

Laboratory: System Concepts

PSK

BODE100 Quickstart for PSK

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Abstract. A short introduction is given how to measure a Bode diagram using the Bode100 Vector Network Analyzer [1], [2] and the respective software, the Bode 100 analyzer Suite [3]. Working through this is a precondition for several practical courses of the laboratory System Concepts (PSK).

1 Introduction

This document is available at the author's homepage within the practical training of the system concepts course [4].

Opposite to simulation we do not have things like ideal sources or probes in the real world. The test instrumentation is circuitry, too. The most important and complex test instrument in this lab is the *Bode 100* vector network analyzer. Documentation can be obtained from the Omicron-Lab homepage [1], [2] → submenu *Manual* → pdf-files *User Manual* and *Manual Extension: Unwrapped Phase* [2].

2 Getting Started with the Bode 100 Network Analyzer


Fig. 2: *Bode 100* front view



Switch on the power supply for both *Bode 100* and the connected computer and start the *Bode Analyzer Suite* software. While starting it will perform an initial calibration.

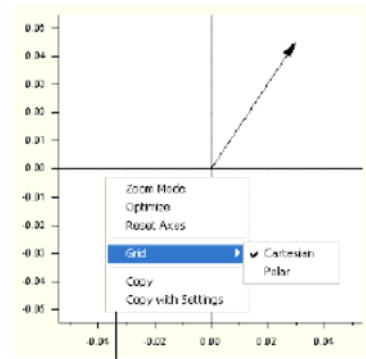
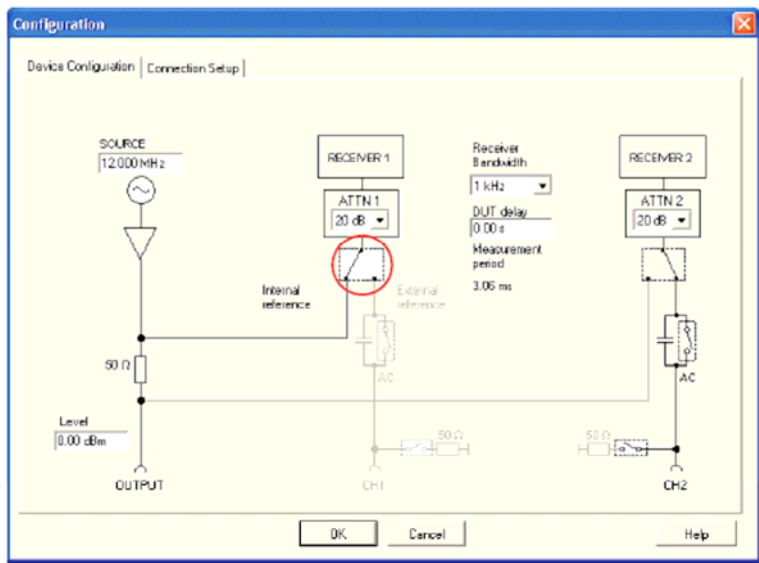
The software has recognized the hardware when in the lower right corner of the window the serial number of the *Bode 100* hardware appears on green background.

2.1 Gain/Phase Mode With Default Calibration

Click the toolbar button  to switch to the *Gain/Phase* mode. Alternatively you can select *Measurement* → *Gain/Phase* from the *Bode Analyzer Suite*'s menu bar. Settings can be saved using *File* → *Save As...* . For more details on this mode can see chapter 3 of the *User Manual*.

The *Bode 100* delivers a sinusoidal voltage signal at *OUTPUT*, measures the voltages at inputs *CH1*, *CH2* and delivers the voltage ratio $V(CH2)/V(CH1)$ as $result_vector = Amplitude \cdot \exp(j \cdot Phase)$.

Consider Fig. 2.1(a). This is the default configuration. To liberate the user from an external connection between *OUTPUT* and *CH1* this connection is made internally. However, this internal connection is intended for 50Ω-measurement engineering assuming a 50Ω load impedance connected from *OUTPUT* to ground.





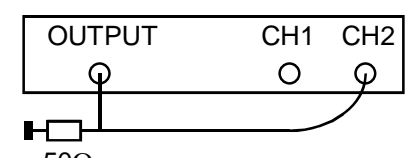
Right-click in the diagram to open the shortcut menu. Use the shortcut menu to optimize the diagram, select the grid and zoom in the diagram. After having zoomed in, click **Optimize** to get back to an optimized diagram.

