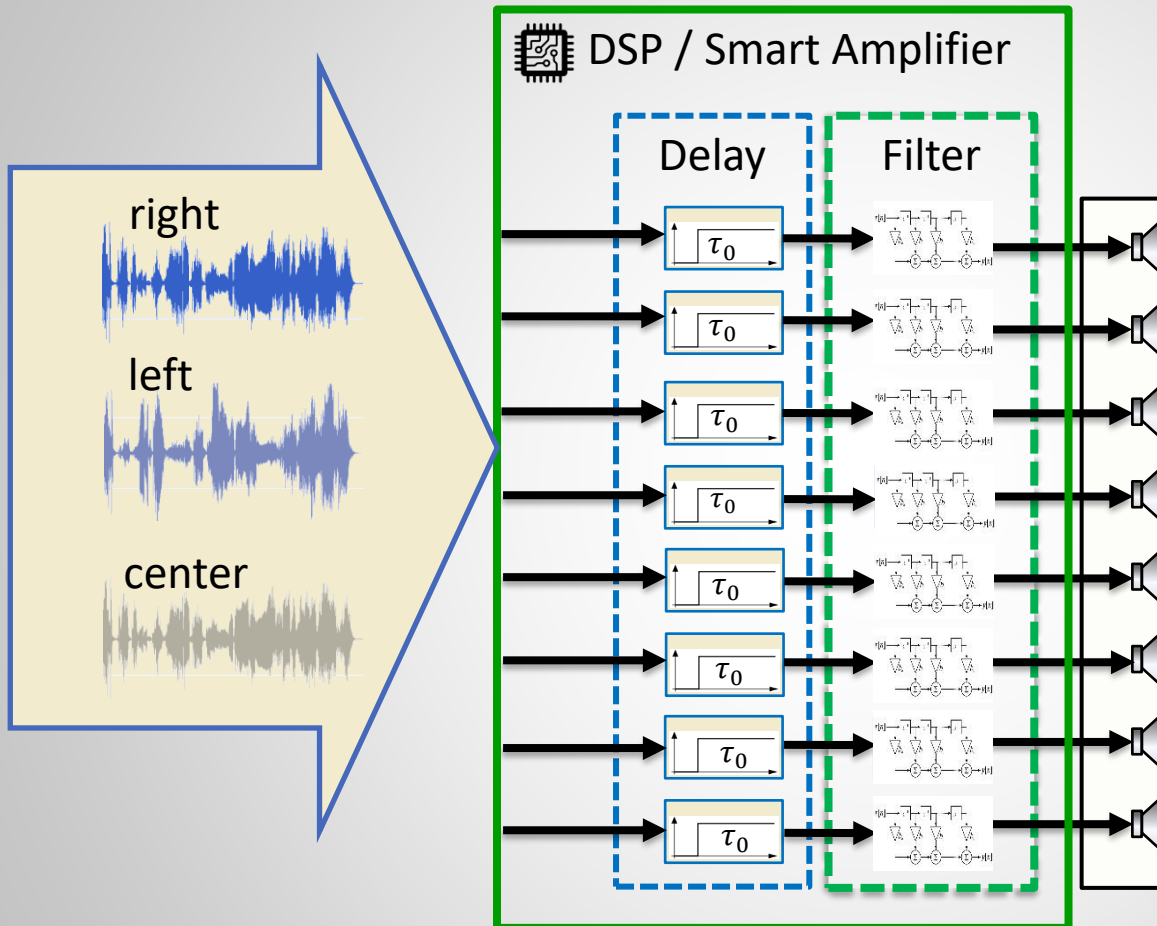
2kHz

Line Array:

- 8 coaxial speakers
- 24 tweeter
- Super position of 8 multipoles



方向性控制 Controlled directivity



Ask Klippel

Second Question:

您能提出一種在產線質量控制中實施方向性測量的好方法嗎？

Can you suggest a good way to implement directivity measurement for production QC on line?

Response WK:

2) 目標Objectives

- 檢查系統方向性是否失敗？

to check that the system has a failure in directivity ?

- 識別缺陷驅動程序（在具有50個驅動程序的陣列中）？

to identify the defect driver (in an array with 50 drivers) ?

- 使用最少的硬件（麥克風數量）？

to use a minimum of hardware (number of microphones) ?

- 盡量減少測量時間

To minimize the measurement time

識別缺陷驅動程序是耗時的要點！

The identification of the defect driver is the time consuming point !



Ask Klippel

Second Question:

您能提出一種在產線質量控制中實施方向性測量的好方法嗎？

Can you suggest a good way to implement directivity measurement for production QC on line?

Response WK:

2) 解決方案Solution

- 使用最少的麥克風（1...4）以確保良好的信噪比（SNR），以測量所有驅動器

Using a minimum of microphones (1 ...4) to ensure good signal to noise ratio (SNR) for measuring all drivers

- 使用分層的迭代測量程序，執行最少的測量（<10），同時測量換相器，以產生最大的聲抵消效果
- Using a hierarchical iterative measurement procedure performing a minimum of measurements (< 10) while measuring transducers switched in anti-phase to generate maximum acoustical cancellation

- 後處理以識別缺陷單元

Post-processing to identify the defect unit

需求Requirements:

- 在終端產線測試期間切換單體

Switching the transducers during the EoL test

- DSP（在音頻設備中）和測量儀器之間的控制接口

Control interface between DSP (in the audio device) and measurement instrument



Question ?



4th KLIPPEL live: **Simulated standard condition at a single evaluation point**

今日主題Topics today:

- 簡化標準測量

Simplifying standard measurements

- 根據IEC 60268-21模擬自由場和遠場條件

Simulation of free-field and far-field condition according IEC 60268-21

- 補償房間影響，不同的位置和距離

Compensation for room influence, different positioning and distance

- 為不同類型的揚聲器創建房間補償功能

Creating room compensation functions for different types of speakers



Poll:

大多數工程師與其他人共享消聲室。 這會妨礙您的工作嗎？

Most audio engineers share an anechoic room with others. Does this hinder your work ?

- Not really
- Sometimes
- Frequently
- Always



尋找替代方案 Searching for an Alternative

目標Targets:

- 在幾乎任何聲學環境中，為一個評估點生成模擬的遠場和自由場條件。

Generating simulated far-field and free-field condition for one evaluation point in almost any acoustical environment.

