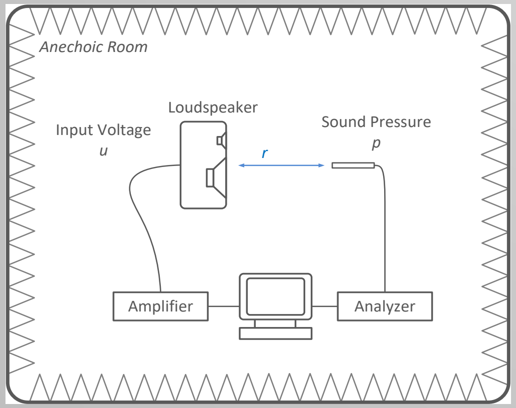
2nd KLIPPEL LIVE webinar

Standard acoustical tests performed in normal rooms

Topics today

1. Problems in practical free-field measurements
2. Alternatives: SIMULATED free-field conditions
3. The practical limits of direct sound windowing
4. A powerful solution: Near Field Scanning
5. Practical Demo in an office room
6. Questions, Discussion

Far-Field Measurement under free field condition



Problems:

- **Low** frequency measurements (accuracy, resolution) limited by acoustical **environment**
- **High** frequency measurements require **far-field** conditions (room size?)
- Accuracy of the **phase response** in the far-field depends on temperature deviations and air movement
- An **anechoic chamber** is an expensive and long-term investment which cannot be moved easily

Problems in the Far-Field

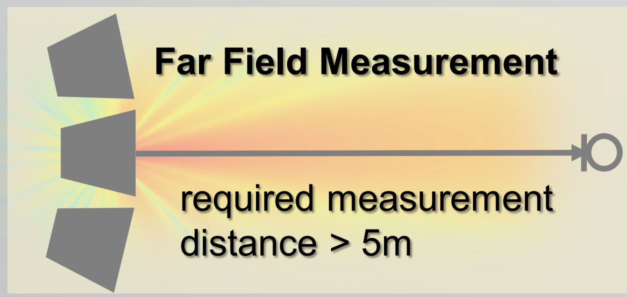
Phase response depends on air temperature

Sound velocity is dependent on air conditions (e.g. temperature)

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

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

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



Deviation:

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

Phase error caused by temperature difference of 2°C during

Frequency	Wave length	Phase Error in 5 m distance
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 !

Far-Field Measurement under simulated free-field conditions

Technology

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

Benefits

- Good suppression of room reflections at higher frequencies
- Higher SNR due to ambient noise separation

Problems

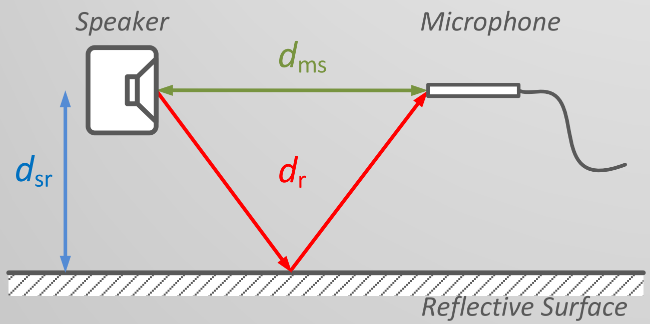
- Short distance to boundaries requires short window to separate direct sound from reflected sound
- Window length limits the frequency resolution
- Short windows can cause significant errors at low frequencies

Poll:

Do you use windowing (or other gating techniques) for separating the direct sound ?

