# LOUDSPEAKER CONE VIBRATION

FUNDAMENTALS | MEASUREMENT | DIAGNOSTICS

## Accumulated Acceleration Level

Definition

$$p_{aa}(\mathbf{r}_a) = \frac{\rho_0 \omega}{2\pi} \int_{S_c} \frac{|\underline{v}(\mathbf{r}_c)|}{|\mathbf{r}_a - \mathbf{r}_c|} dS_c$$

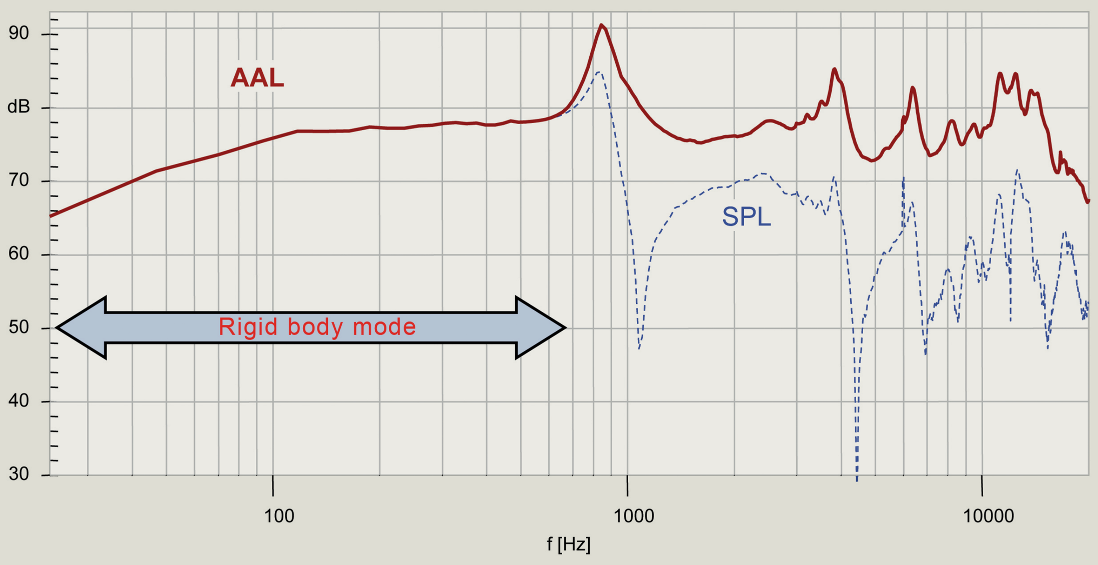
Absolute value of cone acceleration is accumulated over all points $\mathbf{r}_c$ on the radiator's surface $S_c$ weighted by the distance $|\mathbf{r}_a - \mathbf{r}_c|$ and further constants to be comparable with the sound pressure output at observing point $\mathbf{r}_a$ in the far field while neglecting any phase information.

$$AAL(\mathbf{r}_a) = 20 \log \left( \frac{p_{aa}(\mathbf{r}_a)}{\sqrt{2} p_o} \right) dB$$

