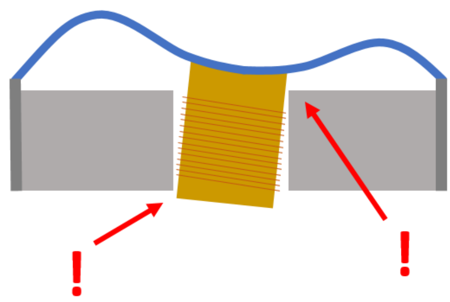
Rocking mode analysis (RMA) AN-80

Module RMA of the KLIPPEL ANALYZER SYSTEM (Document Revision 1.0)

Avoid problems with rocking modes

- **Increase production yield rate**
- **Ensure speaker reliability**
- **Identify root causes**
- **Find remedies**

Rubbing of the voice-coil due to rocking modes!



This application note demonstrates how to solve problems with rocking modes in electrodynamic loudspeaker transducers, with special attention to headphones and microspeaker drivers. Rocking modes (oscillating tilting motion of the diaphragm) at large amplitudes are highly undesired since they can cause impulsive signal distortion, limit the usable output and reduce the durability of the transducer.

Furthermore, the process how to select suitable test objects and assess the severity of the rocking problem on them is described. Using the dedicated software tool *RMA* (available as a module for the *KLIPPEL Analyzer System*) the dominant root cause for the excitation of the rocking can be identified.

RMA will quantify the imbalances in the distribution of moving mass, suspension stiffness and electrodynamic motor strength Bl. It will also indicate the direction where the problem is located on the diaphragm. This leads the way to identify weaknesses in the design and the manucaturing process of the transducer, so that remedy can be developed.

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CONTENT

1 Introduction

Rocking behavior (when the inner part of the diaphragm is tilted as a solid body while the suspension is deformed) is a highly undesired effect in electrodynamic transducers.

A strong rocking mode will affect the *stability* of the driver and might tilt the voice coil so much that it triggers collisions with the surrounding pole pieces, causing *impulsive distortion*. Since these modes are usually highly undamped, small errors in design or production can trigger problems – especially for headphone transducers and microspeakers. Their thin build in relation to diameter, combined with relatively simple suspensions without stabilizing spider makes them sensitive to voice-coil rocking.

The *KLIPPEL Rocking Mode Analysis* module (*RMA*) focusses on the most frequently occurring *root-causes for excitation of rocking-modes*: Inhomogeneous distribution of *mass* ("M"), suspension *stiffness* ("K") and electromagnetic *motor strength* ("Bl"). Each of these imbalances is capable to hold back one side of the diaphragm which converts the axial driving force from the voice-coil into a tilting momentum that excites the rocking. RMA is designed to quantify this effect and identify the main root-cause contributing to it.

In this AN you will learn how to use *RMA* to

- Determine the **severity** of the problem
- Investigate, identify and quantify the **physical root-causes**
- Locate the **imbalances** on the diaphragm
- Assess your design and the **stability of the manufacturing** process
- **Find remedy** for your problem
- Perform **good quality measurements** on rocking modes with less than 10 minutes scanning time.

This document aims to support a structured process of working with rocking mode issues. Where possible we will offer guidance by rules of thumb for practical design. To get a quick overview, just read the bold text in the left column. More details can be found further right and, where needed, in exact references to the *RMA* manual.

2 Basic analysis in *KLIPPEL Scanning System* Software

2.1 Selection of suitable DUT

The first step is to select a meaningful candidate for your in-depth-analysis of rocking modes.

