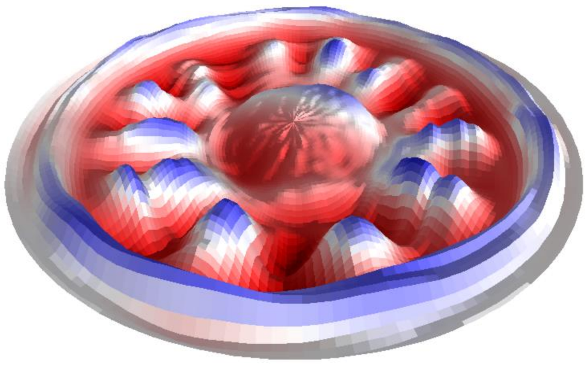
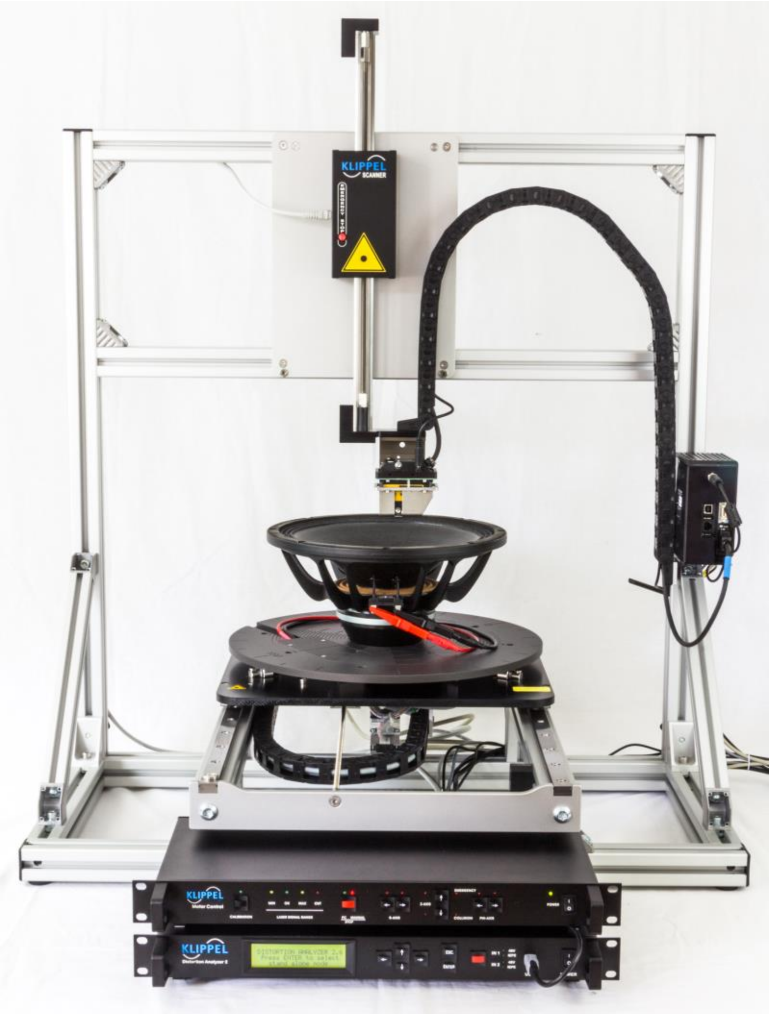
Scanning Vibrometer C5

Hardware and Software Module of the KLIPPEL ANALYZER SYSTEM (Document Revision 2.1)

FEATURES

- Measures geometry and mechanical vibration of the transducer
- Visualizes the vibration behavior
- Shows contribution to sound pressure output
- Predicts directivity pattern
- Separates radial and circular modes
- Analyzes actively radiating cone regions
- Detects loudspeaker defects



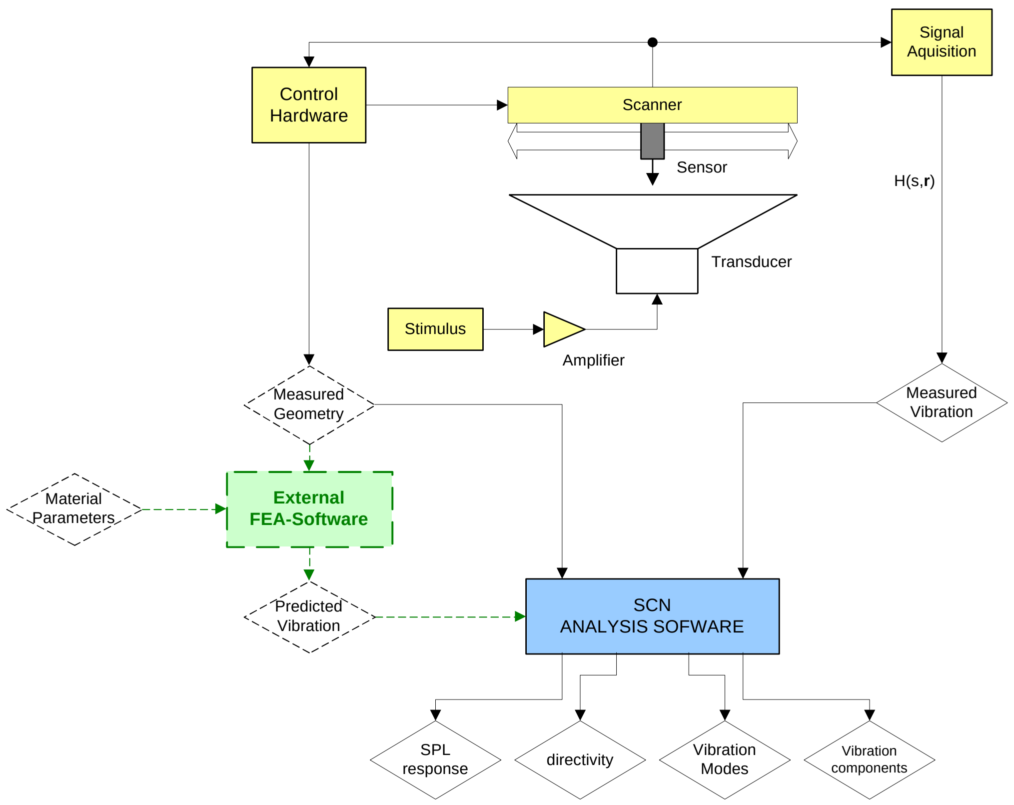


The Scanning Vibrometer (SCN) performs a non-contact measurement of the mechanical vibration and the geometry data of cones, diaphragms, panels and enclosures. One rotational and two linear actuators (ϕ, r, z) move a laser displacement sensor over a user-defined grid. At each measurement point the transducer is excited by a stimulus giving sufficient spectral resolution and high SNR in the measured response over the whole audio band (< 25 kHz). The collected data can be analyzed within the SCN software or exported to other FEA/BEA applications for further processing. Modern techniques of image processing are used for enhancing relevant information, suppressing noise and animating the vibration as a stroboscopic video. The sound pressure output in the far field and the directivity pattern are calculated and the contribution of each vibrating point on the vibrating surface is visualized. The software indicates critical vibration pattern and uses decomposition techniques for separating radial and circular modes.

Article Numbers:	2510-001	SCN Vibrometer
	2510-010/2510-011 (USB Dongle)	SCN Analysis Software
	2510-020	SCN Import/Export Interface
	2510-030	SCN Radiation Area SD
	2510-040	SCN Sound Power / Directivity

CONTENT

1 Principle

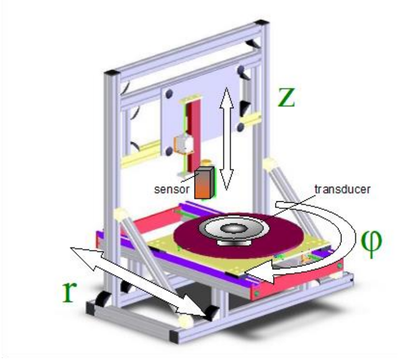
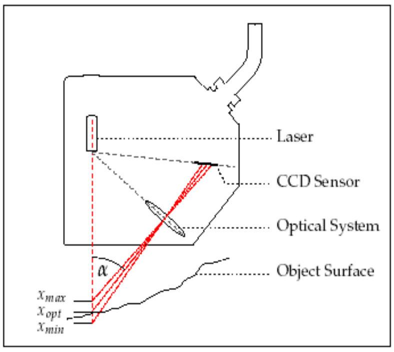


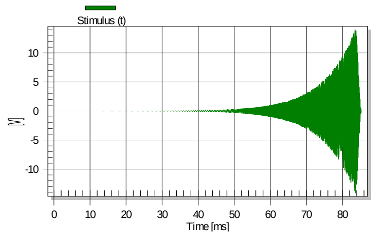
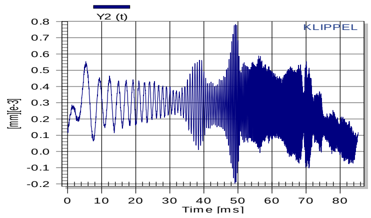
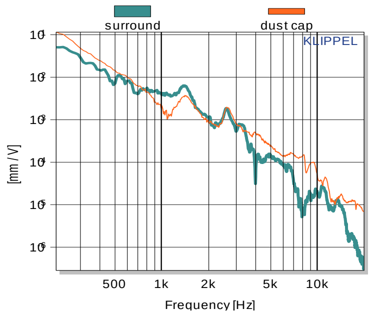
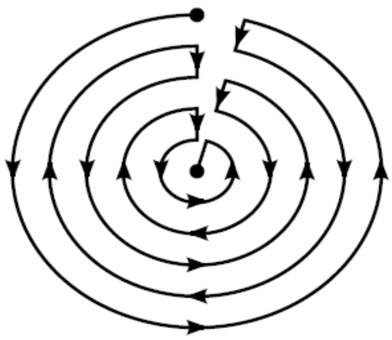
The **SCN Vibrometer** is dedicated to loudspeakers, micro-speakers, headphones and other electro-acoustical or electro-mechanical transducers. The Vibrometer uses standard modules of the KLIPPEL R&D System such as a displacement triangulation laser sensor, the Distortion Analyzer DA2 and the Transfer Function Module (TRF) to excite the loudspeaker under test with a pre-shaped sweep and to perform the signal acquisition and spectral analysis. The scanning hardware uses a turntable with two additional linear actuators and control hardware to scan the target surface in polar coordinates.

