Product: Vector Network Analyzer R&S®ZVB

Performing Amplifier Measurements with the Vector Network Analyzer ZVB

Application Note

This document describes typical measurements that are required to be made on amplifiers and how the measurement can be implemented on the ZVB Vector Network Analyzer. The document describes the concepts and setups required to perform Gain, Isolation, input impedance measurements, then goes on to describe how more uncommon measurements are made with the ZVB like Harmonics, Stability Factor and compression point.

ROHDE&SCHWARZ

Subject to change – Jamie Lunn, 01.2007 – 1EZ54_0E

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1 Introduction

This document is designed to be a guide to help point the user in the right direction for configuring the ZVB Vector Network Analyzer to make important measurements on amplifiers.

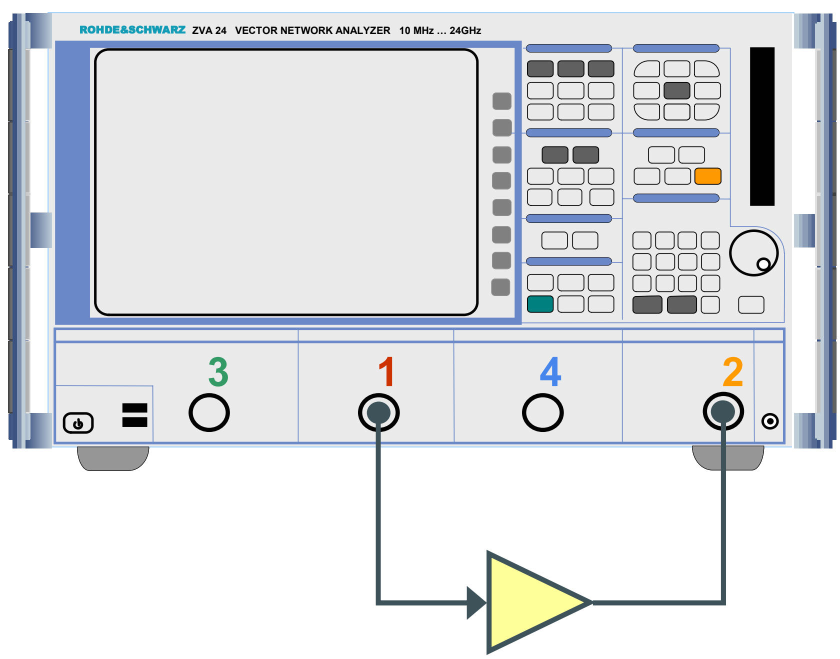
For further information please refer to the internal help of the ZVB [ ] or alternatively you can access the help online at the Rohde & Schwarz website,

http://www.rohde-schwarz.com/webhelp/zvb/start.htm

Text marked with grey highlight indicates either a dedicated button press on the front panel or a selection within the softkey menu at the side of the display.

2 Amplifier Measurement Configuration for ZVB

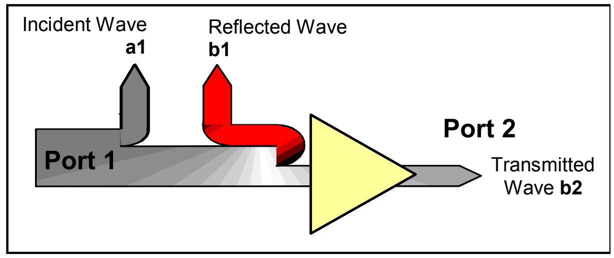
To characterize the 2-Port amplifier, the device should be connected directly to the test ports 1 and 2 of the ZVB, as indicated below.



3 S-Parameter Measurements

Perform a full 2-Port calibration (TOSM) by either using an appropriate manual calibration kit (e.g. R&S ZV-Z32) or using the R&S ZV-Z5x automatic calibration unit.

The ZVB is capable of characterizing the input of a device by measuring its input reflection coefficient. This is realized by an internal reflectometer on each test port that has a dedicated receiver for measuring both the incident power wave or *reference power* (**a1**) and also the reflected power wave or *measured power* (**b1**).



This measured parameter is displayed on the network analyzer as the *S-Parameter*, $\mathbf{S_{11}}$ which is the ratio of the *measured power* **b1** divided by the *reference power* **a1**:

$$\underline{s}_{11} = \frac{\underline{b}_1}{\underline{a}_1}\bigg|_{\underline{a}_2=0}$$

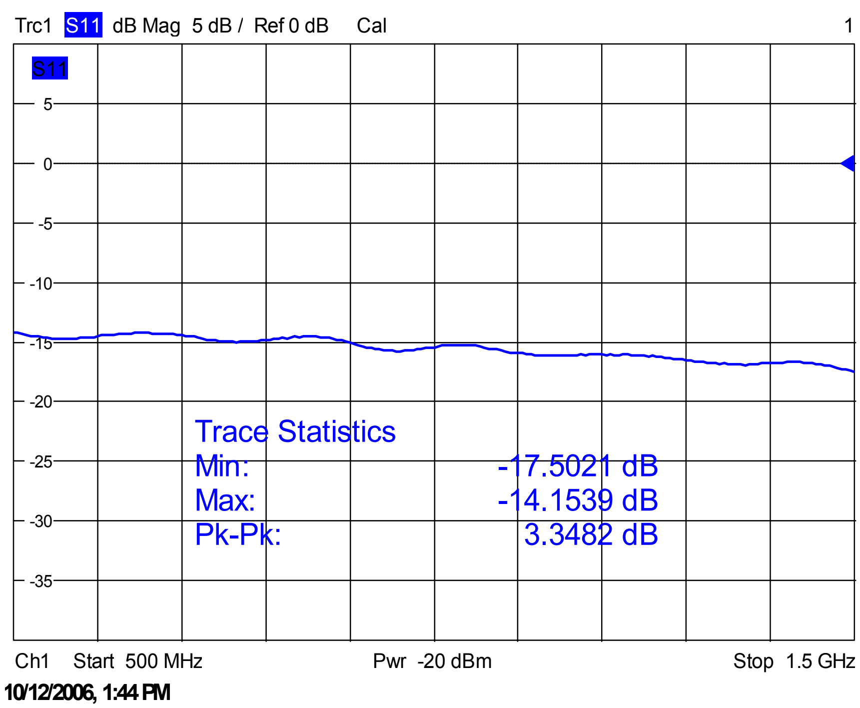
This *S-Parameter* is called the *reflection coefficient* Γ, the complex data from this measurement can be formatted in a number of different ways on the ZVB to display the desired result.

