Near Field Scanner 3D (NFS) C8

Hardware and Software Module of the KLIPPEL R&D SYSTEM (Document Revision 1.16)

FEATURES	BENEFITS
• SPL at any point in 3D space • Directivity in near / far field • High angular resolution • Balloon / Polar plot • Power response • Non-moving loudspeaker • Open export interface	• Non-anechoic measurement • Fast measurement • Comprehensive radiation data set • Portable measurement equipment • Flexible dimensions • Negligible reflections from equipment • Applicable to large loudspeakers (500 kg)

The Near-Field-Scanner 3D (NFS) offers a fully automated acoustic measurement of direct sound radiated from the source under test.

The radiated sound is determined in any desired distance and angle in the 3D space outside the scanning surface.

Directivity, sound power, SPL response and many more key figures are obtained for any kind of loudspeaker and audio system in near field applications (e.g. studio monitors, mobile devices) as well as far field applications (e.g. professional audio systems).

Utilizing a minimum of measurement points, a comprehensive data set is generated containing the Loudspeakers high resolution, free field sound radiation in near and far field.

Article Numbers:	2520-010	Near Field Scanner System
	2520-012	Direct Sound Separation Module
	2520-013	Near Field Analysis Module
	2520-016	Complex data Export Module
	2520-015	Comparison Module
	2520-017	Multi Source Superposition Module
	2520-019	Holographic Parameter Export
	2520-018	Baffle Measurement Module
	2520-025	Baffle Hardware

CONTENTS:

1 Principle

OBJECTIVE

The objective of this measurement system is the easy and reliable measurement of directivity and sound pressure in any distance.

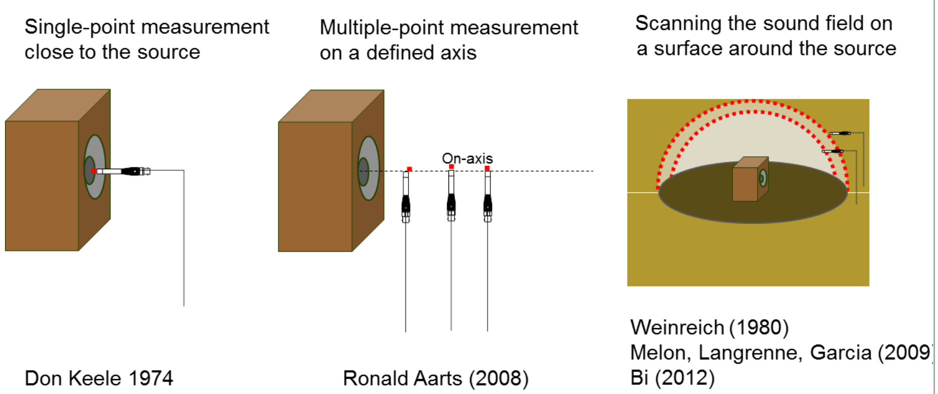
Traditionally such measurements are done in far field under anechoic conditions.

The new method of holographic sound field expansion characterizes the whole sound field (near and far field) with a simple set of parameters. This set of parameters can be identified from a measurement in near field.

HISTORY

The first approach of using near field measurements was employed by Don Keele in 1974. Starting from this idea, to use the near field response to predict the far field response, more complex approaches were published.

The holographic sound field expansion is the most complex and complete method in this development.



BENEFITS

Advantages of sound field expansion using Near Field Measurement data over traditional far field measurements.

- **Applicable to large loudspeakers**
  Due to non-moving loudspeaker, large loudspeakers can be measured, being supported by a crane from ceiling.
- **Avoiding air diffraction problems for far field measurements**
  Far field measurements of large loudspeakers will require large anechoic chambers to ensure far field conditions. Such measurements will suffer from diffraction problems caused by temperature differences in the air over distance and time, leading to high errors in the phase response in upper frequency bands.
  A temperature change of only 2°C will result in a phase error of 180 degree at 10kHz in 5m measurement distance.
- **No anechoic room needed**
  Radiated sound can be separated from reflected sound of the room by using Direct Sound separation technique
- **Higher accuracy than anechoic chamber measurement**
  Below 100Hz no room correction curve needed.
- **Fast measurement**
  Standard 3D acoustic measurements like sound power are done in less than 20 minutes for typical 2-way systems.
- **High Signal-to-Noise-Ratio**

<table>
<tr>
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High sound pressure level in near field. Less critical ambient noise requirements

Comprehensive radiation data set
Radiation data set gained from near field measurement provides SPL at any point in 3D space. Near and far field data is provided without the need of further measurements.
Provides full 3D Near Field Data
Near field data is provided at any point outside the scanned surface.
High angular resolution <1° with low number of points
Angular resolution is not depending on number of measurement points (Traditional far field measurements require 64800 measurement points for 1° Resolution)

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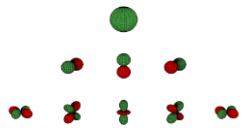
<tr>
<td>MEASUREMENT METHOD

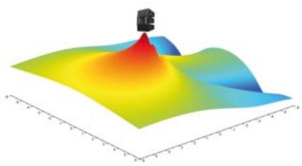
RESULT DATA</td>
<td>
The Near-Field Scanner 3D (NFS) uses a moving microphone to scan the sound pressure in the near field of a compact sound source such as a loudspeaker system or a transducer mounted in a baffle. The device under test (< 500 kg) does not move during the scanning process. The reflections in the non-anechoic environment are then consistent and can be monitored with our novel analysis software, which uses acoustical holography and Direct Sound separation techniques to extract the direct sound and to reduce room reflections.



Multi-pole Expansion

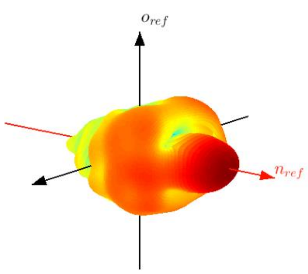
The sound field generated by the source is reconstructed by a weighted sum of spherical harmonics and Hankel functions which are solutions of the wave equation.

The weighting coefficients in this expansion represent the unique information found in the near-field scan while gaining a significant data reduction.



Near-Field Analysis

The wave expansion provides the sound pressure at any point outside the scanning surface which is required for assessing studio monitors, mobile phones and tablets and other personal audio devices where the near field properties are important.



Far-Field Extrapolation

The near-field data, measured at a high SNR, is the basis for predicting the direct sound at larger distances. This avoids diffraction problems of classical far-field measurements (non-homogeneous media).
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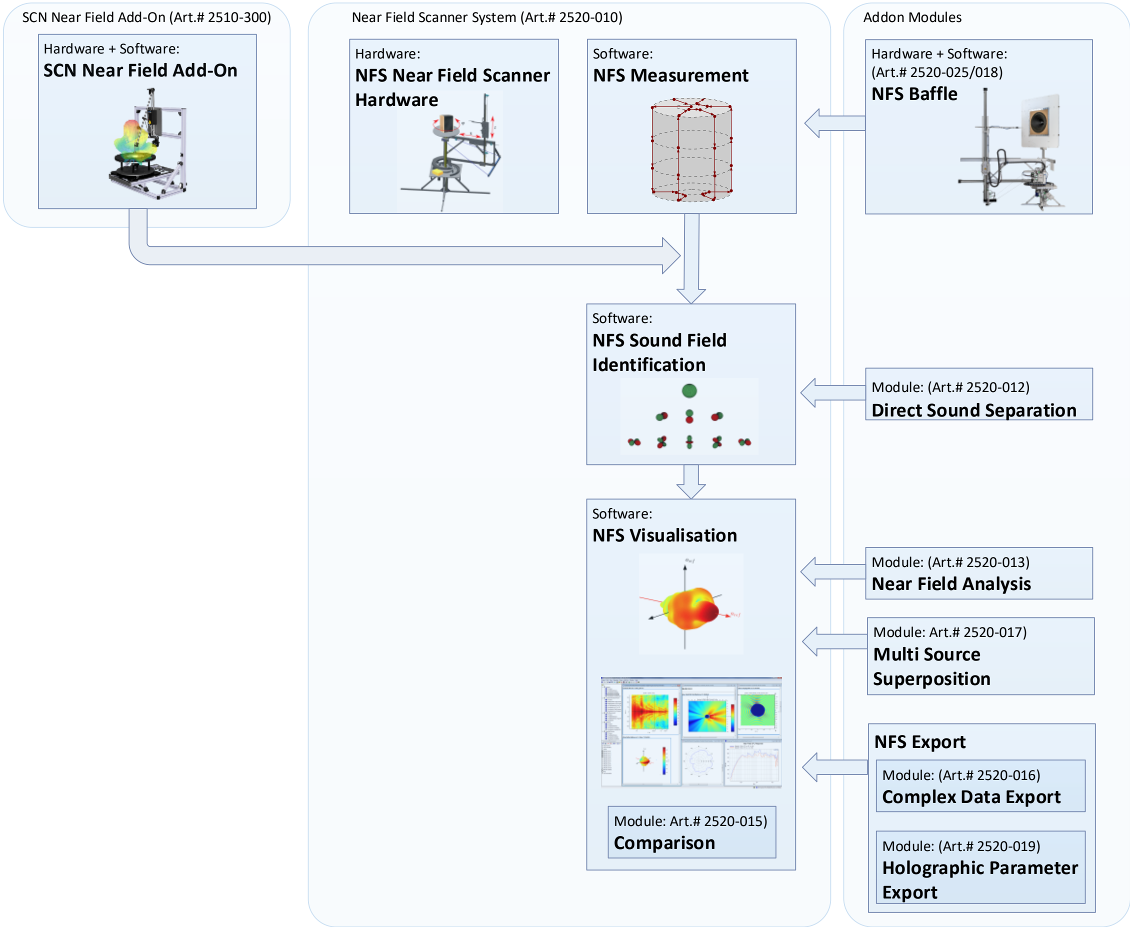
2 Structure



The Klippel Near Field Scanner is a measurement system, to measure the radiation characteristic of all sorts of sound sources. The principle of acoustic holography is used to combine the benefits of a near field measurement with the demand of the radiation characteristic in any distance.

Based on the sound pressure measured in the very close near field, free field sound pressure is calculated at any distance.

NFS Measurement page 8

The Near Field Scanner Hardware precisely positions a microphone in the near field of the sound source in an automated process. In addition to do measurements in half space (2π), the scanning can be performed using the NFS Baffle hardware (11) or the SCN Near Field Add-on [3].

