Bode 100 - Application Note

Impedance Measurements using the Bode 100

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Table of Contents

Note: Basic procedures such as setting-up, adjusting and calibrating the Bode 100 are described in the Bode 100 user manual available at:
https://www.omicron-lab.com/downloads/vector-network-analysis/bode-100/

Note: All measurements in this application note have been performed using the Bode Analyzer Suite V3.23 Use this version or a newer version to perform the measurements shown in this document. You can download the latest version at
https://www.omicron-lab.com/downloads/vector-network-analysis/bode-100/

1 Introduction

This application note discusses how to choose the correct impedance measurement method when measuring impedance using the Bode 100 and how to improve results.

It is recommended to think about the following parameters prior to the measurement:

1. What is the expected impedance of the device under test (DUT)?
2. What is the frequency range of interest?
3. How can the DUT be connected to the Bode 100?

Before starting with the details of the measurement methods some basics of passive components and impedance data will be discussed in the following section. The experienced reader might continue with the section “Impedance Measurement ” on page 11ff.

1.1 Impedance of Passive Components

Theoretically, an inductor or a capacitor is a purely reactive element that does not show resistive behavior and therefore is lossless. In real-life, parasitics will strongly influence the behavior of passive components, especially at higher frequencies. The following list shows some of the main reasons for frequency-dependent parasitics of passive components:

Inductor:

- The wire has a resistance that is frequency-dependent due to proximity effect and skin-effect.
- The windings also form an electric field causing a parasitic capacitance that forms a parallel resonator with the inductance.
- The core is not lossless, causing AC losses at higher frequencies, damping the parallel resonance.

Capacitor:

- The plates are made of metal having a finite conductivity causing a resistive loss that can depend on frequency.
- Sometimes the rolling of foils creates inductance that forms a series-resonance circuit with the capacitance.
- The insulator / dielectric material is not lossless and can cause a loss tangent especially at low frequencies.

1.2 Impedance – Reactance – Resistance

When measuring impedance, one needs to consider that the impedance Z is a complex value consisting of a real part (resistance R) and an imaginary part (reactance X).

$$Z = R + j\,X \tag{1}$$

The real part corresponds to the ohmic losses caused by dissipating energy in form of heat.

The imaginary part is called reactance that can be of either capacitive or inductive nature.

In the inductive case, the reactance X_L is calculated as follows:

$$X_L = \omega \cdot L = 2\pi f \cdot L \tag{2}$$

In the capacitive case, the reactance X_C is calculated by the following equation:

$$X_C = \frac{-1}{\omega \cdot C} = \frac{-1}{2\pi f \cdot C} \tag{3}$$

The following figure shows an inductive impedance Z_L as well as a capacitive impedance Z_C drawn in the complex number plane. The x-axis corresponds to the real part, the y-axis to the imaginary part.

The main difference between the inductive and the capacitive case is the phase φ. In the inductive case, the phase is positive whereas the capacitive impedance has a negative phase. In an ideal case with zero resistance R (no loss), the phase angle would be +90° in the inductive case or -90° in the capacitive case.

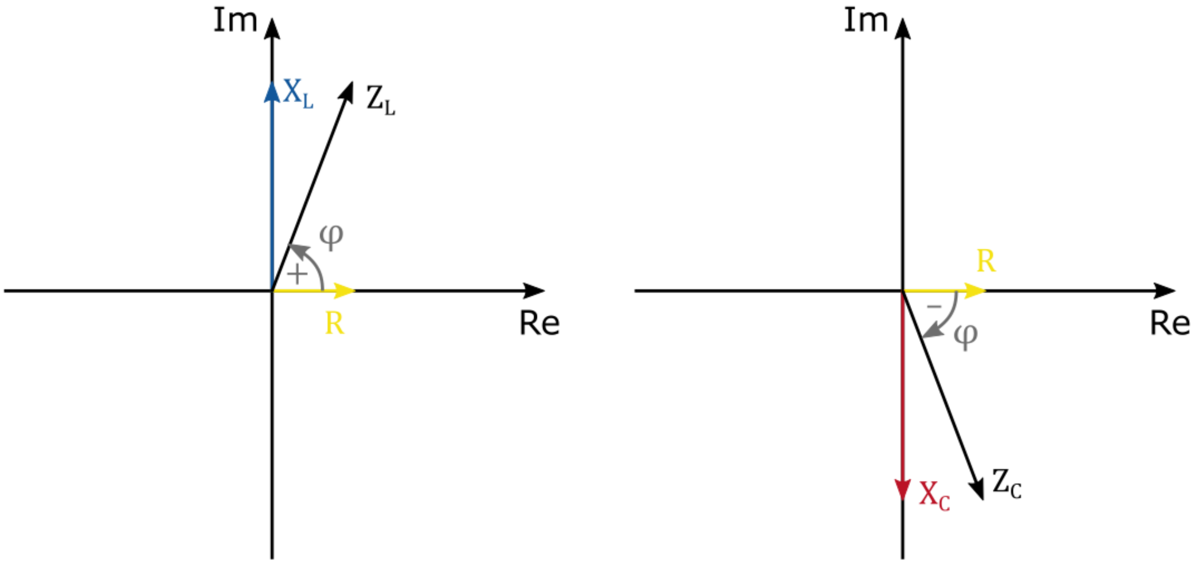


Figure 1: Inductive impedance versus capacitive impedance

1.3 Impedance over Frequency

Looking at the equations of capacitive and inductive reactance, one can clearly see that the reactance depends not only on the inductance L and the capacitance C but also on the frequency f.

For now, let's assume that the impedance is only composed of pure reactance (no resistance).
In the inductive case, the impedance rises with frequency, in the capacitive case, impedance falls with frequency as shown in Figure 2 below where the impedance magnitude of a 10 µF capacitance (red) and a 10 µH inductance (blue) is plotted on a double logarithmic scale.

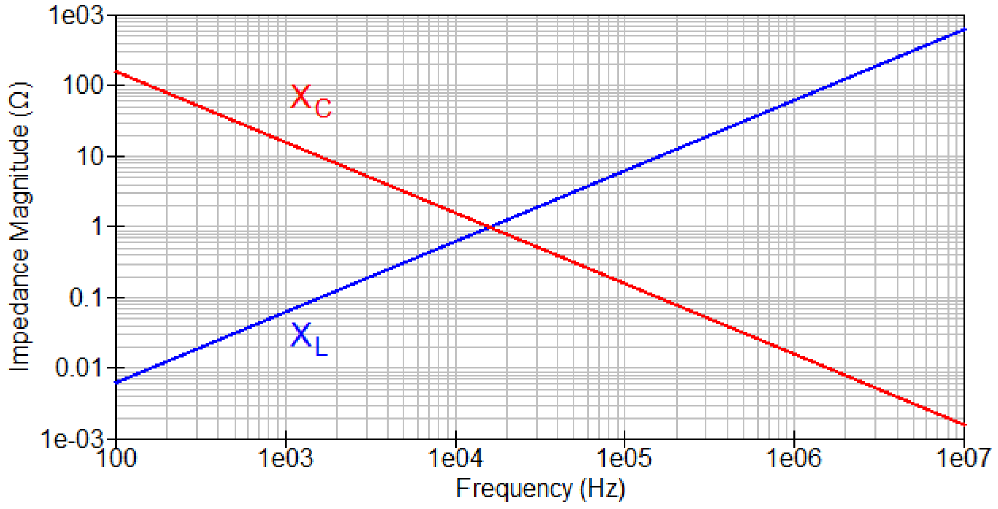


Figure 2: Impedance of inductance and capacitance versus frequency

In real life, there is always some non-zero resistive loss. Adding a 100 mΩ series resistance to the inductance as well as the capacitance changes the frequency response as shown below:

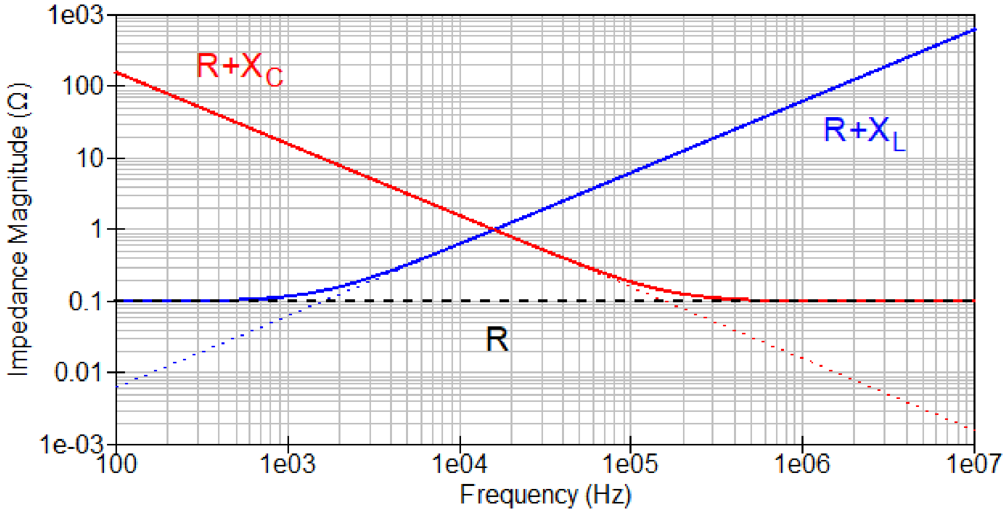


Figure 3: Inductance and capacitance with resistance over frequency

From the previous figures, one can see the "inductive slope" and "capacitive slope" in an impedance spectrum. A pure inductance causes a straight line rising with a slope of +1 (10 times the frequency causes 10 times the impedance). A pure capacitor causes a falling line with a slope of -1 or -20 dB/decade. This helps to interpret more complex impedance spectra.