4 Input Reflection Parameters

The *input return* loss is calculated from the logarithmic value of the magnitude part of the *reflection coefficient* Γ.

$$\text{Return Loss} = -20\log\left(\rho\right) \qquad \rho = \left|\Gamma\right|$$

This can be displayed directly on the ZVB with a $\mathbf{S_{11}}$ trace formatted using the [dB Mag] selection within the [FORMAT] menu.



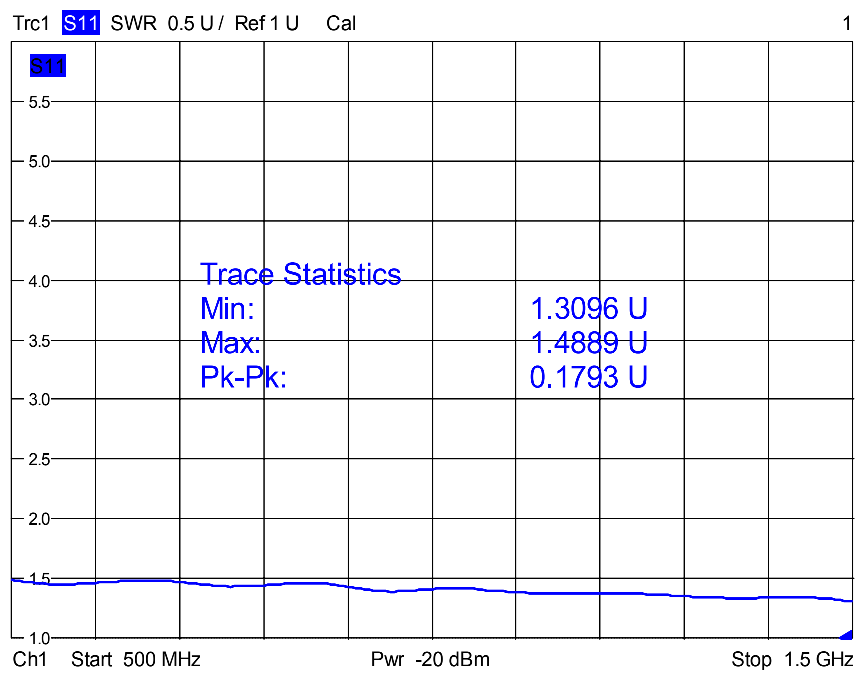
A nice feature of the ZVB is the ability to display the statistical analysis of a desired trace. This can be accessed in the [TRACE FUNCTION] x2 menu and then [Trace Statistics], within this menu you can then choose the required read-out (Min/Max/Peak-Peak etc).

*Hint, when using Trace Statistics you can define an evaluation range for which the analysis is to be performed, therefore giving the characteristics over a defined bandwidth.

The reflection coefficient can also be displayed in a **VSWR** format (**V**oltage **S**tanding **W**ave **R**atio or more commonly **SWR**). This is the ratio of the maximum to minimum values of the *standing wave* pattern that is created when signals are reflected on a transmission line.

$$\text{VSWR} = \frac{\text{Vmax}}{\text{Vmin}} = \frac{1+\rho}{1-\rho}$$

This can be displayed directly on the ZVB with a $\mathbf{S_{11}}$ trace formatted using the [SWR] selection within the [FORMAT] menu.



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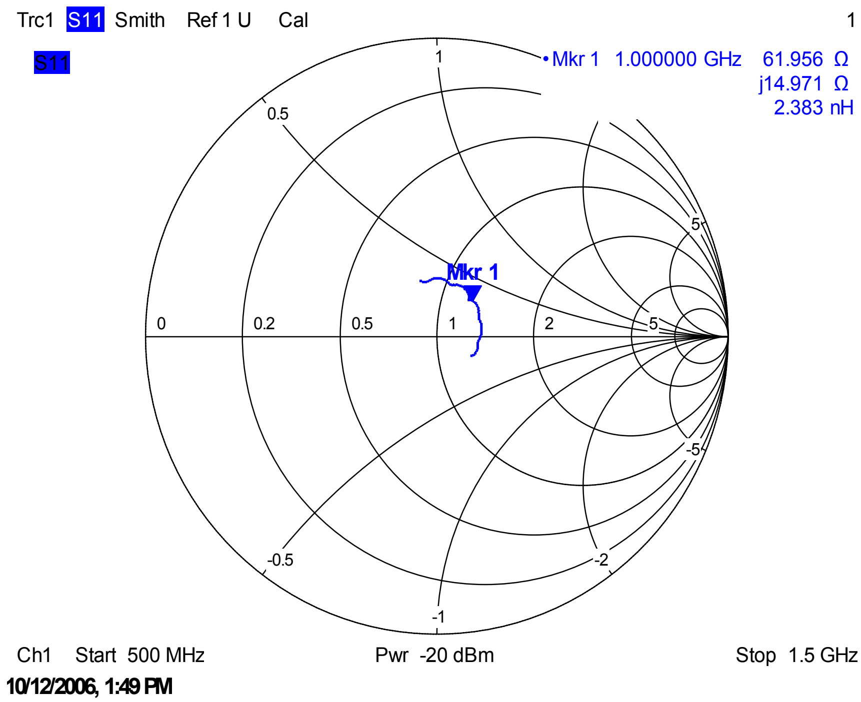
The reflection coefficient can also be displayed in a complex input impedance format that is mapped directly onto the smith chart. This can be accessed using the [Smith] selection within the [FORMAT] menu.



