

Power Added Efficiency Measurement with R&S®ZNB/ R&S®ZVA

Application Note

Products:

- | R&S®ZNB
- | R&S®ZVA

Power Added Efficiency (PAE) is a key parameter for the characterization of an amplifier.

This application notes introduces two alternative methods how to do the Power Added Efficiency measurement. The first one is based on the R&S®ZNB vector network analyzer (VNA) measurement function. Alternatively to this, the PAE tracer macro is introduced. This macro offers to make the PAE at an user selected compression point of the amplifier versus frequency.

The PAE tracer macro is provided together with this application note.

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1 Introduction

Besides the four s-parameters, hot-s22 and stability, the Power Added Efficiency (PAE) is a key value for an amplifier which represents how efficient the amplifier converts DC energy to RF energy.

A common definition of PAE is:

$$\text{PAE (in percentage)} = \frac{\text{RF Power}_{\text{out}} - \text{RF Power}_{\text{in}}}{\text{DC Power}} * 100\%$$

The objective of the PAE measurement is to find the point where the amplifier has its best efficiency. At this point, the ratio of the converted RF power with respect to the DC power is maximum.

Beyond this point, the amplifier generates e.g. more heat and the efficiency droops. Below the maximum PAE, the amplifier is still very linear.

In particular for mobile microwave applications like cell phones, there is a strong demand to extend the battery life time. According to this market requirement, the RF design engineer has to optimize the power amplifier to achieve a high efficiency. Mostly, the amplifiers have to be used closed to their 1dB compression point or even beyond.

The R&S®ZNB and R&S®ZVA vector network analyzers provide a PAE measurement function. Besides a DC power supply, this function requires an external high precision shunt resistor for the DC current measurement. These measurements are done by the VNA too.

This application note explains how to make a PAE measurement based on the measurement function of the Vector Network Analyzer with main focus on the R&S®ZNB.

Further on, the application note also comes with the PAE tracer that can be installed on the network analyzer. This macro supports besides the standard measurement types as the PAE measurement (PAE versus frequency sweep and PAE versus power sweep) the possibility to characterize the PAE at an user selected compression point versus frequency sweep of the amplifier.

2 PAE measurement

The PAE measurement can be done either directly with the DC measurement function on the R&S®ZNB / R&S®ZVA vector network analyzer or with the PAE tracer macro. The macro has to be installed first. A brief description how to do the installation can be found in chapter 3.

How to choose either the measurement function of the VNA or the PAE tracer macro depends on the requirement and the available hardware.

The PAE tracer macro provides the additional function to measure the PAE at an user selected compression point of the amplifier. This allows to characterize the amplifier on system level.

By using the PAE tracer macro, the DC voltage and DC current measurements are done by the power supply. Therefore, the DC power supply has to be a remote control unit. In the current version of the macro, the R&S®NGMO1/ R&S®NGMO2 power supplies are supported.

The measurement results will be displayed on the Graphical User Interface (GUI) and on the VNA screen as a memory trace. A continuously update of the PAE measurement results is therefore not possible.

By using the PAE measurement function of the R&S®ZNB / R&S®ZVA vector network analyzer supports the measurement based on the selected sweep mode of the VNA (frequency or power sweep mode). Further on, the measurement function provides a continuous update of the measurement results. This allows to verify the PAE measurement together with other important parameters of the amplifier like S21 and stability.

This PAE measurement function is based on the VNA's DC measurements. For the R&S®ZNB, the DC inputs option (R&S®ZNB-B81) is needed. The R&S®ZVA has the DC inputs already mounted on the basic unit, for this the corresponding cables (R&S®ZV-Z71) are needed. Additional, an external shunt resistor is needed for the R&S®ZNB and R&S®ZVA.

2.1 PAE measurement with R&S®ZNB firmware

The R&S®ZNB firmware provides the measurement function for the PAE. The function is available for the R&S®ZNB without any additional software option. For the DC measurement, the DC inputs are mandatory (hardware option: R&S®ZNB-B81). The DC input connectors are BNC – female.

2.1.1 PAE measurement function

The PAE measurement is based on the DC measurement function of the R&S®ZNB as shown in the picture below.

