2nd KLIPPEL LIVE webinar

第二次KLIPPEL LIVE网络研讨会

Standard acoustical tests performed in normal rooms

在普通房间进行标准声学测试

Topics today

今日话题

1. Problems in practical free-field measurements
   实际自由场测量中的问题
2. Alternatives: SIMULATED free-field conditions
   替代方案：模拟自由场条件
3. The practical limits of direct sound windowing
   直达声加窗处理的实际限制
4. A powerful solution: Near Field Scanning
   强大的解决方案：近场扫描
5. Practical Demo in an office room
   在普通办公室里进行实践演示
6. Questions, Discussion
   问题、讨论

Acoustical Standard Measurements

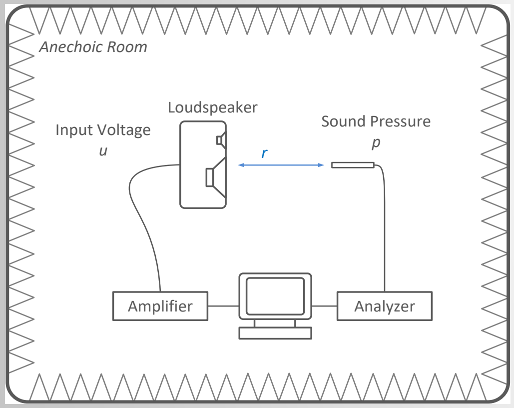
声学标准测量

1. **Far-Field Measurement under free field condition**
   自由场条件下的远场测量
   - **Measurement in free air** ("flying" speaker, ground floor measurement)
     自由空气中的测量（悬吊扬声器，地面测量）
   - **Anechoic Chambers** (half space, full space)
     消声室（半空间，全空间）
2. **Far-Field Measurement under simulated free-field conditions**
   模拟自由场条件下的远场测量
   - Non-anechoic testing (minimum distance to boundaries) + windowing the impulse response (suppressing reflections)
     非消声测试（到边界的最小距离）+ 脉冲响应加窗处理（抑制反射）
3. **Near-Field Measurement under simulated far-field, free-field conditions**
   模拟远场、自由场条件下的近场测量
   - Near-field scanning in any non-anechoic environment + wave expansion + direct sound separation + far field extrapolation
     在任何非消声环境中的近场扫描+波形扩展+直达声分离+远场外推

Applicable to a normal office room
适用于普通办公室

Far-Field Measurement under free field condition

自由场条件下的远场测量



Problems:

问题：

- **Low** frequency measurements (accuracy, resolution) limited by acoustical **environment**
  低频测量（精度、分辨率）受声学**环境**的限制
- **High** frequency measurements require **far-field** conditions (room size?)
  高频测量需要**远场**条件（房间大小？）
- Accuracy of the **phase response** in the far-field depends on temperature deviations and air movement
  远场中**相位响应**的精度取决于温度偏差和空气流动
- An **anechoic chamber** is an expensive and long-term investment which cannot be moved easily
  消声室是一项昂贵且长期的投资，无法轻松移动

Problems in the Far-Field 远场中的问题

Phase response depends on air temperature 相位响应取决于空气温度

Sound velocity is dependent on air conditions (e.g. temperature) 声速取决于空气条件（例如温度）

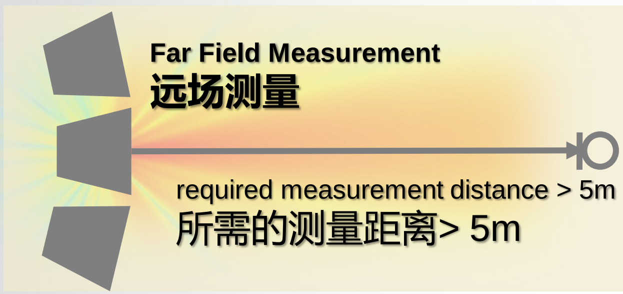
$$\vartheta_1 = 20°C \rightarrow c_1 = 343.4 m/s$$
$$\vartheta_2 = 22°C \rightarrow c_2 = 344.6 m/s$$
$$\vartheta_3 = 24°C \rightarrow c_3 = 345.8 m/s$$

A temperature difference of $\Delta\vartheta$=2°C will change the sound velocity by Δc≈1.2 m/s

$\Delta\vartheta$ = 2°C的温差将使声速改变Δc≈1.2m / s

Depending on the distance, the temperature difference will influence the sound wave propagation time:

根据距离的不同，温差会影响声波的传播时间：



Deviation:

偏差：

$$\Delta t = 0.05 ms$$
$$(\Delta r = 17.2 mm)$$

Phase error caused by temperature difference of 2°C 2°C的温差引起的相位误差

Frequency 频率	Wave length 波长	Phase Error in 5 m distance 5 m距离内的相位误差
f=2kHz	λ=171.7mm	36° (0.1 λ)
f=5kHz	λ=68.7mm	90° (0.25 λ)
f=10kHz	λ=34.3mm	180° (0.5 λ)

Far field measurement are prone to phase errors !

远场测量容易出现相位误差！

Far-Field Measurement under simulated free-field conditions

模拟自由场条件下远场测量

Technology 技术

Using **gating** or **windowing** the impulse response (Heyser 1967-69, Berman and Fincham 1973) to separate direct sound from room reflections

使用**门控**或**加窗**脉冲响应（Heyser 1967-69，Berman和Fincham 1973）将直达声与房间反射分开

Benefits 优点

- Good suppression of room reflections at higher frequencies
  在较高频率处良好地抑制房间反射
- Higher SNR due to ambient noise separation
  由于环境噪声分离，SNR更高

Problems 问题：

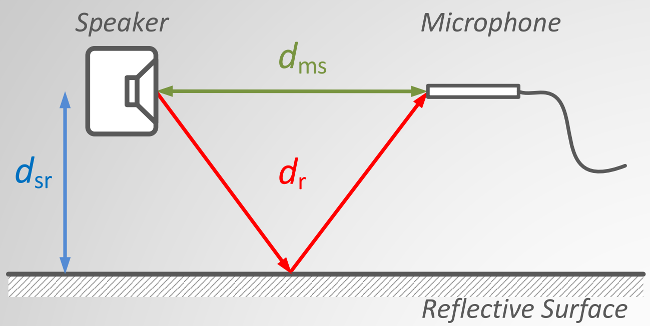
- Short distance to boundaries requires short window to separate direct sound from reflected sound
  与边界的距离较短，需要短时窗才能将直达声与反射声音分开
- Window length limits the frequency resolution
  时窗长度限制了频率分辨率
- Short windows can cause significant errors at low frequencies
  低频处的短时窗可能会导致显著错误

Poll:
投票：

Do you use windowing (or other gating techniques) for separating the direct sound ?
您是否使用加窗（或其他门控技术）来分离直达声?

