Bode 100 - Application Note

Loudspeaker and Audio Crossover Measurements

By Tobias Schuster

Visit www.omicron-lab.com for more information.
Contact support@omicron-lab.com for technical support.

Table of Contents

Note: Basic procedures such as setting-up, adjusting and calibrating the Bode 100 are described in the Bode 100 user manual. You can download the Bode 100 user manual at www.omicron-lab.com/bode-100/downloads#3

Note: All measurements in this application note have been performed with the Bode Analyzer Suite V3.0. Use this version or a higher version to perform the measurements shown in this document. You can download the latest version at www.omicron-lab.com/bode-100/downloads

1 Summary

This application note explains how to measure the impedance of loudspeakers as well as how to measure the voltage transfer function of audio crossovers using the Bode 100 VNA.
After a short introduction to the measurements it is shown how to configure the Bode 100 and how to connect the DUT[1] for each measurement.

2 Measurement Task

The following measurements are outlined in this application note:

- Impedance measurement of loudspeakers
- Measurement of each path of an audio crossover
- Comparison of the measurement and the simulation results of an audio crossover

The measurements are performed on self-made loudspeakers.
These loudspeakers are part of a self-developed sound system, developed by the electronics teacher Dipl.-Päd. Ing. Michael Kvasznicza at the Federal Higher Technical institute for Education and Experimenting in Bregenz. The system was refined and extended with a Bluetooth connection to android devices during a diploma thesis project.

---

[1] Device Under Test

3 Loudspeaker Details

The loudspeakers we are using, are passive loudspeakers. The satellite speakers consists of a tweeter and a mid-range driver as well as a self-made audio crossover. The woofer is installed in a separate wooden housing, therefore no audio crossover is needed for the woofer.

The built-in speakers are:

- Tweeter: Visaton DTW 72 8 Ω
- Mid-range driver: Visaton W 100 S 4 Ω
- Woofer: Visaton W 200 SC 4 Ω

Figure 1: Satellite speaker including tweeter, mid-range driver and audio crossover

4 Measurement Setup & Results

4.1 Input impedance of the Loudspeakers

4.1.1 Bode 100 Setup

For the input impedance measurement we perform a logarithmic frequency sweep from 10 Hz to 100 kHz and use an output level of 0 dBm such that the sound of the loudspeakers during the measurement is not too loud.

The other setup parameters can be seen in the following:

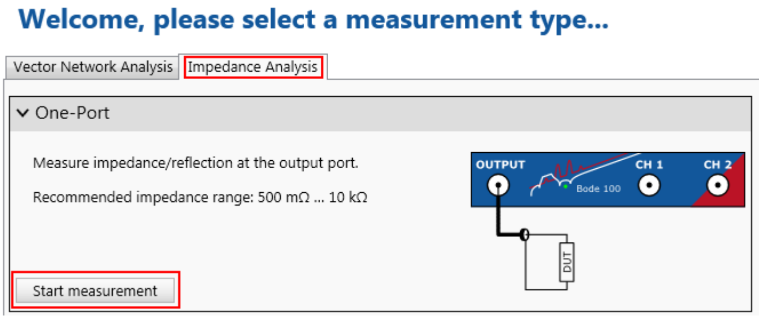

Figure 2: select measurement type one-port

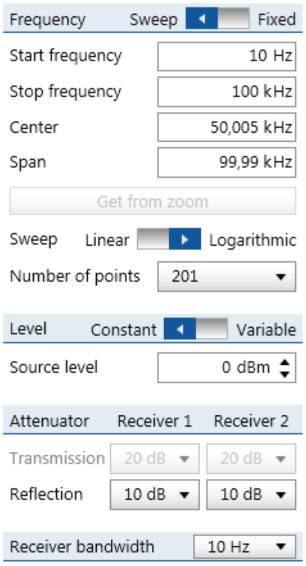

Figure 3: measurement settings – one-port

4.1.2 Connecting the Speakers

We connect either the satellite speaker or the woofer to the output of the Bode 100 via a BNC cable and a self-made adapter (see Figure 5).

Figure 4: Impedance measurement of the loudspeakers

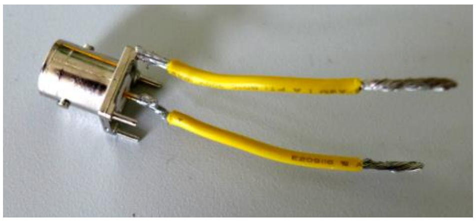

Figure 5: BNC - wire – adapter for connection between BNC and loudspeaker

4.1.3 Measuring the Complete Speaker Box

First of all we measure the complete satellite speakers (including the build-in audio crossover) and the woofer.