5 Transmission Parameters

In addition to reflection measurements, the forward transmission coefficient can be measured by referencing the transmitted power on the *measured power* (**b2**) receiver of Port 2 to the *reference power* (**a1**) receiver of Port 1.

$$\underline{s}_{21} = \left.\frac{\underline{b}_2}{\underline{a}_1}\right|_{\underline{a}_2=0}$$

The ratio of these parameters will give the *forward transmission coefficient* (**S_{21}**) which can be converted into the *transmission gain* by taking the logarithmic value of its magnitude:

$$\text{Gain (dB)} = 20\,\text{Log}\,|S_{21}|$$

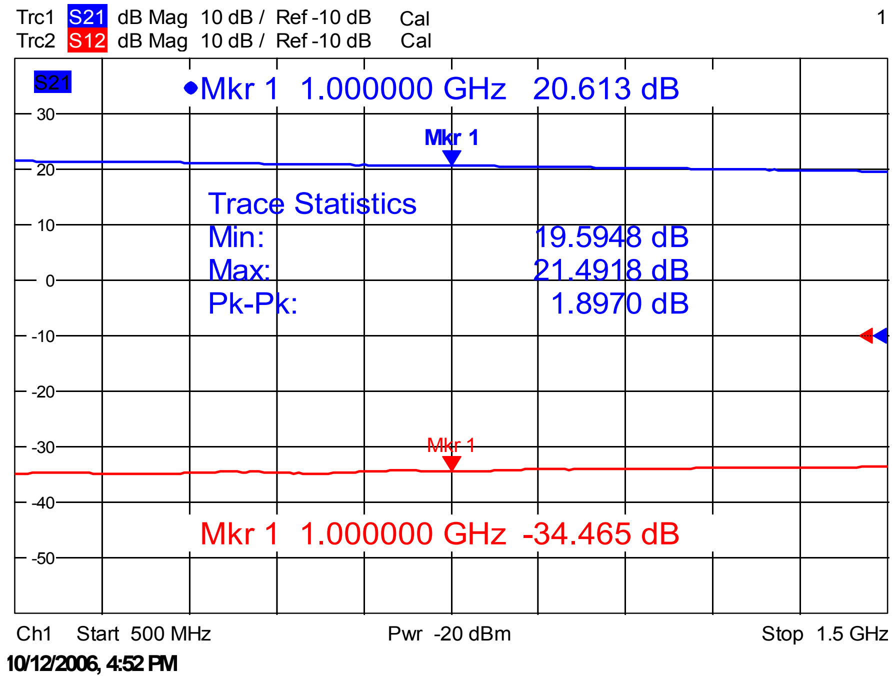
The ZVB is also capable of performing a reverse sweep measurement, so that the stimulus can be applied from Port 2 and the *reverse transmission coefficient* can be found, commonly known as the *isolation characteristics*.

$$\underline{s}_{12} = \left.\frac{\underline{b}_1}{\underline{a}_2}\right|_{\underline{a}_1=0}$$

The *reverse transmission coefficient* can be measured by referencing the transmitted power on the *measured power* (**b1**) receiver of Port 1, to the *reference power* (**a2**) receiver of Port 2.

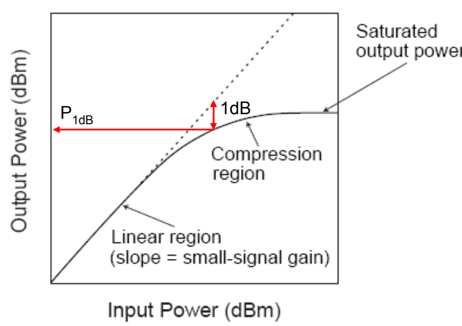
$$\text{Isolation (dB)} = -\,20\,\text{Log}\,|S_{12}|$$

Both the Gain and Isolation can be displayed directly on the ZVB using the relevant S-Parameters **S_{21}** & **S_{12}** and formatting these using the [dB Mag] selection within the [FORMAT] menu.

