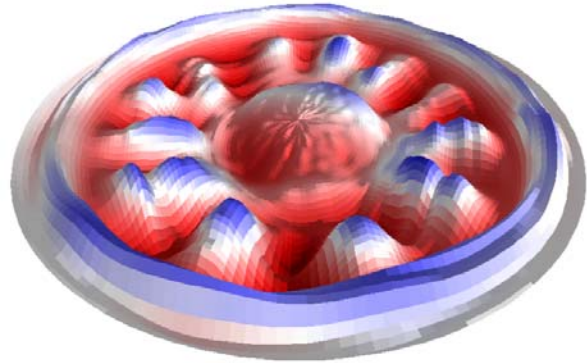


FEATURES

- Measure geometry and mechanical vibration of the transducer
- Visualize the vibration behavior
- Show contribution to sound pressure output
- Predict directivity pattern
- Separate radial and circular modes
- Analyze actively radiating cone regions
- Detect loudspeaker defects



updated Januar 12, 2011

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:	SCN Vibrometer	2510-001
	SCN Analysis Software	2510-010/2510-011 (USB Dongle)
	SCN Interface for FEA / BEA	2510-020
	SCN Radiation Area SD	2510-030
	SCN Sound Power / Directivity	2510-040

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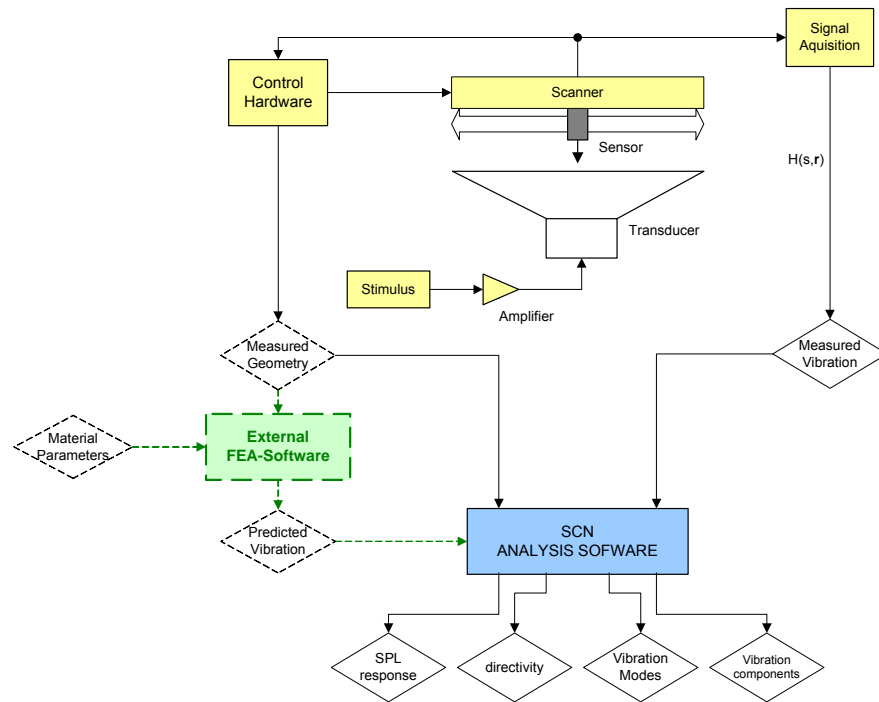
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Principle



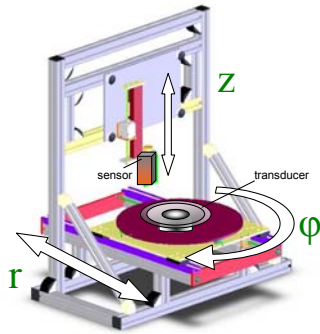
The **SCN Vibrometer** is dedicated to loudspeakers, micro-speakers, headphones and other electro-acoustical or electro-mechanical transducers. The Vibrometer uses standard modules of the KLIPPEL R&D System such as a displacement triangulation laser sensor, the Distortion Analyzer DA2 and the Transfer 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 an 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 half-space sound field. Novel decomposition techniques show radial and circular modes and vibrations components related with the SPL output. It is the target of the analysis to provide a better understanding of the interaction between vibration and radiation.

The **SCN Interface for FEA / BEA** (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 may provide the E modulus and loss factor of the cone and suspension material.

SCN Vibrometer

3D Scanner



Mechanical scanning system with one rotational (ϕ) and two linear actuators (r, z).

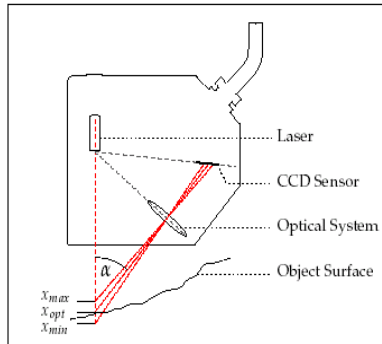
Most electro-acoustical transducers use a single motor which excites the diaphragm, cone or panel in one direction (z dimension). Thus the measurement of the displacement in this direction can be accomplished by using a displacement sensor scanning 2 dimensions (radius r and angle ϕ) of the target surface. 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



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 micro-processor provides state information of the Scanning Hardware for the software and controls the 3 built in step-per motor drivers for actuating each agitation axis.

