Noise Figure Measurement without a Noise Source on a Vector Network Analyzer
Application Note

Products:

| R&S®ZVA | | R&S®ZVAB-K30 |
| R&S®ZVT | | R&S®NRP-Z55 |

This application note describes the noise figure measurement using the R&S Vector Network Analyzers of the ZVA and ZVT series. It explains the concept of measuring noise figure without the need for a characterized noise source. Furthermore, it discusses different measurement applications and the respective setup and implications. Some examples guide through the instrument setups and show measurement results as well.

ROHDE & SCHWARZ

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1 ZVAB-K30 – Noise Figure Measurement

Noise figure measurements are one of the basic applications to be performed in the RF and µW world. The R&S network analyzer families R&S ZVA and R&S ZVT are able to cover these applications in a fast, accurate and easy way.
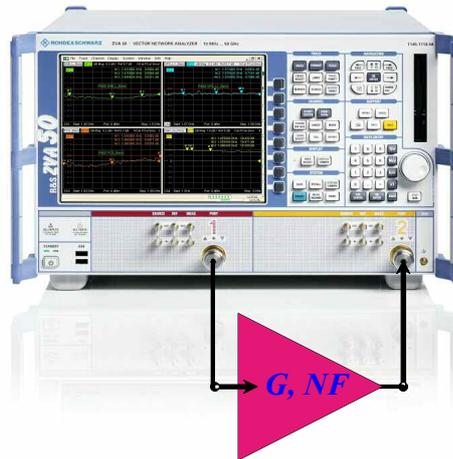
A new and smart method allows to measure noise figure with a Rohde & Schwarz vector network analyzer. The rather simple and straight forward approach requires neither an impedance tuner nor a calibrated noise source with a given ENR (Excess Noise Ratio). Instead, the technique uses the CW signal from the VNA source. Using different detectors it measures the 'signal' respectively and the 'signal + noise' output power of the DUT. Out of this information and based on the calibration results it calculates the noise figure of the device under test.

Due to the simple setup the method allows to measure the noise figure and for example the scattering matrix of the DUT in parallel using a single connection. That way a full characterization is possible without reconnecting the device.

1.1 Measurement Principle

1.1.1 Definition of the Noise Figure.

The noise factor F of a linear device is defined as the ratio of the signal to noise power ratios (SNR) at the input and output of the device, assuming a matched input source and ideal input noise power $N_0 = kT_0B$. The symbol $k = 1.3806 \cdot 10^{-23}\,\text{J/K}$ represents the Boltzmann constant, T_0 the device temperature and B the effective system bandwidth.

Although a more general definition of the noise figure is possible, which results in the definition of four noise parameters (F_{min}, R_N, G_{opt}, Phi_{opt}), this application note deals with the standard noise figure case.
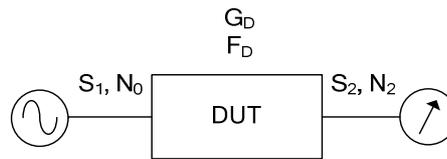
$$F_D = \frac{\dfrac{S_1}{N_0}}{\dfrac{S_2}{N_2}} = \frac{S_1 N_2}{S_2 N_0} = \frac{S_1 N_2}{S_1 G_D N_0} = \frac{N_2}{G_D N_0}$$

In the above equation S denotes the signal power and N the noise power. At the device under test (DUT) input according to the definition the noise power has to be equal to N_0. The gain G_D of the DUT is defined in the context of this application note as the power gain

$$G_D = \frac{S_2}{S_1} .$$

When expressing the noise factor in decibel the resulting quantity is called the noise figure NF. Because the noise factor is a ratio of power values, the conversion to dB is calculated as follows

$$NF_D = 10 \log(F_D) .$$

If the input noise is not equal to N_0 the noise factor can be calculated as follows.
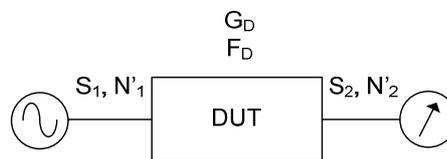
$$N_1' = N_0 + \Delta N$$
$$N_2' = N_2 + G_D \Delta N$$

$$F_D = \frac{N_2}{G_D N_0} = \frac{N_2' - G_D \Delta N}{G_D N_0} = \frac{N_2' - G_D (N_1' - N_0)}{G_D N_0} = \frac{N_2'}{G_D N_0} - \frac{N_1'}{N_0} + 1$$

1.1.2 AVG and RMS Detectors

The main step for noise figure measurement is to measure the gain of the DUT and the noise power at the output of the DUT generated by the DUT itself. Gain measurement is a basic task for a vector network analyzer. The challenge is to determine the noise power in the possible presence of a CW signal correctly.
Unlike the widely and commonly used approach of measuring the NF with the Y-Factor method utilizing a noise source with a given ENR the ZVAB-K30 works differently.