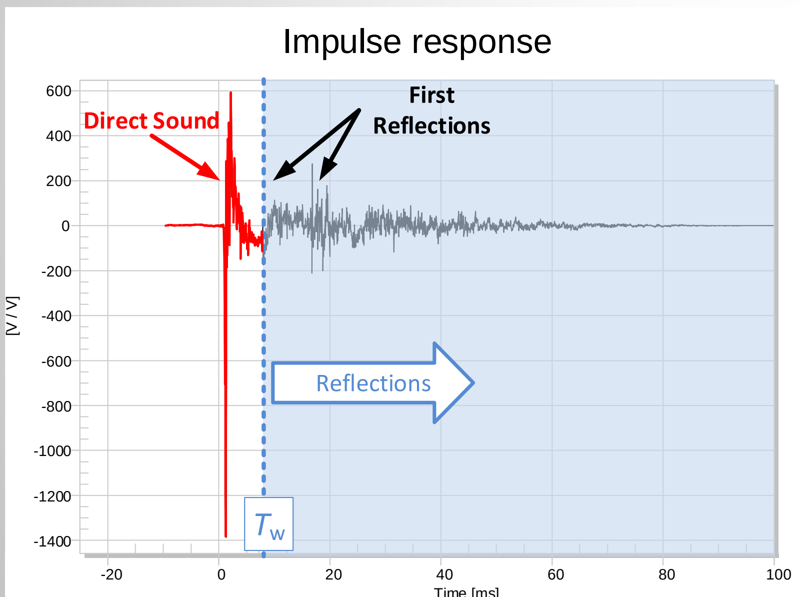
- always
  总是
- sometimes
  有时
- never
  从不

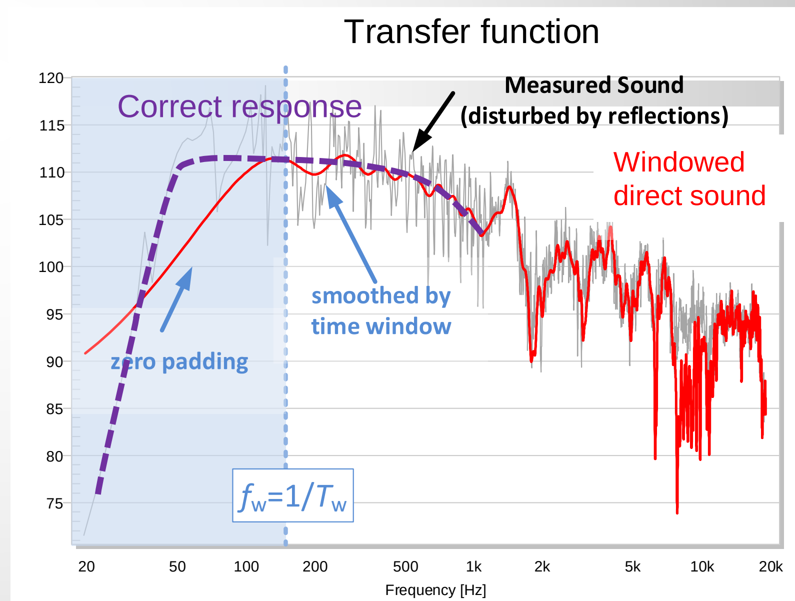
Problem with Short Windows
短时窗的问题



$$d_r = 2\sqrt{\left(\frac{1}{2}d_{ms}\right)^2 + (d_{sr})^2}$$

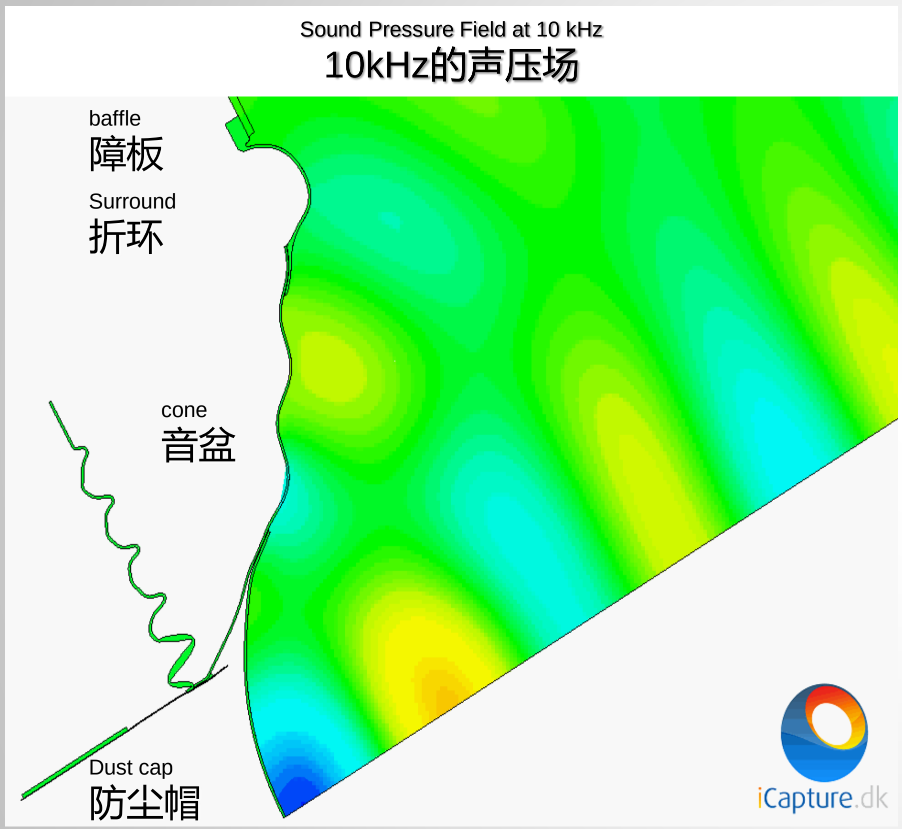
$$T_w < T_{max} = \frac{d_r - d_{ms}}{c}$$