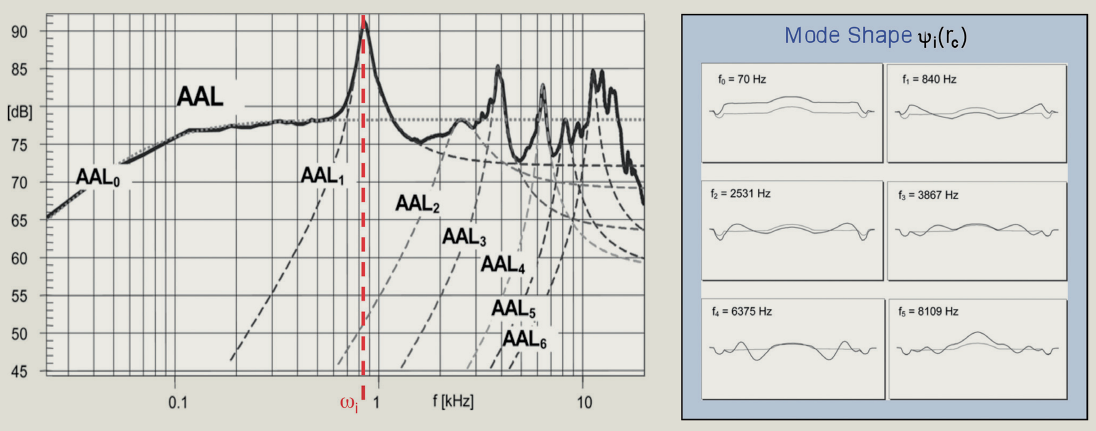
Reference sound pressure $p_0$

Accumulated Acceleration Level (AAL)

- describes total mechanical vibration
- is comparable with SPL($\mathbf{r}_a$) at point $\mathbf{r}_a$
- is never smaller than SPL($\mathbf{r}_a$)
- predicts potential acoustical output
- neglects acoustical cancellation
- is identical with SPL for a rigid body mode

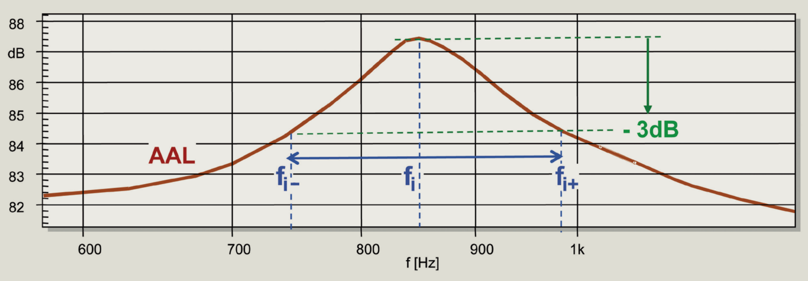



## Modal Analysis




$$\underline{a}(\mathbf{r}_c) = \sum_{i=0}^{\infty} \underline{H}_i(j\omega)\psi_i(\mathbf{r}_c) \qquad \underline{H}_i(j\omega) = \frac{\omega^2}{1 + \eta_i j\omega/\omega_i - (\omega/\omega_i)^2}$$

The acceleration a($\mathbf{r}_c$) of each point $\mathbf{r}_c$ on the radiator's surface can be expressed as a sum of orthogonal modes whereas each mode is represented by a characteristic mode shape $\Psi_i(\mathbf{r}_c)$, natural frequency $\omega_i$ and a modal loss factor $\eta_i$ in the modal frequency response $\underline{H}_i(j\omega)$.

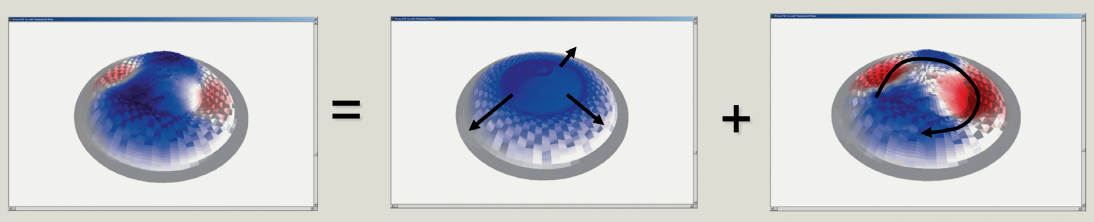



$$\eta_i = \frac{f_{i+} - f_{i-}}{f_i}$$

Modal Loss Factor

- is defined as 3 dB bandwidth at the modal resonance divided by natural frequency
- describes the used material (independent of the geometry)
- depends on frequency and temperature