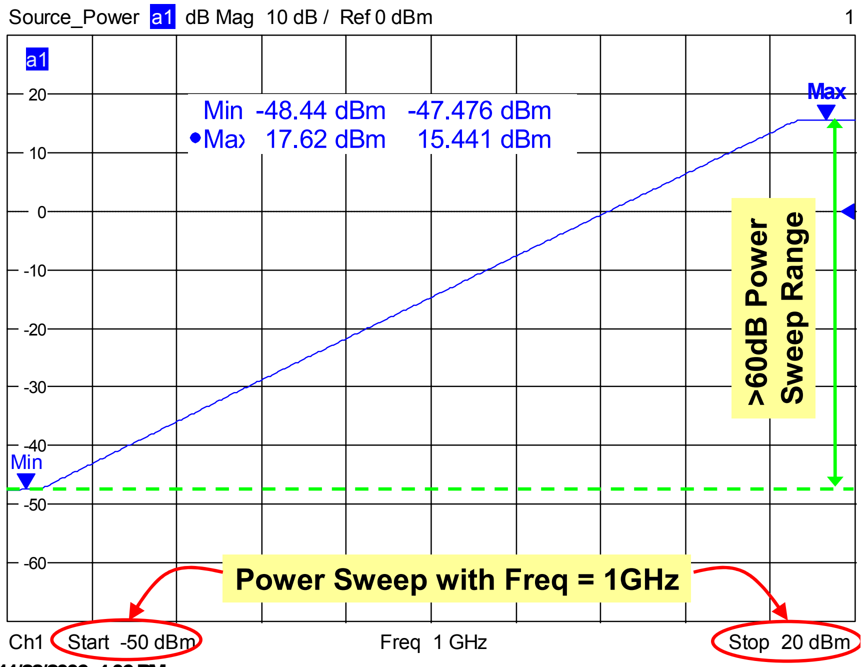


6 Compression Point

Compression point is a measure of linearity of a device. It is always defined at a specified value of which can be referenced to the input or the output power that is present at that device. For instance the 1dB compression point of an amplifier defines the output level at which the amplifier's gain is 1dB less than the small signal gain, or is compressed by 1dB.



On the ZVB it is possible to not only sweep the measurement versus frequency, but you can also choose power as the swept variable. The ZVB has a very large sweep range available from its generators (typically 60dB), it does this completely electronically without the need for mechanical step attenuators. This makes the ZVB the perfect instrument to measure non-linearities and compression of an active device.



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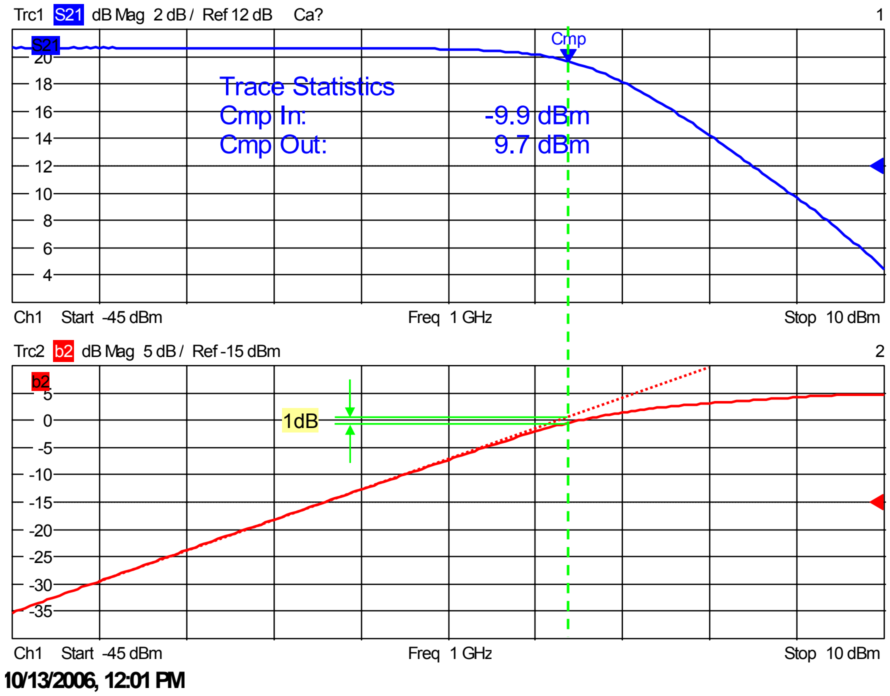
As the S-Parameter $\mathbf{S_{21}}$ is the ratio of the *output power* over *input power*, then this is precisely what is needed to be displayed on the ZVB.

$$\text{Compression } P_{1dB} = P_{out\,(\text{or in})} \ @\ Gain_{(\text{small signal})} - 1dB$$

By adding a second channel it is possible to perform a completely separate set of measurements, this new channel can be configured to perform a power sweep.

Pressing [CHAN SELECT] and [Add Channel + Trace + Diag Area] will create a new channel, then in the [Sweep] menu select [Power], and choose the fixed frequency at which the power is to be swept over.

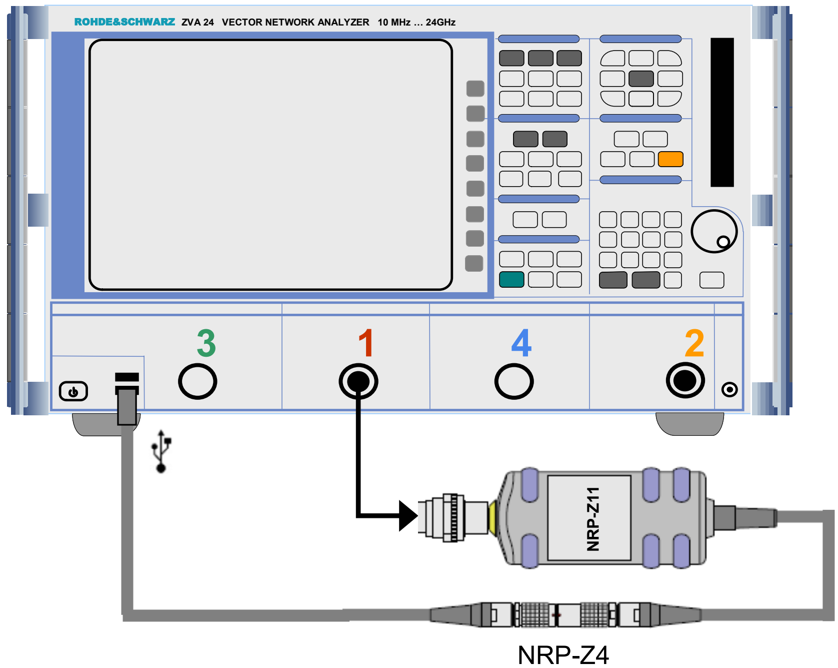
There is an automatic compression point marker available, this can be found be pressing [TRACE FUNCT] x2 and then choosing [Trace Statistics] and [Compression Point]



*Hint, to select more than one compression point value use additional channels with a power sweep at different fixed frequencies.

