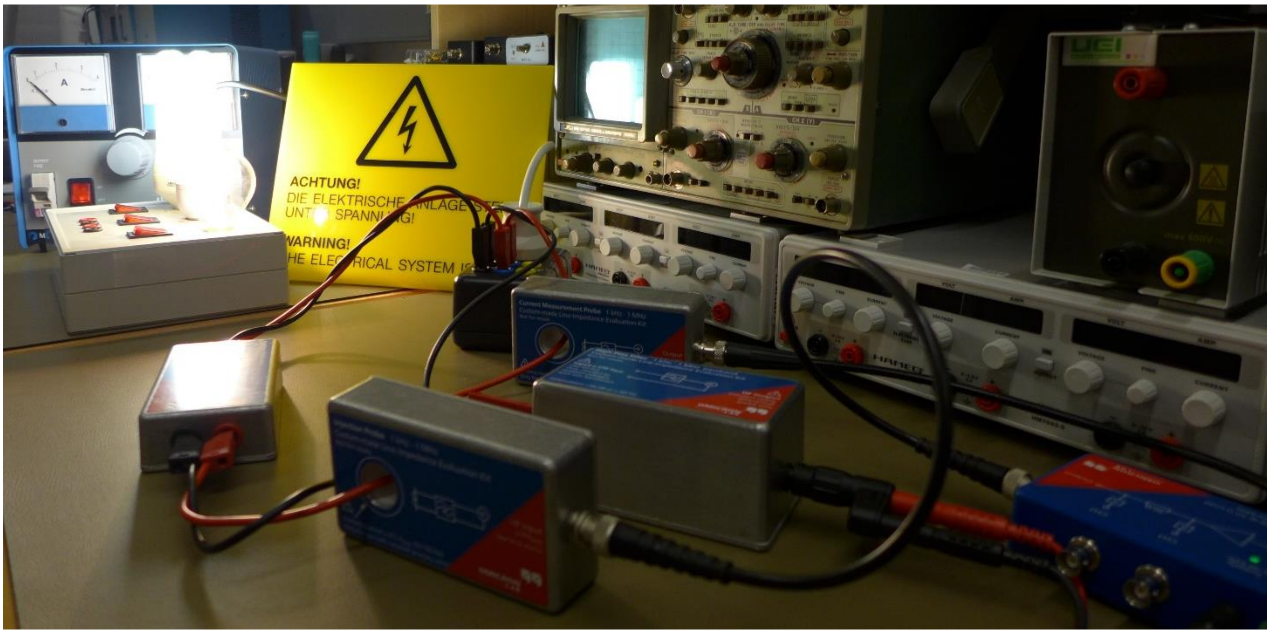
Bode 100 - Application Note

Measuring Power Line Impedance



By Florian Hämmerle & 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 Measurement Task

In this document we show how the Bode 100 can be used to measure the high-frequency impedance of equipment designed to be powered by mains voltage. The frequency range of interest is roughly 1 kHz to 1 MHz. The RF impedance of mains-connected devices is essential for e.g. power-line-communication. Very low impedance values at certain frequencies can drastically influence the transmission quality over the mains cables.

WARNING

Death or serve injury can occur if the appropriate safety instructions are not observed.

Mains voltage levels are hazardous! Use appropriate means to ensure a safe test setup when performing measurements at high voltages.

2 Measurement Equipment

There are several possibilities how to measure RF impedance on high AC voltage. In the following we present a measurement method that uses inductive coupling to inject a RF disturbance signal onto the 230 V 50 Hz voltage that powers the DUT[1].

The measurement setup contains the following parts:

1. Bode 100 Vector Network Analyzer to measure the impedance
2. B-AMP 12 amplifier, to increase the disturbance signal in order to improve signal to noise ratio
3. Testec TT-SI9001 active differential probe to safely measure at 230 V
4. Custom-made injection probe for RF disturbance signal injection onto the 230 V signal
5. Custom-made current measurement probe (1 V/A) with high-pass filter to measure the small RF current flowing into the DUT
6. Custom-made high-pass filter to reject the 230 V signal to be able to measure the small RF voltage at the DUT
7. Custom-made Impedance stabilization device to allow the RF measurement current circulate

In the following we describe the details of these devices.