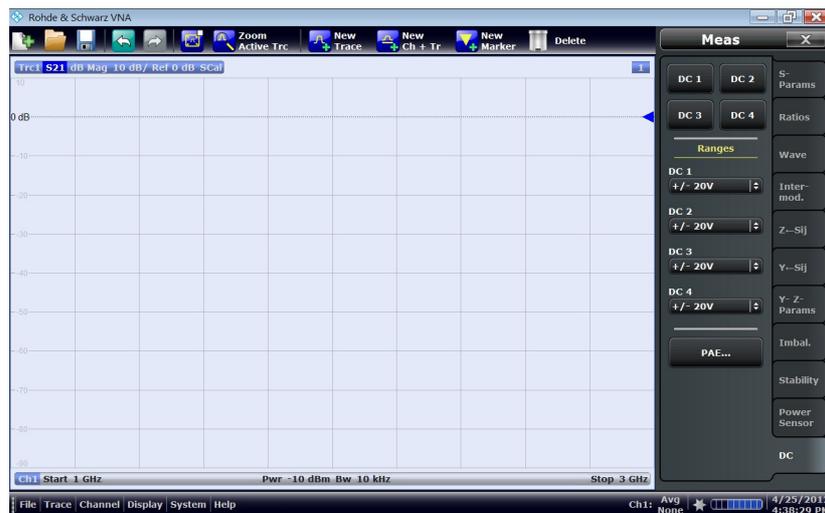


Figure 1: DC measurement function – screenshot R&S@ZNB

For making the PAE measurement, three different measurement types are available:

- **constant voltage source**, including DC current measurement by a shunt resistor
- **constant current source**, including DC voltage measurement
- **DC voltage source and DC current measurement**, (the DC current measurement is done by a shunt resistor)

The selection of the measurement type is depending on the available hardware and the behavior of the DUT (e.g. power consumption).

In most of the cases, the measurement type – DC voltage source, including DC current measurement by a shunt resistor – is preferred. Because, the DC current is measured as a voltage drop over the shunt resistor and the DC voltage at the DUT inputs is measured continuously. By this type, the voltage drop of the DC supply cables will be eliminated and the DC input voltage of the DUT is measured correctly. This is important to calculate the DC power correctly.

As shown in figure 2, the DC measurement provides a feature to select the voltage range according to the measurement set up of each DC inputs. This allows to optimize the DC voltage measurement accuracy.

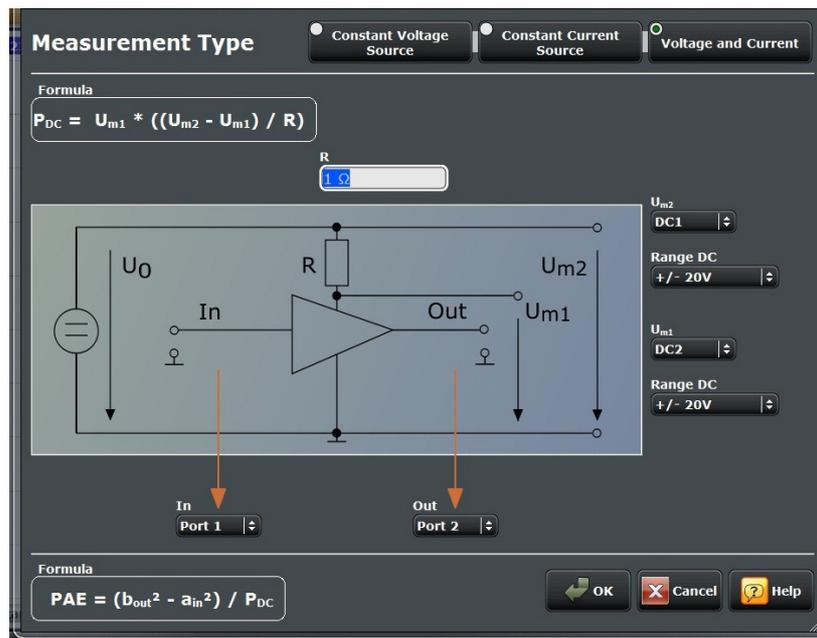


Figure 2: Measurement Type – variable voltage and current measurement

2.1.2 Making the PAE measurement with the Firmware function

The following example shows how to make the PAE measurement with the firmware function of the R&S@ZNB.

The DUT is a solid state amplifier from 1 GHz to 3 GHz.

For the measurement type, the DC voltage source including DC current measurement by a shunt resistor is chosen. The shunt resistor is 1 Ohm with 1% accuracy.

► Step 1: Measurement set up

The general VNA settings (start- and stop frequency, IF bandwidth, average factor, step attenuators...) have to be done.

► Step 2: Calibration

The calibration consists of a system error correction and a power calibration.

System error correction:

As standard system error correction calibration (e.g. UOSM, TOSM) has to be done at first.

Power calibration:

The measurements of the a1-wave (input power) and b2-wave (output power) of the DUT have to be done at absolute power levels. Therefore, the power calibration of the source port 1 including the a1 reference receiver and b2 measurement receiver of port 2 is required.

It is also recommended, that the Power Cal also includes a flatness calibration. In case that the power sweep (precise input power into the DUT) of the VNA is selected, the flatness calibration is mandatory.

