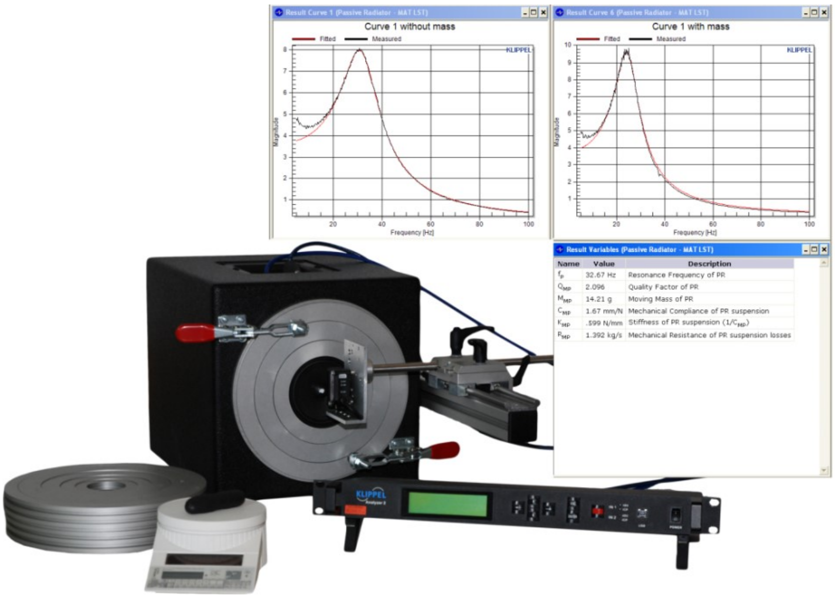
Parameter Measurement of Passive Radiators **AN 57**

Application Note to the KLIPPEL R&D SYSTEM

The knowledge of the linear parameters of passive radiators is necessary for the optimal tuning of the bass response of the complete loudspeaker systems. This application note focuses on measuring these parameters very accurately, using modules of the KLIPPEL R&D SYSTEM. Resonance frequency and Q-factor are determined by a simultaneous measurement of passive radiator deflection and the sound pressure in the test enclosure. By using the *Added Mass Method*, the moving mass of the passive radiator is determined and the remaining lumped parameters are derived.

This Application Note gives a short introduction to the theory of this technique followed by a step-by-step application guide. Furthermore, a tutorial explains how to simulate passive radiator systems using the KLIPPEL SIM module.



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Document Revision 1.0 updated Dezember 19, 2022

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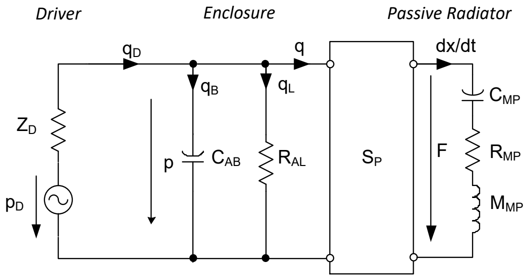
Introduction

Theory

At low frequencies and small amplitudes a passive radiator system can be modeled by linear lumped parameters as shown in the right picture. Driver and enclosure are modeled by an acoustic network and the passive radiator is represented by the lumped elements mechanical mass M_{MP}, mechanical compliance C_{MP} and mechanical resistance R_{MP}.

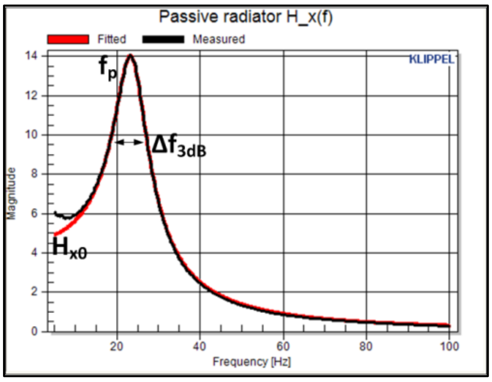


The stimulating driver acts as a sound pressure source which is exciting the passive radiator with the force $F = pS_{\mathrm{P}}$, with S_{P} being the effective cone area of the passive radiator and p being the sound pressure in the enclosure.
From this circuit, the linear transfer function between displacement and sound pressure can be obtained.

$$H_x(j\omega) = \frac{x(j\omega)}{p(j\omega)} = \frac{C_{\mathrm{MP}}S_{\mathrm{P}}}{j\omega R_{\mathrm{MP}}C_{\mathrm{MP}} - \omega^2 M_{\mathrm{MP}}C_{\mathrm{MP}} + 1}$$