- 允許快速測量（無需掃描）

Allowing fast measurements (without scanning)

- 最少設備（僅限麥克風）

Minimum equipment (mic only)

- 適用於其他測量（非線性失真，壓縮）和調諧工作（DSP）

Applicable to other measurements (nonlinear distortion, compression) and tuning work (DSP)

- 結合感性評估（聽）

Combination with perceptual evaluation (listening)

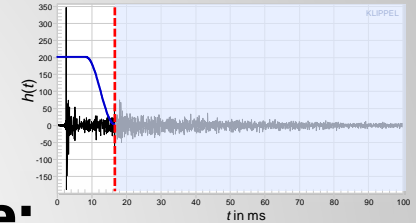


模擬自由場條件 Simulated free field conditions

According IEC 60268-21

時域 Time Windowing:

- 消除脈衝反應中的反射 cutting out reflections in impulse response
- 低頻衰退 fails at low frequencies

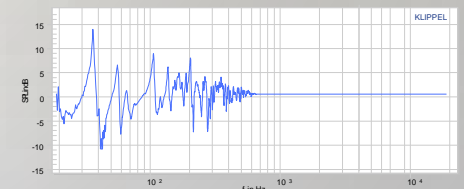
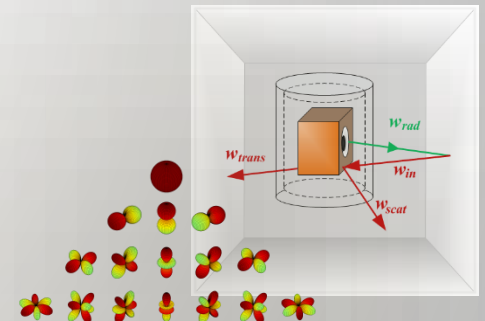


全息量測技術 Holographic measurement technique:

- 直接聲音分離 (球面波擴展) Direct sound separation (spherical wave expansion)
- 掃描需要機械化 Scanning requires robotics
- 測量時間更長 Longer measurement time

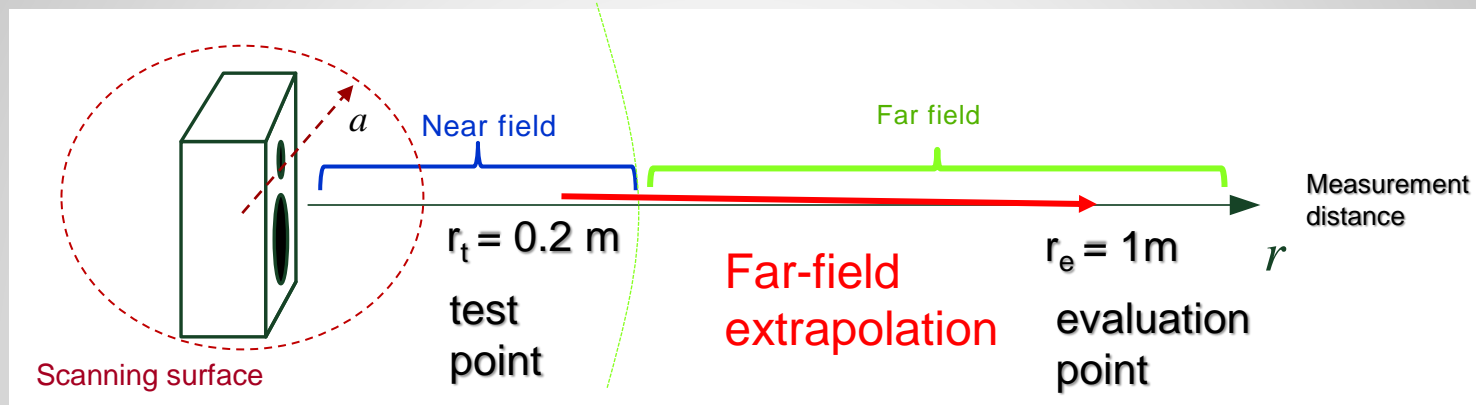
補償功能 Compensation Function

- 快速測量 (僅1點) Fast measurement (only 1 point)
- 複合濾波麥克風信號 Complex filtering the microphone signal
- 需要準確的參考信息 requires accurate reference information



模擬遠場條件 Simulated Far-Field Condition

according IEC 60268-21

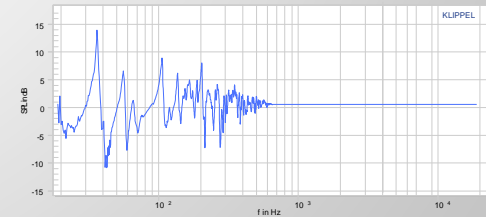


全息量測技術 Holographic measurement technique:

- 基於球面波展開的外推 Extrapolation based on spherical wave expansion
- 掃描過程需要機器人 Scanning process requires robotics

補償功能 Compensation Function

- 快速測量（僅1點） Fast measurement (only 1 point)
- 麥克風信號的複雜濾波 Complex filtering of the microphone signal
- 需要準確的參考信息 requires accurate reference information



在我辦公室做的測量 Standard Testing in My Office?



需要解決以下問題 I have to cope with the following problems:

- 房間面積小 (到邊界的距離 <1.5 m) Small room size (distance to the boundaries < 1.5 m)
- 典型的混響時間 ≈ 0.5 s (書籍, 地毯, 椅子) Typical reverberation time ≈ 0.5 s (books, carpet, chairs)
- 大桌子 (房間中間3平方米) Large table (3 m² in the middle of the room)
- 環境噪聲 (同事, 音樂學校, 交通) Ambient noise (coworker, music school, traffic)