WARNING

Do **not directly connect** any self-made or custom-made evaluation equipment **to mains voltage** to avoid the risk of high-voltage transients.
Use appropriate isolated voltage generators to avoid transients.

[1] Device Under Test

2.1 Injection Probe

In order to be able to inject a RF disturbance signal onto the 50 Hz 230 V signal we use a coupling current probe (current transformer) with one primary winding. Note that the 50 Hz primary current must not saturate the current transformer. Saturation effects will introduce nonlinearities to the setup and corrupt the results. We use a coaxial core with multiple secondary windings and a high-pass filter to suppress the reverse injected 50 Hz current signal. Note that the high-pass filter must provide low impedance at 50 Hz in order to not saturate the core. The high-pass filter provides > 50 dB attenuation at 60 Hz and its corner frequency is roughly at 600 Hz in order to have low attenuation at 1 kHz. The following picture shows our custom-made evaluation injection probe:

Figure 1: Custom-made injection probe

We have designed the core in a way that it supports up to 4.5 A_{RMS} at 50 Hz before it starts saturating. DC current is not allowed and will immediately saturate the core.

2.2 Current Measurement Probe

For the impedance measurement we need the small RF current signal that is overlaid by the high 50 Hz load current of the DUT. We have designed a current probe with one primary winding that provides 1 Volt per Amp. To suppress the high signal at 50 Hz the current transformer is followed by a high-pass filter that acts as a shortcut below 60 Hz. Corner frequency is roughly at 600 Hz and the passband above 1 kHz. It is important that the 50 Hz load current of the DUT does not saturate the core. A saturated core would introduce nonlinearities and corrupt the measurement results. The following picture shows our custom-made current measurement probe that can withstand up to 4.5 A_{RMS} at 50 Hz:

Figure 2: Custom-made current measurement probe

2.3 High-Pass Voltage Filter

In addition to the RF current flowing into the DUT we need the RF voltage at the DUT to measure the input impedance of the DUT. However, the small signal RF voltage is superimposed by the 230 V_{RMS} voltage. Therefore we use a passive LC high-pass filter to suppress the 50 Hz signal. Since the filter is directly connected to high voltage, we use a Y-capacitor for safety reasons. The filter has to provide relatively high impedance to the 50 Hz signal. However this impedance can't be made infinitely high. Therefore we use a measurement setup where the current probe is directly connected to the DUT input to ensure a correct current measurement. For safety resons, the output of the high-pass filter is connected to a high-voltage differential probe in 10:1 setting. The following picture shows our custom-made high-pass filter for the voltage measurement:

Figure 3: Custom-made high-pass voltage filter

CAUTION

Use appropriate high-voltage differential probes to isolate the Bode 100 inputs from any high voltage.
Make sure that the safety ground connectors of the probes are connected to safety ground.

2.4 Impedance Stabilization

Since many voltage sources act as a high-impedance source at frequencies > 1 kHz a low impedance path must be provided for the measurement signal. Therefore we connect an appropriate capacitor in parallel to the 50 Hz voltage source. This capacitor provides a low-impedance path for the injected RF current flowing into the DUT. The following picture shows our custom made impedance stabilization device:

Figure 4: Custom-made impedance stabilization

3 Measurement Setup

The following picture shows a schematic of the measurement setup. Preferably use an isolated signal source that creates a pure sine wave without harmonic distortion. The harmonic distortions might easily reach the 1 kHz region and disturb the measurement result.