Using easy interpretable derived parameters like f_{P} (resonance frequency of the passive radiator) and $Q_{\mathrm{MP}} = \frac{f_{\mathrm{P}}}{\Delta f_{3dB}}$ the magnitude response is modeled by this equation:

$$H_x(f) = \left| \frac{H_{x0}}{\frac{jf}{Q_{\mathrm{MP}}} - \frac{f^2}{f_{\mathrm{P}}^2} + 1} \right|$$



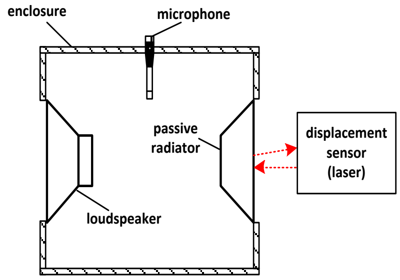
The picture on the right shows a fitted response based on this model and the actually measured transfer function.

Measurement Principle

Measuring the Transfer Functions:
The tools for obtaining the transfer function are provided by the KLIPPEL TRF module [1]. The TRF stimulates the loudspeaker with a frequency sweep so that the passive radiator gets pneumatically excited. The transfer function $H_x(j\omega)$ is derived from the measured sound pressure in the test box and the passive radiator deflection which is measured by a triangulation laser sensor.
After attaching the additional mass the *Added Mass Method,* the TRF operation has to be performed twice.

Calculating the parameters:
The linear parameters are determined by the CAL operation *Calc Parameters*. This operation computes the Q-factor Q_{MP} and resonance frequency f_{P} by employing a fitting algorithm. The mechanical compliance and resistance are calculated from the resonance frequency, Q-factor and moving mass.

Measurement Setup:



Measurement procedure:
1. Mounting the DUT (Device Under Test)
2. Setting up the stimulus
3. Performing a TRF measurement
4. Adding mass to the DUT
5. Performing another TRF measurement
6. Passing the TRF results to a CAL operation
7. Running the CAL operation

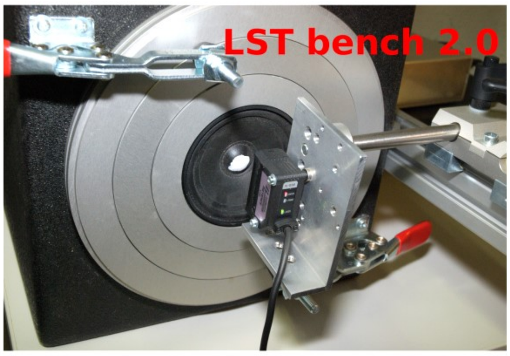
Requirements

Test bench

The basic elements of the test bench are a built in low frequency loudspeaker driver, a laser mounting platform, an opening for the microphone and a clamping platform for mounting the passive radiator.

It is recommended to use the *KLIPPEL LST Bench* for external laser mounting. A custom clamping system may be installed to mount the passive radiator in vertical position (e.g. like on the picture below). For circular geometries up to a diameter of 222 mm the *Klippel SPM/LST Ring Set* may be used to clamp the DUT.

Also the *SPM bench* may be used for passive radiators with low resonance frequencies (f_{P} < 80 Hz recommended).