在現有條件下做最好 Making the best out of this

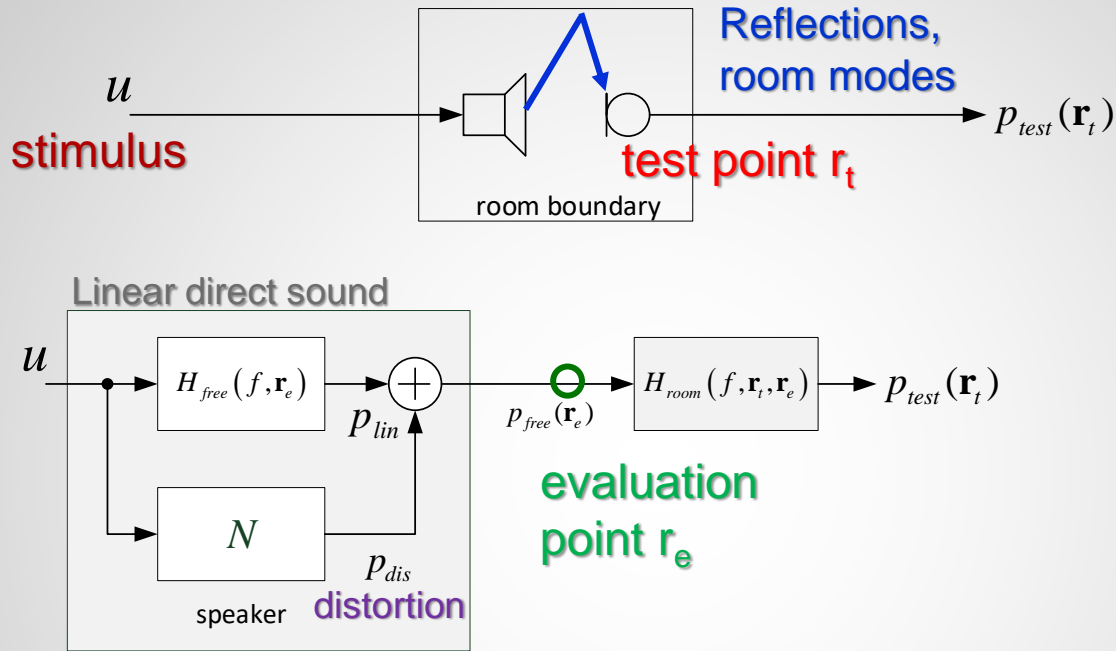
結論 Consequences

- Small room size (distance to the boundaries < 1.5 m)
 - 較小的範圍 (在 $f < 500$ Hz時限制分辨率) short window length (limits resolution at $f < 500$ Hz)
 - 麥克風位置靠近揚聲器 (r_t) microphone position close to the speaker (r_t)
 - 近場條件 (需要遠場外推) near-field condition (far-field extrapolation required)
- Typical reverberation time ≈ 0.5 s (books, carpet, chairs)
 - 房間模式會影響低頻響應 room modes will affect the low frequency response
 - 所需的麥克風信號濾波複雜 complex filtering of the mic signal required
- Large table (3 m^2 in the middle of the room)
 - 地面測量 (半空間) ground floor measurement (half space)
 - 桌子邊緣的反射 (較小的範圍) reflections at the table edges (short window length)
- Ambient noise (coworker, music school, traffic)
 - 短距離, 近場測量 short distance, near-field measurement



揚聲器建模，環境，位置

Modelling Speaker, Room, Position



- 麥克風處於固定測試位置 r_t (通常在近場中)

Microphone at a fixed test position r_t (usually in the near field)

- 揚聲器產生非線性失真 (THD, IMD, 異音)

Speaker generates nonlinear distortion (THD, IMD, rub & buzz)

- 在模擬自由場和遠場條件下，在評估點 r_e 上生成準確的結果

Generating accurate results at an evaluation point r_e under simulated free-field and far-field conditions

- 測試點 r_t 和評估點 r_e 可以不同

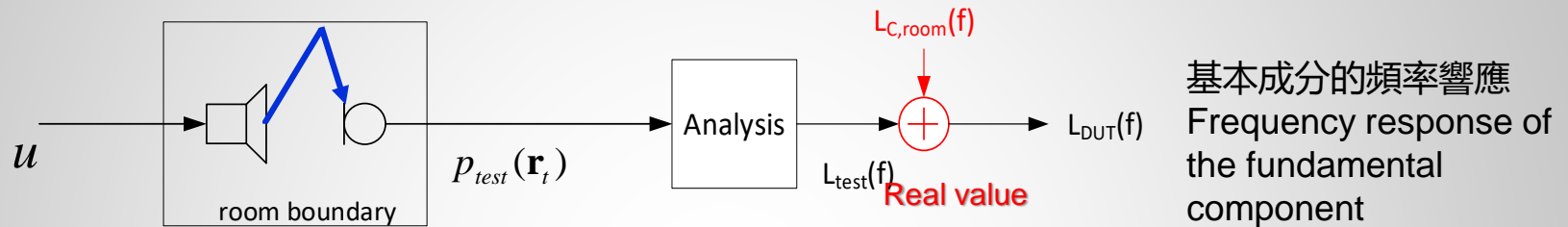
Test point r_t and evaluation point r_e can be different



模擬標準條件 Simulated Standard Conditions

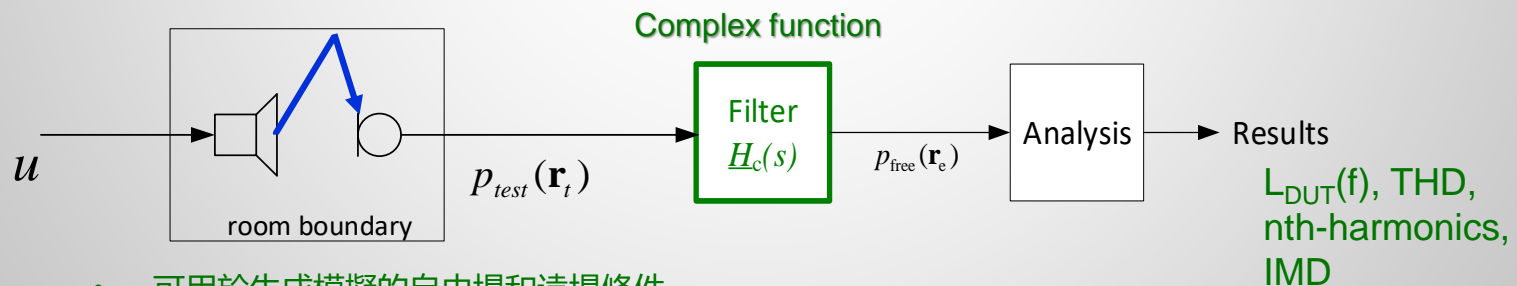
Correction Techniques defined in IEC 60268-21

Method 1: Correction of the amplitude response (clause 19.5.2)



- 用於生成“房間校正功能”
Used for generating a „room correction function“
- 不適用於失真測量（例如Farina）！
Not useful for distortion measurements (e.g. Farina) !

Method 2: Correction of the measured sound pressure signal (clause 19.5.1)



- 可用於生成模擬的自由場和遠場條件
Can be used to generate simulated free-field and far field condition
- 可以應用於任何分析（例如Farina）
Can be applied to any analysis (e.g. Farina)



Poll:

您是否對幅度響應應用校正功能以補償消聲室的不足（方法1）？

Do you apply a correction function to the amplitude response to compensate insufficiencies of your anechoic room (method 1) ?