Displacement Sensor

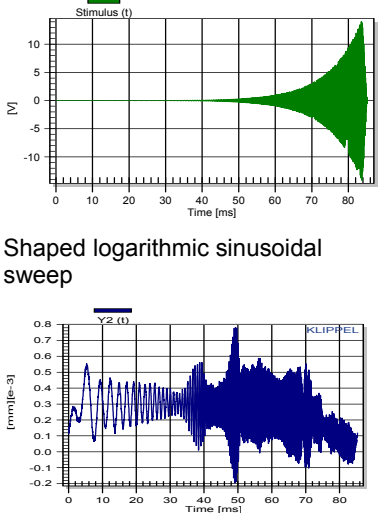
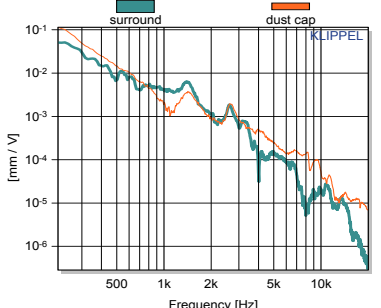
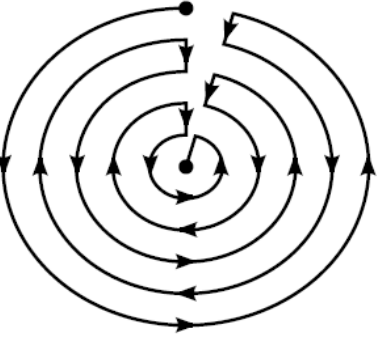


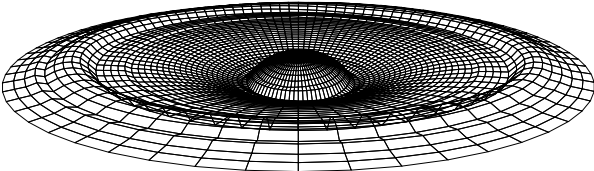
Displacement sensor based on the triangulation principle

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.

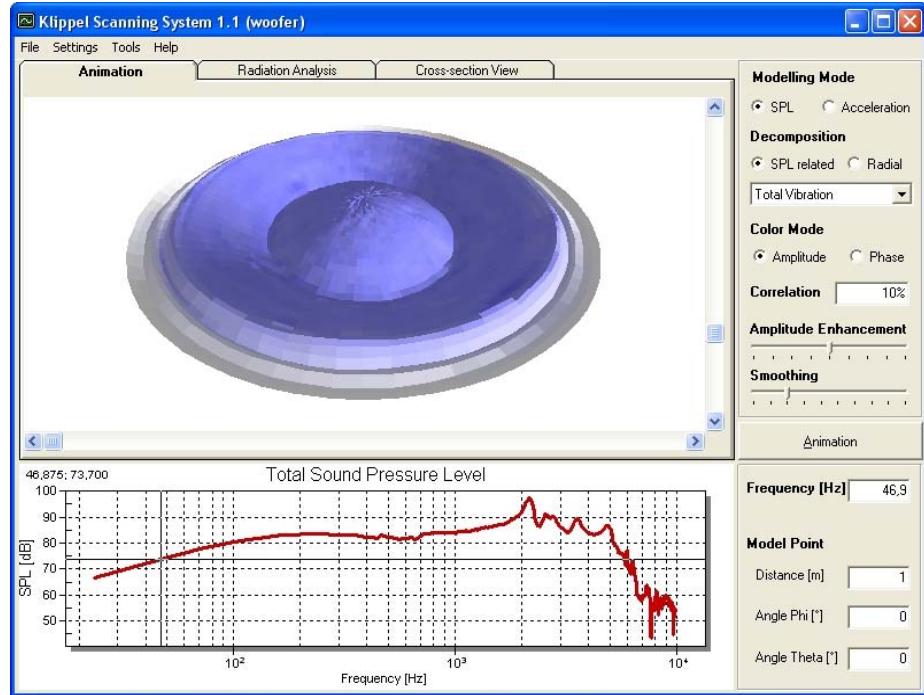
Since triangulation sensors provide primarily displacement, advanced signal processing is required to measure the break-up modes up to 25 kHz at sufficient signal to noise ratio.

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 $x_{peak}(f_s) = 1\text{mm}$ at the resonance frequency $f_s = 20\text{ Hz}$ but would produce only 10^{-6} mm (1nm) peak displacement at 20 kHz.

<p>Shaping of the Stimulus</p>	 <p>Shaped logarithmic sinusoidal sweep</p> <p>Averaged displacement signal</p>	<p>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.</p> <p>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.</p> <p>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)</p>
<p>Displacement Transfer Function</p>	 <p>Transfer function $H_x(s)$ measured at the dust cap and at the surround</p>	<p>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).</p>
<p>Grid and scanning path</p>	 <p>The scanning starts at the outside rim and proceeds inwards.</p>	<p>The target is scanned in polar coordinates (r, φ) due to the turntable and the radial actuator used.</p> <p>The grid can be generated automatically or manually to provide sufficient resolution at areas of particular interest.</p> <p>The scanning process can be performed in sequential steps</p> <ol style="list-style-type: none"> a) profile scan at constant angle φ (50 points) b) explore scan (450 Points) c) detailed scan (3200 Points)

