

Application Note: Advanced Measurements with the TBVNA-6000 Bode Analyzer

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Application Note: Advanced Measurements with the TBVNA-6000 Bode Analyzer

1. Introduction

This application note explains how to normalize TBVNA-6000 Bode analyzer measurements and how to implement customized measurements using the equation feature.

The Bode analyzer option enables simultaneous measurement of four input channels using a dedicated high-power signal source. It provides full-power operation from DC to 200 MHz and measurements up to 500 MHz with reduced source power.

A configurable **frequency–power table** allows the entire measurement range to be optimized by defining the output power, resolution bandwidth (RBW), and input-channel attenuation as a function of frequency. This enables optimum signal levels and dynamic range across the complete operating frequency range.

2. Switching to Bode Mode

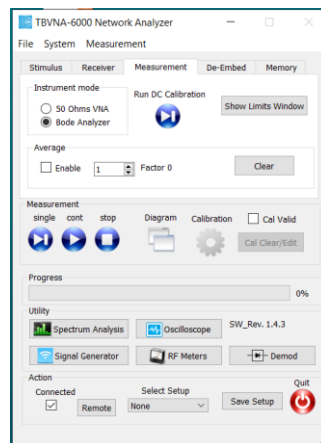


Fig. 2.1: Main Window – Measurement Tab

In the **Measurement** tab of the main window, click the "**Bode Analyzer**" radio button to switch to **Bode Measurement** mode.

Please note that when switching to Bode mode, the **Bode Sweep List** window is displayed automatically. This window remains open and cannot be closed while the instrument is operating in Bode Measurement mode.

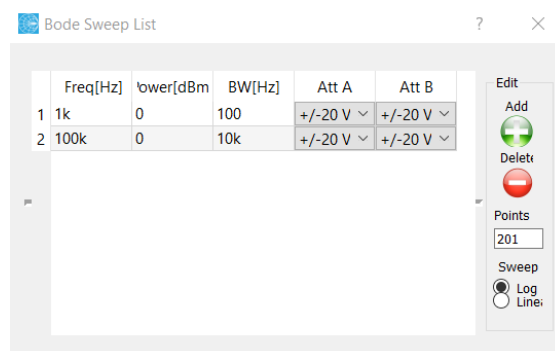


Fig 2.2: Bode Sweep List

The **Bode Sweep List** allows the user to configure the frequency sweep by specifying the signal output power, measurement bandwidth (RBW), and input attenuator setting for each frequency range. This

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enables the sweep parameters to be optimized across the entire measurement frequency range. An unlimited number of sweep ranges can be added, with each range configured independently. This allows different signal power levels, measurement bandwidths (RBW), and input attenuator settings to be applied to different segments of the frequency sweep.

In addition to these individual settings, several global parameters apply to the entire sweep, including the total number of measurement points and the sweep type (linear or logarithmic).

3. Inputs and Output

In Bode Mode all four Inputs are enabled for measurement, with some minor restrictions.

- Channel A and B: +/- 0.5V, +/-5V and +/- 20V range with 1M Ω input impedance in parallel with 15 pF of input impedance. This will allow to use standard oscilloscope passive probes using standard frequency compensation.
- Port 1 and 2 with 50 Ω , 0 dBm max. or +/- 350 mV, no attenuator switch.

All inputs work well to above 500 MHz without any compression.

The BNC output port can deliver up to 12 Vpp into 50 Ω systems and 24 Vpp in high impedance loads. The full power bandwidth of the output is approximately 200 MHz.

4. Measurement

4.1 Trace function overview

Following pre-defined trace functions are available for diagrams in BODE mode:

| Trace Function | Short Description |
|----------------|--|
| CH 1 | Level Channel 1 |
| CH 2 | Level Channel 2 |
| CH A | Level Channel A |
| CH B | Level Channel B |
| CH A / CH B | Channel A to Channel B ratio |
| CH B / CH A | Channel B to Channel A ratio |
| CH A / CH 1 | Channel A to Channel 1 ratio |
| CH A / CH 2 | Channel A to Channel 2 ratio |
| CH 1 / CH A | Channel 1 to Channel A ratio |
| CH 2 / CH A | Channel 2 to Channel A ratio |
| CH B / CH 1 | Channel B to Channel 1 ratio |
| CH B / CH 2 | Channel B to Channel 2 ratio |
| CH 1 / CH 2 | Channel 1 to Channel 2 ratio |
| CH 2 / CH 1 | Channel 2 to Channel 1 ratio |
| CLA pos B/A | Closed loop analysis for positive loop gain |
| CLA neg B/A | Closed loop analysis for negative loop gain |
| Impedance | U/I - Impedance measurement with CH A = voltage and CH B = current |

Table 4.1: Trace functions

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The predefined trace functions cover the majority of common measurement tasks. More complex calculations and custom trace operations can be implemented using the **Equation** function, providing virtually unlimited flexibility for data analysis.

4.2 Calibration

Accurate **Bode** measurements require a normalization procedure to achieve accurate results. Four available memory slots, Memory 1 – Memory 4, provide the capability to store reference traces. Reference traces are used to perform normalization and to compensate the frequency response of the measurement setup. One Memory slot will hold the reference data for all four inputs.

The **Level** functions (**CH1**, **CH2**, **CHA**, and **CHB**) do not provide accurate absolute measurements of the input voltage and should therefore be used only in conjunction with a normalization procedure.

Absolute measurement levels are still reliant on the applied signal power even after normalization. Consequently, it is not advised to use Levels alone to characterize electrical networks. Instead, normalized ratio functions should be utilized for precise gain or transfer-function measurements..