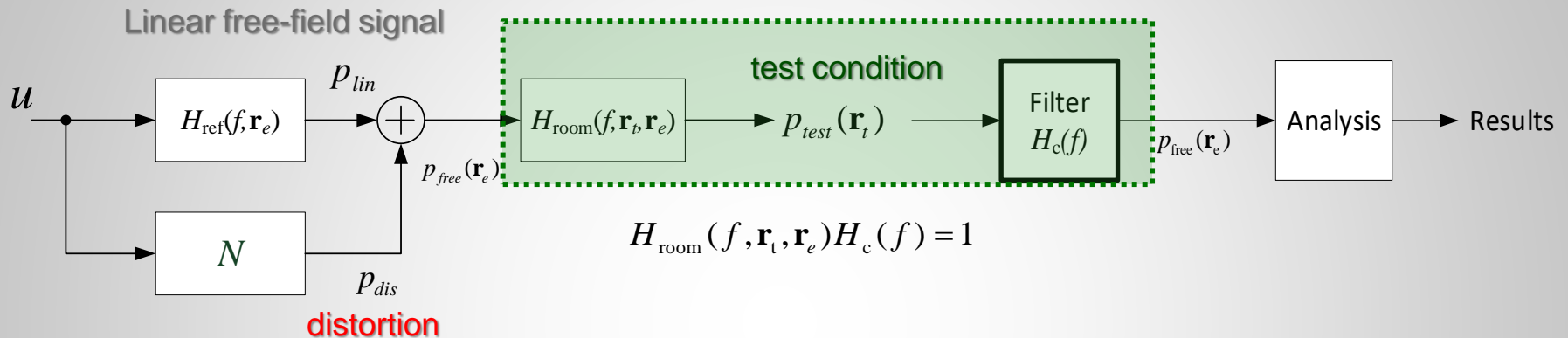
- Yes
- No



校正測得的聲壓

Correction of the measured sound pressure

method according clause 19.5.2 in IEC 60268-21



$$H_c(f) = \frac{1}{\underbrace{H_{\text{room}}(f, \mathbf{r}_t)}_{\text{room influence}}} \frac{\underbrace{H_{\text{free}}(f, \mathbf{r}_e)}_{\text{Standard evaluation point}}}{\underbrace{H_{\text{free}}(f, \mathbf{r}_t)}_{\text{test point}}}$$

解決方案：過濾麥克風信號 $p_{\text{test}}(\mathbf{r}_t)$ 以補償

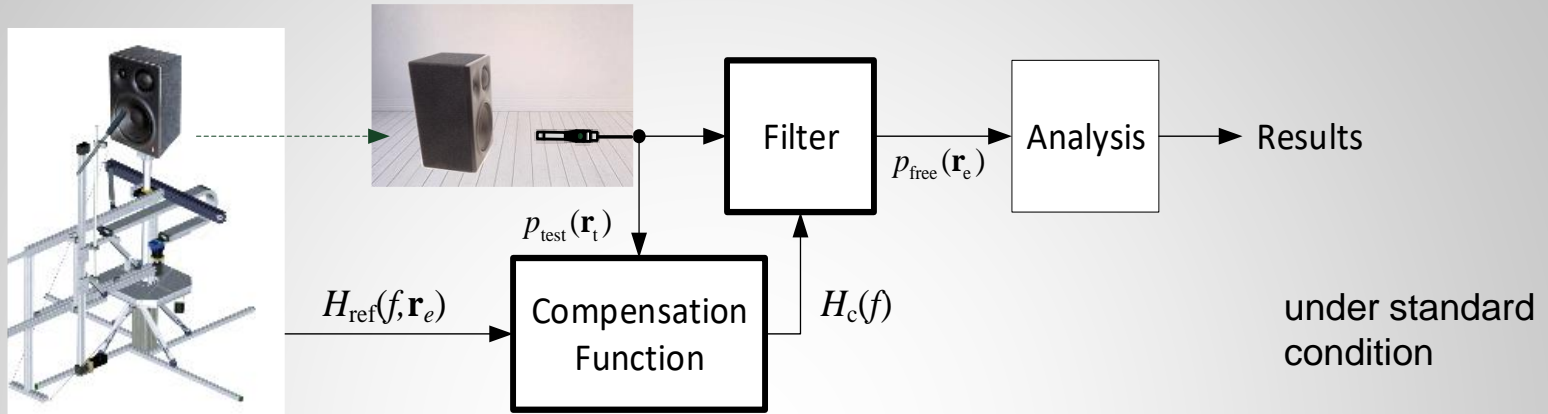
Solution: Filtering the microphone signal $p_{\text{test}}(\mathbf{r}_t)$ to compensate for

- 房間影響 room influence
- 測量點的位置（距離，角度） position of the measurement point (distance, angle)
- 複數補償函數 $H_c(f)$ （相位和幅度信息） Complex compensation function $H_c(f)$ (phase and amplitude information)



補償過濾器的工作流程

Work Flow with a compensation filter



- 在所需評估點 $\mathbf{r_e}$ (例如在遠場) 提供準確的參考響應 $\mathbf{H_{ref}(f, r_e)}$

Provide an accurate **reference** response $H_{ref}(f, \mathbf{r_e})$ at the desired **evaluation point** $\mathbf{r_e}$ (e.g. in the far field)

- 在沒有補償過濾器的測試條件下, 在測試點 (例如, 近場) 中測量聲壓 $p_{test}(\mathbf{r_t})$ 併計算傳遞函數 $\mathbf{H_{test}(f, r_t)}$

Measure the sound pressure $p_{test}(\mathbf{r_t})$ at the **test point** (e.g. in the near field) and calculate transfer function $H_{test}(f, \mathbf{r_t})$ under test conditions without compensation filter

- 根據傳遞函數 $\mathbf{H_{test}(f, r_t)}$ 和 $\mathbf{H_{ref}(f, r_e)}$ 計算補償函數 $\mathbf{H_c(f)}$

Calculate the **compensation** function $H_c(f)$ based on the transfer functions $H_{test}(f, \mathbf{r_t})$ and $H_{ref}(f, \mathbf{r_e})$

- 使用補償函數 $\mathbf{H_c(f)}$ 對測得的聲壓 $p_{test}(\mathbf{r_t})$ 進行濾波, 以根據標準條件在評估點生成直接聲音 $\mathbf{p_{free}(r_e)}$

Filter the measured sound pressure $p_{test}(\mathbf{r_t})$ with the compensation function $H_c(f)$ to generated the **direct sound** $p_{free}(\mathbf{r_e})$ at the evaluation point according standard condition



$$H_c = \frac{H_{ref}}{H_{test}}$$



如何提供準確的參考響應 $H_{ref}(f, r_e)$?

How to provide accurate reference response $H_{ref}(f, r_e)$?

- 消聲室（低頻引起的錯誤）

Anechoic room (error caused at low frequencies)

- 外部自由場測量（由氣候，風，環境噪聲引起的誤差）

Outside free-field measurement (error caused by climate, wind, ambient noise)

- 全息近場掃描（為3D空間中的任何測試點和評估點提供準確的數據）

Holographic near field scanning (provides accurate data for any test point and evaluation point in 3D space)

recommended !



Question ?



