Bode 100 - Application Note

Solar Cell Impedance Measurement

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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 V3.0. 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 Introduction

The impedance of a solar cell depends on the frequency and the DC operating point of the cell. It can therefore make sense to dynamically characterize photovoltaic (PV) modules. In this document we show a method how to measure the dynamic impedance of a PV module using the frequency response analyzer Bode 100. For simplification the impedance of the solar cell is measured in a dark environment. The operating point is then chosen by applying an external DC[1] voltage bias. In this document we show how the AC[2] impedance of a PV module can be measured using the Bode 100 in conjunction with the J2130A DC Bias Injector from Picotest.

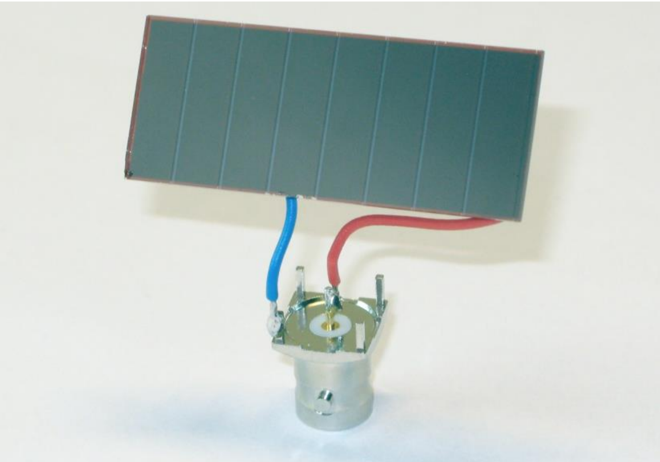


Figure 1: Solar Cell under test soldered to a BNC connector

The figure below shows a simplified equivalent circuit model of a photovoltaic module.

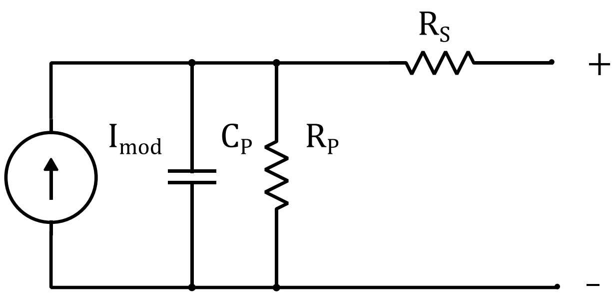


Figure 2: Dynamic equivalent circuit model

The equivalent circuit consists of the following parameters which can be determined by the measurements detailed in this document:

- parallel capacitance C_P(consists of the diffusion- and the transition capacitance)
- parallel resistance R_P (dynamic resistance of the diode)
- series resistance R_S

[1] Direct Current
[2] Alternating Current

2 Measurement Setup

2.1 High Impedance Bridge

The impedance of the examined photovoltaic module is very high (in the range of several $100\ \mathrm{k\Omega}$). To improve the measurement accuracy in this impedance range, the following impedance measurement bridge is used in conjunction with the Bode 100:

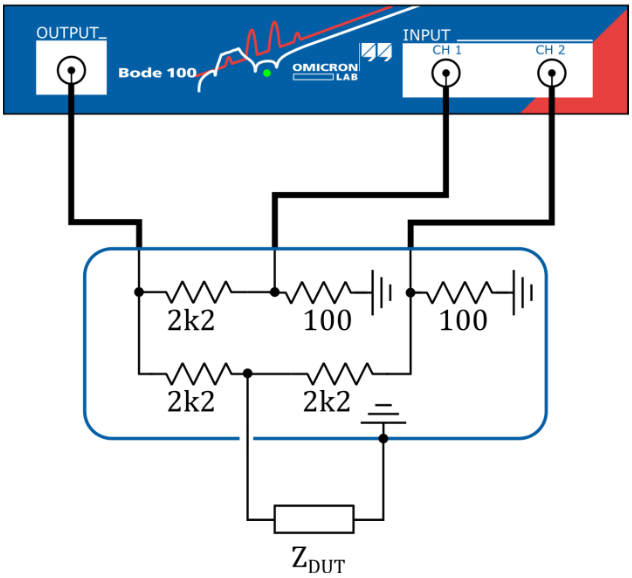


Figure 3: high impedance Measurement Bridge

The bridge can be built using standard THT resistors as shown in the following figure. The impedance/reflection calibration of the Bode 100 will compensate the parasitics of the bridge.