When performing absolute power measurements like compression point, it is important to have the correct power level feeding into the DUT, it is recommended to perform a *Power Calibration*. This can be performed easily with the R&S NRP power sensor and the NRP-Z4 USB cable connected directly to the ZVB, alternatively a SCPI compliant power meter connected to the IEEE bus may also be used if you have the ZVAB-B44 option (USB-GPIB converter).

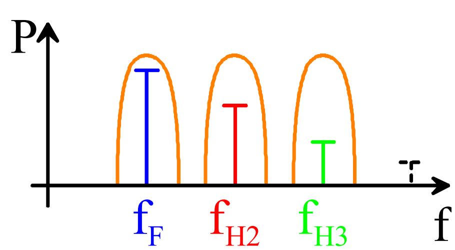
When the channel is configured correctly, select [CAL] and choose [Start Power Cal], you can then perform a [Source Power Cal] with the NRP power sensor connected directly to the end of the cable on Port 1. In addition, the receiver (and cable loss) on Port 2 can also be calibrated by simply connecting the '*calibrated*' source of Port 1 to the receiver of Port 2, this can be done using the [Receiver Power Cal].



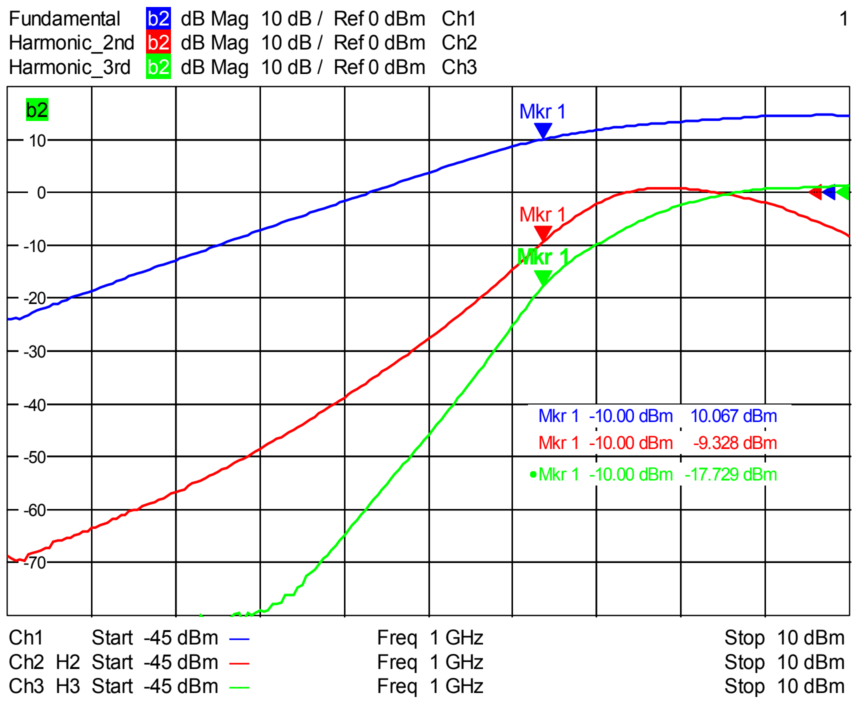
You can change the parameters that are used during the measurement sweep by the [Modify Settings] tab within the Power Cal menu. For more information on this and power calibration in general, please refer to the ZVB help.

7 Harmonic Measurements

Due to non-linearities in active devices as an amplifier moves out of its linear region and gets close to compression, distortion effects will start to become apparent. One of these distortion effects will manifest itself into power at the harmonics, i.e. additional frequency components at multiples of the fundamental frequency.



The flexible hardware concept of the ZVB makes it possible to introduce a frequency offset between the generators and the receivers of the instrument (requires ZVB-K3 option). This gives the ability to stimulate the device at the fundamental frequency and then measure the transmission response from the device at a different (multiples of) frequency.



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Create a new channel by pressing [CHAN SELECT] and [Add Channel + Trace + Diag Area], and now assign the traces containing the harmonic values to this channel. Select [MODE] and [Harmonics], then choose either 2nd Harmonic, 3rd Harmonic or another integer multiple of fo from the soft key menu. Multiple harmonic traces can be created by adding a new channel for each, [CHAN SELECT] and [Add Channel + Trace].

As with the Compression point measurement, it is important to calibrate the correct power levels at all of the harmonic frequencies to be measured on the reference receiver [**b2**] of Port 2. In the [MODE] menu select [Harmonics] and, [Harmonics Power Cal], it is then possible to calibrate the ZVB in much the same way as before.

8 Stability Factor

Amplifiers have the ability to become unstable at certain operating conditions. This can cause the device to start to oscillate, resulting in spurious frequencies to be produced at the output. Spurious frequencies are those that are not associated with or related to the fundamental frequency. Stability refers to the amplifiers ability to not produce any of these spurious oscillations.

The stability factor can be defined in a number of ways, the ZVB allows for three methods of stability factor to be calculated automatically, and are defined from the small signal 2 Port S-Parameters of the device.