(a) Config. with *OUTPUT* internally connected to *CH1* (b) Resulting *result_vector*

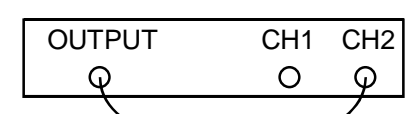
Fig. 2.1: Gain/Phase measurement: $result_vector = Amplitude \cdot \exp(j \cdot Phase)$

Look on which side of the output resistor the reference channel *CH1* is internally connected to *OUTPUT*. This delivers correct results for $V(CH2)/V(CH1)$ with a 50Ω load impedance connected to *OUTPUT*. As illustrated in the figure below. We will now figure out what happens when the 50Ω load impedance is removed as shown in the bottom figure below.

Use the  and  toolbar buttons to start and stop the following measurements:

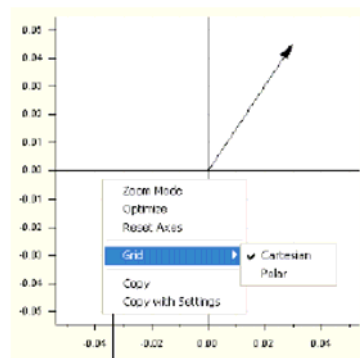
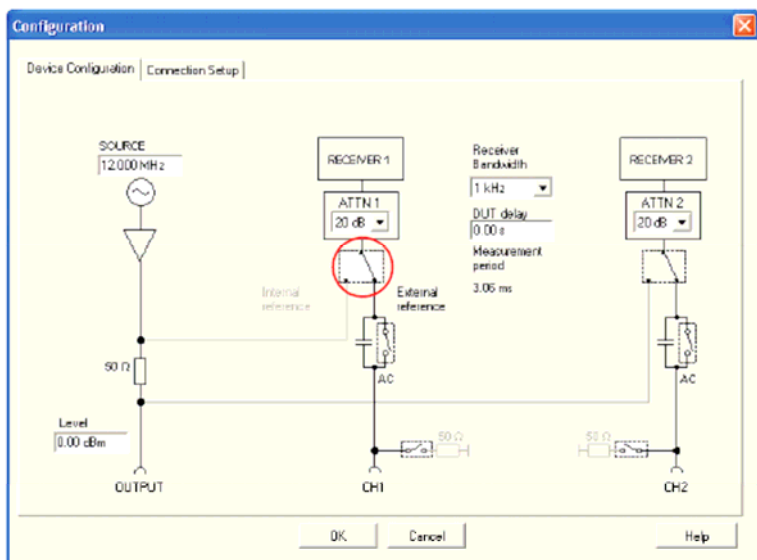
<p>A BNC 50Ω termination resistor is used as external load to <i>OUTPUT</i>. Which amplification do you measure in the <i>Gain/Phase</i> mode (dB and factor)?</p> <p style="text-align: center;">0dB = Factor 1</p>	
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Remove the 50Ω resistor and measure again as shown in the figure below.

<p>Which amplification do you measure for this short circuit (dB and factor)?</p> <p style="text-align: center;">6dB = Factor 2</p>	
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It is seen that the measurement delivers wrong results, when the load impedance at *OUTPUT* is not exactly 50Ω . There are two ways to get accurate results: Using *CH1* and calibration.

2.2 Using Reference CH1 for Accurate Measurements



Right-click in the diagram to open the shortcut menu. Use the shortcut menu to optimize the diagram, select the grid and zoom in the diagram. After having zoomed in, click **Optimize** to get back to an optimized diagram.

(a) Config. with *OUTPUT* not internally connected to *CH1* (b) $Vector = V(CH2)/V(CH1)$

Fig. 2.2: Gain/Phase measurement: $Vector = V(CH2)/V(CH1) = Amplitude \cdot \exp(j \cdot Phase)$.
Images taken from *Bode 100 User Manual* [2].

Click the *Device Configuration* toolbar button or select *Configuration* → *Device Configuration...* from the *Bode Analyzer Suite*'s menu bar or to get into the configuration menu. Click on the switch circled red in Fig. 2.2 to get the illustrated setting of the switch. The connection between *OUTPUT* and reference input *CH1* has now to be made externally. Note to which side of the output resistor the reference channel *CH1* is connected now. The measurement will always be correct independently of the load resistor. Use the setup of Fig. 2.2 with a source frequency 1KHz to try the two situations below:

Which amplification do you measure for this short circuit (dB and factor)? <p style="text-align: center; color: blue;">0dB = Factor 1</p>	
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Which amplification do you measure now (dB and factor)? <p style="text-align: center; color: blue;">0dB = Factor 1</p>	
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This kind of measurement is always correct but a more uncomfortable due to the required additional cable connected to the reference channel *CH1*.