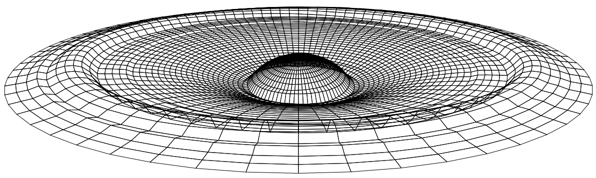
The scanning vibrometer provides vibration data and the cone geometry to the **SCN Analysis Software** which performs visualization, animation of the mechanical vibration and the prediction of the sound pressure output at any point in the half-space sound field. Novel decomposition techniques show radial and circular modes and vibration components related to the SPL output. It is the target of the analysis to provide a better understanding of the interaction between vibration and radiation.

The **SCN Import/Export Interface** (an add-on of the KLIPPEL Scanning Vibrometer) provides the measured cone geometry and vibration data for further processing with any third-party software. This may be useful to check the geometrical variations in quality control and to investigate design choices by performing a vibration and radiation analysis based on FEA or BEA. The material parameter measurement module MPM of the KLIPPEL R&D Software provides the E modulus and loss factor of the cone and suspension material.

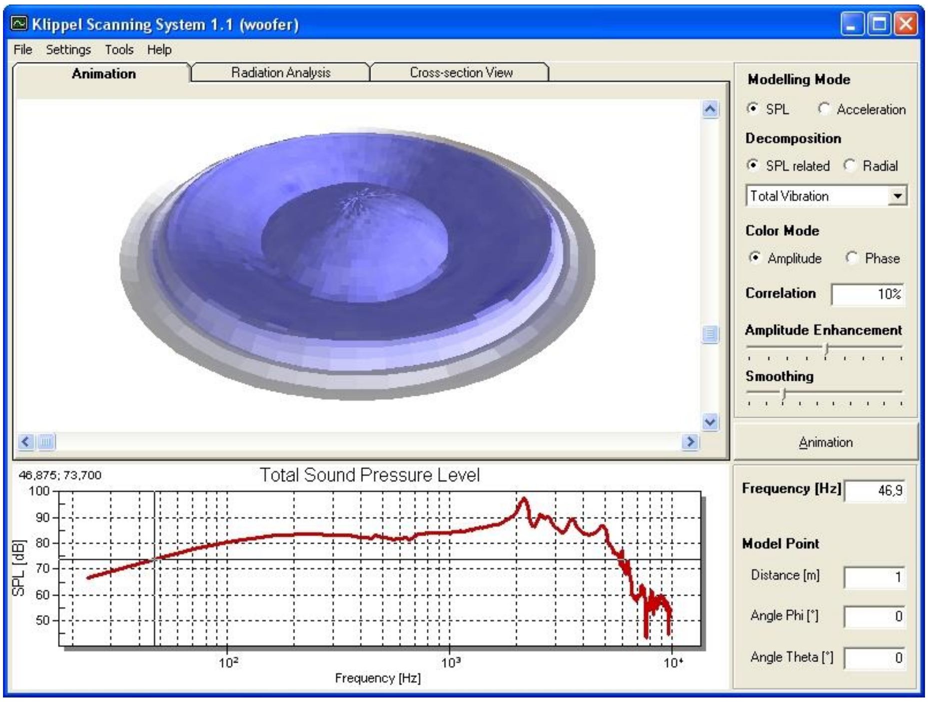
2 SCN Vibrometer

3D Scanner	 Mechanical scanning system with one rotational (ϕ) and two linear actuators (r, z).	Most electro-acoustical transducers use a single motor which excites the diaphragm, cone or panel in one direction (z dimension). Thus the measurement of the displacement in this direction can be accomplished by using a displacement sensor scanning 2 dimensions (radius r and angle ϕ) of the target surface. The transducer under test is rotated by a turn table (ϕ coordinate) and shifted by a linear actuator (r coordinate). An additional actuator is required to adjust the laser to the optimal distance V_d in the z dimension.
Motor Control		The Motor Control is the hardware control unit for the 3D Scanner. Connecting a computer via USB-interface the Scanning and Visualization Software (SCN) can be used to control the unit and gather measuring results for the following visualization. The integrated microprocessor provides state information of the Scanning Hardware for the software and controls the 3 build in stepper motor drivers for actuating each agitation axis.
Displacement Sensor	 Displacement sensor based on the triangulation principle	Optical measurement of loudspeaker cone vibration (scanning vibrometry) can also be accomplished by using Laser triangulation technique which is a cost effective alternative to Doppler interferometry. Since triangulation sensors provide primarily displacement, advanced signal processing is required to measure the break-up modes up to 25 kHz at sufficient signal to noise ratio. The voice coil displacement decreases with 12 dB per octave above resonance frequency where the mass is dominant. Thus a sinusoidal sweep with constant voltage generates $x_{peak}(f_s)$= 1mm at the resonance frequency f_s = 20 Hz but would produce only 10^{-6} mm (1nm) peak displacement at 20 kHz.

Shaping of the Stimulus	 Shaped logarithmic sinusoidal sweep  Averaged displacement signal	The decay of the displacement above resonance frequency can be compensated by using a stimulus where the higher frequency components are emphasized inversely. The amplitude is not constant but rises quadratically with frequency from 0.1 mV up to 10 V rms. Repeating the measurements with the same stimulus 2^n times and averaging the measured displacement responses will improve the signal to noise ratio by 3*n dB. Due to the shaping of the stimulus the displacement at the resonance (about 100 Hz) is in the same order of magnitude (about 0.5 µm) as at high frequencies. The noise floor stays at 5nm giving sufficient signal to noise ratio (> 40 dB)
Displacement Transfer Function	 Transfer function |Hx(s)| measured at the dust cap and at the surround	Due to the shaping of the stimulus the output signal of the triangulation laser corresponds with the acceleration of the target point. Since the shaping is not relevant for further analysis it is more convenient to calculate the transfer function $H_x(s,r)=X(s)/U(s)$ by referring the displacement X(s) to the voltage U(s) of the stimulus (0dB=1mm/V).
Grid and scanning path	 The scanning starts at the outside rim and proceeds inwards.	The target is scanned in polar coordinates (r, φ) due to the turntable and the radial actuator used. The grid can be generated automatically or manually to provide sufficient resolution at areas of particular interest. The scanning process can be performed in sequential steps a) profile scan at constant angle φ (50 points) b) explore scan (450 Points) c) detailed scan (3200 Points)
Scanning Modes	The height of the laser sensor is automatically adjusted during the scanning process according to the following modes • Normal Scan In this mode the optimal height of the laser head is calculated	

	from the geometry of the target object identified during the scanning process. In this mode the laser follows the slope of the cone profile and makes it possible to measure a dust cap which is at a much lower position than the surround. This mode assumes that the cone angle is lower than 60 degree and there are no steps larger than 20 mm. This mode works for most transducers and is recommended for woofer systems. • Flat Scan In this mode the vertical position of the laser head is not changed during the scanning. This mode gives the highest accuracy in measured geometry. It is recommended for tweeters, micro-speakers, panels where the geometry varies less than 10 mm. • Floating Scan In this mode the vertical position of the laser will always stay above a minimal value. This mode is required to measure the vibrations of transducers operated in a vacuum chamber where a glass plate is placed between target and laser head. Furthermore the specification of certain dangerous scanning radii can be used to locate critical spots on the cone for the normal and floating scanning mode. At these dangerous radii the vertical position of the laser will only be adjusted to absolutely safe values.
Geometry Measurement	A particular scanning mode is provided for measuring the geometry only. Hereby no excitation of the transducer is required and the total measurement time can be significantly reduced. 
Configuration	The SCN Vibrometer comprises the following components: • 3D Scanner (3 actuators move the displacement sensor in polar coordinates) • Scanning Control Hardware • Scanning Control Software • Cables Other modules of the KLIPPEL R&D SYSTEM • Laser-DisplacementSensor (see A2 Laser Displacement Sensor) • Distortion Analyzer DA2 • TRF Transfer Function Module Additional equipment: • Power Amplifier

3 SCN Analysis Software



The SCN Analysis Software is optimized for the visualization of the vibration data of loudspeaker cones.