Hint:

For the R&S@ZNB, the SMARTerCal combines the power correction calibration with the system error correction calibration automatically. After the SMARTerCAL, has been done, a source Power Cal including flatness cal should be done to get a flat input power at the DUT, because, the SMARTerCal is calibrating the reference receivers of the VNA correctly but does not include a flatness cal of the source. The SMARTerCal and the source Power Cal are standard features of the R&S@ZNB and can be selected on the CAL menu.

► Step 3: Connect the DUT

The DUT has to be connected to port 1 (DUT input) and port 2 (DUT output) to the VNA. Further on, the DUT has to be also connected to the power supply and to the DC inputs of the VNA as shown in the picture below. The DC inputs are ground-signal based.

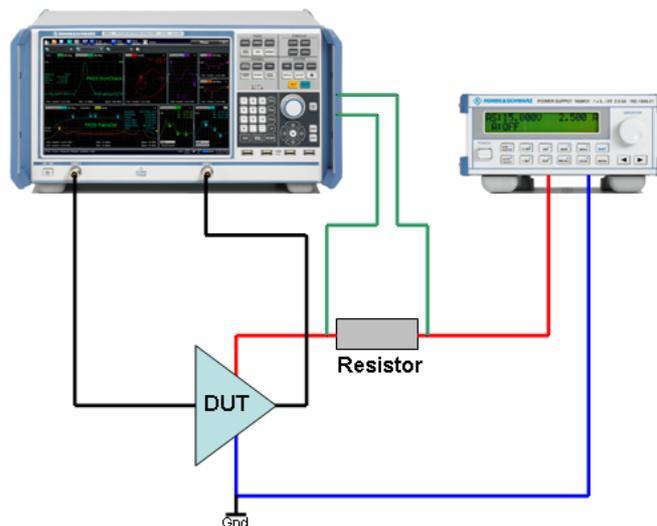


Figure 3: Set up of the PAE measurement with the DC function

Hint:

For the R&S@ZVA, the function of the SMARTerCal is not available as a separate calibration function. To achieve the same performance as the SMARTerCal, please perform a full two port calibration and afterwards a power calibration. In the next step the calibration option enhanced wave correction and load match correction have to be activated.

To compensate the mismatch error between the source port match and the input impedance of the DUT, a flatness cal based on reference receiver only should be done after connecting the DUT to the VNA.

► Step 4: Making the Measurements

After all settings are done, the measurement will be started by clicking on the *OK Button* in the measurement type menu. The VNA creates a new trace and displays the measurement result.



Figure 4: Measurement result of the PAE versus frequency based on DC function

2.2 PAE measurement with PAE tracer macro

The macro provides the capability to measure the PAE in two modes, either in a frequency sweep or in a power sweep. The settings for each sweep have to be done manually before starting the macro.

In both modes, port 1 of the VNA has to be connected to the DUT input and port 2 has to be connected to the DUT output.

A further function of the macro is to measure the PAE at a user selected compression point of the amplifier in frequency sweep. At this, the frequency sweep of the VNA has to be adjusted before. The macro validates on each frequency step if the selected compression is available. Therefore, the macro does a power sweep (from min to max power level) at each frequency step. In case that the compression can not be measured, the macro provides an error message. The min and max power level have to be entered into the GUI.

To measure the user selected compression point correctly and to avoid any damage of the DUT, the min and max level for the input power has to be added into the GUI.

Before the macro can be used, it has to be installed on the VNA. A brief description of the installation procedure can be found in chapter 3 of this application note.

2.2.1 PAE Tracer GUI

The PAE tracer macro starts with following graphical user interface:

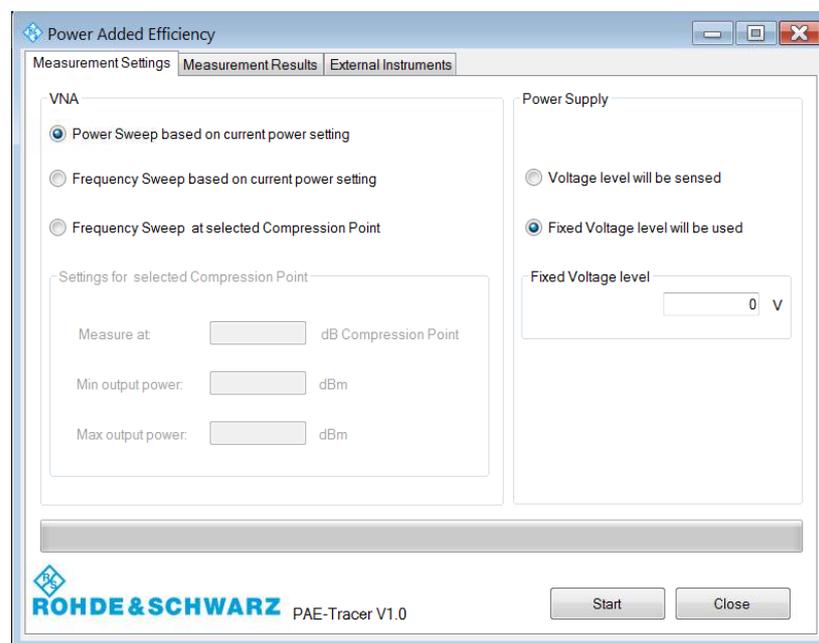


Figure 5: PAE tracer GUI – Tab Control - Measurement Settings

As shown in the picture below, at the tab *measurement setting*, the PAE measurement can be done at different modes:

- Power Sweep based on current power setting (a1 power level range)
- Frequency Sweep based on current power setting (a1 fixed level)
- Frequency Sweep at selected compression point

VNA

- Power Sweep based on current power setting
- Frequency Sweep based on current power setting
- Frequency Sweep at selected Compression Point

Settings for selected Compression Point

Measure at: dB Compression Point

Min output power: dBm

Max output power: dBm

Figure 6: Selection of the PAE measurement type

For the measurement type *Frequency Sweep at selected Compression Point*, the VNA varies the a1 input power into the DUT to measure the compression point for each frequency step first. In case that the compression point is not available within the selected power range, the macro provides an error message. In this case the power range has to be changed.

To achieve a correct result, the min level of the input power has to be in the linear area of the DUT.

For the remaining measurement types (*Power Sweep* and *Frequency Sweep*), the PAE measurement will be made according to the adjusted power and frequency settings of the VNA.

Power Supply

- Voltage level will be sensed
- Fixed Voltage level will be used

Fixed Voltage level V

Figure 7: Settings for Power Supply Measurement

For the calculation of the DC power, the DC current will be measured directly by the power supply. To compensate the DC voltage droop of the power supply cables to the DUT, the voltage at the DUT can either be sensed by the power supply or manually controlled.

In case that the DC voltage will be manually controlled, the target DC voltage level has to be entered in the GUI and the option box has to be selected.

Otherwise, the DC voltage will be sensed, the option box has to be selected and the macro reads out the voltage value of the power supply.

To prevent any damage of the DUT, the macro does not switch the DC power on or off. This has to be done manually.

At the tab *measurement results*, the PAE measurement results will be displayed. Besides this, the measurement results will be also displayed on the VNA screen.

At the tab *external instruments*, the address of the DC power supply and connection type have to be entered. The DC power supply has to be connected via LAN or GPIB to the VNA.

The macro expects that the corresponding NI-Visa drivers are installed on the VNA.

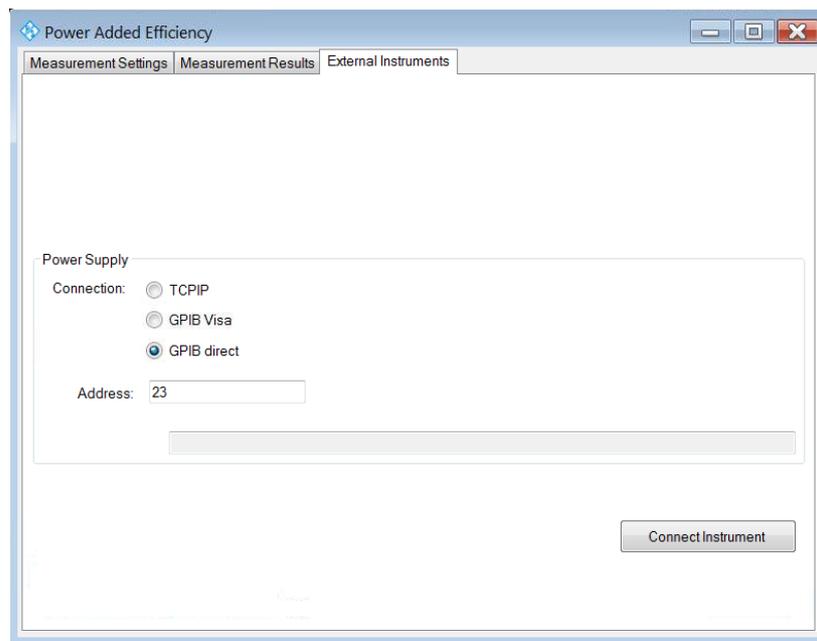


Figure 8: : PAE tracer GUI – Tab Control – External Instruments

2.2.2 Making PAE measurement with the PAE Tracer

In the following example, the PAE measurement will be done by using the PAE measurement type *Frequency Sweep at selected Compression Point*. The DC voltage level will be manually controlled.