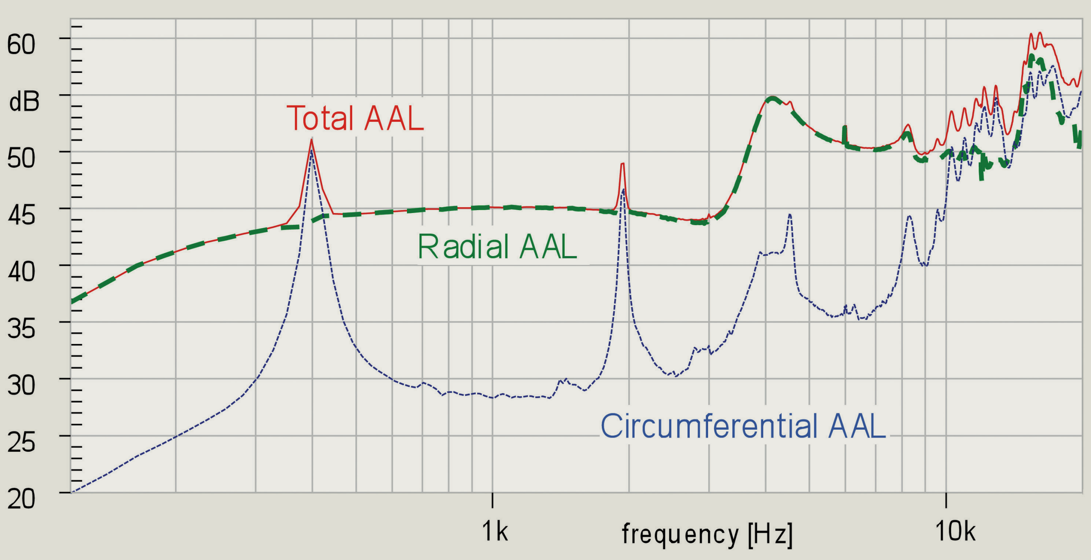
## Axial-Symmetrical Decomposition



Total vibration = Radial vibration modes + Circumferential vibration modes

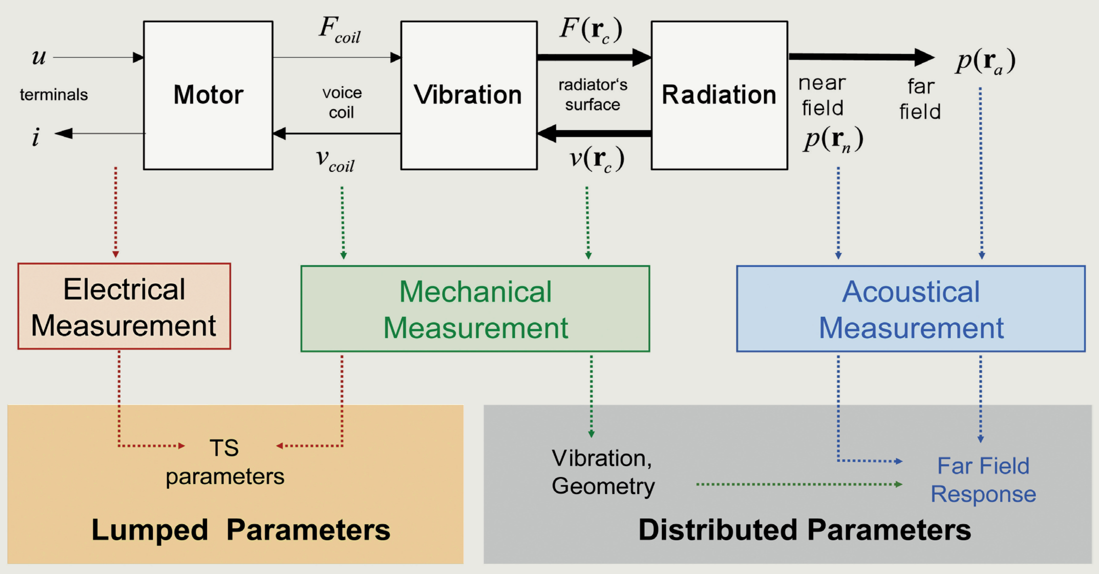
$$\underline{v}_{total} = \underline{v}_{circ} + \underline{v}_{rad} \qquad \underline{v}_{rad} = \frac{1}{2\pi}\int_0^{2\pi} \underline{v}_{total}(\varphi) d\varphi \qquad \underline{v}_{circ} = \underline{v}_{total} - \underline{v}_{rad}$$

If the radiator has a round shape the modes propagating in radial direction can be calculated by averaging the vibration versus the circumference. The circumferential component is the difference between total vibration and radial component. Both components can be separately animated and assessed by SPL and AAL quantitatively.