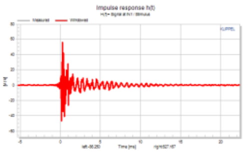
NFS Field Identification page 15

Utilizing holographic sound field expansion a solution of the wave equation is identified that matches the measured sound pressure around the sound source. This solution of the wave equation, describes the free field sound pressure at any point in near and far field.

The Direct Sound Separation Module provides a more advanced wave expansion method , which separates room modes, enabling measurements under non-anechoic conditions (e.g. office room).

From the holographic sound field expansion, near and far field analysis measurement results are calculated and shown commonly used visualizations.

The Scanning System Hardware is a 3-Axis microphone positioning system, which enables the automatic measurement of the near field sound pressure.

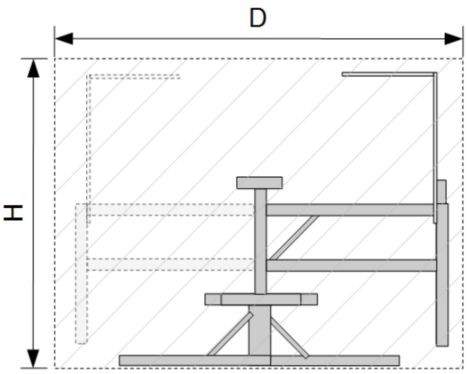
3 Required Components			SPEC #
Near Field Scanner 3D		3D microphone positioning system comprising Hardware, Measurements Software and Visualization Software.	C8
KA3 / DA2		Distortion Analyzer 2 or the Klippel Analyzer 3 is the hardware platform for the measurement modules performing the generation, acquisition and digital signal processing in real time	H1/ H3
TRF		The Transfer function (TRF) is a dedicated PC software module for measurement of the transfer behavior of a loudspeaker.	S7
Microphone[1]		Free field microphone with omnidirectional directivity characteristic over the desired measurement bandwidth.	A4
Amplifier		Amplifier with a flat frequency response over the desired measurement bandwidth	
Multiplexer (optional)		8 channel multiplexing hardware that is directly controlled by the Klippel Software. (Required for Multi Source Superposition Module)	A8
Klippel Baffle Hardware (optional)		Hardware add-on to perform half space measurements of transducers with the Near Field Scanner	C8

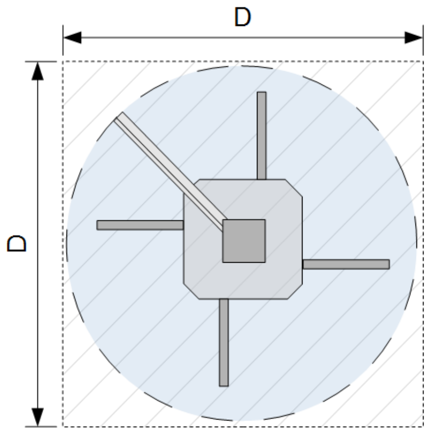
[1] The Near Field Scanner System cannot compensate for the directivity of the microphone. Using non-omnidirectional microphones will limit the accuracy of the scan on the top and bottom surface, typically at $\vartheta = \pm 90°$ vertical off-axis for f>10 kHz. It is recommended to use microphones with a small capsules (e.g. 1/4”) that are less directional at high frequencies than larger capsules (e.g. 1/2”).

4 Typical Operating Conditions

Measurement Condition if not otherwise stated: Sinusoidal stimulus at 1kHz, 94dB SPL.

Parameter	Conditions	Min	Typ	Max	Unit
GENERAL PARAMETERS					
Measurement speed			300	500	Points/h
Measurement Points		10		10000	Points
Measurement accuracy	In maximum SPL direction [1]		+/- 0.1		dB
	In all directions		+/- 1		dB
BANDWIDTH					
Standard System					
Measurement Bandwidth	Anechoic	10		20000	Hz
	Non-anechoic	2000		20000	Hz
Incl. Direct Sound Separation Module					
Measurement Bandwidth	Anechoic	10		20000	Hz
	Non-anechoic	10		20000	Hz
PHYSICAL DIMENSIONS					
The NFS can be set up in various size configurations to accommodate different room and DUT sizes. The R-Axis of the NFS can be mounted in a compact or extended position. The Z-Axis can be ordered in standard or extended length.					
Room Size					
Required Room Size (length, width)	Compact R-Axis	2.5	3.0		m
	Extended R-Axis	3.6	4.0		m
Required Room Height [2]	Standard Z-Axis	2.2	2.5		m
	Extended Z-Axis	3.0	3.5		m
NFS Measurement System					
D – Diameter	Compact R-Axis		2500		mm
	Extended R-Axis		3600		mm
H – Height [2]	Standard Z-Axis	2000		2300	mm
	Extended Z-Axis	2800		3400	mm
Weight			75		kg
Device under test [3]					
Maximum DUT Diameter (Full Cylinder Scan)	Compact R-Axis			1000	mm
	Extended R-Axis			1600	mm
Maximum DUT Diameter (Lateral Cylinder Surface Scan only)	Compact R-Axis			1600	mm
	Extended R-Axis			2800	mm
Maximum DUT Height [2]	Standard Z-Axis	570		870	mm
	Extended Z-Axis	1170		1770	mm
Maximum DUT Weight	mounted on NFS platform [0,5]			5	kg
	supported by crane [0,0,6]			500	kg
	fully suspended by crane [7]			>500	kg





[1] Assuming the reference axis points in the direction of maximum SPL.
[2] The NFS height can be reduced by Z-Axis end-switch mounting position to enable operation in smaller rooms. This will reduce Z-Axis travel and therefore also the reduce maximum DUT height by the same amount. The setup of all Z-size configurations and resulting DUT sizes between given max and min values is possible.
[3] If measured on 1 layer (no direct sound separation). Measurements with direct sound separation will reduce maximum DUT dimensions by 50 mm in Z direction and 100 mm in R direction.
[4] Center of gravity must be less than 250mm away from the center of the platform. The maximum torque (e.g. by placing the DUT off center) induced to the platform must be smaller than 250Nm when DUT is placed on platform
[5] The maximum lateral force induced to the platform must be smaller than 250N when DUT is positioned on platform
[6] Crane suspension should keep the majority of the weight while the stand is used to keep the DUT at the optimum position
[7] The full weight of the DUT must rest on the crane and the crane must hold the DUT in the optimum position

5 Environment

The NFS measurement system does not need a specially treated acoustic environment and can be used in almost every room.

Required:

- solid ground floor, which can be drilled (the robot must be bolted to the ground)
- room dimensions larger than the specified physical dimensions of the Hardware
- for large/heavy devices (professional audio) additional support from the top (winch/crane)

Recommended:

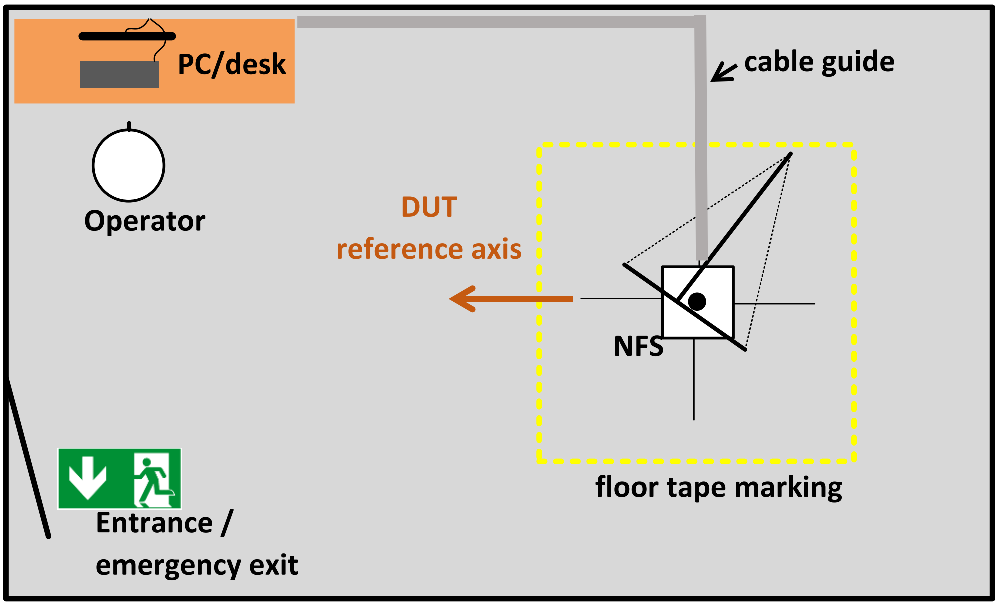
- use a separate room to reduce external noise and increase signal to noise ratio
- avoid cubical room shapes, rectangular or irregular room layouts are beneficial
- in small rooms, some absorbing and diffusing elements or furniture are beneficial
- place the robot in the room center with maximum distance to the 1st reflecting obstacle

Typical locations:

Office

Warehouse

Layout example:



6 Typical Measurement Applications

6.1 Standard acoustic measurements

Application	Recommended Modules	Time	Points
SPL On-Axis (Single Driver) *anechoic conditions, 1m distance*	• TRF Transfer function	<1 min	1
SPL On-Axis (Single Driver) *Non-anechoic conditions*	• Near Field Scanner System • Direct Sound Separation • Near Field Analysis • TRF Transfer function • In Situ Room Compensation	1 min[8]	1[8]
Sound power + directivity index *anechoic conditions*	• Near Field Scanner System	20 min	>100
Directivity Axial Symmetric *anechoic conditions*	• Near Field Scanner System	5 min	25
Additional Measurement time/points in bad acoustical conditions *Non-anechoic conditions*	• Direct Sound Separation	+30 min	+250

6.2 Typical Directivity measurements

Application	Recommended Modules	Time	Points
Subwoofer *Sound power / Directivity* *(10Hz – 200Hz)*	• Near Field Scanner System • Direct Sound Separation	10min	50

Hifi Speaker *mirror symmetric* *Sound power / Directivity* *(20Hz – 10kHz)*	• Near Field Scanner System • Comparison	30 min	250
Smart phone *Sound power / Directivity* *(50Hz – 10kHz)*	• Near Field Scanner System • Near Field Analysis	30 min	250
Laptop/Tablet PC *Near field On-Axis Response* *Sound Power* *(200Hz – 10kHz)*	• Near Field Scanner System • Direct Sound Separation • Near Field Analysis • Sound Field Parameter Export	30 min	>500
Additional Measurement time/points in bad acoustical conditions *Non-anechoic conditions*	• Direct Sound Separation	x2 (double)	x2 (double)
6.3 High accuracy directivity measurements			
PA Speaker *Complete EASE data set* *(20Hz – 20kHz)*	• Near Field Scanner System • Direct Sound Separation • Complex data Export	7 hours	2000
Laptop/Tablet PC *Accurate 3D near field sound pressure* *(20Hz – 20kHz)* *Personal acoustic zone related sound pressure (IEC 62777)*	• Near Field Scanner System • Direct Sound Separation • Near Field Analysis • Sound Field Parameter Export • Comparison	7 hours	2000

[8] Using correction curve determined by a direct sound separation measurement applied to a loudspeaker having a similar geometry (same type) located at the same position.

