Acoustical Measurement of Sound System Equipment according IEC 60268-21

KLIPPEL- live

a series of webinars presented by

Wolfgang Klippel
1. Modern audio equipment needs output based testing
2. Standard acoustical tests performed in normal rooms
3. Drawing meaningful conclusions from 3D output measurement
4. Simulated standard condition at an evaluation point
5. Maximum SPL – giving this value meaning
6. Selecting measurements with high diagnostic value
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 behaviour, 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 a product
15. Smart speaker testing with wireless audio input

Previous Sessions:

1st Session
2nd Session
3rd Session
4th Session
5th Session
6th Session
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Acoustical testing of a modern active audio device

Previous Sessions
2nd Session 3rd Session 6th Session

KLIPPEL LIVE #11: Testing with Wireless Audio Input
今日话题 Topics today:

• 现代音频设备中的新挑战 New challenges in modern audio devices
• R&D和QC终端线测试的解决方案 Solutions for R&D and QC end-of-line testing
• 普遍问题概述 Overview on common problems
• 确保可靠测试数据的实用建议 Practical tips to ensure reliable test data
• 演示 Demos
Poll:

Which transmission way do you prefer for testing active audio system (if available)？

A. 模拟线缆  Analog cable
B. 数字线缆（例如Toslink、HDMI、LAN） Digital cable (e.g. Toslink, HDMI, LAN)
C. 无线（WLAN） Wireless (WLAN)
D. 无线（蓝牙） Wireless (Bluetooth)
E. 异步传输（例如播放和录制音频文件） Asynchronous transmission (e.g. playing and recording an audio file)
F. 其他 others
方案1: 闭环测试（模拟）
Scenario 1: Closed-Loop Testing (Analog)

DUT直接连接到分析仪输出端
Analyzer Output Directly Connected to DUT
Bluetooth Technology Overview

- 短距离通信  Short range communication
- 配对连接  Pairing and connection
- 蓝牙音频  Bluetooth Audio
  - 典型音频  Classic Audio
  - 蓝牙LE音频（低功耗） - 新！
    Bluetooth LE Audio (low energy) – NEW!
- 不同音频配置  Different audio profiles
- 许多专有音频编解码器  Many proprietary audio codecs
方案2：闭环测试（无线）

Scenario 2: Closed-Loop Testing (Wireless)

使用蓝牙传输器（模拟或者USB） Using Bluetooth Transmitter (Analog Input or USB)
KLIPPEL’s solution
Hardware (QC & RnD)

• MegaSig U980
  – 通过USB配置（集成到QC和RnD软件） Configurable over USB (integrated in QC & RnD software)
  – 蓝牙v4.2 Bluetooth v4.2
  – 支持主要的音频配置及codecs Supports major audio profiles & codecs
  – 直接连接到KA3/PA/DA Connects directly to KA3/PA/DA
Bluetooth Speaker Test
With Optional Hands-free Microphone Test

Test Enclosure

- Active Speaker (opt.)
- Test Mic 1
- Ambient Mic (opt.)
- DUT
- Test Mic 2 (opt.)
- Speaker Tag

QR Code Scanner (opt.)

PASS

PC

MegaSig U980

XLR-BNC Adaptor

KLIPPEL Analyzer 3

XLR Card

Laser Card

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Bluetooth Headset Test
Including ANC Performance Test
方案3：开环测试  Scenario 3: Open-Loop Testing

独立播放激励信号 (发生器不在链路循环中)
Independent Stimulus Playback (Generator not in Loop)

Klippel Analyzer

External Player

Smart Speaker

Microphone

Stimulus (WAVE)

Cloud Service
Problem in Open Loop Testing

1) Chirp stimulus is played again and again (asynchronously)

2) TRF records the waveform and calculates the impulse response

How to detect the variable delays?
开环测试 Open Loop Testing

1) 纯软件方案 (外部同步)  
Pure Software solution (External Synchronization)

2) 附加硬件方案  
Additional Hardware Solution

测量响应同步到激励信号  
Measurement response is synchronized to stimulus
Solution: Use a 2nd microphone for synchronization