現場補償方法概述

Overview of the In-situ Compensation Schemes

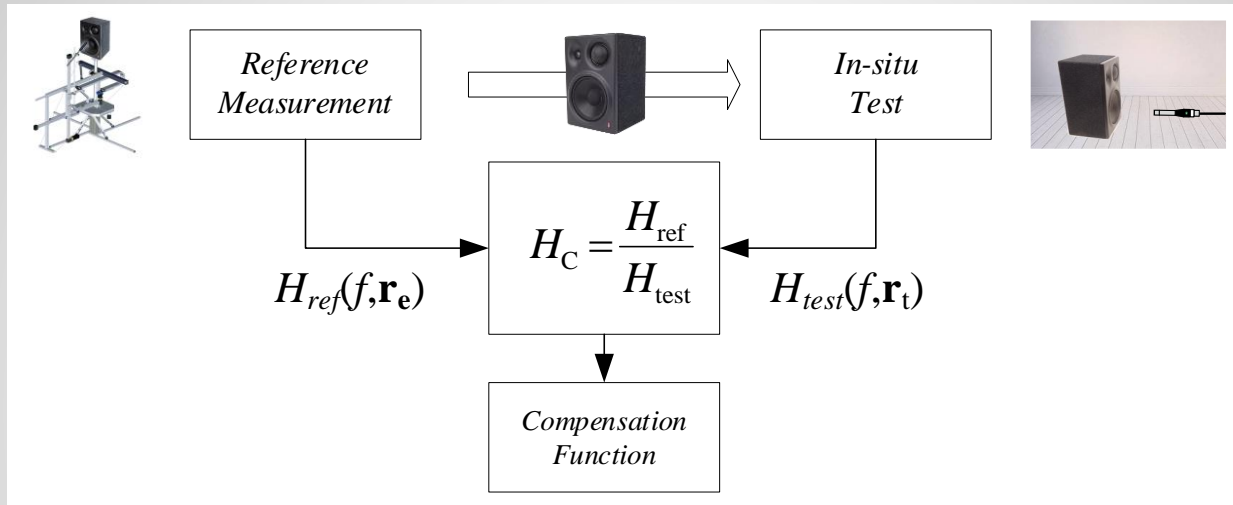
方法Method	FC-FR 全頻段參考的全補償 Full compensation with full-band reference	FC-LR Full compensation with low frequency reference	LC-LR Low frequency compensation with low-frequency reference
模擬自由場條件 Simulated free-field condition	任意環境 (房間、測試箱、測試臺) in any environment (room, test box, stand)	Workshops, Offices sufficient distance to the Boundary (walls)	Small room with anechoic condition at higher frequencies
提供的模擬遠場條件 Simulated far-field condition provided	所有頻率 For all frequencies	For lower frequencies	For lower frequencies
得到精確參考數據所花精力 Effort for providing accurate reference data	一般掃描Normal Scan (20 min*)	Short Scan (7 min*)	Short Scan (7 min*)

* 針對KLIPPEL LIVE系列研討會中使用的小藍牙音箱
Small Bluetooth speaker used in webinar KLIPPEL live



全補償 Complete Compensation

基於全頻段參考測量(FBR) based on a full-band reference measurement (FBR)



特點 Features:

- 優點 PROs
 - 補償房間影響（反射、半/全空間、夾具） compensates for room influence (reflections, half/full space, clamping)
 - 補償測試點 \mathbf{r}_t 和評估點 \mathbf{r}_e 的差異 compensates for difference in test point \mathbf{r}_t and evaluation point \mathbf{r}_e
- 缺點 CONS
 - 需要所有頻率處精確且分辨率足夠的參考響應 $H_{ref}(f, \mathbf{r}_e)$ requires accurate reference response $H_{ref}(f, \mathbf{r}_e)$ with sufficient resolution at all frequencies
 - DUT和麥克風位置的任意移動都會影響補償函數 $H_c(f)$ Any shift of DUT and microphone position affects the compensation function $H_c(f)$



Practical Demo



評估點1m距離處模擬自由場、遠場條件 Simulated Free-field, Far-field condition at evaluation point 1m distance

- 現場全補償 – 全參考技術 (FC-FR) In-situ full compensation - full reference Technique (FC-FR)
- 需要20分鐘掃描時間獲取參考數據 scanning time 20 min required for generating reference data



Question ?



現場補償方法概述

Overview of the In-situ Compensation Schemes

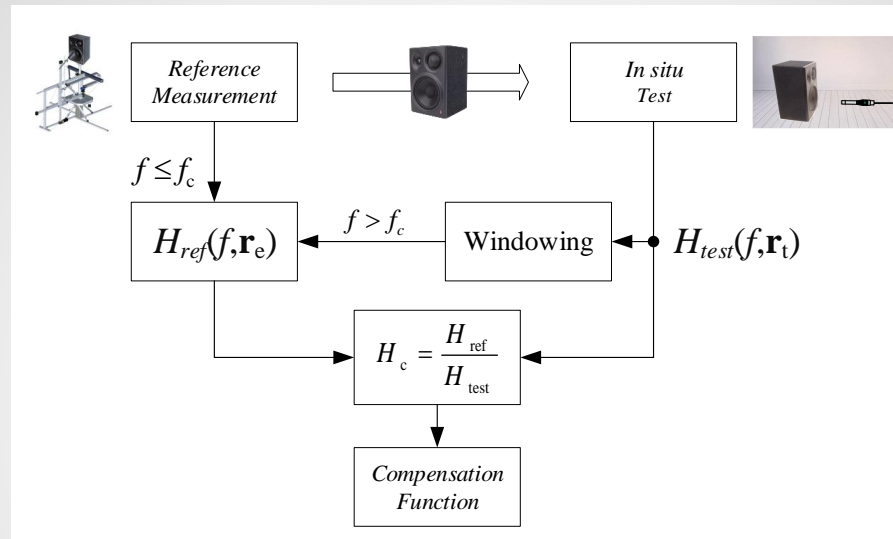
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模擬自由場條件 Simulated free-field condition	任意環境（房間、測試箱、測試臺） in any environment (room, test box, stand)	車間、辦公室，至邊界（牆面）有足夠的距離 Workshops, Offices sufficient distance to the Boundary (walls)	Small room with anechoic condition at higher frequencies
提供的模擬遠場條件 Simulated far-field condition provided	所有頻率 For all frequencies	低頻段 For lower frequencies	For lower frequencies
得到精確參考數據所花精力Effort for providing accurate reference data	一般掃描 Normal Scan (20 min*)	短掃描 Short Scan (7 min*)	Short Scan (7 min*)

* 針對KLIPPEL LIVE系列研討會中使用的小藍牙音箱
Small Bluetooth speaker used in webinar KLIPPEL live



全補償 Full Compensation

基於低頻參考測量(FC-LR) based on a low-frequency reference measurement (FC-LR)