Finally, a real inductor and a real capacitor are never just composed of inductance and capacitance with added resistance. As mentioned in the beginning, an inductor also has capacitance and a capacitor also has inductance. Let’s add parasitic values of 100 nF and 100 nH to the components. The resulting frequency response is shown below:

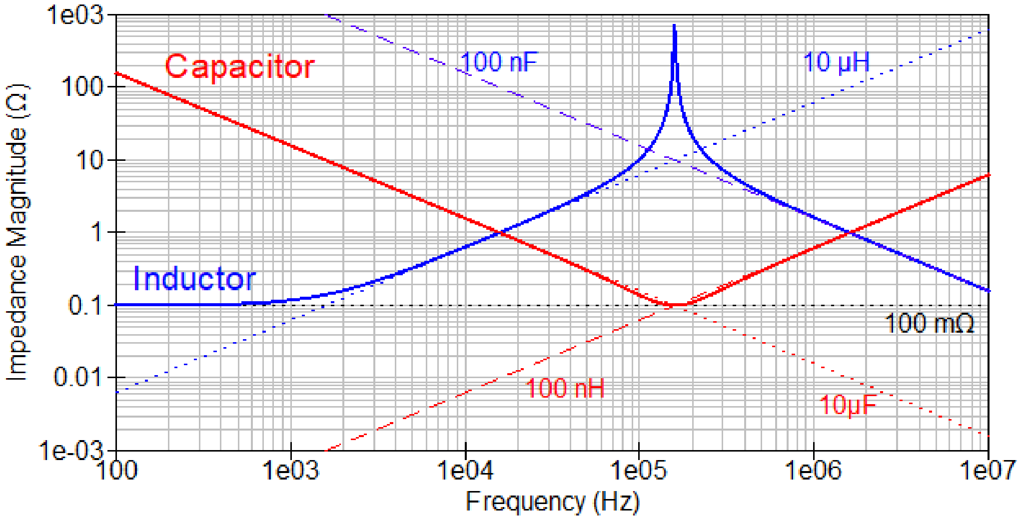


Figure 4: Capacitor & Inductor versus frequency (Impedance Magnitude)

The red curve shows the capacitor that equals the behavior of a series-resonance circuit with series damping. The blue curve shows the inductor curve with a low-frequency resistance that is equal to the series resistor and a parallel resonance at high frequency caused by the parasitic capacitance.

The different parts of the curves can also be identified by looking at the phase of the impedance. In Figure 5 below, the impedance phase of the inductor is plotted in blue, the phase of the capacitor in red. The inductor (blue) starts with resistive behavior (0°) and turns more towards purely inductive (+90°) at higher frequencies. Above the self-resonance frequency, the phase is capacitive (-90°) since the parasitic capacitance dominates. The capacitor (red) starts with -90° capacitive behavior, reaches 0° at self-resonance and turns inductive (+90°) above the resonance frequency where the parasitic inductance dominates.

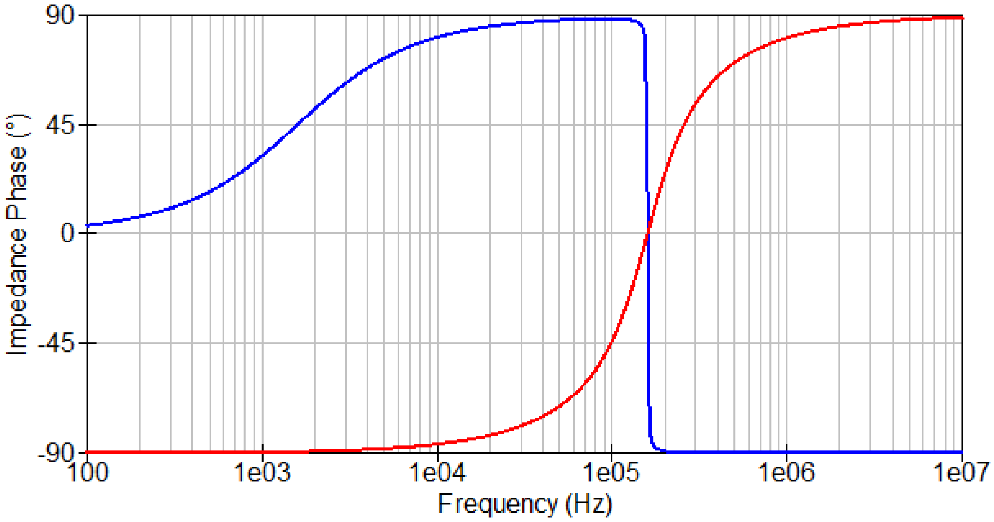
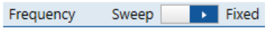


Figure 5: Capacitor & Inductor versus frequency (Impedance Phase)

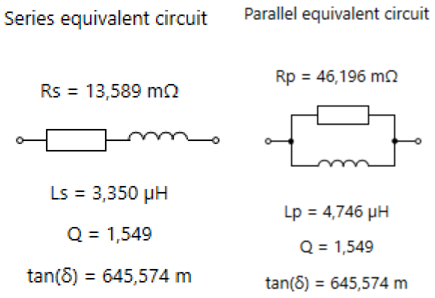
1.4 Result Format

Impedance or Admittance are complex-number results and therefore not always simple to interpret. The Bode Analyzer Suite offers several result formats to simplify the interpretation of impedance measurement data.

1.4.1 Fixed Frequency Measurements

The Bode Analyzer Suite allows measuring impedance at one specific frequency using the fixed frequency measurement setting. 

In this continuous-wave measurement setting, the measured impedance or admittance can directly be transformed into a simple series or parallel equivalent circuit model as shown below:



Series equivalent circuit

Rs = 13,589 mΩ

Ls = 3,350 µH

Q = 1,549

tan(δ) = 645,574 m

Parallel equivalent circuit

Rp = 46,196 mΩ

Lp = 4,746 µH

Q = 1,549

tan(δ) = 645,574 m

The series equivalent parameters Rs and Ls or Cs will be displayed as well as the parallel equivalent parameters (Rp and Lp or Cp). Bode Analyzer Suite will display the inductance (Ls and Lp) if the impedance phase is positive or the capacitance (Cs and Cp) if the impedance phase is negative.

1.4.2 Swept Frequency Measurements

In case of a frequency sweep measurement, the impedance phase will change over frequency and a simple series equivalent or parallel equivalent circuit model cannot describe the complex behavior of a real device under test which is influenced by parasitic behavior. A very simple equivalent circuit model for a capacitor and an inductor is shown in Figure 6 below.

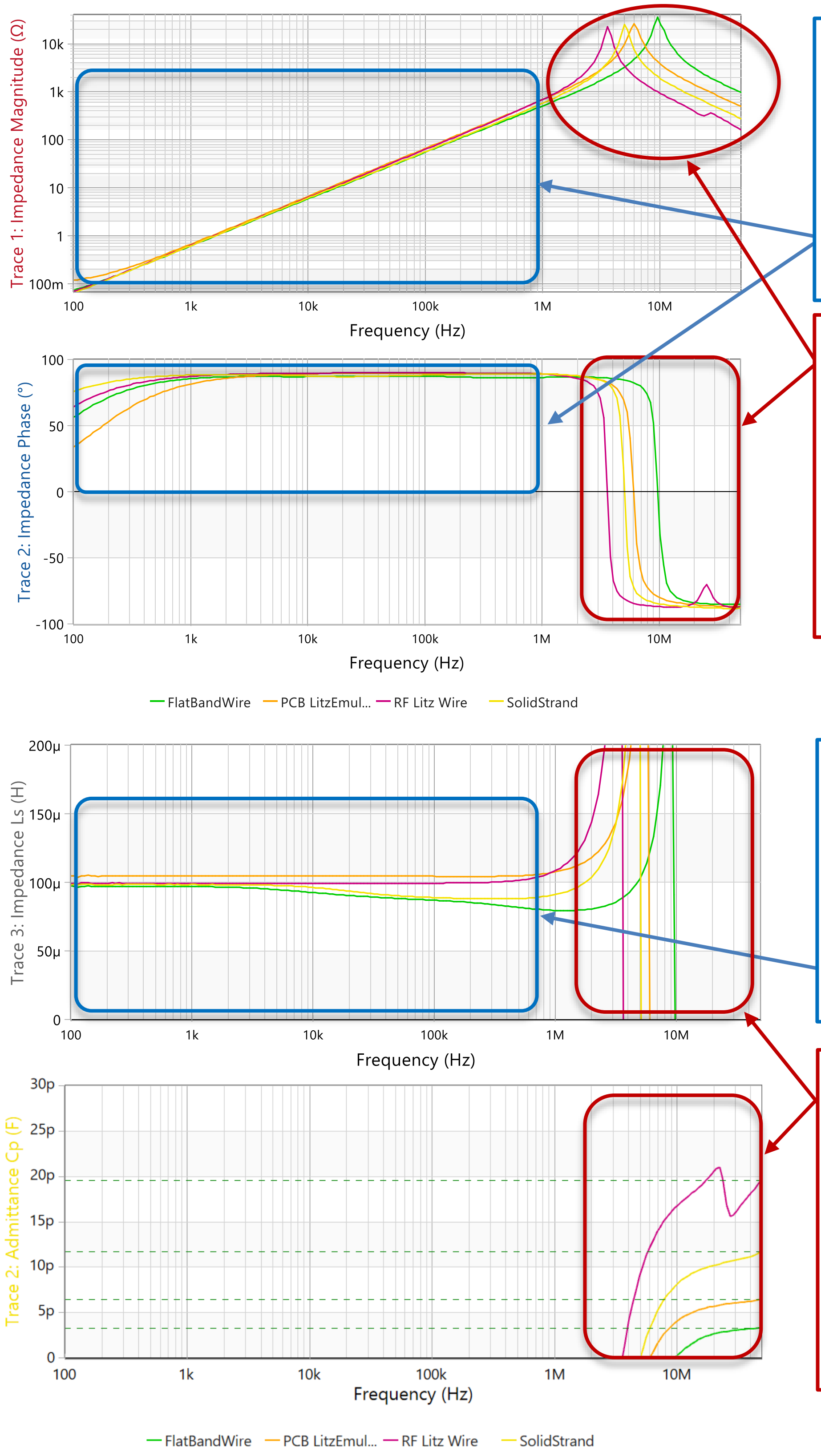
Figure 6: Simple equivalent circuit models