1) Stimulus is played by an internal wav-player

2) Microphone 2 detects time delay

3) Detected delay is removed from the measurement microphone

Result: Synchronized Impulse Response
NFS: 全息方向扫描  Holographic Directivity Scanning
一款智能扬声器的开环测试  Open loop testing of a smart speaker

问题 Problems:
- 无模拟输入  No analog input
- 长时延且可变（延迟） Long and varying time delay (latency)
- 外部同步不适用  External synchronization is not applicable

方案：使用固定位置处的第二支麦克风（参考） Solution: 2nd microphone at fixed position (reference)
- 提供测试麦克风的高精度幅值和相位响应  provides high accuracy of amplitude and phase response of the test microphone
- 检测掉线、采样率漂移、环境噪声和其他问题  Detects dropouts, sample rate drift, ambient noise and other problems
- 简单鲁健且高效经济的方案  is a simple, robust and cost-efficient solution
**Directivity of a MEMS Microphone**

**Requirements**
- Sufficient accuracy in the absolute transfer functions (affected by setup)
- High accuracy in the relative amplitude and phase response (between mics)

**Solution**
- Using one microphone in the MEMS as a reference
- Recording or transmitting at least two signals (test + reference microphone)
### Wireless Testing

**KLIPPEL Analyzer (R&D modules)**

<table>
<thead>
<tr>
<th>Module</th>
<th>Description</th>
<th>Closed loop setup</th>
<th>Open loop setup</th>
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<tbody>
<tr>
<td><strong>TRF</strong></td>
<td>测量频响、脉冲响应和谐波失真 Measurement of frequency response, impulse response &amp; harmonic distortion</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td><strong>DIS</strong></td>
<td>测量谐波失真和互调失真 (稳态) Measurement of harmonic distortion and intermodulation distortion (steady state)</td>
<td>✔️</td>
<td>✗</td>
</tr>
<tr>
<td><strong>TBM</strong></td>
<td>猝发音测量 (瞬时) 最大SPL峰值、谐波失真 Tone Burst Measurement (transient) maximum peak SPL, harmonic distortion</td>
<td>✔️</td>
<td>✗</td>
</tr>
<tr>
<td><strong>MTON</strong></td>
<td>多音测量 多音失真，压缩，最大连续SPL Multi-Tone Measurement multi-tone distortion, compression, maximum continuous SPL</td>
<td>✔️</td>
<td>(✗)</td>
</tr>
<tr>
<td><strong>NFS</strong></td>
<td>扬声器的3D方向性 (近场 + 远场) 测量（适用于非消声室） 3D directivity (near + far field) measurement of loudspeakers (applicable in non-anechoic room)</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td><strong>POL</strong></td>
<td>扬声器和麦克风的2D方向性 (气球图) (需要消声室) 2D directivity (balloon) of loudspeakers and microphones (anechoic room needed)</td>
<td>✔️</td>
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</tbody>
</table>
产线上的无线设备测试  Wireless Device Testing in Production

产线终端测试的要求  Requirements in End-of-Line Testing

- 快速全面的测试  Fast and comprehensive testing
- 检测缺陷的高灵敏度  high sensitivity for defects
- 使用简便  Simple to use

关键问题  Critical Issues:

- 自动配对  Automatic Pairing
- 流畅的蓝牙设置  Smooth Bluetooth Setup
- 同步（延迟检测和补偿）  Synchronization (Delay detection and compensation)
## Wireless Testing

**KLIPPEL Analyzer (QC modules)**

QC Base Version, QC Standard or QC Stand-alone (v6.3)

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<tr>
<td>SPL</td>
<td>测量频响、脉冲响应、谐波和脉冲失真 Measurement of frequency response, impulse response, harmonics &amp; impulsive distortion</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>ALD</td>
<td>空气泄漏检测 Air Leak Detection</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>SAN</td>
<td>频谱分析 Spectrum Analysis</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>EQA</td>
<td>均衡&amp;对齐 Equalization &amp; Alignment</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>
Poll:

使用数字/无线测试通道时您发现了什么问题？
Which problems do you see using digital/wireless transmission channels?