Measurements in the Near Field

近场测量



Advantages 优点：

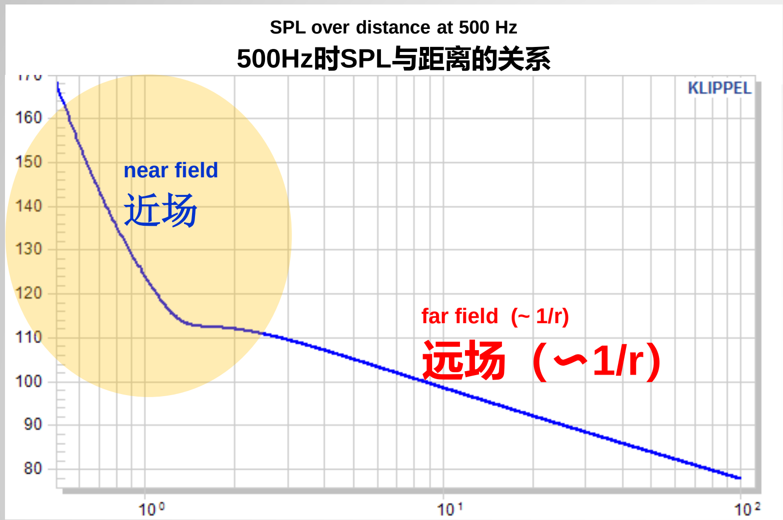
- High SNR
  高信噪比
- Amplitude of **direct sound** much greater than room reflections providing good conditions for simulated free field conditions
  直达声的幅值远大于室内反射，为模拟自由场条件提供了良好条件
- Minimal influence from **air properties** (air convection, temperature deviations)
  空气特性（空气对流、温度偏差）的影响最小

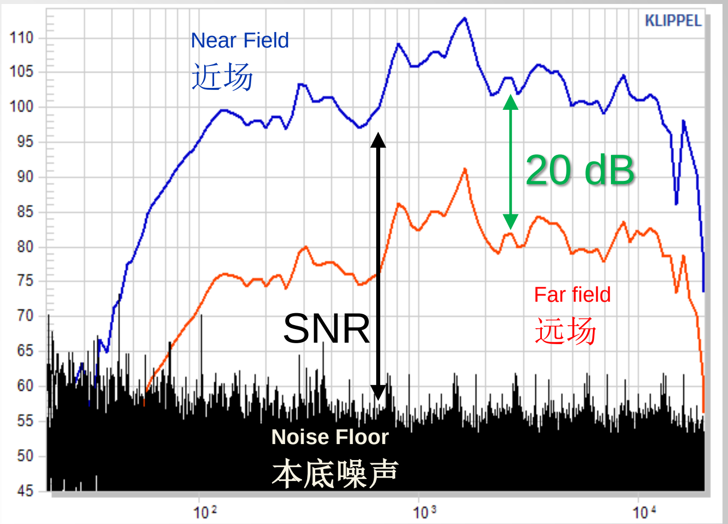
Disadvantages 缺点：

- Not a plane wave
  不是平面波
- Velocity and sound pressure are out of phase
  速度和声压异相
- 1/r law does not apply, therefore, no sound pressure extrapolation into the far-field (**holographic processing** required)
  1/r法则不再适用，因此，声压不能外推至远场（需要**全息处理**）

Good SNR in the Near-Field !

近场中信噪比好!





Near-field measurements have the following benefits:

近场测量具有以下优点:

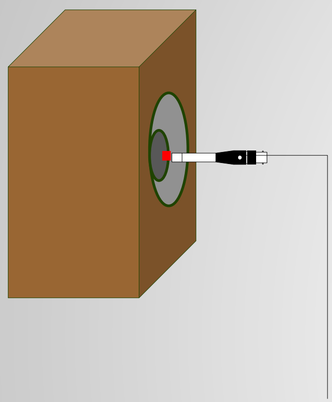
- **Higher SNR** (typically 20 dB more than far field measurements)
  更高SNR（通常比远场测量高20 dB）
- Measurement can tolerate some **ambient noise** (office, workshop)
  测量可以容忍一些**环境噪声**（办公室、车间）
- Faster measurements since **no averaging** required
  无需平均，测量速度更快

Short History on Near-Field Measurements

近场测量的简史

Single-point measurement close to the source

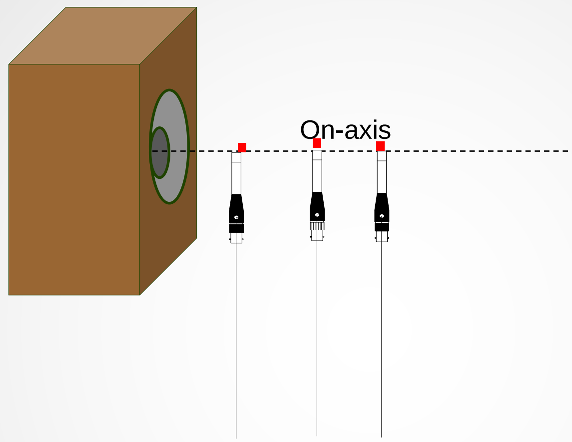
接近声源的**单点测量**



Don Keele 1974

Multiple-point measurement on a defined axis

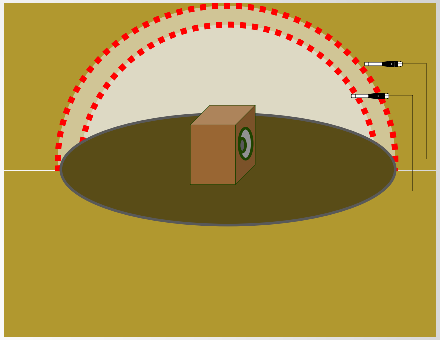
在定义轴上的**多点测量**



Ronald Aarts (2008)

Scanning the sound field on a surface around the source

在声源周围的表面**扫描声场**



Weinreich (1980), Evert Start (2000)
Melon, Langrenne, Garcia (2009)
Bi (2012)

Robotics required 需要机器人

Postprocessing of the scanned data required 需要对扫描数据进行后处理

Poll:

投票：

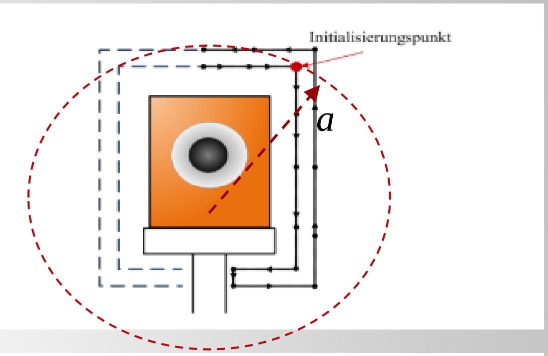
Do you use Don Keele‘s **single point measurement** for subwoofers (sealed boxes) ?