Please note that these rather simple models contain 4 parameters that can be derived manually from the measurement data. Alternatively, curve-fitting methods or numeric optimizers can support parameter identification.

Currently, the Bode Analyzer Suite requires a manual parameter identification process to derive equivalent circuit models. Note that the Ls, Rs, and Cs or Lp, Rp and Cp data helps to interpret the impedance measurement results and to derive parameter data.

1.4.3 Inductor Result Example

In the following, four 100µH inductors with different winding types were measured:



Inductive frequency range, inductance starts to dominate above 1 kHz for all winding types. Phase approaches +90° and stays around 90° until close to the self-resonance frequency.

Self-resonance area and capacitive range above self-resonance. The self-resonance frequency depends on the capacitance. Above self-resonance the phase approaches -90°.

Inductive region where the inductance is relatively constant (depending on the winding construction). An equivalent inductance of approximately 100 µH is the result for all inductors.

At and above the self-resonance frequency, the inductance Ls is not visible anymore since the impedance turns capacitive. Therefore, the capacitance result shows positive values, where one can read the parasitic capacitance.

Figure 7: Impedance spectrum of four different winding types on a 100 µH inductor

An important measure for losses in an inductor is the series resistance Rs. The following figure shows the measured Rs values over frequency. Note that the values above 1 MHz are strongly influenced by the vicinity of the self-resonance frequency.

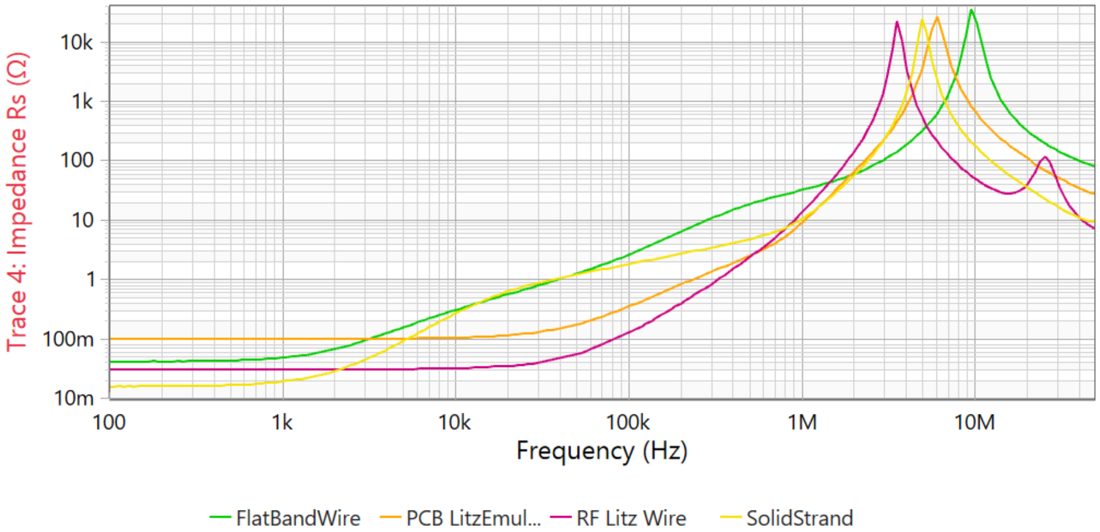


Figure 8: AC resistance over frequency for different wire types

At frequencies below 1 kHz, the AC resistance is equal to the DC resistance which can be seen by the constant value over frequency. Between 1 kHz and 30 kHz, the resistance starts to rise due to skin effects and proximity effect. Especially the flat-wire and the solid strand winding show an early rise of resistance with frequency. The RF litz wire and a PCB winding structure show a constant AC resistance over frequency up to nearly 30 kHz. The following table compares the AC resistance at 100 Hz with the resistance at 250 kHz:

Cursor name	Frequency (Hz)	FlatBandWire (Ω)	PCB LitzEmulation (Ω)	RF Litz Wire (Ω)	SolidStrand (Ω)
Cursor 1	100	0,04	0,10	0,03	0,02
Cursor 2	**250000**	**8,17**	**1,05**	**0,57**	**3,01**

The flat band wire has an AC resistance of 8 Ω at 250 kHz which is quite astonishing since it only has a DC resistance of around 40 mΩ. Note that this also means that losses caused by AC currents are increased by a factor of 200 if the frequency is changed from 100 Hz to 250 kHz.

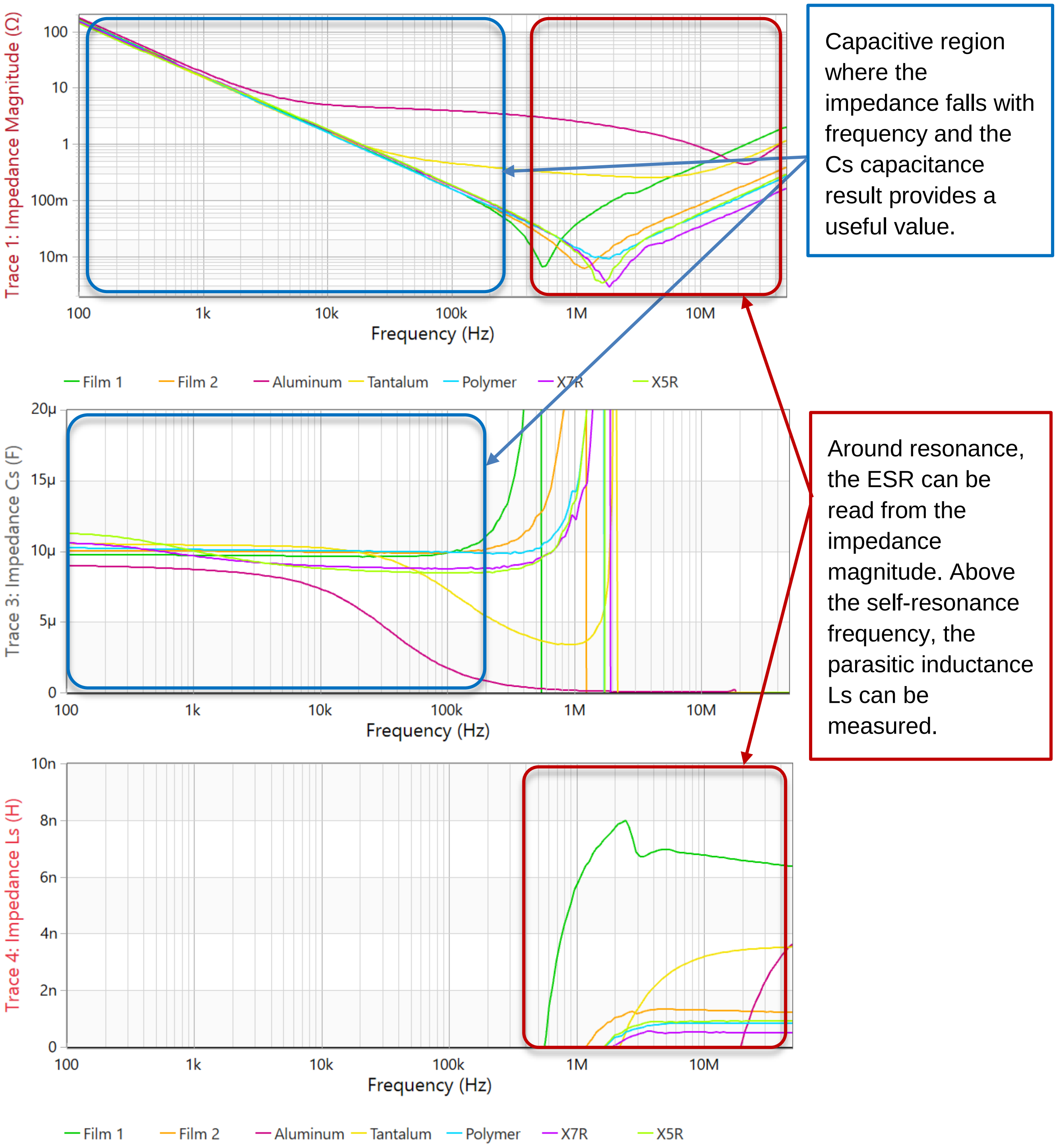
The RF litz wire shows the best behavior with a DC resistance of roughly 30 mΩ that increases by a factor of 20 to 570 mΩ at 250 kHz.