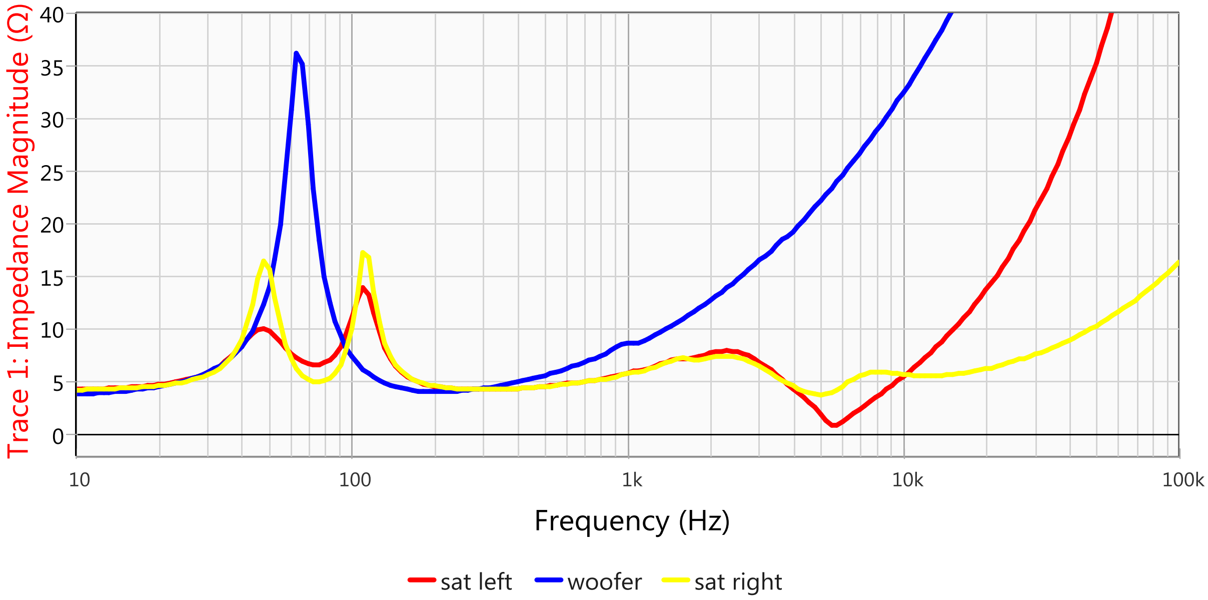

Figure 6: Impedance measurement of the loudspeakers

The impedance curves of the satellite speakers and the woofer are nonlinear and different. Especially the two satellite speakers are different. This is caused by the self-made audio crossovers including self-wound inductors.

4.1.4 Measuring the tweeter, mid-range driver and woofer

For this measurement we choose the same settings like in the previous measurement but we change the start and stop frequency to 20 Hz and 20 kHz and the y-axis from 0 to 50 Ω. These values are typically used to create datasheet diagrams.