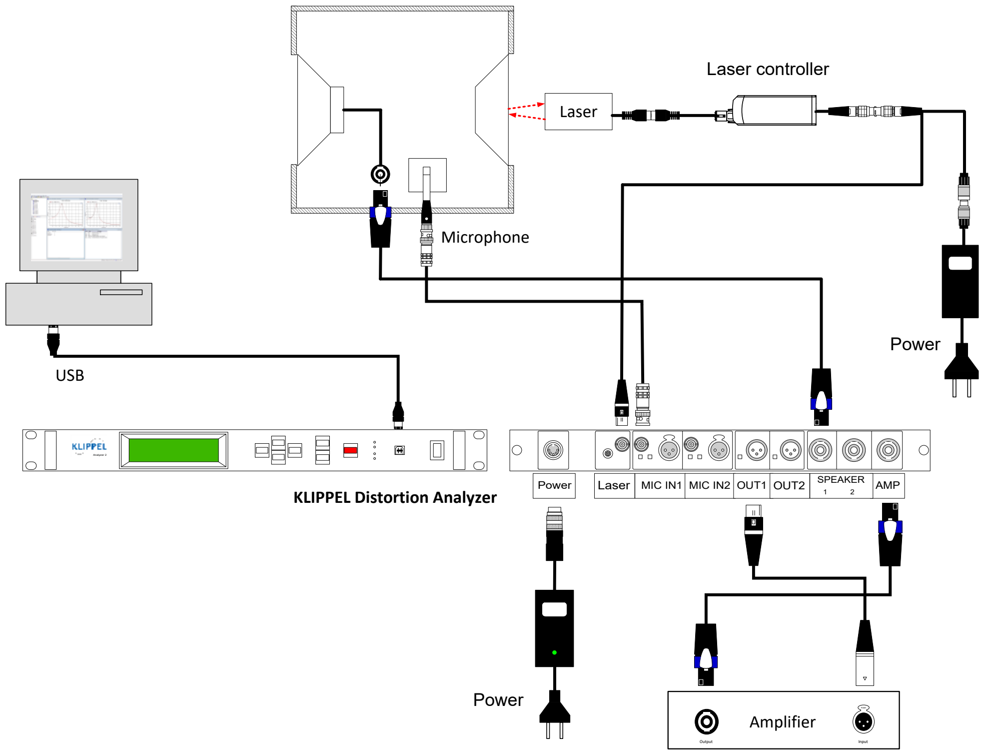


Displacement sensor	A laser displacement sensor based on the triangulation principle is required to measure the excursion of the passive radiator. A low-noise sensor should be used due to small cone excursions. <u>Recommended types:</u> • Keyence IL30 • Keyence H52 • Keyence G82
Microphone	The microphone should have a linear frequency response at low frequencies and sufficient max SPL due to relatively high sound pressure levels which may occur in the test enclosure. <u>Recommended types:</u> • MI17 • MIC 7052 • MK 250
Miscellaneous	• KLIPPEL Distortion Analyzer • SPM/LST ring set (optional) • Audio Amplifier • Personal Computer (Windows XP or Windows 7) • Piece of mass (e.g. clay) which can be added to the diaphragm • High precision scale to determine the exact added mass
Software	• dB-Lab • TRF module • CAL operation *SPMlite* • Template *T:SPM Lite* • Optional: SIM and LPM module

Preparation of Hardware and Software

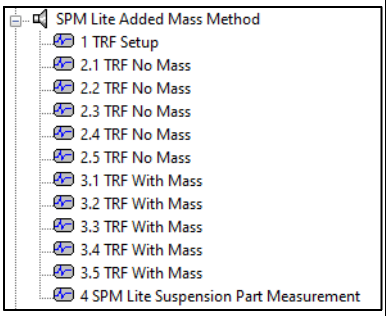
Hardware setup:

- Mount the passive radiator on the test enclosure (see next section)
- Insert the microphone into the enclosure
- Connect the hardware according to the wiring diagram
- Calibrate the laser sensor to measure the maximal peak displacement during measurement correctly (not required for the precise measurement of the linear parameters)



Software setup

Start dB-Lab and create a new object using the object template *SPM Lite Added Mass method.*



This template contains:

- *1 TRF Setup* may be used to setup the measurement parameters
- TRF operations for the main measurements without and with added mass (five operations for each step for optional spatial averaging)
- one SPM Lite operation which calculates the fitted curves and the linear parameters

Mounting

LST bench

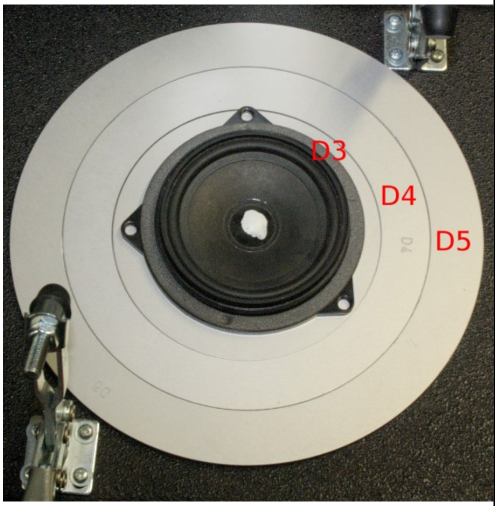
KLIPPEL offers the SPM/LST ring set which is a very suitable tool for mounting circular passive radiators. Information about the set can be found in document [2].

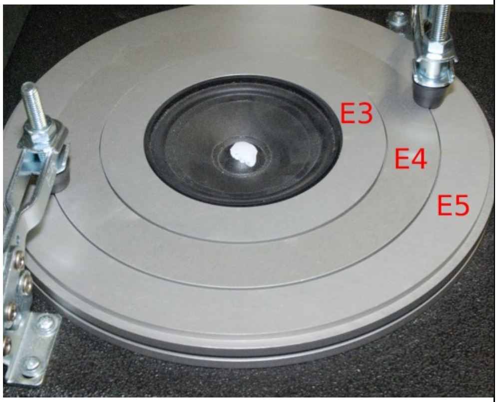
Instructions:

1. Place the LST bench on its feet so that the mounting hole is facing up
2. Select a suitable ring which fits the DUT best
3. Complete the lower ring set by adding the rings of the same letter (in the picture rings *D3-D4-D5* are used)
4. Put the rings and the passive radiator on the mounting hole
5. The upper ring set is used to clamp the DUT; again, choose the ring set which fits best
6. Fasten the fast clampers. Readjusting the length of the thread screws of the clampers might be required.
7. Tilt the enclosure to the side
8. Position the laser sensor (compare picture in paragraph *Requirements→Test bench*), it should point to the center of the DUT. The distance should be set to the center of the working range.