A linear circuit is said to be *unconditionally stable* if no combination of passive source or load can cause the circuit to oscillate. *Conditionally stable* refers to a circuit that is stable when its input and output impedance are matched to the correct impedance, but under mismatch conditions their may a combination of input and output impedance that causes the device to oscillate. The stability factors K, μ_1 and μ_2 are real functions of the (complex) S-parameters, defined as follows:

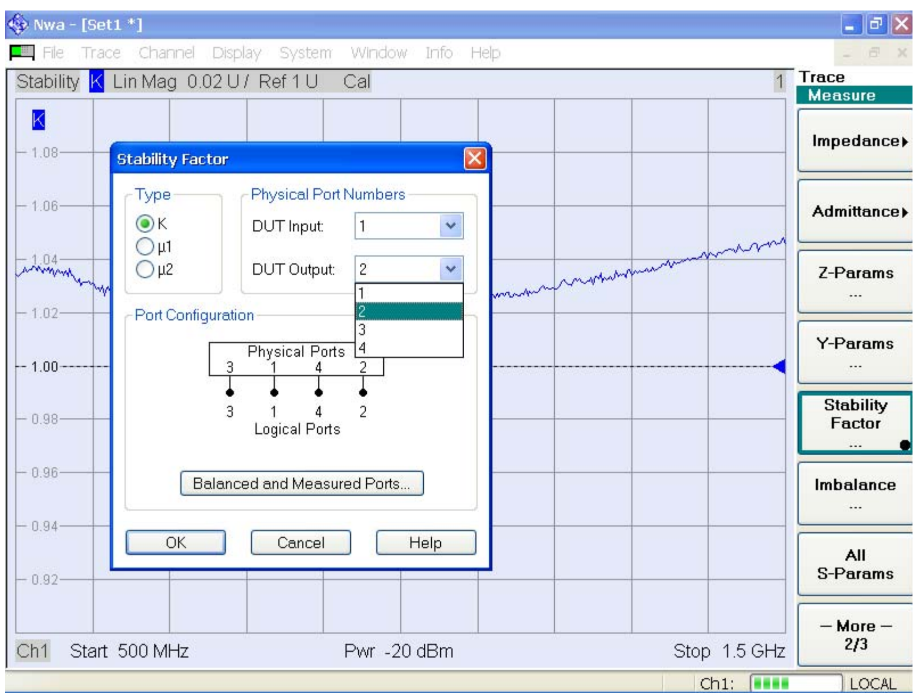
$$K := \frac{1-|S_{11}|^2-|S_{22}|^2+|S_{11}\cdot S_{22}-S_{12}\cdot S_{21}|^2}{2\cdot|S_{12}\cdot S_{21}|}$$

$$\mu_1 := \frac{1-|S_{11}|^2}{|S_{22}-\overline{S_{11}}\cdot(S_{11}\cdot S_{22}-S_{12}\cdot S_{21})|+|S_{12}\cdot S_{21}|}$$

$$\mu_2 := \frac{1-|S_{22}|^2}{|S_{11}-\overline{S_{22}}\cdot(S_{11}\cdot S_{22}-S_{12}\cdot S_{21})|+|S_{12}\cdot S_{21}|}$$

where $\overline{S_{xx}}$ denotes the complex conjugate of S_{xx}.

- The K-factor provides a necessary condition for unconditional stability: A circuit is unconditionally stable if K>1 and an additional condition is met. The additional condition can be tested by means of the stability factors μ1 and μ2.
- The μ1 and μ2 factors both provide a necessary and sufficient condition for unconditional stability: The conditions μ1>1 or μ2>1 are both equivalent to unconditional stability. This means that μ1 and μ2 provide direct insight into the degree of stability or potential instability of linear circuits.



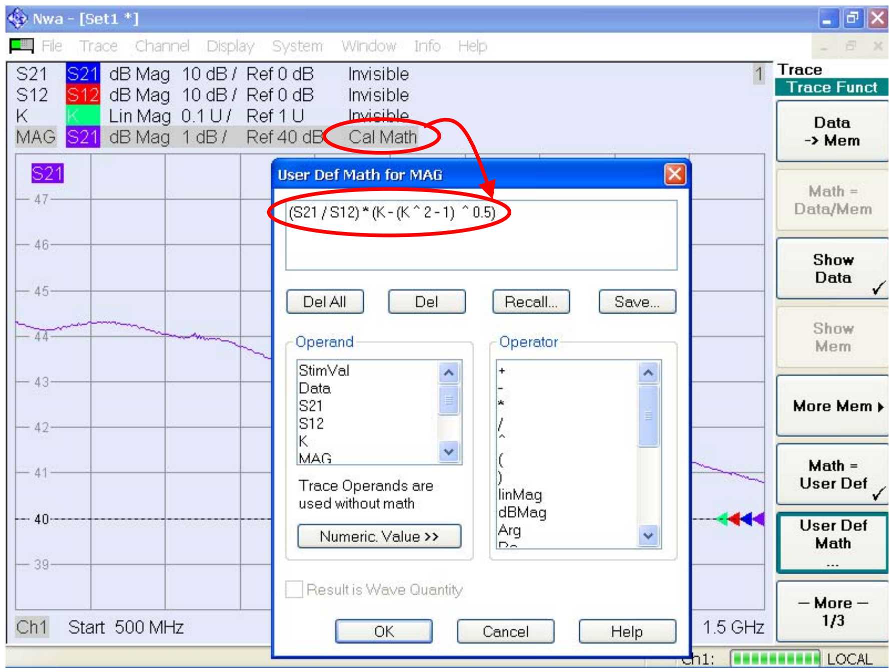
9 User Definition of Measurements

The ZVB has a very powerful equation editor allowing the user to configure almost any arbitrary formula for further processing of data. Even very complex derived quantities are displayed in real time along with the standard S-Parameters.

