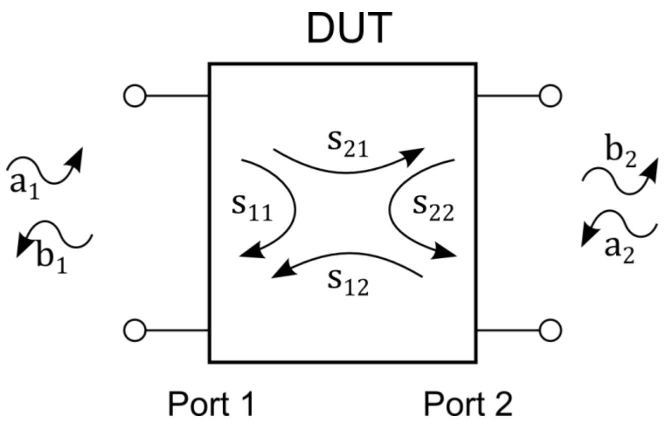
S-Parameter Measurements with the Bode 100



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

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Note: All the variables displayed in this document are complex numbers consisting of a real and imaginary part (e.g. $s_{11} = \mathrm{real}\{s_{11}\} + i \cdot \mathrm{imag}\{s_{11}\}$)

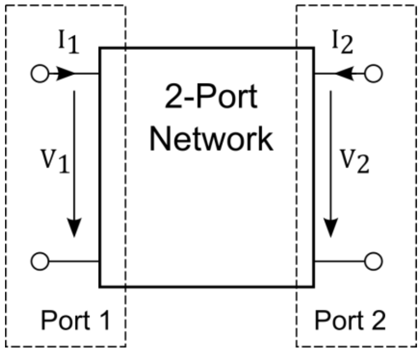
Note: Basic procedures such as setting-up, adjusting and calibrating the Bode 100 are described in the Bode 100 user manual.

Note: All measurements in this application note have been performed with the Bode Analyzer Suite V2.31. Use this version or a higher version to perform the measurements detailed in this application note.

You can download the latest version at http://www.omicron-lab.com/downloads.html.

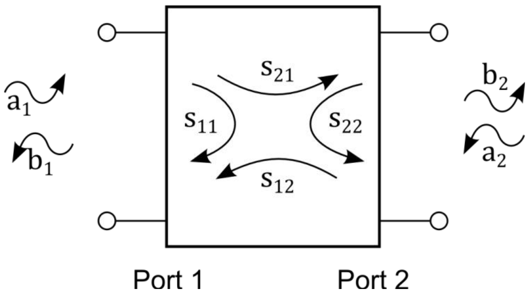
1 S-Parameters

S-Parameters (scattering parameters) have been introduced to describe linear networks at high frequencies. S-parameters can be used to fully describe linear multi-port networks and are supported by many simulation tools.
In the following the parameters are explained on a 2-port network. The figure below shows a 2-port network with port 1 on the left side and port 2 on the right side.



Such a network can be described using conductance parameters (y), resistance parameters (z), with a mixture of both (h-parameters) or using s-parameters.

S-parameters describe the network in terms of travelling waves. An incoming wave a_1 reaching a two port network is partially reflected at the input port, resulting in b_1 and partially transmitted to the output port, resulting in b_2. The following figure illustrates the incoming and outgoing waves at the two port network.



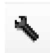
The S-parameters describe the relation between the reflected and transmitted waves.