<p>Scanning Modes</p>	<p>The height of the laser sensor is automatically adjusted during the scanning process according to the following modes</p> <ul style="list-style-type: none"> • Normal Scan <p>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.</p> <ul style="list-style-type: none"> • Flat Scan <p>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.</p> <ul style="list-style-type: none"> • Floating Scan <p>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.</p> <p>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.</p>
<p>Geometry Measurement</p>	<p>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.</p> <div style="text-align: center;">  </div>
<p>Configuration</p>	<p>The SCN Vibrometer comprises the following components:</p> <ul style="list-style-type: none"> • 3D Scanner (3 actuators move the displacement sensor in polar coordinates) • Scanning Control Hardware • Scanning Control Software • Cables <p>Other modules of the KLIPPEL R&D SYSTEM</p> <ul style="list-style-type: none"> • Laser-Displacement Sensor (see <i>A2 Laser Displacement Sensor</i>) • Distortion Analyzer DA2 • TRF Transfer Function Module <p>Additional equipment:</p> <ul style="list-style-type: none"> • Power Amplifier

SCN Analysis Software



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

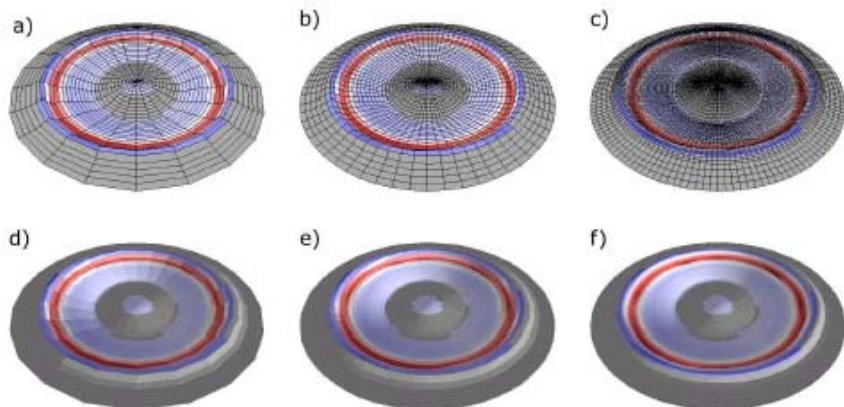
This software only requires the results (data file) of the SCN Vibrometer. The software is free for the visualization of digitally signed scan data by Klippel, for other data files a licence is required.

Data Processing

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

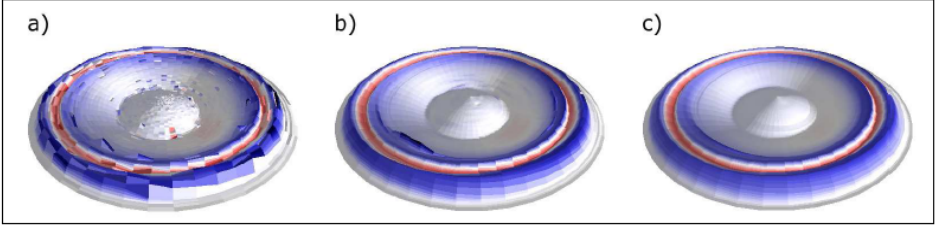
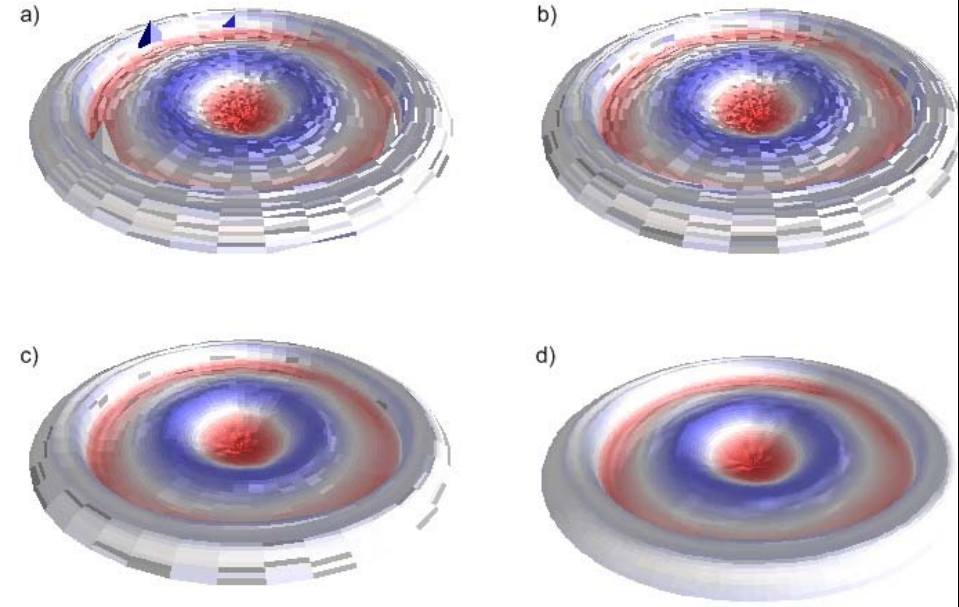
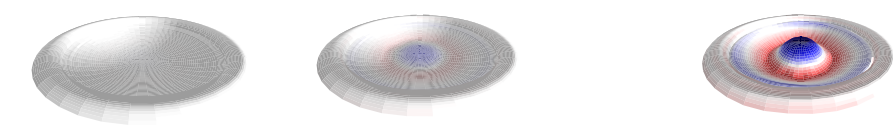
INTERPOLATION:


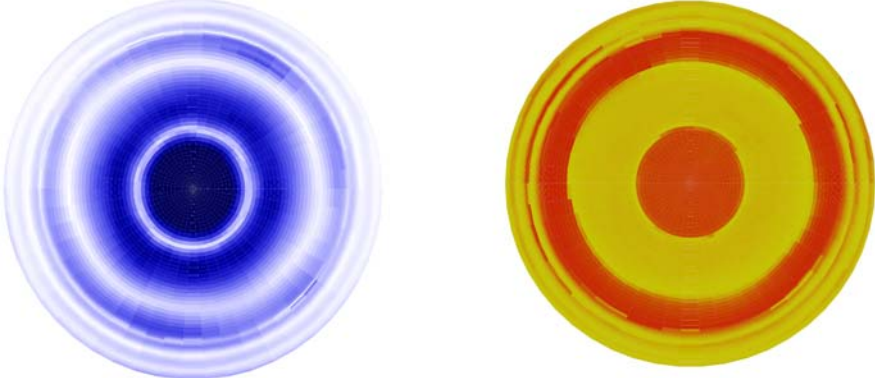
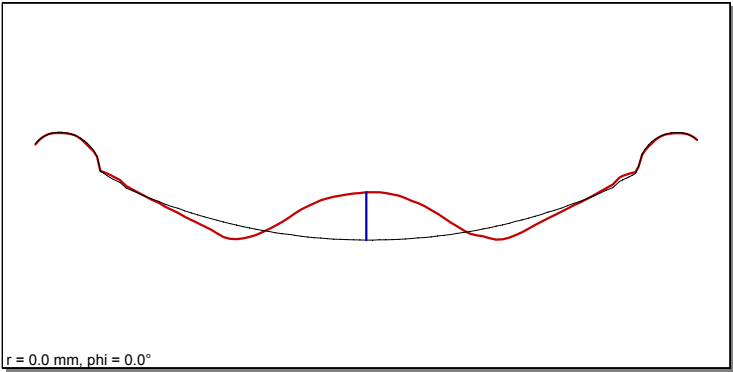
The optical resolution can be increased by interpolating between the measured points.



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

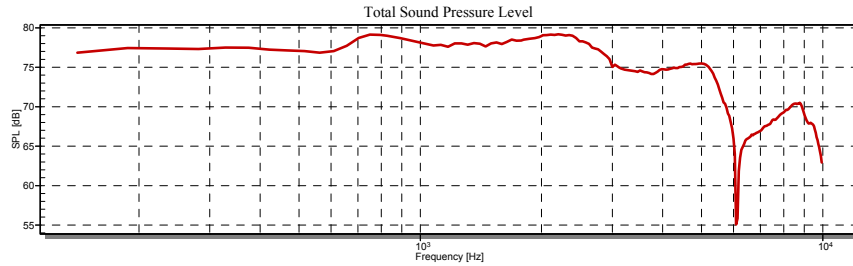
SMOOTHING:

	<p>Noise in the vibration data can be suppressed by applying two-dimensional smoothing:</p>  <p>a) original vibration , b) medium smoothing c) maximal smoothing</p> <p>ERROR CORRECTION: Measurement errors can be detected and removed by a correlation technique.</p>  <p>a) original vibration data, b) applying the error correction c) applying smoothing d) increased visual resolution</p>
<p>3D Animation</p>	<p>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.</p> <p>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.</p>  <p>geometry only geometry with low vibration enhanced vibration</p>
<p>Coloration Schemes</p>	<p>The color of the three-dimensional cone surface can be used to display different vibration properties. It is possible to choose a coloration according to the instantaneous amplitude or according to the instantaneous phase of the vibrating points. Also monochrome representations can be selected for easier printing.</p>

	<div style="display: flex; justify-content: space-around; align-items: center;">  </div> <p>Blue and red colors represent positive and negative displacement (phase), respectively, color intensity represents relative displacement (amplitude)</p> <p>Yellow and red colors represent positive and negative displacement (phase only)</p>
<p>2D plots</p>	<p>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.</p> <div style="display: flex; justify-content: space-around; align-items: center;">  </div> <p>The vibration amplitude is represented as blue color intensity revealing areas of minimal and maximal vibration (nodes).</p> <p>The phase of the vibration is represented as yellow and red colors</p>
<p>Vibration of the Cone Profile</p>	<p>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. Here modes of vibration and the position of nodes can be determined more easily.</p> <div style="text-align: center;">  <p><small>r = 0.0 mm, phi = 0.0°</small></p> </div>
<p>Vibration of one point on the cone</p>	

Sound Radiation

Frequency Response

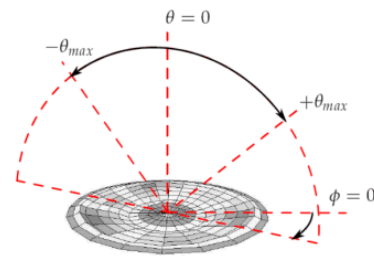
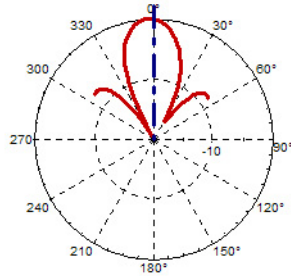


Using the geometry and the vibration data the SPL response is predicted in the far-field at the point $r(r_o, \phi, \theta)$ on the basis of the Rayleigh equation.