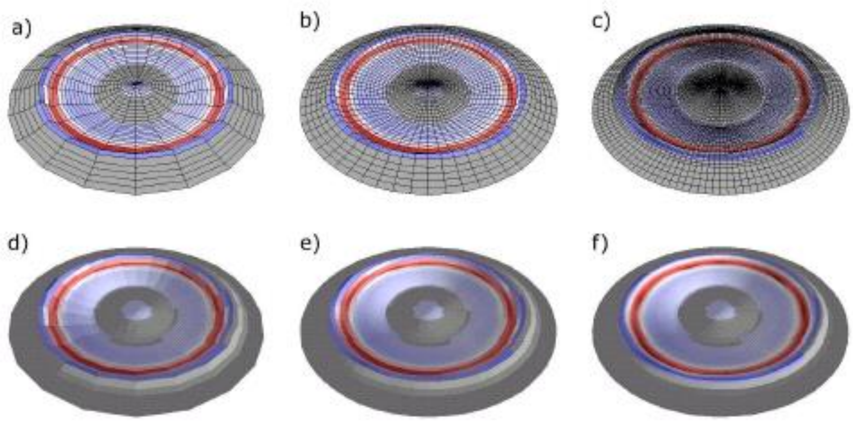
This software only requires the results (data file) of the SCN Vibrometer. The software is free for the visualization of digitally signed scan data by Klippel, for other data files a license is required.

Data Processing

The measured vibration and geometry data is prepared for an optimal visualization:

INTERPOLATION:

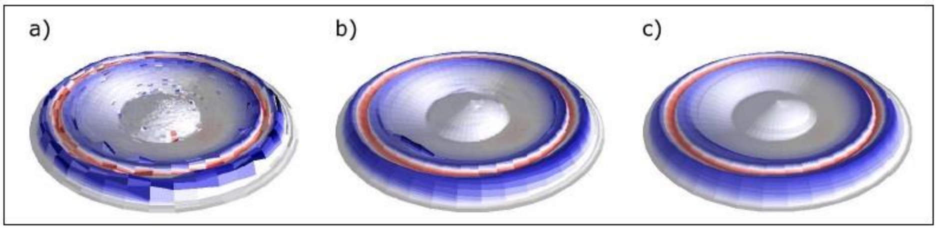
The optical resolution can be increased by interpolating between the measured points.



a) original data (744 points), b) interpolated data (2000 points) c) interpolated points (10000 points), d-f) Shaded versions of the pictures above

SMOOTHING:

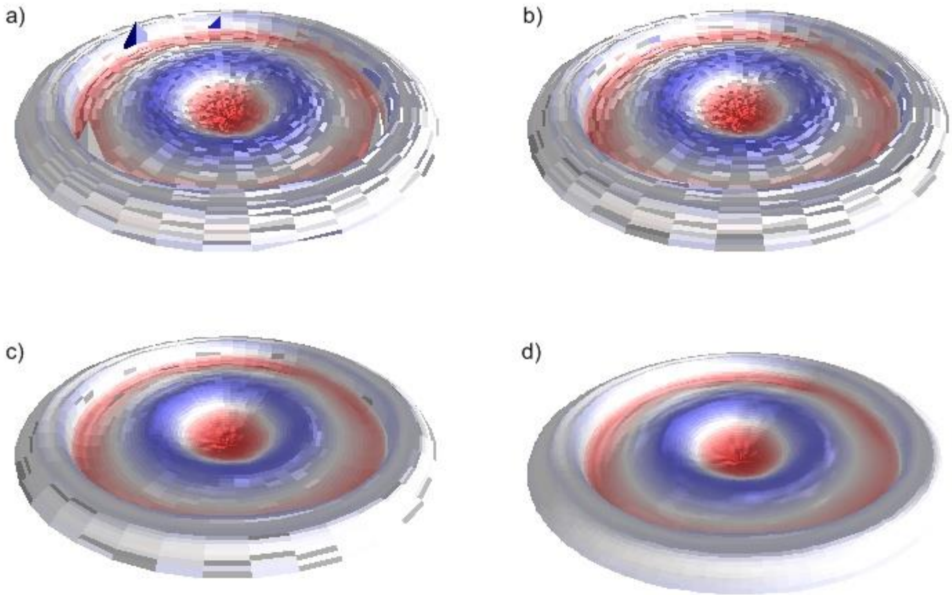
Noise in the vibration data can be suppressed by applying two-dimensional smoothing:



a) original vibration , b) medium smoothing c) maximal smoothing

ERROR CORRECTION:

Measurement errors can be detected and removed by a correlation technique.

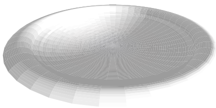
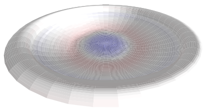
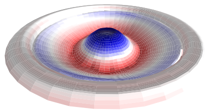
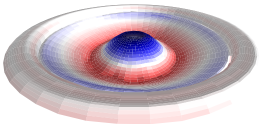
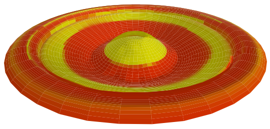
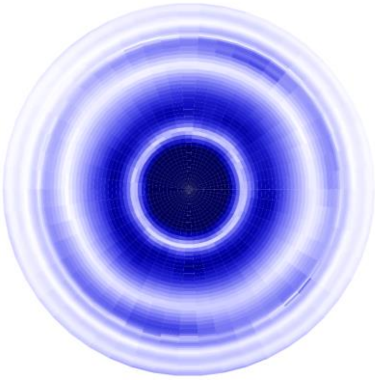
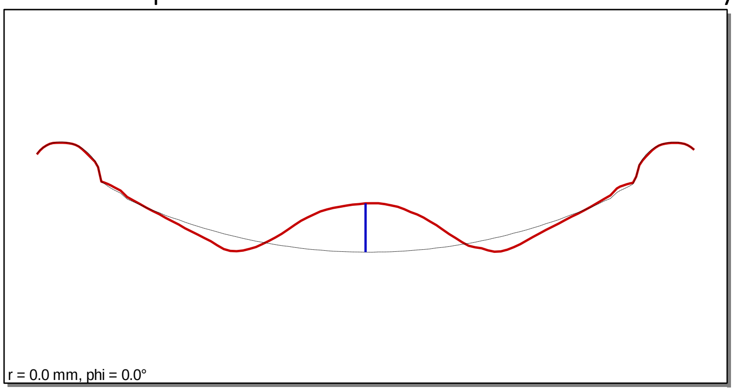


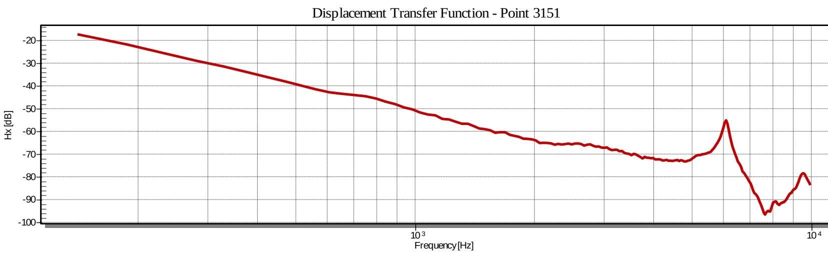
a) original vibration data, b) applying the error correction c) applying smoothing d) increased visual resolution

3D Animation

From the measured geometry a three-dimensional representation of the cone is created and the vibration at each measurement point is illustrated as an offset superposing the pure cone geometry.

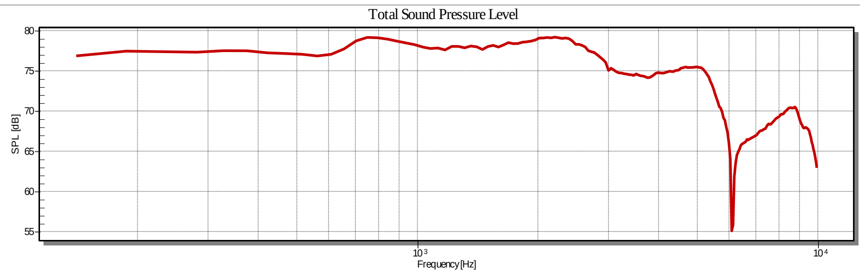
By rotating the vibration phase around the unit circle at each measurement point a continuous animation of the cone motion is created. The amplitude of the superposing offset can be manually increased to visually emphasize small vibrations.

	 geometry only  geometry with low vibration  enhanced vibration
Coloration Schemes	The color of the three-dimensional cone surface can be used to display different vibration properties. It is possible to choose coloration according to the instantaneous amplitude or according to the instantaneous phase of the vibrating points. Monochrome representations can also be selected for easier printing.  Blue and red colors represent positive and negative displacement (phase), respectively, color intensity represents relative displacement (amplitude)  Yellow and red colors represent positive and negative displacement (phase only)
2D plots	A 2D plot is provided where the vibration data are projected on the measured geometry. A cursor may be used to locate critical vibration modes and to measure the distances between nodes in mm.  The vibration amplitude is represented as blue color intensity revealing areas of minimal and maximal vibration (nodes).  The phase of the vibration is represented as yellow and red colors
Vibration of the Cone Profile	A two-dimensional plot shows the profile of the measured target surface for any angle ($0 < \varphi < 360\,^{\circ}$) in mm and the overlaid vibration pattern. Modes of vibration and the position of nodes can be determined more easily. 
Vibration of one point on the cone	A cursor (blue bar) in the Cone Profile may be used to select a point of the cone and to show the measured displacement transfer function Hx in mm per Volt.



3.1 Sound Radiation

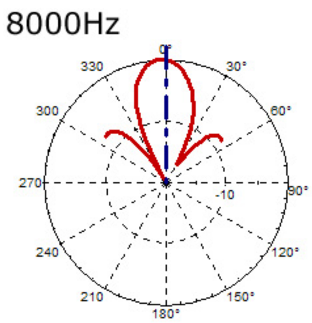
Frequency Response

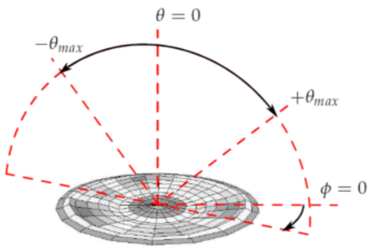


Using the geometry and the vibration data the SPL response is predicted in the far-field at the point r(ro,ϕ, θ) on the basis of the Rayleigh equation.