7 Features

Feature	Near Field Scanner System[9, 14]	Add-on Modules				
FF – Far Field NF – Near Field		Direct sound Separation[10]	Baffle Measuremen	Near Field Analysis[11]	NFS Export[12,13]	Multi Source superposition[1]
Automated Near Field Measurement	x		x			
Measurement in half space (2π)			x			
Non-anechoic Measurement		x				
FF Directivity Balloon	x					
FF Contour Plot	x					
FF Polar Plot	x					
FF SPL Response	x					
Sound Power	x					
FF Export Amplitude	x					
CEA 2034	x					
IEC 62777				x		
FF Export Amplitude /Phase Data (EASE)					x	
NF Spatial Sound pressure distribution (Mag. + Phase)				x		
NF SPL Response				x		
FF Phase Response	x					
FF Phase Balloon	x					
FF Group Delay	x					
FF Impulse Response	x					
Holography Parameter Export					x	
Comparison of all Far Field Plots	x					
Superposition of multiple sound sources						x

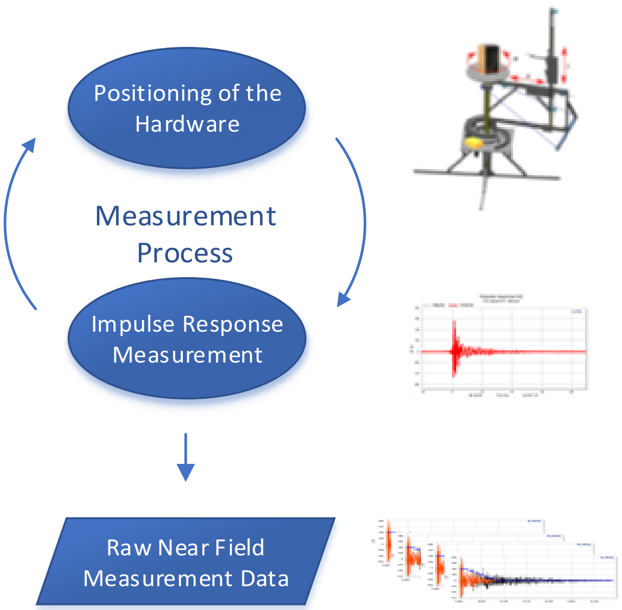
Required Licenses:

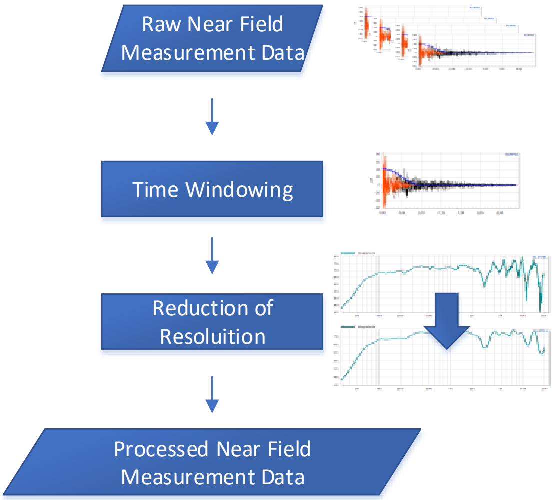
[9] NFS Field Identification, NFS Visualization, NFS Robotics
[10] NFS Direct Sound Separation Module
[11] NFS Near Field Analysis Module
[12] NFS Complex data Export
[13] NFS Holographic Parameter Export (not released)
[14] NFS Comparison
[15] NFS Multi Source Superposition

8 NFS Measurement

The measurement process is structured into data acquisition and data preprocessing.

Transfer function measurements are done on multiple positions along a surface very close to the sound source.

Data Acquisition	 **Data Acquisition:** According to the required Setup, a grid of measurement points is calculated. The System automatically positions the hardware and runs a measurement of the Impulse response at every single point.	
	Positioning of the Hardware	Connected to the Klippel NFS Hardware, the Software precisely positions the microphone.
	Impulse Response Measurement	Using the Klippel Distortion Analyzer and the TRF measurement module, the Impulse Response is measured. It is done using the well sophisticated sweep technique, providing accurate amplitude and phase results.
	Raw Near Field Measurement Data	The raw TRF measurement data is stored for calculation of the sound radiation characteristic. Additionally the TRF measurement operation of each point can be stored for verification use.

<table>
<tr><td>Data Processing</td><td colspan="2">

Data Processing: The raw measurement data is being preprocessed to the desired window length and frequency resolution.</td></tr>
<tr><td>Asynchronous Measurement
for wireless devices (e.g. Bluetooth®, Wifi, etc.)</td><td colspan="2">To measure audio devices that don't have analog inputs, the stimulus can be transmitted via a wireless connection or can be play as a wav-file on the device itself.
By using a 2nd microphone, the variable delays are detected automatically and the impulse responses of the measurement microphone are synchronized to ensure an accurate phase measurement.</td></tr>
<tr><td rowspan="2"></td><td>Time Windowing</td><td>Time windowing is used, to cut out noise and reflected sound which is not directly radiated by the measured sound source. The window length is defined from the desired frequency resolution, and will be chosen accordingly.
The closest distance, the microphone will approach to any reflecting obstacle (wall, ceiling) defines the lower end of the reflection free Bandwidth.</td></tr>
<tr><td>Reduction of resolution</td><td>For easier interpretation, the frequency resolution is reduced to any desired value. (e.g. 1/12th octave bands)</td></tr>
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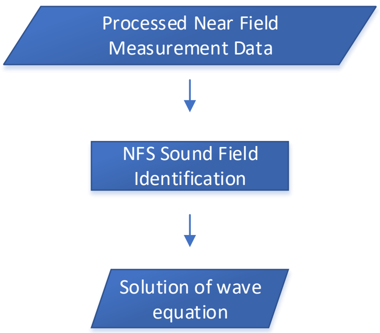
9 NFS Sound Field Identification

<table>
<tr><td>Target</td><td>The Sound Field Identification processes the measured near field data to fit solution of the wave equation which describes the free field sound radiation of the sound source.</td></tr>
<tr><td>Sound Field Identification</td><td>


The sound field is identified as a weighted sum of spherical waves, which are built up by spherical harmonics $Y_n^m(\theta,\phi)$ multiplied with Hankel functions $h_n(kr)$ 14.1, solving the wave equation.

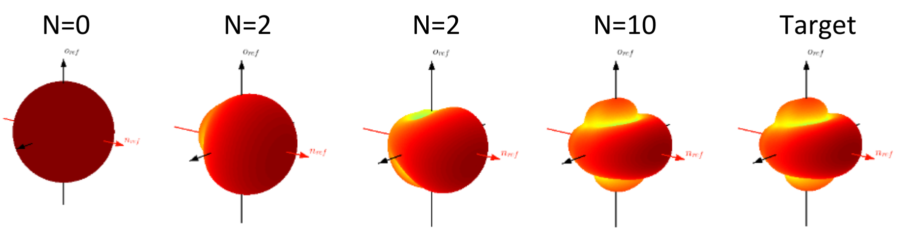
$$p(r,\theta,\phi,\omega) = \sum_{n=0}^{N} \sum_{m=-n}^{n} C_{nm}(\omega)\, h_n(kr) \cdot Y_n^m(\theta,\phi)$$

A set of parameters $C_{nm}(\omega)$ is calculated which, used in the above equation, corresponds with the measured sound pressure in the near field.

Any near field or far field sound pressure, calculated with this equation represents the free field sound pressure of the measured sound source as the equation is a valid solution of the wave equation.

The Order N describes the maximum order up to the module develops the sound field into spherical waves.

The more complex a sound field is, the more orders of expansion are needed to fully describe it. The following example shows the sound field identification of the radiated sound field of a loudspeaker at 2kHz. As seen in the picture, the sound field is completely characterized by spherical harmonics up to order N=10.



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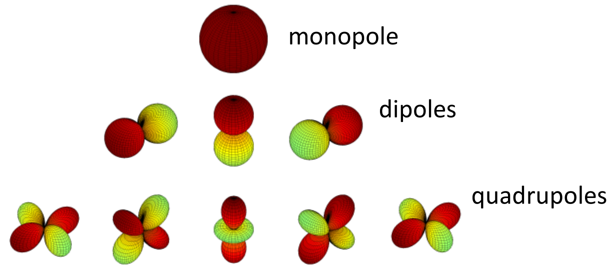
Spherical Harmonics

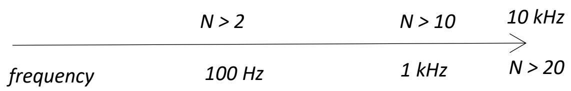
The key elements of the solution of the wave equation are the spherical harmonics. They represent the trivial solutions of the wave equation widely known as monopole, dipole, etc.



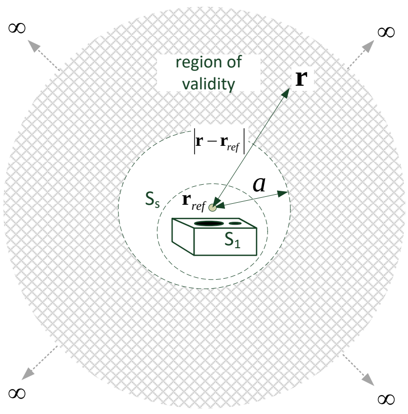
As these spherical harmonics are orthogonal, the superposition of these elementary solutions also solves the wave equation.