It measures the power of the CW-signal and determines the signal respectively the signal + noise power by calculating the average and the root mean square (rms) value of the DUT output signal within the bandwidth used by the VNA. The R&S ZVA and R&S ZVT use the digitized IF samples for this purpose.
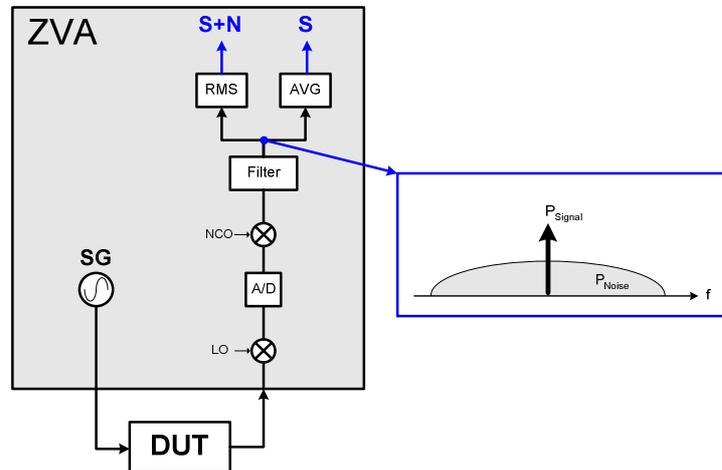
Given a sequence x_i of complex, filtered, measurement samples (voltages) the VNA calculates the average value x_{AVG} and the rms value x_{RMS} value of the samples

$$x_{AVG} = \frac{1}{M} \sum_{i=1}^{M} x_i \tag{1}$$

$$x_{RMS} = \sqrt{\frac{1}{M} \sum_{i=1}^{M} |x_i|^2} \tag{2}$$

The number of samples M is determined by the VNA from the measurement time set by the user. The averaging process can be regarded as a narrow filter, which extracts the CW carrier from the IF signal. By increasing the measuring time, and consequently the number of samples, the bandwidth of the filter narrows. The square of the average value represents the power of the CW signal, only.

The square of the rms value represents the power of the total signal, CW signal and the noise power, within the measurement bandwidth. By increasing the measurement time the variance of the power measurement decreases, yielding into a more stable power value. The noise power at the output of the DUT is the difference between the rms power and the average power.

The next section gives a more detailed explanation of the calculation.

1.1.3 Calculating the Noise Power out of AVG and RMS Detector Values

For a more detailed derivation we assume that the down converted, filtered, complex digital input signal is of the form

$$x_i = s + n_i \, .$$

Here s denotes the complex carrier amplitude and n_i the noise signal. The squared detector values will then result to

$$x_{RMS}{}^2 = \frac{1}{M} \sum_{i=1}^{M} |s + n_i|^2 = |s|^2 + \frac{1}{M} \sum_{i=1}^{M} |n_i|^2 + \frac{1}{M} \sum_{i=1}^{M} \left(s n_i^* + s^* n_i \right)$$

$$|x_{AVG}|^2 = \left| \frac{1}{M} \sum_{i=1}^{M} (s + n_i) \right|^2 = |s|^2 + \left| \frac{1}{M} \sum_{i=1}^{M} n_i \right|^2 + \frac{1}{M} \sum_{i=1}^{M} \left(s n_i^* + s^* n_i \right)$$

So the difference of the two squared detector values is

$$x_{RMS}{}^2 - |x_{AVG}|^2 = \frac{1}{M} \sum_{i=1}^{M} |n_i|^2 - \left| \frac{1}{M} \sum_{i=1}^{M} n_i \right|^2 \, . \tag{3}$$

The first term on the right hand side represents the mean power of the noise signal. As the average value of white noise in the RF or IF domain is zero, the second term rapidly converges to zero with large M.
The noise power N of the digital input signal is finally calculated by

$$N = \frac{1}{2R_L} \left(x_{RMS}{}^2 - |x_{AVG}|^2 \right) \tag{4}$$

whereas R_L represents the system impedance of 50Ω

The factor "2" is introduced in the above equation due to the single conversion concept without image rejection of network analyzers.
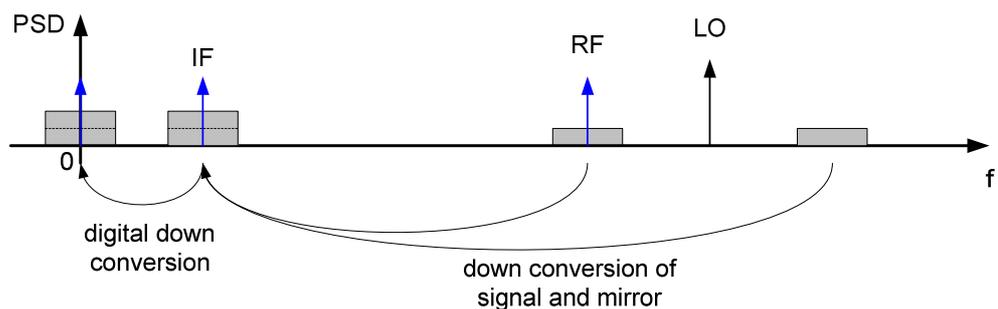
When down converting the RF signal to the intermediate frequency (IF) a double side band mixer is used. It converts both sidebands, the upper $f_{LO} + f_{IF}$ and the lower $f_{LO} - f_{IF}$, to the IF frequency. In the figure above the network analyzer source is operated in the lower side band. As there is no signal present in the upper side band this is not an issue for network analyzers. However, the noise of a device under test is present in both sidebands. So at the intermediate frequency the noise power of both side bands is added. Since the power calibration is performed on the signal power, the actual noise power in one sideband in RF domain is half of the noise power measured in the IF or base band domain. Prerequisite is that the noise power in the two sidebands is equal.