It must be mentioned, that these measurements are small-signal measurements. In a large-signal application, additional saturation effects might increase losses even further.

Note: Please refer to our webinar recording to learn more about this specific inductor and see the measurement live: https://youtu.be/T2OqewIUL3M?t=2754

1.4.4 Capacitor Result Example

In addition to the inductor presented in the previous section, in the following seven different 10 µF capacitors are measured and the results are analyzed by looking at the impedance magnitude, capacitance Cs and series inductance Ls.



Capacitive region where the impedance falls with frequency and the Cs capacitance result provides a useful value.

Around resonance, the ESR can be read from the impedance magnitude. Above the self-resonance frequency, the parasitic inductance Ls can be measured.

Figure 9: Impedance spectrum seven different 10 µF capacitors

Note: Please refer to our webinar recording to see this measurement live: https://youtu.be/T2OqewIUL3M?t=1813

2 Impedance Measurement Techniques

The Bode 100 offers the following seven different impedance measurement possibilities:

- **One-Port** Reflection (1-port technique) see 2.2.1 on page 13
- **Impedance Adapter** (3-port technique) see 2.2.2 on page 14
- **Shunt-Thru** (2-port technique) see 2.2.3 on page 16
- **Extended Shunt-Thru** with series resistance (2-port technique) see 2.2.4 on page 18
- **Series-Thru** (2-port technique) see 2.2.5 on page 20
- **Voltage-Current Gain** (3-port technique) see 0on page 21
- **External Bridge** / external coupler (3-port technique) see 0on page 22

The high variety of impedance measurement possibilities brings great flexibility but also some complexity. In the following, we will present all the measurements and their advantages / disadvantages to help you to select the right measurement for your application.

2.1 Selecting the Right Setup

The most important selection criterion is the **impedance magnitude of the DUT.** And please note that the impedance magnitude changes with frequency (see Introduction).

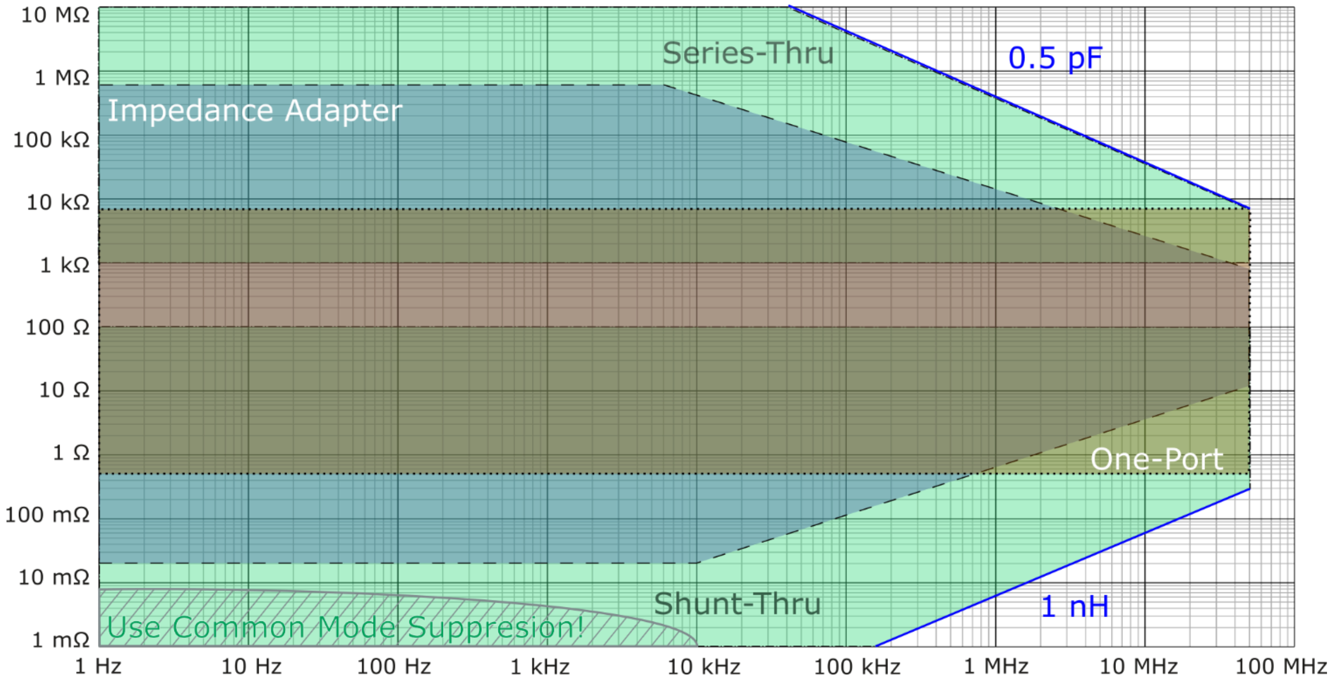


Figure 10: Impedance range chart

Figure 10 shows the recommended impedance range coverage of different measurement methods.

Please note the 0.5 pF and 1 nH limit lines. They do not mean that you cannot measure below 0.5 pF and 1 nH but special care must be taken when approaching these extreme values. Especially during Open and Short calibration, the calibration elements itself might easily have parasitics that come close to what you want to measure. A BNC thru-connector can easily have 1 pF capacitance.

A shorting bar can easily have 1 nH of inductance. These parasitics must be considered when trying to measure extremely small capacitance values or inductance values.

Some Selection Hints

The “Impedance Adapter” method covers the widest impedance range and frequency range. If the DUT can be connected to the B-WIC or the B-SMC component test fixtures, it is always a good starting point.

The One-Port measurement is a purely coaxial method that is not limited in frequency and offers a simple possibility to start. Please note that the sensitivity at high or low impedance values is limited. It is therefore not suitable to measure mΩ or MΩ values.

If you need to measure very low impedance values where contact resistance plays an important role such as a shunt-resistor or the ESR of a ceramic capacitor, please consider using the Shunt-Thru setup which offers a four-wire connection that can overcome the contact resistance.

If you need to measure very high impedance values above several 100 kΩ, consider using the Series-Thru setup that offers the highest sensitivity in the upper impedance range.

Sometimes, the impedance of a DUT covers a very wide range over a wide frequency range. Let’s consider a high-Q ceramic capacitor with a small capacitance of 2.2 nF. At 100 Hz, the capacitor has a reactance of $\frac{1}{2\pi f C} = 723\ k\Omega$. So nearly one MΩ. At the self-resonance frequency, the capacitor will only show its ESR which can be in the single mΩ range. Depending on what is of interest, if it might be necessary to choose more than one setup for one DUT. The following figure gives an overview on how to start selecting the measurement setup:

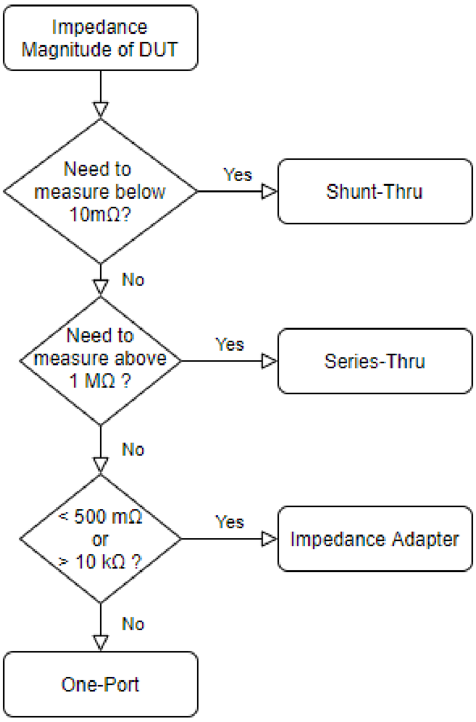


Figure 11: Select the best suitable measurement setup

In the following, details and examples for the various measurement setups are discussed.

2.2 Detailed Description of Measurement Setups

2.2.1 One-Port

The Bode 100 can directly measure impedance/reflection at the output port. It uses the internal 50 Ω source impedance to derive the impedance connected at the output. The DUT must be connected directly to the output as shown in the following figure:

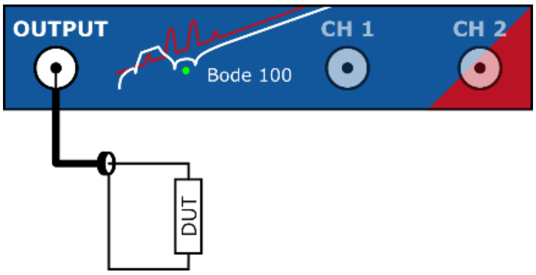


Figure 12: One-Port measurement setup

The optimum range for this measurement is from **≈ 0.5 Ω … 10 kΩ**. When performing a careful Open / Short / Load calibration (preferably the User-Range calibration), the impedance range can further be extended towards lower and higher impedance values.
Please note that it is a **two-wire connection** that is subject to contact resistance errors. Furthermore, note that one point of the DUT is connected to the Bode 100 housing (**GND**) via the BNC shield.