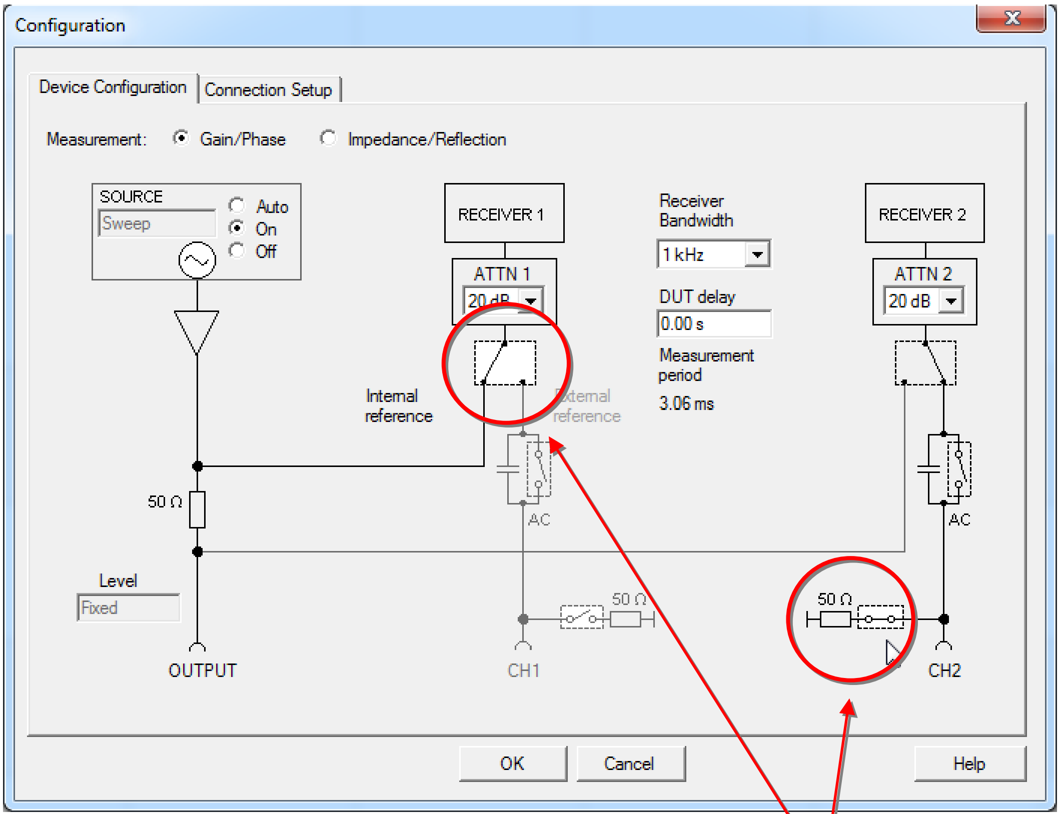
$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \underbrace{\begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix}}_{\text{scattering matrix}} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

The elements of the scattering matrix are called s-parameters. The parameters s_{11} and s_{22} have the meaning of reflection coefficients, the parameters s_{21} and s_{12} the meaning of transmission coefficients.
A big advantage of the s-parameters is that all the measurements to determine the parameters can be done in a system with defined reference impedance (e.g. $Z_0 = 50\Omega$). This enables the use of matched cables without influencing the measurement.

2 S-Parameter Measurement with the Bode 100

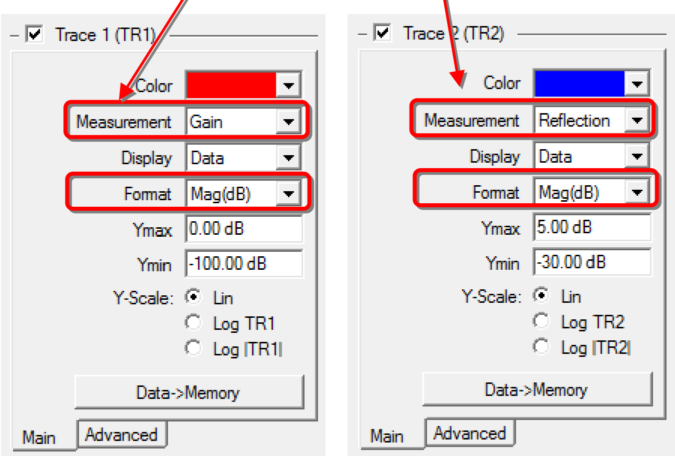
2.1 Device Setup

The Bode 100 supports the measurement of s-parameters. For the s-parameter measurement, it is important that the channel 2 input impedance is set to 50Ω and the channel 1 is set to internal reference.
These settings can be applied in the device configuration window. 