1.1.4 System Model

For the calculation of the noise figure of the DUT the following system model is used.
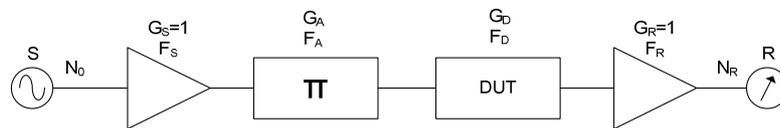
In the model the source (S) generator is assumed to be ideal, producing besides the CW signal only the theoretical noise power $N_0 = kT_0B$. The excess noise of the generator is modeled by an virtual amplifier with noise factor F_S. The non-ideal CW signal amplitude of the real generator is assumed to be compensated by a conventional source power calibration of the VNA, so the choice $G_S = 1$ is made for the virtual amplifier. The possible external attenuators or internal step attenuators (A) are characterized by their power gain $G_A < 1$ and noise figure $F_A = 1/G_A$.
The power gain G_D of the DUT is measured by the VNA in parallel to the noise measurement and the noise factor F_D is to be determined. The last element in the chain is the ideal receiver (R). Like with the source generator its non ideal noise properties are modeled by an amplifier noise factor F_R. Non ideal CW signal properties of the receiver are assumed to be compensated by a conventional receiver power calibration, so the choice $G_R = 1$ is made.

On the basis of the system model, the R&S ZVAB-K30 calculates the noise factor F_D of the DUT out of the measured noise power N_R, the measured DUT gain G_D and the system parameters G_A, F_R and F_S using the formula

$$F_D = \frac{N_R}{N_0 G_D} + (1 - F_S)G_A - \frac{F_R - 1}{G_D}.$$

The unknown parameters G_A, F_R and F_S of the system model are determined during the noise calibration procedure, described subsequently.

1.2 Recommended Equipment

For the R&S ZVAB-K30 noise figure measurement option, for the most flexibility and ease of use it is recommended to use a ZVA type network analyzer with direct receiver access option R&S ZVAxy-B16 and internal generator step attenuator option R&S ZVAxy-B2z.

If the network analyzer at hand does not have the direct receiver access option or internal step attenuators, the noise measurement with the ZVAB-K30 option is still possible and the general procedure stays the same, although several setup choices might not be possible or slightly different.

In order to simplify the subsequent noise figure setups only measurement ports with the direct receiver access connectors R&S ZVAxy-B16 are shown schematically as illustrated below.
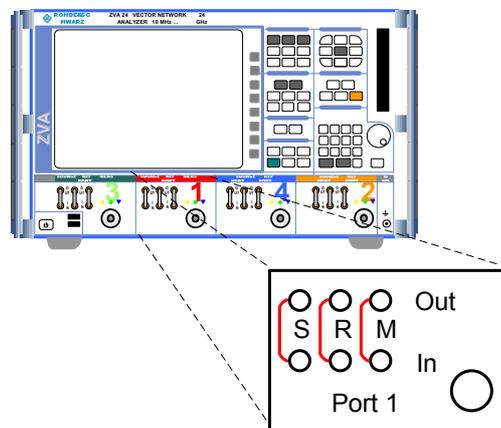
The direct receiver connectors are abbreviated as follows:

S	Source path
R	Receiver path
M	Meas path

For a better understanding of several setup options, the internal structure of the port and the connection of the step attenuator is shown in the figure below. In the drawing a backward directional coupler is assumed.
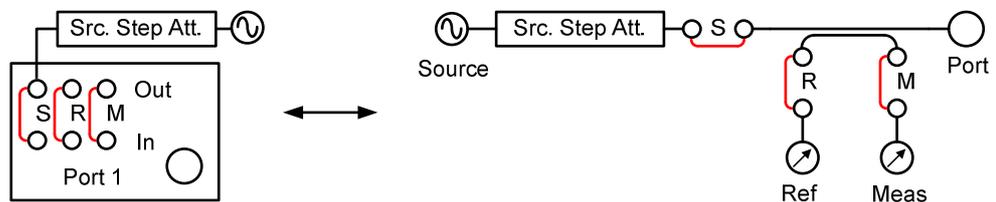
1.3 Measurement Setup Choices

For the noise figure measurement a large number of different setups is possible, depending on the properties of the DUT, the used vector network analyzer and the hardware options which are available on the instrument. The following figure and chapters give an overview of possible setup options which can also be combined in one or the other way in order to meet application requirements. A practical guide for choosing the right setup for the measurement task at hand is given afterwards in chapter 1.4.