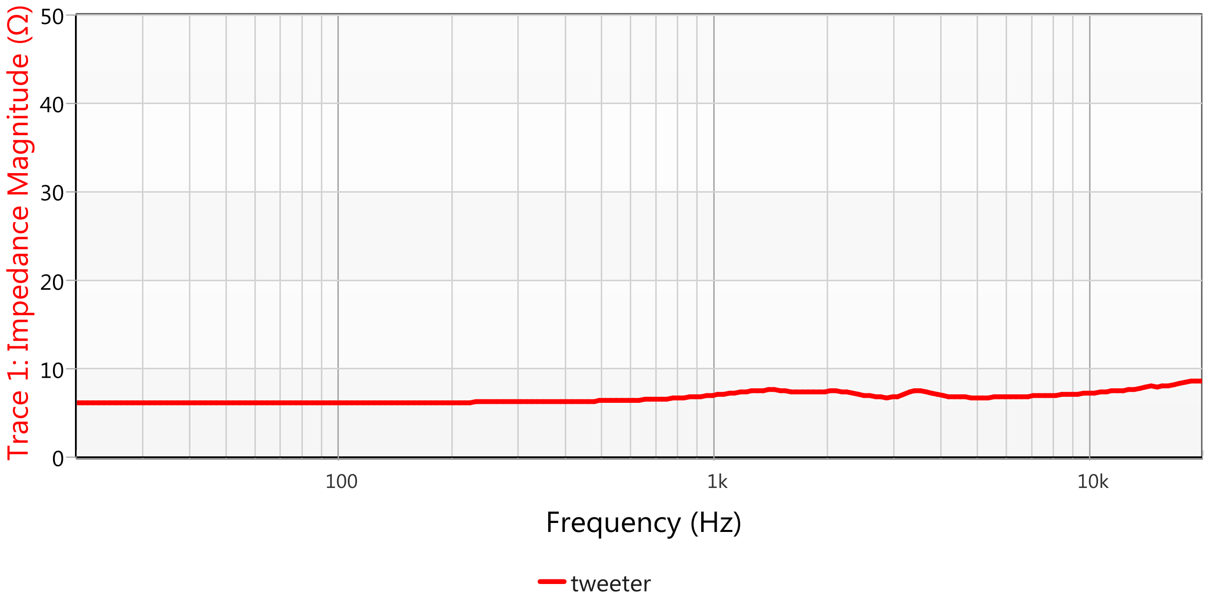

Figure 7: Tweeter impedance measurement

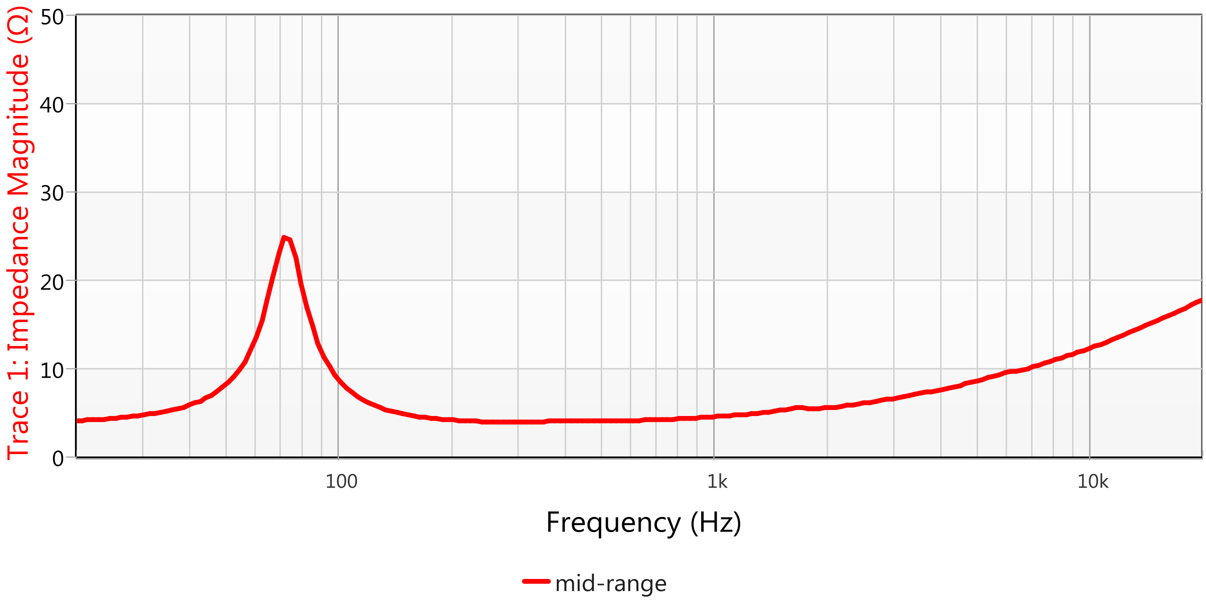

Figure 8: Mid-range driver impedance measurement

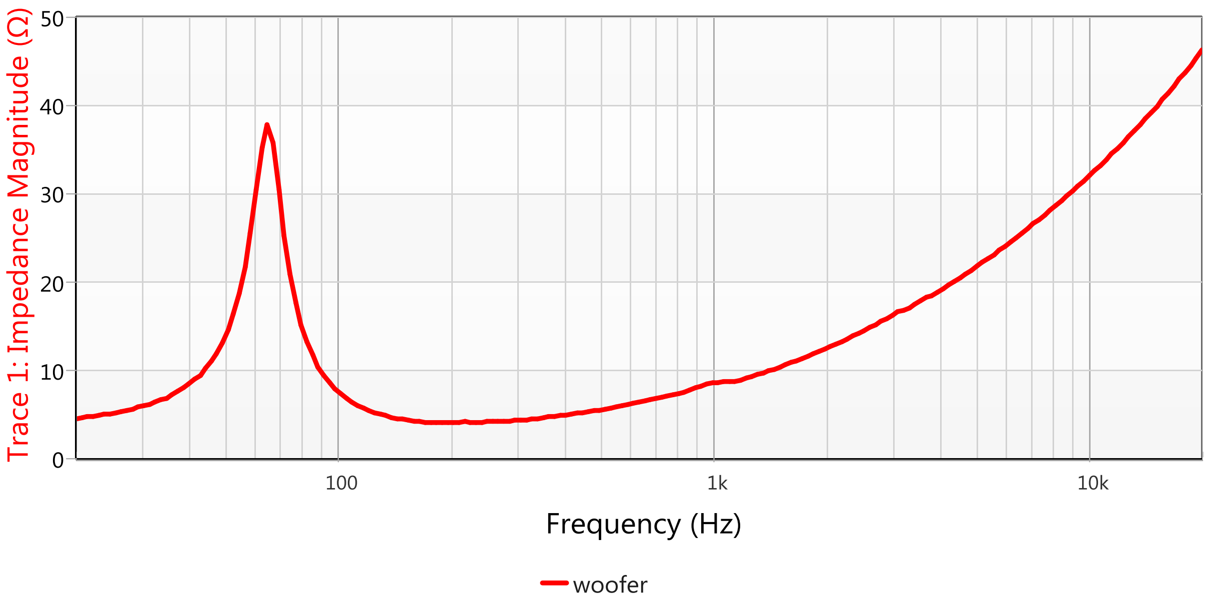

Figure 9: Woofer impedance measurement

The measurements show that the tweeter impedance is flat at 8 Ω whereas the mid-range driver and the woofer show a clear peak and an increase of the impedance at higher frequencies.
These peaks are typical for woofers and mid-range drivers and the curves in the datasheets are similar. The operating range of them normally starts after the peak and the higher the impedances are in the high frequencies, the less you can hear them with the woofer or mid-range driver themselves. Therefore, with this speakers we could hardly hear the high frequencies without the tweeter.

4.2 Audio Crossover Transfer Function

4.2.1 Bode 100 Setup

If we measure a filter, in this case an audio crossover, the most meaningful measurement for is the voltage transfer function of the filter. To measure the voltage transfer function with the Bode 100 we have to do a frequency sweep with the following settings:

- Start Frequency: 10 Hz
- Stop Frequency: 100 kHz
- Sweep Mode: Logarithmic
- Number of Points: 201
- Level: -10 dBm

This means the measurement type *Gain / Phase* has to be selected:

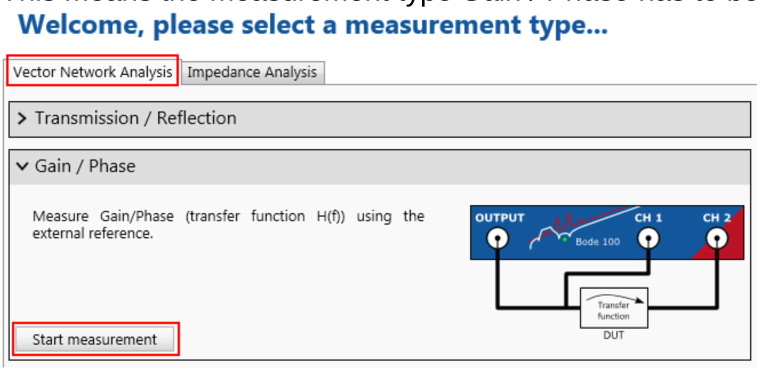

Figure 10: Audio crossover measurement – measurement type

Receiver 1 is set to external reference to use both input channels. This allows us to pick up the input signal of the audio crossover with Ch1 and the output signal of the crossover with Chanel 2. To ensure that we get “real-life” results for the voltage transfer function we keep the speakers connected during the measurements.