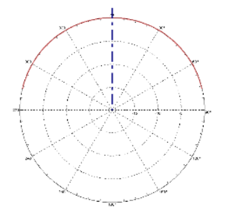
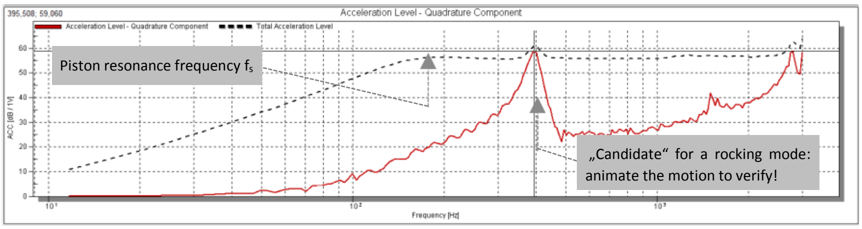
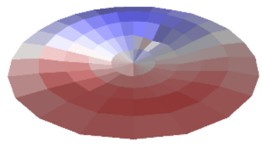
Select a suitable transducer to be analyzed	Especially interesting candidates for deep analysis of *RMA* are: • Golden DUTs – "How good is your product on average?" • Defective DUTs that have been sorted out at production line due to failures for impulsive distortion, rub and buzz – "What made it fail? What to improve?" • R&D prototypes – "How good is this design? Systematical problems?" NOTE: Your DUT should not be the complete speaker, but the transducer alone.

2.2 Acquisition of scanning data for a first overview

For rocking-mode-analysis you need distributed vibration-data of your loudspeaker diaphragm. You can record data either with a *KLIPPEL Scanning Vibrometer SCN* or a *Polytec LDV* device. In the last case data can be imported to the *KLIPPEL SCN* software using the module *Poly2SCN*.

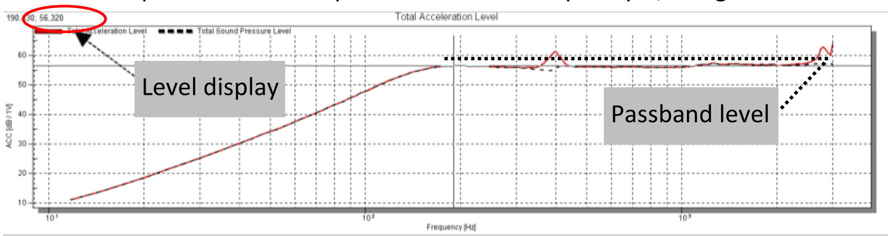
Start the *KLIPPEL SCN* software and open a scan-file of your transducer	Virtually any kind of scan (except line-scan) can be used as long as it includes the frequency range 1 octave below and 3-4 octaves above piston resonance frequency. In case you do not have any scanned data yet, we recommend you to set up a new measurement using the step-by-step instruction in chapter 5 of this application note.

2.3 Find rocking frequencies

In the *KLIPPEL SCN* software: Make sure you are showing data "on axis"	Switch over to tab "radiation analysis". In the left diagram showing the polar plot, make sure that the directional cursor is set to on-axis-position (0°) [blue dotted line pointing straight up – drag with your mouse to move it if needed.] Switch back to tab "animation". 
Investigate peaks in on-axis quadrature component of the spatially averaged acceleration level AAL [1]	Select the following settings (in the grey shaded area to the right of the screen): Modelling mode > *Acceleration*, Decomposition > *SPL-related*. Choose "*Quadrature component*" from the dropdown menu below. In the diagram "*Acceleration level – Quadrature Component*" in the lower part of the screen look for peaks in the red curve that appear relatively close to the fundamental piston resonance frequency of the speaker. Click on the peak to set the cursor to that respective frequency. 
Check whether the peak actually belongs to the rocking modes[1]	Press the button "*animation*" to the right and search for tilting oscillation of the diaphragm without deformation. Repeat the process of picking different frequencies with the cursor until you have found the rocking modes. You might have to carefully increase "amplitude enhancement".  Note down the rocking frequency and piston mode resonance frequency.

2.4 Assess severity: Relative rocking level

Relative rocking level (RRL) compares the averaged acceleration levels AAL of the rocking modes with the piston mode and serves as an indicator for the severity of the problem.