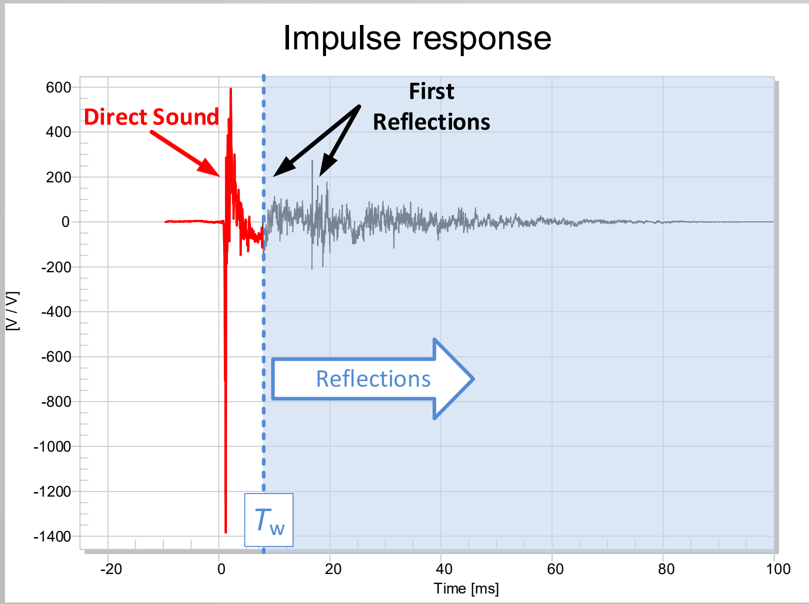
- always
- sometimes
- never

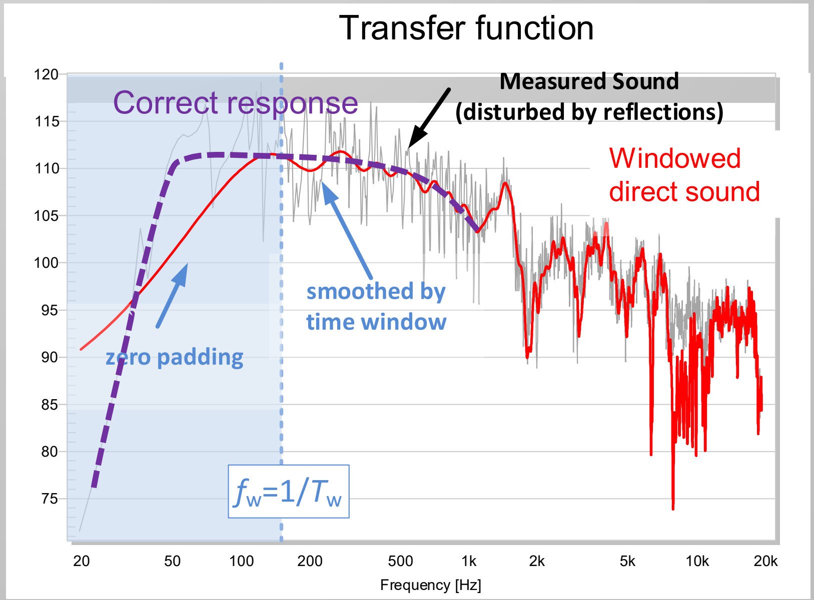
Problem with Short Windows



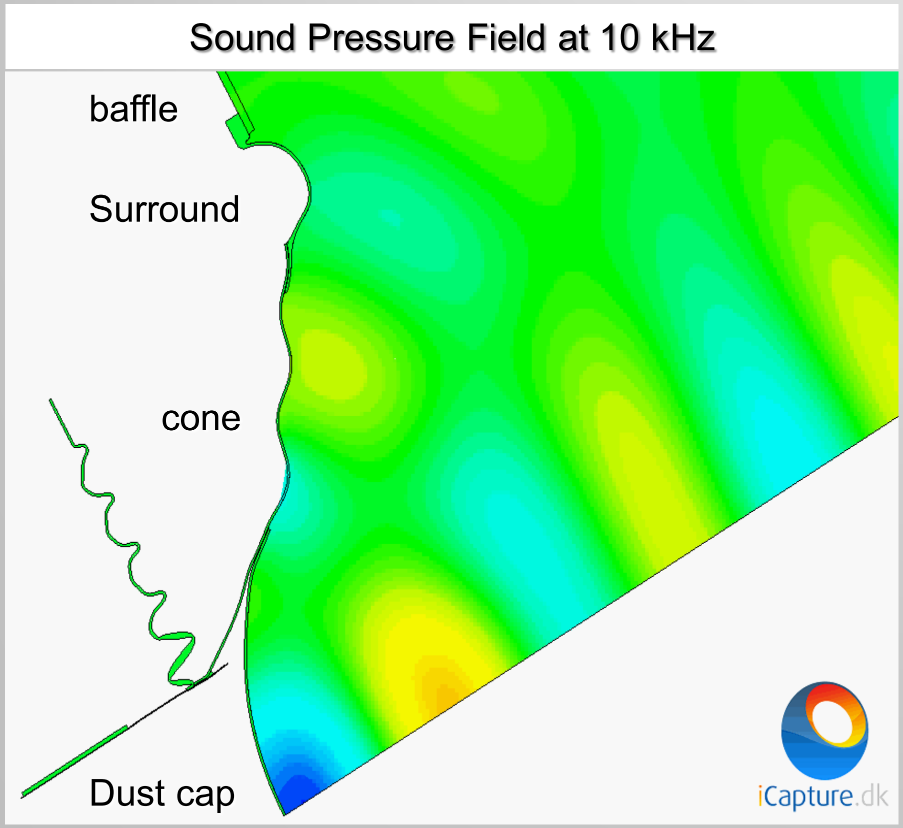
$$d_r = 2\sqrt{\left(\frac{1}{2}d_{ms}\right)^2 + (d_{sr})^2}$$

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





Measurements in the Near Field



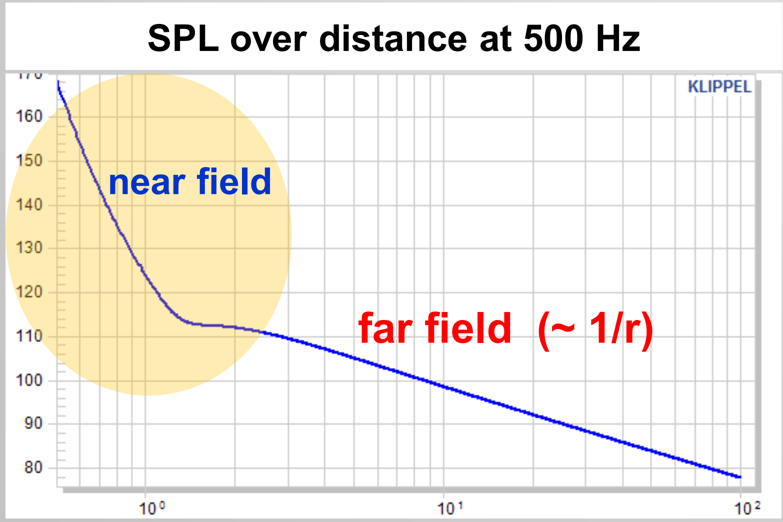
Advantages:

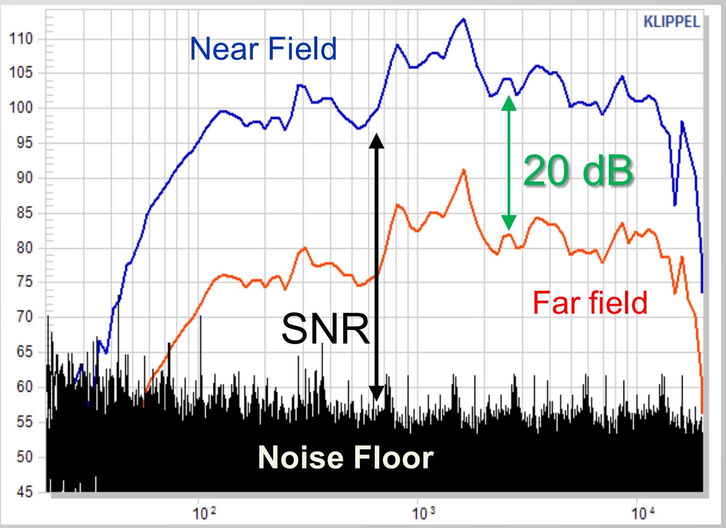
- High SNR
- Amplitude of **direct sound** much greater than room reflections providing good conditions for simulated free field conditions
- Minimal influence from **air properties** (air convection, temperature deviations)

Disadvantages:

- Not a plane wave
- Velocity and sound pressure are out of phase
- 1/r law does not apply, therefore, no sound pressure extrapolation into the far-field (**holographic processing** required)

Good SNR in the Near-Field !



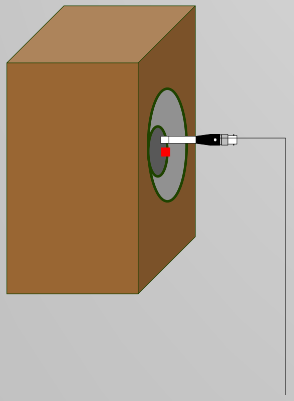


Near-field measurements have the following benefits:

- **Higher SNR** (typically 20 dB more than far field measurements)
- Measurement can tolerate some **ambient noise** (office, workshop)
- Faster measurements since **no averaging** required

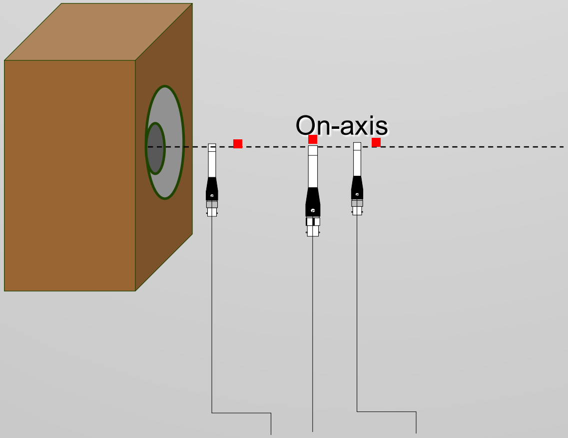
Short History on Near-Field Measurements

Single-point measurement close to the source



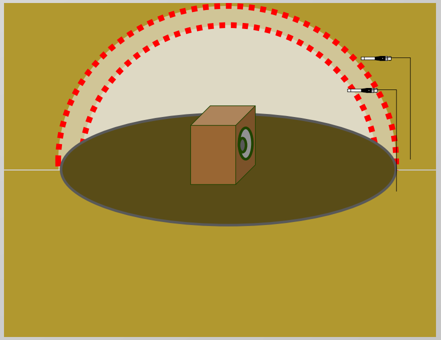
Don Keele 1974

Multiple-point measurement on a defined axis



Ronald Aarts (2008)

Scanning the sound field on a surface around the source



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

Robotics required

Postprocessing of the scanned data required

Poll:

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

- always
- sometimes
- never

Holographic Measurement

using spherical waves and Hankel functions as basic functions

1st step: Measurement

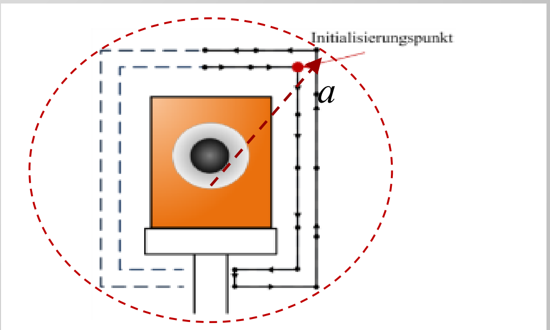
- Scanning the sound pressure in the near field of the source at a single or multiple surfaces