Note:
CH1 reference and input impedance can be toggled by clicking on the switch symbols.

To display of s_{21} in trace 1 and s_{11} in trace 2 the following trace settings have to be set:



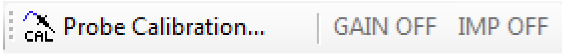
Note:

Gain $\triangleq s_{21}, s_{12}$
Reflection $\triangleq s_{11}, s_{22}$

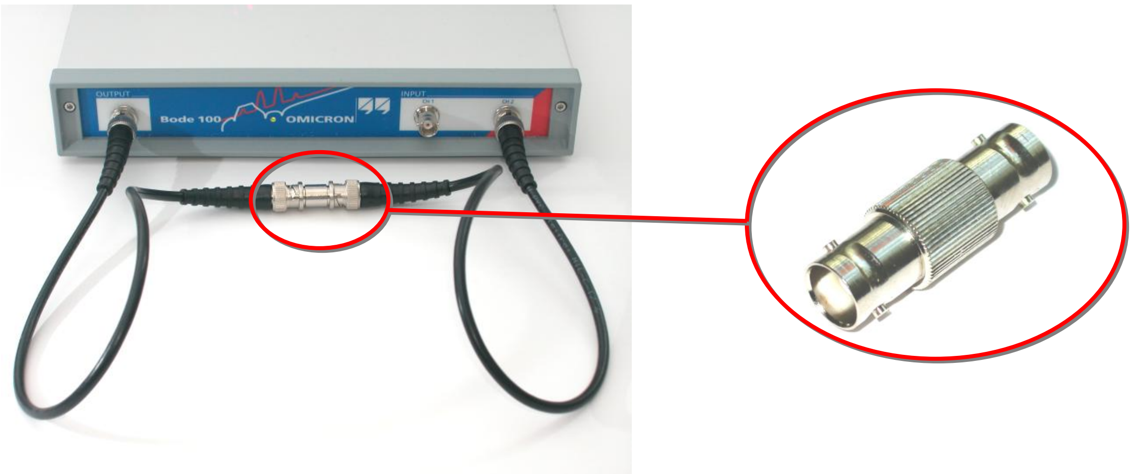
(Details on this can be found in the Appendix)

2.2 Calibration

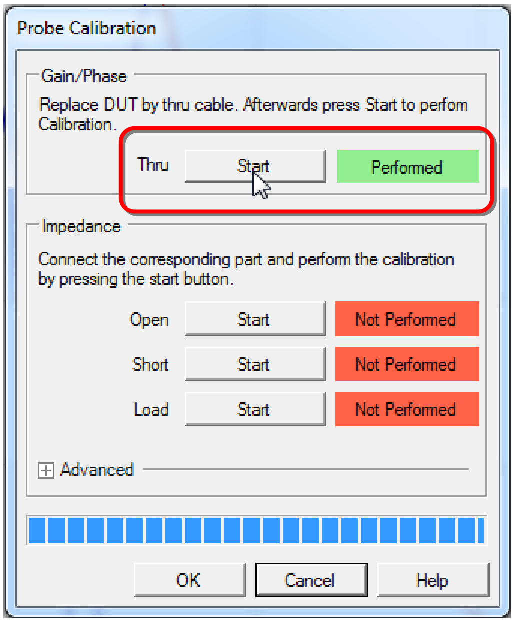
It is recommended to perform a probe calibration before performing the measurement.



To calibrate the s_{21} measurement a **thru** calibration has to be performed. To do so, connect the output of the Bode 100 with CH2 using connection cables and a thru connector as shown in the pictures below.