Read relative rocking levels from the AAL diagram	In the diagram "*Acceleration level – Quadrature Component*", note the maximum AAL of the rocking mode with your cursor. It will be displayed in the upper left corner. In the dropdown menu "*Decomposition*" to the right, select "*Total vibration*". Read and note the passband level at piston resonance frequency f_s, using the cursor.  Calculate relative rocking level: $RRL=AAL_{Rockingmode}-AAL_{Passband}$
Rule of thumb:	*If your RRL is larger than -20 dB[2], your rocking problem shall be analyzed in detail.*

[1] There are always two rocking modes. They will lie so closely together in frequency that they most probably will not be visible separately in the *SCN* software due to a rough frequency resolution.
[2] Only in rare cases, with extraordinarily narrow clearances in the magnetic gap, even lower values might be necessary.

3 Root-cause analysis with *KLIPPEL RMA* module

Now that you have a rough impression of how large the rocking problem is, we will look for solutions using the dedicated software module *RMA*.

Example RMA operations for evaluation can be found in the *dB-Lab* example database in section *Scanning Laser Vibrometer (SCN, RMA, HMA) > Rocking Mode Analysis (RMA).* Double-click on the *RMA* operation in *dB-Lab* to open the result windows.

The RMA user interface is centered around the result window "Summary" which gives a condensed overview of all important results. It is designed to answer three key questions in sequential order.

How severe is the rocking problem?	Here we start again with "Relative Rocking Levels RRL". This is very similar to step 2.4 above, but a more exact view on both[3] rocking modes separately. The table shows which of the modes oscillates at higher amplitude (dominant mode), states its resonance frequency and how the main tilting axes is oriented. The severity is graded on a 4 step scale.
Which is the dominant root cause?	This is answered by the "Combined Force Ratio CFR" below. It describes the strength of excitation from each type of evaluated root-cause - distribution of mass (m), suspension stiffness (k) and electrodynamic force factor (Bl). The CFR quantifies the magnitude of the forces that excite the rocking in relation to the axial forces driving the piston mode (voice coil force). The ratio is given in percent. The table indicates the dominant root cause.
Rule of thumb:	*To avoid problems with rocking, the CFR should usually be kept smaller than 1%.*
Where is the imbalance located on the diaphragm?	At the bottom of the window you find the imbalance diagram. It states the position[4] where the respective centers of the distribution of mass (=center of gravity), stiffness and electrodynamic force factor Bl are located on the diaphragm. This offers valuable information about where to search for the underlying problem in design or manufacturing. A black dotted line indicates the main direction of motion for rocking mode 1 and a double-dotted line for mode 2.
Optional: Detailed modal parameters for rocking mode 1 and 2	The result windows "Rocking mode 1/2" offers more details on the separate modes. The mode-shape view at the top shows the orientation of the modal displacement together with the active measurement points of the scanning grid. At the bottom of the page you find parameters of the rocking resonator. The Q-factors and modal gain give an impression of the damping of the modes, which is usually very low.
Measurement issues? Can I trust the result? How to improve?	*RMA* extracts diagnostic information from measurement content that is many dB weaker than the response of the piston mode. Therefore, it may not always be possible to identify results with good accuracy. In cases of reduced accuracy, you will note that the fitting between the dotted (measured) and solid curves (modelled) in result windows "AAL total" and "Fitted Phase" is less close. This effect scales with the quality of the input data. *RMA* assists the user to get the best possible result by the following means: • *RMA* features a thorough feedback-system relying on a four-step grading that allows the user to assess the quality of its result. It is found in the result window "Errors/Warnings". • If the deviation is too large, it will raise a warning. • In case a warning is raised, the module offers guidance on what can be done to improve the accuracy of the result. Section 5 of this application note provides a step-by step instruction on how to generate high-quality input data for *RMA*, while keeping scanning times low (<10 min).

[3] Since both the acoustical load and the shape is highly symmetrical on headphones, we often only see one dominant rocking mode.
[4] The angular information is given relative to the position of the loudspeaker on the *SCN* turntable during the scan. The distance stated under "Imbalances" is relative to the geometrical center of the transducer.

More details on result variables can be found in the *RMA* manual section “Tutorial 1 – Viewing the results”.