Connection Examples:

The simplest connection can be done by soldering the DUT directly to a BNC plug and connecting it to the Bode 100 output or a BNC cable.

Note that 0.5 m of RG58 coaxial cable has a parasitic capacitance of ≈ 45 pF respectively a parasitic inductance of ≈ 150 nH. You can use a calibration at the end of the cable to remove the influence of the cable on the DUT. For more details, please have a look at section Perform a Calibration on page 24ff.

Figure 13: One-Port – solder DUT to BNC

If soldering is not an option, a BNC to 4 mm banana adapter can be used for THT components.

Figure 14: One-Port – connect to BNC adapter

As mentioned, the one-port measurement has limited sensitivity for small and high impedance values. The Impedance Adapter setup overcomes this limitation.

2.2.2 Impedance Adapter

The “Impedance Adapter” mode is used to measure impedance in conjunction with the B-WIC or B-SMC component test fixtures. The following figure shows the connection setup and the simplified measurement principle.

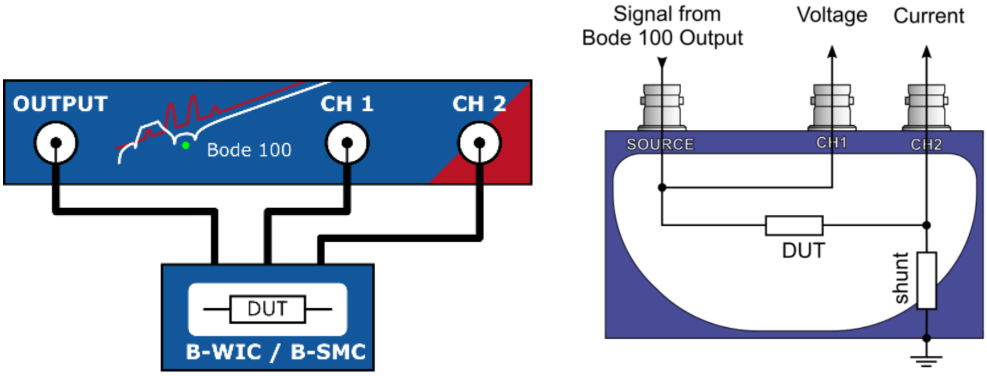


Figure 15: Impedance adapter measurement setup & principle

The impedance adapter measurement uses both input channels of the Bode 100 and therefore offers a wider measurement range than the one-port measurement. The optimum range is from **≈ 20 mΩ - 600 kΩ**. The lower 20 mΩ limit is recommended since the B-WIC and B-SMC do not feature a Kelvin connection. The gold-plated contacts keep the contact resistance low, but it can easily reach 1 mΩ.

Please note that the DUT must **not** be **connected** to **GND** (otherwise the shunt resistor will be by-passed) and note that **Open / Short / Load** calibration must be performed to remove the parasitics of the test fixtures.

Be aware that the B-WIC and B-SMC are not designed for physically big components. Long leads should not be attached since stray capacitance can introduce an error (see Figure 16). When measuring physically large components, please use the one-port measurement.

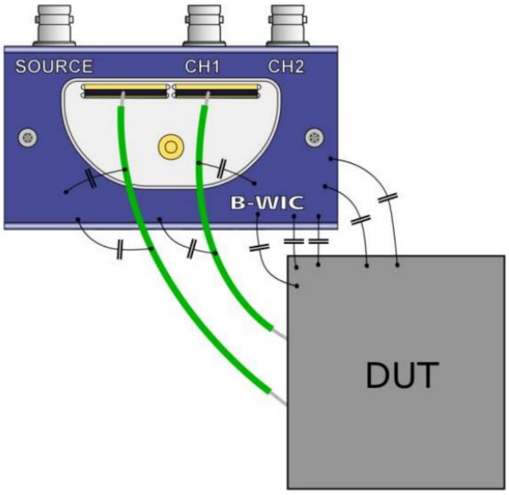


Figure 16: Stray capacitance to GND

Measurement setup examples:

The following pictures show a typical measurement setup where a THT capacitor as well as a SMD capacitor are measured using the B-WIC respectively B-SMC.

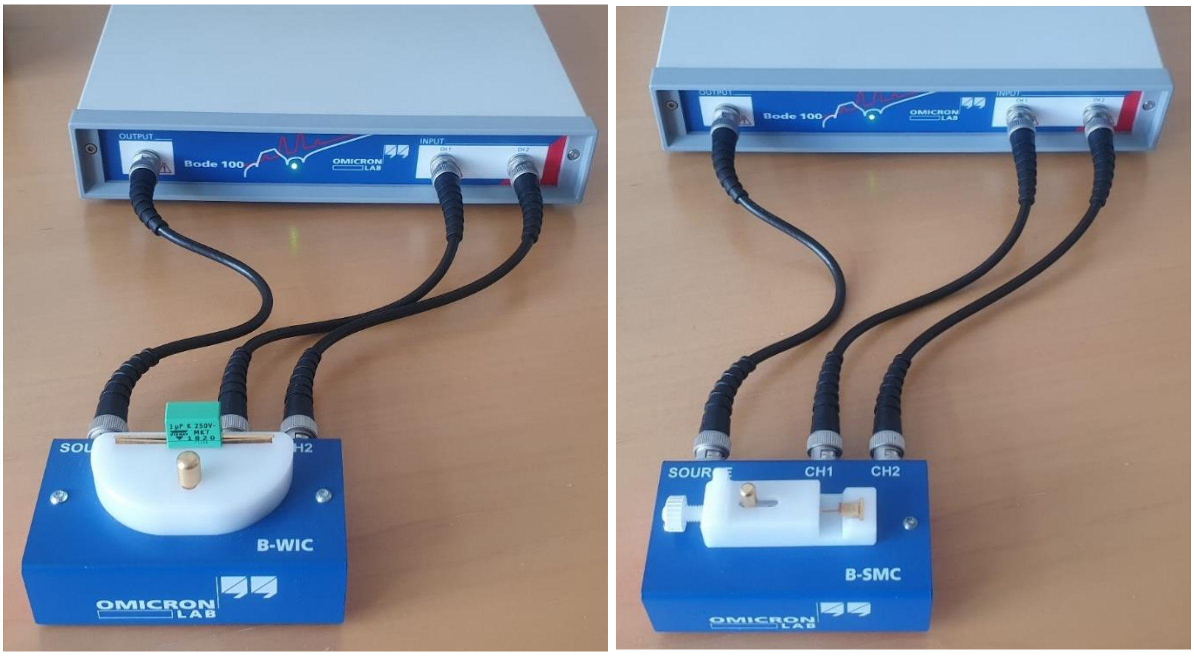


Figure 17: Impedance adapter - setup example

For more information on measurements with the B-WIC and B-SMC, please refer to the user manual available from: https://www.omicron-lab.com/products/vector-network-analysis/accessories/impedance-test-fixtures-b-wic-b-smc/

2.2.3 Shunt-Thru

Whenever a very low impedance shall be measured, the Shunt-Thru method is the method of choice. The Shunt-Thru measurement emulates a Kelvin connection. The signal source drives a current thru the DUT whereas CH2 measures the voltage drop at the DUT. The following figure shows the connection setup:

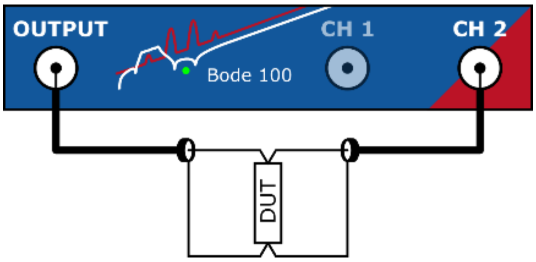


Figure 18: Shunt-Thru measurement setup

The Shunt-Thru measurement is an S21 measurement that is translated to impedance using:

$$Z = 25\Omega \frac{S_{21}}{1 - S_{21}} \tag{4}$$

The measurement can be either calibrated by performing a Thru calibration (calibrating the underlying S21 measurement) or doing a full impedance calibration (Open / Short / Load).

The optimum measurement range is from **≈ 1 mΩ to 100 Ω**. With care, impedance measurements below **100 µΩ** up to **several kΩ** can be taken. Note that one point of the DUT is connected to GND via the cable shield.