4.2.2 Measurement and Calibration Setup

Before we start the measurement we perform a THRU-calibration. To do so we connect the cables and the probes to the same point in the circuit

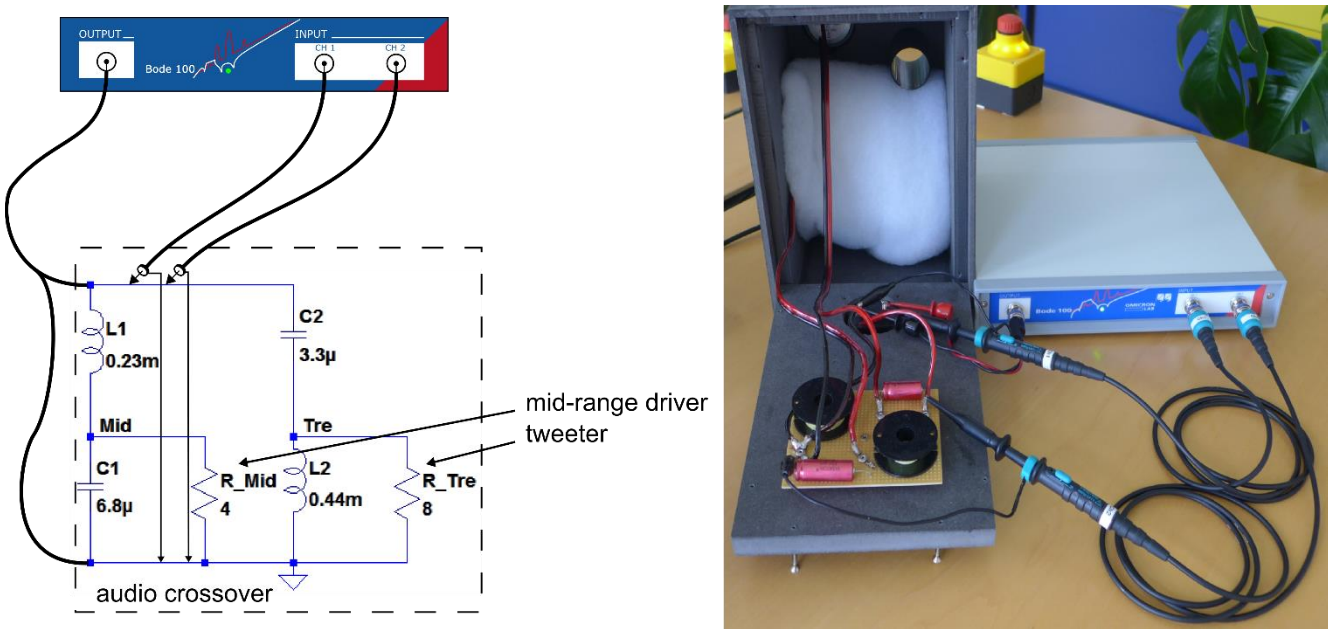

Figure 11: Audio crossover setup - calibration setup

Two transfer functions can be measured. First we measure the input-to-tweeter transfer function and then the input-to-midrange transfer function. Therefore we have to connect CH2 either to the tweeter path or to the midrange path as shown in the figures below.