Now the calibration can be started. After the calibration process is finished the indicator field turns from red to green color.

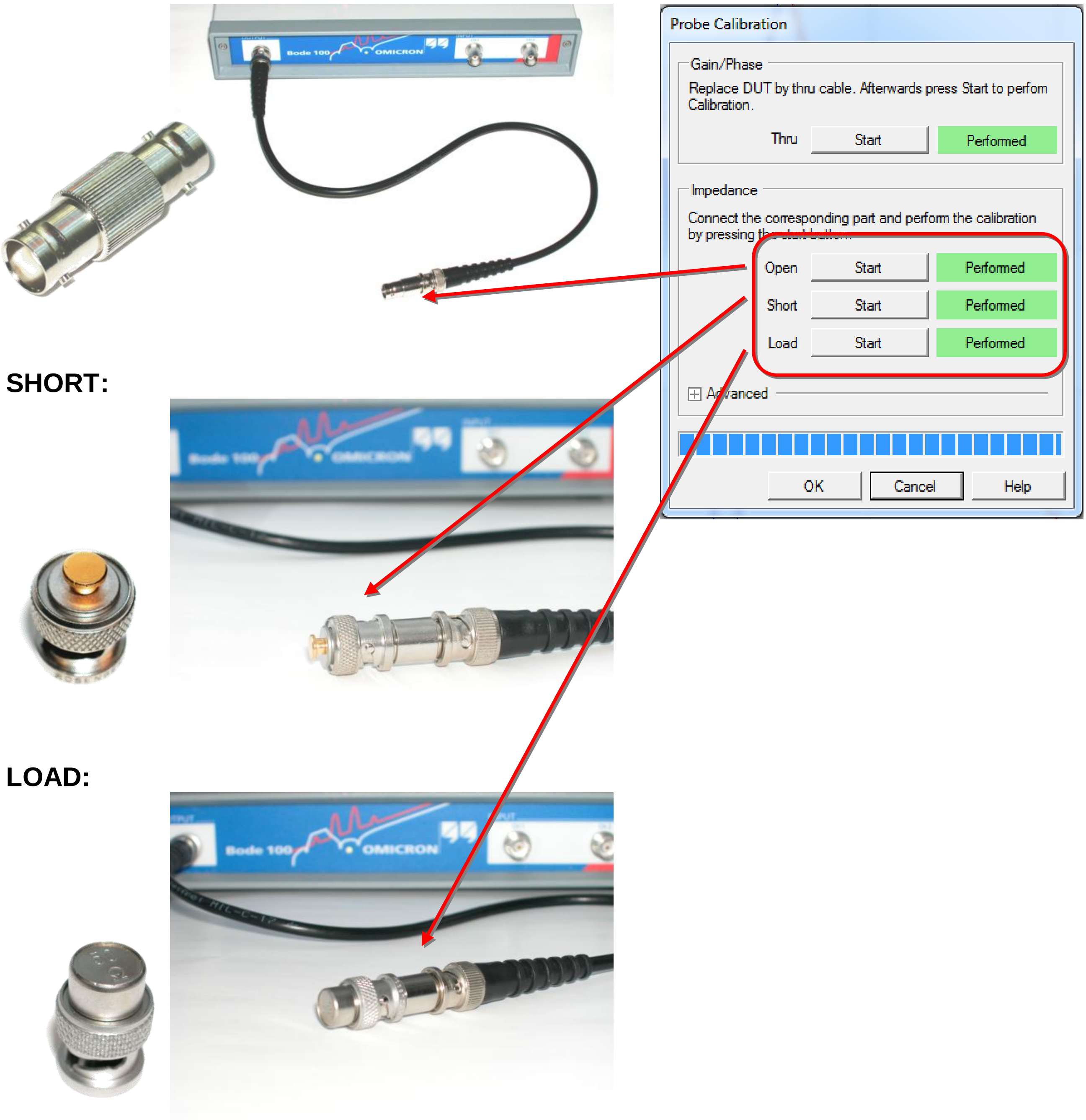


To calibrate the s_{11} measurement a **reflection/impedance** calibration has to be performed. To do so, connect the **open**, **short** and **load** standards as shown in the pictures below.

