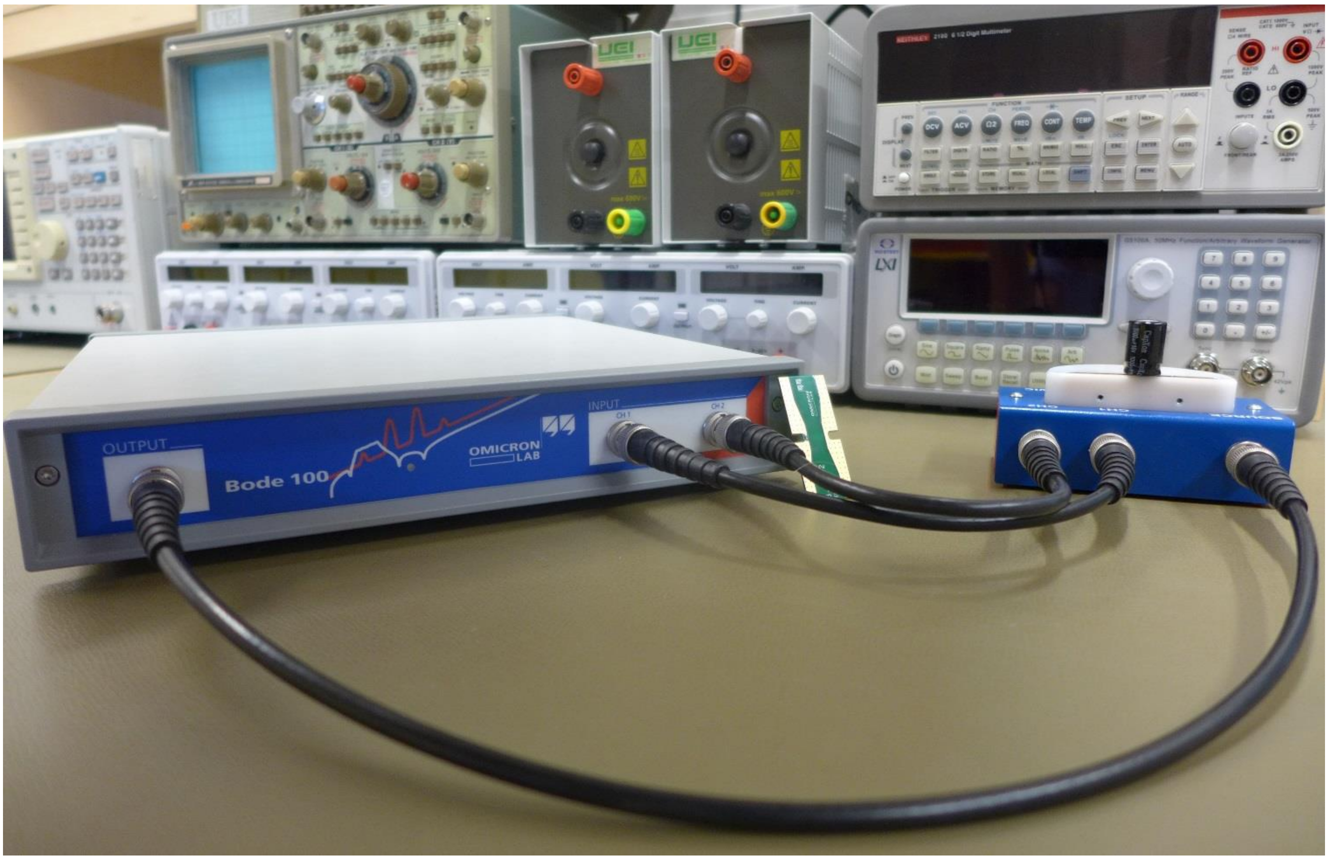
Bode 100 - Application Note

Capacitor ESR Measurement



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Contact support@omicron-lab.com for technical support.

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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 V3.23. 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 Executive Summary

This application note describes how to measure the equivalent series resistance (ESR) of a capacitor using the Bode 100 vector network analyzer in conjunction with the B-WIC Impedance Adapter.