Using this solution, the comprehensive radiation characteristic of a sound source can be represented by a set of coefficients C_{nm}. Because typical loudspeakers only have a limited complex sound field, it is possible to characterize their sound field by a limited number of coefficients.

Depending on the frequency, a typical minimum order of expansion is needed to characterize the sound field



Sound field extrapolation



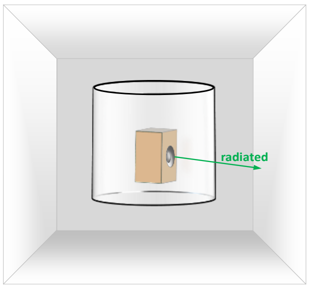
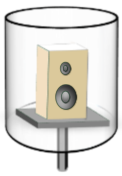
Under the assumption that all sound sources are inside the scanned surface with a minimum radius a (free field conditions), the wave equation completely defines the outgoing sound pressure field at any point outside the scanning surface.

This area defines the region of validity of the comprehensive radiation data set, representing the outgoing sound waves

9.1 Identification modes: Standard Sound Field Identification

The Standard Sound Field Identification is processing measurements on a closed surface around the sound source in the near field. A solution of the wave equation is calculated to match the measured transfer behavior of all points.

The measurement close to the sound source provides a high level of direct sound which dominates the total sound pressure. Thus reflections or room resonances of an imperfect measurement room have a minor influence. This allows high accuracy measurements in large or anechoic rooms. In small reverberating rooms the bandwidth is limited to high frequencies.

Field Identification		The Sound Field Identification is based on the measured sound on a single surface around the sound source. This is fitted to a single sound source located within the scanned surface. In this mode, no external sound sources or reflections are regarded, and will lead to lower accuracy measurement, if dominant.
Measurement Grid	Single Layer 	Scanning is done on a complete three dimensional cylindrical surface. The grid is generated automatically, it just requires the upper/lower borders and the radius of the cylinder.
Application	**This mode is suited for measurements in anechoic conditions or large rooms, where the direct sound dominates the measured sound pressure over reflected sound.**	
Typical Measurement Bandwidth	Anechoic Chamber	10Hz – 20kHz
	Small Room (3m x 3m x 3m)	2kHz – 20 kHz

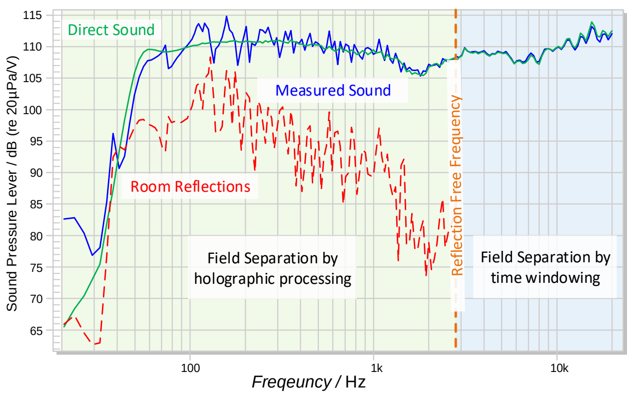
9.2 Identification modes Input/Output Field Separation

Requires Module: 2520-012 Direct Sound Separation

Performing a measurement in a small or reverberant room, the influence of the room cannot be neglected. For high frequencies windowing techniques can be applied, but not for low frequencies.

The Direct Sound Separation approach solves this issue providing a separation of the radiated sound from the reflections and room resonances.

This method is useful for low frequencies (below 1 kHz) where windowing techniques cannot be applied. In such frequency bands, even in well-built anechoic rooms, room modes build up. The measurement is automatically merged with results using the windowing technique, to acquire data of highest precision.

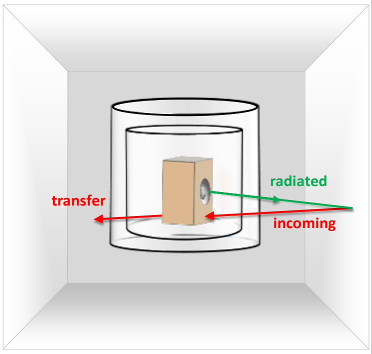


Measured sound (blue): Microphone signal measured in the near field. It is separated into radiated and transferred sound.

Radiated Sound (green solid): Part of the sound which is radiated from the measured DUT.

Transferred Sound (red dashed): Part of the sound which originates from sources outside the scanning surface (e.g. reflections, room modes)

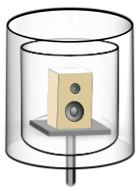
Field Identification



The Direct Sound Separation uses a double layer Scanning for identifying the direction of the sound waves. The Sound Field is fitted to a single sound source in the scanned surface and reflected sound passing through the scanned surface. Thereby radiated sound of the speaker is separated from reflected sound in the room (room modes). This powerful method allows a directivity measurement under non-anechoic conditions.

Measurement Grid

Double Layer



Scanning is done on two nested three dimensional cylindrical surfaces.

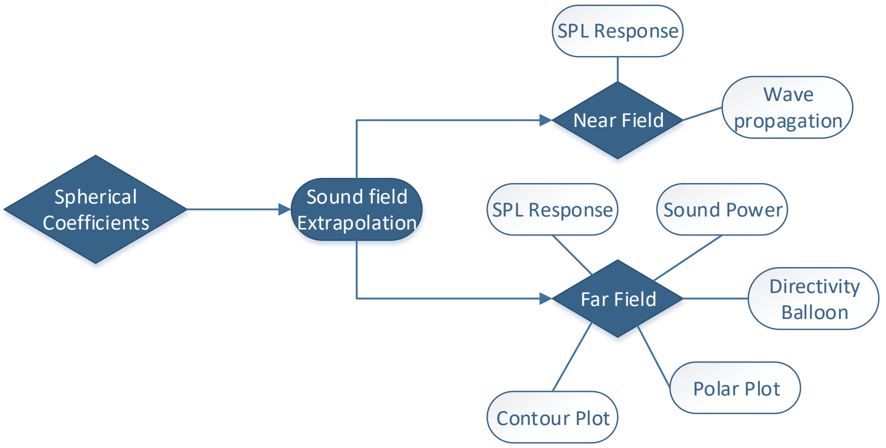
The grid is generated automatically, it just requires the upper/lower borders and the radius of the inner cylinder.

Application	**This mode is suited for measurements in all kind of rooms. Good results are reached in small and reverberant rooms.**	
Typical Measurement Bandwidth	Anechoic Chamber	10Hz – 20kHz
	Small Room (3m x 3m x 3m)	10Hz – 20 kHz

10 NFS Visualization

The NFS Visualisation provides the extrapolation of the free field sound radiation characteristic from the solution of the wave equation. A wide set of analysis tools is provided, structured into various addon modules.

Overview



10.1 Standard NFS Visualization

Far Field Analysis, included in Near Field Scanner System (Art.#2520-010)

The Standard NFS Visualization Software provides a classical far field 3D directivity analysis of a sound device. It includes the most common far field visualizations like Frequency Response, Sound Power, Contour Plot, Polar Plot and Directivity Balloon. All plots are freely configurable using parameters like distance, angle resolution, etc.

Application	3D Directivity Analysis in the Far Field (e.g. for Professional Systems)

Coordinate Definition

Using the comprehensive data set of the Field Identification the far field characteristics can be calculated freely by:

- Radius
- Angular Resolution
- Phi (Circular Angle)
- Theta (Polar Angle)

Linear Scaling

Reference Voltage:

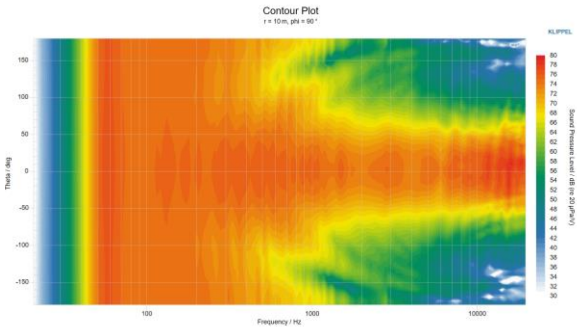
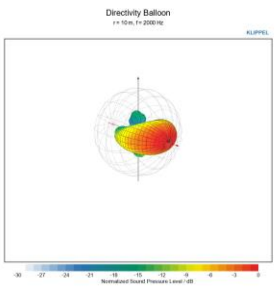
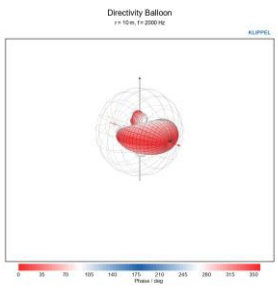
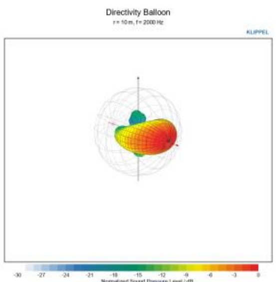
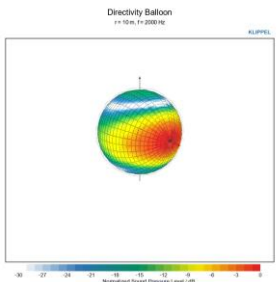
Per default the Visualization is showing transfer function which are related to 1 V_{rms}. In order to display the measured SPL output of a device. A reference voltage (e.g. 2.83V) can be defined. All graphs are scaled linear with this voltage.