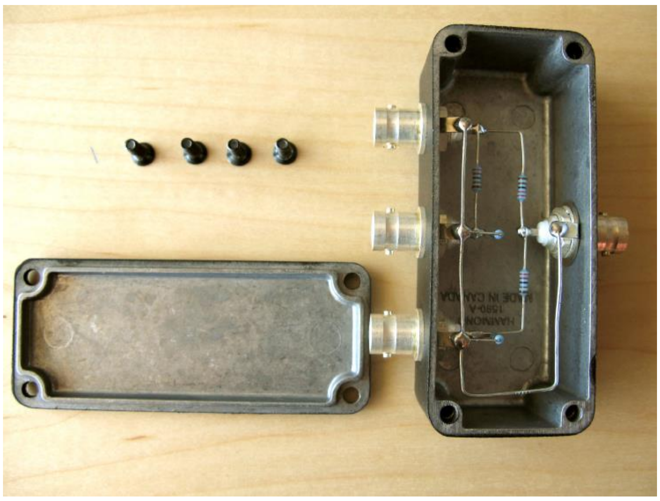


Figure 4: built up Measurement Bridge

2.2 DC Bias Injector

We need to bias the solar cell with a DC voltage during the measurement. To protect the source of the Bode 100 from the DC voltage we need to block the voltage. This can be done using i.e. the DC Bias Injector from Picotest. The following picture shows the final measurement setup with the Bode 100 connected to the measurement bridge and the DC Bias Injector placed between the solar cell and the high-impedance bridge. The DC bias voltage is applied using a laboratory power supply.