2 Measurement Task

The ESR[1] of a capacitor strongly influences its characteristic behavior. When isolation losses are neglected, the behavior of a capacitor below the self-resonance frequency can be modeled according to the equivalent circuit model shown below.

Figure 1: Capacitor equivalent circuit model

In some applications the series resistances influences the behavior or the system, the capacitance is applied to. Therefore it is essential to know the ESR value of the capacitor. Generally, the manufacturers of capacitors do not provide much information about the ESR.

This document shows how the ESR of a capacitor is measured from 10 Hz to 1 MHz using the Bode 100 vector network analyzer.

[1] Equivalent Series Resistance

3 Measurement Setup & Results

3.1 Measurement Equipment

- Bode 100 Vector Network Analyzer
- Impedance Test Fixture (B-WIC or B-SMC)
- Test object (In this case we use a non-polarized electrolytic capacitor with 1000 µF and 16 V operating voltage)
- Calibration board B-CAL

3.1.1 Test Object Data

The datasheet of the capacitor does provide the following information about the ESR of the capacitor: At 120 Hz and 20 °C the $\tan\delta$ respectively the Dissipation Factor DF is specified with a maximum value of 20% (= worst case).

3.1.2 ESR Specification

Assuming the equivalent circuit model shown on the previous page, the following relation between dissipation factor and ESR is valid:

$$\tan\delta = \mathrm{ESR} \cdot \omega \cdot C \tag{1}$$

Using the data from the datasheet, the ESR at 120 Hz and 20 °C can be calculated as follows:

$$\mathrm{ESR} = \frac{0{,}2}{2\pi \cdot 120\ \mathrm{Hz} \cdot 1000\ \mu\mathrm{F}} = 265\ \mathrm{m}\Omega \tag{2}$$

Now we will use the Bode 100 to check if our capacitor does show a similar ESR value.

3.2 Measurement Setup and Calibration

3.2.1 Measurement Setup

The Impedance Adapter B-WIC is connected to the Bode 100 as shown in the following picture.

Figure 2: Measurement setup

After starting the Bode Analyzer Suite the Impedance Adapter measurement is selected within the "Impedance Analysis" methods by clicking the "Start measurement" Button.

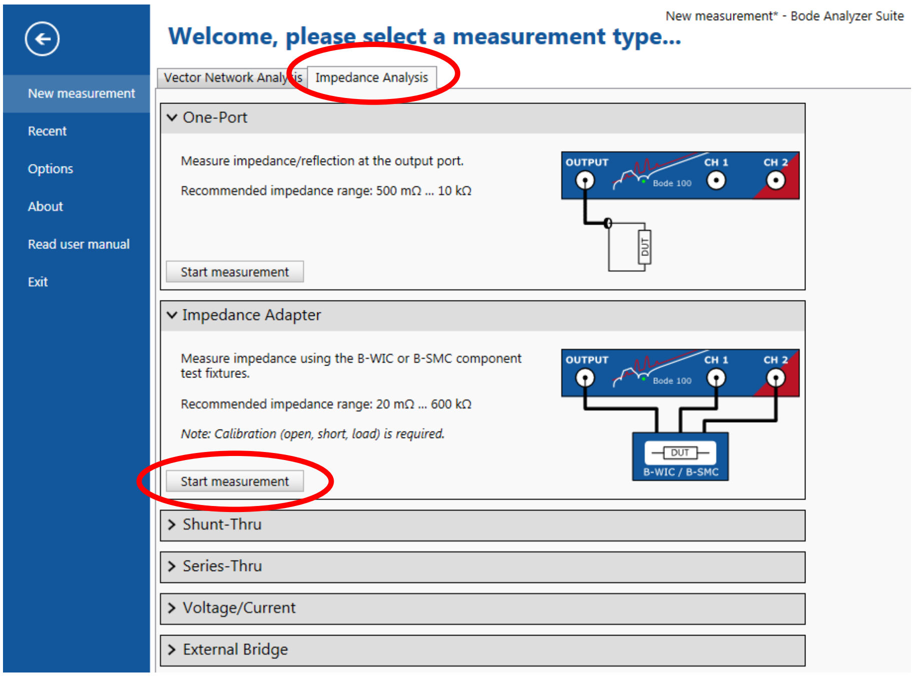

Figure 3: Start menu

3.2.2 Calibrating the Impedance Adapter

Impedance calibration has to be performed prior to the measurement. Calibration of the B-WIC adapter is done by using the B-CAL calibration board which is delivered with the B-WIC adapter.