Directivity Pattern

The sound pressure modeling can also be used to evaluate the directivity of the sound radiation.

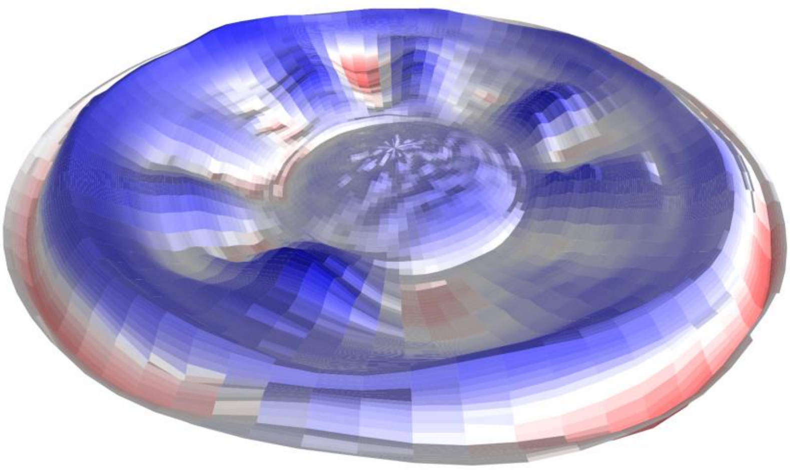




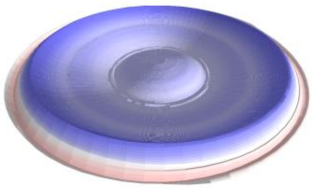
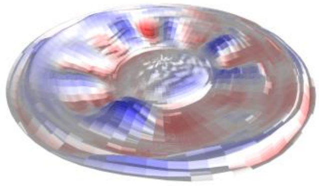
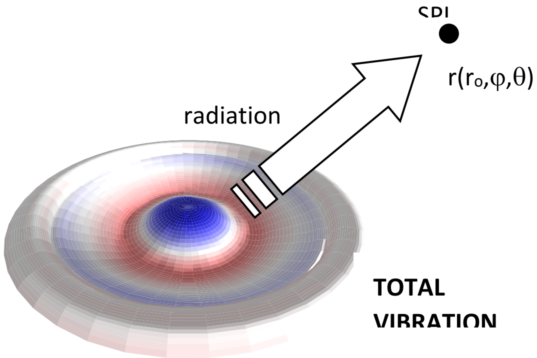
For a certain selected frequency the total sound pressure at certain points on a hemisphere over the cone is determined and displayed in a polar plot.

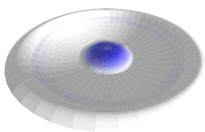
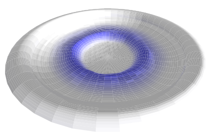
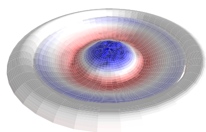
3.2 Analysis and Decomposition

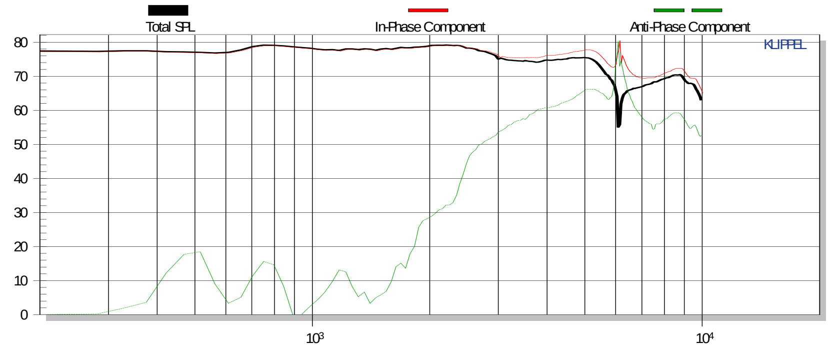
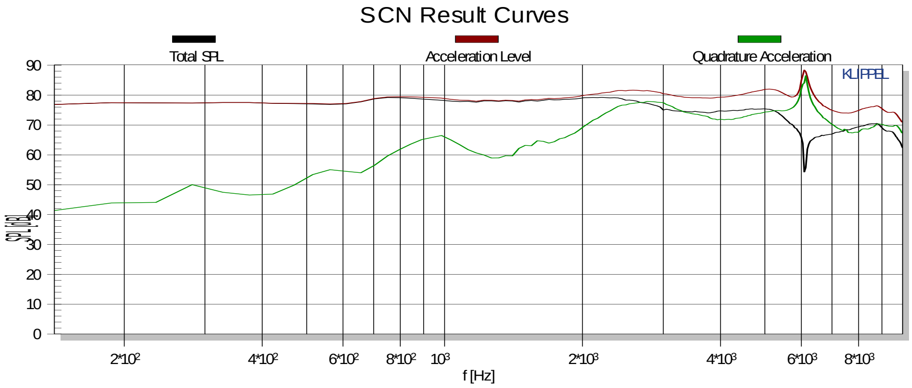
Radial and circular modes



<table>
<tr><td rowspan="3"></td><td colspan="3">Total component</td></tr>
<tr><td colspan="3">The cone vibration can be separated into single components with special relevance for the analysis by novel data decomposition techniques. The total vibration is divided into a radial component and a circumferential component. Each of them can be analyzed separately. The sound pressure produced by the respective component can be regarded independently, too.

$$\overline{x}_{total} = \overline{x}_{rad} + \overline{x}_{circ}$$</td></tr>
<tr><td>
Radial component</td><td colspan="2">
Circular component</td></tr>
<tr><td rowspan="4">Decomposition related to the sound pressure output</td><td colspan="3">

A second decomposition technique is capable of separating vibration components according to their contribution to the total sound pressure at a certain listener position $\boldsymbol{r}(r_o,\varphi,\theta)$.</td></tr>
<tr><td colspan="3">$$\overline{x}_{total} = \overline{x}_{in} + \overline{x}_{anti} + \overline{x}_{out-of}$$</td></tr>
<tr><td>
In-phase
Component</td><td>
Anti-Phase
Component</td><td>
Quadrature
Component</td></tr>
<tr><td colspan="3">The in-phase component of the vibration contributes to the sound pressure at the listening point. The anti-phase component of the vibration reduces the sound pressure output. The quadrature component produces positive and negative volume velocity which cancels out in the near field and will not contribute to the total sound pressure at the listening position.</td></tr>
</table>

	The SPL frequency response of the total output can be compared with the in-phase and anti-phase component.  The dashed anti-phase component in the diagram above produces a very low SPL output before the cone breaks up (< 2 kHz). At 6 kHz the anti-phase component almost equals the in-phase component causing a dip in the total SPL output at the listener position.
Acceleration Level	Looking at the accumulated acceleration level of the cone surface motion is a good indication for the Eigen frequencies (Natural Frequencies) and the mechanical damping of the cone's Eigen modes (Natural Modes). The total acceleration level is shown in relation to the total sound pressure level to allow a quick comparison of true cone vibration and the actual sound radiation. The acceleration level can be combined with the decomposition technique to investigate i.e. the vibration level of the quadrature component, which does not produce sound but still comprises a certain amount of vibration energy.  The in-phase and anti-phase components are always equal in acceleration level and sound pressure level.

3.3 Data Import and Export

Scan Data	All results from the scanning process (Vibration Data, Cone Geometry, status information) are stored in KLIPPEL SCN Format and are the basis for performing an SCN Analysis.
All Curves to dB-Lab	Export of all result curves of the SPL modeling and the acceleration level into a Klippel Database file which can be opened using the Klippel dB-Lab.
Single Curve	Export of vibration amplitude and modeled sound pressure curves in a text

	based format which can be easily imported into SCILAB / MATLAB and the dB LAB software by KLIPPEL by using the clipboard.
Pictures and Movies	All graphical objects can be exported as single pictures (bmp, jpg, png, vectorgraphics) or in case of an animation as a movie file. Thereby a compressed video stream is created and saved in the AVI video format which can be watched using any common movie player software.
Export and Import of Geometry and Vibration Data	The geometry of the scanned surface (in polar or cartesian Coordinates) and the vibration data (transfer function between terminal voltage and displacement at point r) can be exported and imported by using the module SCN Import/Export Interface.

4 SCN Import / Export Interface

High precision Geometry Scanning	The module Import/Export Interface is an optional Add-On for the SCN Analysis Software. It provides access to the geometry of a 3D object scanned from one side at high precision. This data is very useful for loudspeaker development and quality control. Here some examples: 1. Measuring the shape of loudspeaker parts (cones, horn geometries) where no specification is available 2. Checking the geometry of a prototype in R&D and production samples in Quality Control 3. Providing input for BEA and analyzing output from FEA
Geometry Export	Export of the measured geometry in high precision. Three different DXF (Drawing Exchange Format) export options are supported: 1. **3D Faces**: All points are connected to a mesh to reproduce the surface of the measured cone. 2. **Lines**: The surface of the cone is given by single lines connecting the measured points 3. **Points**: Only the measured points are included in the DXF export There is also the option of exporting the geometry in STL (stereo lithography) format.
Geometry and Vibration Export	Geometry and vibration data can be exported into text file in ASCII format. The data may be used for enhanced sound radiation modeling (BEA) and any other kinds of post processing. The geometry may be provided in Polar Coordinates (angle ϕ, radius r, height z) or in Cartesian Coordinates (x,y,z). The vibration data is provided as a transfer functions Hx(f)=X(f)/U(f) between voltage U(f) in Volt at the terminals and displacement X(f) in mm at each measured point. The transfer function consists of an amplitude response (0dB = 1mm /V) and the phase response (rad). These are the following options: 1. Export of the **Raw Data**: The original data is provided without applying any kind of correction. 2. Export of the **Interpolated Data**: The SCN Analysis Software is used to

interpolate missing data points, for smoothing the data and for applying error correction if an optical error is identified.