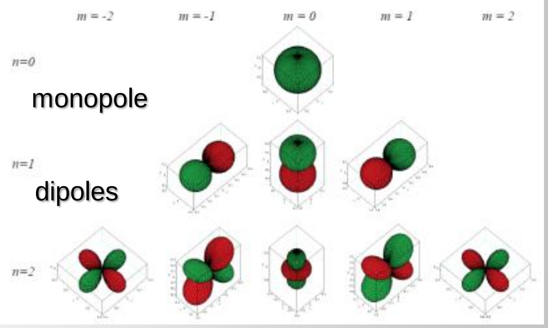
您是否使用Don Keele的**单点测量方法**测量超低音扬声器（密封箱体）？

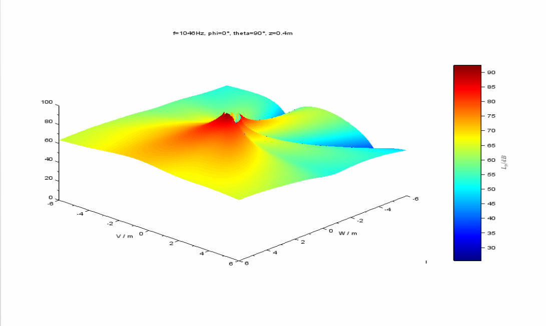
- always
  总是
- sometimes
  有时
- never
  从不

Holographic Measurement using spherical waves and Hankel functions as basic functions

使用球面波和汉克尔函数作为基本函数的全息测量







1st step: Measurement

第一步：测量

- Scanning the sound pressure in the near field of the source at a single or multiple surfaces
  在单个或多个表面上扫描声源近场中的声压

2nd step: Holographic Data Processing

第二步：全息数据处理

- Expansion into spherical waves using Legendre and Hankel functions
  使用Legendre和Hankel函数扩展为球面波
- Optimal estimation of the free parameters of the expansion (order N(f) and coefficients C(f))
  波形展开中自由参数（阶数N(f)和系数C(f)）的最佳估计

3rd step: Extrapolation

第三步：外推

- Calculation of the **transfer function** H(**r**,f) between input u and sound pressure *p*(**r**) at an arbitrary point **r** in the 3D space outside the scanning surface
  计算输入u和扫描表面外部3D空间中任意点r处的声压p(r)之间的**传递函数**H(r,f)
- Calculation of **derived characteristics** (directivity, beam pattern, sound power)
  计算**派生特性**（方向性、波束方向图、声功率）

Holographic Nearfield Measurement

全息近场测量

Number of points 点数	application 应用
1	*In-situ testing* *现场测试*
	Subwoofer *超低音*
	sound power *声功率*
100	*Directivity full-band single plane symmetry* *单平面对称全频带扬声器的方向性*
	Directivity full-band no symmetry *非对称全频带扬声器的方向性*
1000	
	Professional Speakers *专业扬声器* *Sound bars* *声霸*
5000	

Number of scanning points M depends on:

扫描点数M取决于:

- Total number of **coefficients** J in the expansion (M>1.5J)
  展开时**系数**J的总数（M> 1.5J)
- Maximum **order** N of the expansion $J=(N+1)^2$
  展开的最大**阶数**N：$J=(N+1)^2$
- **Loudspeaker type** (size, number of transducers)
  扬声器类型（尺寸、换能单元数量)
- **Symmetry** of the loudspeaker (axial symmetry)
  扬声器的**对称性**（轴向对称性)
- **Application** of the data (e.g. EASE data)
  数据的**应用**（例如EASE数据)
- Field separation (non-anechoic conditions)
  声场分离（非消声条件)

Benefit of using a Spherical Wave Expansion:

使用球面波展开的好处:

Number of measurements points M required is **much lower** than the final angular resolution of the calculated directivity pattern!

所需的测量点数M远低于所算方向图的最终角分辨率!

How long is the Measurement ?

测量多长时间?

The measurement time depends

测量时间取决于

→ **fitting** error in the wave expansion (self-test)

→波形展开中的**拟合**误差（自检）

→ optimum **order** N of the wave expansion

→波形展开的最佳**阶数**N

→ number of the **Scanning Points**

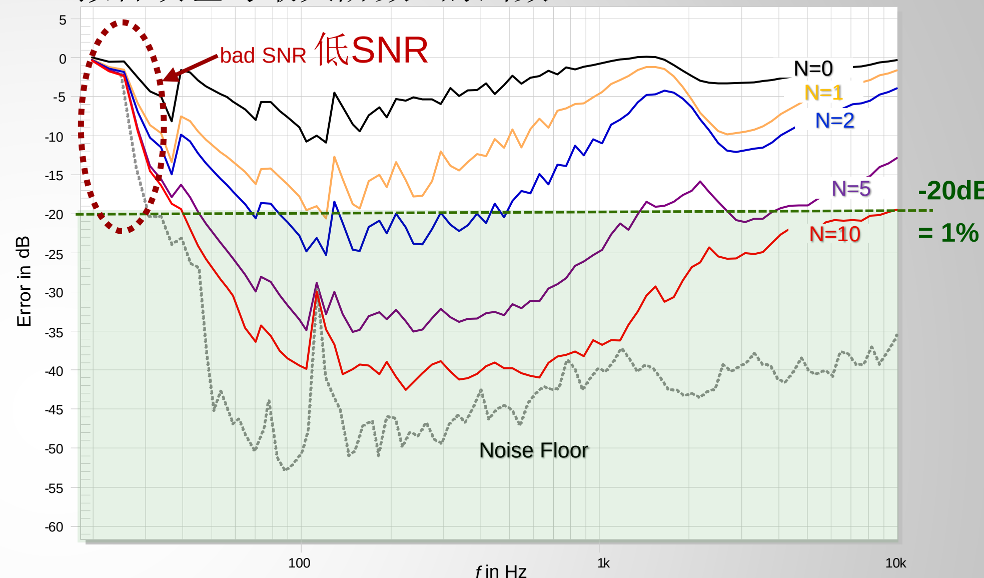
→扫描点数

→ speed of the **robotics**

→机器人的速度

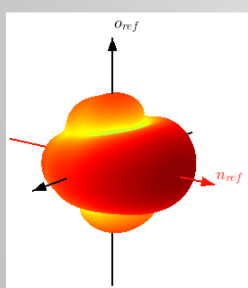
Fitting error as a function of the maximum order N