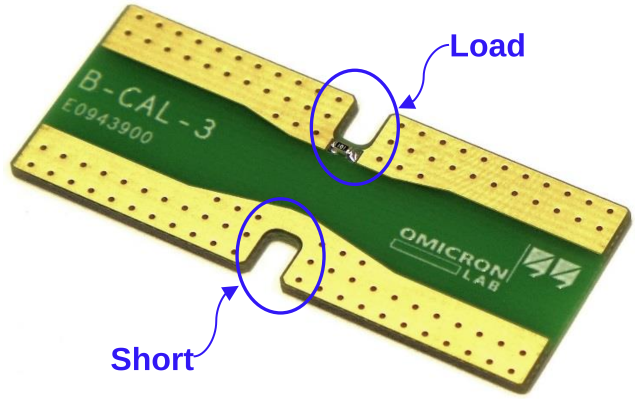

Figure 4: B-CAL calibration board

To calibrate the impedance adapter click on the Full-Range Icon and perform a new calibration.

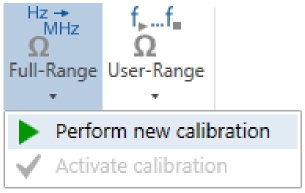

Figure 5: perform calibration

In the calibration window, start the three calibration points by clicking on the Start buttons.

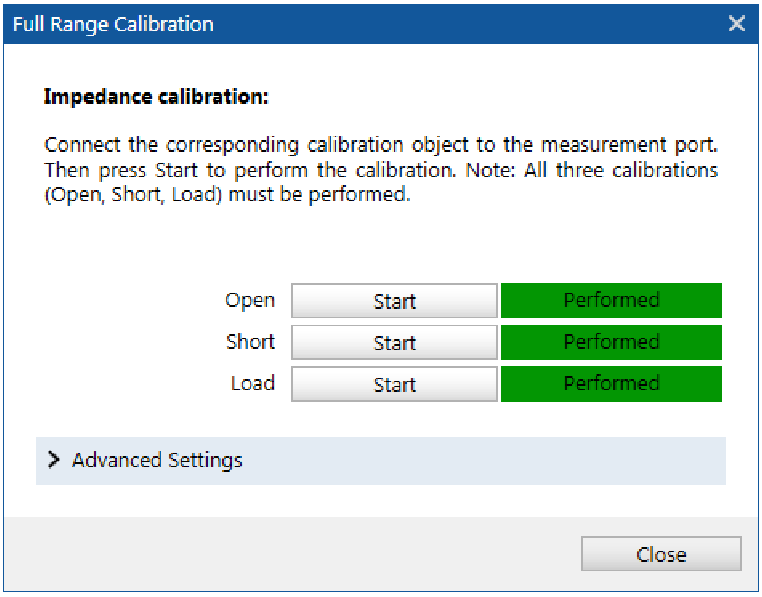

Figure 6: Probe calibration window - performed

Every calibration point (open, short and load) must be measured with the correct impedance connected to the adapter. The following pictures show the correct calibration setups.