Following example shall illustrate this effect

Measurement Setup: A 5m RG-58 cable is connected between the Bode Output and Channel A. No termination is used. The sweep list is configured as below:

| | Freq[Hz] | Power[dBm] | BW[Hz] | Att A | Att B |
|---|----------|------------|--------|---------|---------|
| 1 | 100 | 0 | 100 | +/-20 V | +/-20 V |
| 2 | 100k | 0 | 10k | +/-20 V | +/-20 V |
| 3 | 10M | 0 | 10k | +/-20 V | +/-20 V |

Fig. 4.1: Example Sweep list from 100 Hz to 10 MHz

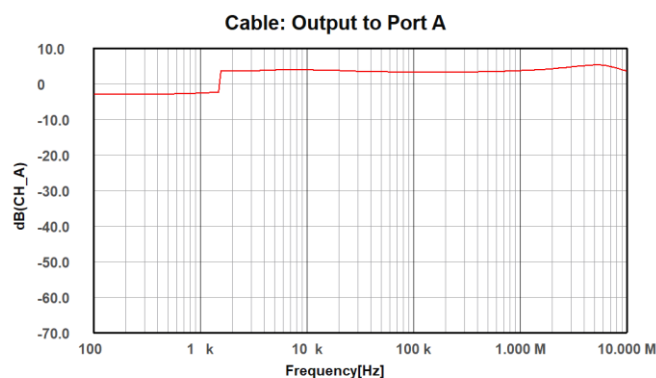


Fig. 4.2: Sweep result

As shown in **Figure 4.2**, the level measurement of **Port A** does not produce a flat trace at **0 dBm**. Moreover, it exhibits a step at approximately **1.5 kHz**. These artefacts are caused by internal filter switching within the **TBVNA** and do not represent actual changes in the input signal level.

Furthermore, the measured level does not equal **0 dBm** because **Port A** is not terminated with a **50 Ω** load. Consequently, the measured voltage differs from the voltage that would be obtained with a matched 50 Ω termination.

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Next, transfer the measurement to memory slot 1. Click on “Copy from Data” on the main windows “Memory” Tab.

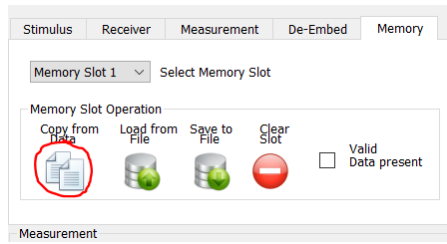


Fig. 4.3: Copy current sweep to Memory

After completing this operation, the "Valid Data Present" indicator will be enabled, confirming that the current sweep has been stored in the selected memory slot. Now, the active trace can be normalized using **Memory Slot 1** as the reference. This is configured in the **Trace Edit** dialog by selecting the appropriate normalization function.

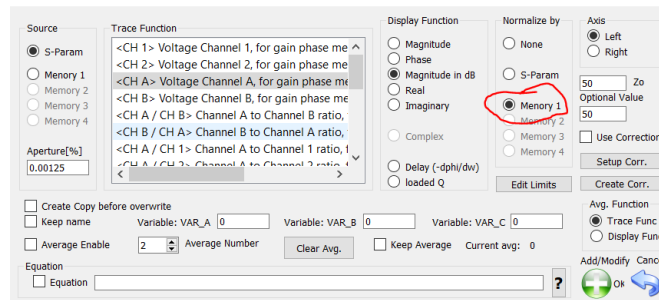


Fig. 4.4: Trace Edit Menu, setting trace normalization

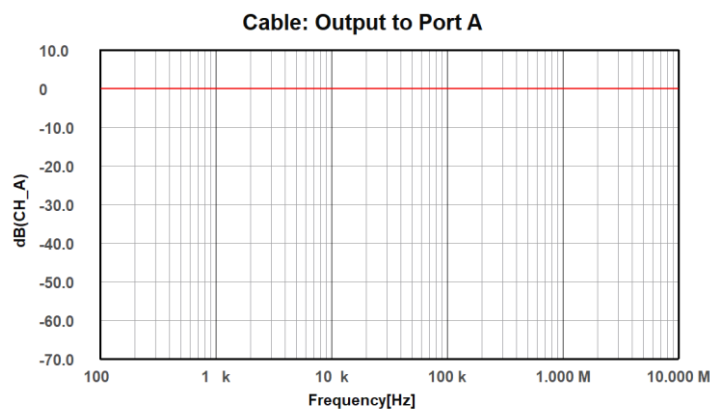


Fig. 4.5: Sweep result after normalization

Now, the trace is flat at 0 dB , meaning 0 dB with respect to the normalization power.