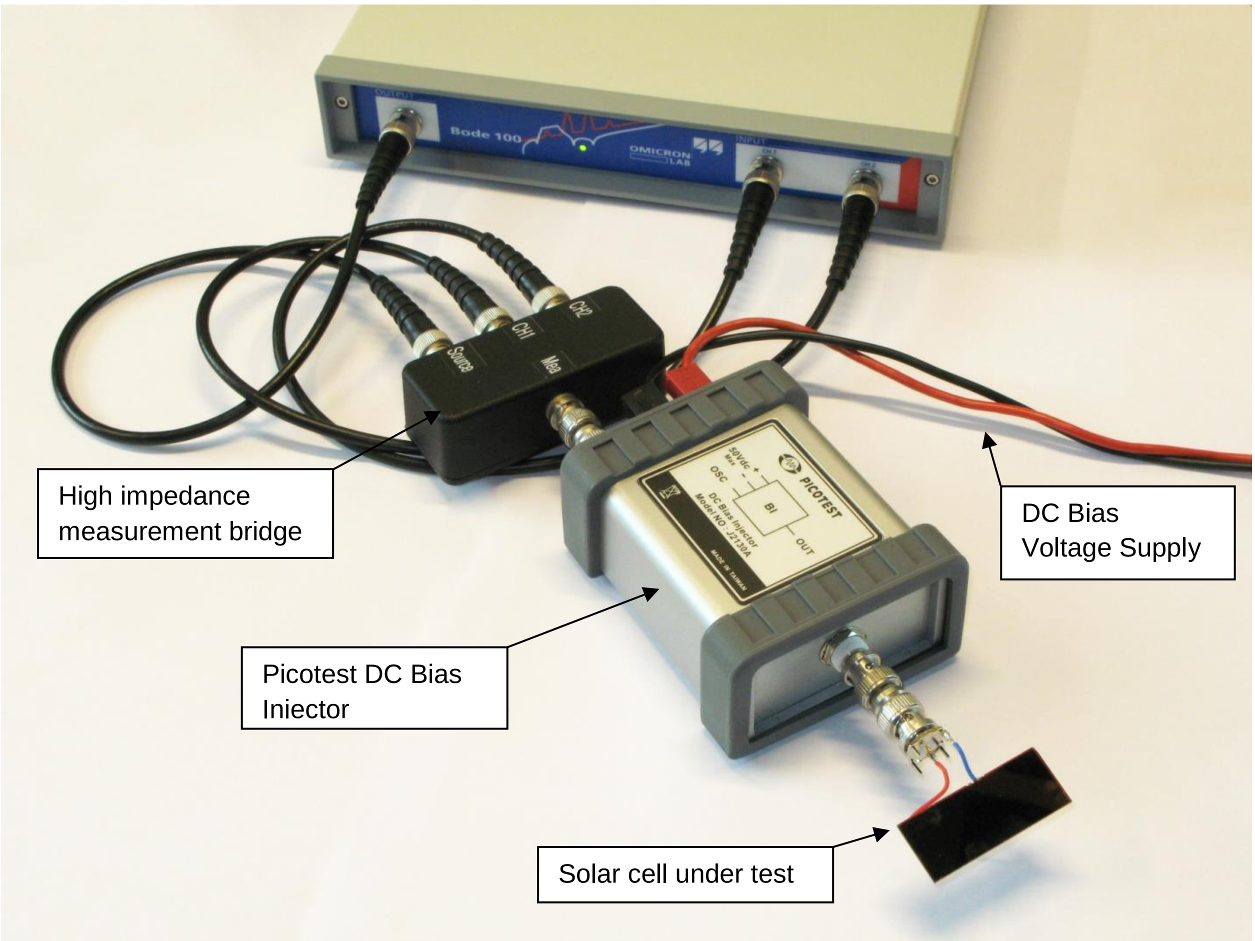


Figure 5: Measurement Setup

Note: We measure the solar cell at dark conditions and control the applied DC voltage. Therefore the solar cell needs to be protected from light during the measurements!

Note: Further details and information regarding the J2130A DC Bias Injector can be found in the Application note: "DC Biased Impedance Measurements", available from our webpage: http://www.omicron-lab.com/application-notes/dc-biased-impedance-measurement

3 Device Configuration

Measurements with the high impedance measurement bridge must be performed in the **External Bridge** mode of the Bode Analyzer Suite:

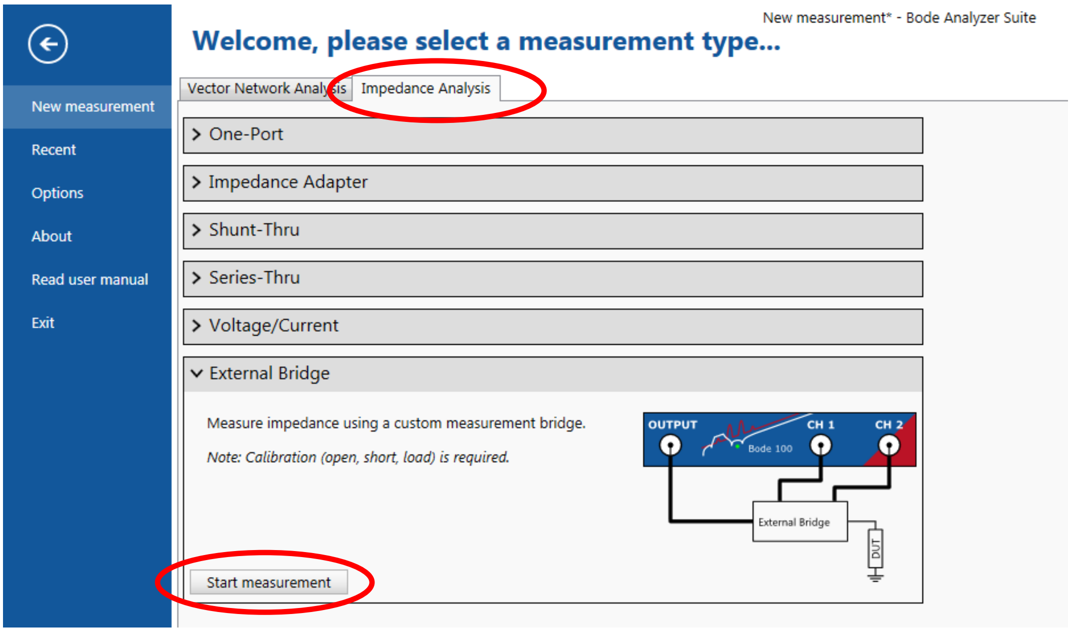


Figure 6: Start menu

Further settings are chosen as shown below:

Start Frequency: 10 Hz
Stop Frequency: 100 kHz
Sweep Mode: Logarithmic
Number of Points: 201 or more
Level: 0 dBm
Attenuator CH1 & CH2: 0 dB
Receiver Bandwidth: 10 Hz

The settings for trace 1 & 2 are chosen as follows:

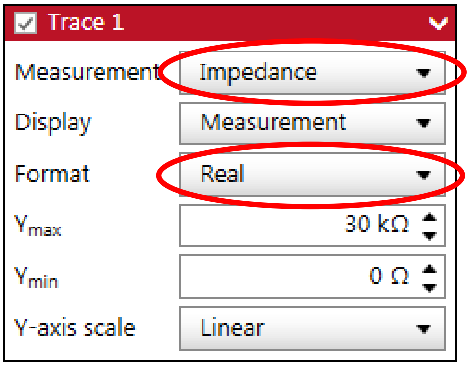


Figure 7: Settings Trace 1

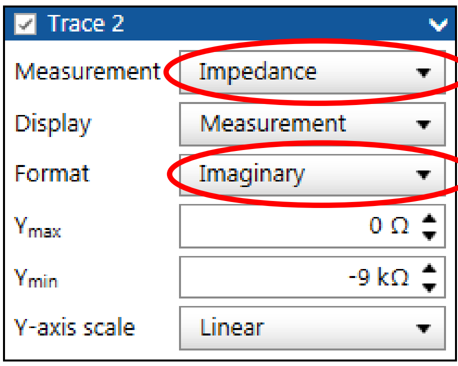


Figure 8: Settings Trace 2

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

4 Calibration

We recommend performing a User Calibration for accurate results. The calibration window is opened by clicking on the User Calibration Icon:

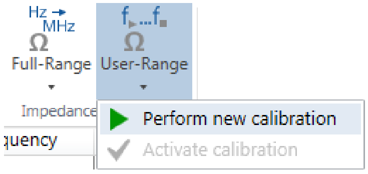


Figure 9: perform calibration

OPEN, SHORT and LOAD calibration needs to be performed:

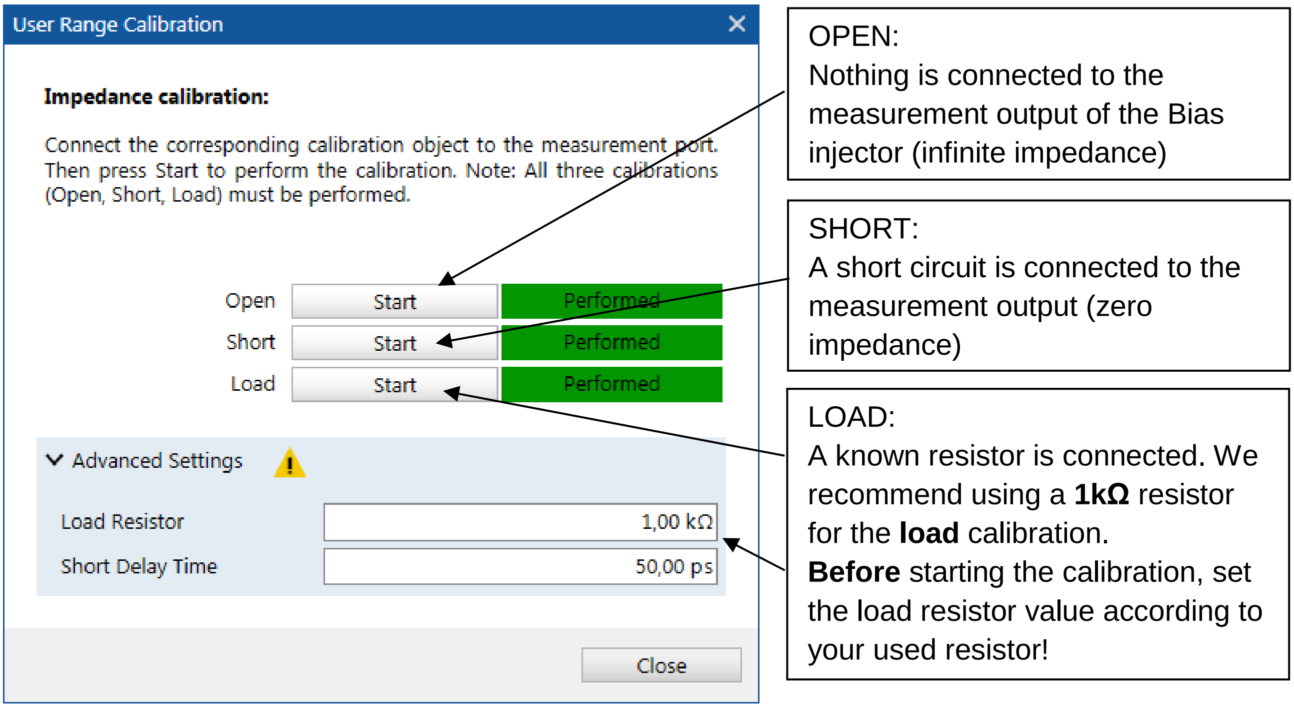


Figure 10: User Range Calibration window

After calibration is performed, the measurement can be started.

5 Measurement & Results

A DC bias voltage of 5.6 V is applied to the photovoltaic module. This results in a voltage drop of 0.7 V per cell (8 cells are connected in series in the examined cell)
Starting a single sweep results in the following curve:

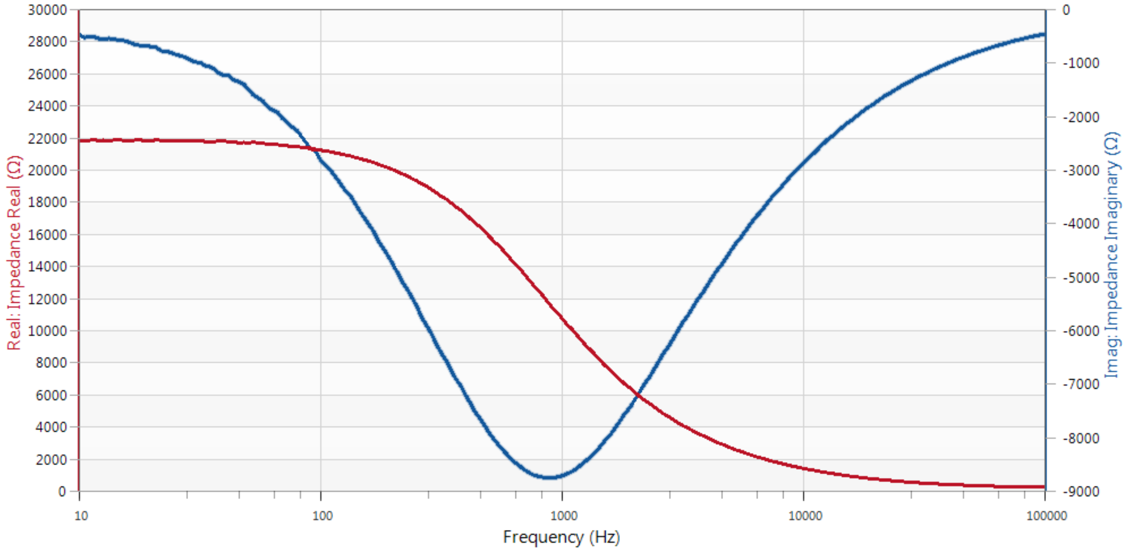


Figure 11: Measurement result - Real and Imaginary

From this curve the equivalent circuit model of the PV module can be derived. At low frequencies the real part of the impedance equals $\mathrm{real}\{Z\} \approx 21.291\ \mathrm{k\Omega}$. At $100\ \mathrm{kHz}$ the real part of the impedance equals $\mathrm{real}\{Z\} = 248\ \Omega$.

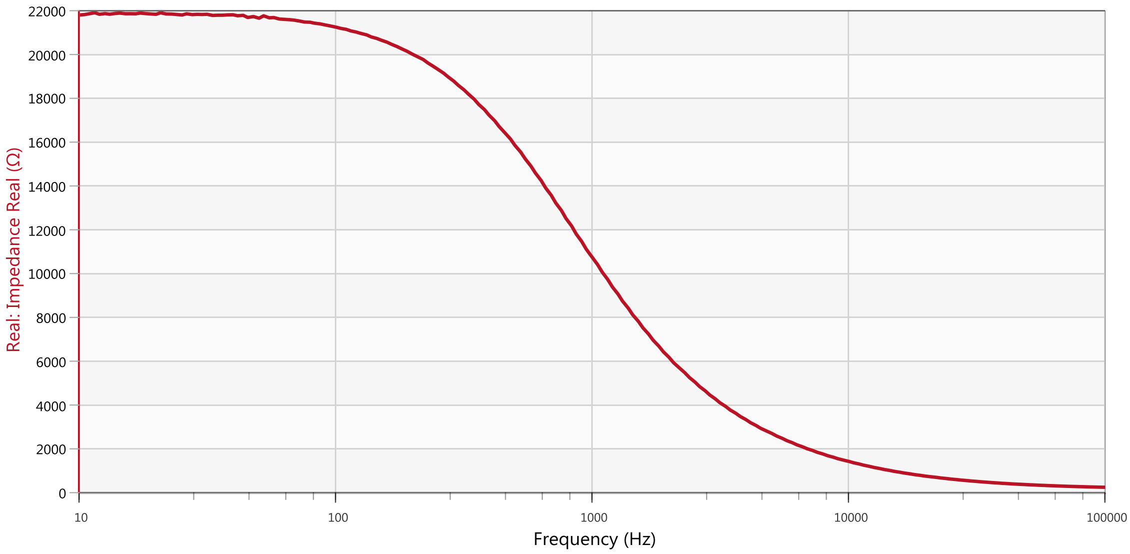


Figure 12: Measurement result – Real

From these results the resistors of the equivalent circuit model can be calculated as follows:

$$R_s = 248\ \Omega$$
$$R_p = 21291\ \Omega - 248\ \Omega \approx 21\ \mathrm{k\Omega}$$

The capacitance can be derived from the measured admittance of the photovoltaic module. Neglecting the series resistance the capacitance can directly be measured in the Bode Analyzer Suite by selecting:

- Measurement: Admittance
- Format: Cp

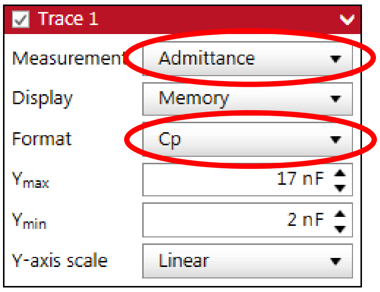


Figure 13: Settings Trace 1

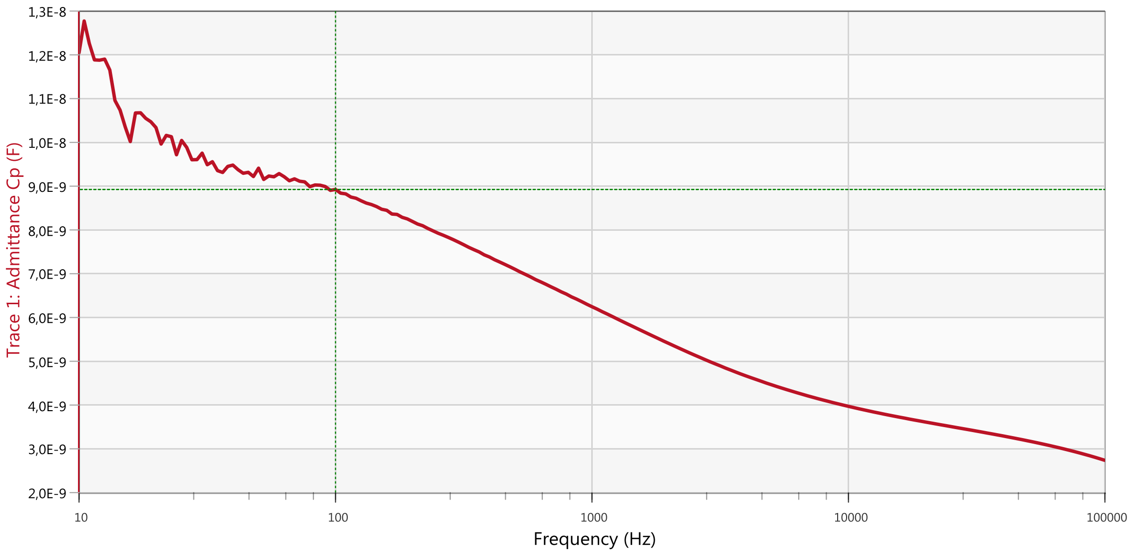
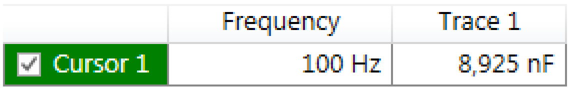


Figure 14: Measurement result



	Frequency	Trace 1
Cursor 1	100 Hz	8,925 nF

Figure 15: Cursor 1 @ 100 Hz

This results in a parallel capacitance of $C_p \approx 8.9\ \mathrm{nF}$.

Note: We took the first measureable value without a signal noise to maintain the accuracy of the measurement.

We therefore arrive at the following simplified equivalent circuit model of the measured photovoltaic module:

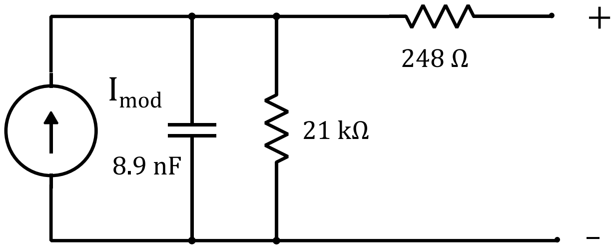


Figure 16: Equivalent circuit model of photovoltaic module

Note: This model is only valid for a bias voltage of 5.6 V applied to the photovoltaic module. The parameters depend on the applied DC voltage respectively the amount of light the solar cell is exposed to.

As mentioned the parameters depend on the applied DC bias voltage. Different bias voltages lead to different results. The following curves show the real and imaginary part of the module impedance with 0.55 V, 0.6 V, 0.65 V and 0.7 V bias voltages **per cell** applied to the photovoltaic module. (The module consists of 8 cells therefore the total voltage equals 8 times the voltage per cell.)