Open Calibration:

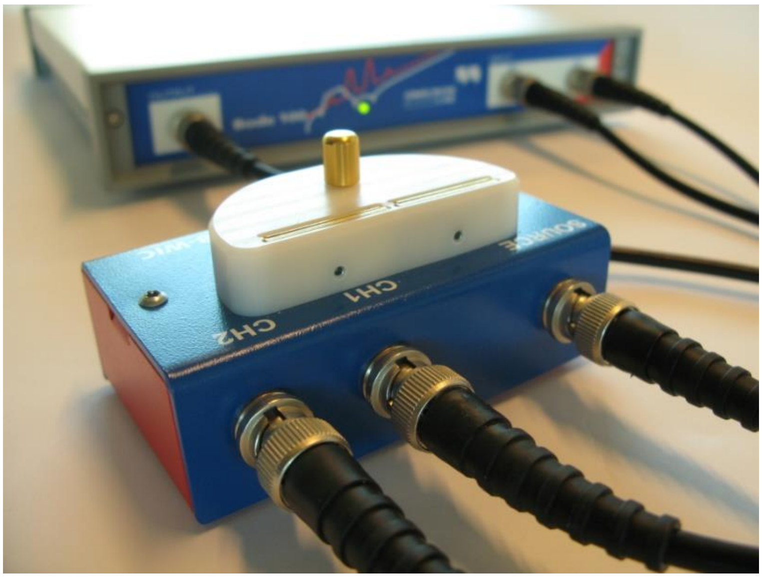

Figure 7: Impedance adapter without a load

No DUT[2] is connected to the impedance adapter and the OPEN calibration is performed.

Note: The OPEN calibration is sensitive to changes in the electric field. Do not move your hands or any other parts close to the electrodes of the impedance adapter during calibration.

Short Calibration:

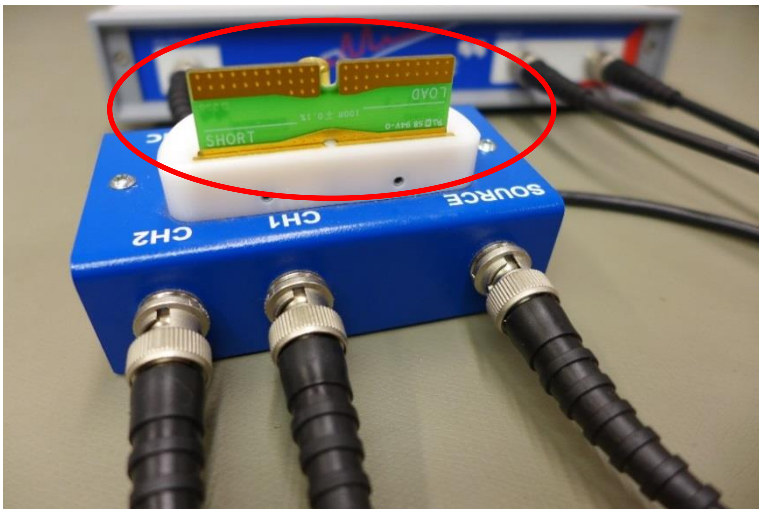

Figure 8: Short-circuited impedance adapter

The shorting bar of the calibration board is connected to the impedance adapter as shown in the picture above. Ensure good contact and put the board horizontally into the adapter to perform the SHORT calibration.

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[2] DUT...Device Under Test

Load Calibration:

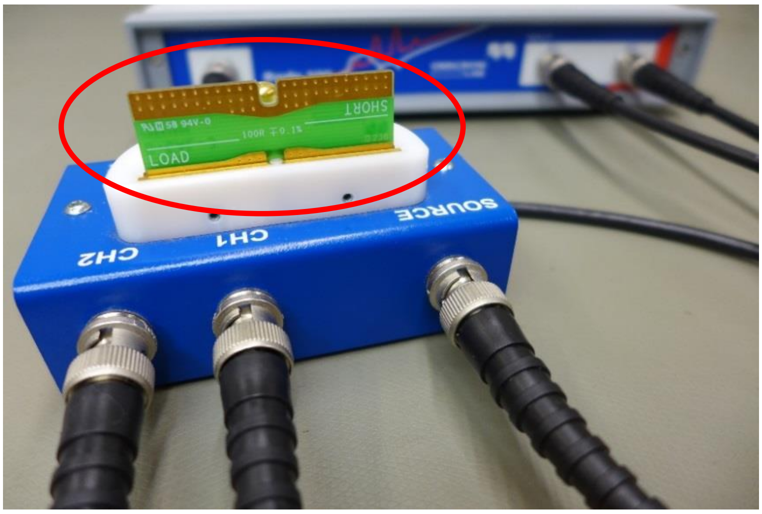

Figure 9: Impedance adapter with 100Ω load

The LOAD side of the calibration board is horizontally connected to the adapter and a LOAD calibration is performed.