The output power can be configured arbitrarily. See the example below:

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| | Freq[Hz] | Power[dBm] | BW[Hz] | Att A | Att B |
|---|----------|------------|--------|-----------|-----------|
| 1 | 100 | 0 | 100 | +/-20 V ▾ | +/-20 V ▾ |
| 2 | 100k | 10 | 10k | +/-20 V ▾ | +/-20 V ▾ |
| 3 | 10M | 0 | 10k | +/-20 V ▾ | +/-20 V ▾ |

Fig. 4.6: ascending / descending power ramp

Which results in:

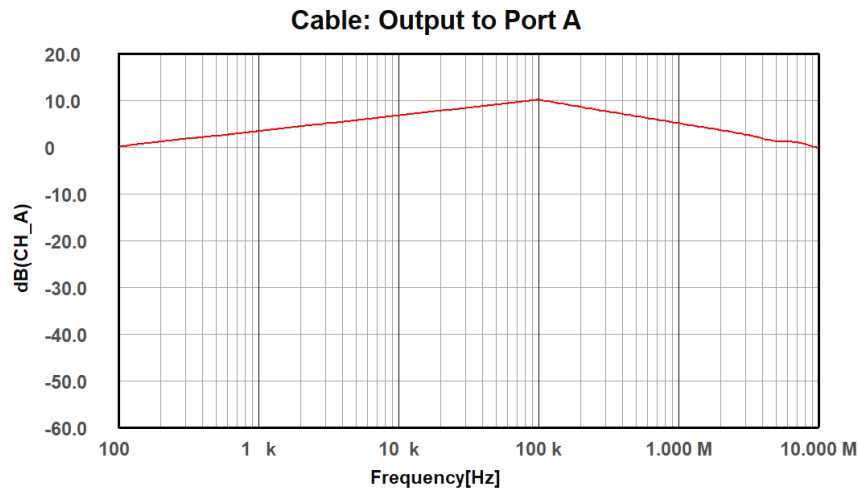


Fig. 4.7: Power ramp corresponding with the settings in Fig. 4.6

A slight nonlinearity can be observed in the power sweep at approximately **5 MHz**. This is caused by the programmable attenuator of the signal source and further illustrates, why absolute level measurements are not recommended. Such measurements are influenced by cumulative tolerances and accuracies of the instrument's internal signal path.

For accurate characterization of electrical networks, normalized ratio measurements should be used whenever possible.

However, there may be circumstances where this kind of measurement feature will be convenient and the intrinsic errors and tolerances can be accepted.

This measurement can alternatively be implemented using an equation. Open the **Trace Edit** dialog and enable the **Equation** checkbox. The equation replaces any pre-defined trace function. The displayed trace will be calculated according to the equation entered in the **Equation** field.

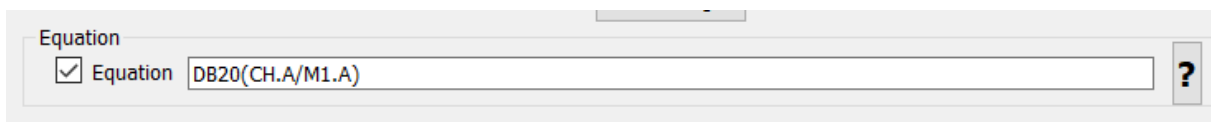


Fig.4.8: Equivalent measurement Equation

Where:

DB20() function.....corresponds to $20 \cdot \log_{10}()$

CH.ALevel Measurement Channel A

M1.A.....Memory slot 1, reference data for Channel A

Running the measurement will give exactly the same trace as shown in Fig. 4.7

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4.3 Ratio measurements

Use following setup to normalize ratio measurements:

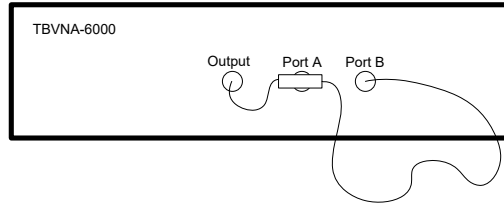


Fig. 4.9: Ratio Measurement Setup

In this setup, a short coaxial cable is used to connect the signal output to **Port A**. A coaxial T-adaptor is then used to connect **Port B** to **Port A**. In this configuration, **Port A** serves as the reference channel, while **Port B** is the measurement channel.

The quantity of interest is the transfer gain from **Port A** to **Port B**. For example, if the cable between **Port A** and **Port B** is replaced with a different cable or any device under test, the measured transfer function directly represents its gain or attenuation relative to the reference channel.

Sweep list setup-example:

| | Freq[Hz] | Power[dBm] | BW[Hz] | Att A | Att B |
|---|----------|------------|--------|---------|---------|
| 1 | 100 | 0 | 100 | +/-20 V | +/-20 V |
| 2 | 100k | 0 | 10k | +/-20 V | +/-20 V |
| 3 | 10M | 0 | 10k | +/-20 V | +/-20 V |

Fig. 4.10: Sweep list for ratio measurement

Perform a reference measurement and save it to memory slot 1:

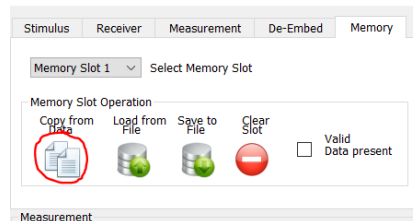


Fig. 4.11: Copy current sweep to Memory

Change the trace setup to CHB/CHA and uncheck the equation checkbox. Normalize by Memory 1.

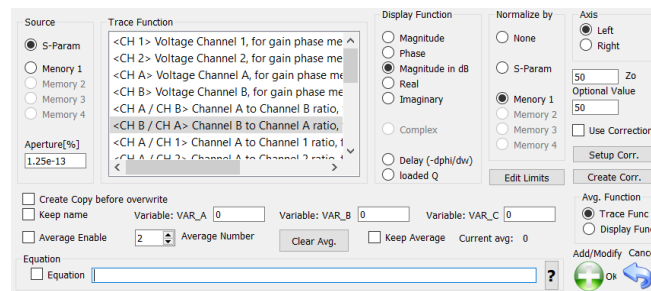


Fig. 4.12 Trace Edit Menu, setting trace normalization

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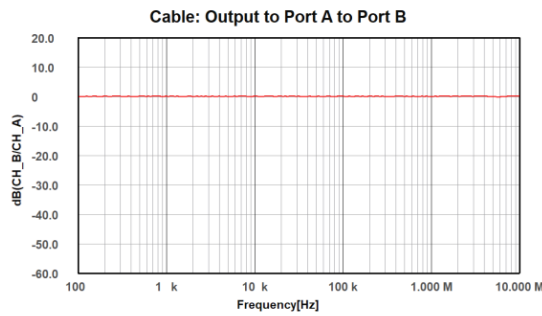


Fig. 4.13 Sweep result after normalization.