Ground-Loop Error:

Since the grounds of the signal source and the input channel are connected internally in the Bode 100, a ground loop is formed. This ground loop can cause a current that does not return to the source but flows to the CH2 GND, causing a systematic error. The ground-loop error is larger when measuring smaller impedance at lower frequencies. A typical error is shown in the following figure:

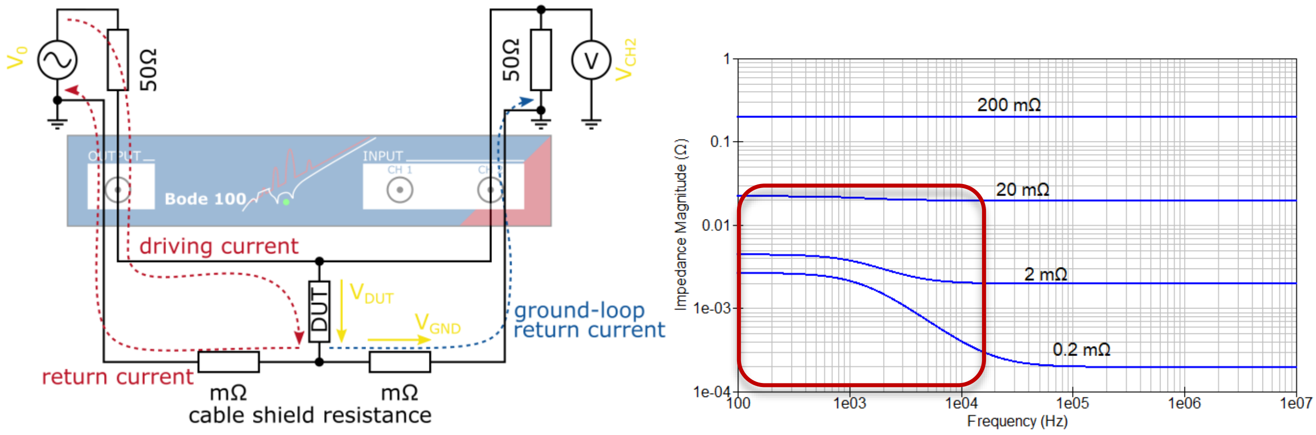


Figure 19: The ground-loop error & typical effect on the impedance measurement

If impedance values < 20 mΩ should be measured below ≈ 10 kHz, a common mode choke like the B-LCM or a differential amplifier like the Picotest J2113A is, can be used to suppress the ground loop error.

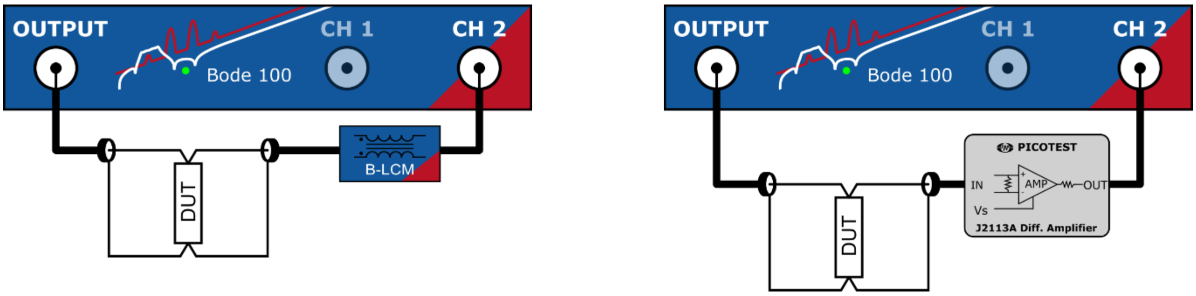
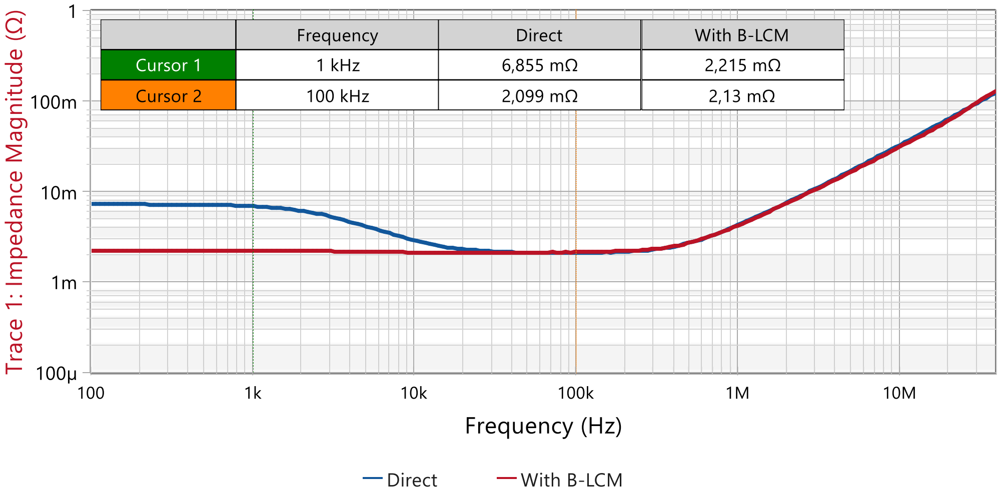


Figure 20: Suppressing the ground-loop error using a common mode choke or differential amplifier

The following figure shows a measured 2 mΩ resistor with and without a common-mode choke. The rising impedance at low frequency can clearly be seen. Introducing a common mode choke, suppresses the ground loop current and therefore reduces the measurement error. At very low frequencies (below 10 Hz in this case) the error will still arise since a choke will not work at DC. An active isolator such as the J2113A from Picotest will also work down to DC.



	Frequency	Direct	With B-LCM
Cursor 1	1 kHz	6,855 mΩ	2,215 mΩ
Cursor 2	100 kHz	2,099 mΩ	2,13 mΩ

Figure 21: Measured ground-loop error on a 2 mΩ resistor DUT

If very low impedance values of 1 mΩ and below shall be measured, it is recommended to use an amplifier to increase the signal/noise ratio. The B-AMP 12 can be used to boost the Bode 100 signal source from 13 dBm to 25 dBm.

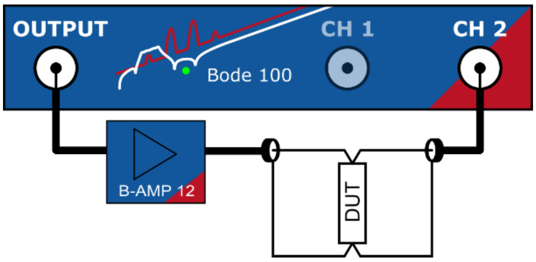


Figure 22: Shunt-Thru with B-AMP 12 amplifier

Shunt-Thru connection examples:

The following figure shows typical applications for a Shunt-Thru measurement.

In the left picture, the DUT (an inductor) is driven by the B-AMP 12 and the B-LCM is used to suppress the ground-loop. With this setup, even low-loss inductors can be characterized at low frequency.

The right image shows typical test fixtures to solder the DUT. Either on PCB or directly between two BNC connectors.

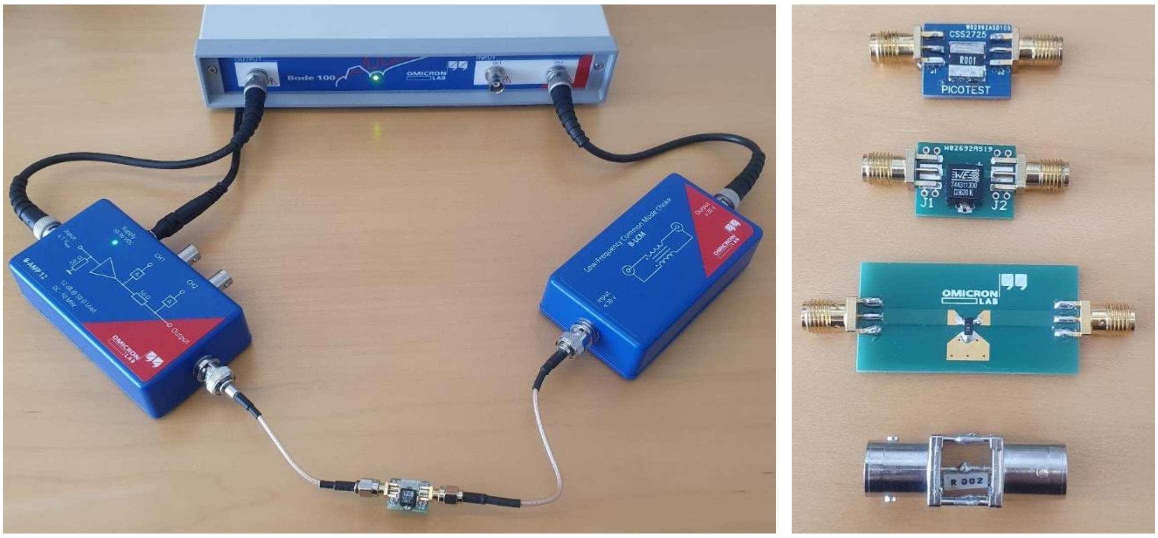


Figure 23: Shunt-Thru measurement example and DUTs

Please refer to the user manual for more details on the shunt-thru measurement or check out our impedance webinar at: https://youtu.be/T2OqewIUL3M?t=3381

2.2.4 Extended Shunt-Thru with Series Resistance

In addition to the standard Shunt-Thru measurement, the Bode 100 enables you to measure impedance using the extended version of the Shunt-Thru method. The additional series resistance shifts the recommended measurement range to higher impedance values.

Besides that, the Rs resistors divide DC voltages. So if you want to measure active or charged devices, this method provides some protection to the Bode 100 by the series resistors. The following figure shows the measurement setup.

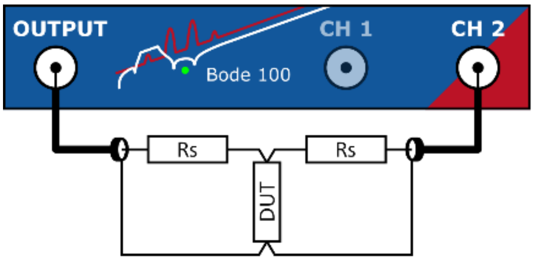


Figure 24: Shunt-Thru measurement setup

The optimal impedance range depends on the value of the series resistor. With a series resistor of Rs = 200 Ω the optimum impedance range is from 5 mΩ to 1 kΩ. With a resistor of Rs = 499 Ω, the optimal range is from 11 mΩ to 2.5 kΩ.