The DUT is a solid state amplifier from 1 GHz to 3 GHz.

► Step 1: Measurement Set up:

The general VNA settings (start- and stop frequency, IF bandwidth, average factor, step attenuators...) have to be done.

► Step 2: Calibration:

The calibration can be divided into system error correction and power calibration.

System error correction:

A standard system error correction (e.g. UOSM, TOSM) has to be done first.

Power calibration:

The measurements of the a1-wave (input power) and b2-wave (output power) of the DUT have to be done at absolute power levels. Therefore, the power calibration of the source port 1 including the a1 reference receiver and b2 measurement receiver of port 2 is required.

Hint:

For the R&S®ZNB, the SMARTerCal combines the power correction calibration with the system error correction calibration automatically. After the SMARTerCAL, has been done, a source Power Cal including flatness cal should be done to get a flat input power at the DUT, because, the SMARTerCal is calibrating the reference receivers of the VNA correctly but not includes a flatness cal of the source. The SMARTerCal and the source Power Cal are standard features of the R&S®ZNB and can be selected on the CAL menu.

► Step 3: Connect the DUT

The DUT has to be connected to port 1 and port 2 of the VNA and to the DC power supply.

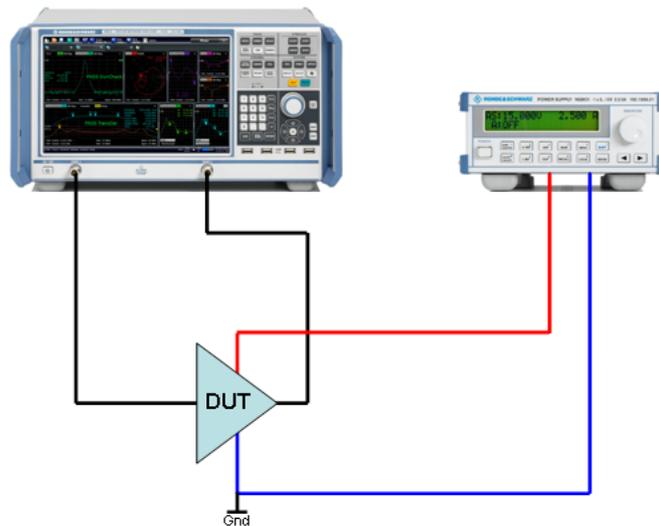


Figure 9: Set up of the PAE measurement with the macro

Further on, the DC power supply has to be connected by LAN or GPIB with the VNA.

► **Step 3: Enter the measurement settings into the PAE tracer GUI**

The settings for the minimum and maximum output power of the VNA and the selected compression point of the DUT have to be entered in the PAE tracer GUI. The compression point can be entered either as positive or negative value. (e.g. -0.1 or 0.1)

It has to be marked whether the voltage level will be manually controlled or sensed by the DC power supply.

In this example, the supply voltage of the DUT is 12V and will be manually controlled. This means, the entered value is the DC voltage at the DC inputs of the DUT. To compensate the voltage drop of the DC power cables, the DC output voltage has to be increased according to their losses. In this example around 0.03 V.

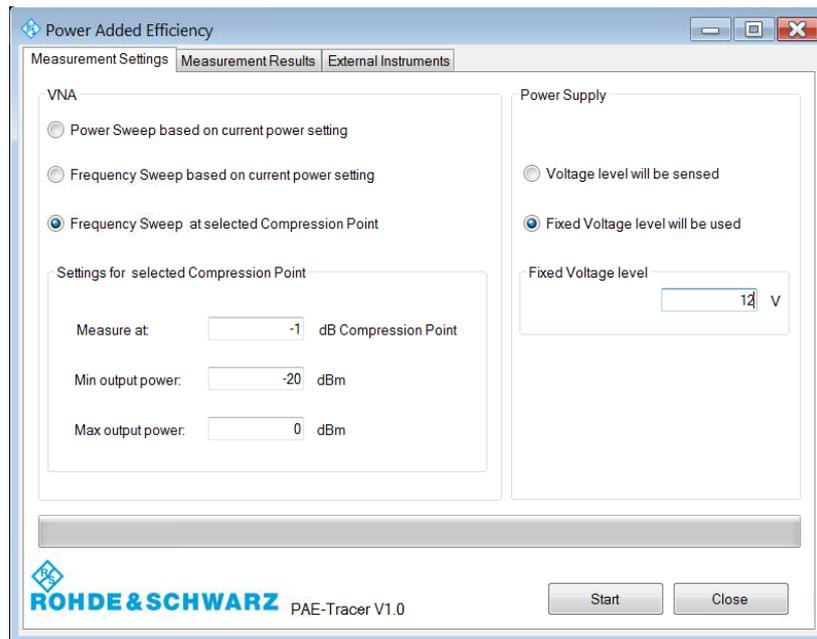


Figure 10: Enter measurement settings

► Step 4: Making the measurement

To connect the VNA with the DC power supply, the *Connect Instruments Button* in the *External Instruments* tab has to be pressed.