<u>For highest accuracy it is important that the measurements are accomplished with the DUT being in a vertical position</u> (LST bench has to be tilted to the side). A horizontal orientation can lead to an incorrect measurement of the moving mass if the passive radiator suspension is very soft.

In case the ring set is not applicable or non-circular passive radiators shall be measured, a custom-made wooden board may be used for mounting.



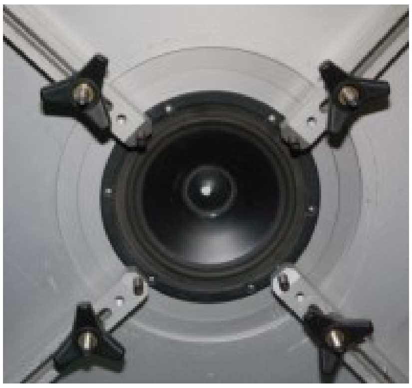


Mounting

SPM bench

Circular passive radiators can be mounted easily using the SPM/LST ring set (see last section). In contrast to the LST bench, the upper ring set is not required because the DUT may be fastened by the four clamping levers.

A custom-made board may be used if the ring set is not applicable for the specific device.



Setting up the Stimulus

1 General

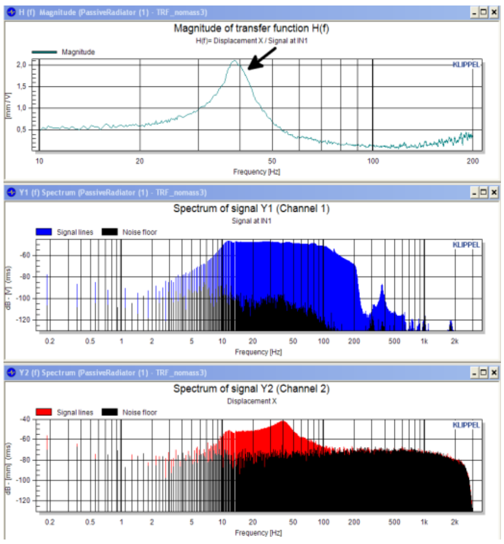
Motivation: In most cases, the amplitude and possibly also the shape of the stimulus have to be set manually. Those parameters depend on the volume of the test enclosure, the internal driver and passive radiator. Therefore it is not possible to define a default stimulus.

<u>The target is driving the DUT in the small signal domain while having a good SNR (Signal-To-Noise Ratio) in the displacement laser signal.</u> At the same time microphone clipping has to be prevented. This is achieved by setting up a suitable stimulus voltage. A shaping of the stimulus might be necessary to avoid high SPL at low frequencies when measuring passive radiators with high resonance frequencies.

2 Tracking the resonance frequency

Run the object *1 TRF setup* with the default settings. In case of warnings or errors refer to [5] or to the section *Troubleshooting* at the end of this document.

Double-click on the object *1 TRF setup* to see the curves *H(f)* and the spectrums of the microphone and laser signals. The *H(f)* curve should show a peak caused by the passive radiator resonance.
<u>It is important that you see a typical resonance curve as shown on the right (highest magnitude occurs around the resonance frequency f_p of the passive radiator).</u> If this condition is not fulfilled, limit the frequency range or define a shaping profile. Otherwise, f_p may not be identified by the algorithm.



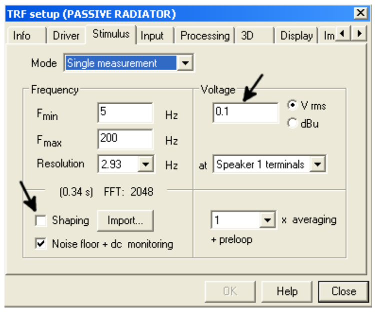
Setting up the Stimulus

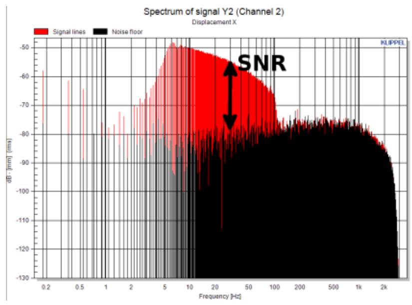
3 Adjusting the stimulus voltage

If the resonance peak looks clean you may decrease the stimulus voltage in the property page of *TRF Setup.* Since the $K_{ms}(x)$ nonlinearity is causing a change of the resonance frequency if the cone excursion was too high during the measurement, keep the maximum displacement below 1 mm.