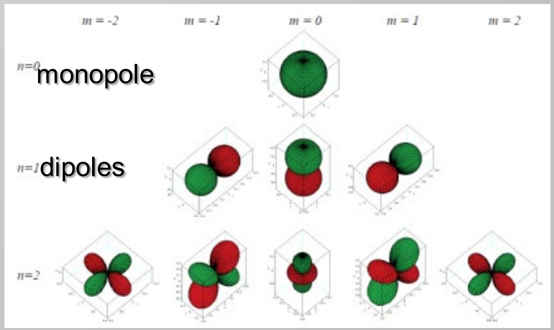
2nd step: Holographic Data Processing

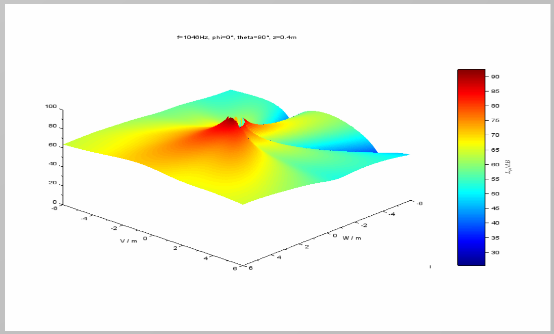
- Expansion into spherical waves using Legendre and Hankel functions
- Optimal estimation of the free parameters of the expansion (order N(f) and coefficients *C*(f))

3rd step: Extrapolation

- 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
- Calculation of **derived characteristics** (directivity, beam pattern, sound power)







Holographic Nearfield Measurement

Number of points	application
1	*In-situ testing*
	Subwoofer
	sound power
100	
	Directivity full-band single plane symmetry
	Directivity full-band no symmetry
1000	
	Professional Speakers Sound bars
5000	

Number of scanning points M depends on:

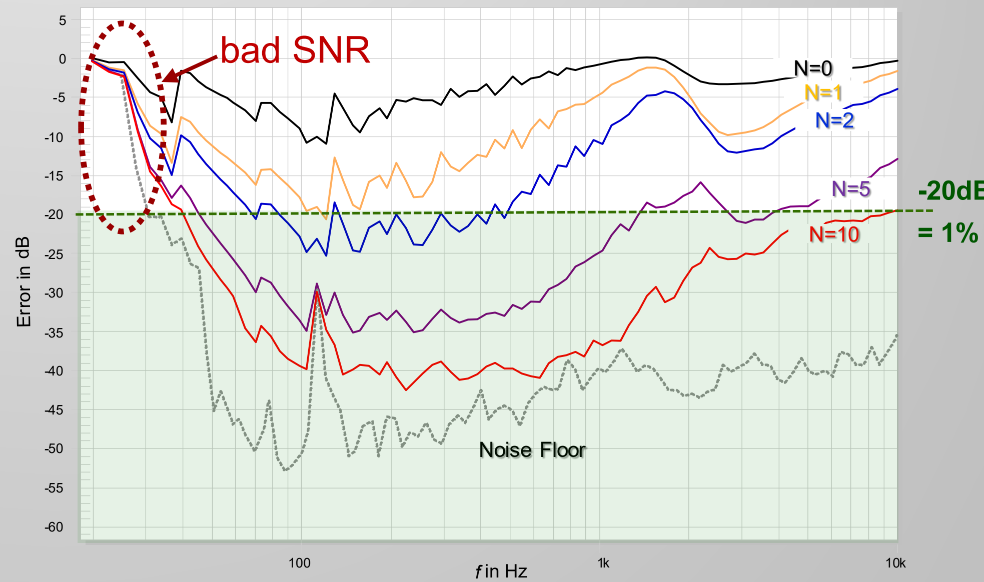
- Total number of **coefficients** J in the expansion (M>1.5J)
- Maximum **order** N of the expansion $J=(N+1)^2$
- **Loudspeaker type** (size, number of transducers)
- **Symmetry** of the loudspeaker (axial symmetry)
- **Application** of the data (e.g. EASE data)
- Field separation (non-anechoic conditions)

Benefit of using a Spherical Wave Expansion:
Number of measurements points M required is **much lower** than the final angular resolution of the calculated directivity pattern!