Now the power is ramped up at 100 kHz and then ramped down to 10 MHz:

| | Freq[Hz] | Power[dBm] | BW[Hz] | Att A | Att B |
|---|----------|------------|--------|---------|---------|
| 1 | 100 | 0 | 100 | +/-20 V | +/-20 V |
| 2 | 100k | 10 | 10k | +/-20 V | +/-20 V |
| 3 | 10M | 0 | 10k | +/-20 V | +/-20 V |

Fig.4.14 Power ramp to 10 dBm

The measurement result will be normalized with respect to the output port power:

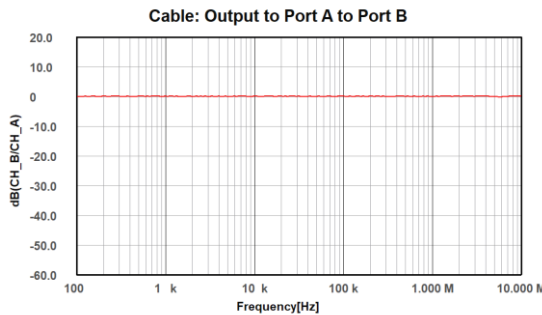


Fig. 4.15: Sweep result with power ramp.

As shown in **Figure 4.15**, the measurement result is now independent of the sweep power. The ratio measurement effectively cancels variations in the source output level, resulting in highly stable and repeatable measurements that are largely unaffected by internal instrument errors, component tolerances, or output level variations.

Consider proper termination of the high-impedance input ports at higher frequencies. Depending on the operating frequency and the length of the connecting cables, appropriate input terminations are required to minimize reflections and measurement errors.

The corresponding equation for a normalized ratio measurement is:

Equation

Equation ?

Fig. 4.16 Ratio measurement equation.

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4.4 Measurement Example, insertion loss of an audio transformer

A 4:1 audio power transformer shall be characterized in the range from 30 Hz to 250 kHz. The transformer output shall be loaded with 0.5Ω. This transforms to an input impedance of 2 Ω. An auxiliary power amplifier is required to drive the low impedance of the loaded transformer. The setup is shown below:

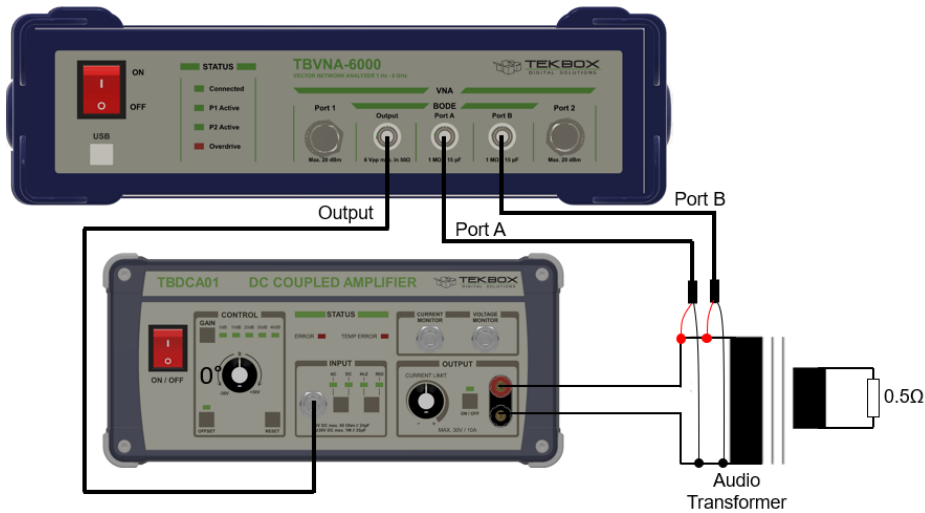


Fig. 4.17: Normalization setup

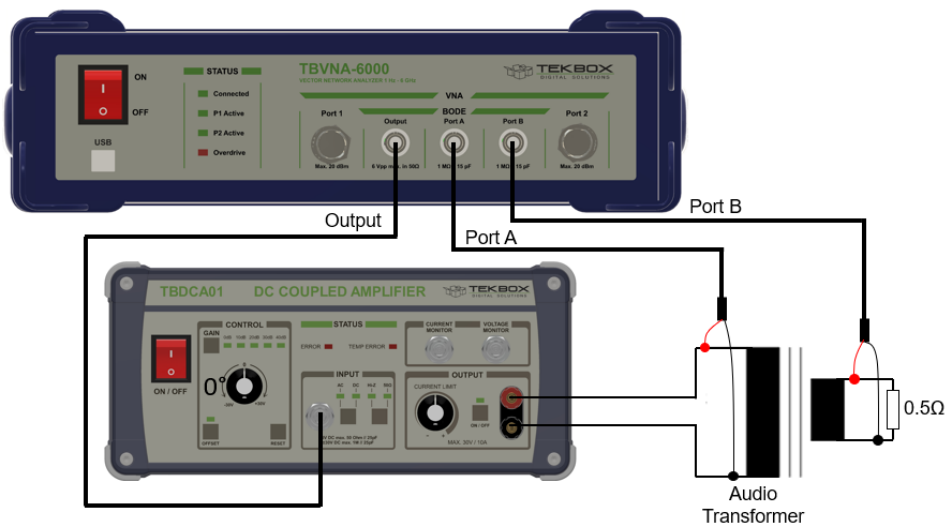


Fig. 4.18: Measurement setup

The sweep list is setup as:

| | Freq[Hz] | Power[dBm] | BW[Hz] | Att A | Att B |
|---|----------|------------|--------|---------|---------|
| 1 | 30 | 3 | 100 | +/-20 V | +/-20 V |
| 2 | 1k | 3 | 100 | +/-20 V | +/-20 V |
| 3 | 250k | 6 | 1k | +/-20 V | +/-20 V |

Fig. 4.19: Sweep List Setup

Set the amplifier gain to 0 dB and the input impedance to High Z. Perform a reference measurement using the normalization setup depicted in Fig. 4.17.

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The trace setup is configured to CHB/CHA, uncheck the equation checkbox.

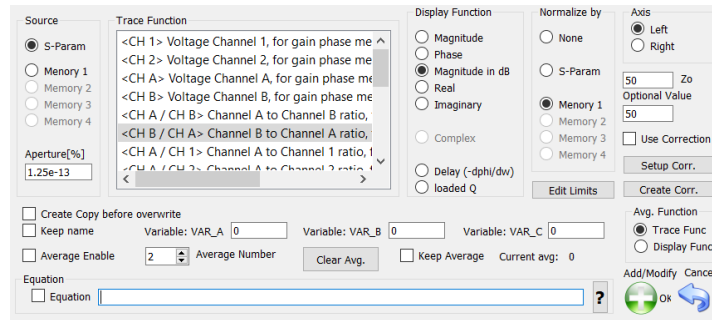


Fig. 4.20: Trace Edit Menu, setting trace normalization

Perform a measurement.

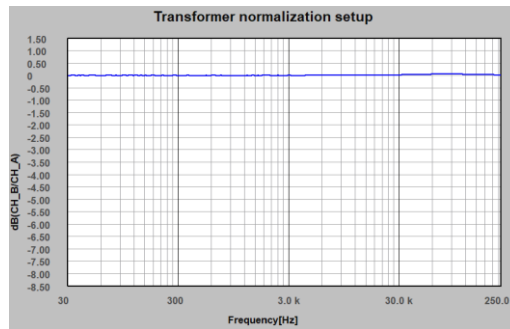


Fig. 4.21: Normalization measurement

Save it to memory slot 1.

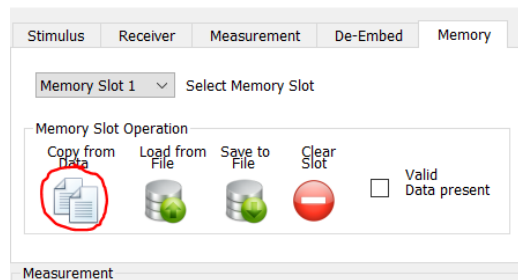


Fig. 4.21: Copy current sweep to Memory

The transformer’s turns ratio of **2:1**, would introduce an additional loss of 6 dB, if the measurement only considers the output and input voltage. The real insertion loss is obtained by the ratio of output power to input power. As we know the voltages and the load impedances, we can set up following equation:

$$Insertion Loss [dB] = 10 \log \left(\frac{P_{out}}{P_{in}} \right) = 10 \log \left(\frac{V_{out}^2}{\frac{0.5\Omega}{V_{in}^2}} \right) = 10 \log \left(\frac{V_{out}^2}{V_{in}^2} \right) + 10 \log \left(\frac{2\Omega}{0.5\Omega} \right) = 20 \log \left(\frac{V_{out}}{V_{in}} \right) + 10 \log(4)$$

$$Insertion Loss [dB] = 20 \log(V_{out}) - 20 \log(V_{in}) + 10 \log(4) \quad [1]$$

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The **Equation** function provides a convenient way to implement the formula so that the displayed gain directly represents the transformer's insertion loss.

The voltages of channel A and B are entered as **CH.A** and **CH.B**. To normalize it, divide the voltages by the values saved in Memory slot 1: **CH.A/M1.A** and **CH.B/M1.B**

Enter the equation into the diagram window: **DB20(CH.B/M1.B) -DB20(CH.A/M1.A)+DB10(4)**

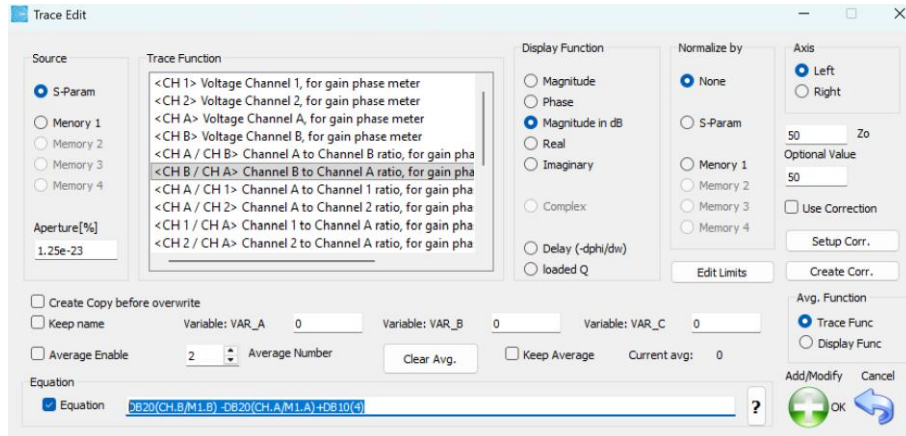


Fig. 4.22: equation for transformer insertion loss

Setup the measurement according to Figure 4.18 and press the measurement button.