3.2.3 Capacitor Measurement

The capacitor is connected as shown in the following picture. Make sure, that the capacitor is plugged in as deep as possible to keep the lead length short to minimize the parasitic inductance. Otherwise, the lead length could influence the measurement results.

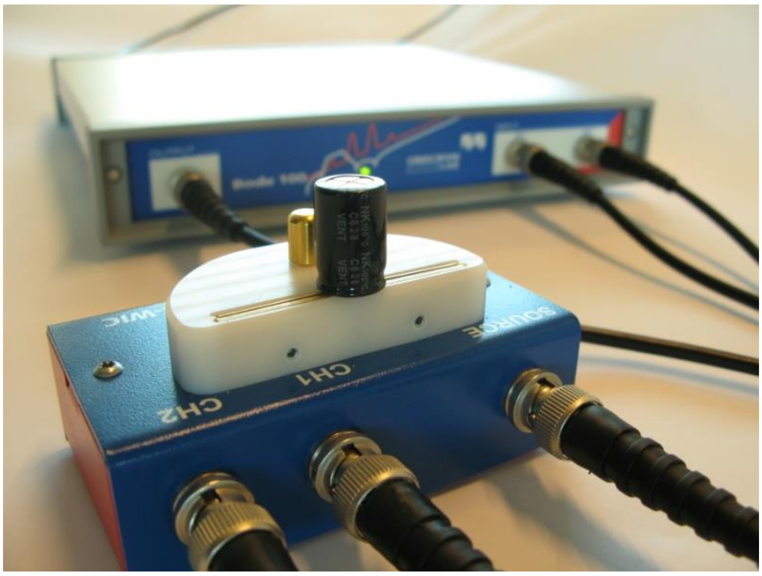

Figure 10: Capacitor connected to impedance adapter

For the capacitor measurement the sweep parameters are set to:

Start Frequency:	10 Hz
Stop Frequency:	1 MHz
Sweep Mode:	Logarithmic
Number of Points:	201 or more
Source level:	13 dBm
Receiver Bandwidth:	30 Hz

First, the impedance magnitude and phase are measured to see the frequency response of the capacitor impedance. To conduct the measurement of the impedance magnitude and phase the following trace settings are required.

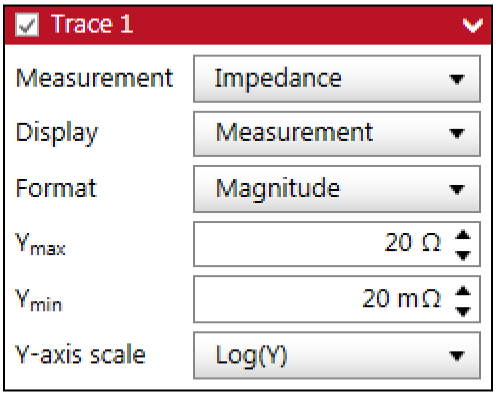

Figure 9: Settings Trace 1 - Magnitude

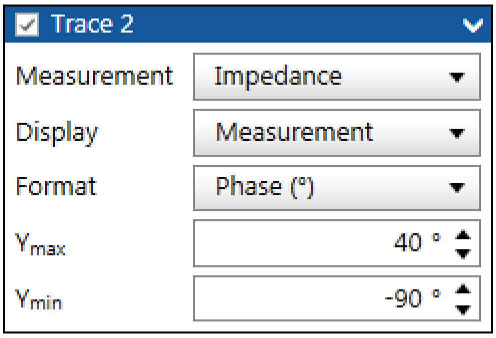

Figure 10: Settings Trace 2 - Phase (°)

Performing a single sweep measurement Single with all the settings and calibration mentioned above leads to the measurement results shown on the next page.