2.3 User Calibration for Accurate Measurements Without CH1

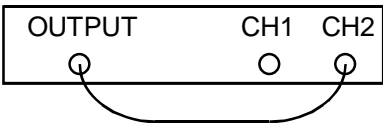

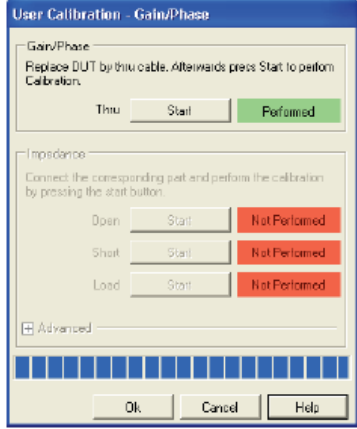
		
<p>(a) Setup schematics</p>	<p>(b) Photo of physical setup</p>	<p>(c) User calibration menu</p>

Fig. 2.3: Setup for User Calibration with default configuration. Figs. (b), (c) taken from [2]

Return to the default configuration shown in Fig. 2.1 and connect *OUTPUT* with *CH2* as illustrated above.

Set the source frequency in the *Gain/Phase* menu to 1000 Hz. We should now measure 6dB amplification again. Select *Calibration* → *User Calibration...* from the *Bode Analyzer Suite*'s menu bar to get into the calibration menu. Then select → *Thru: Start*. Close the *Calibration* menu with *OK* and measure again. What amplification do you measure for this short circuit now?

0dB = Factor 1

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Change the source frequency supplied to *OUTPUT* from 1000 Hz to 1001 Hz. Look at the measurement and look at the calibration menu. Is the last calibration still valid?

No, measured result jumps from 0 to 84dB.

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New calibration is required for the new settings

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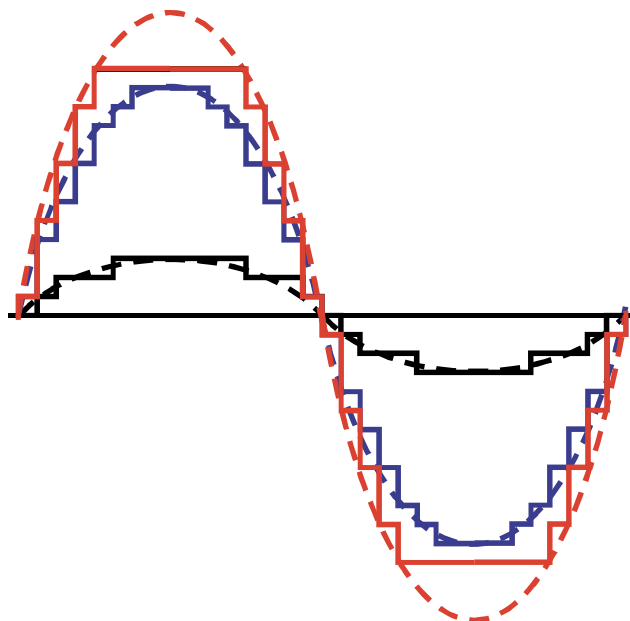
Calibration of the Bode 100 performs a measurement which will be the 0dB/0°-reference for subsequent measurements. New settings require new calibration.

When several setup changes are required it is easiest to connect *OUTPUT* and *CH1* externally and use the default calibration.

2.4 Optimizing the Measurement

Both *CH1* and *CH2* contain a 24-bit $\Delta\Sigma$ -ADC, delivering $f_{s,out}=50$ Ksps (Kilo-samples per second). Experts only: The Main clock rate is $f_{s,in}=12,8$ MHz. Consequently, the oversampling rate is $OSR=f_{s,in}/f_{s,out}=256$.

To take advantage of the ADC's 24 bit (!) resolution input amplitudes must be adjusted as large as possible (blue curve in the figure on the right hand side) but not overloaded (red curve). Overloaded amplitudes introduce large errors by clipping while too small amplitudes lose accuracy by not using the most significant bits of the ADC (black curve).



To optimize the measurement the user can adjust the source's *OUTPUT* amplitude using *Level*, and the attenuation switches for the inputs *CH1* and *CH2*. The attenuators affect the measured accuracy but not its displayed amplitude.

For this lab: Externally connect *OUTPUT* an *CH1*. Prefer a source frequency of 1 KHz and a receiver bandwidth of 100Hz.

Hint: A higher receiver bandwidth allows faster measurements, a lower receiver bandwidth increases the measurement accuracy.