## Loudspeaker Measurements

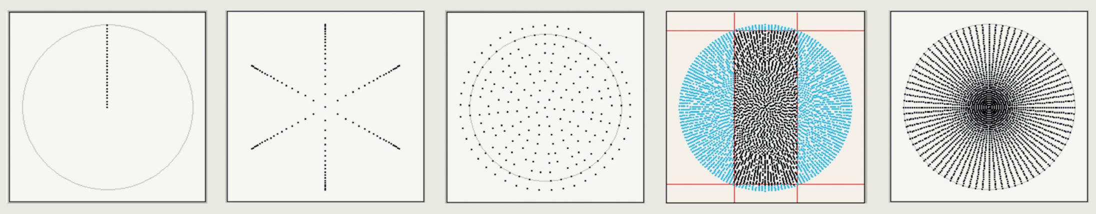
for assessing small signal performance




Distributed Loudspeaker Parameters

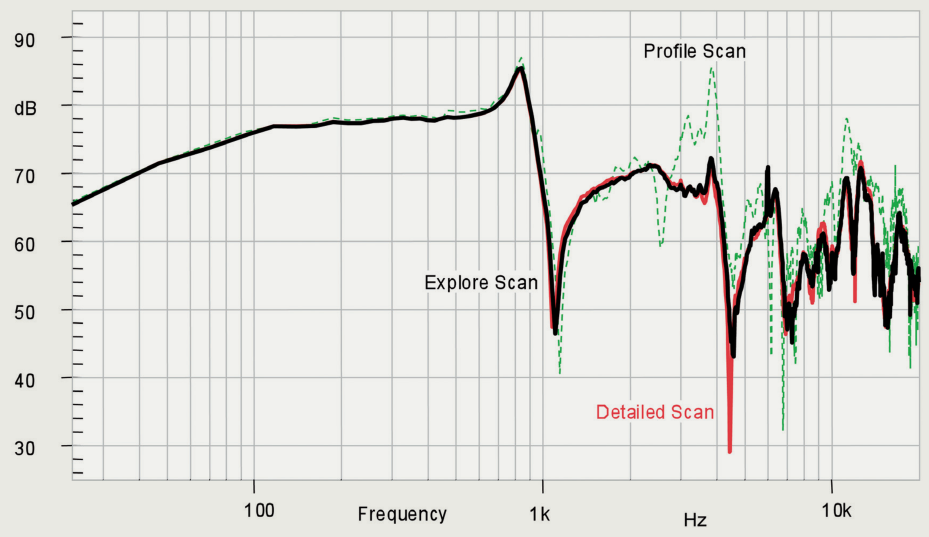
A laser triangulation scanner provides Vibration and Geometry of the radiator's surface to high accuracy. These mechanical distributed parameters are important data for assessing the mechanical behavior, predicting the sound pressure output and selecting optimal transducer for the particular application.