In case the resonance peak is corrupted by noise due to a low SNR of the laser signal, increase the voltage and restart the measurement.

It is advised to check the SNR of the displacement laser sensor (*Y2(f) Spectrum*). It has been found that a SNR of about 25-30dB at the resonance frequency is sufficient for determining the linear parameters accurately.





Setting up the Stimulus

4 Shaping

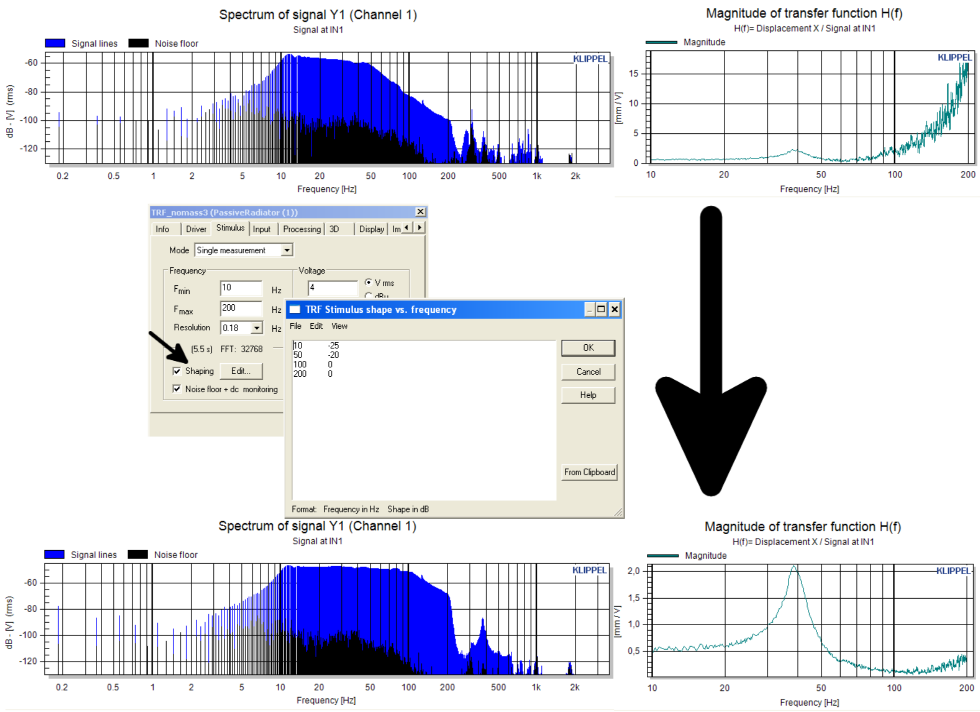
Motivation: Because the SPL in the enclosure is decreasing towards high frequencies, the passive radiator may not be deflected sufficiently. As a consequence, the SNR of the laser signal gets very poor and the *H(f)* curve gets highly distorted. A further increase of the stimulus voltage may not be possible (clipping of the microphone at low frequencies) or desirable.

Two problems arise:

1. When measuring passive radiators with high resonance frequencies the resonance peak is distorted, hence the Q-factor and f_P cannot be determined accurately → **shaping is necessary**
2. Artifacts in the laser signal can occur at high frequencies so that the algorithm cannot track the actual resonance peak → **a shaping can be used or the frequency range can be limited**

How to define a shaping profile:
Open the property page of *TRF Setup* → *Stimulus* → *Shaping*. A shaping profile can be defined by giving a two-column matrix with the frequency in the first and the corresponding amplitude in dB in the second column.

The desired target sound pressure should be constant in the rough frequency range of the passive radiator resonance. Approximately inverting the magnitude response of the sound pressure signal (Spectrum of Channel 1) is a good approach to do so. It is sufficient to apply a linearization up to a frequency which is slightly higher than f_P. This procedure is illustrated by the following picture. The linearization of the sound pressure results in a much cleaner *H(f)* curve.



5 Applying the settings to the main measurement

When the measurement setup is completed, copy the stimulus settings of operation *1 TRF Setup* to all the remaining TRF operations in the template which you want to use. The object *PASSIVE RADIATOR* may be renamed and saved as a template for the specific device.

Parameter Measurement

1 TRF measurements

1. Prepare the mass which will be added to the cone. The mass should have a weight of about 60% of the estimated moving mass of the passive radiator. The value of the mass has to be weighed with a high precision scale because the exact value is required for the accurate calculation of the parameters. If you use clay, form a roll so that it can be added to the cone symmetrically to the center (as shown on the right picture).
2. Perform up to five measurements without added mass to get spatial averaging (one TRF operation at each position).
3. Carefully add the mass to the passive radiator cone.
4. Perform the measurement(s) with mass.