Directivity Pattern

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

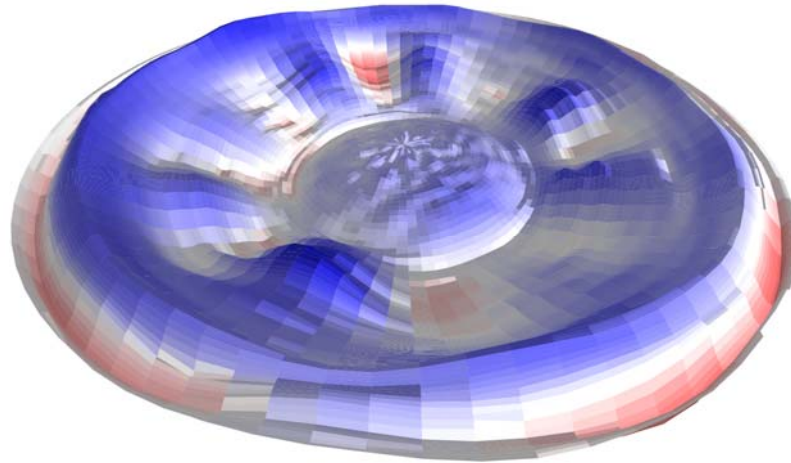
8000Hz



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.

Analysis and Decomposition

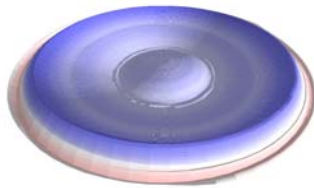
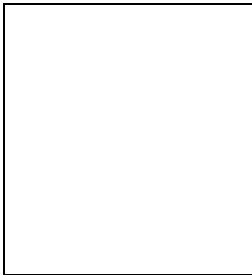
Radial and circular modes



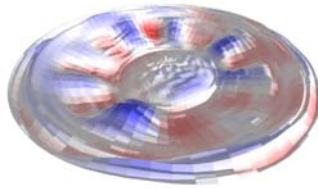
Total component

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 and each of them can be analyzed separately. Also the sound pressure produced by the respective component can be regarded independently.

$$\bar{x}_{total} = \bar{x}_{rad} + \bar{x}_{circ}$$

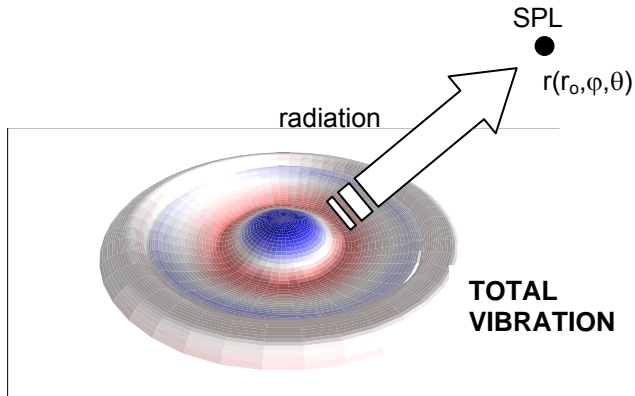


Radial component



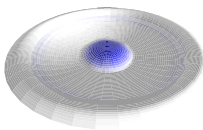
Circular component

Decomposition related to the sound pressure output

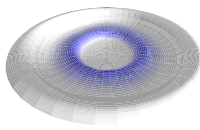


A second decomposition technique is capable of separating vibration components according to their contribution to the total sound pressure at a certain listener position $r(r_0, \varphi, \theta)$.

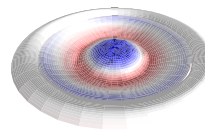
$$\bar{x}_{total} = \bar{x}_{in} + \bar{x}_{anti} + \bar{x}_{out-of}$$



In-phase Component



Anti-Phase Component



Quadrature Component

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.

The SPL frequency response of the total output can be compared with the in-phase and anti-phase component.

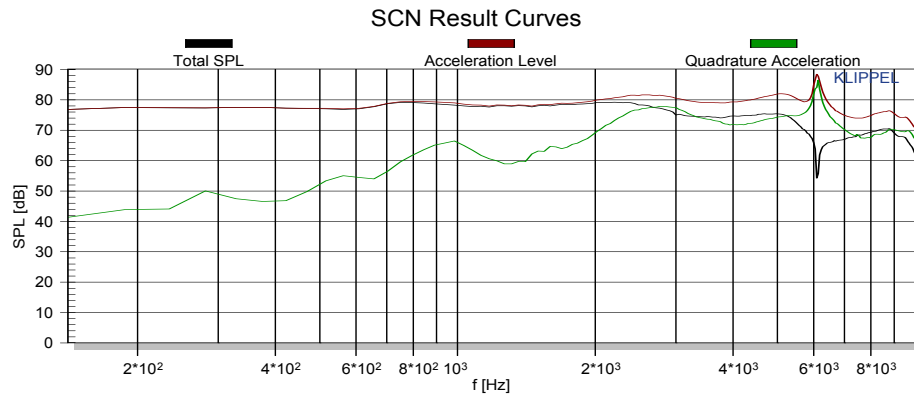


The dashed anti-phase component in the diagram above produces a very low SPL output before the cone breaks up (< 2 kHz). At 6 kHz the anti-phase component almost equals the in-phase component causing a dip in the total SPL output at the listener position.

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.

Data Import and Export

Scan Data All results from 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 Interface for FEA / BEA.