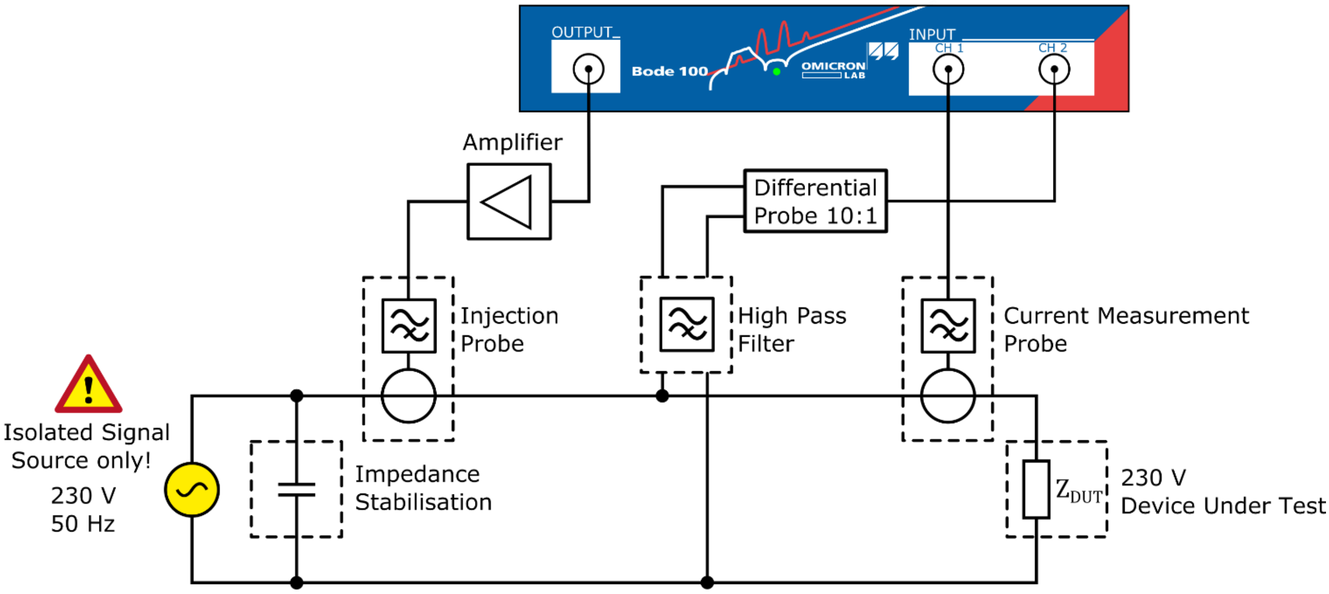


Figure 5: Measurement setup

Before the measurement can be started, the setup has to be calibrated.

4 Calibrating the Setup

In the Bode Analyzer Suite the Voltage/Current impedance measurement mode is chosen:

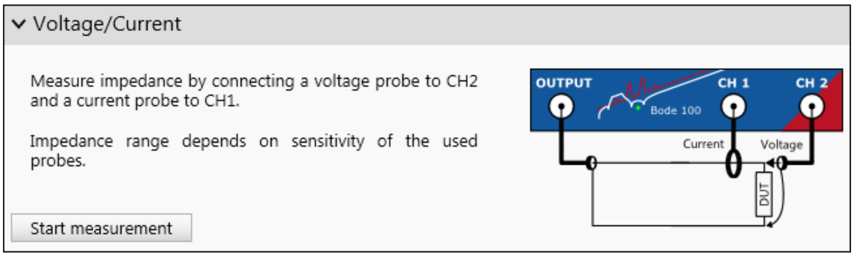


Figure 6: Voltage/Current measurement mode

Then the following settings are applied:

- Start Frequency: 1 kHz
- Stop Frequency: 1 MHz
- Source Level: 13 dBm
- Attenuator CH 1: 0 dB
- Attenuator CH 2: 0 dB
- Receiver Bandwidth: 30 Hz

In the Hardware Setup  the Channel 2 external probe is set to 10:1:

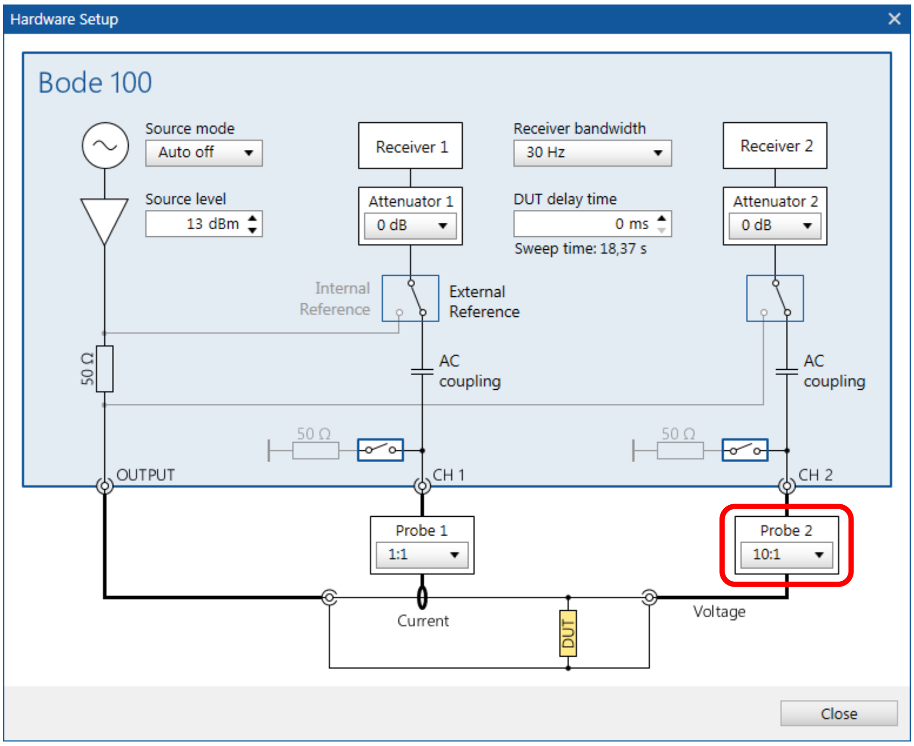


Figure 7: Bode 100 Hardware Setup

CAUTION

Switch OFF the 230V signal source during calibration!

The setup must be calibrated using the Open, Short and Load calibration. Therefore the DUT will be replaced by Open, Short and Load connections during calibration as shown in the figure below:

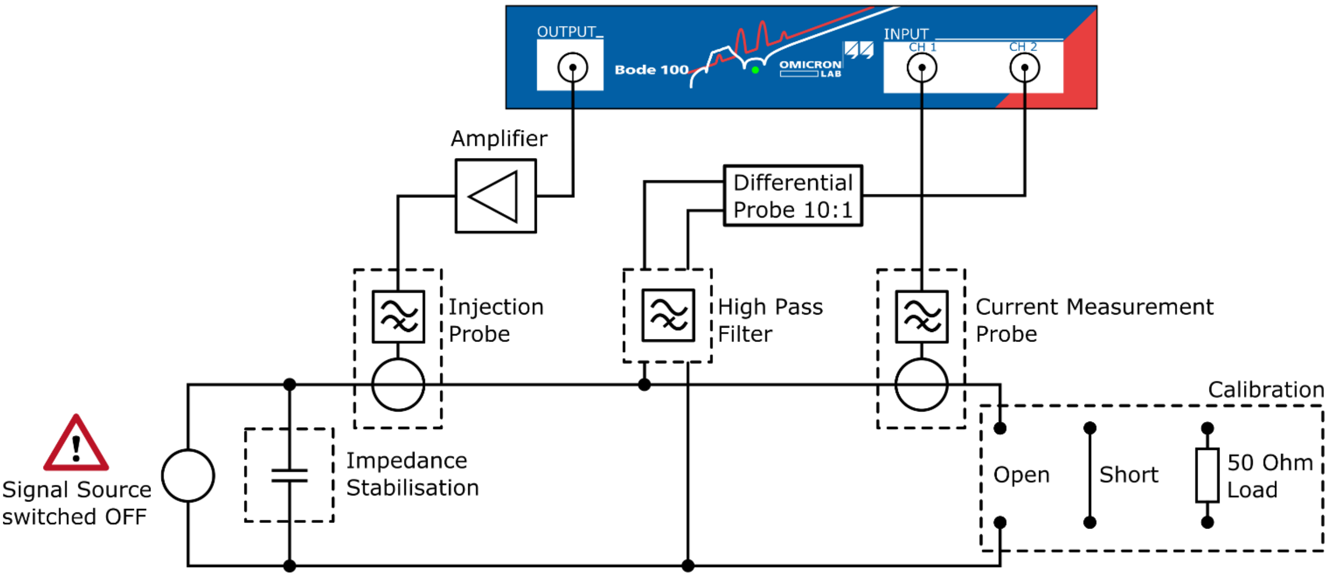


Figure 8: Calibration Setup

Instead of a DUT a coaxial connector is used for simple Open, Short and Load connection.