EXAMPLE:

```
;Klippel 3D Scanner Data
;driver.asc
;Created: 20.05.2008 15:17:15
;###########################################
;Measurement Points (geometry)
;Format: i x_i y_i z_i
;i = point number from 1 to n
;x_i = coord x of point i in millimeter (accuracy 0.05mm)
;y_i = coord y of point i in millimeter (accuracy 0.05mm)
;z_i = height of point i in millimeter (accuracy 0.05mm)
;
1 0 0 4.1
2 0 2.5 4.25
3 -0.65 2.41 4.15
4 -1.25 2.17 4.05
5 -1.77 1.77 3.9
6 -2.16 1.25 3.8
7 -2.41 0.65 3.7
8 -2.5 0 3.65
9 -2.41 -0.65 3.6
10 -2.17 -1.25 3.55
;
;############################
;Measurement Data
;Format: Frequency = fj
;Format: i x_i(f_j) p_i(f_j)
;i = point number from 1 to n
;x_i(f_j) = displacement amplitude of point i, frequency j in dB - [mm/V]
;p_i(f_j) = displacement phase of point i, frequency j in Radian
;
Frequency=140.63
1 -7.124 -0.53407
2 -7.08 -0.52461
3 -7.058 -0.52497
4 -6.97 -0.53189
5 -7.224 -0.53094
6 -7.324 -0.52497
7 -7.271 -0.53329
8 -7.227 -0.52956
9 -7.268 -0.52895
10 -7.203 -0.53399
Frequency=187.5
1 -12.806 0.15132
2 -12.763 0.1524
3 -12.753 0.13918
4 -12.607 0.14999
5 -12.85 0.15638
6 -12.862 0.15395
```

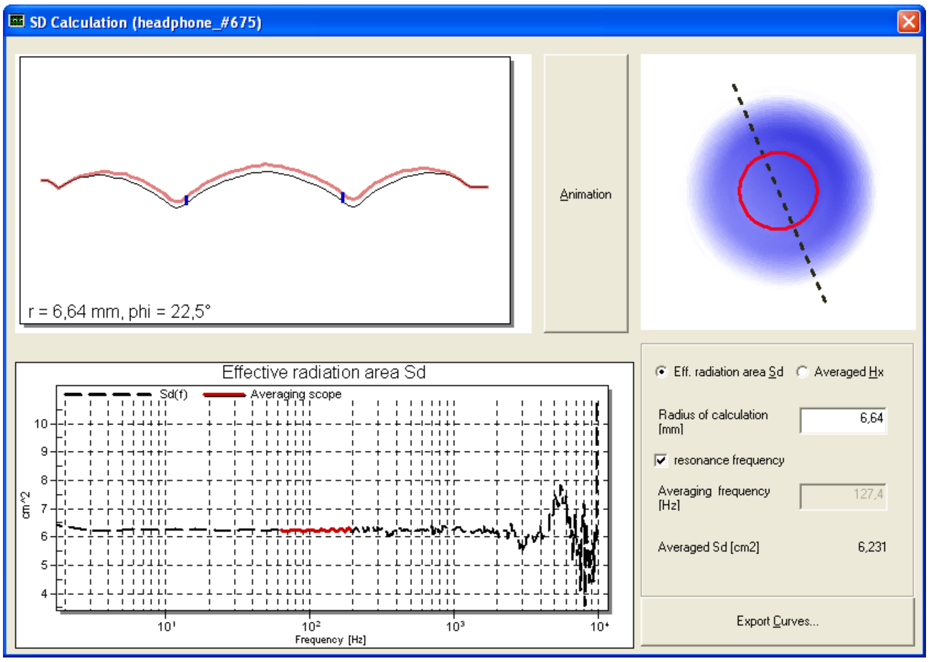
	7 -12.882 0.14751 8 -12.828 0.14894 9 -12.845 0.14988 10 -12.91 0.1522 A second export option is the generation of a text based file which can be processed by SCILAB software. That **Scilab Export File** can also be imported again after individual post processing steps.
Geometry and Vibration Import	External geometry and vibration data can be imported for Analysis. That can be used to import data generated by simulation tools or by external measurements. The import is based on a text file format which can be processed by SCILAB. Especially data which has been exported in Scilab Export File format can be directly imported again. Certain restrictions apply for a Scilab script to comply with the import functionality of the Klippel Scanning System. EXAMPLE:

```
// ----------------------------------------------------
// example file for producing valid scilab data for
// import into Klippel Scanning System 1.3
//
// Copyright by Klippel GmbH, Dresden, Germany ©2011
// ----------------------------------------------------

// ----------------------------------------------------
// define required import constants
%SCN_FILE_VERSION = 1.1;
%SCN_COORDINATE_SYSTEM = "polar";

// ----------------------------------------------------
// define geometry matrix:
//        first column  = point number
//        second column = radius in [mm]
//        third column  = angle in [rad]
//        fourth column = height in [mm]
//
// outer radius = 20mm
// regular polar grid with 17 points
geometry=[
1     0     0         0;
2     10    0         2;
3     10    1/4*%pi   2;
4     10    2/4*%pi   2;
5     10    3/4*%pi   2;
6     10    4/4*%pi   2;
7     10    5/4*%pi   2;
8     10    6/4*%pi   2;
9     10    7/4*%pi   2;
10    20    0         3;
11    20    1/4*%pi   3;
```

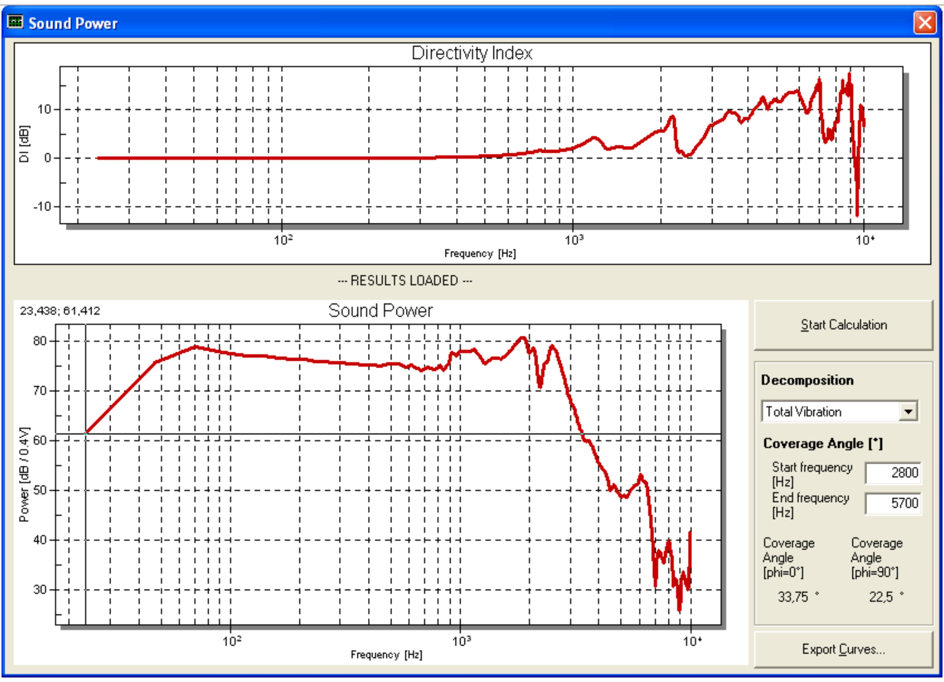
```
12        20        2/4*%pi   3;
13        20        3/4*%pi   3;
14        20        4/4*%pi   3;
15        20        5/4*%pi   3;
16        20        6/4*%pi   3;
17        20        7/4*%pi   3];

// ----------------------------------------------------
// define three frequencies
frequency = [100;200;400];

// ----------------------------------------------------
// define displacement amplitude:
// for each point specified in geometry array
// for each frequency
// amplitude given in dB [mm / V]
amplitude=[
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44;
-20       -32       -44];

// ----------------------------------------------------
// define displacement phase:
// for each point specified in geometry array
// for each frequency
// phase given in [rad]
phase=[
0         0         0;
0         0         0;
0         1/4*%pi   1/4*%pi;
0         1/2*%pi   2/4*%pi;
0         1/4*%pi   3/4*%pi;
0         0         4/4*%pi;
0         7/4*%pi   5/4*%pi;
0         3/2*%pi   6/4*%pi;
0         7/4*%pi   7/4*%pi;
0         0         0;
0         1/4*%pi   1/4*%pi;
```

	0 1/2*%pi 2/4*%pi; 0 1/4*%pi 3/4*%pi; 0 0 4/4*%pi; 0 7/4*%pi 5/4*%pi; 0 3/2*%pi 6/4*%pi; 0 7/4*%pi 7/4*%pi];

5 SCN Radiation Area SD

Effective Radiation Area SD	 The application Radiation Area SD is an optional add-on for the SCN Analysis Software. It provides an accurate result for the effective radiation area, particularly for small drivers and asymmetric driver shapes. This application needs a separate license and requires only the results (data file) of the SCN Vibrometer. A scanning measurement with an appropriate number of measurement points on the diaphragm delivers the needed data. By dividing the total volume flow with a representative voice coil displacement a frequency dependent SD-graph is obtained. That curve will be averaged over frequency. With an adjustable averaging frequency a very stable and significant value can be derived. The averaging radius can be adjusted as well and is illustrated on the related driver plots.
Displacement transfer function H_x	By clicking the Option buttons the graph plot can be switched between the Sd-parameter curve and the averaged displacement transfer function $H_x(f)$. The latter curve is yielded by a spatial averaging of all given displacement curves at a chosen radius. The averaged displacement curve is also used to obtain the SD(f) curve. After a calculation the data can be exported and reviewed in the Klippel dBLab.