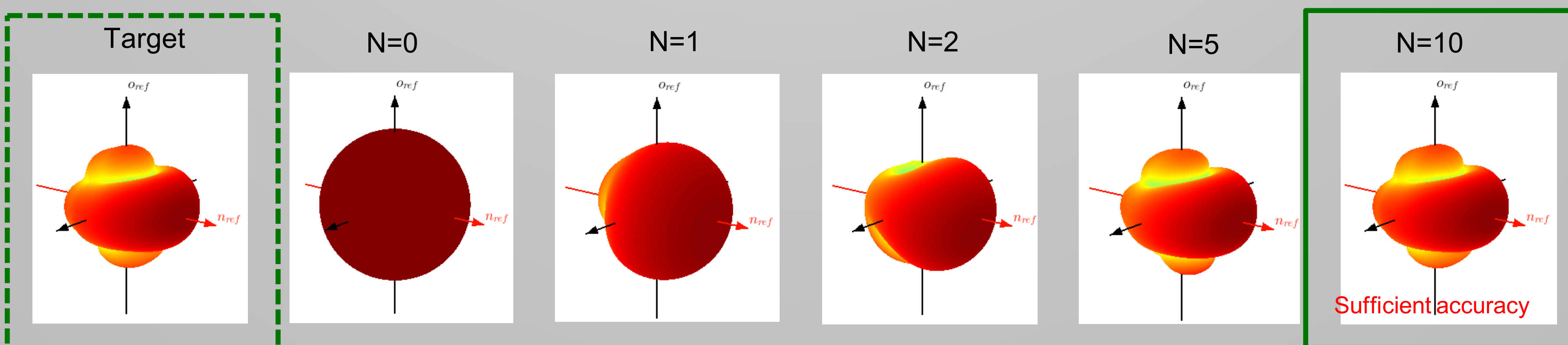
How long is the Measurement ?

The measurement time depends
→ **fitting** error in the wave expansion (self-test)
→ **optimum order** N of the wave expansion
→ number of the **Scanning Points**
→ speed of the **robotics**

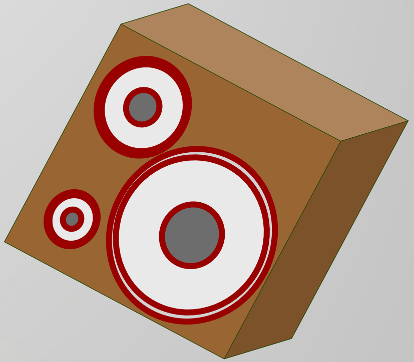
Fitting error as a function of the maximum order N



Directivity at 2kHz:



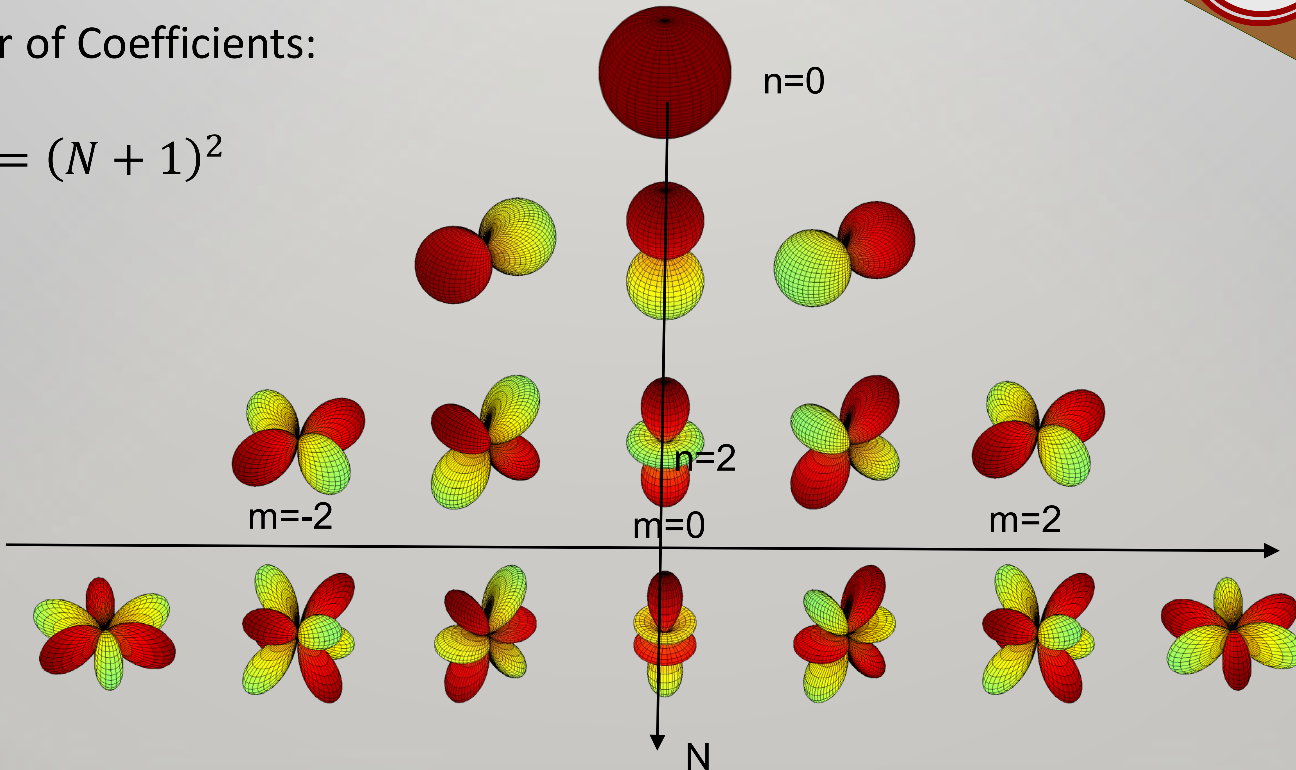
No Symmetry



Condition for used Spherical harmonics:
All orders used

Number of Coefficients:

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



Single Plane Symmetry (1PS)

symmetry axis aligned to the coordinate system $\phi_s = 0$

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

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

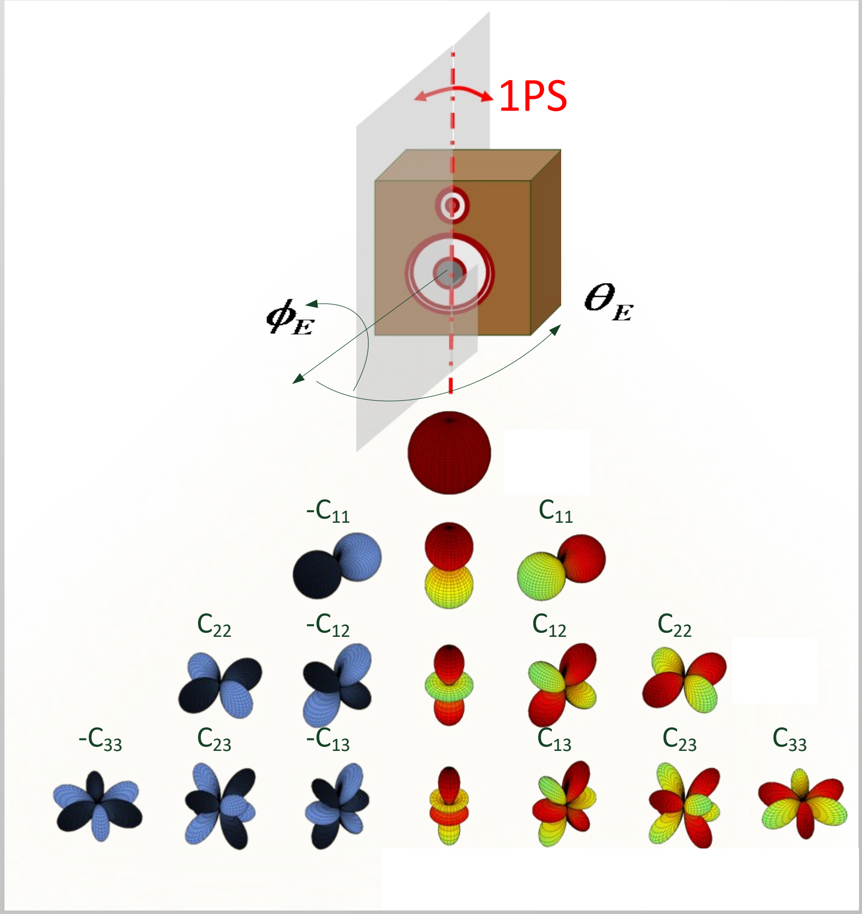
Reduction of Coefficients:

48%

(compared to no symmetry, for N = 30)

Automatic Check for Single Plane Symmetry

- Additional Scanning Points
- Metric $S_{1PS} > 0.95$



Dual Plane Symmetry (2PS)

symmetry axes ϕ_s=0 and $\phi_s = 90°$ aligned to the coordinate system

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

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

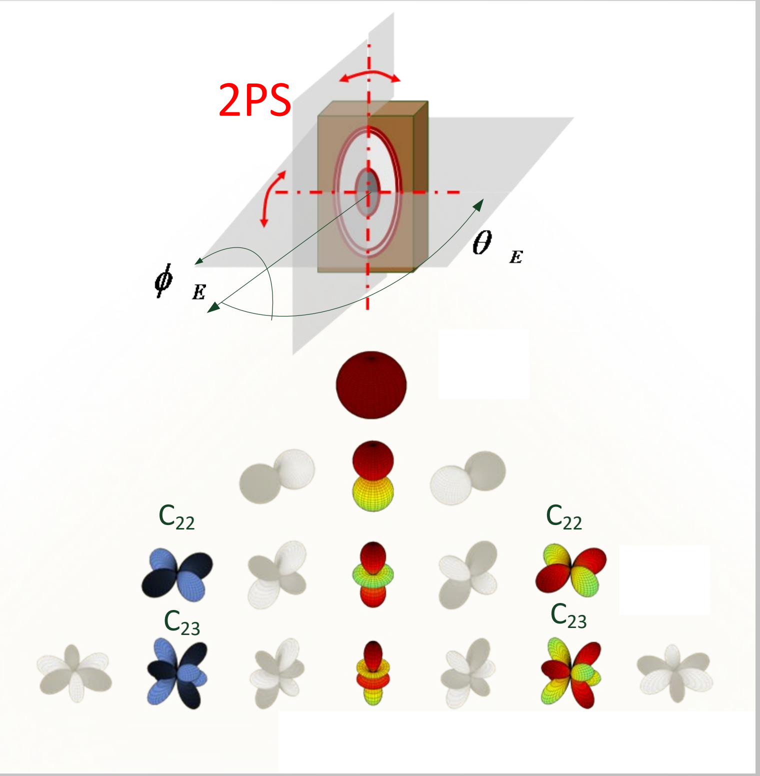
Reduction of Coefficients:

73%

(compared to no symmetry, for N = 30)

Automatic Check for Dual Plane Symmetry

- Additional Scanning Points
- Metric $S_{2PS} > 0.95$



Rotational Symmetry (RS)

no phi dependency

Condition for used Spherical harmonics:

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

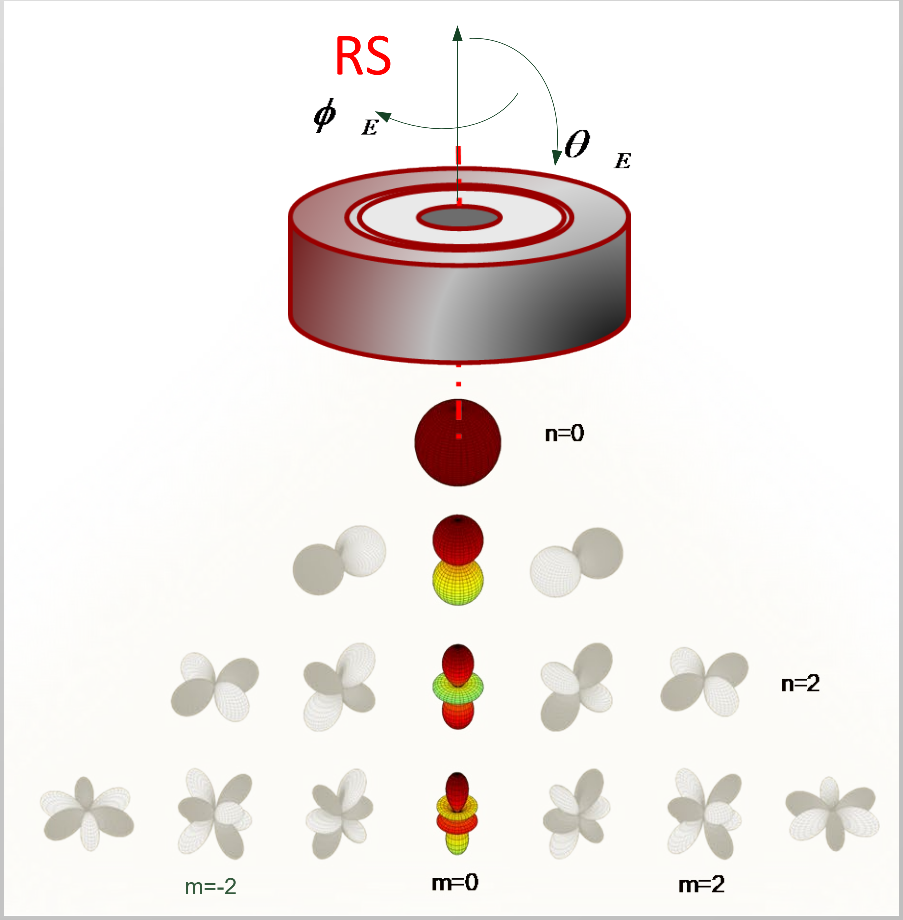
Reduction of Coefficients:

73%

(compared to no symmetry, for N = 30)

Automatic Check for Dual Plane Symmetry

- Additional Scanning Points
- Metric $S_{RS} > 0.95$



Reduction of Scanning Effort
(Loudspeaker System)

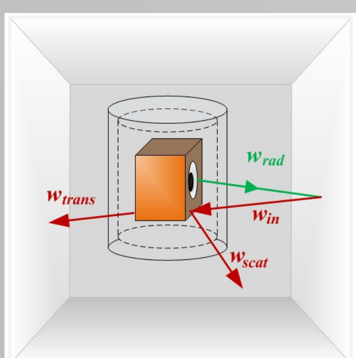
Example: wave expansion with maximum order N=30

Symmetry	Number of Coefficients	Reduction of measurement samples
No Symmetry	961	0%
Single plane symmetry	496	48%
Dual plane symmetry	256	73%
Rotational symmetry	31	97%

Knowing the **symmetry properties** (a prior user input or automatic detection) can reduce the number of **measurement points** significantly.