3.3 Measurement Results

The graph below shows the magnitude of the capacitor impedance from 10 Hz to 1 MHz.

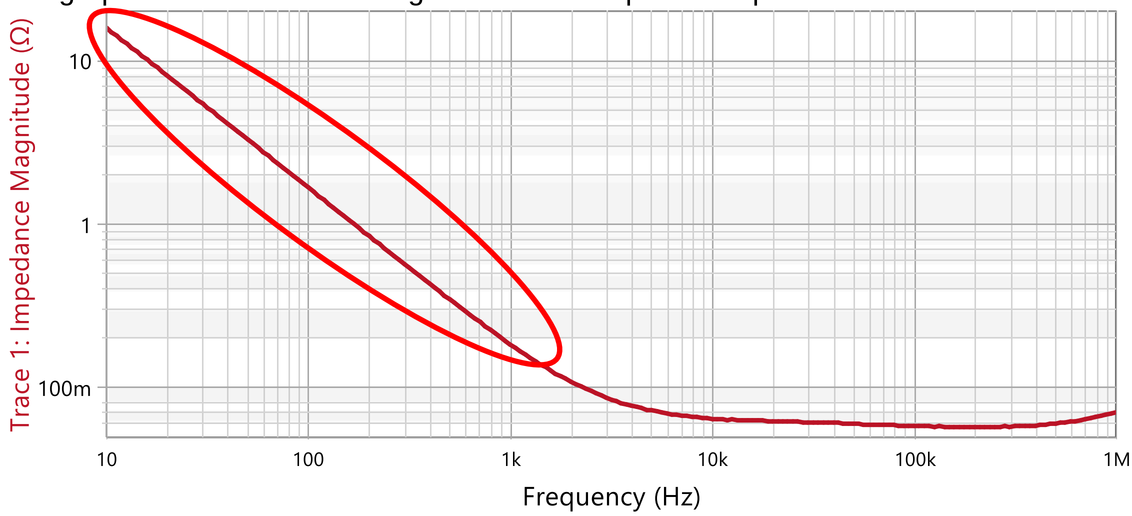

Figure 11: Frequency-dependent Impedance Magnitude

Taking a look at the result, we can see a straight line from the start frequency to approximately 1 kHz. In this area, the parasitic inductance and resistance don't have a mentionable influence and therefore the impedance of the capacitor is mainly consisting of the reactance $X_c = \frac{1}{\omega C}$. The double logarithmic display does, therefore, show a linear curve.

At the resonance frequency, the capacitive part of the impedance is canceled out by the parasitic inductance. As a result, only the resistive behavior caused by the ESR can be seen. The ESR does damp the resonance peak. In this case, we have quite high ESR and therefore a very flat resonance.