拟合误差与最大阶数N的函数

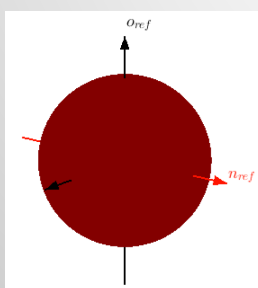


Directivity at 2kHz: 2kHz处的方向性:

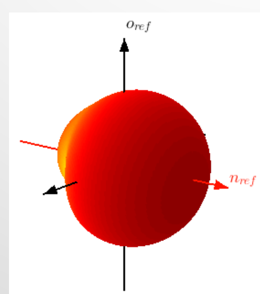
Target



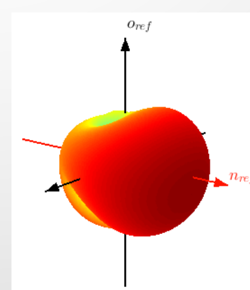
N=0



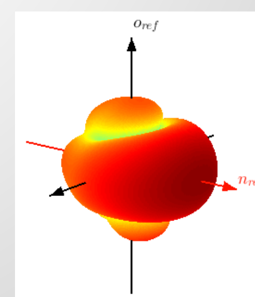
N=1



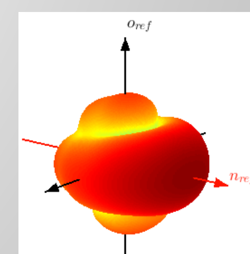
N=2



N=5



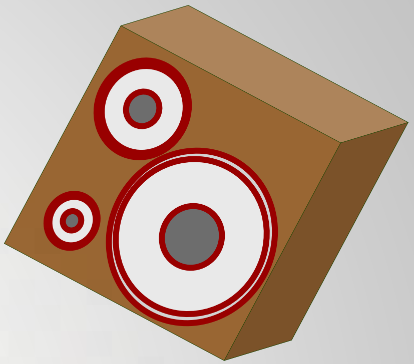
N=10



Sufficient accuracy足够精确度

No Symmetry

无对称



Condition for used Spherical harmonics:

使用的球谐条件：

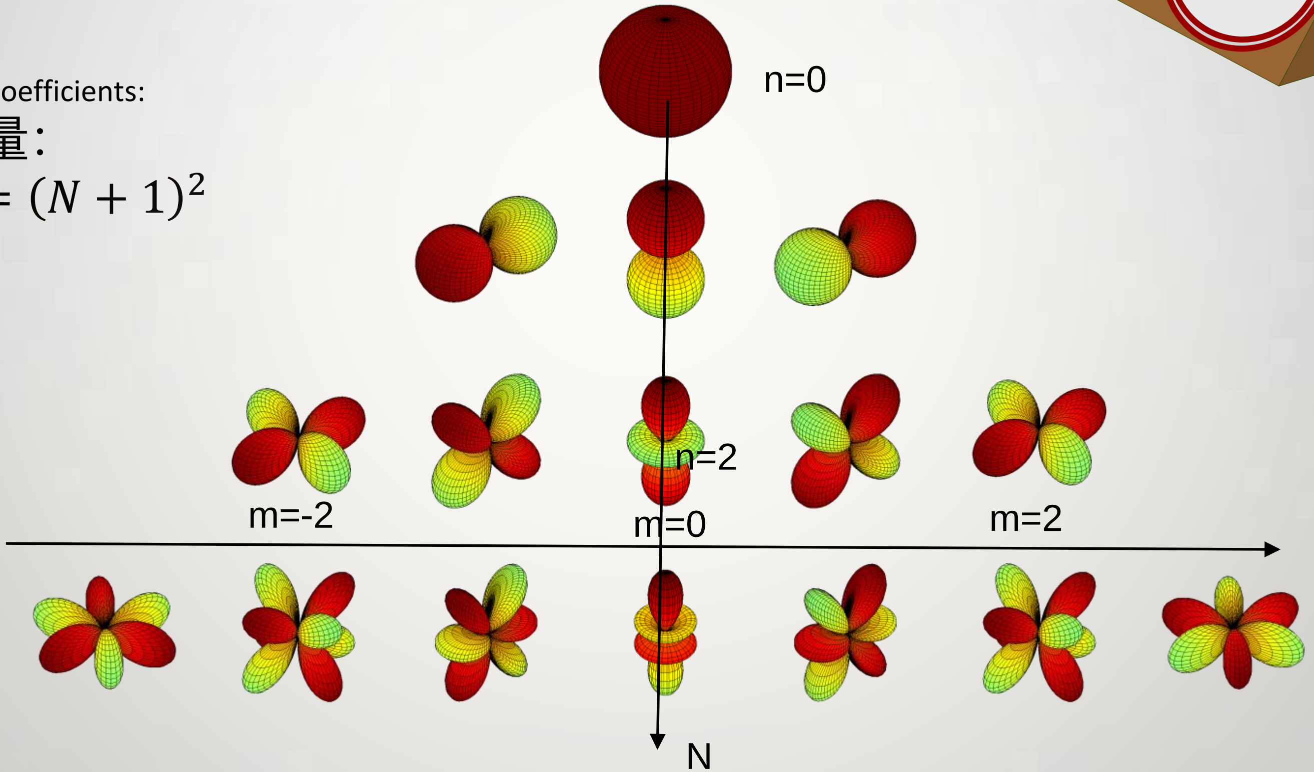
All orders used

需要使用所有阶

Number of Coefficients:

系数数量：

$$J = (N + 1)^2$$



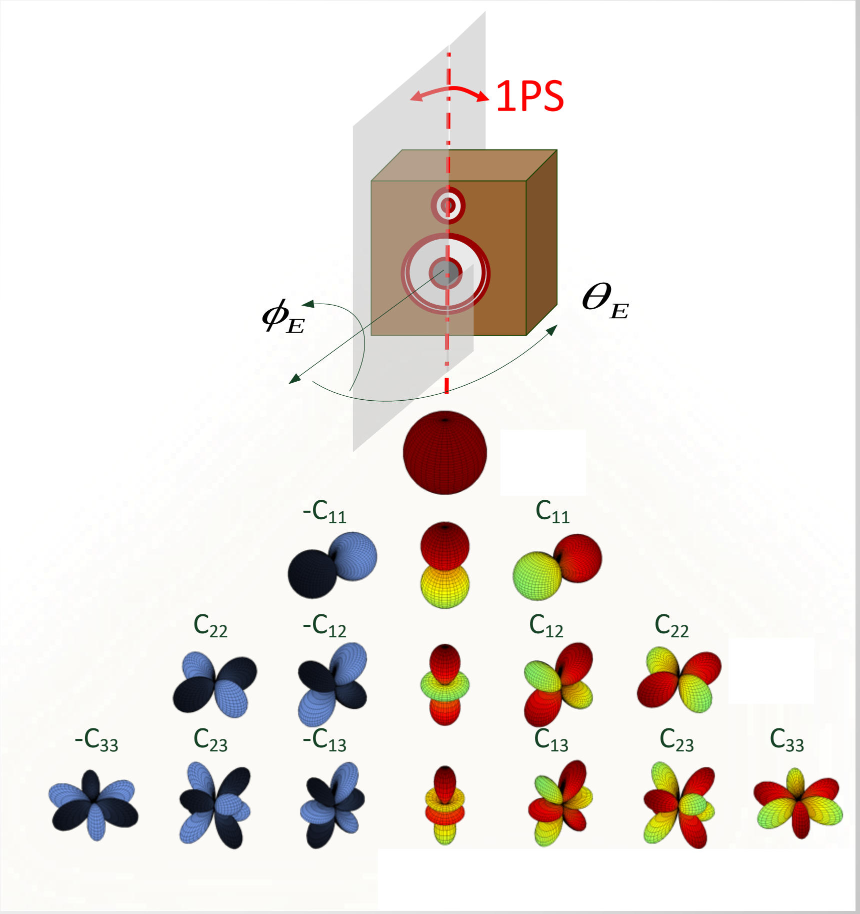
Single Plane Symmetry (1PS) 单平面对称（1PS）

symmetry axis aligned to the coordinate system $\phi_s = 0$ 对称轴对准坐标系$\phi_s = 0$

Simple coupling of the coefficients on the left side (m < 0) on the right side (m > 0)

左侧（m < 0）和右侧系数（m > 0）的简单耦合

$$C_{mn}(f) = C_{-mn}(f)(-1)^m \quad with \quad \begin{matrix} 0 \le m \\ 0 \le n \le N \end{matrix}$$



Reduction of Coefficients:

系数数量减少：

48%

(compared to no symmetry, for N = 30)

（与无对称比较，N = 30）

Automatic Check for Single Plane Symmetry

自动检查单平面对称性

- Additional Scanning Points
  附加扫描点
- Metric $S_{1PS} > 0.95$
  度量标准$S_{1PS} > 0.95$

Dual Plane Symmetry (2PS) 双平面对称（2PS）

symmetry axes ϕ_s=0 and $\phi_s = 90°$ aligned to the coordinate system 对称轴ϕ_s=0和$\phi_s = 90°$对准坐标系

Simple coupling of the coefficients on the left side (m < 0) on the right side (m > 0)
左侧（m < 0）和右侧系数（m > 0）的简单耦合

$$\left.\begin{aligned} C_{-(m-1)n}(f) &= 0 \\ C_{(m-1)n}(f) &= 0 \\ C_{mn}(f) &= C_{-mn}(f)(-1)^m \end{aligned}\right\} m = 2s, s = 1,2,3$$

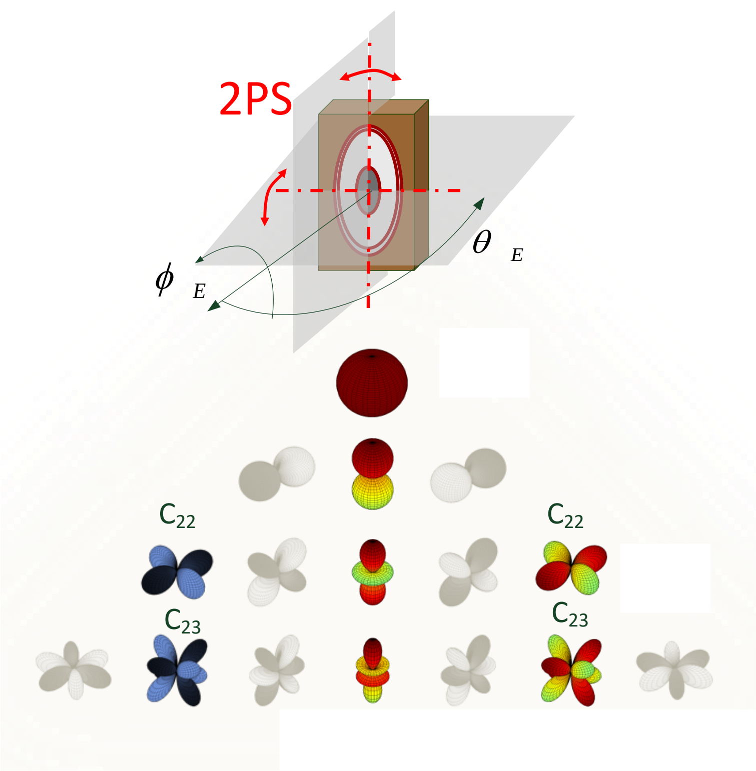
Reduction of Coefficients:
系数数量减少：

73%

(compared to no symmetry, for N = 30)
（与无对称比较，N = 30）

Automatic Check for Dual Plane Symmetry
自动检查双平面对称性

- Additional Scanning Points
  附加扫描点
- Metric $S_{2PS} > 0.95$
  度量标准$S_{2PS} > 0.95$