Setup Option 1: Basic Configuration
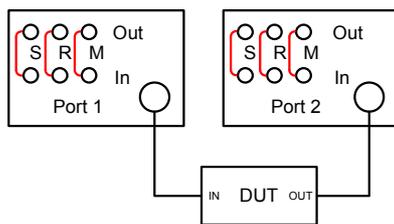
Setup Option 2: Source Step Attenuator
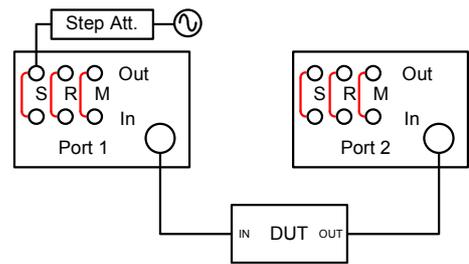
Setup Option 3: Additional External Attenuator
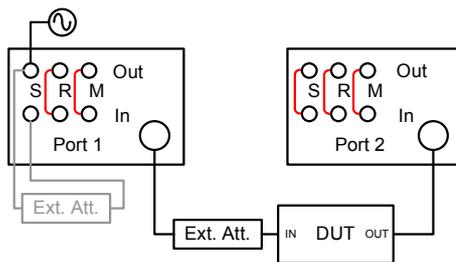
Setup Option 4: Direct Receiver Access
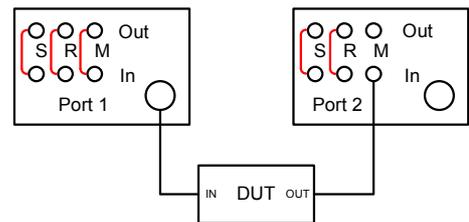
Setup Option 5: Pre-Amplifier in Meas Path
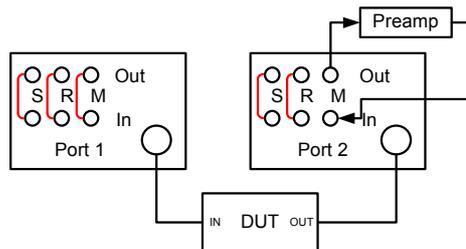
Setup Option 6: Pre-Amplifier in Front of Port
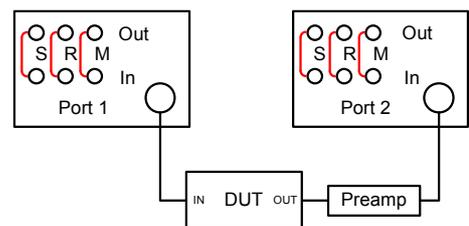
Setup Option 7: One Port Setup
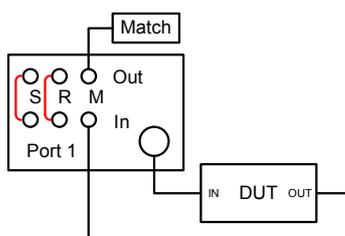
Setup Option 8: Increased Matching
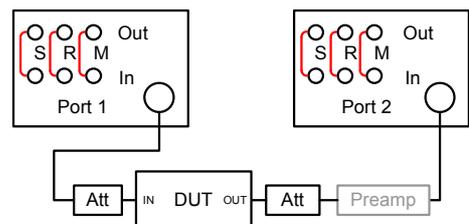
1.3.1 Basic Setup

In the simplest case the DUT is directly connected between two ports of the analyzer without any further components. Although this is the easiest setup the range of devices that can be measured is be limited. Usually additional attenuation in front of the DUT in order to reduce the input power and improve matching, or a preamp behind the DUT to reduce the receiver noise figure, is required.

1.3.2 Setup With Internal Step Attenuator Option

To keep the input power of the DUT below the allowed maximum value, in many cases additional attenuation is needed at the output of the generator due to a limited operating range of the electronic attenuators. In addition the use of the electronic attenuator increases the source noise for low output powers.
If the analyzer has the generator step attenuator option available, it should be the first choice to use the internal step attenuator due to the ease of use as well as to the previously discussed performance advantages.

1.3.3 Setup With Additional External Attenuator

If no internal step attenuator is available, an external one can be used as well but has to be considered during power calibration. If the direct receiver access option is available, the external attenuator can be connected in the source path, otherwise at the port connector. In both cases activate the checkbox "Additional External Attenuator" in the noise calibration dialog if the attenuator values are different between source noise calibration and DUT measurement.