If using only one measurement each, it is advised to direct the laser beam to the center of the cone. When performing multiple measurements, the laser may be directed to different points (see picture on the right) to account for rocking modes and to get more accurate results.

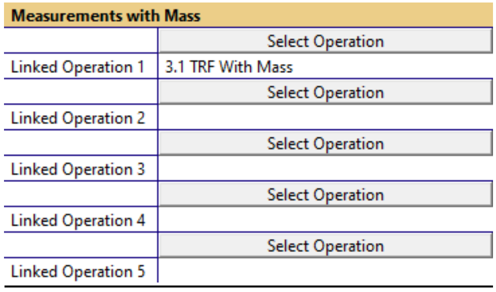
Parameter Measurement

2 Linking the measured TRF operations

After the main measurements are finished, the parameters can be calculated. In order to do this, the results of the previous measurements have to be linked in the Setup of the SPM Lite Operation. When using the Klippel template, this is already prepared.

Note: If the names of the TRF Operations have been changed, the corresponding operation has to be linked manually. To do so, click on the button *Select Operation* above the corresponding parameter *Linked Operation 1…5.*

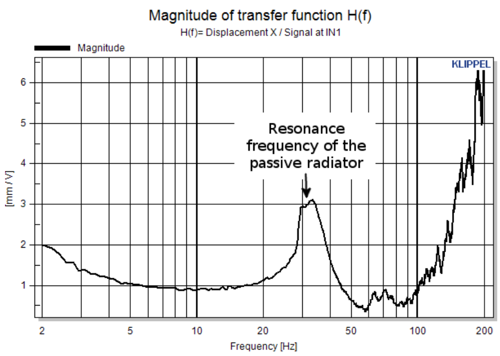
Then enter the value of the added mass (in grams) in the input field of the parameter *Added Mass*.



3 Specifying additional input parameters

<u>Two additional parameters are available:</u>

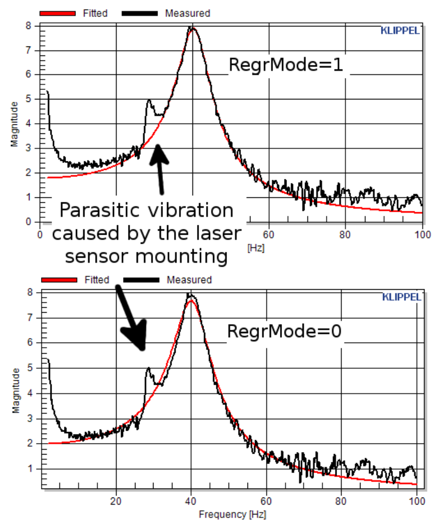
Maximum Frequency (default = 100 Hz)
→ It is important that the maximum magnitude of the transfer function occurs at the passive radiator resonance frequency. If this condition is not fulfilled, limit the frequency range using this parameter (e.g., the maximum frequency of 100Hz is a good value for the curve which can be seen on the right picture). If passive radiators with high frequencies are measured, it might be necessary to increase *Maximum Frequency.*



Remove Outliers (default is checked)
→ This parameter defines the behavior how the fitting function is calculated

- *Box unchecked:*
  → a standard data fitting algorithm is applied to the input data
- *Box checked*
  → an iterative weighting of the input data is performed

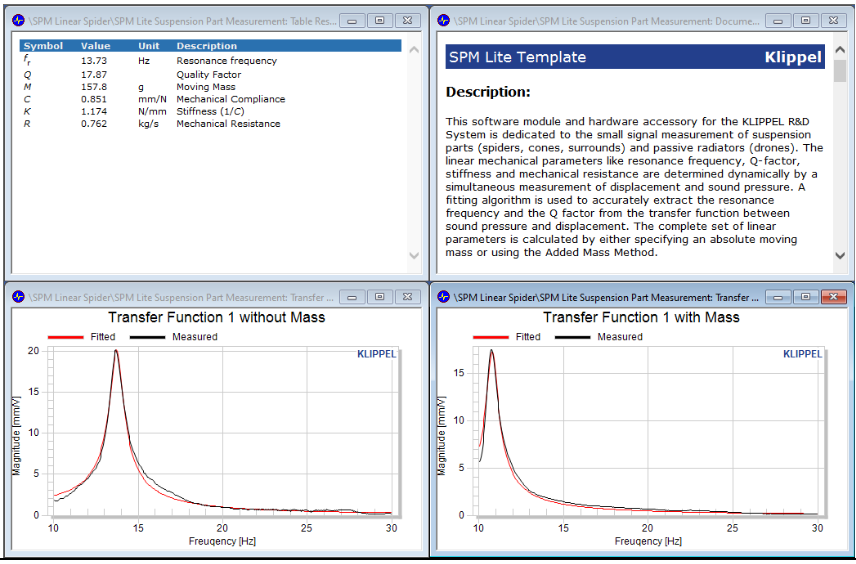
As can be seen on the right picture, the iterative algorithm copes much better with wild shots or parasitic narrow-band peaks/dips. The non-iterative fitting mode should only be chosen if problems occur using the iterative algorithm.