SCN Interface for FEA / BEA

High precision Geometry Scanning	<p>The module Interface for FEA / BEA 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:</p> <ol style="list-style-type: none"> 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. Provide input for FEA analysis
Geometry Export	<p>Export of the measured geometry in high precision.</p> <p>Three different DXF (Drawing Exchange Format) export options are supported:</p> <ol style="list-style-type: none"> 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 <p>There is also the option to export the geometry in STL (stereo lithography) format.</p>
Geometry and Vibration Export	<p>Export of 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 $H_x(f)=X(f)/U(f)$ 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).</p> <p>There are the following options:</p> <ol style="list-style-type: none"> 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. <p>EXAMPLE:</p> <pre> ;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 </pre>

```

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 from 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:

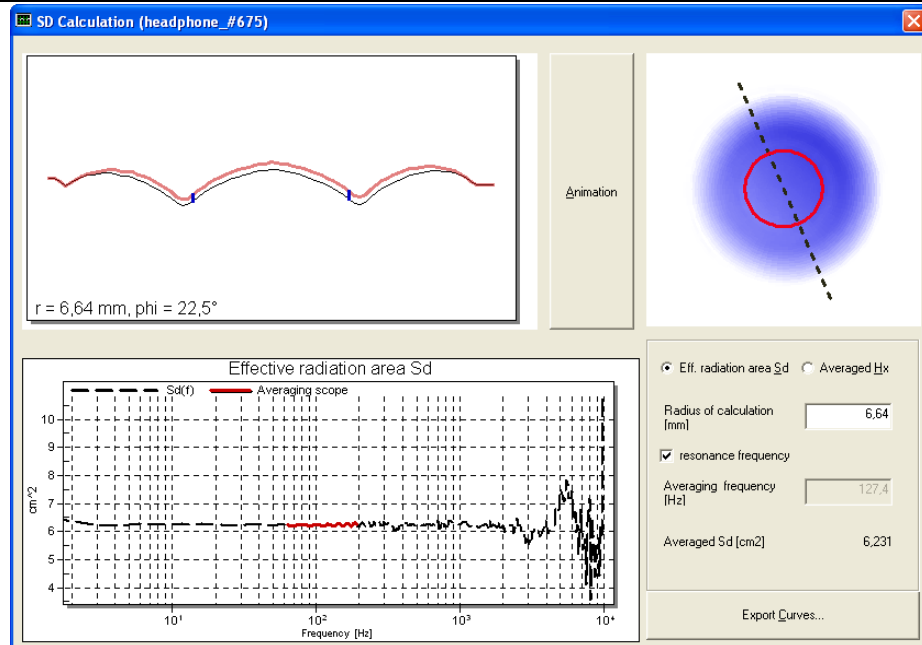
```