6 SCN Sound Power / Directivity

Sound Power	 The Sound Power application is another optional add-on for the SCN Analysis Software. It can calculate the sound power radiation into the half space without requiring a special acoustic room. The evaluation of the frequency dependent Sound Power is based on the Rayleigh integral. A reference voltage of 0.4V is used for the calculation which allows a direct comparison of the Sound Power Level and the SPL in 1m distance. The Decomposition into the Sound Power contributions of radial and circular vibration components can be applied, as described above in the section SCN Analysis Software. After a calculation the data can be exported and reviewed in the Klippel dBLab.
Directivity Index	The Directivity Index DI shows the ratio of the SPL on axis to the overall SPL averaged in the half space.
Coverage Angle	The Coverage Angle of the driver is calculated within an adjustable frequency range according to the IEC standard 60268-5.

7 Typical Configurations

COMPONENTS REQUIRED	SCANNING + ANALYSIS	ANALYSIS ONLY	GEOMETRY MEASUREMENT
Components of the Scanning Vibrometer			
Scanning hardware (stand with turntable)	x	-	x

Motor Control (Scanning control device)	x	-	x
Software modules			
SCN Analysis Software	x	-	x
SCN Analysis Dongle Software	-	x	-
Additional Klippel-R&D-System Requirements			
Distortion Analyzer Hardware (DA2)	x	-	x
TRF-Module	x	-	x
Laser Keyence G32 / G82 / H052	x	-	x
Dongle	-	x	-
Additional Requirements			
Amplifier	x	-	x

8 Limits

8.1 DUT

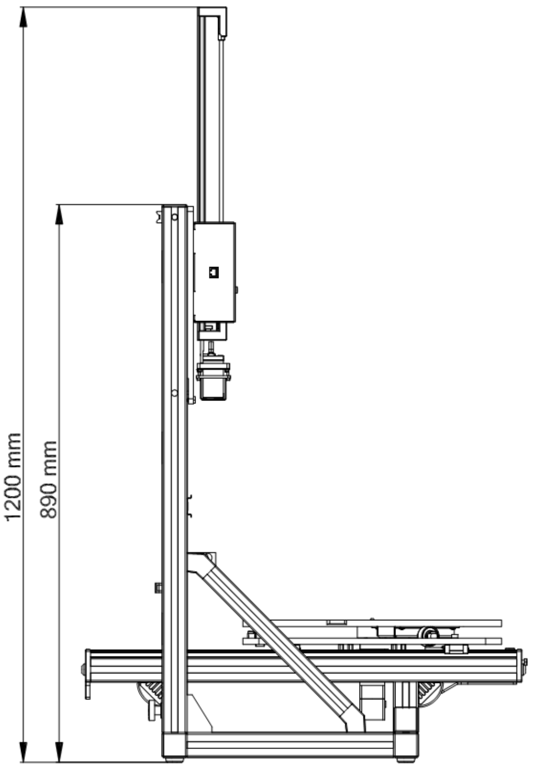
Parameter	Symbol	Min	Typ	Max	Unit
Maximal Diameter	*D*			76	cm
Height	*H*			33	cm
Mass	*M*			70	kg
Vertical steps in DUT surface[6] with LK-H052				45	mm
Vertical steps in DUT surface[6] with LK-G32				25	mm
Optical surface properties	diffuse reflective material of any color (white coating of transparent and highly reflective material is recommended)				
Target Application	dedicated to transducers (woofer, tweeter, micro-speaker, compression driver, headphone)				

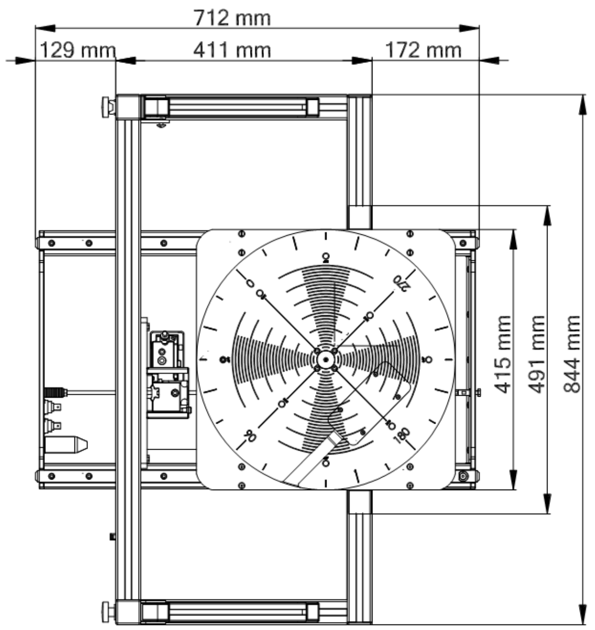
8.2 Scanning Hardware rev. 2.0

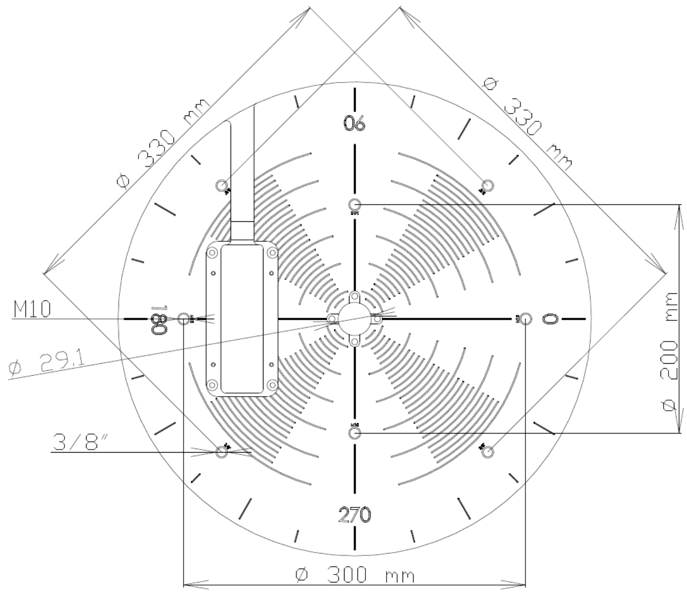
<table>
<tr><td colspan="2">Parameter</td><td>Symbol</td><td>Min</td><td>Typ</td><td>Max</td><td>Unit</td></tr>
<tr><td colspan="2">Sensor</td><td colspan="5">Non-contact triangulation displacement sensor</td></tr>
<tr><td colspan="2">Laser Protection Class</td><td colspan="5">Class II, eye-safe, visible
CAUTION! Laser Radiation!
Avoid direct or indirect (e.g. reflection) exposure of human eyes to beam.</td></tr>
<tr><td colspan="2">Scanning Grid</td><td colspan="5">Polar coordinate system (φ, r), tangential triangulation</td></tr>
<tr><td colspan="2">Vertical laser position (corresponds with height profile which could be measured)</td><td>z</td><td>0</td><td></td><td>310</td><td>mm</td></tr>
<tr><td colspan="2">Free space between turn table and Z-axis-frame (corresponds with height of DUT[5])</td><td>z</td><td>0</td><td></td><td>340</td><td>mm</td></tr>
<tr><td colspan="2">Horizontal Shift (radius of circular area scanned)</td><td>r</td><td>0</td><td></td><td>300</td><td>mm</td></tr>
<tr><td colspan="2">Free space between stands (corresponds with Diameter of the DUT)[5]</td><td>d</td><td></td><td></td><td>760</td><td>mm</td></tr>
<tr><td colspan="2">Angle of turntable</td><td>φ</td><td>0</td><td></td><td>360</td><td>degree</td></tr>
<tr><td colspan="2">Error in z position</td><td>Δz</td><td></td><td>10</td><td>30</td><td>µm</td></tr>
<tr><td colspan="2">Error in r position</td><td>Δr</td><td></td><td>10</td><td>30</td><td>µm</td></tr>
<tr><td colspan="2">Error in φ position</td><td>Δφ</td><td></td><td>0.2</td><td>0.5</td><td>degree</td></tr>
<tr><td colspan="2">Error in measured Geometry (0 < z < 10 mm)[1]</td><td></td><td></td><td>5</td><td></td><td>µm</td></tr>
<tr><td colspan="2">Scanning Speed[2]</td><td></td><td></td><td>0.3</td><td>1</td><td>points/s</td></tr>
<tr><td colspan="2">Time for profile scan (50 points) [3]</td><td></td><td></td><td>10</td><td></td><td>min</td></tr>
<tr><td colspan="2">Time for explore scan (450 points) [3]</td><td></td><td></td><td>1</td><td></td><td>h</td></tr>
<tr><td colspan="2">Time for detailed scan (3200 points) [3]</td><td></td><td></td><td>8</td><td></td><td>h</td></tr>
<tr><td colspan="2">Time for geometry scan only (3200 points) [3]</td><td></td><td></td><td>5</td><td></td><td>h</td></tr>
<tr><td rowspan="3">Working distance of laser head, refer to *A2 Laser Displacement Sensor*</td><td>Keyence LK-G32</td><td>*d*</td><td>25</td><td>30</td><td>35 / 31.8[4]</td><td>mm</td></tr>
<tr><td>Keyence LK-G82</td><td>*d*</td><td>65</td><td>80 / 68[4]</td><td>95 / 71[4]</td><td>mm</td></tr>
<tr><td>Keyence LK-H052</td><td>*d*</td><td>40</td><td>50</td><td>60</td><td>mm</td></tr>
<tr><td colspan="2">Sensor output</td><td colspan="5">ac-displacement of target, distance to target</td></tr>
<tr><td colspan="2">Lowest frequency displacement signal</td><td>f_{min}</td><td>0</td><td></td><td></td><td>Hz</td></tr>
</table>