特點 Features:

優點 PROs

- 需要低頻段的精確參考響應 $H_{ref}(f, \mathbf{r}_r)$ requires accurate reference response $H_{ref}(f, \mathbf{r}_r)$ at low frequencies
- 高頻段使用加窗技術 uses windowing at higher frequencies
- 小位置錯誤不重要 small positioning error is not critical

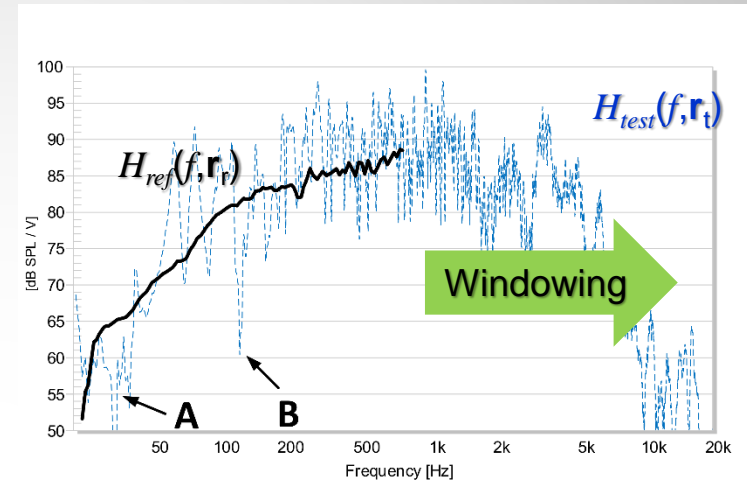
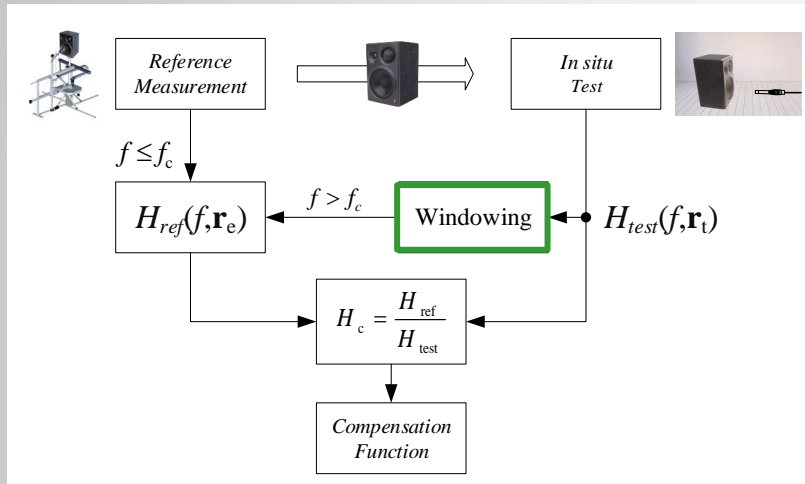
缺點 CONS

- 高頻段的加窗需要至邊界有足夠距離 windowing requires sufficient distance from boundaries at higher frequencies



Example of LFR Method

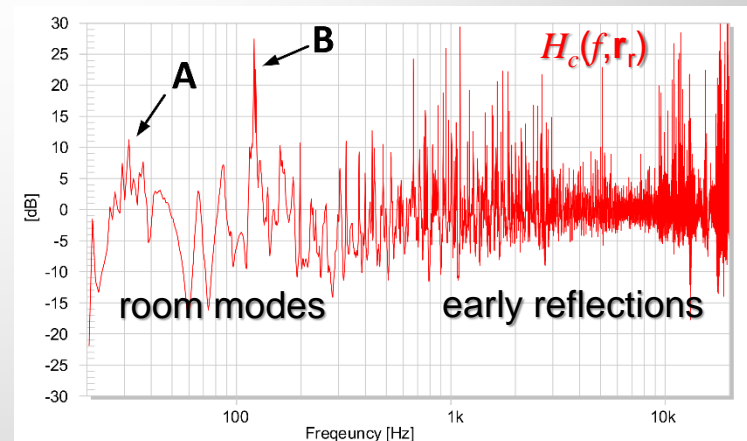
Low frequency
reference (LFR)



補償函數 $H_c(f)$

Compensation function $H_c(f)$

- 改變測得的聲壓信號的幅度和相位 (> 20 dB)
changes amplitude and phase of the measured sound pressure signal (> 20 dB)
- 僅對固定測試點有效
only valid for a fixed test point



Practical Demo



- 評估點1m距離處模擬自由場、遠場條件 Simulated Free-field, Far-field condition at evaluation point 1m distance
- 現場全補償 – 低頻參考技術(FC-LR) In-situ Full compensation - low frequency reference (FC-LR) technique
 - 7分鐘掃描時間 scanning time 7 min



Question ?



現場補償方法概述

Overview of the In-situ Compensation Schemes

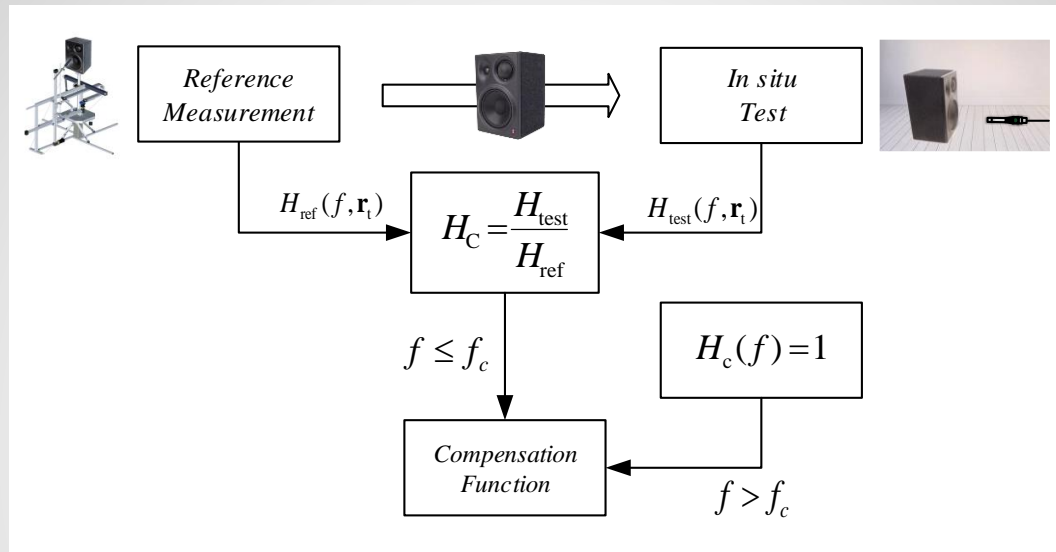
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提供的模擬遠場條件 Simulated far-field condition provided	所有頻率 For all frequencies	低頻段 For lower frequencies	低頻段 For lower frequencies
得到精確參考數據所花精力 Effort for providing accurate reference data	一般掃描 Normal Scan (20 min*)	短掃描 Short Scan (7 min*)	段掃描 Short Scan (7 min*)