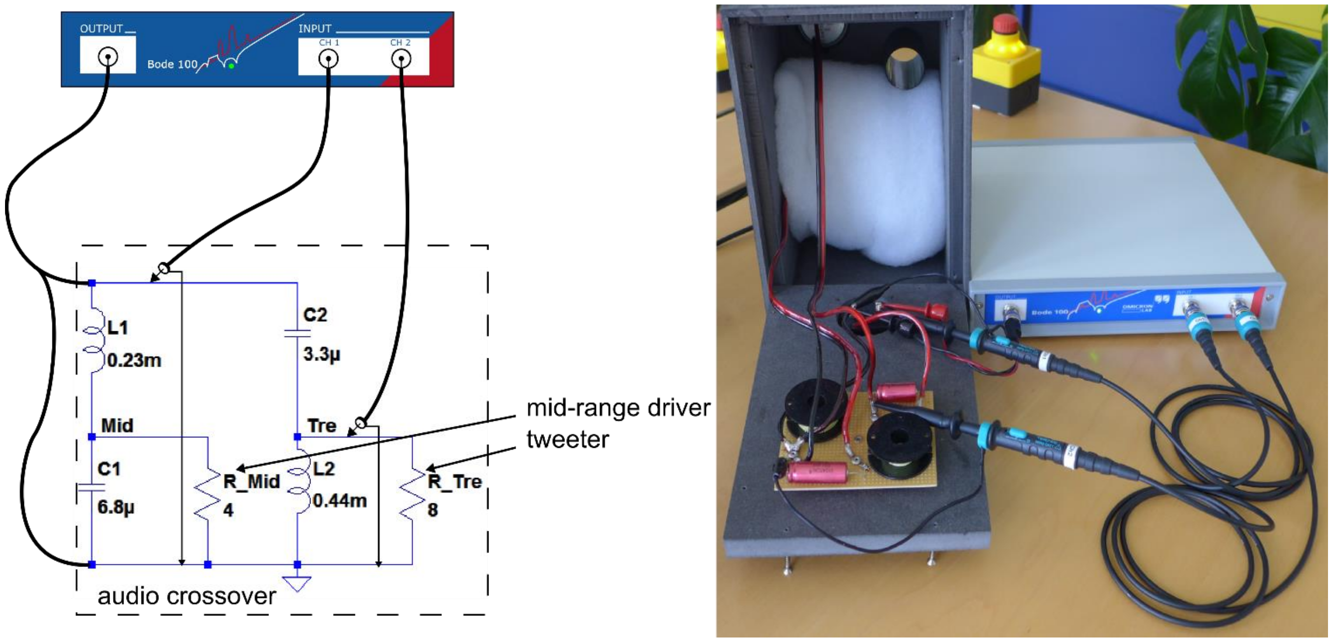

Figure 12: Audio crossover setup - tweeter path

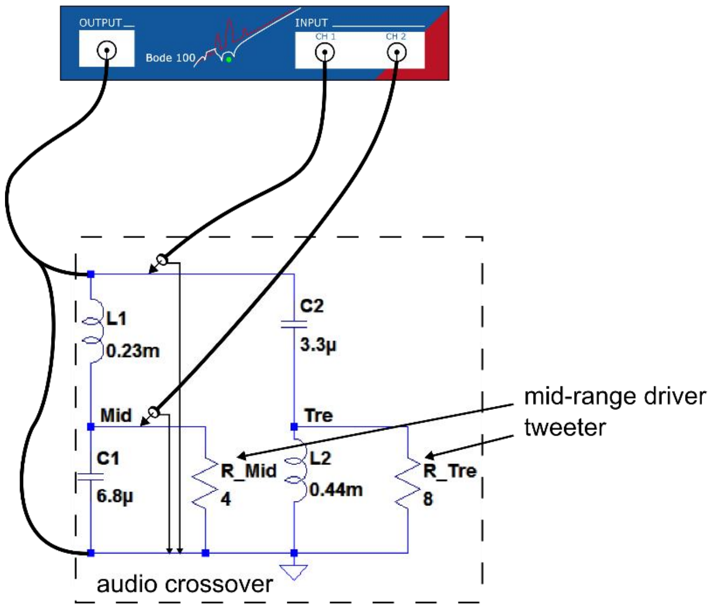

Figure 13: Audio crossover setup - mid-range driver path

Note: The resistors shown in the schematic are resistors which stand for the impedance of the loudspeakers. These resistors are needed for the simulation later on.

4.2.3 Measurement Result

In the following we perform two different measurements and get three curves.

1. Input-to-tweeter transfer function
2. Input-to-midrange transfer function
3. The sum of the two measurement results in the overall frequency response of the satellite speaker.

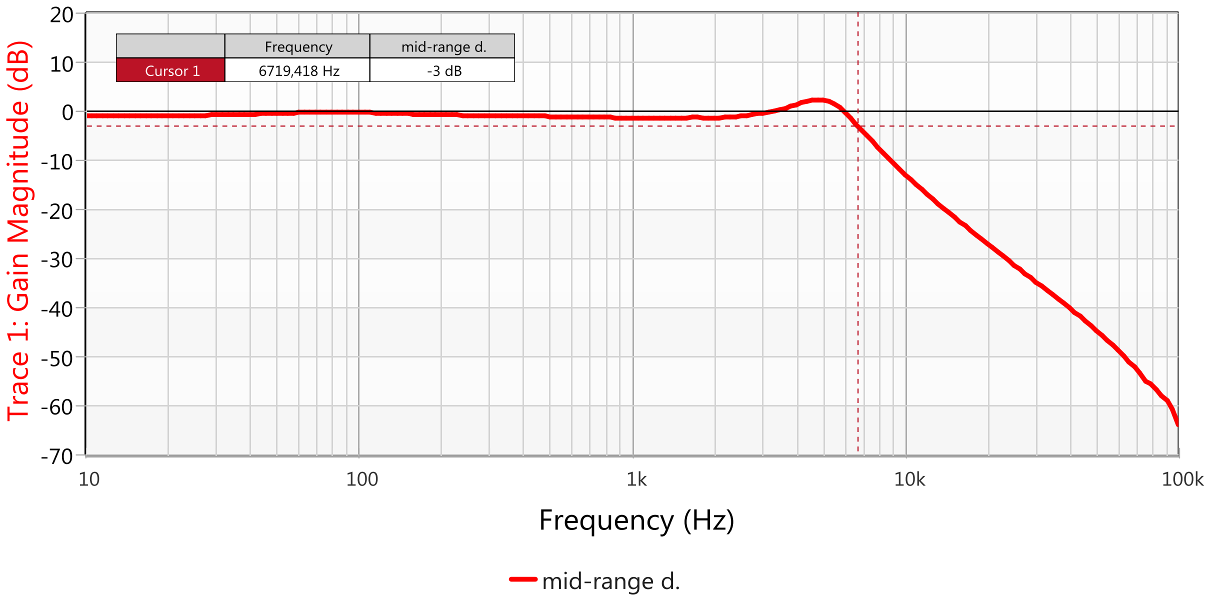

Figure 14: Audio crossover measurement - mid-range driver

The mid-range driver path of the audio crossover is a LC-low pass with a cutoff frequency of 6.7 kHz.