One possible use for this could be to measure the *Maximum Available Gain* (MAG) from a device when the K factor is greater than 1.

$$MAG = \frac{S_{21}}{S_{12}}\left(K - \sqrt{K^2 - 1}\right)$$

A dedicated trace can be configured to display the required user defined math function as shown, below.



The math editor can be found in the [TRACE FUNCT] menu and then [User Def Math]

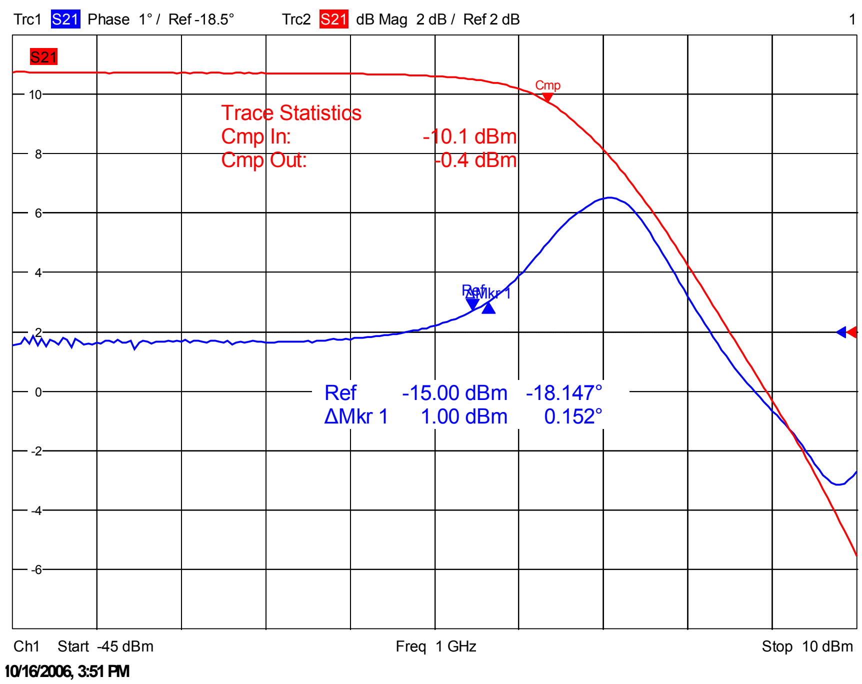
10 AM to PM Conversion Measurement

Measurements of *Amplitude Modulation* to *Phase Modulation* are characteristics of non-linear behavior of amplifiers. They give a measure of the unwanted phase distortion that may occur in an amplitude varying system.

AM to PM conversion is defined as the change in output phase for a 1 dB increment in the input power to the amplifier, which is expressed in degrees/dB.

The AM to PM conversion can be measured easily on the ZVB by using the power sweep mode. As before when configuring the compression measurement press [CHAN SELECT] and [Add Channel + Trace] create a new channel, then in the [Sweep] menu select [Power], and choose the fixed frequency at which the power is to be swept over.

You can then choose a point at which the amplifier is to be used and by using the delta marker select 1dB, and read off the value of phase change. In this case for -15dBm input power the AM to PM conversion is 0.15º/dB.



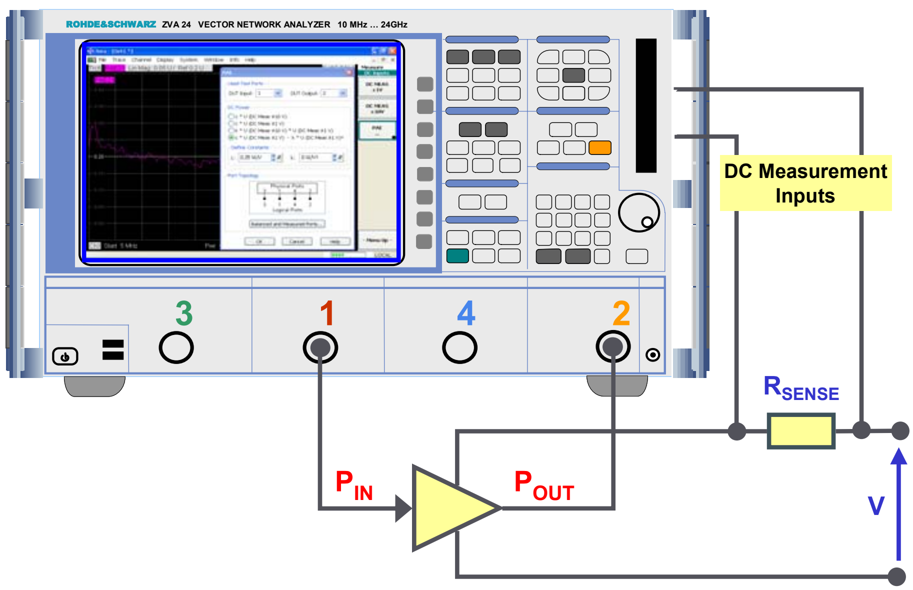
11 Power Added Efficiency

Another feature of the ZVB is the ability to measure DC voltages from the two DC Measurements inputs located at the rear of the instrument (±1V & ±10V ranges available). These inputs allow a DC voltage to be sampled and either displayed real-time on the ZVB or the result of DC quantities derived from the user-defined equation editor.