Highest frequency limit displacement signal	f_{max}	$>f_{min}$	10	25	kHz
Signal to Noise ratio[3]	*SNR*		30		dB
Noise level in displacement output[3]	x_{noise}				µm
Detection of optical errors	Reliability check by correlating two measurement at different distances and calculating S/N ratio				
Stimulus used for excitation	Shaped logarithmical sine sweep				
Mechanical Protection	Independent emergency stop if the laser head has mechanical contact with target				
Recommended workspace width	*w*	85			cm
Recommended workspace depth	*d*	61	80		cm
Recommended workspace height	*h*	120			cm

Physical dimensions	See following side and top view drawing





Mounting points for accessories	
2 x M10 thread (pitch = 1.5) @ ø = 200 mm 2 x M10 thread (pitch = 1.5) @ ø = 300 mm	
4 x 3/8" – 16 UNC thread @ ø = 330 mm (Rev. >= 1.6)	
M10 and 3/8" screws must not reach through the turntable! Could cause damages during movement of the turn-table. Max. thread length inside turntable 10 mm.	

Diameter of centering hole: ø = 29.1H7 mm (29.1 +0.05/-0 mm) Diameter of centering piece ø = 29.1H7 mm (29.1 +0/-0.02 mm)	

[1] Laser sensor is kept on fixed vertical position and the vertical scanning range is limited by the peak-to-peak value of the laser sensor. In this case the laser sensor determines the error of the measured geometry.

[2] only positioning of the laser sensor (without vibration measurement)

[3] depends on averaging, laser settings, target surface and stimulus

[4] for measurements above f_{max} =10kHz

[5] The DUT is placed on the turntable with the surface to be scanned on the upper side

[6] A vertical step in the DUT surface above the specified maximum may cause:

- A collision of the laser sensor with the DUT if H_1 @ outer radius < H_2 @ inner radius (step up)
- Unmeasured points if H_1 @ outer radius > H_2 @ inner radius (step down), H = DUT height

8.3 Motor Control

Parameter	Symbol	Min	Typ.	Max	Unit
Electrical Characteristics Stepper Motor Outputs					
Output Voltage (peak to peak)	U_{out}		24		V
Output Current (max)	I_{out}			2	A
Output Current (adjusted for R- & Z-axis)	I_{out}		0.9		A
Output Current (adjusted for Phi-axis)	I_{out}		0.5		A
Recommended Operating Conditions					
Power supply voltage	V_{AC}	100		240	V
Power AC-frequency	f_{AC}	47		63	Hz
Operating ambient temperature	T_A	0	25	50	ºC
Input power	P		10	20	W

Primary power supply connection with protective earth conductor is required!

Power supply connection with removed earth contact could cause high voltages at the enclosure of the device.

8.4 Setup Parameter of Scanner

Parameter	Symbol	Min	Typ	Max	Unit

Scanning Grid					
Increments of radius r	r_{Step}	0.02	1		mm
Minimal radius	r_{min}	0			mm
Maximal radius	r_{max}			300	mm
Increments in angle φ	Dφ	0.03	4.5	360	°
Manual grid control	• remove/add single radii • indicate critical radii (activate diving scanning mode)				
Vertical control mode	• Variable (normal) • Fixed (good for scanning of flat DUTs) • Minimal distance $z > z_{min}$ (good for vacuum measurements) • Mark additional dangerous radii for safe scanning				
Scanning Mode	• Vibration + Geometry • Geometry only				
Generator / Signal Acquisition					
Minimal Frequency	f_{start}	0		$< f_{end}$	Hz
Maximal Frequency	f_{end}	$> f_{start}$	10	25	kHz
Frequency Resolution	Δf		23.44		Hz
Stimulus Shaping	S	0	9	12	dB/oct
Maximal Voltage	U_{max}	0	10	100	V
Averaging	N	1	64	256	

8.5 Vibration and Radiation Analysis (Results)

Parameter	Comments	Unit
Amplitude displacement transfer function	$H_x(f)$ for any cone point **c**(z,φ, r) for • Circular and radial vibration mode • In-phase component • Anti-phase component • Quadrature component	dB (1 mm/V = 0dB)
3D Vibration Animation (Cone Surface)	Enhanced cone vibration at frequency f is superimposed with measured geometry Vibration can be decomposed in • Circular and radial vibra-	Geometry and vibration is relative

	tion mode • In-phase component • Anti-phase component • Quadrature component Color Mode: • Phase • Amplitude (viewing angle and distance may be changed, rotation and scaling of DUT possible)	
2D Vibration Magnitude and Phase Plot	Magnitude and phase of vibration is plotted versus projected geometry Vibration can be decomposed in • Circular and radial vibration mode • In-phase component • Anti-phase component • Quadrature component Color Mode: • phase • amplitude	Vibration is relative but geometry is in mm
2D Vibration Animation (Cone Profile at φ)	Enhanced cone vibration at frequency f is superimposed with measured cone profile at angle φ Vibration can be decomposed in • Circular and radial vibration mode • In-phase component • Anti-phase component • Quadrature component The transfer function H(f) of any cone point can be selected	Geometry in mm, vibration relative
Geometry of target surface	Polar coordinates of cone point **c**(z,φ, r)	mm
Directivity plot	Γ(ϑ) at frequency *f* in plane at φ for • Circular and radial vibration mode • In-phase component • Anti-phase component • Quadrature component	dB

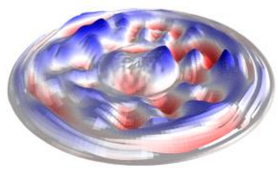
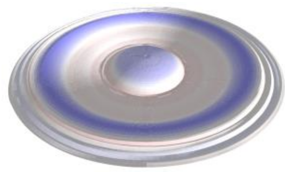
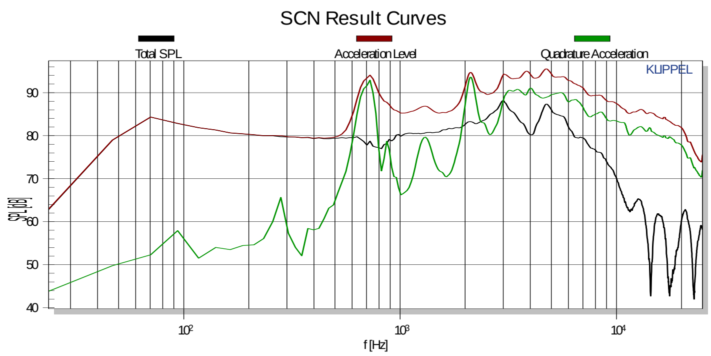
	Averaged $\Gamma(\vartheta)$ at frequency *f* for all φ	
Total SPL response	SPL(f) at field point **r**(r_o,φ,ϑ)	dB
SPL response of in-phase component	$SPL_{in\text{-}phase}$(f) at field point **r**(r_o,φ,ϑ)	dB
SPL response of anti-phase component	$SPL_{anti\text{-}phase}$(f) at field point **r**(r_o,φ,ϑ)	dB
SPL response of radial mode	SPL_{radial}(f) at field point **r**(r_o,φ,ϑ)	dB
SPL response of circular mode	$SPL_{circular}$(f) at field point **r**(r_o,φ,ϑ)	dB
Total Acceleration Level	Absolute summation of the cone acceleration. Scaled to be directly comparable to SPL	dB
Acceleration Level of radial mode	Cumulated acceleration of radial mode	dB
Acceleration Level of circular mode	Cumulated acceleration of circular mode	dB
Acceleration Level of quadrature component	Cumulated quadrature acceleration	dB
Acceleration Level of in-phase component	Identical to In-Phase SPL level	dB
Acceleration Level of anti-phase component	Identical to Anti-Phase SPL level	dB