Parameter Measurement

4 Viewing the results

Run the SPM Lite operation. In case of errors or warnings refer to *Troubleshooting.*
By double-clicking on the *4 SPM Lite Suspension Part Measurement* operation, the results are shown. To be sure that they were determined correctly, you may check the Result Curves and compare the measured curves (black) with the fitted curves (red).



Application: Simulation of a passive radiator system using the SIM module

General

The KLIPPEL SIM [3] module is a powerful tool to simulate the small and large signal performance of transducers and complete loudspeaker systems. This paragraph gives instructions on simulating passive radiator systems in the small signal domain. Based on the linear parameters of a transducer and a passive radiator, the performance of the complete system can be predicted.

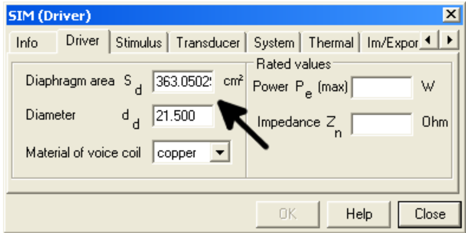
Prerequisites

1. Determine the linear parameters of the transducer by performing a *Linear Parameter Measurement (LPM)* [4]
2. Perform a measurement of the linear parameters of the passive radiator as described in this Application Note
3. Measure the cone areas of the passive radiator and the transducer

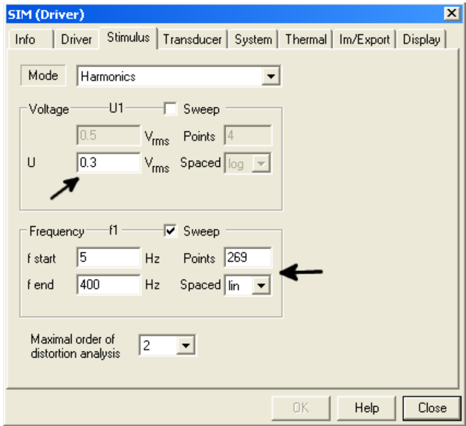
Entering Parameters

Create a new SIM operation and open its property page.

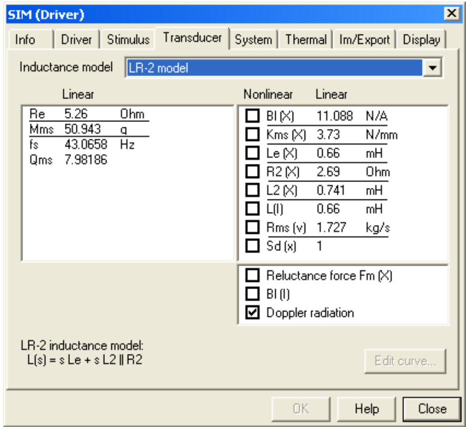
1. Enter the diameter or diaphragm area of the transducer.



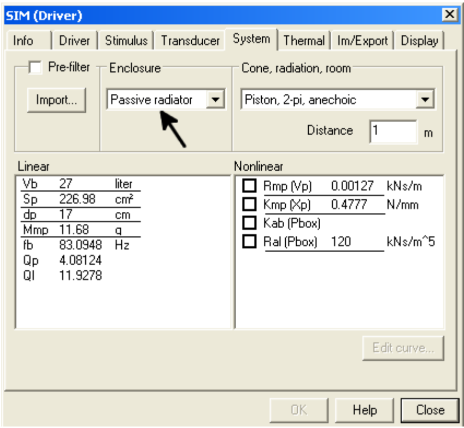
2. Define the stimulus settings (voltage, frequency range, resolution).



3. Enter the lumped parameters of the transducer obtained by the LPM. Resonance frequency and *Qms* are calculated by the program based on the given parameters.



4. In the *System* settings, choose *Passive radiator* as enclosure type. Then enter
   - the parameters Rmp, Kmp and Mmp which were determined by the passive radiator measurement
   - the diaphragm area Sp or diameter dp of the passive radiator
   - a value for the enclosure volume Vb