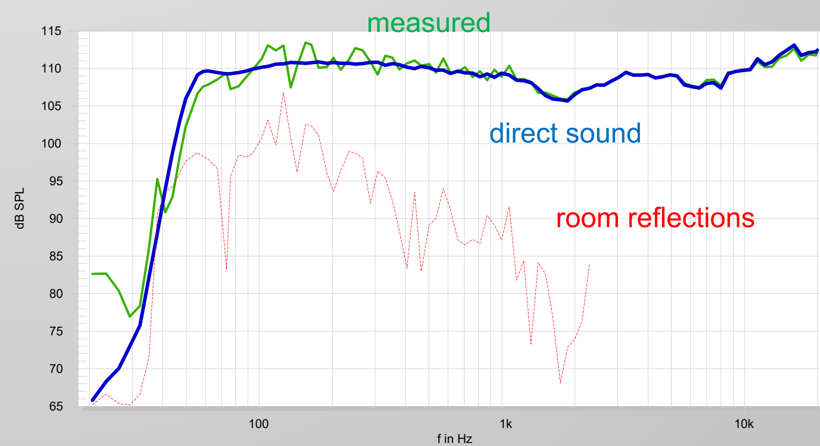
Direct Sound Separation

measurement performed in a normal office

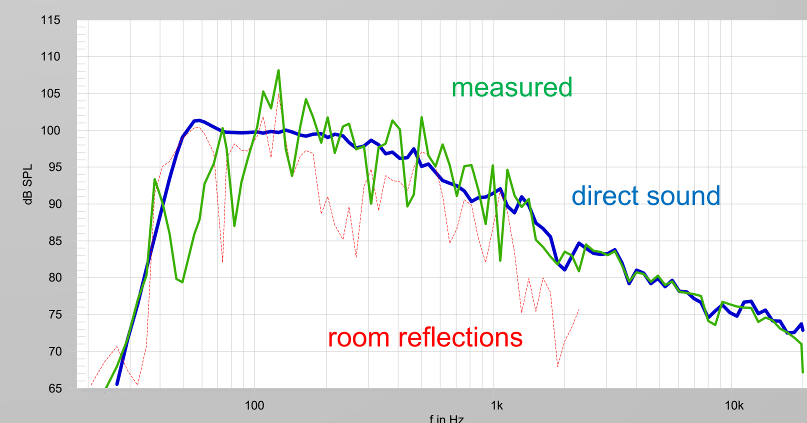


Double layer scanning + holographic processing allows separation of direct sound from room reflections

Front side (on axis)



Rear Side

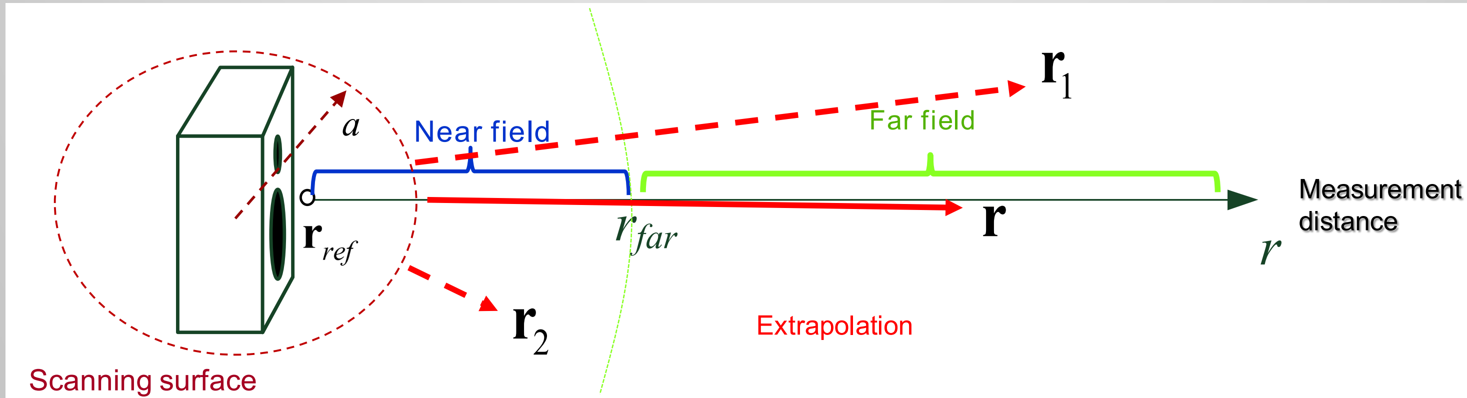


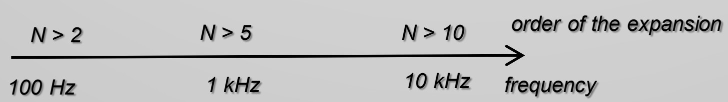
Live Near-field Measurement

Our Expert Today: Christian Bellmann

Holographic Measurements

Near Field Scanning + Wave Expansion + Direct Sound Extrapolation





Summary

- Nearfield measurement has a better SNR than far-field test
- Comprehensive assessment of direct sound in 3D space (near + far field)
- Self-check of the test using the fitting error
- Accurate phase and time delay information (speaker is not moved)
- Angular resolution is larger than number of coefficients
- No anechoic room required

Discussion

Open Questions

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

- How to present and interpret the 3D sound data?
- What is important for my application?

The upcoming 3rd webinar will address:

- Far field directivity (e.g. professional application)
- Mean values at selected angles (spin-o-rama) (e.g. consumer-home application)
- Mean values of a listening zone in 3D space (e.g. personal audio devices)
- Accurate complex data for beam steering (e.g. loudspeaker panels)

Next Webinar

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 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 a product
15. Smart speaker testing with wireless audio input

Thank You !