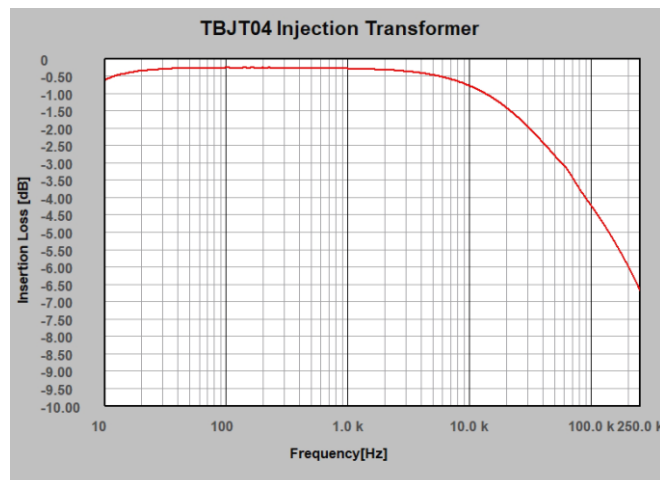


Fig. 4.23: Normalized measurement result

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4.5 Measurement Example, source resistance of an audio transformer

To predict the voltage drop of the transformer based on load resistance R_L , it is necessary to know the transformer's source resistance R_I .

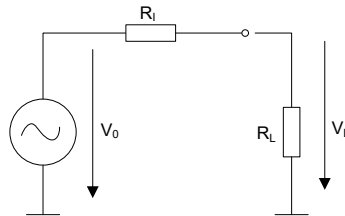


Fig 4.24: Equivalent circuit of the loaded transformer

A standard method for measuring source resistance is to measure the freewheeling voltage V_0 and the output voltage under load V_L . Knowing both voltages and the load resistance value R_L allows you to calculate the source resistance R_I .

$$R_I = R_L \frac{V_0 - V_L}{V_L} = R_L \left(\frac{V_0}{V_L} - 1 \right) \quad [2]$$

Measuring the unloaded transformer gain in dB and subtracting the loaded transformer gain in dB will give the required ratio in dB, which will be transformed to the linear domain to calculate the resistance.

First, configure a CH_B/CH_A measurement.

Setup the normalization according to Fig. 4.17, but disconnect the 0.5 Ω load resistor.

Perform a measurement with the normalization setup and copy the result to Memory slot 1.

Setup the measurement according to Fig. 4.18, but disconnect the 0.5 Ω load resistor.

Enable an equation to compensate for the winding ratio: **DB20(CH.B/M1.B) -DB20(CH.A/M1.A)+DB20(2)**

Perform a measurement.

Open the diagram properties window and create a copy of the unloaded transformer gain trace.

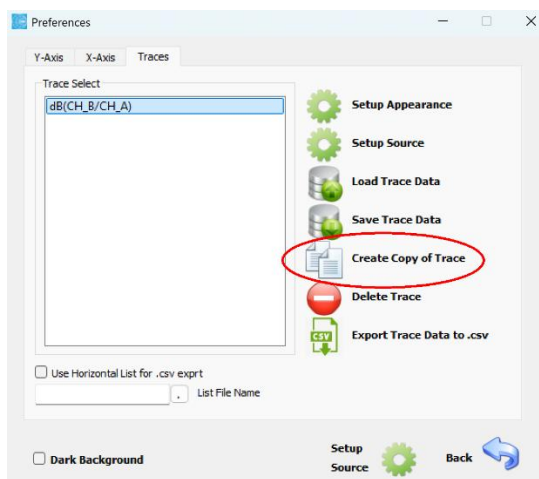
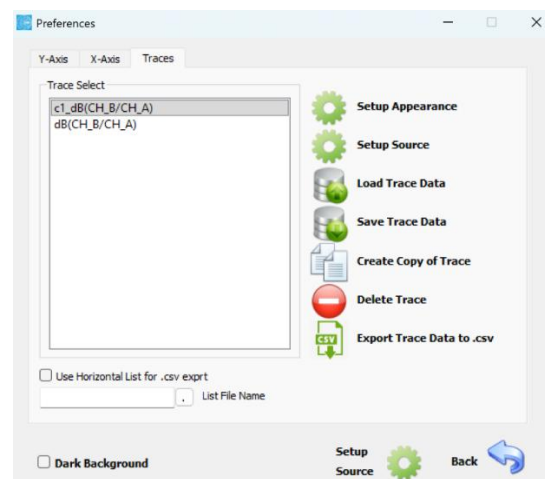


Fig 4.25: Diagram properties, traces tab



traces tab with copy of trace

The copy of the trace is static, which means that the trace data will not change with any further measurement. Click on "Setup Appearance" and change the name to "Vo" and change the color of the trace to blue.

Next, re-connect the 0.5 Ω load resistor to set up the normalization according to Fig. 4.17,.

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Perform a measurement with the normalization setup and copy the result to Memory slot 1.

Enter the equation to compensate for the transformers winding ratio and perform a measurement according to Fig. 4.18.