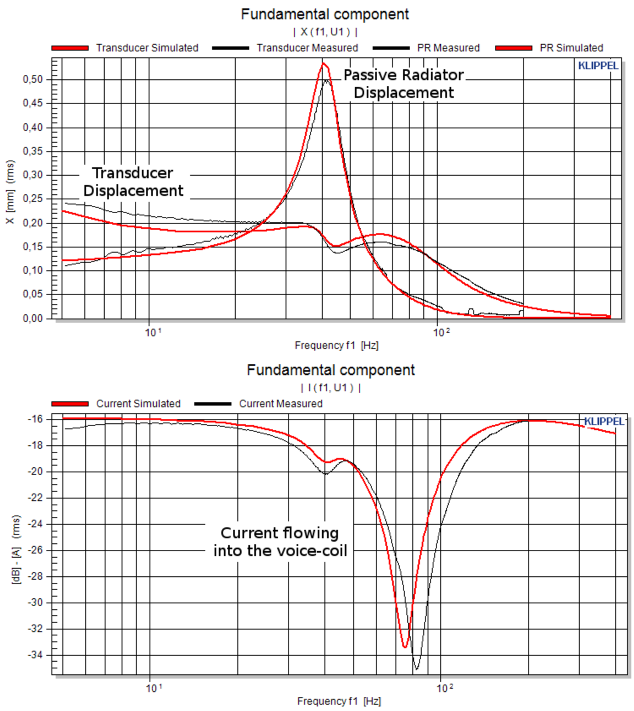
At the end ensure that Ql > 5 by varying Ral which is representing leakage losses.

5. Run the SIM operation.

Verification of the results

The described passive radiator measurement technique combined with the SIM module are very useful tools for the development of passive radiator systems. This shall be illustrated by comparing curves obtained by real measurements and curves which were predicted by the SIM module.

The picture below shows a comparison between measured and simulated displacement of transducer and passive radiator as well as voice-coil current. As can be seen, a very good correlation between the curves was achieved.



Troubleshooting

Errors

"Channel 1 is limiting."	**Symptom:** This error is generated by the TRF module. It is caused by microphone clipping. **Remedy:** • Decrease the stimulus voltage • If the resonance peak in the $H_x(f)$ curve is distorted and an increase of the stimulus voltage is not possible, a shaping profile has to be defined to equalize the sound pressure spectrum.
"Either a value for AddedMass or DUTmass has to be given."	**Symptom**: This error occurs due to missing input data. The value of the added mass or the moving mass is a compulsory information and necessary for the calculation of the linear parameters. **Remedy:** • Specify a value for the input variable *AddedMass*
"No valid curve for the measurement without mass is available" *"No valid curve for the measurement with mass is available"*	**Symptom**: 1. No curve is given for the particular measurement type. 2. No curve from which parameters can be derived is given. **Remedy:** 1. Make sure that data was passed to both input curve types *Inp_NoMass* and *Inp_Mass.* 2. See warning message *"The resonance peak of Curve 'Inp_…' was not determined correctly. This curve is not considered for the calculation."* for instructions.
"The resonance frequency of the measurements with mass is higher than without mass"	**Symptom**: The measurement with added mass is not causing a decrease of the resonance frequency. **Remedy:** • Make sure that the input curve types *Inp_NoMass* and *Inp_Mass* were not mixed up
"The resonance frequencies with mass and without mass are identical."	**Symptom**: Input curves with and without mass are identical. **Remedy:** • Make sure that you have inserted the correct curves into the input variables • Was a mass attached to the passive radiator?

Troubleshooting

"The frequency resolution of Inp… is not sufficient."	**Symptom:** The frequency resolution is not sufficient to determine resonance frequency and Q-factor with adequate accuracy. **Remedy:** Increase the frequency resolution to e.g. 0.05 Hz.
Warnings	
"The resonance peak of Curve 'Inp_…' was not determined correctly. This curve is not considered for the calculation."	**Symptom**: The particular curve is not suitable for the calculations. **Remedy:** • Make sure that the highest magnitude occurs at the resonance frequency of the passive radiator. Fix this by limiting the frequency range, using the input parameter *MaxFrequency* or by defining a shaping profile. • If the curve does not look like a typical $H_x(f)$ curve, check the measurement setup
"Decrease the added mass to increase accuracy."	**Symptom**: The deviation between the resonance frequencies of the measurements with mass and without mass is too high.
"Increase the added mass to increase accuracy."	**Symptom**: The deviation between the resonance frequencies of the measurements with mass and without mass is too small. **Remedy:** Repeat the added mass measurements with a smaller/bigger mass. If you are sure that the weight of the added mass is suitable, make sure that the measured curves have been passed to the CAL operation correctly
"The resonance frequency of the measurements with mass is very low." *"The resonance frequency of the measurements without mass is very low."*	**Symptom**: The resonance frequency is below 10 Hz.

More Information

[1] S7 - Specification of the KLIPPEL TRF module
[2] C2 - Specification of the KLIPPEL Suspension Part Measurement Set
[3] S3 - Specification of the KLIPPEL SIM module (Version 2)
[4] S2 - Specification of the KLIPPEL LPM module
[5] Manual to the KLIPPEL TRF module

updated December 19, 2022

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