To complement this feature the ZVB also has a built-in function to allow the real time characterization of the Power Added Efficiency (PAE) of an amplifier. The PAE is defined as the ratio of the difference of the output and input signal to the DC power that the device is consuming:

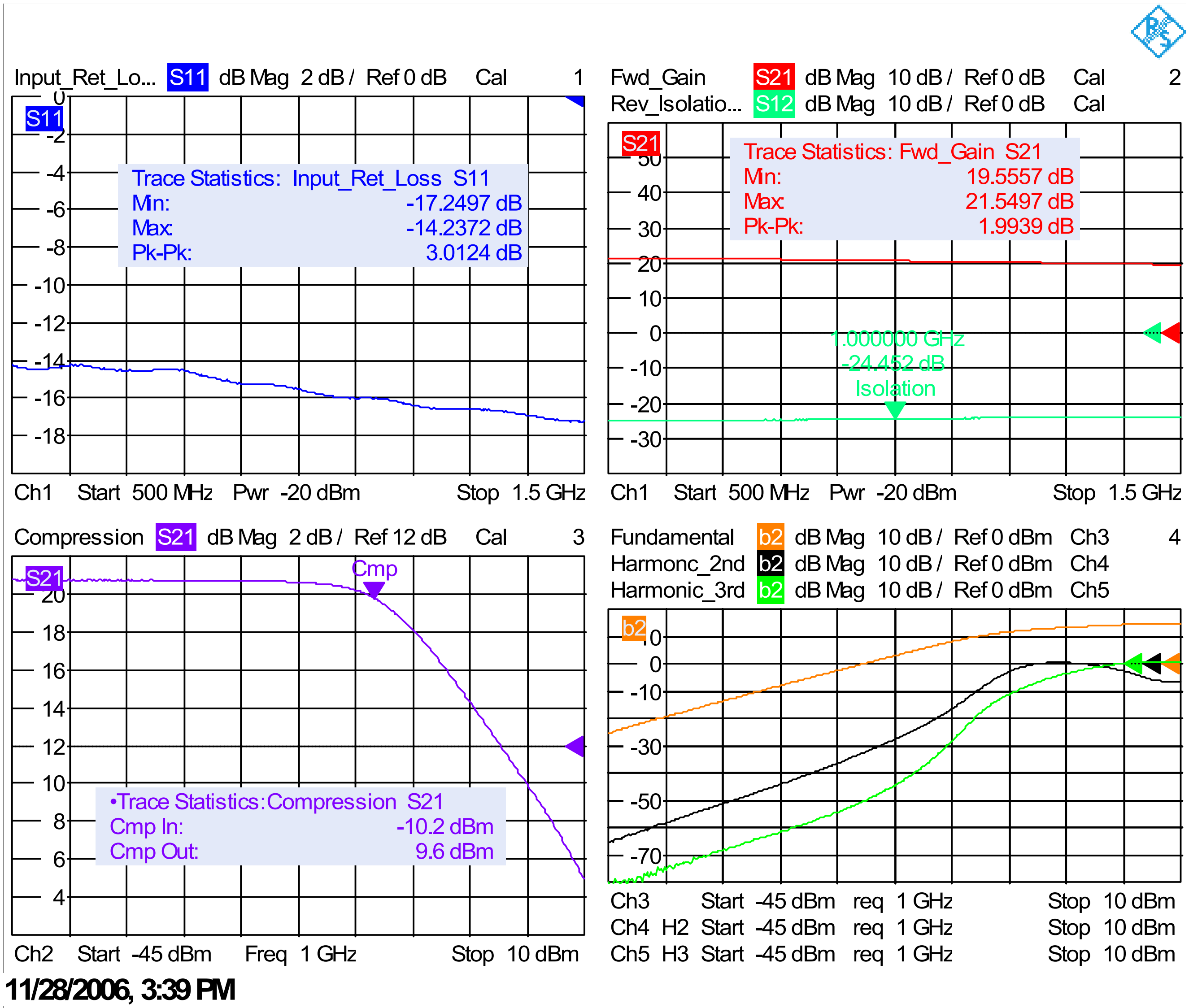
$$PAE = \frac{(P_{out(dB)} - P_{in(dB)})}{P_{DC}}$$

This feature can be accessed in the [MEAS] followed by [DC Meas] and [PAE].



Connection to the DC measurement inputs on the rear of the ZVB can be made with the optional ZV-Z71 cable.

12 Typical Set of Measurements…



13 Additional Information

This Application Note is updated from time to time. Please visit the website **1EZ54** to download the latest versions.

Please send any comments or suggestions about this application note to **sales@rsuk.rohde-schwarz.com**.

14 Ordering Information

Listed are all R&S ZVB network analyzers and most important options. Of course, accessories like test cables, or manual and automatic calibration kits are available in addition. There is also a wide variety of R&S NRP test heads for power measurement and power calibration. For details, please contact your local R&S sales office, or the R&S web site.

Order No.	Type	Designation
1145.1010.04	R&S ZVB4	Vector Network Analyzer, 2 Ports, 4 GHz
1145.1010.05	R&S ZVB4	Vector Network Analyzer, 3 Ports, 4 GHz
1145.1010.06	R&S ZVB4	Vector Network Analyzer, 4 Ports, 4 GHz
1145.1010.08	R&S ZVB8	Vector Network Analyzer, 2 Ports, 8 GHz
1145.1010.09	R&S ZVB8	Vector Network Analyzer, 3 Ports, 8 GHz
1145.1010.10	R&S ZVB8	Vector Network Analyzer, 4 Ports, 8 GHz
1145.1010.20	R&S ZVB20	Vector Network Analyzer, 2 Ports, 20 GHz
1145.1010.22	R&S ZVB20	Vector Network Analyzer, 4 Ports, 20 GHz
1164.1592.02	R&S ZVB-K3	Mixer and Harmonic Measurements
1302.5544.02	R&S ZVAB-B44	USB-to-IEC/GPIB Adapter
1161.8473.02	VISA I/O BIB.	Visa I/O library for instrument control

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