ALL IMPORTANT PARAMETERS ON ONE PAGE

RMA Result

Severity: Relative Rocking Levels RRL

Description	Frequency [Hz]	Direction [°]	RRL [dB]
Rocking mode 1 (Dominant) (Details)	**151**	**9**	**8.9**
Rocking mode 2 (Details)	129	99	-9.5
Piston mode 0	79	-	0 (= ref.)

Rocking excitation: Combined Force Ratio CFR_E

For f_m = 139 Hz, d_{ref} = 16 mm

Description	Parameter	Value [%]	Dominant Excitation
Mass	CFR_M	1.89	
Stiffness	**CFR_K**	**2.66**	**Stiffness asymmetry**
Bl	CFR_{Bl}	- no indication -	

The contribution that induces the largest excitation force for rocking motion at f_m is most beneficial to improve ("dominant excitation").

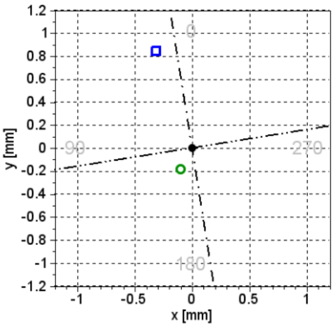
Root causes: Imbalances

Offsets in the distributions of mass and stiffness from the geometrical center of the diaphragm.

Description	Parameter	Mark	Offset [mm]	Direction [°]
Center of Mass	d_M	O	.21	152
Center of Stiffness	**d_K**	**□**	**.9**	**21**

In this example, the dominant root cause is an asymmetric distribution of suspension stiffness with the stronger side shifted towards the “North” direction (21°) on the turntable of the *KLIPPEL Scanning Vibrometer*. The influence of the Bl imbalance was very small.

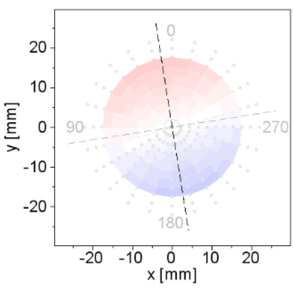
IMBALANCE CENTER POSITIONS



MODE SHAPE VIEW

Rocking Mode 1 (Dominant)

Resonance frequency f_1 = 151 Hz, Orientation α_1 = 9°



4 Searching for remedy

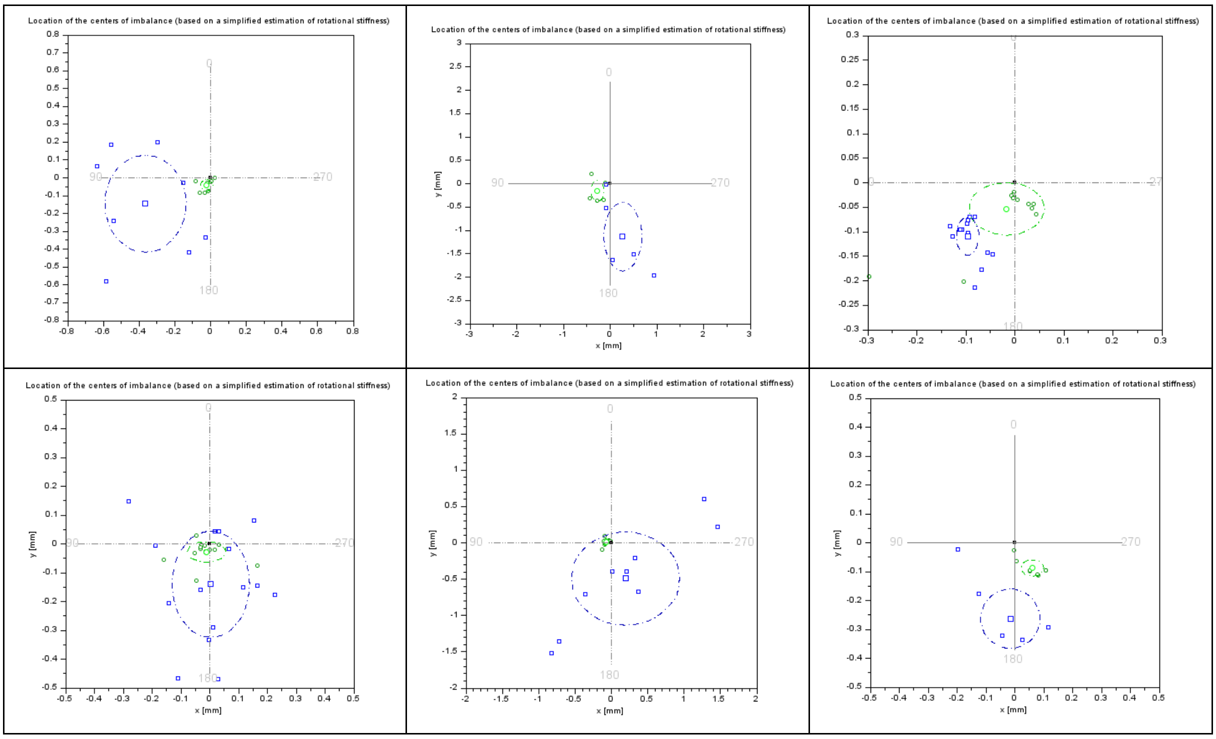
From the *RMA* result above, we know the character of the disturbance and the direction where its center is located on the diaphragm. From here, we recommend the following next steps to find and solve the underlying problem.