Figure 9: Measurement setup for calibration

4.1 Open Calibration

Before starting the Open calibration, make sure that the 230 V signal source is switched OFF and the Open connection is in place as shown in the figure below:

Figure 10: Open connection

Now start a single sweep to check if no overload occurs . If the measurement works fine, the Open Calibration can be performed. The User-Range calibration is the right calibration for this measurement since it calibrates exactly at the frequencies that are configured in the current sweep settings .

Perform the Open calibration by clicking on the Open Start button shown in the figure below:

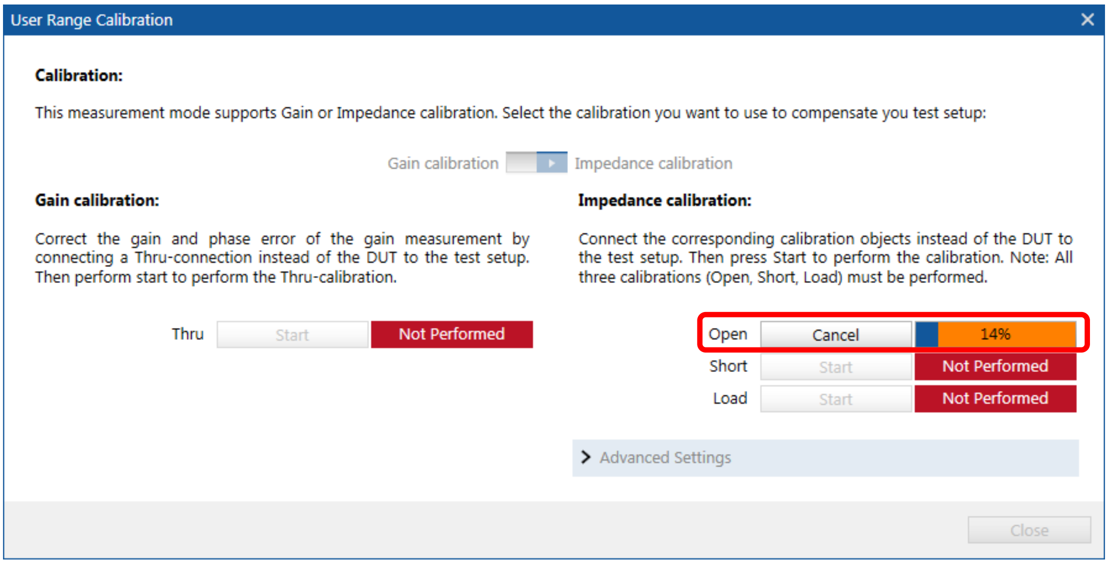


Figure 11: Open Calibration

After the Open calibration has been performed 

, close the window.

4.2 Short Calibration

Connect the Short connector as shown in the figure below:

Figure 12: Short connection

Due to the short connection, the resistance in the RF path will be very low. Therefore the injected current will be much higher and Channel 1 of the Bode 100 needs to be prevented from overloading. To avoid overloading of Channel 1 the following settings are applied for the Short calibration:

- Attenuator CH 1: 20 dB
- Source Level: 6 dBm

To check if the setting is sufficient, a single sweep is performed. 

If no overload occurs, Short-User-Range calibration can be started. 

After calibration has been performed, the window is closed and Load calibration can be prepared.

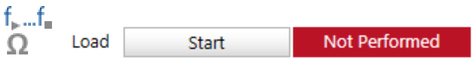
4.3 Load Calibration

Connect the Load resistor as shown in the picture below:

Figure 13: Load connection

For the load calibration the following settings are applied:

- Attenuator CH 1: 0 dB
- Source Level: 13 dBm

Perform a single sweep to check if no overload occurs. If the measurement works, Load-User-Range calibration can be performed: 

After Load calibration has finished, the impedance calibration is automatically activated. Close the window to return to the measurement screen that now shows an active User-Range calibration by indicating a green background on the calibration icon: 

Calibration is now finished.
To check if it works, a single sweep is performed. It should show a flat line at 50 Ω.