After a successful connection of the DC power supply to the VNA, the DC power supply replies its IDN-String and the background color of the *Connect Instrument* button turns to green color.

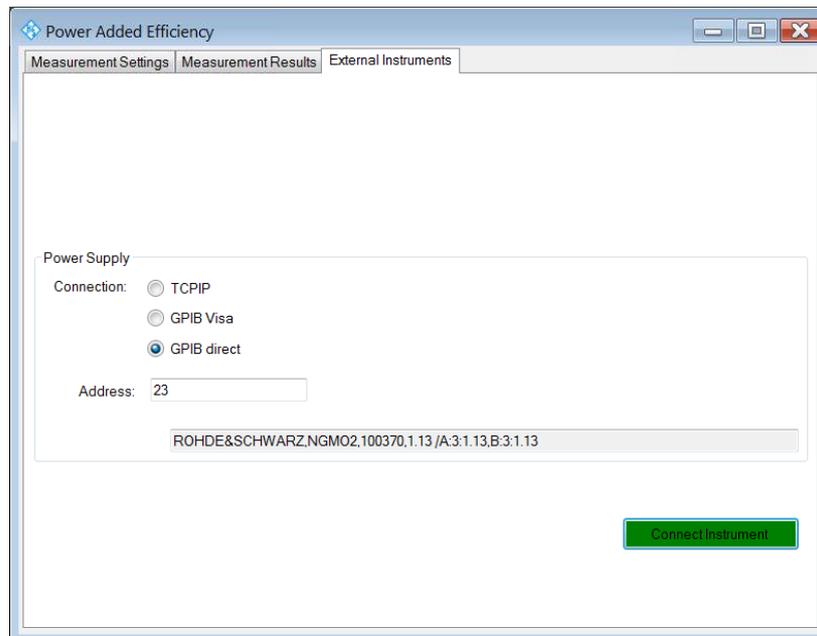


Figure 11: Connect external power supply

In the next step the measurement can be done by pressing the *Start Button* on the *Measurement Settings* tab.
The progress bar in the GUI shows the status of the measurement steps.

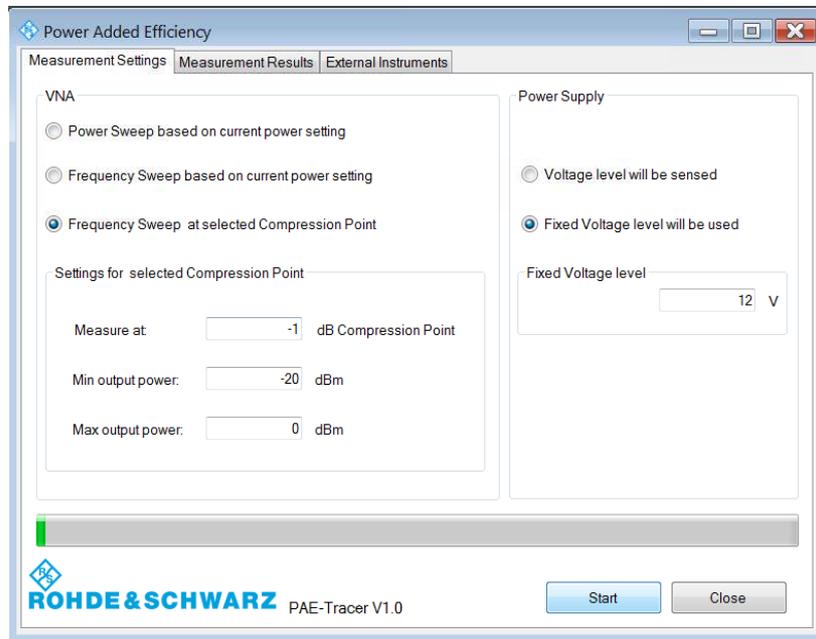


Figure 12: Making the PAE measurement

Below, the measurement results show the PAE vs. frequency at the 1dB compression point of the DUT.

The result is displayed in the *Measurement Results* tab. Further on, the result is also shown on the VNA screen directly.