// -----
// 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=[

```


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 licence 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.

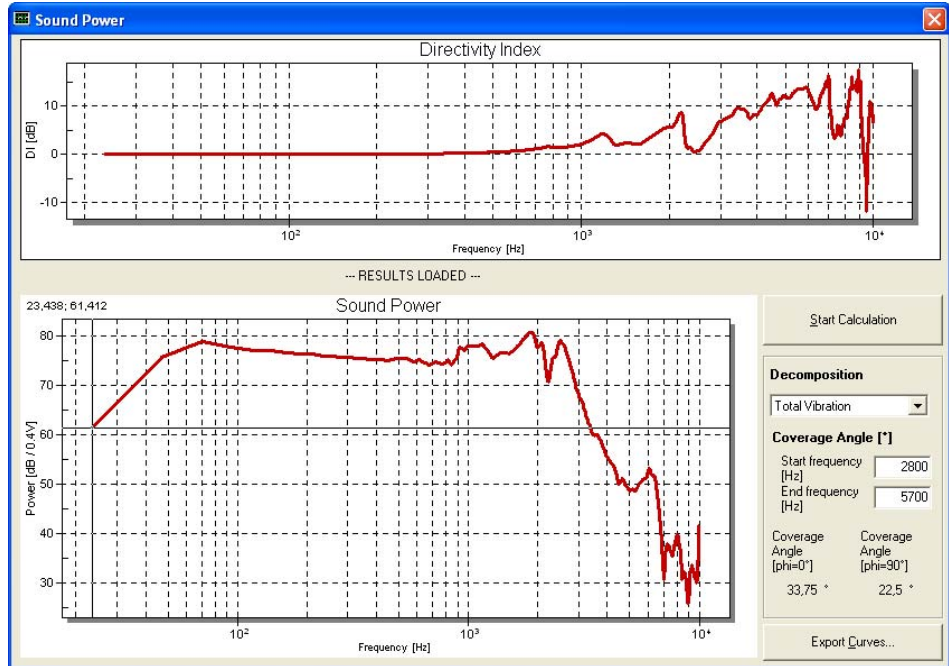
Displacement transfer function H_x

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.

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.

Typical Configurations

Components required	Scanning + Analysis	Only Analysis	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

Limits

DUT

Parameter	Symbol	Min	Typ	Max	Unit
Maximal Diameter	D			76	cm
Height	H			33	cm
Mass	M			70	kg
Steps in Cone Profile				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)				

Scanning Hardware

Parameter	Symbol	Min	Typ	Max	Unit	
Sensor	Non-contact triangulation displacement sensor					
Laser Protection Class	Class II, eye-safe, visible CAUTION ! Laser Radiation ! Avoid direct or indirect (e.g. reflection) exposure of human eyes to beam.					
Scanning Grid	Polar coordinate system (φ , r), tangential triangulation					
Vertical laser position (corresponds with height of DUT ⁵)	z	0		305	mm	
Free space between stands (corresponds with Diameter of the DUT) ⁵	d			760	mm	
Horizontal Shift (radius of circular area scanned)	r	0		300	mm	
Angle of turntable	φ	0		360	degree	
Error in z position	Δz		10	30	μm	
Error in r position	Δr		10	30	μm	
Error in φ position	$\Delta\varphi$		0.2	0.5	degree	
Error in measured Geometry ($0 < z < 10$ mm) ¹			5		μm	
Scanning Speed ²			0.3	1	points/s	
Time for profile scan (50 points) ³			10		min	
Time for explore scan (450 points) ³			1		h	
Time for detailed scan (3200 points) ³			8		h	
Time for geometry scan only (3200 points) ³			5		h	
Working distance of laser head, refer to A2 Laser Displacement Sensor	Keyence LK-G32	d	25	30	35 / 31.8 ⁴	mm
	Keyence LK-G82	d	65	80 / 68 ⁴	95 / 71 ⁴	mm
	Keyence LK-H052	d	40	50	60	mm

Sensor output	ac-displacement of target, distance to target				
lowest frequency displacement signal	f_{min}	0			Hz
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				

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 $f_{max}=10\text{kHz}$

⁵ The DUT (device under test) is placed on the turntable with the surface to be scanned on the upper side

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	$^{\circ}\text{C}$
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.					

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	$D\varphi$	1	80		
Manual grid control	<ul style="list-style-type: none"> remove/add single radii indicate critical radii (activate diving scanning mode) 				
Vertical control mode	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	

Vibration and Radiation Analysis (Results)

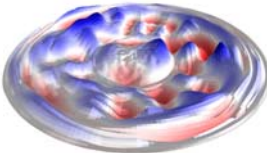
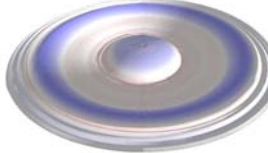
Parameter	Comments	Unit
Amplitude displacement transfer function	$H_x(f)$ for any cone point $\mathbf{c}(z, \varphi, r)$ for <ul style="list-style-type: none"> • Circular and radial vibration mode • In-phase component • Anti-phase component • Quadrature component 	dB (1 mm/V = 0dB)
3D Vibration Animation (Cone Surface)	Enhanced cone vibration at frequency f is superimposed with measured geometry Vibration can be decomposed in <ul style="list-style-type: none"> • Circular and radial vibration mode • In-phase component • Anti-phase component • Quadrature component Color Mode: <ul style="list-style-type: none"> • Phase • Amplitude (viewing angle and distance may be changed, rotation and scaling of DUT possible)	geometry and vibration is relative
2D Vibration Magnitude and Phase Plot	Magnitude and phase of vibration is plotted versus projected geometry Vibration can be decomposed in <ul style="list-style-type: none"> • Circular and radial vibration mode • In-phase component • Anti-phase component • Quadrature component Color Mode: <ul style="list-style-type: none"> • 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 <ul style="list-style-type: none"> • 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 $\mathbf{c}(z, \varphi, r)$	mm
Directivity plot	$\Gamma(\vartheta)$ at frequency f in plane at φ for <ul style="list-style-type: none"> • Circular and radial vibration mode • In-phase component • Anti-phase component • Quadrature component Averaged $\Gamma(\vartheta)$ at frequency f for all φ	dB
Total SPL response	SPL(f) at field point $\mathbf{r}(r_o, \varphi, \vartheta)$	dB