A. 无 None
B. 高延迟 Large latency (delay)
C. 可变延迟（相对于时间） Varying latency (versus time)
D. 抖动、时钟漂移、采样率不匹配 Jitter, Clock Drift, Sampling Rate Mismatch
E. 掉线、插值样本 Drop-outs, interpolated samples
F. 其他 others
High Latency Problem in Bluetooth Devices

The delay of a Bluetooth® speaker is typically between 30 and 400 ms!

Single Sweep Asynchronous Mode with preloop

Missing late response in a single sweep test

Conclusion:
Play multiple loops of the stimulus

Typical Bluetooth® speaker delay is between 30 to 400 ms!
1st Solution: Additional Excitation

Coping with High Latency in DIS 3D Distortion Measurement

Pre-excitation

stimulus

Response

Complete response

in TRF Transfer Function Module

Pre-loop

stimulus

Response

Complete response

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第二方案：外部同步 2nd Solution: External Synchronization

应对高延迟 Coping with High Latency

同步信号 Sync-Signal:
- 宽带信号 Broadband signal
- 短同步信号 (200ms) Short sync signal (200ms)
- 标识符编码 Identifier encoded
- 伪随机特性 pseudo-random properties

益处 Benefits:
- 延迟无限制 No limitation with of the latency
- 最适合开环测试 Best for open loop testing
- 快速产线终端测试 Fast EoL-testing
- 激励信号识别 Identification of the stimulus
- 链接激励和分析 Linking stimulus and analysis
- 检测采样率不匹配 Detection of sample rate mismatch

外部同步 (SYN) 在 QC 系统中在 KLIPPEL 分析仪系统中

External Synchronization (SYN) in the QC system in KLIPPEL Analyzer System
Demo

Tools: Using dedicated software modules of the KLIPPEL Analyzer

- QC End-of-Line Testing (External synchronization)
可变延迟 Varying Latency
蓝牙设备中的问题 Problem in Bluetooth Devices

后果 Consequences:
• 影响相位响应 (在全息近场扫描中非常关键) Affects phase response (very critical in holographic near field scanning)
• 与其他问题相关 (掉线、采样率漂移等) Related to other problems (drop outs, sample rate drift, …)

方案 Solution:
• 参考测量 (近场中使用第二支麦克风) 获取相干扫描数据 Reference measurements (second microphone in the near field) for coherent scanning data

Mean delay $\approx 155$ ms
($\approx 53$ m distance)

Variance +/- 35 ms (+/- 12 m)
抖动、时钟漂移、采样率不匹配

Jitter, Clock Drift, Sampling Rate Mismatch

蓝牙设备中的问题 Problem in Bluetooth Devices

根本原因：播放和捕获转换器中的晶体不同！
Root Cause: Crystals of Playback and Capture converters are different!

症状 Symptom:
激励和响应的长度不同
Stimulus and response have a different length

\[ T_s \neq T_r \]

对传输行为的影响 Impact on the transfer behavior:
- 频率转换 Frequency transformation
- 输入和输出之间的非线性关系（不相干） Nonlinear (non-coherent) relationship between input and output
- 随着时间延迟会变得更糟糕 Delay becomes worse over time
- 重采样或者样本校正可以改善（掉线、插值） Resampling or sample correction (dropouts, interpolation) can help
采样率漂移的后果  Consequences of Sample Rate Drift

漂移会降低以下精度  Drift degrades accuracy in:
- 频率检测  Frequency detection
- 基波和失真的分离  Separation of distortion and fundamentals
- 失真测量  Distortion measurements
- 相位测量  Phase measurements

建议：避免（如果可以）  Tips: Avoid (if you can):
- 长测量（以得到高的频率分辨率）  Long Measurements (to get high frequency resolution)
- 长平均  Long averaging
- 将记录的时间信号包裹到FFT中  Wrapping recorded time signal in an FFT

Example: Bluetooth speaker

Multi-tone distortion (analog input)

![Spectrum of In (f) for analog input](image)

- Fundamental
- Speaker Distortion
- Noise

Multi-tone distortion (bluetooth input)

![Spectrum of In (f) for Bluetooth input](image)

- Fundamental
- Speaker Distortion
- Noise

40 dB more distortion
Avoid Long Averaging!