1.3.4 Setup With Direct Receiver Access

In order to increase the sensitivity of the receiving port, the output of the DUT can be directly connected to the "Meas In" connector of the direct receiver access. By-passing the directional coupler results in an improved receiver noise figure of the network analyzer. The enhancement is in the same order as the coupling loss of the by-passed coupler. As a limitation of this setup only forward measurements are possible in this configuration.

1.3.5 Setup With Pre-Amplifier in Meas Path of Direct Receiver Access Option

For DUTs with a low gain and a low noise figure, the receive noise figure of the network analyzer might be too high to get accurate results. In this case an additional low noise pre-amplifier can be looped in the measurement receiver path of the instrument. As a rule of thumb, the sensitivity of the instrument is improved by the gain of the pre-amplifier. This configuration allows bidirectional measurements and to gather the full set of s-parameters from the DUT.

1.3.6 Setup With Pre-Amplifier in Front of the Receiving Port

If no direct receiver access option is available, the pre-amplifier has to be connected between the DUT and the receiving port. However, this setup only allows unidirectional measurements.

1.3.7 One Port Setup for Parallel Testing

If a direct receiver access option is available, the measurement of a DUT can be performed on a single analyzer port, thus enabling the parallel testing of four devices on a four port analyzer. However only unidirectional measurements are possible, which excludes for example system error corrected gain and match measurements.

1.3.8 Setup for Increased Matching

Noise figure measurements, especially for small noise figures, are sensitive to the mismatch between the analyzer ports and the DUT. This situation can be improved by placing additional matching pads at both sides of the DUT. The attenuators are part of the measurement setup and therefore have to be considered during the setup calibration process.

> **Application Hint:** If a source step attenuator option is available for the *receiving* port, it can additionally be used to increase the receiving port match by setting a attenuation value different from 0dB.

1.4 Practical Guide for Choosing the Setup

As discussed before, a vast variety of setup choices are supported for the noise measurement option R&S ZVAB-K30 in order to meet the engineers needs and requirements. After the brief overview of different setups, now a general procedure to select the right setup and settings, suitable for a given measurement task, is described.

1.4.1 Identify Relevant ZVA Specifications

In order to select an appropriate receiver setup, the receiver noise figure NF_R of the network analyzer and the 1 dB compression point P_{1dB} (designated $L_{P,1dB}$ if specified in dBm) needs to be known. Depending on the frequency range of interest and the network analyzer type, identify the two specifications out of Table 1 and Table 2.

Both tables are referring to different instruments (column "Devices") and are providing typical receiver noise figure values and the input compression point versus frequency for different inputs "Port" or "B16". The corresponding row has to be selected depending on whether the DUT output is connected to the "Port" connector or directly to the "Meas In" connector.

Typical ZVA/B Properties

Receiver Noise Figure NF_R over Frequency

Device	Input	4 GHz	8 GHz	12 GHz	16 GHz	20 GHz	24 GHz	28 GHz	32 GHz	36 GHz	40 GHz	44 GHz	50 GHz
ZVA8	Port	35	35										
	B16	23	23										
ZVA24	Port	42	42	42	45	45	45						
	B16	31	31	31	33	33	33						
ZVA40	Port	35	35	35	35	35	35	48	48	48	50		
	B16	28	28	28	28	28	28	38	38	38	38		
ZVA50	Port	35	35	35	35	35	35	48	48	48	50	53	53
	B16	28	28	28	28	28	28	38	38	38	38	40	40

Table 1: Typical ZVA/B Receiver Noise Figure.

Typical ZVA/B Properties

1 dB Compression Point

Device	Input	$L_{P,1dB}$
ZVA8	Port	10 dBm
	B16	-5 dBm
ZVA24	Port	6 dBm
	B16	-10 dBm
ZVA40,	Port	3 dBm
	B16	-10 dBm
ZVA50	Port	3 dBm
	B16	-10 dBm

Table 2: Typical ZVA/B receiver compression point values for devices with R&S ZVAxy-B16 and low noise IF gain.

The two tables are containing typical data, that in most cases is sufficient for selecting the correct setup. If more accurate values for the receiver noise figure F_R are desired, they can be obtained by performing a normal power and noise calibration for a standard setup without preamp as described in chapter 1.5. After the receiver noise calibration step, the exact receiver noise figure is shown in the diagram area of the "Noise Figure Calibration" dialog.

1.4.2 Receiver Setup and Preamp Decision

The decision on the receiver setup, including the need for a preamp, is based on the previously determined receiver noise factor F_R of the analyzer and the gain of the DUT G_D. In order to be able to measure the noise figure of the DUT, the noise created by the receiver itself may not shadow the noise that is created by the DUT .