8.6 Setup Parameter Analyzer

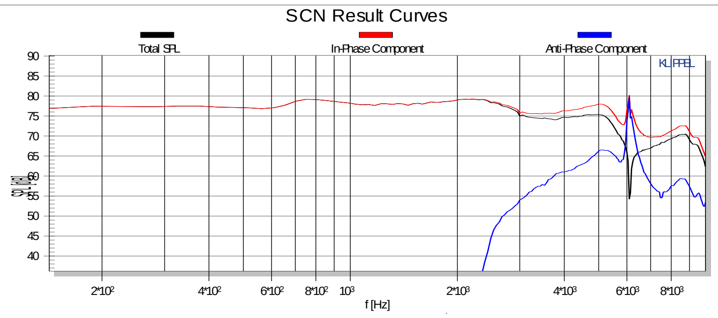
Parameter	Symbol	Min	Typ	Max	Unit
Frequency	f	f_{start}		f_{end}	Hz
Distance to field point **r**	r_o				m
Angle (off- axis)	ϑ	0		360	degree
Angle (of the turn-table)	φ	0		360	degree
Decomposition	• Radial, circular modes • SPL related (In-phase, Anti-phase, Quadrature)				
Color Modes	• Amplitude • Phase				
Modeling Modes	• Sound Pressure Level • Acceleration Level				
Amplitude Enhancement	*H*	-20	0	20	dB
Smoothing	*S*	0	2	9	relative
Graphical Resolution			3200	50000	points
Period Time in Animation		0.1	1.5	10	seconds
Options (Checkbox)	• Mark interpolated points / mark sparse grid points				

	• Increase visual grid resolution • Average directivity

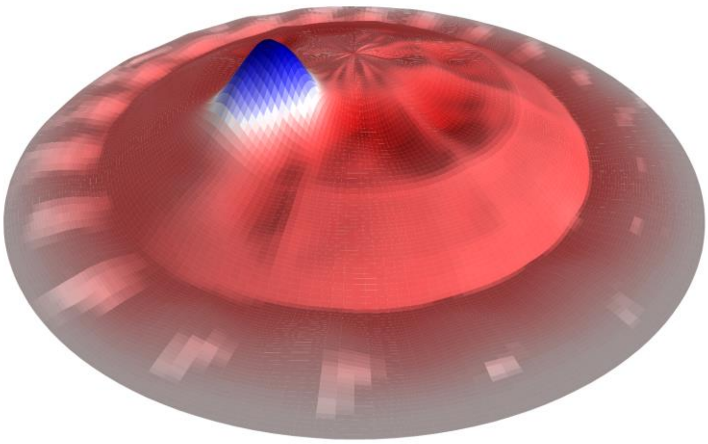
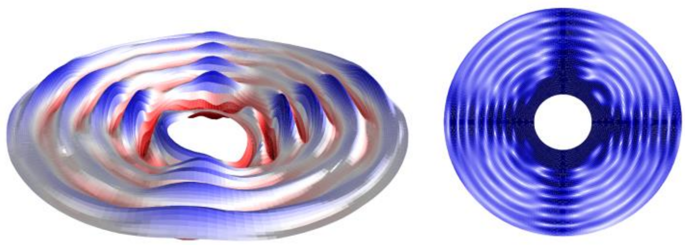
9 Diagnostics

<table>
<tr><td rowspan="2">Visualize regular vibration modes</td><td colspan="2">The sound pressure output of axis-symmetrical cones highly depends on the regular modes which propagate in radial direction on the cone. The radial modes can be enhanced by using the decomposition technique. The measured behavior may be compared with the results predicted by axial-symmetrical FEA to show
limits of the piston mode
first ring resonance, surround resonance,
bending modes
membrane modes</td></tr>
<tr><td>
Total vibration modes</td><td>
Radial modes only</td></tr>
<tr><td>Separate Vibration and Radiation Effects</td><td colspan="2">The Total Acceleration Level compared to the Total Sound Pressure level summarizes the effect of the surface motion on the radiated sound.

The quadrature acceleration shows the vibration level which does not produce any sound at the receiver point. It comprises asymmetric motions, rocking and motion where the surface vibration phase gets orthogonal to the radiated sound.

The frequencies and quality of the mechanical modes can be found easily from the total acceleration level.</td></tr>
<tr><td>Analyze acoustical cancellation</td><td colspan="2">Acoustical cancellation occurs when the volume flow q of the cone area vibrating in phase with the total sound gets close to the volume flow of the area vibrating 180° phase shifted.</td></tr>
</table>

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


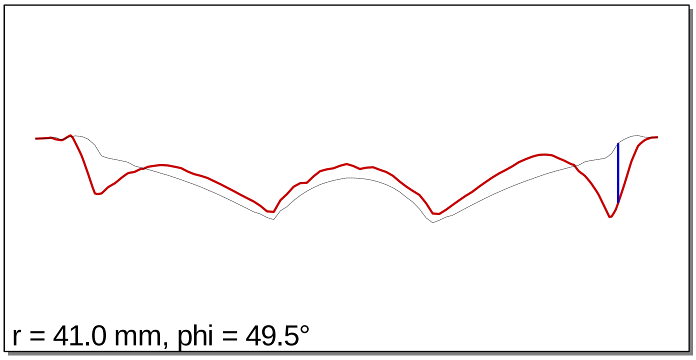
If the in-phase and anti-phase components get close to each other, there will be a strong dip in the produced sound pressure at the receiver point.

A design goal of good loudspeakers should be to always keep a certain minimal distance between both components to avoid acoustical cancellation effects.
</td>
</tr>
<tr>
<td>Visualize irregular vibration behavior</td>
<td>
Flexible wires and irregularities in the geometry (e.g. cone thickness) and density of the material may cause significant circular modes on the cone. These modes may be enhanced by viewing the circular modes only (Decomposition method).

Diaphragm of a horn compression drivers with irregular thickness
</td>
</tr>
<tr>
<td>Anisotropic materials</td>
<td>
Some material used for loudspeaker cones and diaphragms have anisotropic properties which produce a vibration pattern that depends on the direction. For example, the vibration of the Kevlar cone becomes maximal in the direction of the fibers.

</td>
</tr>
<tr>
<td>Localize Cause of Nonlinear Distortion</td>
<td>
If cone or surround displacement is high compared to the geometry the cone behaves nonlinearly and produces nonlinear distortion of the output signal.
Analysis: At critical excitation frequency search for regions of
</td>
</tr>
</table>

maximal displacement in the 3D surface animation or 2D profile animation.

Target: Reduce the Quadrature and anti-phase vibration components which do not contribute to the SPL but generate nonlinear distortion.

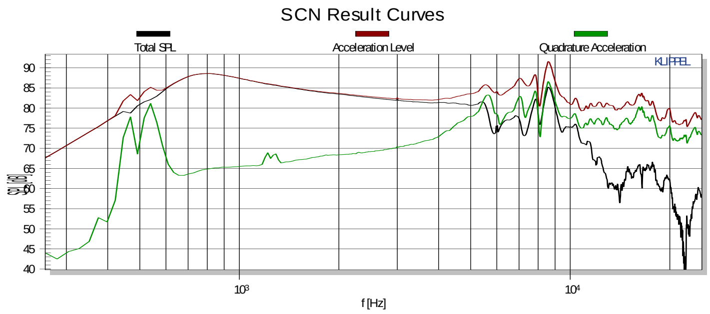
Remedy: Investigate design choices (different geometry and material) by using FEA



The first bending anti-resonance produces high displacement and large bending moments at the outer rim of the cone.

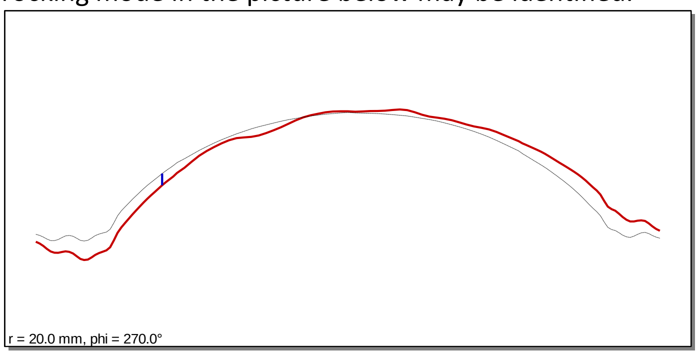
Rocking Modes

Rocking modes can easily be detected by looking at the quadrature acceleration level.



If the surface vibrates as a rigid body the quadrature component is very small. A rocking motion does not produce much radiated sound but contains substantial vibration energy. This leads to a peak in acceleration level (in the example at 470Hz and 540Hz)

After setting the cursor to the critical frequency 470 Hz the rocking mode in the picture below may be identified.



Diaphragm of a horn compression driver performing rocking mode and causing rub&buzz problems.

10 Evaluation

Measurement Service	The Vibrometer and Analysis Software may be evaluated by sending a transducer to KLIPPEL GmbH (ask for details service@klippel.de). After performing a detailed scan the results (vibration + geometry) and the SCN Analysis Software will be provided for evaluation (animation, visualization, SPL response, directivity, decomposition). Besides a Windows PC no hardware is required.

11 References

Papers	[1] W. Klippel, J. Schlechter, "Measurement and Visualization of Loudspeaker Cone Vibration", presented at the 121st Convention of the AES in San Francisco, CA, USA, 2006, October 5-8. [2] W. Klippel, J. Schlechter, "Distributed Mechanical Parameters of Loudspeakers 1: Measurements", JAES Volume 67, Issue 7/8 pp. 600-611, July 2009 [3] W. Klippel, J. Schlechter, "Distributed Mechanical Parameters of Loudspeakers 2: Diagnostics", JAES Volume 67, Issue 9 pp. 696-708, September 2009 [4] W. Klippel, J. Schlechter, "Dynamical Measurement of the Effective Radiation Area SD", presented at the 128th Convention of the AES in London, UK, 2010, May 22-25.
Application Notes	Cone Vibration and Radiation Diagnostics, Application Note AN31 Effective Radiation Area SD, Application Note AN32
Manual	SCN Vibrometer, Manual of the Klippel R&D System, 2011

Find explanations for symbols at:

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

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