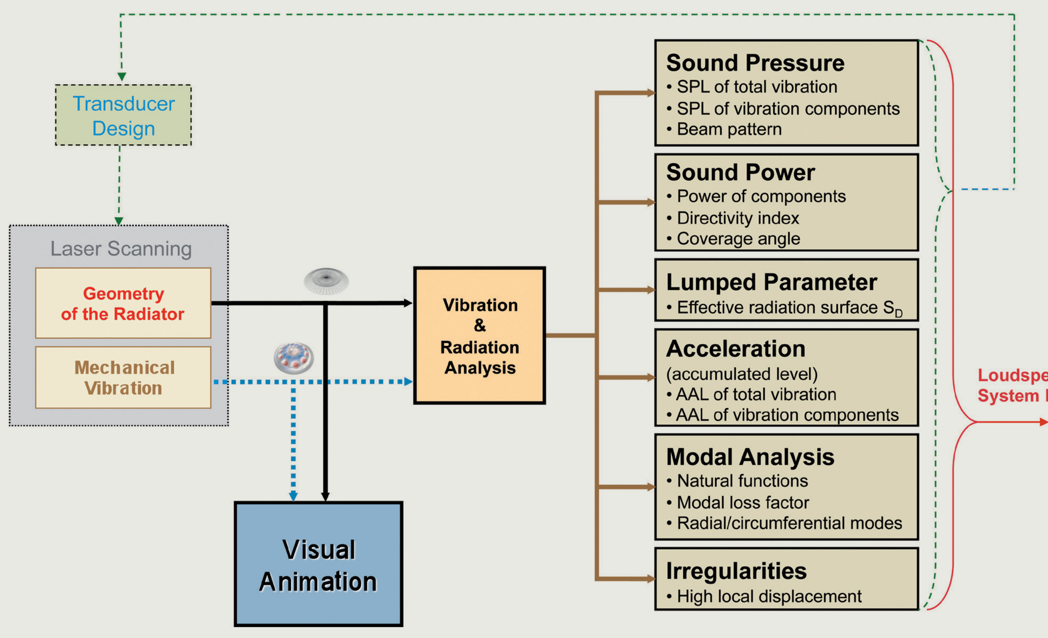
## Optimal Scanning Grid



Profile Scan (27 points) | $S_d$ Scan (100 points) | Explore Scan (226 points) | Rectangular Scan (2000 points) | Detailed Scan (2900 points)

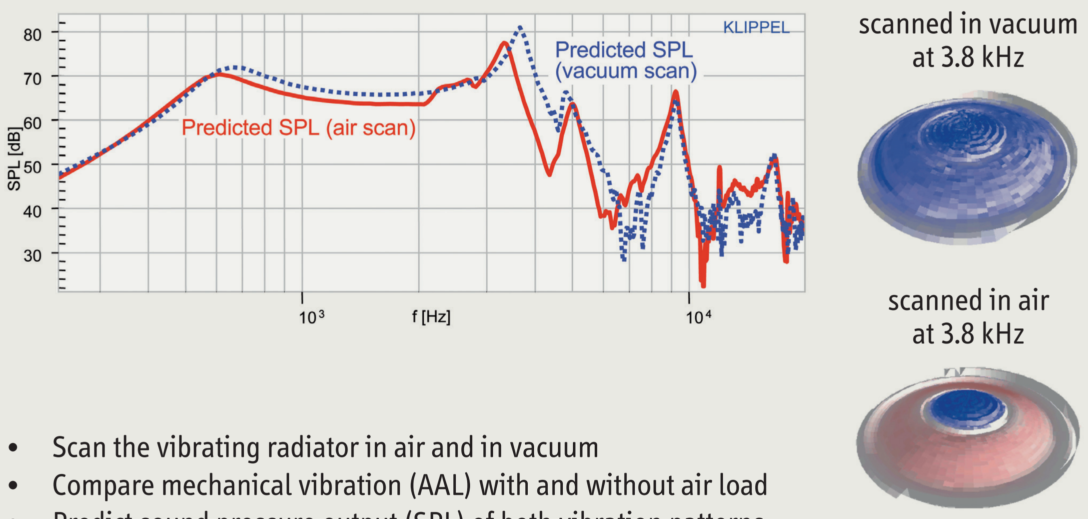
The resolution of the Explore Scan is sufficient to predict the sound pressure output to high accuracy. The Detailed Scan reveals local displacement and other irregularities to high resolution. The Profile Scan can only detect axial-symmetrical vibrations and the accuracy of the predicted sound pressure may be affected by circumferential modes (see deviation at 3.8 kHz below). The Rectangular Scan is time efficient for TV and micro-speakers.




Mechanical and acoustical characteristics derived from the results of laser scanning are helpful for selecting the optimal transducer for the particular application and to develop constructional improvement and alternative design choices.