The noise power at the input of the receiving port can be written as

$$N_R = N_S G_D + (F_D - 1)G_D N_0 + (F_R - 1)N_0 .$$

The first term represents the noise power from the source port, which in most cases can be neglected when high attenuator values are present. The second term is the noise generated by the DUT and the last term the unwanted noise from the receiving port. As stated above for accurate measurement results the receiver noise must not shadow the DUT noise, so the relation

$$(F_D - 1)G_D N_0 > C(F_R - 1)N_0$$

is obtained. The empirical factor C is of value 1/10. This says, that accurate measurement results can be obtained, even if the DUT noise is 10 dB below the receiver noise.
For fast practical calculations the relation can be simplified further. The value of F_R is usually much bigger than 1 and the term $(F_D - 1)$ is around 1 for typical DUTs. This results in the rule of thumb relation

$$F_R < 10 G_D$$

of if expressed in logarithmic quantities

$$NF_R < L_{G_D} + 10\,\text{dB} .$$

This inequality states, that the receiver noise figure should be at maximum 10 dB higher than the DUT gain. The relation is in the following abbreviated by the term "receiver noise figure" (RNF) relation. It is the basic relation for choosing the receiver setup.

As mentioned, the RNF relation is only a rule of thumb for the selection of the measurement setup, however suitable for the selection of most measurement setups. If necessary a more accurate analysis of the measurement error can be performed with the ZVAB-K30 Noise Figure Error Estimation Tool, discussed in chapter 2. The decision procedure, however, stays the same.

The available receiver setup options and the decision procedure to determine the right setup are shown in Figure 1 and Figure 2.

Receiver Setup Option 1

Receiver Setup Option 2

Receiver Setup Option 3

Receiver Setup Option 4
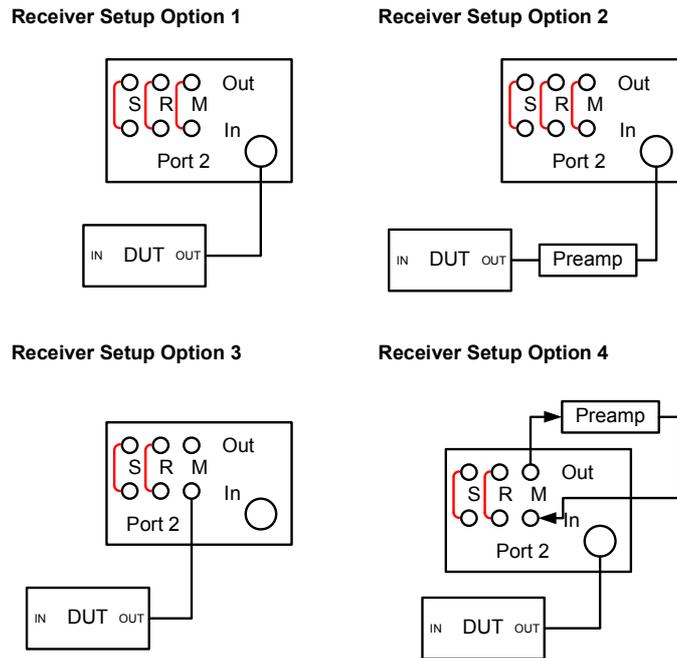
*Figure 1: Receiver Setup Options.*
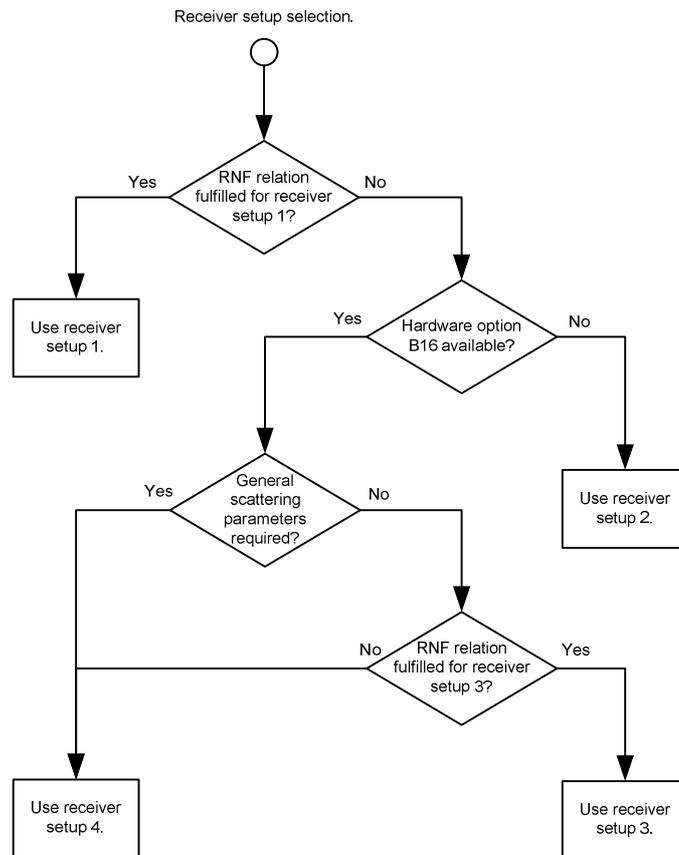
Figure 2: Decision Diagram for Choosing the Receiver Setup.