As with the normal Shunt-Thru measurement, one point of the DUT will be connected to GND via the Bode 100 housing and the setup is subject to the same ground-loop error as the Shunt-Thru measurement.

Note that you must perform at least a thru-calibration for this setup.

Measurement setup examples:

The following picture shows an extended Shunt-Thru measurement setup using the Picotest PITK01 boards:

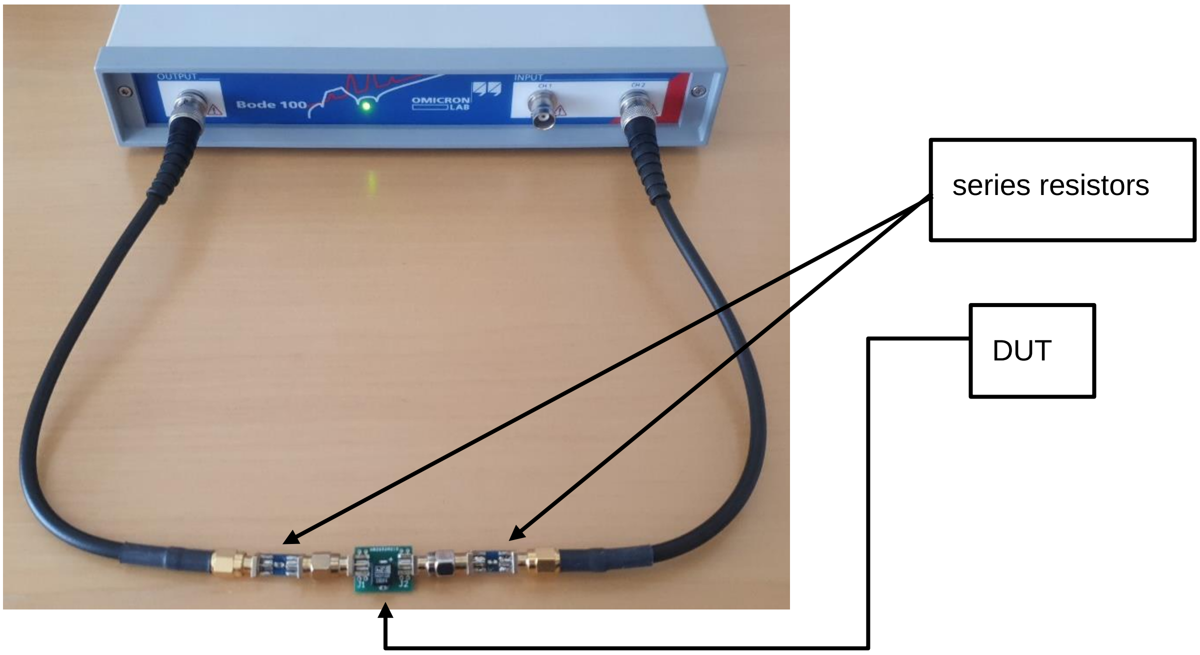


Figure 25: Shunt-Thru with series resistance measurement example

2.2.5 Series-Thru

When high impedance values are of most interest, the Series-Thru setup is the method of choice. The following picture shows the measurement setup:

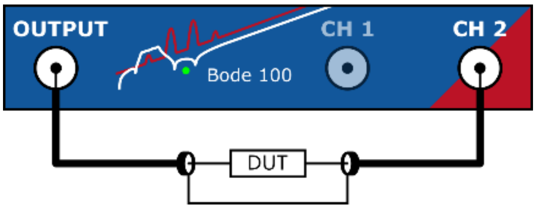


Figure 26: Series-Thru measurement setup

The optimum impedance range is from **≈ 1 kΩ to more than 1 MΩ**. With special care up to 100 MΩ can be measured.
Note that the DUT must not be connected to GND. This measurement setup can be calibrated either with a Thru calibration or an Open / Short / Load impedance calibration.

The Bode 100 measures the S21 parameter and calculates the impedance using

$$Z = 100\,\Omega \cdot \frac{1 - S_{21}}{S_{21}} \tag{5}$$

Measurement setup examples:

The following pictures show a Series-Thru measurement setup with the B-AMP 12 to amplify the output signal of the Bode 100 up to 25 dBm and therefore further increase the impedance range:

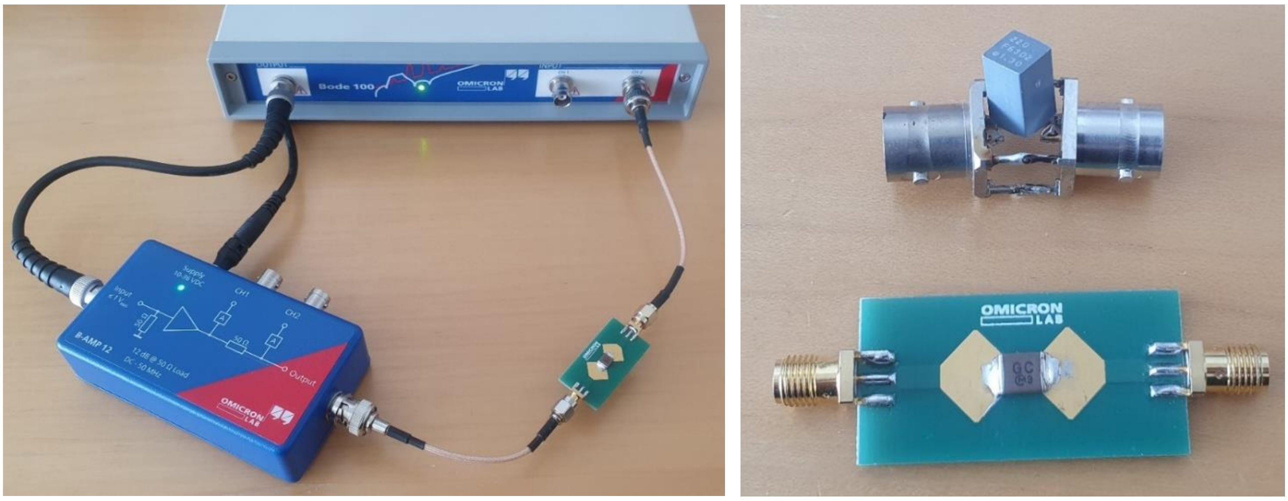


Figure 27: Series-Thru measurement example

2.2.6 Voltage/Current Gain

The Voltage/Current setup measures impedance by dividing voltage over current. The current signal must be fed to CH1 of the Bode 100, the voltage signal to CH2 of the Bode 100. The measured gain then equals the impedance.

$$Z = \frac{V}{I} = \frac{V_{CH2}}{V_{CH1}} \tag{6}$$

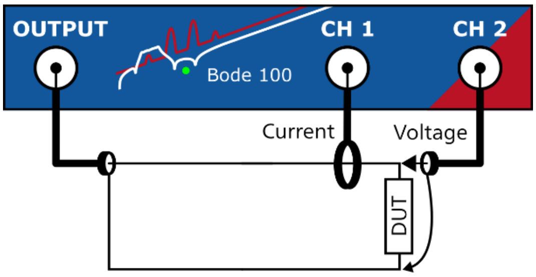


Figure 28: Voltage-Current gain measurement setup

This setup provides many possibilities and the measurable impedance range depends on e.g. the sensitivity of the probes and the AC signal amplitude.
The measurement can be calibrated with either a Thru calibration or an Open / Short / Load calibration.

Usage of this setup:

The Voltage/Current gain measurement setup is often used to measure the impedance of active circuits such as input impedance of a DC/DC converter or output impedance of a voltage regulator. It allows using third-party devices such as the J2111A Picotest current injector or the J2120A or J2121A line injectors from Picotest.

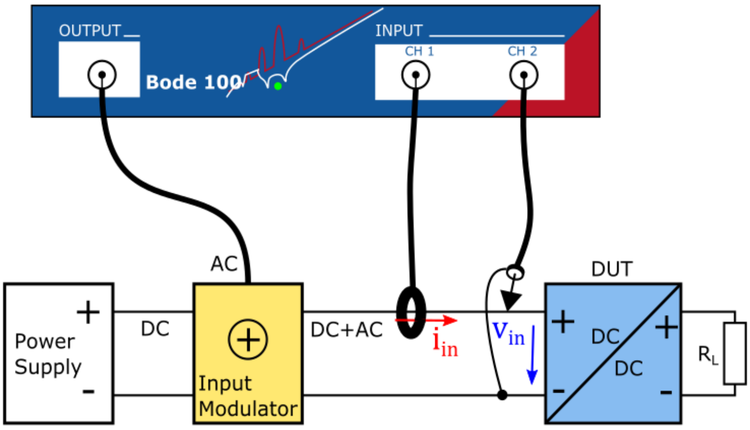


Figure 29: Voltage/Current gain example

For more details on this setup and how to use it, please refer to the corresponding application notes on input impedance measurements or output impedance measurements at www.omicron-lab.com.