* 針對KLIPPEL LIVE系列研討會中使用的小藍牙音箱
Small Bluetooth speaker used in webinar KLIPPEL live



低頻補償 Low Frequency Compensation

基於低頻參考測量(LC-LR) based on a low-frequency reference measurement (LC-LR)



特點 Features:

- 優點 PROs**
- 需要僅低頻段(<1kHz)精確且分辨率足夠的參考響應 $H_{ref}(f, \mathbf{r}_r)$ requires accurate reference response $H_{ref}(f, \mathbf{r}_r)$ with sufficient resolution at low frequencies only (below 1 kHz)
 - 補償函數 $H_c(f)$ 對大部分揚聲器都有效 compensation function $H_c(f)$ is valid for a wide range of speakers
 - 麥克風位置錯誤對補償函數 $H_c(f)$ 影響很小 microphone positioning error has small influence on compensation function $H_c(f)$

- 缺點 CONS**
- 評估點 \mathbf{r}_e 和測試點 \mathbf{r}_t 應該一致 Evaluation point \mathbf{r}_e and test point \mathbf{r}_t shall be identical
 - 房間有充足吸音來抑制高頻反射 room must be sufficiently damped to suppress reflections for high frequencies



Fixed Room Compensation Function (1)

目標 Targets:

- 生成對多個揚聲器有效的固定房間補償功能

Generating a fixed room compensation function valid for multiple speakers

- 避免對每個DUT進行參考測量（掃描）

Avoiding a reference measurement for each DUT (scanning)

需求 Requirements:

- 硬件設置的屬性是恆定的（固定的麥克風位置）

Properties of the hardware setup are constant (fixed microphone position)

- DUT與房間產生類似的交互

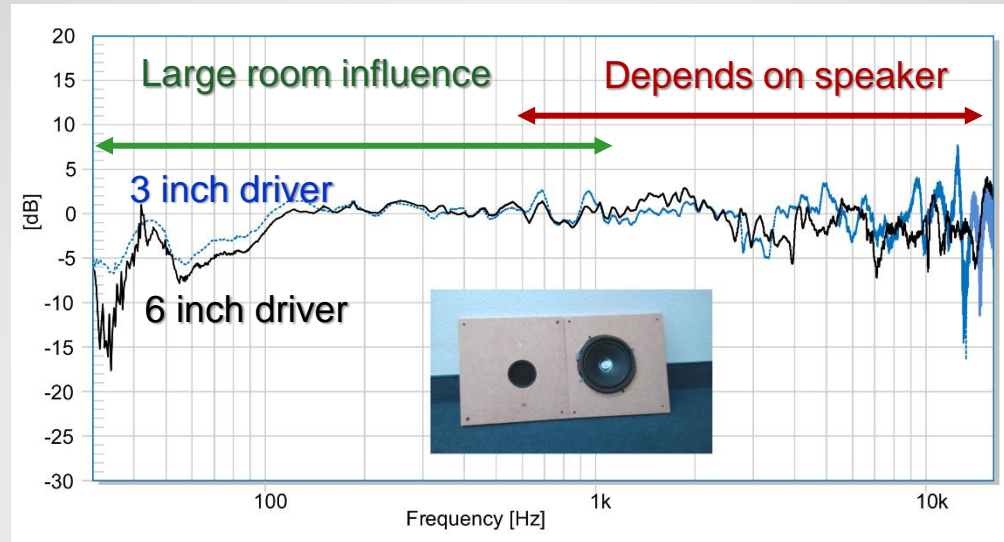
DUTs generate similar interactions with the room

- DUT具有相似的近場特性或測試點 r_t 在遠場中

DUTs have similar near field properties or test point r_t is in the far field



Variance of the Compensation Function



→ 相同 (房間) 補償功能 $H_{c,r}(f)$ 可以應用於低頻 (低於 1 kHz) 的類似揚聲器

The same (room) compensation function $H_{c,r}(f)$ can be applied to similar loudspeakers at low frequencies (below 1 kHz)

→ 限制區間可以在高頻下產生最佳補償功能

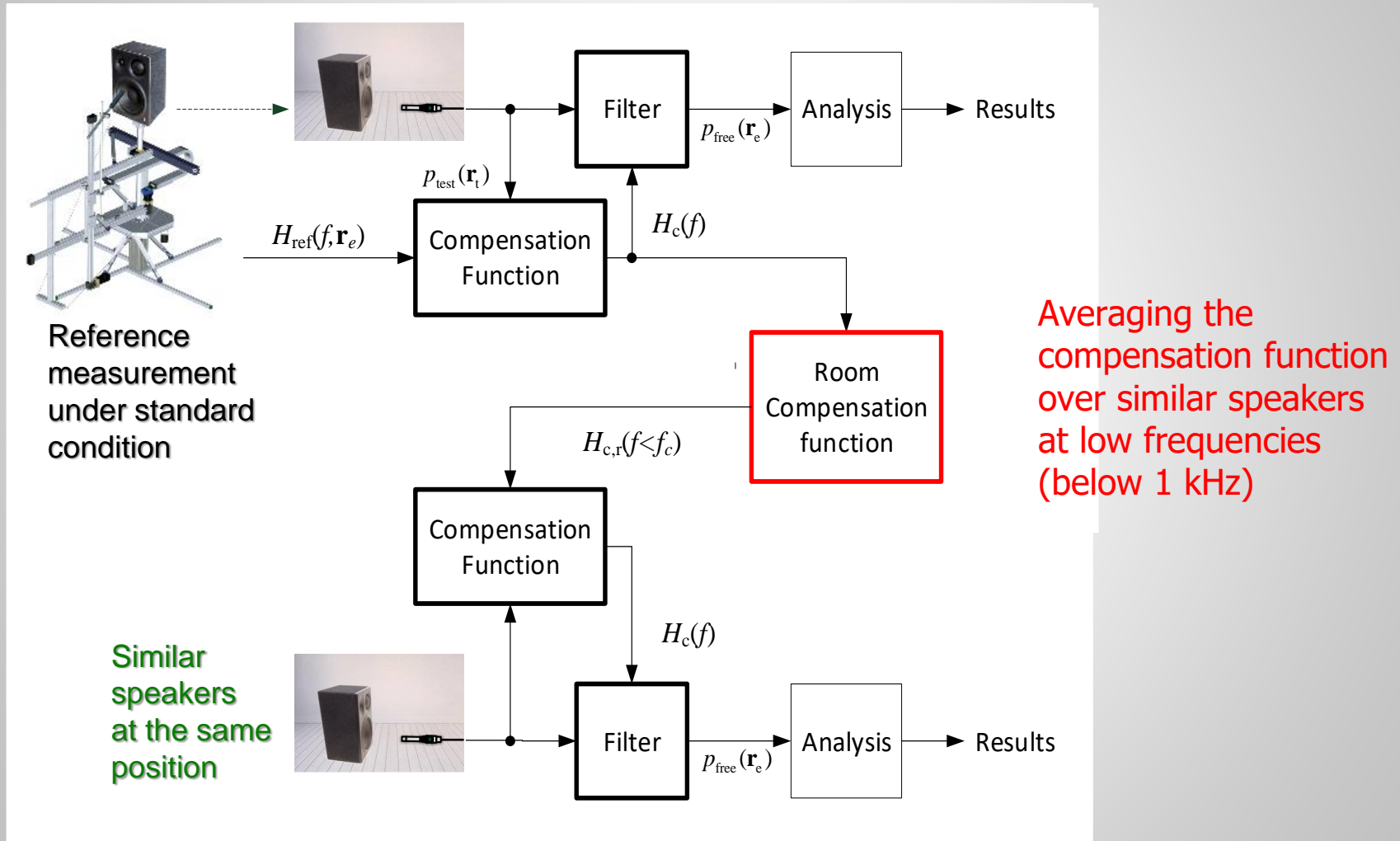
Windowing can generate the optimum compensation function at high frequencies