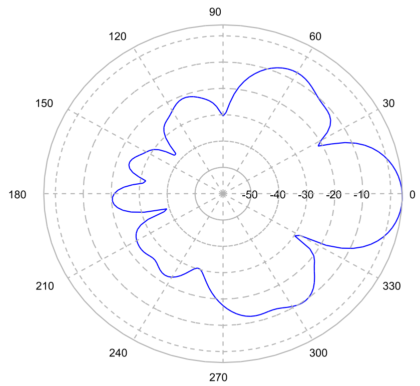
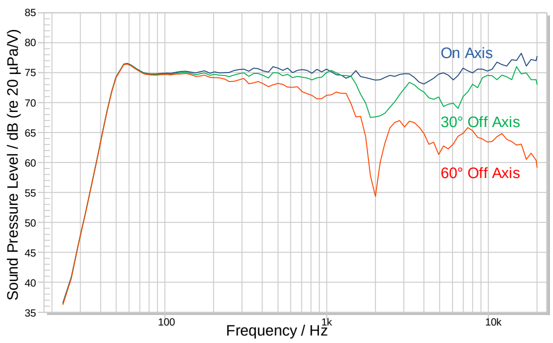
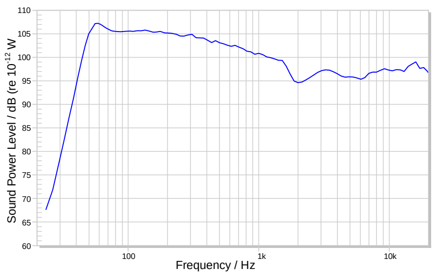
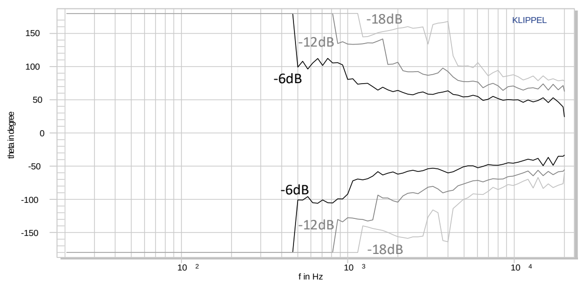
Reference Distance:

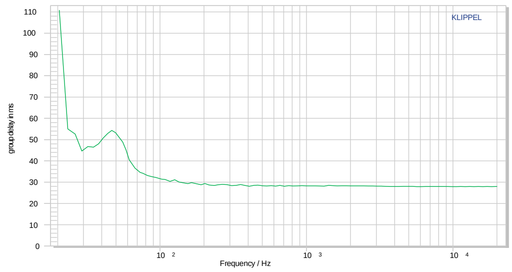
To compare data of different devices, it is useful to scale measurement results to a standard distance (e.g. 1 m)

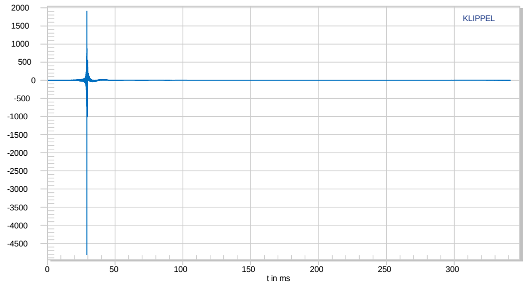
Using the 1/r law, this parameter scales magnitude and phase of all graphs to the specified reference distance.

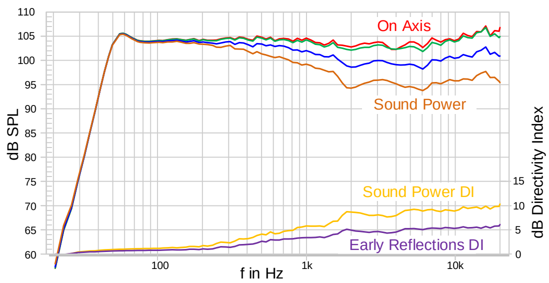
$$\underline{H}(f,r_2,\theta,\phi)=\underline{H}(f,r_1,\theta,\phi)\frac{r_1}{r_2}e^{-jk(r_2-r_1)}$$

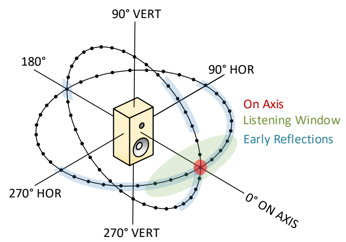
Frequency Spacing & Smoothing	Selection of the displayed frequencies. This can be: • Original (calculated Frequencies of Field Identification) • ISO Frequencies (e.g., R10, R80) • Custom (User Defined Resolution in pts./oct.) Based on the original frequency resolution, the displayed data points will be interpolated. In addition, a user defined smoothing (e.g. 3 pts./oct.) can be applied to all result curves.
	The plot provides a directivity analysis over the full audio band. It shows very clear how the directivity changes over frequency and at which Frequency the first side lobes appear.  Specified parameters: • Radius • Phi angle • Angle Resolution
Directivity Balloon	Plot shows the 3D far field directivity pattern vs. theta (polar) and phi (azimuth). The color map of the graph can visualizes magnitude or phase in different view options as a balloon or a spherical plot. Specified parameters: • Radius • Frequency • Angle Resolution **Color representations:**  *Sound Pressure Level*  *Phase* **Display Options:**  *Balloon*  *Sphere*

Polar Plot (2D directivity pattern vs. polar angle)	Using a polar coordinate system the 2D directivity over theta is visualized. This provides a fast analysis of the frequencies with distinct lobes in the directivity pattern.  Specified parameters: • Radius • Phi angle • Angle Resolution • Frequency
SPL Response	The far field SPL curve shows frequency behavior at the specified Point. (e.g. in main radiation direction)  Specified parameters: • Radius • Phi Angle • Theta Angle • Frequency
Radiated Sound Power	Most comprehensive single value representation of the radiation characteristic, that shows the total amount of sound energy which is emitted by the loudspeaker. 
Beamwidth	Beamwidth visualizes at which radiation angle the SPL is down by a specific value (e.g. 6dB) compared to the On-Axis-SPL.  Specified Parameters: • Radius • Angle Resolution • Phi Angle • dB decrement

<table>
<tr><td>Group Delay</td><td>By calculating the slope of the phase response, the group delay show deviation of the propagating time over the full frequency band.


Specified parameters:
Radius
Phi Angle
Theta Angle</td></tr>
<tr><td></td><td>Transforming the complex transfer function back into time domain, the Impulse Response at any point in 3D space can be extrapolated.


Specified parameters:
Radius
Phi Angle
Theta Angle</td></tr>
<tr><td>CEA 2034</td><td>This graph shows selected frequency responses defined by the ANSI/CEA 2034 standard, which characterizes the performance of the loudspeaker in a normal listening room.




</td></tr>
</table>

Standard Export Interface

(only Magnitude)

The Export is an open interface for far field data. It creates a complete set of far field data for the transfer to external software. All data is exported in common formats like ASCII (compatible to VACS), binary SCILAB and binary MATLAB.

ASCII-Export (compatible to VACS)

The ASCII-export provides the export in the common text format. For each point a separate file is written. The data format is compatible to the VACS import. Each file consists of two sections the file header, which defines the coordinates and data format, and the measurement curve.

Header:

Coordinates

```
Param_Coord_x1     = <Raduis>
Param_Coord_x2     = <Phi>
Param_Coord_x3     = <Theta>
Param_Coord_Type   = Spherical
Param_Coord_AngularFormat=degree
```

Orientation

```
Param_Coord_Front = [<Phi>,<Theta>]
Param_Coord_Top   = [<Phi>,<Theta>]
```

Data-Section

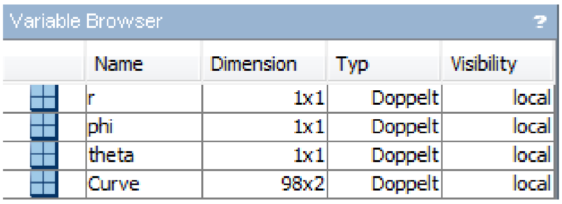
```
Data_Format = LeveldB
Data_Domain = Frequency
Data_LevelType=SoundPressure
```

Curve:

```
Curve=[
f1      SPL(f1)
f2      SPL(f2)
f3      SPL(f3)
 :       :
];
```

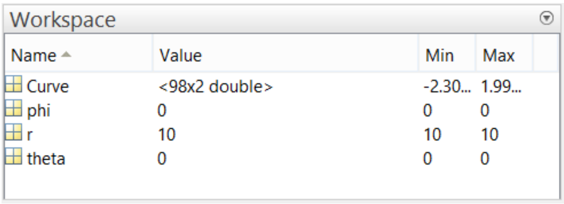
SCILAB-Export

The SCILAB export creates for each point a binary SCILAB file (.bin) with the following variables.



MATLAB-Export

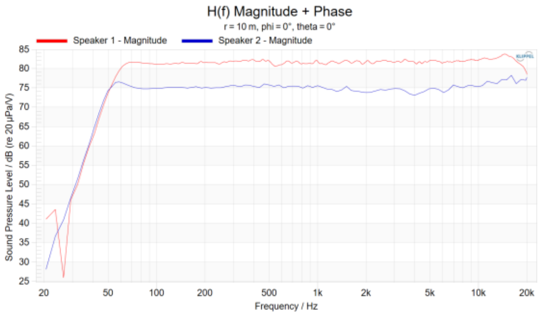
The MATLAB export creates for each point a binary MATLAB file (.mat) with the following variables.



Data Comparison

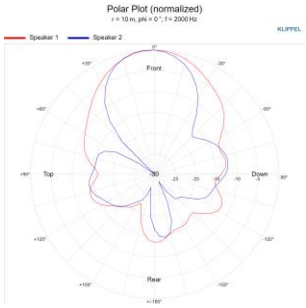
(Art#: 2520-015)

For an easier comparison of different measurements, the NFS Visualization can import two set of holographic coefficients and visualize them simultaneously. In this mode all 2D graphs are showing curves for each speaker and all 3D and color graphs are doubled.