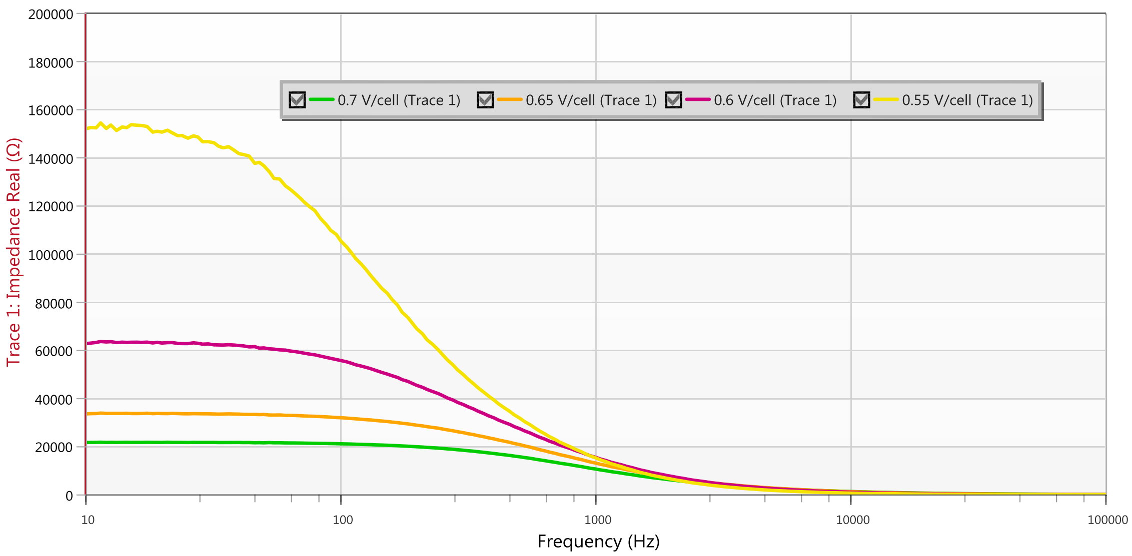


Figure 17: Measurement result - Real

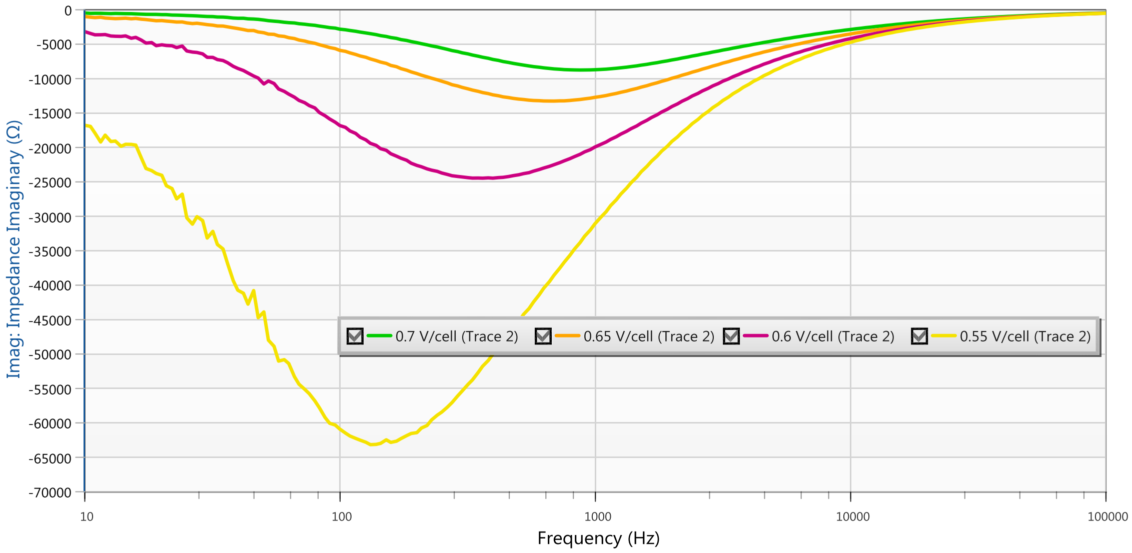


Figure 18: Measurement result - Imaginary

6 Conclusion

In this document we demonstrate how the AC impedance of a photovoltaic module or a single solar cell can be measured using the Bode 100 in conjunction with the Picotest J2130A DC-Bias Injector. The results from this measurement can be used to derive a dynamic small signal model of the solar cell. Such a model can help to ensure the stability of solar driven power systems containing of i.e. solar cell arrays and multiple voltage regulators.

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