If the RNF relation is already valid for the case the DUT is directly connected to the receiver port, as shown in the receiver setup option 1, then this setup should be chosen. For this case choose the NF_R value for the "Port" case of Table 1.

If the inequality is not satisfied, then the next decision depends on whether the direct receiver access option R&S ZVAxy-B16 is available for the receiving port. If the option is not available, then a preamp is needed as shown in receiver setup option 2.

If the R&S ZVAxy-B16 option is available, then the next decision depends on whether general scattering parameter measurements (system error corrected gain and reflection measurements) are required in the same setup. If that is the case, then a preamp is required and has to be connected to the "Meas" path of the R&S ZVAxy-B16, as shown in receiver option 4.

If no system error corrected scattering parameter measurements are required and the RNF relation is satisfied with for the NF_R value for the "B16" case, the receiver setup option 3 can be used. The idea behind that setup is, that the receiver noise figure can be lowered by approximately 10 dB, when connecting the DUT directly to the measurement receiver avoiding the insertion loss of the directional coupler. If the inequality however is still not satisfied the receiver setup option 4 with preamp has to be used.

1.4.3 Preamp Selection

If a preamp is required in the setup, the gain $G_{\mathrm{Pr}e}$ and noise factor $F_{\mathrm{Pr}e}$ of the preamp has to be chosen, so that the effective receiver noise figure (of the preamp and receiving port) is satisfying the RNF relation. The effective receiver noise figure is calculated as

$$F_{R,\mathit{eff}} = F_{\mathrm{Pr}e} + \frac{F_R - 1}{G_{\mathrm{Pr}e}} .$$

To have a more simple relation, again some approximations can be made. Assuming

$$F_{R,\mathit{eff}} \approx \frac{F_R}{G_{\mathrm{Pr}e}}$$

The RNF relation for the preamp case is

$$\frac{F_R}{G_{\mathrm{Pr}e}} < 10 G_D$$

or

$$NF_R - L_{G_{\mathrm{Pr}e}} < L_{G_D} + 10\mathrm{dB} .$$

1.4.4 Attenuation Value

For setting the VNA source power it is recommended to use either the internal step attenuator or external ones. Using the internal *electronic* attenuator (via [Channel]→[Power Bandwidth Average]→[Power …]) will increase the generator noise figure. Hence the generator base power is typically set to 0 dBm.

The required attenuator value - internal step attenuator or external attenuator - can now be determined under consideration of the following conditions:

1. The input power at the DUT should be roughly 10 dB below it's 1 dB compression point (or maximum input power). So the attenuation should be higher than

$$A_1 = 10 \frac{1\text{mW}}{P_{1\text{dB,DUT}}} \, .$$

    The 1 dB compression point has to be entered in [W] in the above equation.
2. The input power at the preamp should be roughly 10 dB below it's 1 dB compression point (or maximum input power). So the attenuation should be higher than

$$A_2 = 10 \frac{1\text{mW}}{P_{1\text{dB,pre}}} G_D$$

    for receiver setup option 2 or

$$A_2 = 100 \frac{1\text{mW}}{P_{1\text{dB,pre}}} G_D$$

    for receiver setup option 4.
3. The input power at the network analyzer should be roughly 10 dB below it's 1 dB compression point obtained out of Table 2. So the attenuation should be higher than

$$A_3 = 10 \frac{1\text{mW}}{P_{1\text{dB,ZVA}}} G_D$$

    for receiver setup option 1, 3 and 4 or

$$A_3 = 10 \frac{1\text{mW}}{P_{1\text{dB,ZVA}}} G_D G_{\text{Pr}e}$$

    for receive setup option 2. For setup option 1, 2 and 4 select the 1 dB compression point out of the row with "Port" in column "Input" and for setup option 3 out of the row with "B16" in column "Input".

The attenuator value A_{DUT} for the actual measurement is obtained by choosing the maximum of the attenuator values A_1, A_2 and A_3. For selecting the attenuator value, always round up. The index DUT in A_{DUT} refers to the attenuator value used during the DUT measurement in contrast to possibly different values during specific calibration steps.

1.4.5 Generator Setup

The suitable generator setup depends on the hardware options available for the generator port. The generator setup options and the corresponding decision diagram is shown in Figure 3 and Figure 4.

If an internal step attenuator is available, it should be used as shown in generator setup option 1. The use of the internal step attenuators is always preferable because they are located in front of the directional coupler, hence the frequency response is measured with the a wave receiver, and basically due to the simplicity of use. That way the directivity of the port is not reduced as with external attenuators. This is especially important if the match of the DUT is to be measured in parallel to the noise figure.

If no internal step attenuator is available, but the direct receiver access option R&S ZVAxy-B16 is available, the external attenuator should be connected to the source path as shown in generator option 2.