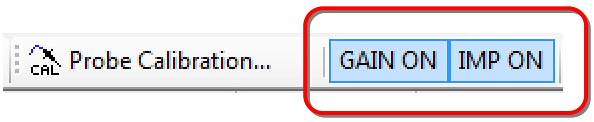
OPEN:

SHORT:

LOAD:



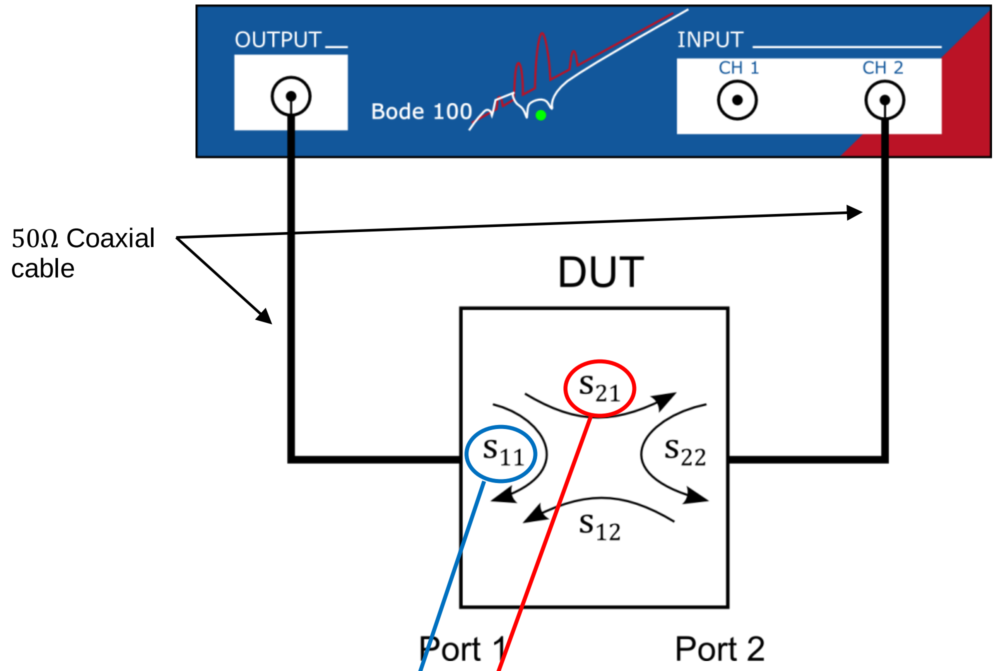
After performing the calibrations the calibration icons turn blue. This indicates that the calibrations are active:



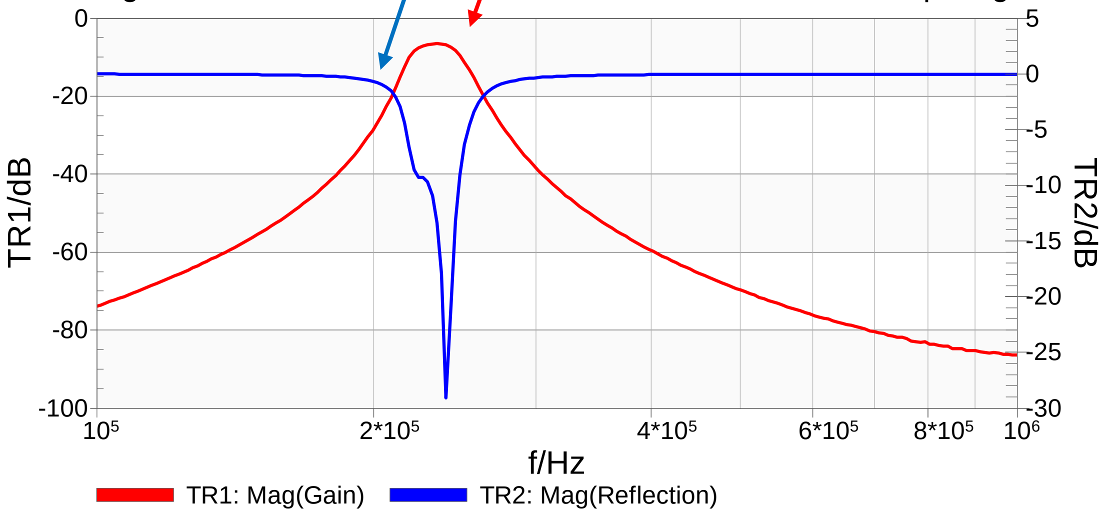
2.3 Measurement

2.3.1 S11 and S21

To measure the device under test (DUT), connect it as shown in the figure below. The Bode 100 output is connected to port 1 of the DUT and port 2 of the DUT is connected to the Bode 100 channel 2.



Performing a measurement leads to a result as shown in the example figure below.

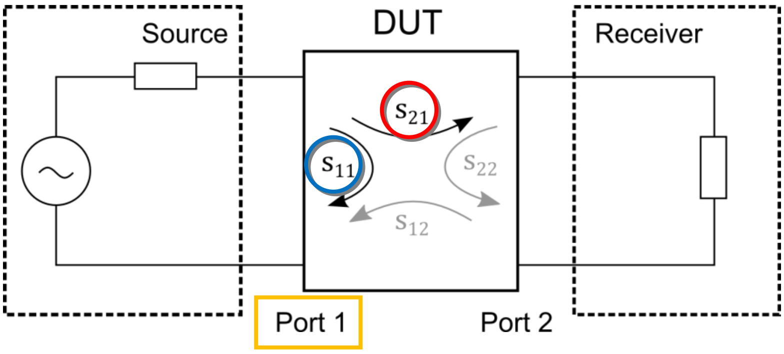


Trace 1 is the transmission coefficient s_{21} in dB ($20\log|s_{21}|$),
trace 2 shows the reflection coefficient s_{11} in dB ($20\log|s_{11}|$).

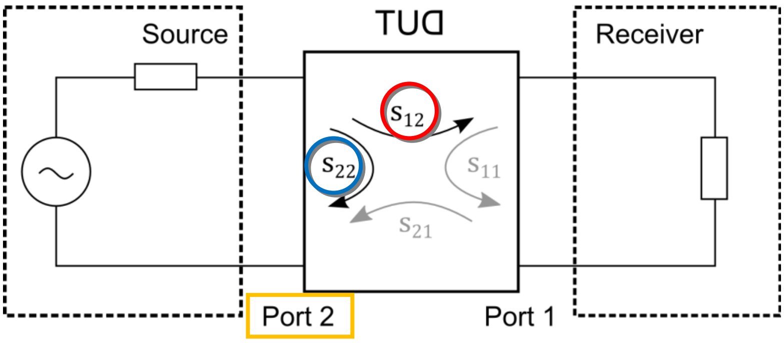
2.3.1 S22 and S12

To measure the reverse transmission and reflection coefficients s_{12} and s_{22} the same setup and calibration can be used simply the DUT has to be reversed.