2.2.7 External Bridge / External Coupler Setup

When using an amplifier or a custom-built impedance bridge, the following tow measurements allow using all three ports of the Bode 100 to measure impedance as shown in the following figure:

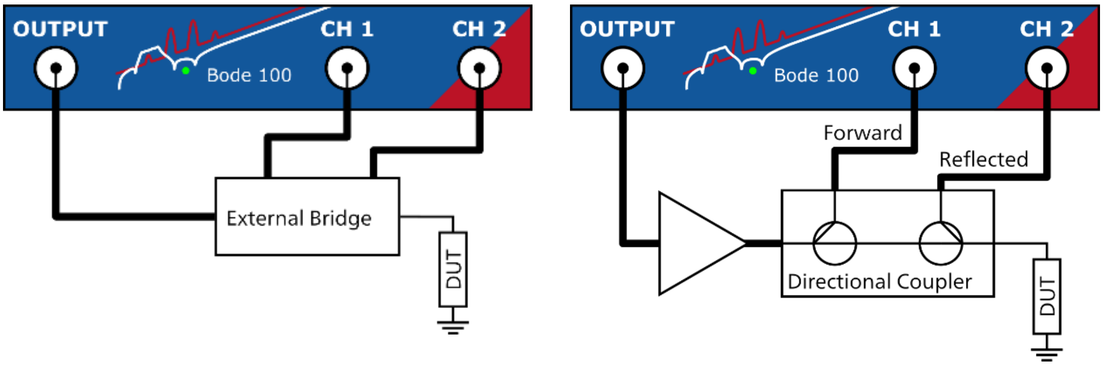


Figure 30: External bridge / coupler measurement setup

The optimal impedance range is variable and depends on various factors such as the directivity of the coupler / bridge and the sensitivity on DUT impedance change.
To be able to measure impedance using an arbitrary coupler / bridge, this measurement must be calibrated using Open / Short / Load calibration.

Usage of this setup:

The external coupler or external bridge setup fits perfectly when using the B-AMP 12 for direct impedance measurements or when using custom bridges as shown below.

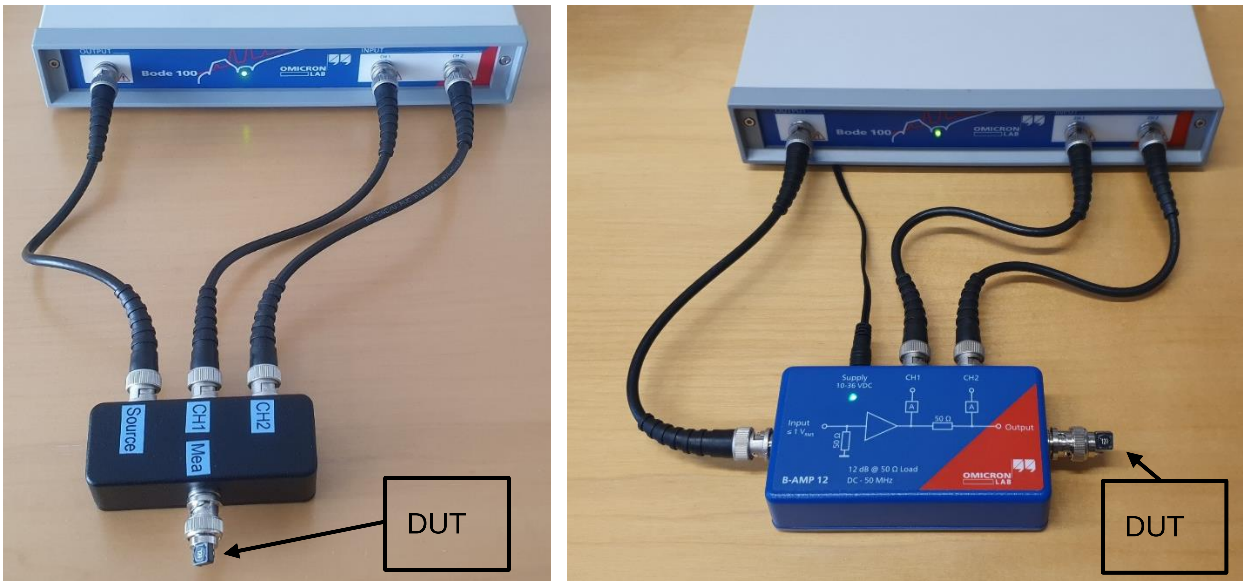


Figure 31: External bridge / coupler measurement example

For more information, please refer to the B-AMP 12 user manual or the application notes available at www.omicron-lab.com.

3 Make Trustable Measurements

Whenever measurements are performed, the question arises: “how accurate are the results”?

Especially for impedance measurements at high frequencies, this question is not easy to answer. The impedance result depends on several factors. The most important ones are listed below:

- Signal / Noise ratio – is the result stable or corrupted by noise?
- Linearity of the test setup – depends on the chosen setup, if it contains nonlinear elements such as voltage-dependent capacitors or inductors / transformers that can change with signal amplitude.
- Point of reference – was a calibration performed? How accurate are the calibration standards?
- Linearity of the Bode 100 – this is normally not an issue if signals are not totally at the limit.

In the following, some tips shall be given on what you can do to increase confidence in your measurement results.

3.1 Verify the Measurement

The simplest way to make a verification is to measure something well-known.

This can be a simple resistor that should not be the same value as the resistor used to perform the Load calibration. SMD thin-film resistors with values around 100 Ω have a very flat frequency response and show resistive behavior up to several 100 MHz.

Even better is using two known values. Measuring a 68 Ω resistor and e.g. a 220 Ω resistor (when Load calibration was performed with 100 Ω) will contain information about all three impedance calibration points.

The best would be to measure something well known that is close to the impedance of the DUT. This might be difficult, however, if the impedance of the DUT changes with frequency.

DUTs for Verification

- SMD resistors around 100 Ω show resistive behavior up to several 100 MHz.
  Please note that:
  - Small value resistors contain significant inductance that can dominate at high frequency.
  - High-value resistors contain significant capacitance that can dominate at high frequency.
- C0G or NP0 capacitors show very linear behavior over frequency.
- Film capacitors show very linear behavior but often have a lower self-resonance frequency than ceramic chip capacitors

Verify Linearity

As a simple verification of linearity, the excitation signal level can be changed. The measurement result should not change except the noise. Lowering the signal level can cause more noise.

3.2 Reduce Noise

For accurate results, the measurement result should not be covered in noise. There are several possibilities to fight noise on the measurement result:

- Use the maximum possible excitation **signal level** for the best signal / noise ratio.
- Use **shaped-level** (variable excitation signal level with frequency) if the signal must be reduced at some frequencies. This can be the case if the DUT is sensitive to high level or slew rate at certain frequencies.
- Select the smallest **attenuator** that does not lead to an overload.
- Use a lower **receiver bandwidth** setting to improve noise rejection. Note that this will slow down the measurement but maybe you can reduce the number of points instead to keep the sweep time low.
- Improve the measurement setup by using **shielded** or **coaxial cable** connections.
- Use **short cables** whenever possible.
- Use sweep-sweep **averaging** to reduce noise.

3.3 Perform a Calibration

Whenever the influence of a test setup or a cable shall be compensated, a calibration can be performed. Note that the Bode 100 offers two different types of calibration: User-range or Full-range calibration. In the following, the differences are explained:

User-Range versus Full-Range Calibration

When performing a **user-range** calibration, the correction values are measured at exactly the frequencies that are currently configured for the sweep. The advantage is, **no interpolation** must be done. The disadvantage is, that the correction factors are lost when the sweep frequencies are changed.

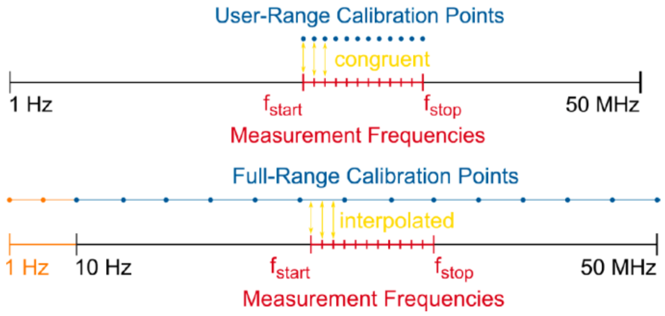


Figure 32: User-Range calibration versus full-range calibration.

The full-range calibration on the other hand, measures the calibration standards at pre-defined frequencies over the full frequency range from 10 Hz to 50 MHz and interpolates in-between to derive the correction factors. The advantage is, that the calibration does not get lost when the sweep frequencies are changed. The disadvantage is, that it cannot correct for quickly changing frequency response curves such as resonances.

4 Conclusion

The Bode 100 offers seven different direct and indirect impedance measurement methods to measure impedance values from mΩ to MΩ over a wide frequency range from 1 Hz to 50 MHz.

The simplest measurement possibilities are the one-port measurement or the impedance-adapter method. If these “simple” measurement possibilities are not good enough (e.g. to measure in the µΩ or mΩ range, the high variety of impedance measurement possibilities allows to choose the optimal setup for your application.

Using calibration / correction, the influence of the test setup including possible amplifiers or attenuators can be compensated for.

Using special measurement modes, even the impedance of active devices such as switching power supplies or power delivery networks can be measured.

For detailed information on single applications, please have a look at our application note section on https://www.omicron-lab.com/applications/vector-network-analysis/application-notes

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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 30 years in-house experience enable the development of innovative products close to the field.

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