## How to Measure the Influence of the Air Load?



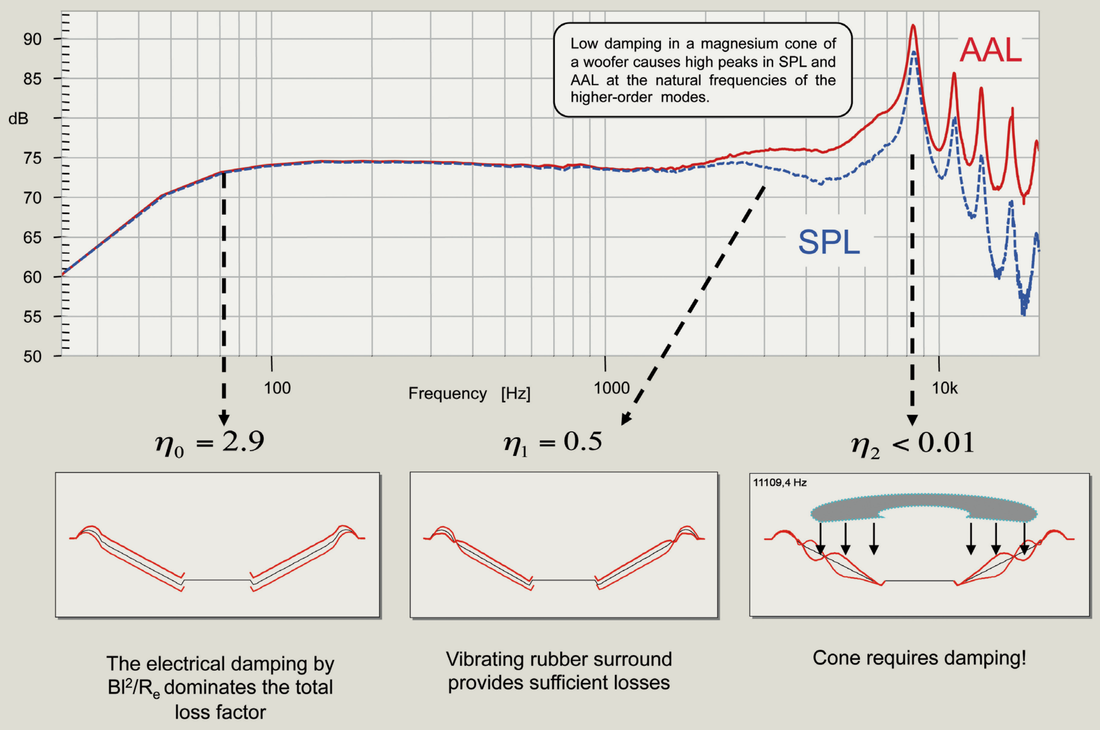

- Scan the vibrating radiator in air and in vacuum
- Compare mechanical vibration (AAL) with and without air load
- Predict sound pressure output (SPL) of both vibration patterns

## Enough Vibration on the Radiator's Surface?

Check for sufficient Accumulated Acceleration Level (AAL) at higher frequencies where higher-order modes generate the sound pressure output. High density of modes each having an optimal loss factor is a prerequisite for a smooth SPL response. The number of bending modes may be increased by using a material with a lower Young's E modulus and reducing the thickness of the cone and the curvature of the radiator in the outside area.

## What Causes Peaks in Frequency Response?

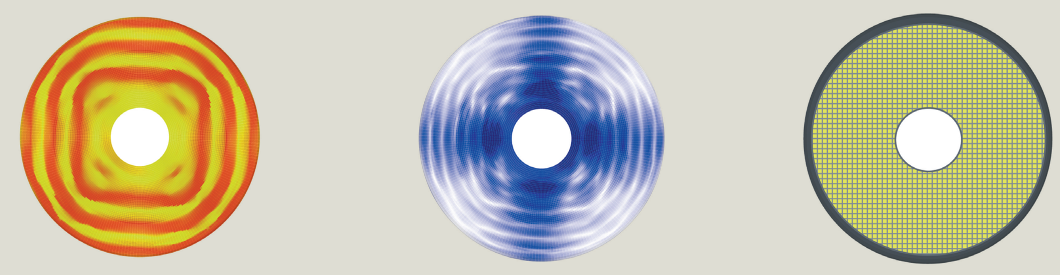
High values of the Accumulated Acceleration Level (AAL) corresponding with excessive peaks in the SPL response are caused by modal resonances having not enough damping. Determine the modal loss factor at the critical natural frequencies by reading the 3 dB bandwidth in the AAL response.