To measure s_{21} and s_{11} port 1 of the DUT is connected to the Bode 100 output:



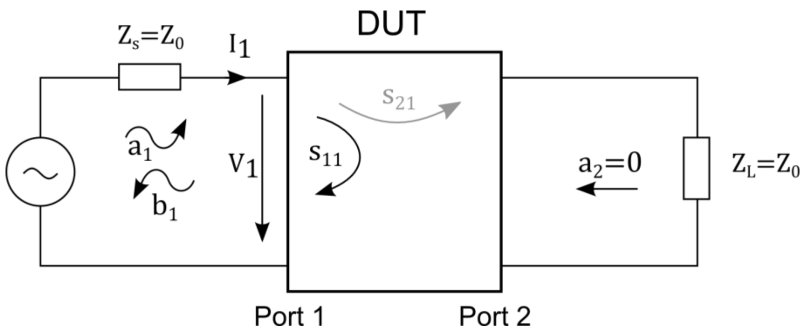
To measure s_{12} and s_{22} port 2 of the DUT is connected to the Bode 100 output:



3 Appendix

1) Reflection Measurement

The S_{11} measurement is performed with matched impedance load and source ($Z_L = Z_s = Z_0 = 50\Omega$) such that there is no reflection from the load ($a_2 = 0$).



In the matched load case s_{11} from the matrix equation results in:

$$s_{11} = \frac{b_1}{a_1}\bigg|_{a_2=0}$$

Where a_1 and b_1 are the wave variables which are defined in terms of voltage and current as follows:

$$a_1 = \frac{V_1 + Z_0 I_1}{2\sqrt{Z_0}} \qquad b_1 = \frac{V_1 - Z_0 I_1}{2\sqrt{Z_0}}$$

Using this relation s_{11} can be rewritten:

$$s_{11} = \frac{V_1 - Z_0 I_1}{V_1 + Z_0 I_1} = \frac{\frac{V_1}{I_1} - Z_0}{\frac{V_1}{I_1} + Z_0}$$

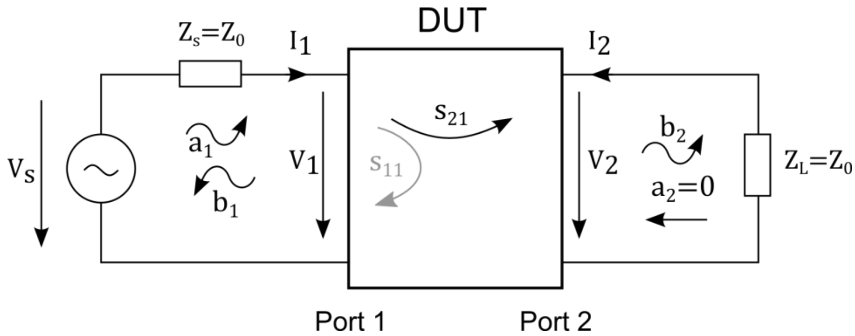
Where $V_1 / I_1 = Z_{11}$ and therefore

$$s_{11} = \frac{Z_{11} - Z_0}{Z_{11} + Z_0} = r \text{ ... reflection coefficient}$$

The reflection coefficient equals the **reflection** measurement of the Bode 100.

2) Transmission Measurement

The S_{21} measurement is performed with matched impedance load and source ($Z_L = Z_s = Z_0 = 50\Omega$) such that there is no reflection from the load ($a_2 = 0$).



In the matched load case s_{21} from the matrix equation results in:

$$s_{21} = \frac{b_2}{a_1}\bigg|_{a_2=0}$$

Where a_1 and b_2 are the wave variables which are defined in terms of voltage and current as follows:

$$a_1 = \frac{V_1 + Z_0 I_1}{2\sqrt{Z_0}} \qquad b_2 = \frac{V_2 + Z_0 I_2}{2\sqrt{Z_0}}$$

Using this relation s_{21} can be rewritten

$$s_{21} = \frac{V_2 + Z_0 I_2}{V_1 + Z_0 I_1}$$

Where $Z_0 I_2 = V_2$ and $V_1 + Z_0 I_1 = V_s$ and therefore

$$s_{21} = \frac{2V_2}{V_s} \ldots \text{ transmission coefficient}$$

This equals the **gain** calculated by the Bode 100 using the internal reference.