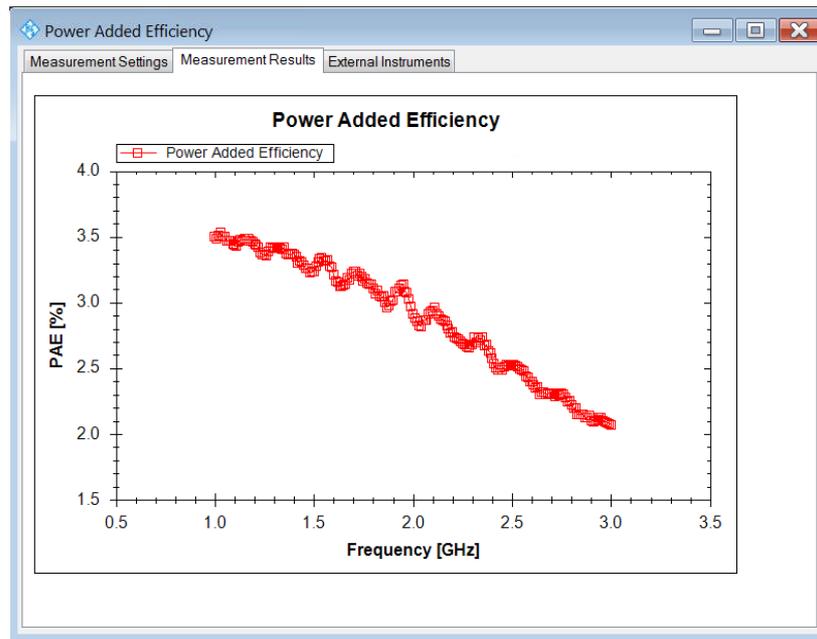


Figure 13: Measurement results

3 Installation of the PAE tracer macro

The macro is provided as a self-instructing file. During the installation, the procedure requests the target directory of the macro.

In case an application softkey button on the R&S@ZNB resp. external tool softkey on the R&S@ZVA shall be available, the macro has to be installed in the corresponding target folder of the VNA.

► **Target folder R&S@ZNB:**

\\Public\Public Documents\Rohde-Schwarz\VNA\External Tools\

► **Target folder R&S@ZVA:**

\\Rohde&Schwarz\NVA\External tools\

The software also creates an entry in the windows start menu where the macro can be started too.

The macro comes with this application note and is available at the Rohde & Schwarz web page: www.rohde-schwarz.com

4 Ordering Information

ZNB		
Basic Unit		
Product	Type	Order No.
Vector Network Analyzer, Two Ports, 4.5 GHz, N	R&S@ZNB4	1311.6010K22
Vector Network Analyzer, Four Ports 4.5 GHz, N	R&S@ZNB4	1311.6010K24
Vector Network Analyzer, Two Ports, 8.5 GHz, N	R&S@ZNB8	1311.6010K42
Vector Network Analyzer, Four Ports 8.5 GHz, N	R&S@ZNB8	1311.6010K44
Options		
Extended Power Range for Two-Port R&S@ZNB4	R&S@ZNB4-B22	1316.0210.02
Extended Power Range for Four-Port R&S@ZNB4	R&S@ZNB4-B24	1316.0233.02
Extended Power Range for Two-Port R&S@ZNB8	R&S@ZNB8-B22	1316.0227.02
Extended Power Range for Four-Port R&S@ZNB8	R&S@ZNB8-B24	1316.0240.02
Receiver Step Attenuator, Port 1, for R&S@ZN	R&S@ZNB4-B31	1316.0185.02
Receiver Step Attenuator, Port 2, for R&S@ZNB4	R&S@ZNB4-B32	1316.0179.02
Receiver Step Attenuator, Port 3, for R&S@ZNB4	R&S@ZNB4-B33	1316.0262.02
Receiver Step Attenuator, Port 4, for R&S@ZNB4	R&S@ZNB4-B34	1316.0433.02
Receiver Step Attenuator, Port 1, for R&S@ZNB8	R&S@ZNB8-B31	1316.0191.02
Receiver Step Attenuator, Port 2, for R&S@ZNB8	R&S@ZNB8-B32	1316.0204.02
Receiver Step Attenuator, Port 3, for R&S@ZNB8	R&S@ZNB8-B33	1316.0162.02
Receiver Step Attenuator, Port 4, for R&S@ZNB8	R&S@ZNB8-B34	1316.0440.02
GPIB Interface	R&S@ZNB-B10	1311.5995.02
DC Inputs	R&S@ZNB-B81	1316.0004.02