→ 確定房間補償功能 $H_{c,r}(f)$ 時需要對幾個選定揚聲器進行參考測量

Reference measurements on a few selected speakers are required for determining a room compensation function $H_{c,r}(f)$



Fixed Room Compensation Function (2)



現場補償方法概述

Overview of the In-situ Compensation Schemes

方法Method	FC-FR 全頻段參考的全補償 Full compensation with full-band reference	FC-LR 低頻段參考的全補償 Full compensation with low frequency reference	LC-LR 低頻參考的低頻補償 Low frequency compensation with low-frequency reference
模擬自由場條件Simulated free-field condition	任意環境 (房間、測試箱、測試臺) in any environment (room, test box, stand)	車間、辦公室，至邊界 (牆面) 有足夠的距離 Workshops, Offices sufficient distance to the Boundary (walls)	較高頻有消聲條件的小房間 Small room with anechoic condition at higher frequencies
提供的模擬遠場條件 Simulated far-field condition provided	所有頻率 For all frequencies	低頻段 For lower frequencies	低頻段 For lower frequencies
得到精確參考數據所花精力 Effort for providing accurate reference data	一般掃描Normal Scan (20 min*)	短掃描 Short Scan (7 min*)	段掃描 Short Scan (7 min*)
生成固定的房間補償 (應用於其他揚聲器) Generating a fixed room compensation (applied to other DuTs)	不推薦 not recommended	低頻段 for lower frequencies	低頻段 for lower frequencies

類似設備無需掃描！ No scanning of similar devices required !

* 針對KLIPPEL LIVE系列研討會中使用的小藍牙音箱
Small Bluetooth speaker used in webinar KLIPPEL live



Practical Tips

固定房間補償功能的其他有趣應用：

Other interesting applications of a fixed room compensation function:

- 半消聲 (小, 便宜, 良好 > 400 Hz) , 麥克風陣列固定在固定位置 (距離 $r > 1\text{m}$)
Semi-anechoic (small, cheap, good > 400 Hz) with microphone array at fixed positions (distance $r > 1\text{m}$)
- 在固定位置 (距離 $r > 1\text{m}$) 的大型房間 (車間, 到牆壁的距離 > 3 m) 中揚聲器的地面測量
Ground floor measurement of speakers in large rooms (workshop, distance to the walls > 3 m) at fixed positions (distance $r > 1\text{m}$)
- 在具有固定DUT和麥克風位置的QC測試箱中以EoL測量的類似DUT (傳感器, 系統)
Similar DUTs (transducer, system) measured in EoL in a QC test box with fixed DUT and microphone positions
- 傳感器在固定麥克風位置 (距離 > 1m) 的擋板 (與其他牆壁的距離 > 3 m) 中測量
Transducer measured in a baffle (distance to other walls > 3 m) with a fixed microphone position (distance > 1m)



Question ?



總結Summary

- 可以在任何聲學環境中模擬標準測量條件（自由場，遠場）
Standard measurement condition (free-field, far-field) can be simulated in any acoustical environment
- 在使用複雜校正函數 $H_c(f)$ 進行信號分析之前，必須對麥克風信號進行濾波
The microphone signal has to be filtered before signal analysis using a complex correction function $H_c(f)$
- 必須使用準確的參考數據針對特定測試點 r_{test} 就地生成校正函數 $H_c(f)$
The correction function $H_c(f)$ has to be generated in-situ for the particular test point r_{test} using accurate reference data
- 球面波模型可在掃描表面之外的3D空間中的任何點提供準確的參考數據
The spherical wave model gives accurate reference data at any point in the 3D space outside the scanning surface
- 可以為一類揚聲器生成固定的（房間）校正功能
A fixed (room) correction function can be generated for a class of speakers



Open Questions

現在可以開始在我的辦公室裏進行標準測試了！

Now, we are ready for performing standard measurements in my office!

第五次KLIPPEL LIVE網絡研討會主題 The 5th KLIPPEL live webinar titled
最大SPL – 賦予該值意義 Maximum SPL – giving this value meaning

將討論 will address

- 選擇能代表典型程序材料的寬帶測試信號 Selecting a broadband test stimulus representing typical program material
- 長時測試（100h功率測試、可靠性、耐久性）的後果 Consequences for long-term testing (100h power test, reliability, endurance)
- 使用SPLmax 校準有源系統的輸入通道 Calibrating the input channel of the active system with SPLmax



Next Section

1. Modern audio equipment needs output based testing
2. Standard acoustical tests performed in normal rooms
3. Drawing meaningful conclusions from 3D output measurement
4. Simulated standard condition at a single evaluation point
5. **Maximum SPL – giving this value meaning**
6. Selecting measurements with high diagnostic value
7. Amplitude Compression – less output at higher amplitudes
8. Harmonic Distortion Measurements – best practice
9. Intermodulation Distortion – music is more than a single tone
10. Impulsive distortion - rub&buzz, abnormal behavior, defects
11. Benchmarking of audio products under standard conditions
12. Auralization of signal distortion – perceptual evaluation
13. Setting meaningful tolerances for signal distortion
14. Rating the maximum SPL value for product
15. Smart speaker testing with wireless audio input