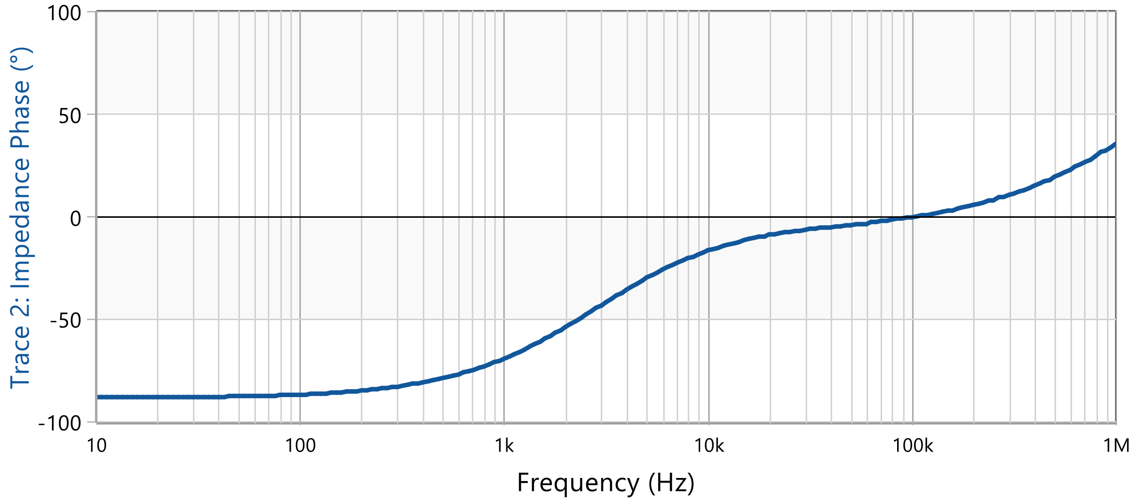

Figure 12: Phase of the impedance

As we stated before, at low frequencies the parasitic effects aren't relevant for the overall impedance. Hence a real capacitor appears like an ideal capacitor and this leads to a phase of -90°. The increasing frequency causes increasing parasitic effects. In the graph, we also see, that the capacitor turns inductive at frequencies above 100 kHz.

The Bode 100 does enable direct measurement of the series equivalent circuit values. For such a measurement the format simply has to be changed to Rs for measuring the ESR or to Cs in order to measure the series capacitance. The pictures below show the chosen trace settings:

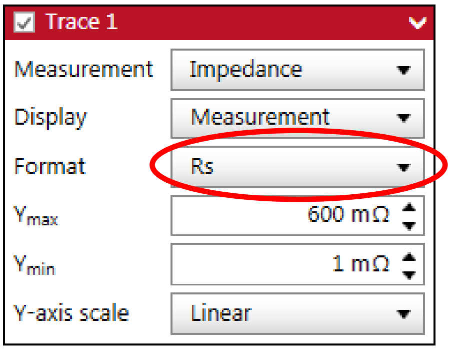

Figure 13: Settings Trace 1 – Rs

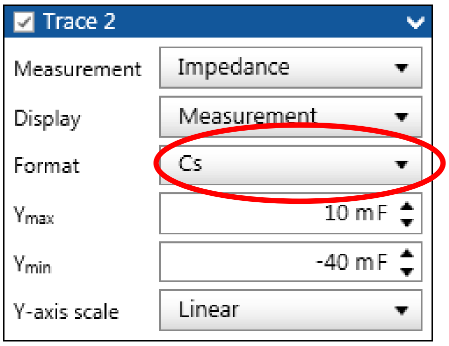

Figure 12: Settings Trace 2 – Cs

Starting a sweep results in the following measurement curve.