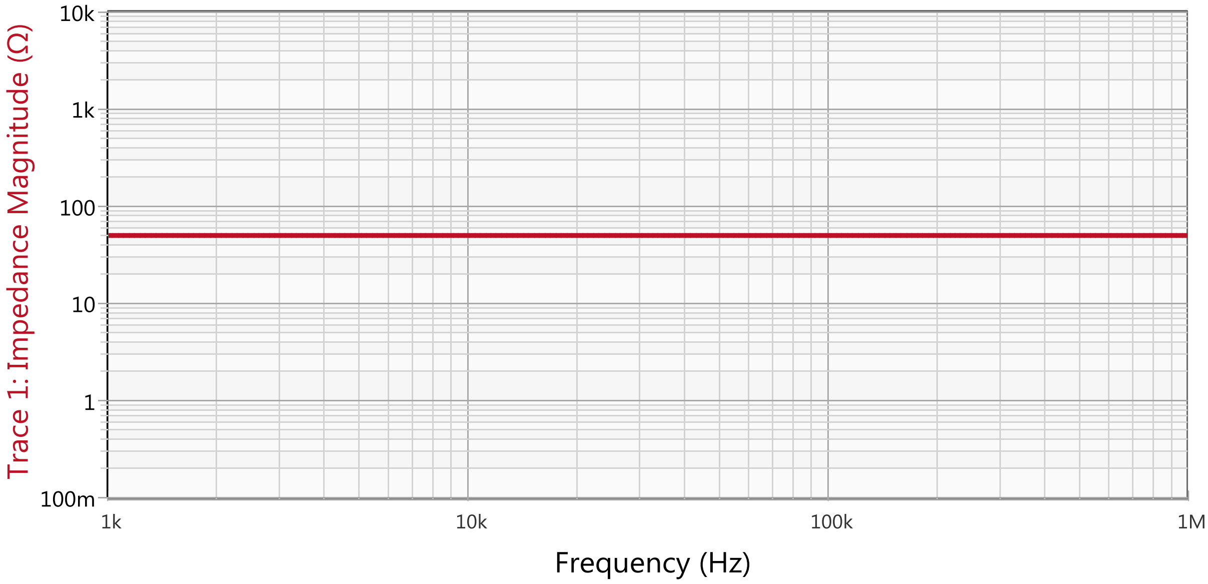


Figure 14: Calibration check measurement

5 Measurement Results

In order to test our measurement setup we use three different lamps as a DUT.

1. Lamp 1 is a classical light bulb with 42 W
2. Lamp 2 is a simple energy saving lamp with 14 W
3. Lamp 3 is a 30 W energy saving lamp with a simple PFC[2] included

The following picture shows the measurement setup with the 3 different lamps as DUT:

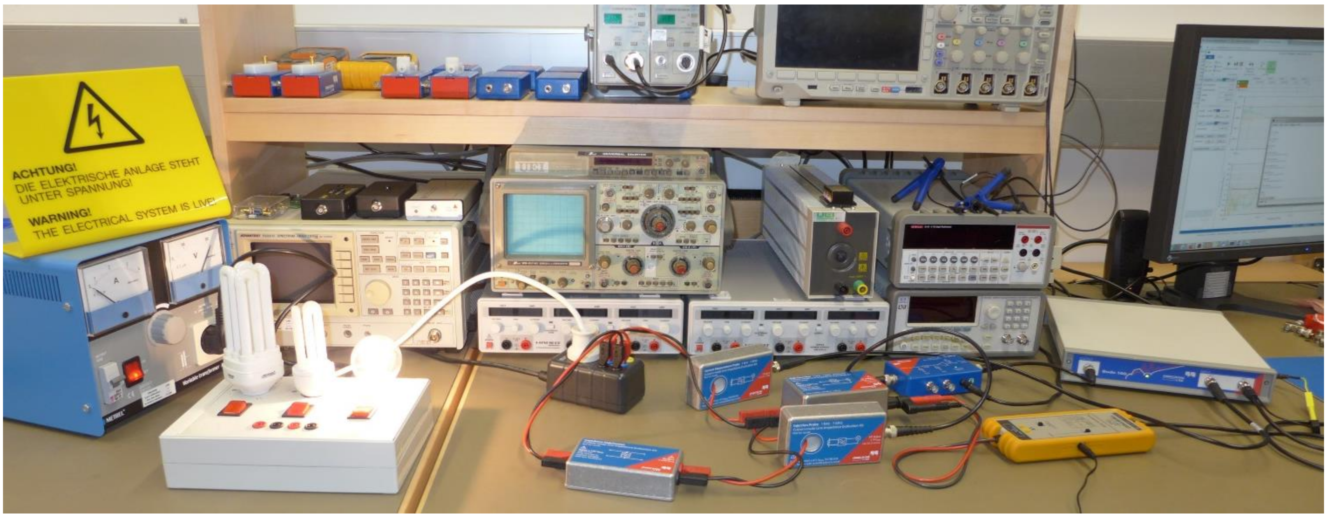


Figure 15: Measurement setup

All three bulbs show different results. The diagram below shows the three curves. The light bulb shows an impedance of roughly 1.2 kΩ which equals the theoretical impedance of $\frac{230V^2}{42W} = 1.2\ k\Omega$.

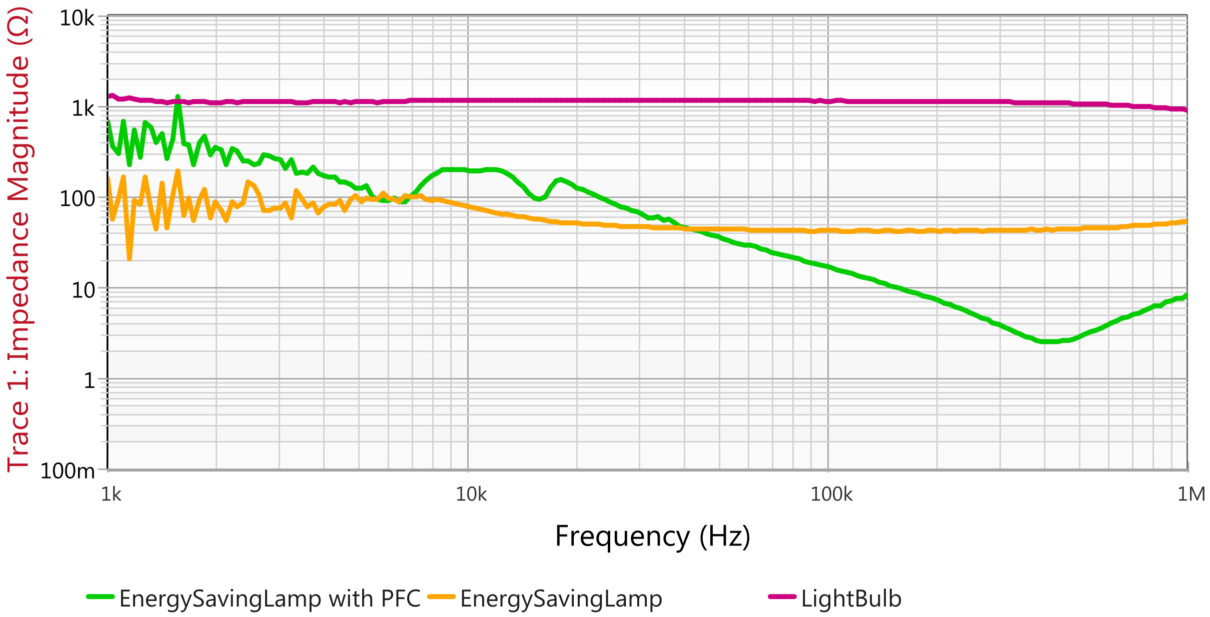


Figure 16: Impedance results

[2] Power Factor Correction

6 Summary

The Bode 100 offers all features that are needed in order to measure the RF impedance of nearly any system. By using appropriate probes and injection equipment the Bode 100 offers a powerful platform for your impedance tests.
This document shows an example measurement how to measure impedance from 1 kHz to 1 MHz on 230 V devices. This document should help you to construct your own measurement and injection equipment exactly for your need.
If you feel that you don’t have the time to build your own injectors and probes, feel free to contact us. We might have time to build a custom evaluation kit for research and development purpose only. However, please note that it won’t be cheap… ☺

WARNING

Measuring on hazardous voltages is dangerous. Take all necessary means to perform safe measurements! Only trained personnel is allowed to operate equipment where hazardous voltage levels are present.

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 50 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 30 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