ZVA		
Basic Unit		
Product	Type	Order No.
Vector Network Analyzer, Two Ports, 8 GHz, N	R&S@ZVA8	1145.1110.08
Vector Network Analyzer, Four Ports, 8 GHz, N	R&S@ZVA8	1145.1110.10
Vector Network Analyzer, Two Ports, 24 GHz, 3.5 mm	R&S@ZVA24	1145.1110.24
Vector Network Analyzer, Four Ports, 24 GHz, 3.5 mm	R&S@ZVA24	1145.1110.26
Vector Network Analyzer, Two Ports, 40 GHz, 2.4 mm	R&S@ZVA40	1145.1110.43
Vector Network Analyzer, Two Ports, 40 GHz, 2.92 mm	R&S@ZVA40	1145.1110.40
Vector Network Analyzer, Four Ports, 40 GHz, 2.4 mm	R&S@ZVA40	1145.1110.45
Vector Network Analyzer, Four Ports, 40 GHz, 2.92 mm	R&S@ZVA40	1145.1110.42
Vector Network Analyzer, Two Ports, 50 GHz, 2.4 mm	R&S@ZVA50	1145.1110.50
Vector Network Analyzer, Four Ports, 50 GHz, 2.4 mm	R&S@ZVA50	1145.1110.52
Vector Network Analyzer, Two Ports, 67 GHz, 1.85 mm	R&S@ZVA67	1305.7002.02
Vector Network Analyzer, Four Ports, 67 GHz, 1.85 mm	R&S@ZVA67	1305.7002.04
Vector Network Analyzer, Two Ports, 80 GHz, 1 mm	R&S@ZVA80	1312.6750.02
Vector Network Analyzer, Two Ports, 80 GHz, 1 m	R&S@ZVA80	1312.6750.03
Vector Network Analyzer, Two Ports, 110 GHz, 1 mm	R&S@ZVA110	1312.7004.03

ZVA		
Options		
Receiver Step Attenuator, Port 1, for R&S@ZVA8	R&S@ZVA8-B31	1164.0044.02
Receiver Step Attenuator, Port 2, for R&S@ZVA8	R&S@ZVA8-B32	1164.0050.02
Receiver Step Attenuator, Port 3, for R&S@ZVA8	R&S@ZVA8-B33	1164.0067.02
Receiver Step Attenuator, Port 4, for R&S@ZVA8	R&S@ZVA8-B34	1164.0073.02
Receiver Step Attenuator, Port 1, for R&S@ZVA24	R&S@ZVA24-B31	1164.0144.02
Receiver Step Attenuator, Port 2, for R&S@ZVA24	R&S@ZVA24-B32	1164.0150.02
Receiver Step Attenuator, Port 3, for R&S@ZVA24	R&S@ZVA24-B33	1164.0167.02
Receiver Step Attenuator, Port 4, for R&S@ZVA24	R&S@ZVA24-B34	1164.0173.02
Receiver Step Attenuator, Port 1, for R&S@ZVA40	R&S@ZVA40-B31	1302.5444.02
Receiver Step Attenuator, Port 2, for R&S@ZVA40	R&S@ZVA40-B32	1302.5450.02
Receiver Step Attenuator, Port 3, for R&S@ZVA40	R&S@ZVA40-B33	1302.5467.02
Receiver Step Attenuator, Port 4, for R&S@ZVA40	R&S@ZVA40-B34	1302.5473.02
Receiver Step Attenuator, Port 1, for R&S@ZVA50	R&S@ZVA50-B31	1305.5716.02
Receiver Step Attenuator, Port 2, for R&S@ZVA50	R&S@ZVA50-B32	1305.5722.02
Receiver Step Attenuator, Port 3, for R&S@ZVA50	R&S@ZVA50-B33	1305.5739.02
Receiver Step Attenuator, Port 4, for R&S@ZVA50	R&S@ZVA50-B34	1305.5745.02
Receiver Step Attenuator, Port 1, for R&S@ZVA67	R&S@ZVA67-B31	1305.7119.02
Receiver Step Attenuator, Port 2, for R&S@ZVA67	R&S@ZVA67-B32	1305.7125.02
Receiver Step Attenuator, Port 3, for R&S@ZVA67	R&S@ZVA67-B33	1305.7131.02
Receiver Step Attenuator, Port 4, for R&S@ZVA67	R&S@ZVA67-B34	1305.7148.02
Cable for DC Input	R&S@ZV-Z71	1307.7400.02

NGMO		
Options		
Single Channel Power Supply	R&S@NGMO1	0192.1500.21
Dual Channel Power Supply	R&S@NGMO2	0192.150.24

About Rohde & Schwarz

Rohde & Schwarz is an independent group of companies specializing in electronics. It is a leading supplier of solutions in the fields of test and measurement, broadcasting, radiomonitoring and radiolocation, as well as secure communications. Established more than 75 years ago, Rohde & Schwarz has a global presence and a dedicated service network in over 70 countries. Company headquarters are in Munich, Germany.

Environmental commitment

- Energy-efficient products
- Continuous improvement in environmental sustainability
- ISO 14001-certified environmental management system



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