<table>
<tr><td>Understand the nature of the problem. Is it systematic? Design or manufacturing flaw?</td><td>Measure more units out of the same group (defective units, golden units, if available) with RMA to find out whether the effects are systematic, reproducible and representative.
Do they point to the same dominant root cause?
In the same direction?
How large is the spread?
Large spread indicates that the stability of the production process is low. If the same effects reappear systematically, this may both be introduced by design or manufacturing.</td></tr>
<tr><td>Investigate direction of dominant imbalance on measured DUTs</td><td>If it can be confirmed that the effects are systematic, search for corresponding underlying faults in design or manufacturing process in the same direction as the dominant imbalance is indicated in the RMA imbalance diagram. Investigate the exact samples that have been measured.
Check the following list of frequent reasons for imbalances:
Voice-coil-leads
Anisotropies in the construction materials</td></tr>
</table>

4 Searching for remedy

	• Non-symmetrical acoustical loading • Errors in the assembly process • Glue-inhomogeneities • Tensions in the diaphragm • Uneven gap geometries or deformed voice-coils • Any other source of asymmetry in the design
Virtual experiments	If you have asymmetries in the design that cannot be avoided and need to find other ways to counteract the effects, consider experimenting with an FEA model. Add the systematic imbalances as additional excitation terms.
Physical experiments	In case of a dominant mass-imbalance, you can experiment with your physical speaker. On stiff diaphragms (e.g. microspeakers) you can counterbalance with a small point mass of clay in opposite direction. This allows you to experience the imbalance physically “at your fingertips” and you can remeasure your speaker afterwards to evaluate its performance without the mass-imbalance.

Below you can investigate the locations of the centers of imbalance of different batches of headphone and microspeaker transducers, considering only mass (green) and stiffness (blue) imbalances. The dashed ellipses indicate the variance of the positions in x-and y directions.



Reviewing the patterns above gives an immediate impression of the stability and spread of the production process and shows whether the problems are systematic or random. The user also gets a clear indication in which direction to search for the underlying root-cause in design or manufacturing. Repeat the measurement series after making a change to track the progress.

This concludes the analytic part of this application note. The following last section provides a step-by-step guideline to measuring good quality input data for *RMA*.

5 Measurement system setup for *RMA*

We have highlighted the importance of good quality input data for *RMA*. Our following instructions will guide you through the setup step by step. Data can also be imported from *Polytec LDV* devices using our bridge-module *Poly2SCN*. The following two pages offer a condensed checklist for use on your measurement lab wall.