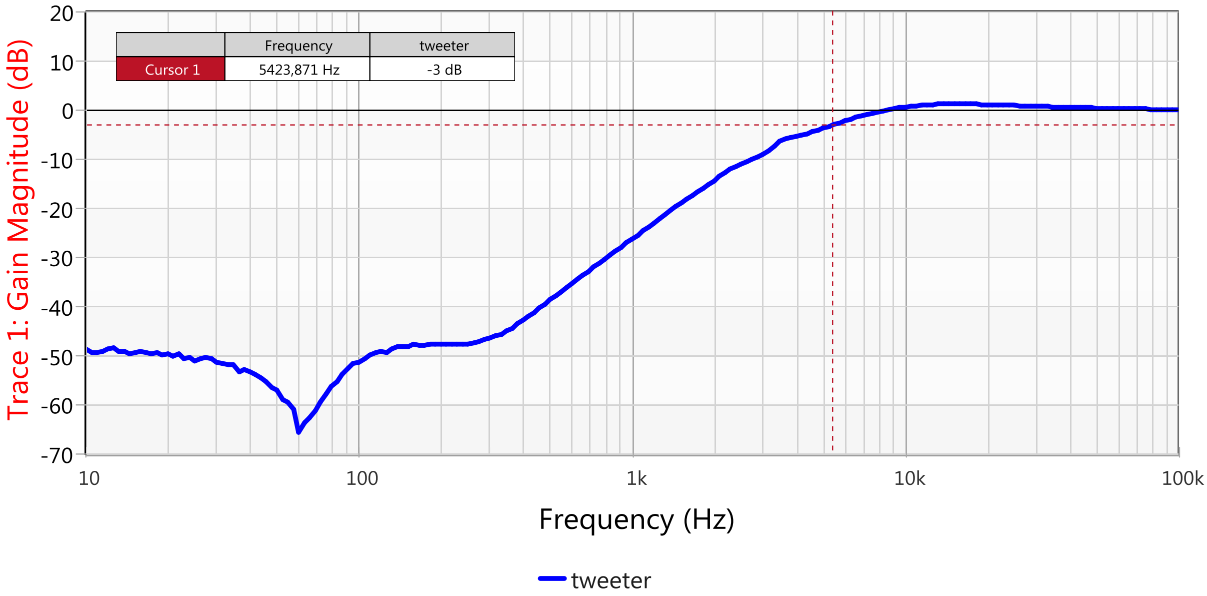

Figure 15: Audio crossover measurement – tweeter

The tweeter path of the audio crossover is a LC-high pass with a cutoff frequency of 5.4 kHz.

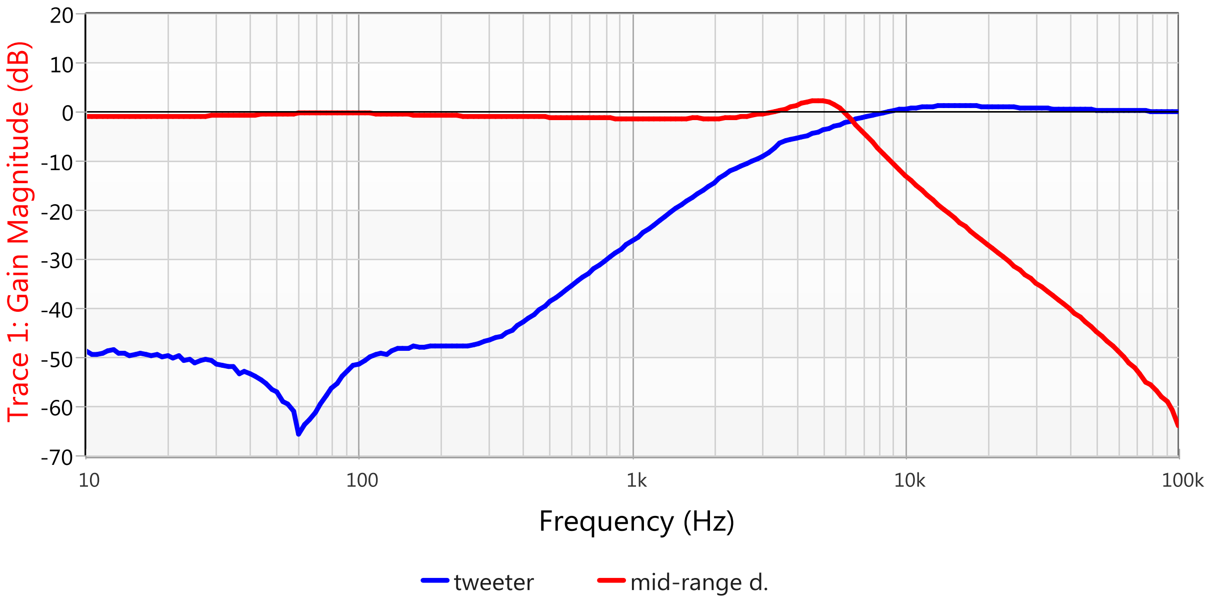

Figure 16: Audio crossover measurement - tweeter and mid-range driver

As we can see in the picture above, the mid-range driver path is conductive up to approximately 6 kHz where it starts attenuating. The tweeter path starts conducting above that frequency.

There are two different methods to get the overall frequency curve of the satellite speaker:

- Directly in the Bode Analyzer Suite
- Export the two curves of the tweeter and the mid-range driver to a spreadsheet program such as Excel® or something similar and sum up the two curves there

In the following we do it directly in the Bode Analyzer Suite.

First of all, we store the mid-range measurement data to the Memory in the Bode Analyzer Suite.

Figure 17: store the measurement data

Then the Trace 1 *Display* is set to *Math* and the memory of the mid-range driver subtracted by the memory of the tweeter:

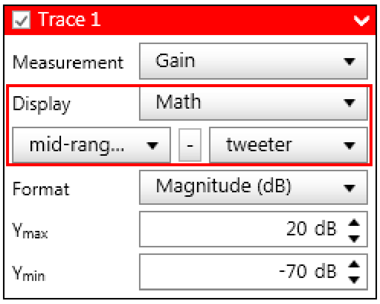

Figure 18: calculation in the BAS

If we have done this we see the overall frequency curve of the satellite speaker.