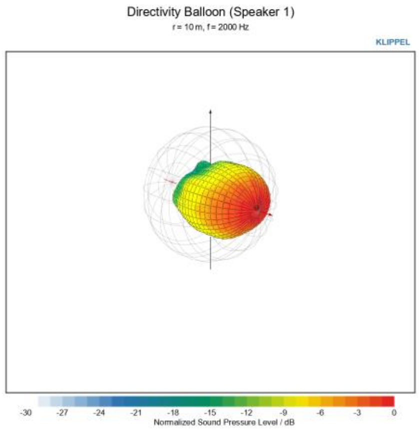
Red Curve – Speaker 1 (On-Axis)

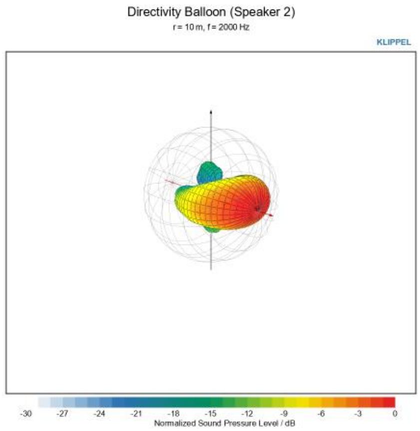
Blue Curve – Speaker 2 (On-Axis)



Red Curve – Speaker 1 at 2kHz

Blue Curve – Speaker 2 at 2kHz

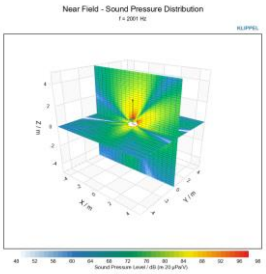
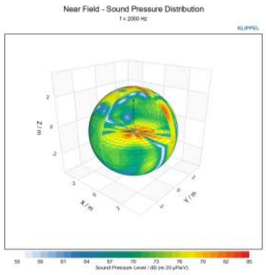
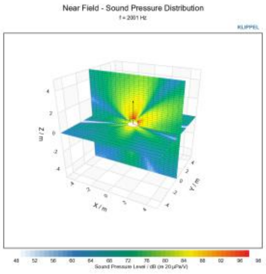
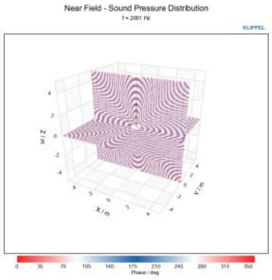
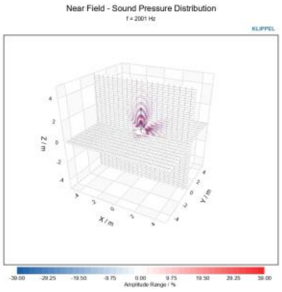
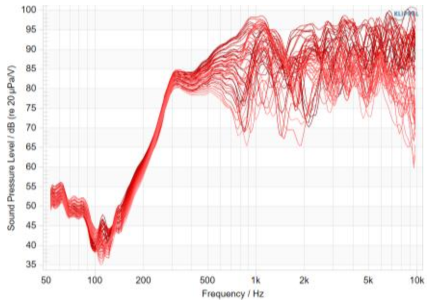
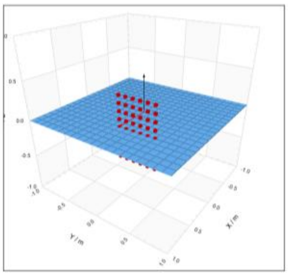




10.2 Add-On Module: Near Field Analysis

Art#: 2520-013

The module provides 3D sound field analysis in the near field of a sound device. At each position around the DUT key features like sound pressure frequency response, spatial sound pressure distribution can be visualized.

<table>
<tr><td>Application</td><td>3D Radiation Analysis in the Near Field
(e.g. for Studio Monitors, Laptop, Smart Phones, etc.)</td></tr>
<tr><td colspan="2">Features</td></tr>
<tr><td>Near Field – Sound Pressure Distribution</td><td>The spatial distribution of the radiated sound pressure field versus distance in the plane is visualized in 3D.
Surface Selection:

Cube

Sphere
Specified parameters of the surface:
• Shape
• Position
• Size
• Spatial resolution
Visualization Types:

Sound Pressure Level

Phase

Sound wave</td></tr>
<tr><td>Near Field – Frequency Response
(Magnitude and Phase vs. frequency at arbitrary points)</td><td>The output shows the frequency behavior of the sound field at chosen positions.

Specified parameters:
• 3D coordinates of listening points

•</td></tr>
</table>

10.3 Add-On Module: Complex Data Export

Art#: 2520-016

The complex data export module provides an export interface to common external software like EASE with full complex response data. In addition, the module includes advanced far field analysis of the exact phase behavior of the sound source. Features like phase balloon, group delay, reconstructed impulse response visualized the sound field.

Phase Export

In Addition to the Standard Export, the module provides the export of phase information. Using the interface, a complete set of far field data (magnitude and phase or impulse responses) can be exported to external software like EASE or VACS. All data is exported in common formats like ASCII, binary MATLAB and binary SCILAB.

VACS (ASCII)

The VACS format is a common text format. For each point a separate file is written. Each file consists of two sections the file header, which defines the coordinates and data format, and the measurement curve.

Header:

Coordinates

```
Param_Coord_x1     = <Raduis>
Param_Coord_x2     = <Phi>
Param_Coord_x3     = <Theta>
Param_Coord_Type   = Spherical
Param_Coord_AngularFormat=degree
```

Orientation

```
Param_Coord_Front = [<Phi>,<Theta>]
Param_Coord_Top   = [<Phi>,<Theta>]
```

Data-Section

```
Data_Format = LeveldB_Phase
Data_Domain = Frequency
Data_LevelType=SoundPressure
Data_Phase_AngularFormat=degree
```

Curve:

```
Curve=[
f1      SPL(f1)         Phase(f1)
f2      SPL(f2)         Phase(f2)
f3      SPL(f3)         Phase(f3)
 :       :               :
];
```

EASE (ASCII)

The data export to EASE is supported using ASCII- files as well. The coordinates are committed by the file name. *(IRxxxxxx.txt)*

The numbers define the angles phi and theta.

For example:

phi=90, theta=10 → `IR090010.txt`

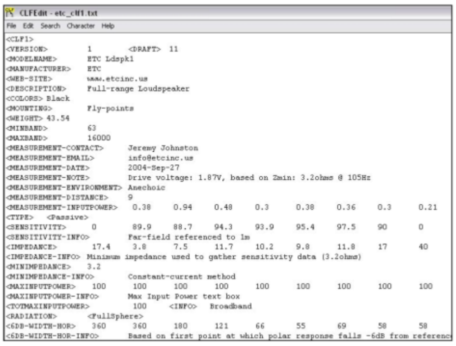
Each text file contains the measured curve of the point. Which can be an impulse response or a transfer function.

Content:

```
  f1     SPL(f1)    PHASE(f1)
  f2     SPL(f2)    PHASE(f2)
  f3     SPL(f3)    PHASE(f3)
   :       :           :
```

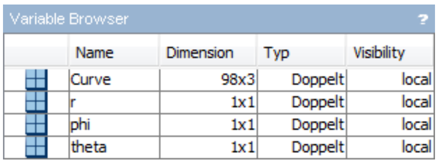
CLF (ASCII)

As well the common CLF text format is supported by the export interface.



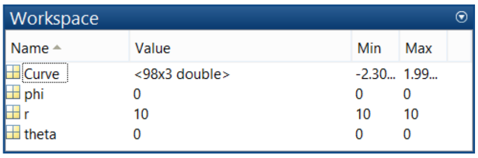
SCILAB-Export

The SCILAB export creates for each point a binary SCILAB file (.bin) with the following variables.



MATLAB-Export

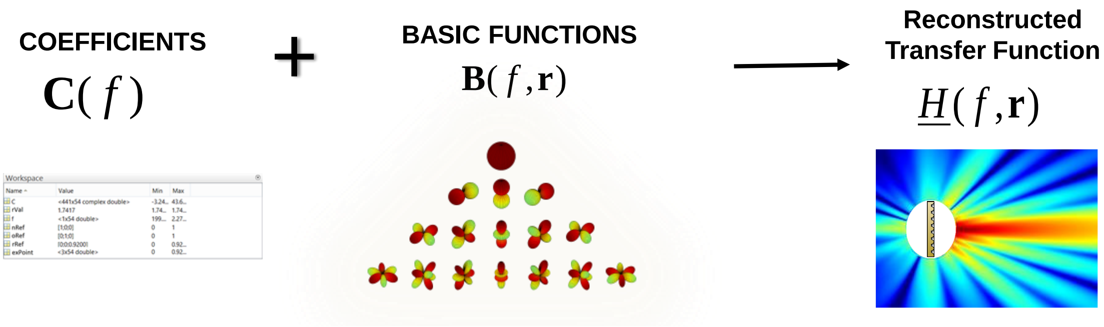
The MATLAB export creates for each point a binary MATLAB file (.mat) with the following variables.



10.4 Add-On Module: Holography Parameter Export

Art#: 2520-019

The Holographic Parameter Export module provides an export of the comprehensive sound field data. Based on this information the sound pressure level at any point outside the scanning surface can be calculated.



The export is available in common data formats like ASCII (.txt), Binary SCILAB (.bin) and Binary MATLAB (.mat).

The files contain the following data:

$\boldsymbol{C}_{nm}(f)$	- Coefficients of spherical wave expansion
r_{val}	- Radius of validity (m)
$\boldsymbol{r}_{\mathrm{ex}}$	- Expansion point (Vector with Cartesian coordinates) (m)
$\boldsymbol{r}_{\mathrm{ref}}$, $\boldsymbol{n}_{\mathrm{ref}}$, $\boldsymbol{o}_{\mathrm{ref}}$	- Reference System (Cartesian Coordinates in m)
$\boldsymbol{f}$	- Frequency Vector (Hz)

SCILAB

The SCILAB export creates a binary SCILAB file .bin with the following variables:

Variable Browser

Name	Dimension	Typ
C	441x54	Doppelt
exPoint	3x54	Doppelt
f	1x54	Doppelt
nRef	3x1	Doppelt
oRef	3x1	Doppelt
rRef	3x1	Doppelt
rVal	1x1	Doppelt

MATLAB

The MATLAB export creates a binary MATLAB file .mat with the following variables:

Workspace

Name	Value	Min	Max
C	<441x54 complex double>	-3.24...	43.6...
rVal	1.7417	1.74...	1.74...
f	<1x54 double>	199....	2.27...
nRef	[1;0;0]	0	1
oRef	[0;1;0]	0	1
rRef	[0;0;0.9200]	0	0.92...
exPoint	<3x54 double>	0	0.92...