On the bottom right side of the measurement window next to the *Bode 100*'s serial number there are amplitude indicators. Their green bar should be as long as possible, but it should not become red indicating ADC overload.


Overload indicators for the channel 1 and channel 2 inputs. If you see a red bar, increase the attenuation of the respective channel or reduce the source level to prevent the overload.



Figures taken from [2]

Lowering the receiver's bandwidth improves the results on the cost of longer measurement times which can be estimated to be larger than or equal $1/\text{bandwidth}$.

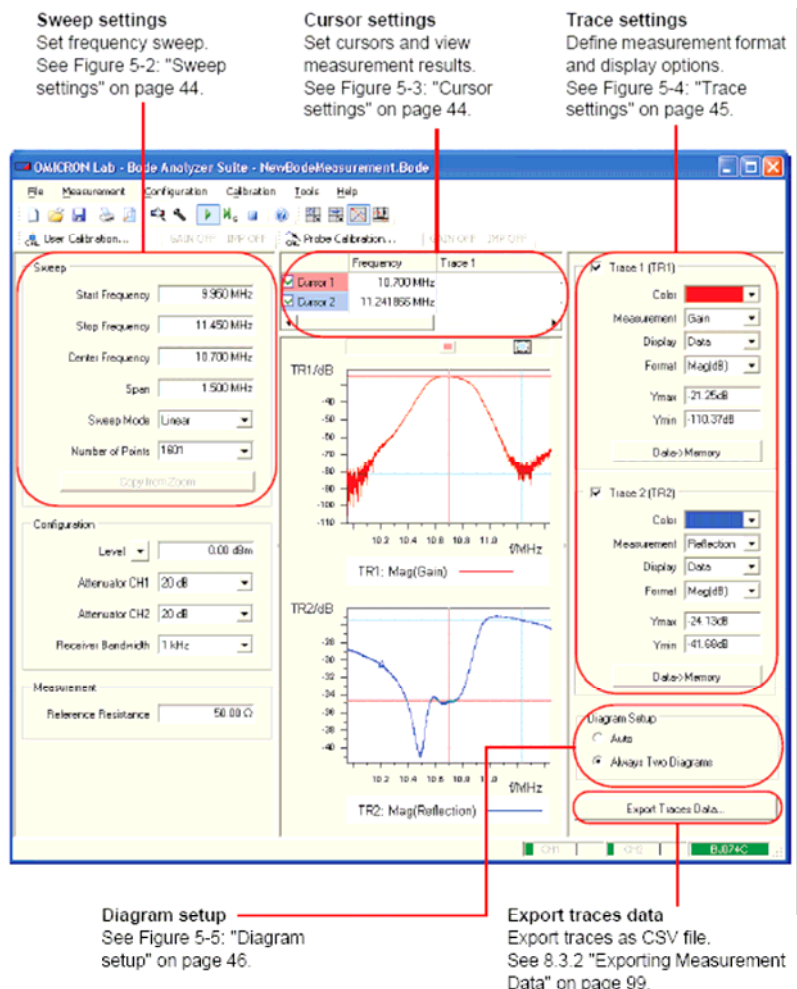
2.5 Frequency Sweep Mode

Click toolbar button  to switch to the *Frequency Sweep* mode. Alternatively, you can select *Measurement* → *Frequency Sweep* from the *Bode Analyzer Suite*'s menu bar.

The frequency sweep mode is documented in chapter 5 of the *User Manual*. A frequency sweep is an assembly of several gain-phase measurements. The result can be presented as Bode-plot as shown on the right hand side.

Anything we said about configuration and calibration for the gain/phase mode holds true for the frequency sweep mode also.

Source level and receiver attenuations have to be set such, that the maximum amplitude is just below overload. Observe the input channel overload indicators on the lower right hand side of the window carefully. Perform test measurements with large bandwidth before doing final, accurate measurement with low bandwidth.



Note: Only window areas specific for the **Frequency Sweep** mode are explained. For window areas common to other measurement modes, see Figure 3-1: "Gain/Phase mode window" on page 17 and Figure 4-1: "Impedance/Reflection mode window" on page 33.




Figure taken from [2]

Check configuration. Setup according to Fig. 2.2, external connection: *OUTPUT* – *CH1*.

Select the following Sweep Mode settings: (Savable using *File* → *Save As...*)

Start Frequency: 100 Hz, *Stop Frequency:* 1 MHz, *Sweep Mode:* Log., *Number of Points:* 201, *Receiver Bandwidth:* 100 Hz. Optimize *OUTPUT Level* and *Attenuators*. (E.g. *OUTPUT Level:* 0dB, *Attenuator CH1* and *CH2:* 20dB.)