Change the name of the measurement trace to “VL” and add a legend. Enter a name for the diagram, such as “Transformer_measurement”. This name will be used in a global equation and shall not contain any space character.

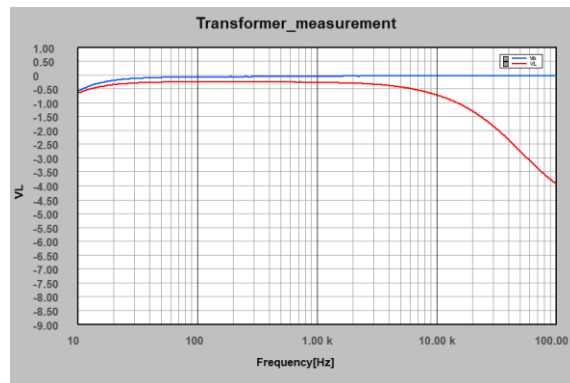


Fig 4.26: blue – unloaded insertion loss; red – loaded insertion loss

For the next steps, it is important to enable “keep name” in the trace properties to prevent the system to change the name of the trace if anything in the trace properties is changed.

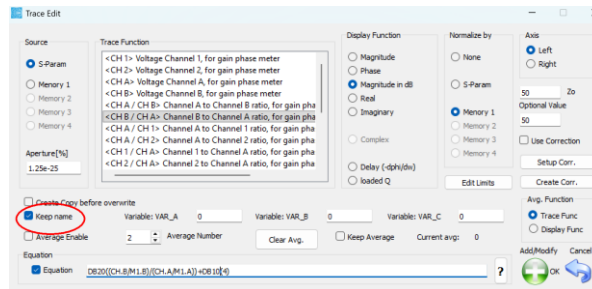


Fig. 4.27: diagram, trace setup; “keep name” enabled

Next, create a global equation to calculate the resistance.

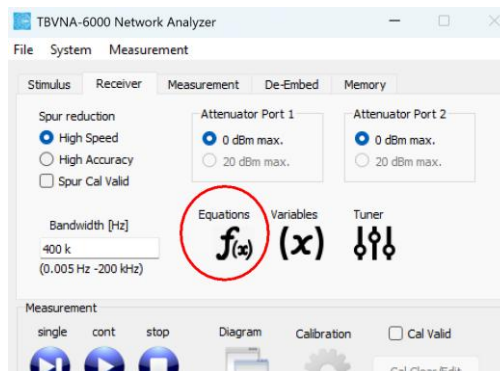


Fig. 4.28: global equation button

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The first equation is named **Vo** and reads out the trace copy of the unloaded transformer voltage Vo. The syntax is: TRC.<diagram_name>.<trace_name>(arg). The diagram name was set to **Transformer_measurement** and the trace name is **Vo**.

The second equation is the measurement result of the loaded transformer. It has to be re-entered, as traces created by equations cannot be used in global equations directly.

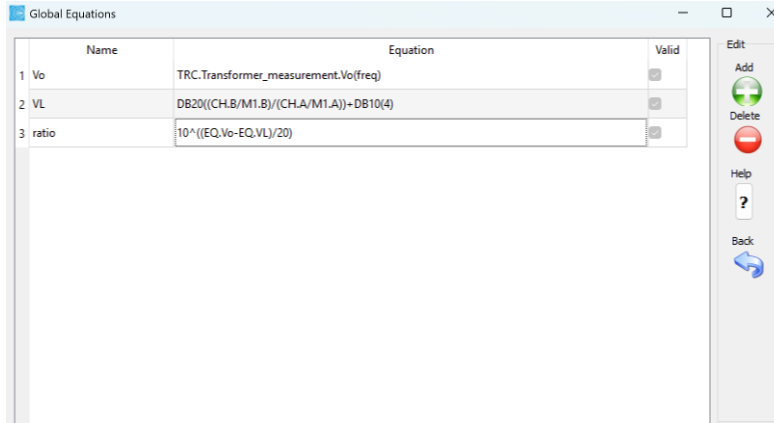


Fig. 4.29: Ratio equation

The ratio equation calculates the linear ratio of loaded and un-loaded insertion loss. Hence, the dB values must be de-logarithmized:

$$ratio = 10^{\left(\frac{V_o - V_L}{20}\right)} \quad [3]$$

In order to create the final equation, it is useful to define the load resistance as variable. Click the back-button to close the global Equations editor and open the Variables editor.

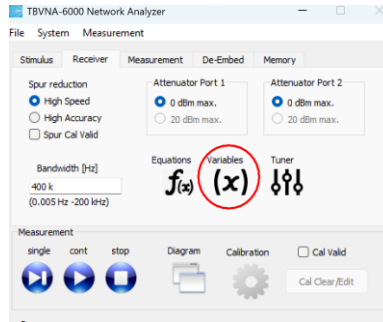


Fig. 4.30: Global Variables Button

Define a variable R_Load with a default value of 0.5 Ω, a range from 0.3 Ω to 10 Ω with a step size of 0.1 Ω and enable it. Note that R_Load could be entered into the equation for Ri as discrete value. Defining it as global variable shall only demonstrate the capability of the tuning feature:

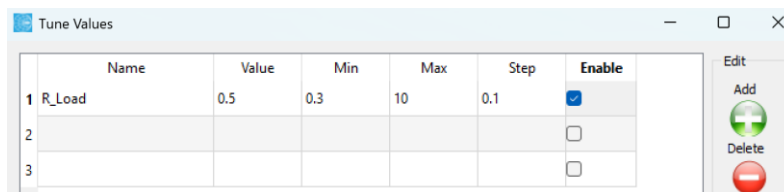


Fig. 4.31: Global Variables definition

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Re-open the global Variable editor to enter the equation to calculate the transformer's source resistance R_i using equation [2] depending on the variable R_{Load} . $R_i = VAL.R_{Load}*(EQ.ratio-1)$

| Name | Equation | Valid |
|---------|---------------------------------------|--------------------------|
| 1 Vo | TRC.Transformer_measurement.Vo(freq) | <input type="checkbox"/> |
| 2 VL | DB20((CH.B/M1.B)/(CH.A/M1.A))+DB10(4) | <input type="checkbox"/> |
| 3 ratio | $10^{((EQ.Vo-EQ.VL)/20)}$ | <input type="checkbox"/> |
| 4 Ri | $VAL.R_{Load}*(EQ.ratio-1)$ | <input type="checkbox"/> |

Fig. 4.31: Equation for R_i

Next define a new diagram to display R_i .

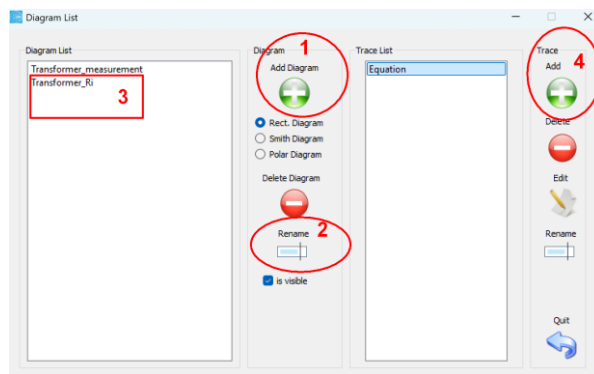


Fig. 4.31: Diagram to display R_i

Add a new trace with following equation EQ.Ri to create the trace of the transformer's source resistance:

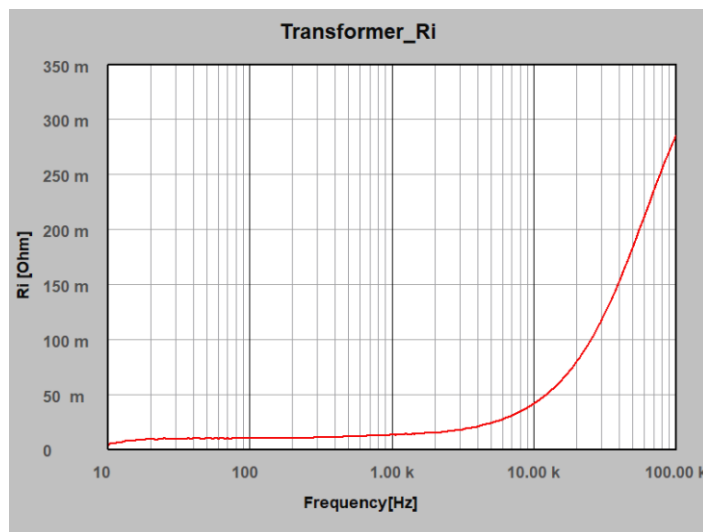
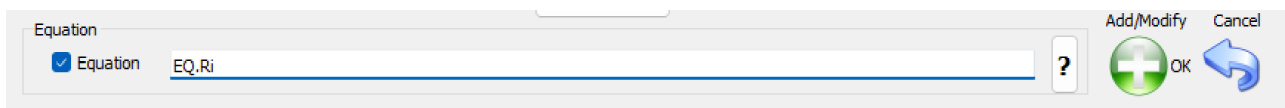


Fig. 4.32: Trace of the transformer's source resistance

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As mentioned before, the load resistance could be directly entered into the R_i equation. Though making no sense with respect to measuring R_i , the load resistance was defined as global variable to demonstrate the capabilities of tuning. Click at the tuner-button to tune the variable:

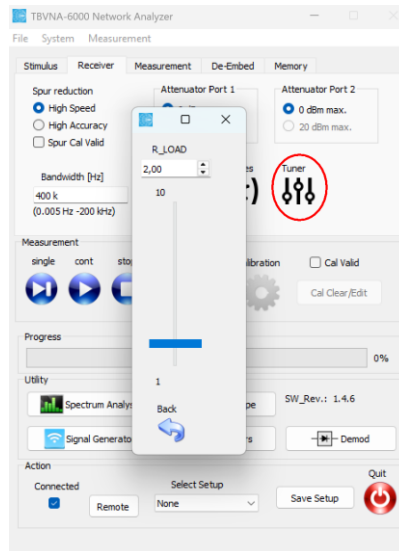


Fig. 4.32: R_{LOAD} tuner

Now the Load resistance can be set conveniently by entering its value or shifting the slider. The effect can be immediately observed in the diagram.

For frequent use, the whole setting may be saved to the file menu.

4.6 Conclusion

As shown throughout this application note, the **TBVNA Bode Mode** is a versatile and powerful measurement tool when used correctly. The programmable sweep list, normalization, user-defined equations, and tunable variables allow for customized and precise measurements across a wide range of applications.

By performing the required calculations and corrections within the instrument, the need for cumbersome external post-processing tools is significantly reduced or eliminated, resulting in a faster and more efficient measurement workflow.

| Version | Date | Author | Changes |
|---------|----------|----------------------|--------------------------|
| V 1.0 | 7.7.2026 | Hofbauer, Mayerhofer | Creation of the document |
| | | | |