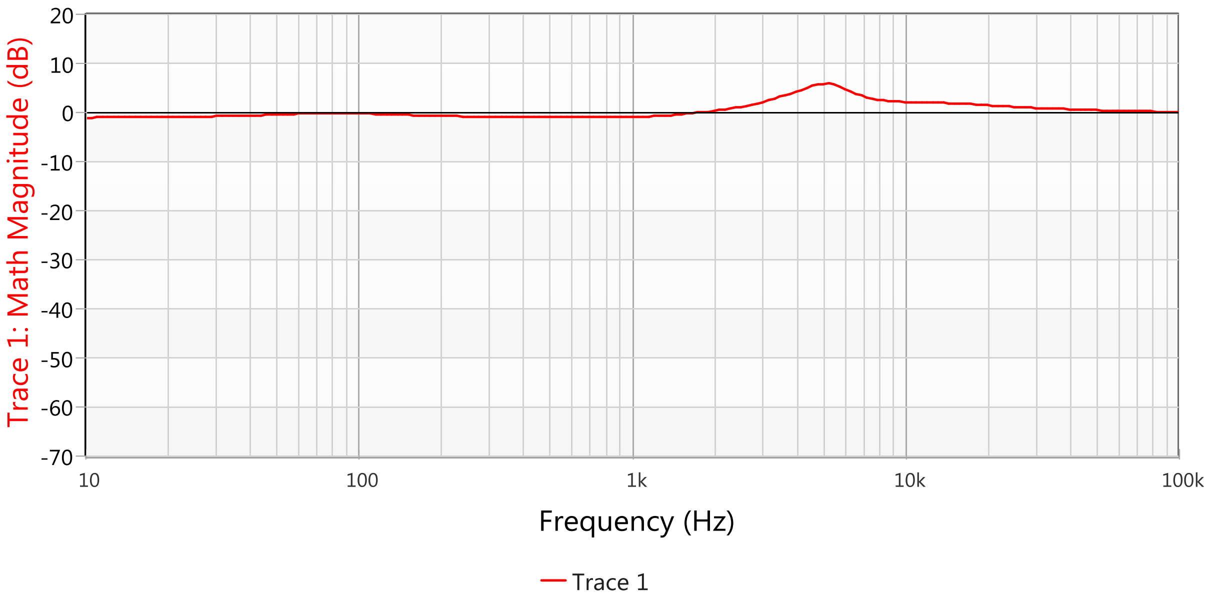

Figure 19: Audio crossover measurement - tweeter and mid-range driver path (overall frequency curve)

The curve should be as close to 0 dB as possible over the entire frequency range. However at approx. 5 - 8 kHz the curve shows some attenuation with a maximum of 10 dB, caused by the cutoff frequencies of the two single paths.

4.2.4 Comparison with LTspice Simulation

In order to compare the measurement with a simulation of the audio crossover, we have exported the tweeter path curve (V(tre)), the mid-range driver path (V(mid)) as well as the overall frequency curve (V(mid)+V(tre)) of the satellite speaker to an Excel® sheet.
For a better comparison between the simulation and the measurement, we also exported the LTspice simulation to an Excel® sheet.

Simulation:

To simulate the audio crossover the following circuit is modeled in LTspice.

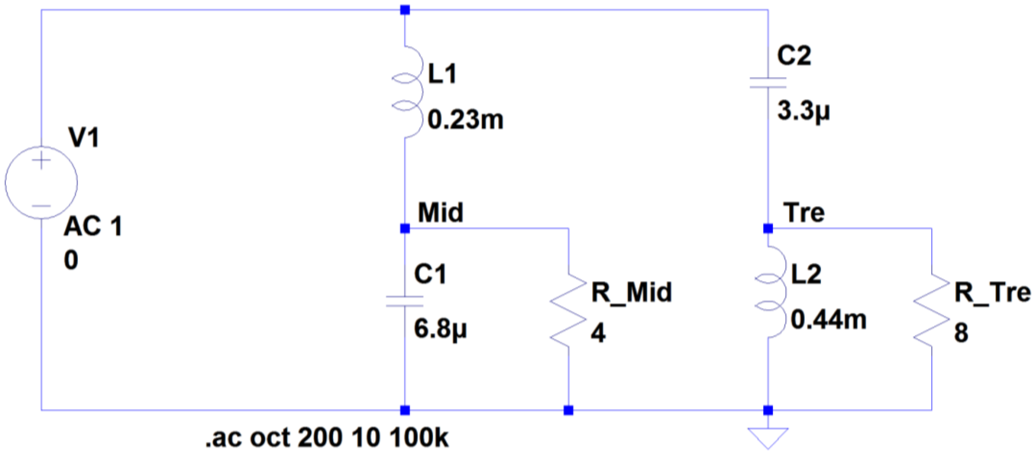

Figure 20: Audio crossover simulation schematic

The nominal values of the capacitors are used for the simulation. Since we do not consider the parasitics of the capacitors and the self-wound inductors, the simulation will not fit perfectly.

Comparison:

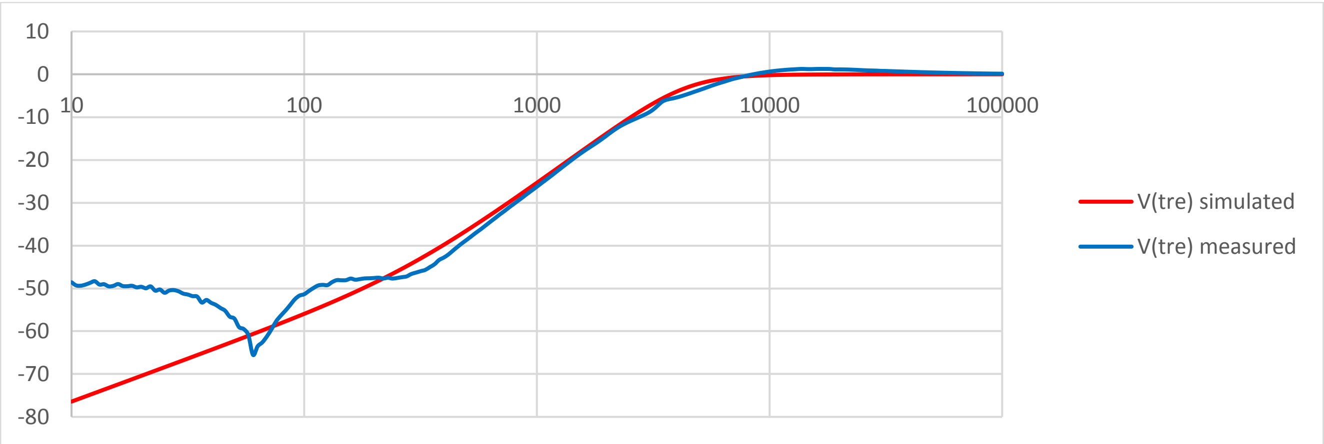

Figure 21: Audio crossover tweeter path

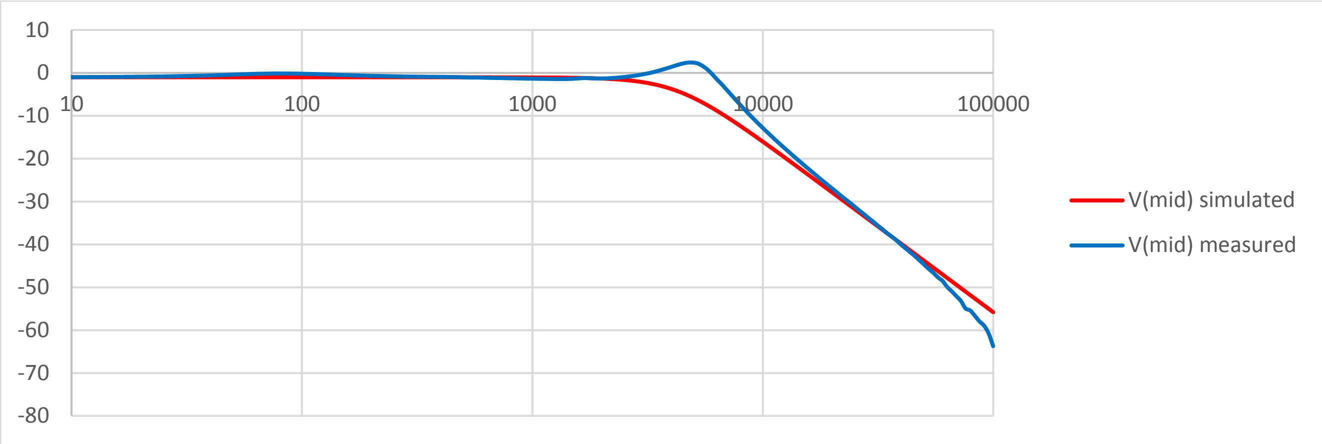

Figure 22: Audio crossover mid-range path

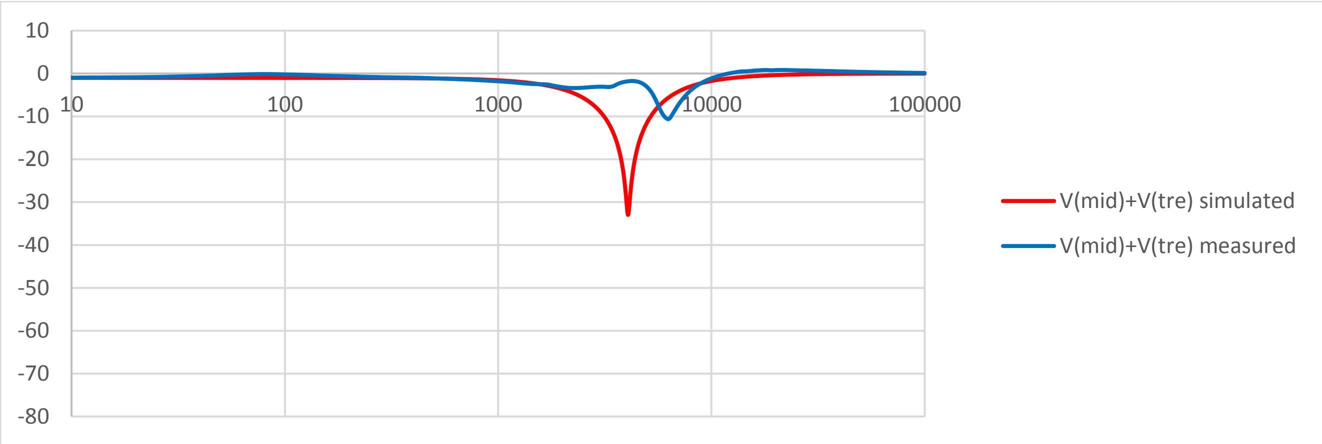

Figure 23: Audio crossover mid-range + tweeter path

The attenuation of the simulated overall frequency curve at the interception point of the tweeter and the mid-range driver is a lot bigger than in the measurement because the ESR of the devices downgrade the Q factor.
That is a deliberated effect because if the attenuation is too big at a small frequency range, we could not hear this frequencies as good as all the others.

5 Conclusion

The Bode 100 enables simple and fast measurements to characterize the input impedance of loudspeakers as well as the voltage transfer function of audio crossovers.

If you would like to have some information how to measure different characteristics of audio amplifiers, check out the application note “Audio Amplifier Frequency Response”.

OMICRON Lab is a division of OMICRON electronics specialized in providing Smart Measurement Solutions to professionals such as scientists, engineers and teachers engaged in the field of electronics. It simplifies measurement tasks and provides its customers with more time to focus on their real business.

OMICRON Lab was established in 2006 and is meanwhile serving customers in more than 40 countries. Offices in America, Europe, East Asia and an international network of distributors enable a fast and extraordinary customer support.

OMICRON Lab products stand for high quality offered at the best price/value ratio on the market. The products' reliability and ease of use guarantee trouble-free operation. Close customer relationship and more than 25 years in-house experience enable the development of innovative products close to the field.

Europe, Middle East, Africa
OMICRON electronics GmbH
Phone: +43 59495
Fax: +43 59495 9999

Asia Pacific
OMICRON electronics Asia Limited
Phone: +852 3767 5500
Fax: +852 3767 5400

Americas
OMICRON electronics Corp. USA
Phone: +1 713 830-4660
Fax: +1 713 830-4661

info@omicron-lab.com • www.omicron-lab.com