Shorten OUTPUT with *CH1* and *CH2*. You should measure 0dB over all frequencies.

Buttons ,  and  are available to start a continuously repeated sweep, a single sweep and to stop the measurement, respectively. **Measure** the short circuit of the cable: Get 0dB?

3 Calibration: Removing Coupling-Capacitor Effects

This sub-chapter illustrates how calibration can remove side effects from measuring the device under test (DUT). We configure *Bode 100* as illustrated in Fig. 2.2 with *CH1* as external reference and connect it to *OUTPUT*. For a frequency sweep from 1Hz...1KHz of the OpAmp circuit shown in Fig. 3-1(a) we expect a line very close to 0dB, but we get the measurement illustrated in Fig. 3-1(b).

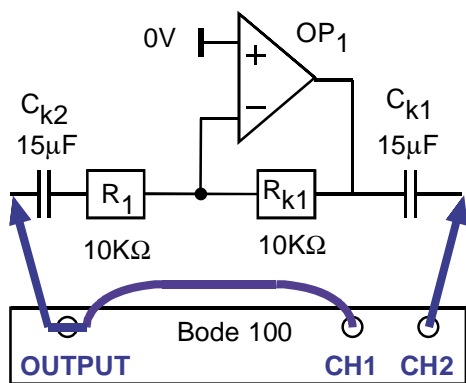
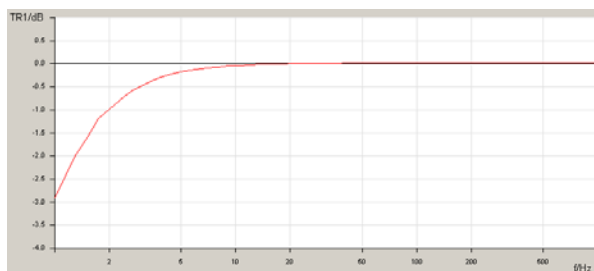


Fig. 3-1: (a) Setup



(b) Uncalibrated measurement

To fix the problem we measure the circuit illustrated in Fig. 3-2(a) and get a measured result very similar to the measurement in Fig. 3-1(b).

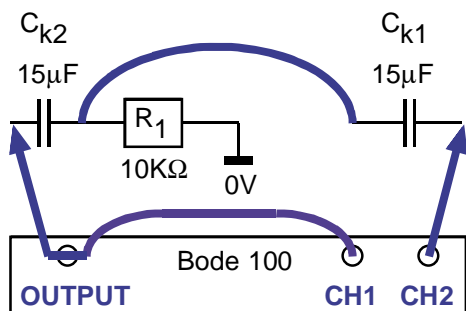
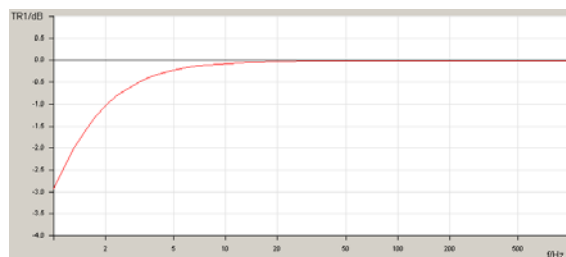


Fig. 3-2: (a) Setup



(b) Uncalibrated measurement

Perform a *User Calibration* with the setup of Fig. 3-2. After this calibration the setup 3-2 delivers a 0db/0°-measurement. With this calibration we measure the setup of Fig. 3-1(a) again and get the result shown in Fig. 3-3.

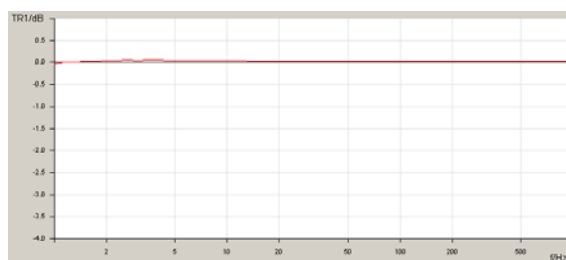


Fig. 3-3: Measured result for the OpAmp circuit after calibration

4 References

- [1] Available <http://www.omicron-lab.com/>
- [2] Bode 100 User Manual, available <http://www.omicron-lab.com/manuals/pdf.html>
- [3] Bode 100 Network Analyzer Suite, available <http://www.omicron-lab.com/downloads.html>
- [4] Homepage of M. Schubert, Regensburg University of Applied Sciences. Available: <http://homepages.fh-regensburg.de/~scm39115/homepage/education/courses/psk/psk.htm>