Rotational Symmetry (RS) 旋转对称（RS）

no phi dependency 与phi无关

Condition for used Spherical harmonics:

使用的球谐条件：

$$C_{mn} = 0 \qquad m \neq 0$$

Reduction of Coefficients:

系数数量减少：

97%

(compared to no symmetry, for N = 30)

（与无对称比较，N = 30）

Automatic Check for rotational Symmetry

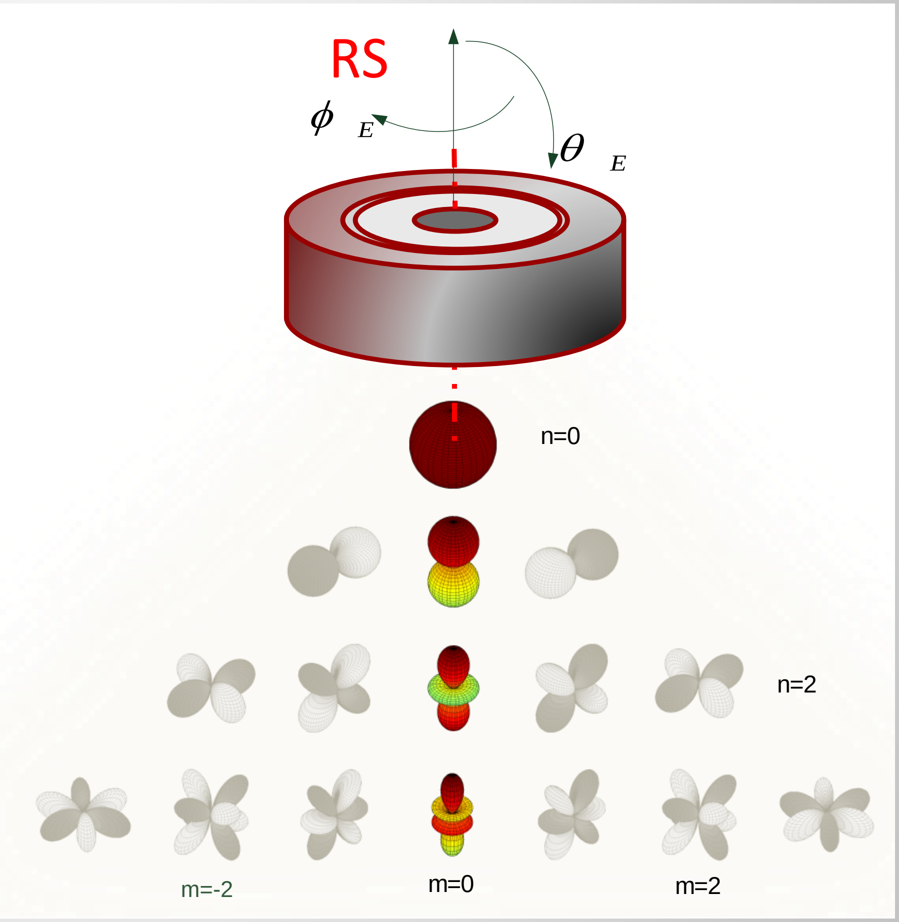
自动检查旋转对称

- Additional Scanning Points

  附加扫描点

- Metric $S_{RS} > 0.95$

  度量标准$S_{RS} > 0.95$



Reduction of Scanning Effort
减少扫描工作量
(Loudspeaker System)
(扬声器系统)

Example: wave expansion with maximum order N=30
示例： 最大阶数N = 30的波扩展

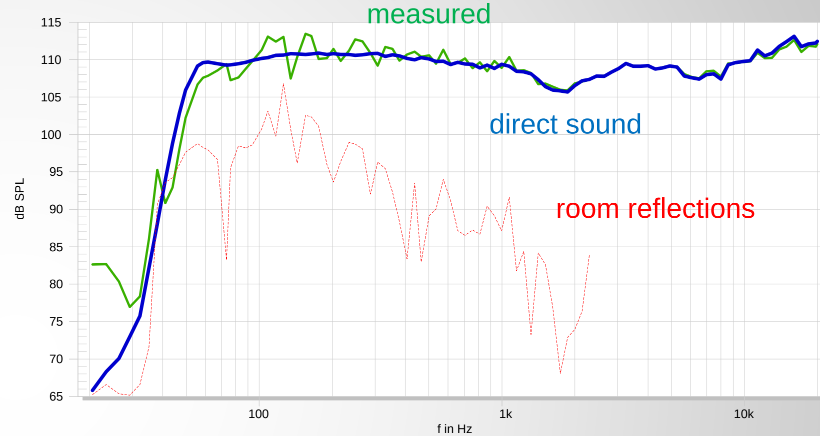
Symmetry 对称性	Number of Coefficients 系数数量	Reduction of measurement samples 减少测量样本量
No Symmetry 无对称	961	0%
Single plane symmetry 单平面对称	496	48%
Dual plane symmetry 双平面对称	256	73%
Rotational symmetry 旋转对称	31	97%

Knowing the **symmetry properties** (a prior user input or automatic detection) can reduce the number of **measurement points** significantly.
了解**对称属性**（用户预先输入或自动检测）可以大大减少测量点的数量。

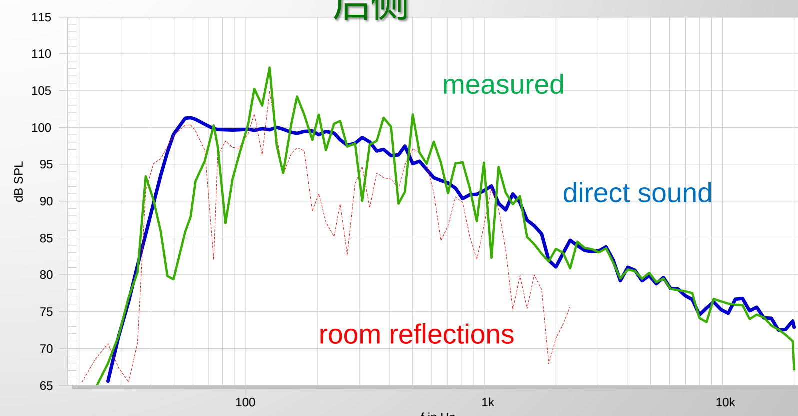
Direct Sound Separation 直达声分离

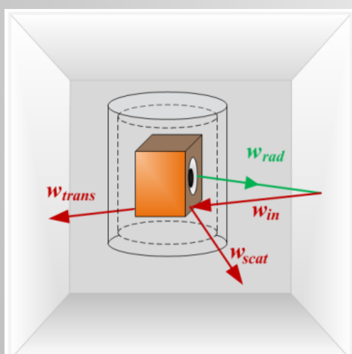
measurement performed in a normal office 在普通办公室进行测量