Coping with Sample Rate Drift

Magnitude of transfer function $H(f)$

Frequency [Hz]

measurement with 4 averages

Sample rate drift generates a cancelation of high frequency components!
**Accurate Testing with a Chirp Signal**

**Coping with Sample Rate Drift**

**PRO:**
- 精度高 Good accuracy
- 无脉冲伪值 no impulsive artifacts
- 用于异音测量 required for rub and buzz

**CONS:**
- 异步处理 Asynchronous processing
- （两个chirp）(2 chirps)

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**使用chirp信号的精确测试**

**Accurate Testing with a Chirp Signal**

**Coping with Sample Rate Drift**

**PRO:**
- 简单的标准测量 Simple standard measurement
- 无脉冲伪值 no impulsive artifacts
- 用于异音测量 required for rub and buzz

**CONS:**
- 幅度响应中有显著错误 Significant error in magnitude response
- 产生咔哒抖动 Click generated
- 不适用于产线终端测试 Not applicable for EoL testing

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**使用chirp信号的精确测试**

**Accurate Testing with a Chirp Signal**

**Coping with Sample Rate Drift**

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- 异步处理 Asynchronous processing
- （两个chirp）(2 chirps)
TRF模组中的自动处理方案  Automatic Solution in TRF Module

应对采样率漂移  Coping with Sample Rate Drift

工作原理 How it works?

1) 通过蓝牙传输器发送激励信号  Send Stimulus via Bluetooth transmitter

2) 检测延迟并给麦克风信号加窗  Detect Delay and window microphone signal

益处 Benefits:

• 最优加窗处理避免任何伪值（咔哒声）  Optimal windowing avoids any artifacts (clicks)
• 用于测量脉冲失真（异音）  Required for measurement of impulsive distortion (rub&buzz)
Impact on Impulsive Distortion Testing
TRF copes with Sample Rate Drift

TRF in normal mode

TRF in asynchronous mode

stimulus
Response

Data Acquisition

Processing

Time Delay

Speedogram
Problems
Dropouts, Glitches, Interpolation Artifacts

根原因 Root Cause:
• 应对采样率漂移的简单算法会产生脉冲失真 Simple algorithms for coping with sample rate drift can generate impulsive distortion

后果 Consequences:
• 随机伪值（不能重复、不可预测） Those artifacts are random (not repeatable, predictable)
• 可能会和换能单元缺陷混合，在产线终端测试中很关键 Maybe mixed with transducer defects critical for end-of-line testing

方案 Solution:
• 重复测量并比较结果 Repeat the measurement and compare the results
• 使用开环测量来分离随机换能单元问题（如松散微粒） Use open-loop measurement to separate random transducer problems (e.g. loose particles)
Corrected Multi-Tone Distortion
Coping with Sample Rate Drift

**Method**

1) Detection of the sample rate drift between stimulus and measured signal in percent
2) Active compensation before performing spectral analysis
Demo

Tools: Using dedicated software modules of the KLIPPEL Analyzer

- TRF (transfer function)
- MTON Multi-tone Distortion Measurement
Discussion
Summary

• 音频信号的无线/数字传输并不是完美的！
  Wireless/digital transmission of the audio signal is not perfect!
• 存在非线性、时变和随机机制，会产生额外失真
  There are nonlinear, time-variant and random mechanisms which generate additional distortion
• 准确测试需要特殊的预防措施
  Accurate testing requires special precaution
• 现代测试设备能提供解决方案
  Modern test instruments provides solutions
Open Questions

We have discussed physical test methods defined in IEC 60268-21 for standard conditions.

The next 12th KLIPPEL live webinar entitled "Benchmarking of audio products under standard conditions" will address the points:

- Which criteria are important?
- How to choose the measurement conditions?
- How to compare the measurement results?
- How to draw meaningful conclusions?
- How to use standards to simplify benchmarking?
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