SPL response of in-phase component	$SPL_{in-phase}(f)$ at field point $\mathbf{r}(r_o, \varphi, \vartheta)$	dB

SPL response of anti-phase component	$SPL_{anti-phase}(f)$ at field point $r(r_o, \varphi, \vartheta)$	dB
SPL response of radial mode	$SPL_{radial}(f)$ at field point $r(r_o, \varphi, \vartheta)$	dB
SPL response of circular mode	$SPL_{circular}(f)$ at field point $r(r_o, \varphi, \vartheta)$	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

Setup Parameter Analyzer

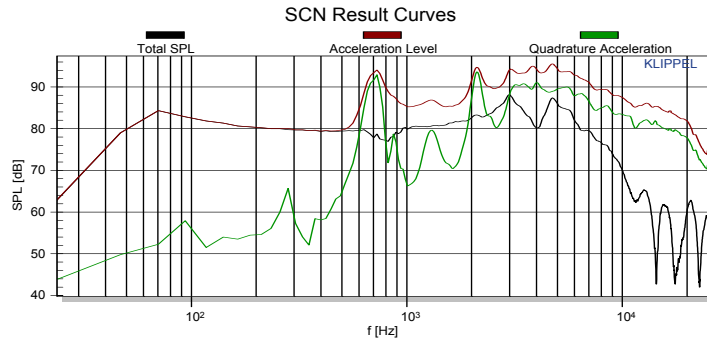
Parameter	Symbol	Min	Typ	Max	Unit
Frequency	f	f _{start}		f _{end}	Hz
Distance to field point r	r _o				m
Angle (off- axis)	ϑ	0		360	degree
Angle (of the turn-table)	φ	0		360	degree
Decomposition		<ul style="list-style-type: none"> • Radial, circular modes • SPL related (In-phase, Anti-phase, Quadrature) 			
Color Modes		<ul style="list-style-type: none"> • Amplitude • Phase 			
Modeling Modes		<ul style="list-style-type: none"> • 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)		<ul style="list-style-type: none"> • Mark interpolated points / mark sparse grid points • Increase visual grid resolution • Average directivity 			

Diagnostics

<p>Visualize regular vibration modes</p>	<p>The sound pressure output of axis-symmetrical cones depends highly on the regular modes which propagate in radial direction on the cone. The radial modes may be enhanced by using the decomposition technique. The measured behavior may be compared with the results predicted by axial-symmetrical FEA to show</p> <ul style="list-style-type: none"> • limits of the piston mode • first ring resonance, surround resonance, • bending modes • membrane modes <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;">  <p>Total vibration modes</p> </div> <div style="text-align: center;">  <p>Radial modes only</p> </div> </div>
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Separate Vibration and Radiation Effects

The Total Acceleration Level compared to the Total Sound Pressure level summarizes the effect of the surface motion on the radiated sound.

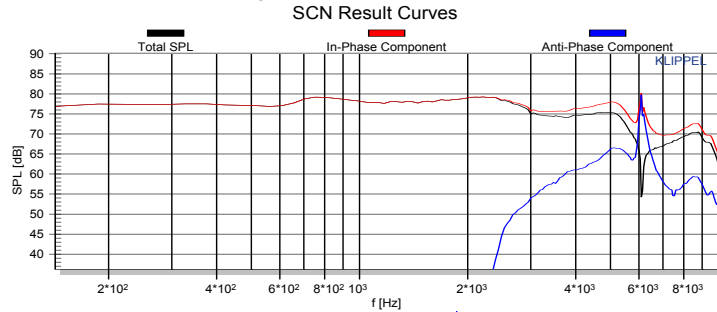


The quadrature acceleration shows the vibration level which does not produce any sound at the receiver point. It comprises asymmetric motions, rocking and motion where the surface vibration phase gets orthogonal to the radiated sound.

The frequencies and quality of the mechanical modes can be found easily from the total acceleration level.

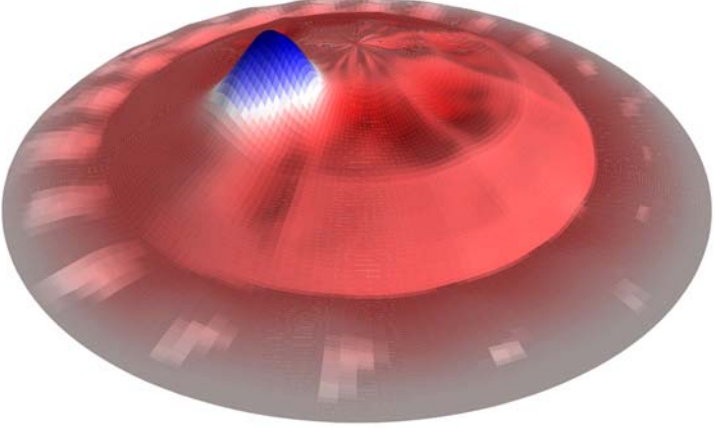
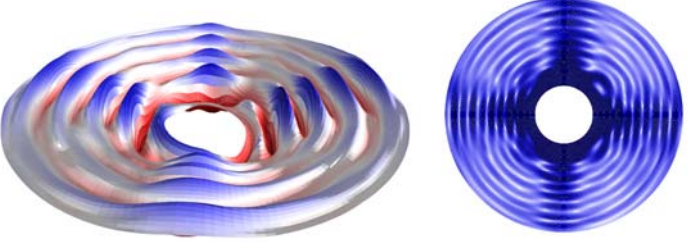
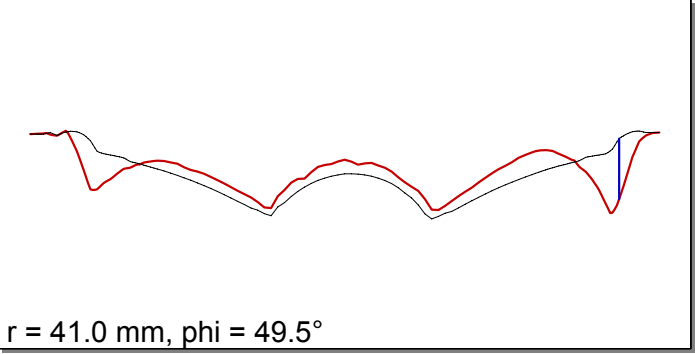
Analyze acoustical cancellation

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.



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 keep always a certain minimal distance between both components to avoid acoustical cancellation effects.

<p>Visualize irregular vibration behavior</p>	<p>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).</p>  <p>Diaphragm of a horn compression drivers with irregular thickness</p>
<p>Anisotropic materials</p>	<p>Some material used for loudspeaker cones, diaphragms have anisotropic properties which produce a vibration pattern which depends on the direction. For example the vibration of the Kevlar cone becomes maximal in the direction of the fibers.</p> 
<p>Localize Cause of Nonlinear Distortion</p>	<p>If cone or surround displacement is high compared to the geometry the cone behaves nonlinearly and produces nonlinear distortion of the output signal.</p> <p>Analysis: At critical excitation frequency search for regions of maximal displacement in the 3D surface animation or 2D profile animation.</p> <p>Target: Reduce the Quadrature and anti-phase vibration components which do not contribute to the SPL but generate nonlinear distortion.</p> <p>Remedy: Investigate design choices (different geometry and material) by using FEA</p>  <p>$r = 41.0 \text{ mm}, \phi = 49.5^\circ$</p> <p>The first bending anti-resonance produces high displacement and large bending moments at the outer rim of the cone.</p>

Rocking Modes

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

SCN Result Curves

Total SPL, Acceleration Level, Quadrature Acceleration, KLIPPEL

SPL [dB] vs f [Hz]

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.

r = 20.0 mm, phi = 270.0°

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

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.

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/docs/symbols.pdf>.