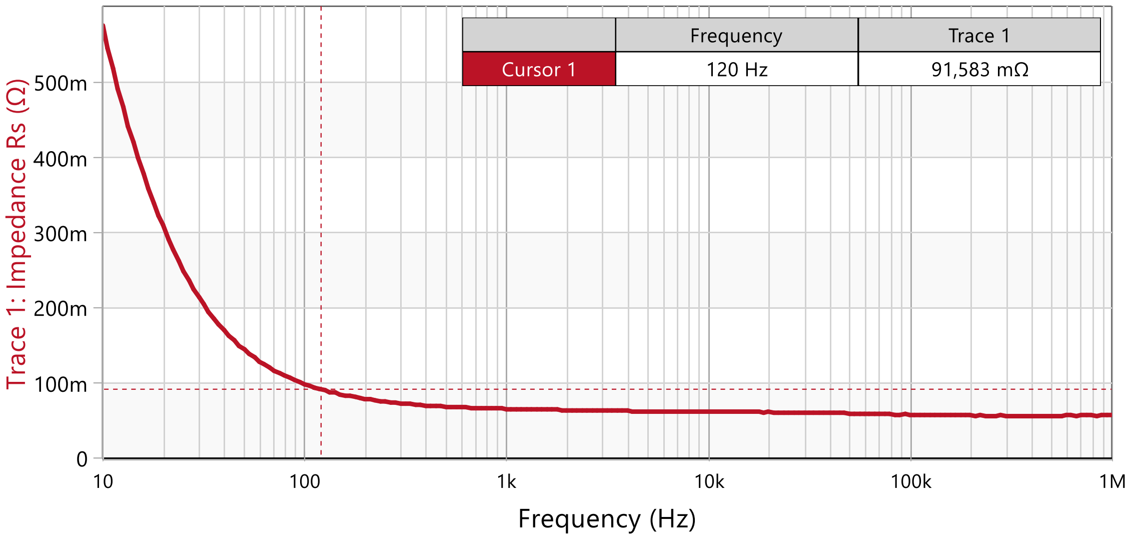

Figure 14: Frequency depending resistance (ESR)

The result shows that the ESR of the capacitor is strongly depending on the frequency.

The next figure shows the series capacitance result. The capacitance at 10 Hz equals 993 µF. At approx. 90 kHz the capacitor shows a series-resonance due to the internal inductance.

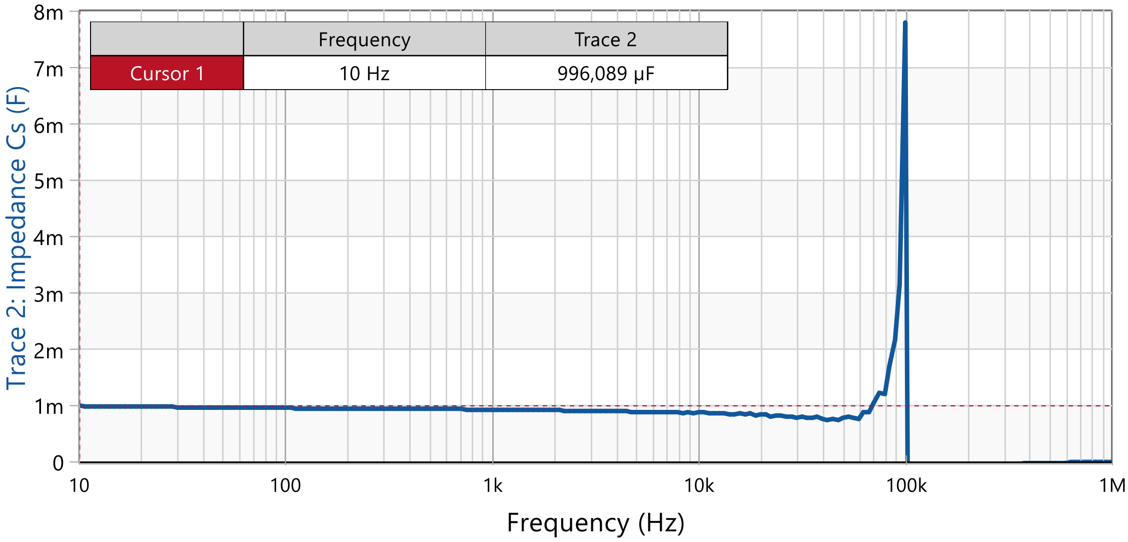

Figure 15: Series capacitance

The exact series-resistance value can easily be measured by activating a cursor. To compare the measured ESR with the value from the datasheet the cursor is set to a frequency of 120 Hz.

	Frequency	Trace 1	Trace 2
Cursor 1	120 Hz	91,583 mΩ	953,941 µF
Cursor 2			
Delta C2-C1			

Figure 16: Cursor window @ 120 Hz

The equivalent series resistance at 120 Hz equals $\mathrm{ESR} \cong 92\ \mathrm{m\Omega}$ and is therefore less than half of the worst-case value calculated from the datasheet information (265 mΩ).

4 Conclusion

The Bode 100 in conjunction with the impedance adapter B-WIC offers an easy and fast possibility to analyze passive components such as capacitors. The results show that the ESR of the measured capacitor strongly depends on the frequency and is approx. one-third of the value stated in the datasheet.
In addition to that the usable frequency range of a capacitor can be checked and resonance frequencies can be identified easily.

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