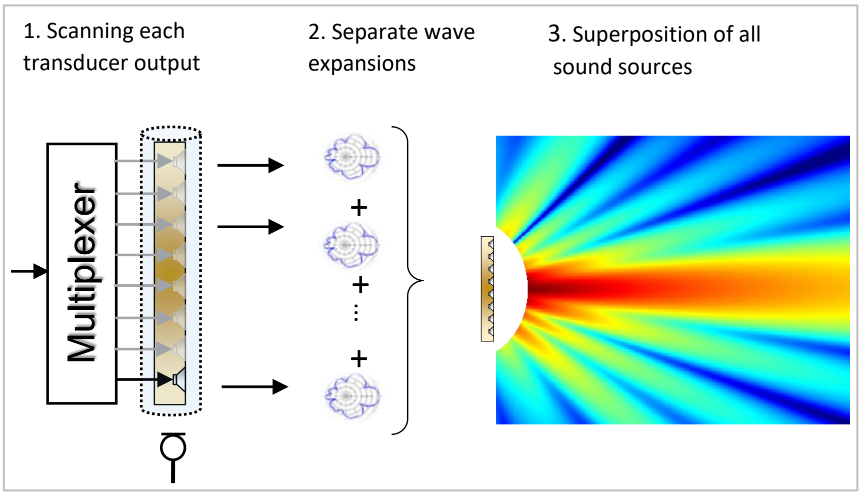
<table>
<tr><td>ASCII</td><td>The ASCII export creates a .txt file with the following content:

<pre>
Matrix of Coefficients: C=[
(Complex Matrix)   C00(f1)   C00(f2)   C00(f3)   … C00(fn)
                             C-11(f1) C-11(f2)   C-11(f3)   … C-11(fn)
                             C01(f1)   C01(f2)   C01(f3)   … C01(fn)
                             C-11(f1) C-11 (f2) C11 (f3) … C11(fn)
                                  :   :
                             CNN(f1)   CNN (f2) CNN (f3) … CNN(fn)
                            ];
Frequency Vector: f=[
                              f1   f2   f3   …   fn
                            ];
Validation Radius: rVal = radius;
Expansion Point: exPoint = [
                            x1 x2 x3 … xn
                            y1 y2 y3 … yn
                            z1 z2 z3 … zn
                            ];
Reference Point: rRef=[
                             x
                             y
                             z
                            ];
Reference Vector: nRef=[
                             x
                             y
                             z
                            ];
Reference Vector: oRef=[
                             x
                             y
                             z
                            ];
</pre>
</td></tr>
</table>

10.5 Add-On Module: Multi Source Superposition Module

Art#: 2520-017

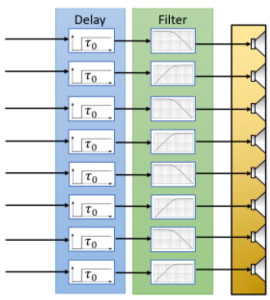
The module provides a convenient solution to measure large loudspeaker array and gaining more versatile and accurate directivity data. Each transducers of the line source is measured separately using a multiplexer (1) and is described by a separate spherical wave expansions (2). Finally all wave expansion are superimposed in the visualization software, determining the total sound pressure output of the device under test (3).



In addition to the analysis of the original sound field, the measured directivity data is an ideal basis for further simulation, because it includes acoustical effects (e.g. diffraction) of the loudspeaker cabinet as well.

Note: For automatic measurement of the individual transducers, it is recommended to performs the measurement with a Multiplexer [A8]

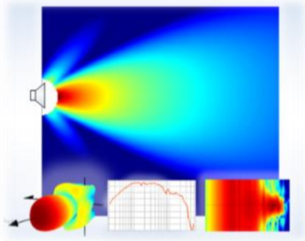
Applying a linear filter or a delay to the source data of each transducer, the beam steering of the device can be simulated.



11 Add-On Module: Baffle Measurement

Art#:2520-025, 2520-018

The 3D sound pressure output in half space (2π) of transducer and in wall speakers can be determined by using the Baffle measurement module. The sound field is measured on a hemi sphere in front of the baffle. The acoustical short cut and diffractions from the baffle's edges are compensated, providing accurate half space measurement data.



11.1 Baffle Hardware:

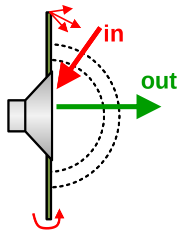
The Klippel Baffle Hardware combines a flexible light weight structure, which is simple to mount by a fast locking mechanism, with the high requirements for acoustical measurement. The vibration and buzzing of the structure is minimized to ensure accurate measurement results.

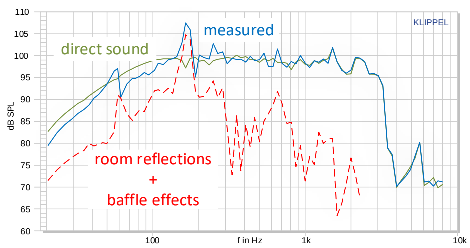
The construction has an additional inner plate for mounting any kind of transducer from µ-speakers to 18'' subwoofers.

11.2 Baffle Measurement Software

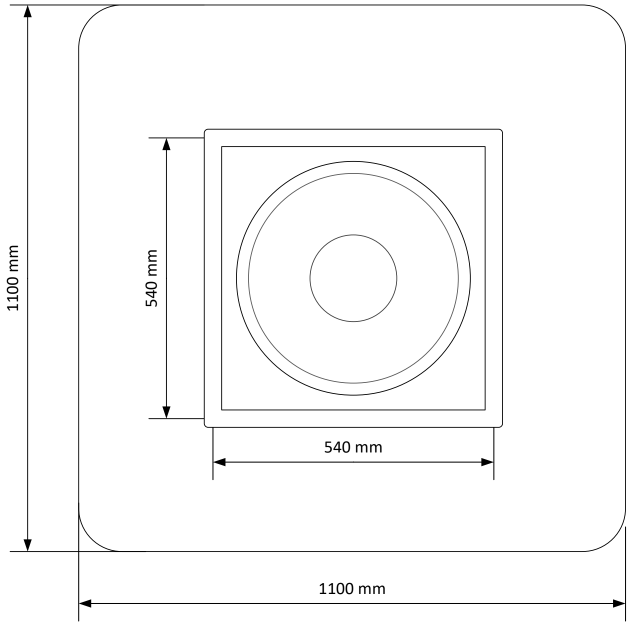
The Baffle measurement software acquires the sound pressure output by scanning on two hemispheres in front of the baffle. The edges of the baffle are outside the scanning surface and the acoustical short cut and diffraction effects are separated by Direct Sound separation from the direct sound of the transducer.

The sound pressure output of the device can be extrapolated and analyzed at any point in half space.





11.3 Physical Dimensions



Parameter	Min	Typical	Max	Unit
Baffle				
Width		1100		mm
Height		1100		mm
Total Height (mounted on NFS)		2500		mm
Weight		16.8		kg
Inner plate (for DUT mounting)				
Height		540		mm
Width		540		mm
Thickness	10	20	25	mm
Device under test				
Diameter			520	mm
Weight			50	kg

12 Applications

12.1 Line Array

Measurement

Line Array Segments are a very critical sound source to be measured in the near field. The critical characteristics are:

- Large Horns
- High directivity
- Complex Near Field

For a good measurement, a relatively far distance of 1m from the reference point is chosen as typical scanning radius.

Comparison

To show the potential of the NFS-Method, the results of this very complex Line Array segment are compared with the traditional state-of-the-art measurement.

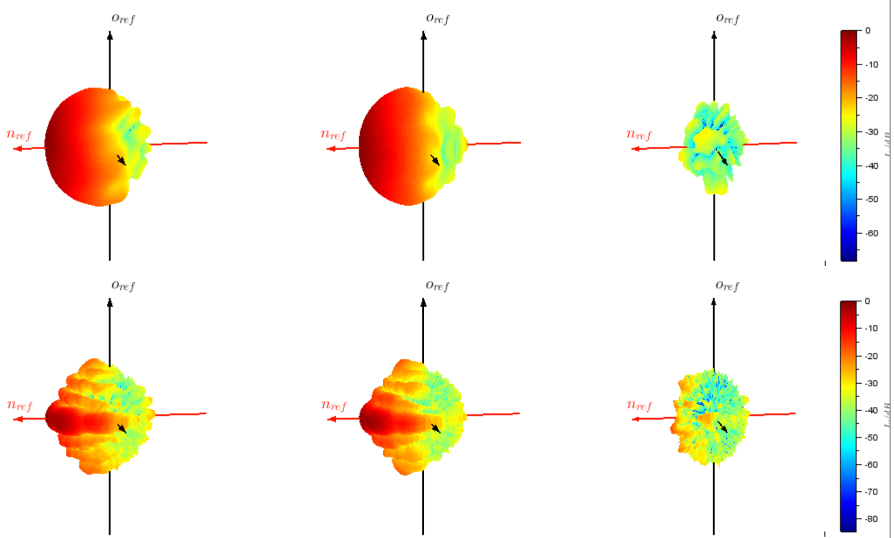
- Reference Measurement:
  - Traditional measurement (16000 points)
  - Anechoic chamber
  - 7m distance
- NFS Measurement (Klippel Near Field Scanner)
  - Near field Scan (4000 points)
  - Anechoic chamber
  - Sound pressure extrapolation to 7m distance

Balloon Plot

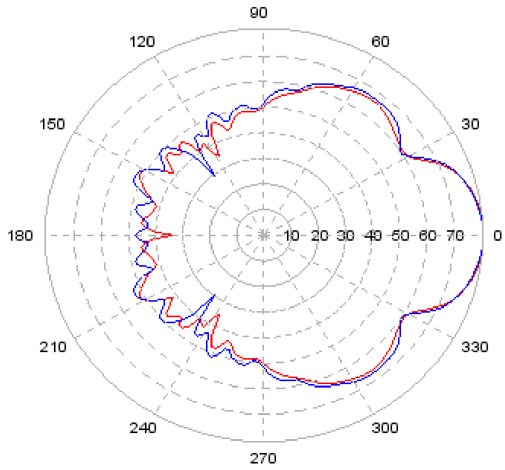
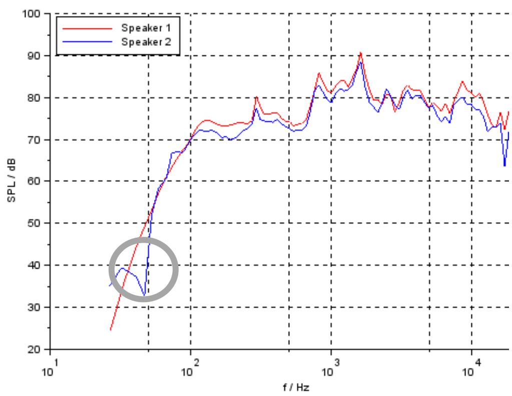
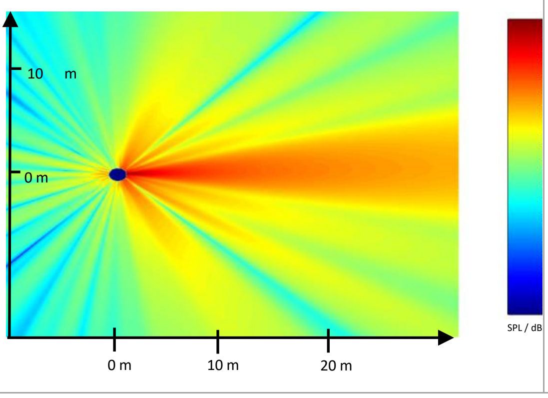
1 kHz