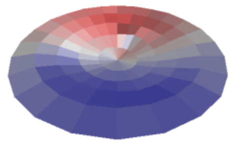
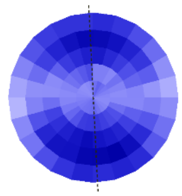
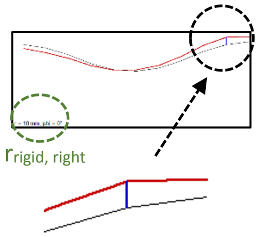
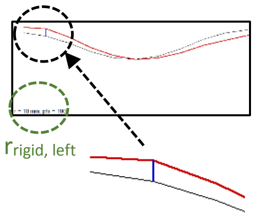
5.1 Setting up the *KLIPPEL Scanning Vibrometer*

These settings are suitable for both headphone transducers and microspeakers – only the scanning grid and the geometrical settings in *RMA* differ slightly (for rectangular diaphragm-shape). Where the instructions below are kept too short, please refer to the more in-depth explanations in tutorial 2 of the manual for the *KLIPPEL RMA* module. We will reference to it here under the acronym ("RMATut2"). See section 6.2 for references.

Prepare your DUT (headphone transducer) for scanning	Gain direct optical access to the diaphragm of the transducer by removing any covers or grilles of your headphone. Detach any acoustical resonators (back-cavities etc.) Treat the DUT with white laser-spray recommended by *KLIPPEL*, so the diaphragm is non-transparent, highly diffusely reflective and particle-free. Spray it thin, but opaque. > RMATut2 step 2
Initiate a new scanning process and mount DUT	Use an appropriate mounting for your headphone transducer to prevent it from undesired travelling and to avoid any artificial air-cavities behind the DUT. If you use a clamping device like the *KLIPPEL Microspeaker Stand*, make sure to clamp the DUT only very lightly, since headphone transducers react very sensitive to deformation of their rim**.** (Otherwise you might change their rocking behavior significantly.) > RMATut2 step 3 and 4
Perform an *LPM*[5]	Measure the centerpoint of the diaphragm. If possible, do not move DUT before scan. > RMATut2 step 5-7
Set *TRF* settings	Always use a stimulus voltage shaping of 5 dB/octave! The measurement frequency range (recommended resolution: 3 Hz) shall include approx. 1.5 octaves above and below both piston resonance and rocking resonances. A max frequency of 6 kHz will be sufficient in almost all cases. Choose excitation voltage so that max displacement is similar to *LPM*. A general recommended excursion range for *RMA* measurements on headphones is 0.025 - 0.1 mm. Do not exceed this range. This is a very important step – make sure to follow instructions in the manual! > RMATut2 step 8
Check S/N ratio	If S/N ratio should not be sufficient (<8 dB) within the required frequency range (see definition above), check remedy proposed in the manual. Also Check whether your laser is sufficiently accurate to measure headphones. Exit setup with "OK". > RMATut2 step 9
Select scan mode	Choose "*Vibration and geometry*". "*Flat scan"* suits most headphones > RMATut2 step 10
Define grid setup	Choose radius step-size so that you get at approximately 6 points in radial direction from the center until the highest point of the surround. Choose 6 angles (60° resolution) in angular direction. This is sufficient for headphones and keeps scanning times down. > RMATut2 step 11
Start the scanning process	Follow the further instructions on the screen and start the scanning process. A usual scan for *RMA* should finish within approximately 10 minutes. Remember to make a note (e. g. photo) how the transducer was oriented on the turntable of the *SCN*.
Consistency check of your scan	Check that your new scan data is valid at all scanned frequencies. Perform a consistency check using part 2.3 and 2.4 in this Application Note.
Remove artifact points and export data from *SCN*	Open menu "Export" > "Export ASCI…"> Select "Polar Grid" and "Interpolated Data" and press "Start". This will generate a file with ending .sce. You will later load it into *RMA*. > RMATut2 step 17-18

[5] May be skipped if you know your laser delay well and have already measured another DUT of the same batch. See section 5.2 below.