Front side (on axis)
前侧（轴上）



Rear Side
后侧





Double layer scanning + holographic processing allows separation of direct sound from room reflections

双层扫描+全息处理可以将直达声与房间反射分开

Live Near-field Measurement

现场近场测量

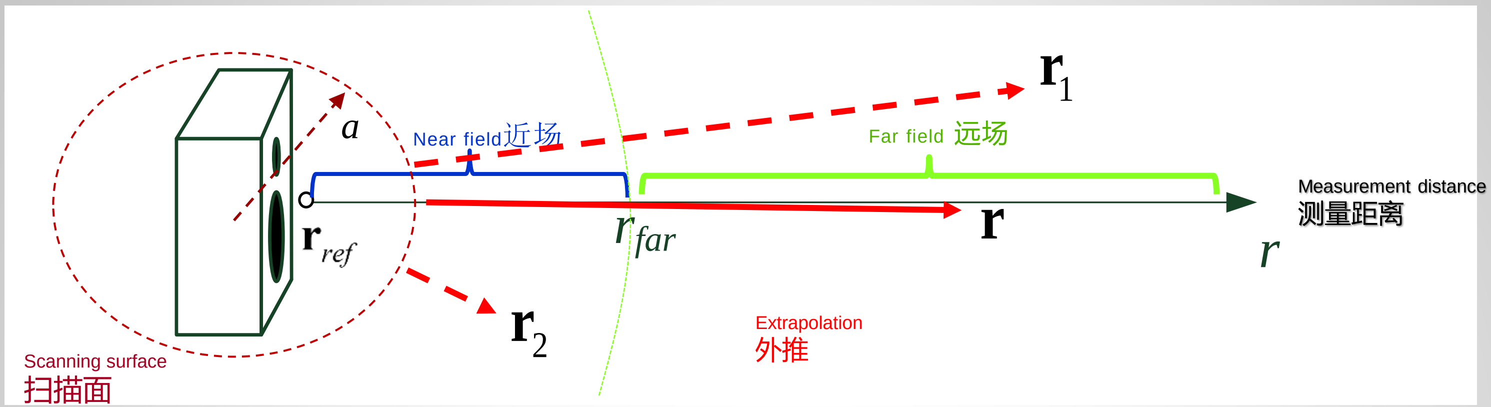
Our Expert Today: Christian Bellman

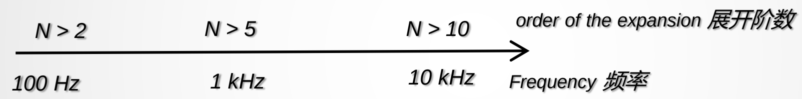
今天的专家：Christian Bellman

Holographic Measurements 全息测量

Near Field Scanning + Wave Expansion + Direct Sound Extrapolation

近场扫描+波形展开+直达声外推





Summary 总结

- Nearfield measurement has a better SNR than far-field test
  近场测量比远场测试具有更好的SNR
- Comprehensive assessment of direct sound in 3D space (near + far field)
  全面评估3D空间（近场+远场）中的直达声
- Self-check of the test using the fitting error
  使用拟合误差对测试进行自检
- Accurate phase and time delay information (speaker is not moved)
  准确的相位和时间延迟信息（扬声器未移动）
- Angular resolution is larger than number of coefficients
  角分辨率大于系数数量
- No anechoic room required
  无需消声室

Discussion
讨论

Open Questions

开放性问题

Direct sound field can be measured at any point outside the scanning surface at high accuracy!

可以在扫描表面以外的任何位置以高精度测量直达声声场！

- How to present and interpret the 3D sound data?
  如何呈现和解读3D声音数据？
- What is important for my application?
  哪些对我的应用重要？

The upcoming 3rd webinar will address:

即将举行的第三次网络研讨会将讨论：

- Far field directivity (e.g. professional application)
  远场方向性（例如专业应用）
- Mean values at selected angles (spin-o-rama) (e.g. consumer-home application)
  选定角度的平均值（spin-o-rama）（例如家用消费级应用）
- Mean values of a listening zone in 3D space (e.g. personal audio devices)
  3D空间中听音区的平均值（例如个人音频设备）
- Accurate complex data for beam steering (e.g. loudspeaker panels)
  波束成形的准确复数据（例如扬声器面板）

Next Webinar

下一次网络研讨会

1. 现代音频设备需要基于输出的测试 Modern audio equipment needs output based testing
2. 普通房间中进行标准声学测试 Standard acoustical tests performed in normal rooms
3. **从3D输出测量中获取有意义的结论 Drawing meaningful conclusions from 3D output measurement**
4. 评估点处的模拟标准条件 Simulated standard condition at an evaluation point
5. 最大SPL – 赋予该值意义 Maximum SPL – giving this value meaning
6. 选择具有高诊断意义得测量 Selecting measurements with high diagnostic value
7. 幅值压缩 – 输入更高但输出更低 Amplitude Compression – less output at higher amplitudes
8. 谐波失真测量 – 最佳实践 Harmonic Distortion Measurements – best practice
9. 互调失真 – 音乐比单音信号更多 Intermodulation Distortion – music is more than a single tone
10. 脉冲失真 – 异音、异常行为、缺陷 Impulsive distortion - rub&buzz, abnormal behavior, defects
11. 标准条件下音频产品的基准 Benchmarking of audio products under standard conditions
12. 信号失真的可听化 – 感知评估 Auralization of signal distortion – perceptual evaluation
13. 为信号失真设定有意义的公差 Setting meaningful tolerances for signal distortion
14. 评定产品的最大SPL值 Rating the maximum SPL value for a product
15. 带无线音频输入的智能音箱测试 Smart speaker testing with wireless audio input

Thank You !
非常感谢！