## Where to Apply Damping?

View the mode shape at the critical resonances where the modal loss factor is too small. Increase the damping in the material where the amplitude of the mechanical vibration is high. Magnesium used as cone material shifts the first break-up to 8 kHz shown in the example above. Additional damping would be required to use this transducer over the full audio band.

## Unexpected Properties of the Material?

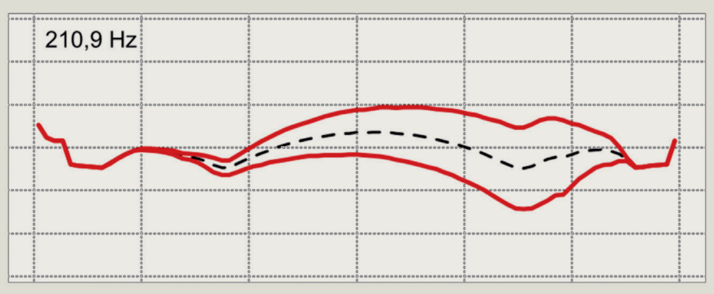


Phase distribution | Amplitude pattern | Fibre structure of the Kevlar material

Scanned vibration pattern reveals anisotropy, inhomogeneity and other special properties of the material used for the radiator. The example above shows the vibration pattern of a midrange driver using a Kevlar cone. The woven structure of the Kevlar cone suppresses the vibration in the diagonal direction affecting the polar pattern of the loudspeaker.

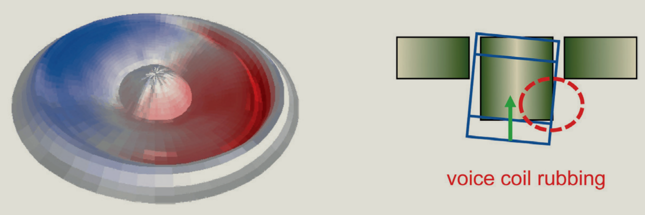
## Asymmetrical Vibration?

Asymmetrical Motion



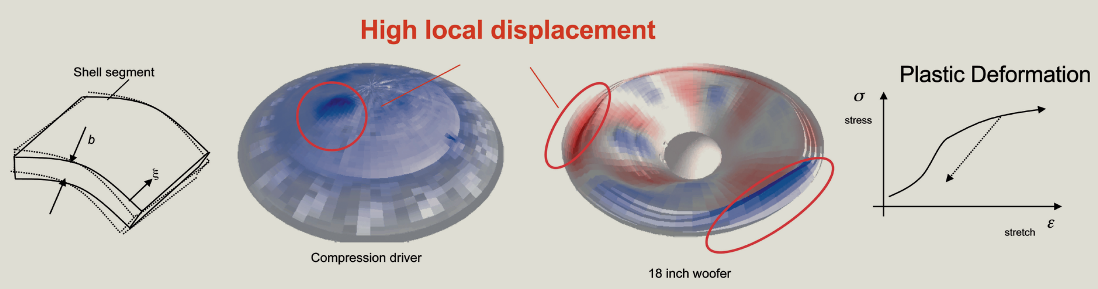

Irregularities in the manufacturing process may cause an uncontrolled vibration of the diaphragm (example: headphone transducer).

## Is the Rocking Mode Too High?




Rocking mode is usually the first circumferential mode which may cause voice coil rubbing. Check that AAL of the quadrature or circumferential component is at least 10 dB below the total AAL!

## What Causes Nonlinear Distortion?

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KLIPPEL Application Notes:

- AN 30 Scanning Rectangular Speakers
- AN 31 Cone Vibration and Radiation Analysis
- AN 24 Measurement of Telecommunication Drivers
- AN 32 Effective Radiation Area Sd
- AN 34 Mean SPL in a stated frequency band
- AN 35 Effective Frequency Range
- AN 38 Near Field Measurement of Systems with Multiple Drivers and Ports
- AN 39 Merging Near and Far Field Measurements
- AN 40 Frequency Response Smoothness

References:


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