5 Measurement system setup for RMA

Measure the rigidly oscillating radius r_{rigid} of your diaphragm at rocking frequency	The value r_{rigid} that we determine here is an important input parameter to the *RMA* module. Note that r_{rigid} is different from and smaller than the maximum dimensions of the diaphragm. Go to tab *Animation* in your *SCN* software to set the cursor at rocking-frequency of the quadrature AAL (compare section 2.3 in this AN). Animate to verify rocking. Switch to tab *Radiation Analysis* and orient the black dotted line in the direction of the maximal rocking amplitude (where the blue color has maximum intensity). Switch to tab *Cross-section view* and animate the motion. Pause the animation at maximum displacement. Locate the outer end of the rigidly oscillating area of your diaphragm. Click on that point to set a cursor (a blue line appears) and verify by animation that you are still within the undeformed region. Beyond your selected point you shall see a distinct change of curvature during one oscillation cycle. Read the radius value in the lower left corner of the animation window. Read also the respective maximum undeformed radius on the other side of the membrane, again using the cursor. If the radius readings on both sides deviate, note down the smaller one. $r_{rigid}=\min(r_{rigid,left}, r_{rigid,right})$. > RMATut2 step 16	   

5.2 Setting up the *RMA* module in *dB-Lab*

The detailed step-by-step instruction for this part is located in tutorial 2 of the *RMA* manual under headline *"Starting and setting up the RMA"*

Open properties of *RMA* operation	Mark the *RMA* operation in *dB-Lab* and right-click on it to select "properties". (Alt+ Enter) > RMATut2 step 18
Tab Input: Specify *SCN* file, *LPM* operation and laser delay	• *SCN*: Load the .sce file that has been generated in part 5.1 above. We recommend to store it in your database. To do so, press "*Load to SCN Datacontainer".* • *LPM*: Select your previously performed measurement. Laser delay: Automatic. • If you are sure about the delay of your laser setup (take average of info given in "Errors/Warnings" of some executed *RMA* operations), specify it manually. In this case it is accurate enough to use an *LPM* belonging to a different DUT the of same batch. > RMATut2 step 19
Specify the geometry of your DUT	Choose diaphragm geometry in the dropdown menu of *RMA* property page. "Circular" is usually appropriate for headphones and "rectangular" for microspeakers. Specify the rigidly oscillating radius r_{rigid} of your DUT. It has been determined in the last step of section 5.1 in this AN. For rectangular speakers please refer to the manual. > RMATut2 step 20
Set processing parameters	Set computation frequency range. It shall include 1.5 octaves above and below both rocking mode resonance frequencies (see section 2.3 of this AN) and the piston resonance frequency (see *LPM*). Use computation speed "normal". > RMATut2 step 21
Run *RMA*	Close the *RMA* property page and start the computation.

6 References

6.1 Related Modules	• *KLIPPEL Scanning* vibrometer *SCN* • other SCN modules (*Higher Modal Analysis HMA*, *Polytec LDV* Import *Poly2SCN*), *Transfer function measurement TRF* • *Linear parameter measurement LPM*
6.2 Manuals	*RMA* Manual – Tutorials in *dB-Lab* Online help: *> Scanning Vibrometer & Part Measurement > RMA – Rocking Mode Analysis > RMA Tutorial* • *Tutorial 1 – Viewing the results* • *Tutorial 2 – Generating RMA results step by step (>"RMATut2")* *KLIPPEL* training #2: http://www.klippel.de/know-how/education/trainings.html
6.3 Publications	[1] Information about AAL: Standard IEC (E) 60268-22 [2] Diagnostics on Cone Vibration and Sound Radiation, W. Klippel, J. Schlechter, AES Convention paper 2008 [3] Modeling of rocking modes in Electro-Acoustical Transducers, W. Klippel, W. Cardenas, JAES Volume 64 Issue 12 pp. 962-968; December 2016 [4] Root Cause Analysis of Rocking Modes, W. Cardenas, W. Klippel, AES Convention Paper 140th Convention 2016-06-04, Paris France

Find explanations for symbols at:
http://www.klippel.de/know-how/literature.html
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