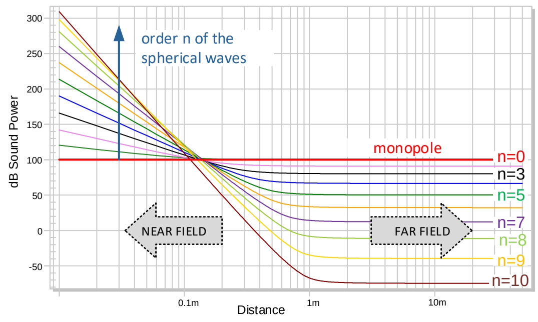
5 kHz

NFS Measurement | Reference Measurement | Difference



The measurements show a very little difference between NFS and Reference measurement. Especially in the most relevant main radiation direction the error is well below 20dB of the main lobes sound pressure

Polar Plot 2.5kHz		Comparison of the polar plot at 2.5kHz shows very low differences. Only on the back side, there are small differences, however 30dB lower in level then the On-Axis SPL. **- Red Curves** NFS Measurement **- Blue Curves** Reference Measurement
On-Axis SPL		The NFS Measurement reveals the inaccuracies of the anechoic chamber. Clearly visible are the room modes of the Reference measurement environment at 20Hz. **- Red Curves** NFS Measurement **- Blue Curves** Reference Measurement
SPL Distribution		SPL distribution over distance shows, how near field effects decay over distance. Near field effects decay very fast, however for complex sound sources they may reach into far distances.

<table>
<tr>
<td>Sound Power distribution</td>
<td>


</td>
<td>Distribution of the sound power over the order of the spherical wave shows the different near / far field border for spherical waves of specific order.

High order spherical waves have a very wide near field.

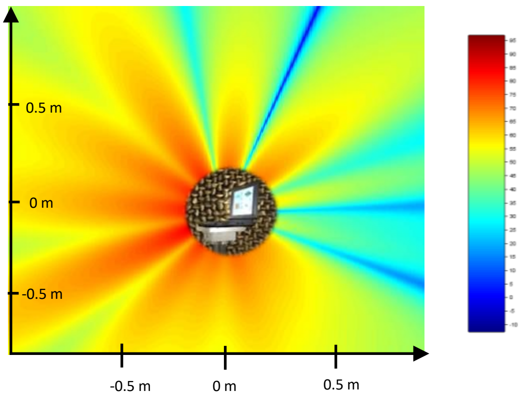
Hence a complex sound source with substantial sound power in high order spherical waves measured in 1m distance still shows near field effects in this distance</td>
</tr>
<tr>
<td colspan="3">

12.2 Notebook

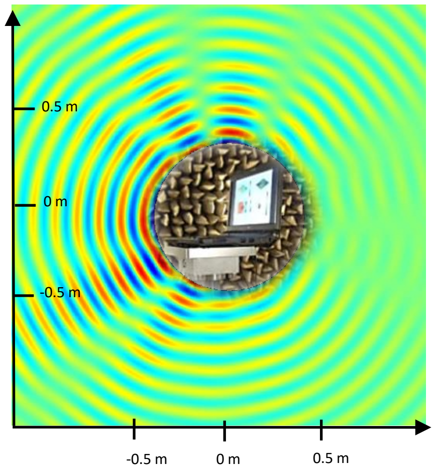
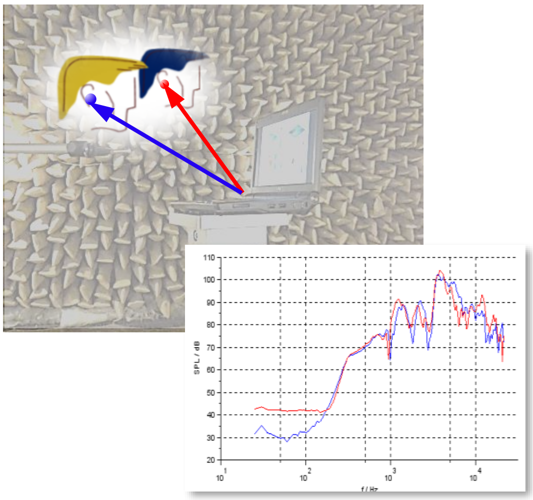
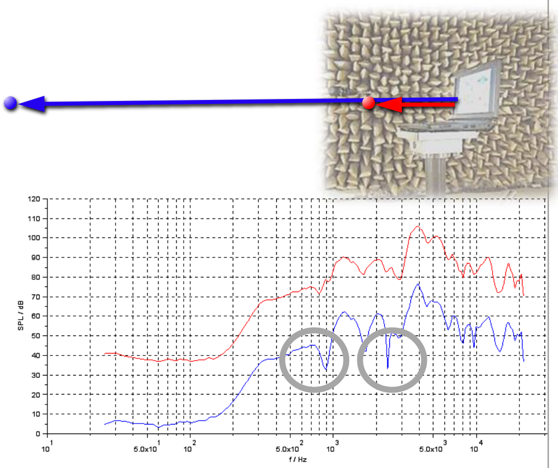
</td>
</tr>
<tr>
<td>Measurement</td>
<td></td>
<td>The Laptop is positioned on the Near field scanner.

The microphone is positioned on points on a surface around the device.

Measurement distance is chosen to be very close to the device so the region of validity reaches very close to the device.</td>
</tr>
<tr>
<td>Near Field SPL Distribution

(f=3.6 kHz)</td>
<td>


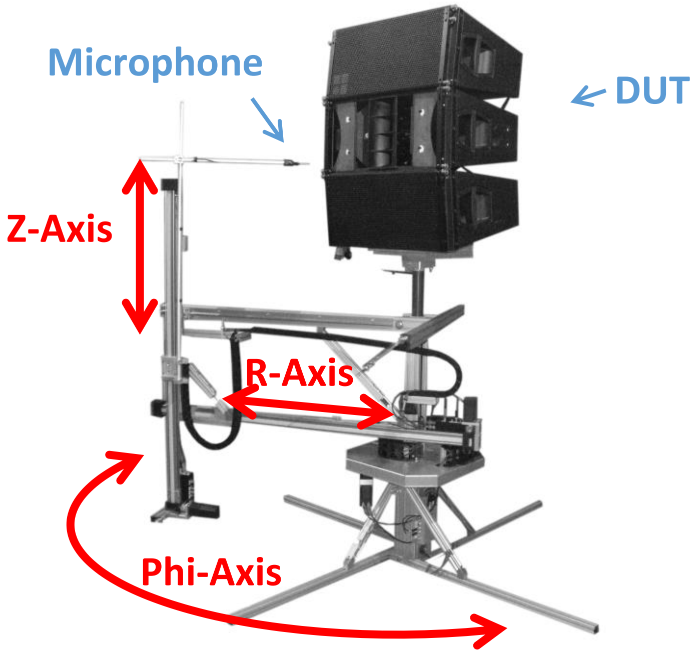
</td>
<td>The Near Field SPL Distribution reveals good and bad radiated areas in the near field.</td>
</tr>
</table>

Wave front animation (f=3.6 kHz)		Visualisation of the animated phase relationship shows the wave propagation in the near field. Clearly visible is the phase shift between neighbouring lobes which result in the steep nothes inbetween. Phase related differences in the near field are especially for binaural applications of specific interest
SPL Response at the Listening points		Once the sound field is identified, the SPL response at any desired position can be calculated. This listening position may be in the near or in the far field.
SPL Response Near Field and Far Field		Sound pressure may be very different between near and far field. Significant sound pressure notches in far field are not seen in near field. **- Red Curve** Near Field SPL Response (Distance 0.2 m) **- Blue Curve** Far Field SPL Response (Distance 10 m)

13 NFS Scanning System Hardware

The Scanning hardware provides a solid loudspeaker stand with a microphone positioning. The Loudspeaker will not move during the measurement placed on a stand solidly mounted on the ground. This enables the measurement even of heavy and hard to handle Loudspeakers.

- Loudspeakers heavier than 100kg are required to be measured hanging on a crane, using the Stand for positioning
- Any Loudspeaker is required to be placed with its center of gravity within a 250mm radius of the stands center



13.1 Safety Requirements

Please operate the device only in a separate room or a fenced area, which prevents from any untrained person having access to the machine during the measurement. Any person operating the device must be trained in handling the risks, related to the operation of this device:

- Risk of stumbling
- Risk of hand injury
- Risk of hearing damage

The device must be mounted to the floor and requires regular checks for any damage or loosened parts. Heavy DUTs must be properly mounted on the platform (if necessary by crane) to avoid any danger from the DUT falling off.

14 References

14.1 Related Modules	[1]. S7 Transfer Function Measurement TRF [2]. H3 Klippel Analyzer 3 [3]. C12 SCN Near Field Add-On [4]. A8 Multiplexer
14.2 Application Notes **14.3 Standards**	[5]. AN70 Directivity of Speaker Arrays [6]. ANSI/CEA-2034: "Standard Method of Measurement for In-Home Loudspeakers",2013, Consumer Electronics Association [7]. IEC 60268-21: "Sound system equipment – Part21: Acoustical (output-based) measurements", 2018, International Electrotechnical Commission
14.4 Papers	[8]. Jörg Panzer : „VACS - Import Control Settings Part 1-3" http://www.randteam.de/VACS/VACS-Docs.html [9]. Earl G. Williams: "Fourier Acoustics: Sound Radiation and Nearfield Acoustical Holography", 1999, ACADEMIC PRESS [10].Olson/Feistel :"Loudspeaker Device File Formats for EASE 4.0 "http://ease.afmg.eu/index.php/documents.html

15 Patents

Germany	102013000684
USA	14/152,556
China	2014100795121

Find explanations for symbols at:

http://www.klippel.de/know-how/literature.html

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