Only then, in all other cases, the external attenuator should be connected directly in front of the DUT as shown in generator option 3.
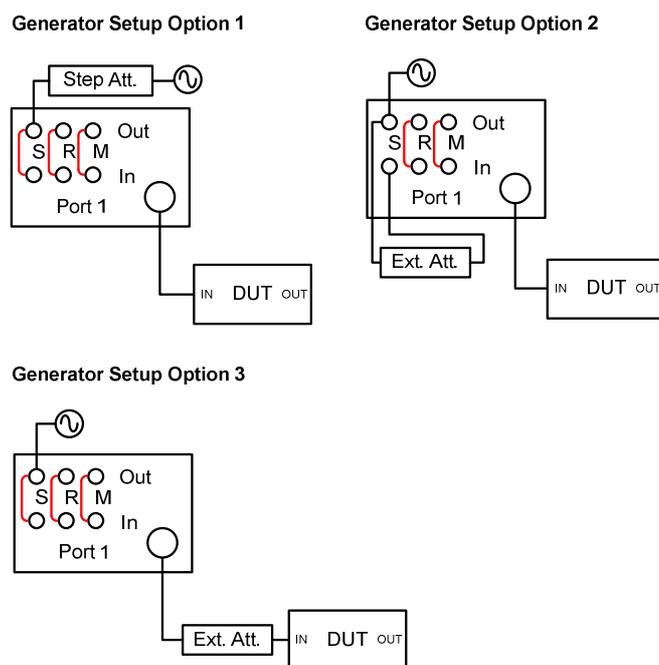
*Figure 3: Generator Setup Options.*
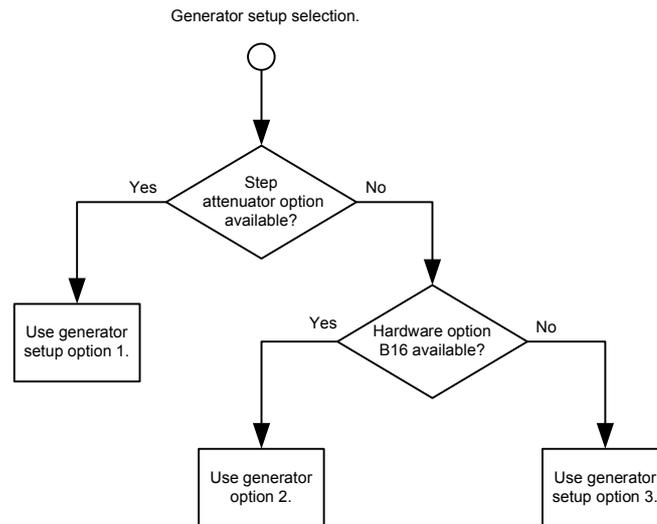
Figure 4: Decision Diagram for Selecting the Generator Setup.

1.5 General Noise Figure Measurement Configuration Steps

After the measurement setup has been determined, the configuration of a noise figure measurement using either a R&S ZVA or R&S ZVT follows the same basic pattern. However, some steps may differ dependent on specifics of the test setup and available options. This section gives an overview of the general procedure and explains general aspects to consider during the setup steps. Examples and variations for more specific setups are discussed in chapter 3.

For the following description of the noise measurement configuration a general measurement setup including attenuators and preamp as shown below is used.
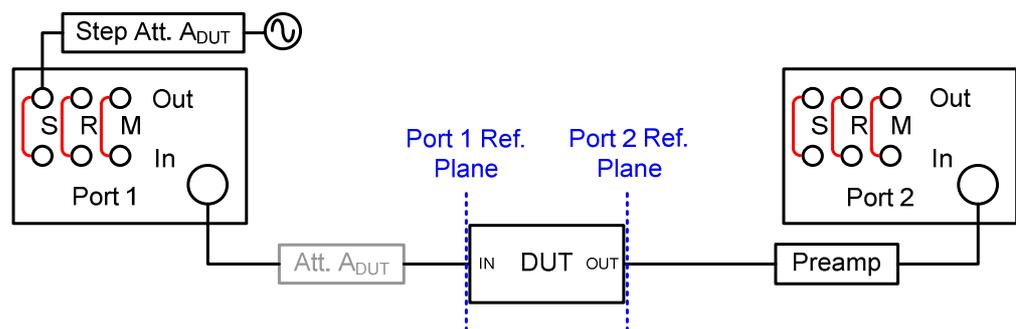

Either internal or external attenuators can be used, depending of their availability and measurement requirements, as discussed in chapter 1.4. However in order to simplify the following description, both internal and external attenuators are shown at the same time. Although uncommon, both types of attenuators could even be used at the same time. The source and receiver reference planes are always assumed to be at the in- and output of the DUT.

1.5.1   Step 1: Basic Configuration

Configure the basic measurement parameters as frequency range, number of points, et cetera. As discussed in chapter 1.4 set the channel base power to 0 dBm via [Channel]→[Power Bandwidth Average]→[Power …].

1.5.2   Step 2: Source Power Calibration

The source power calibration is only needed as a preparation step for the required receiver power calibration. The following block diagram illustrates the test setup.
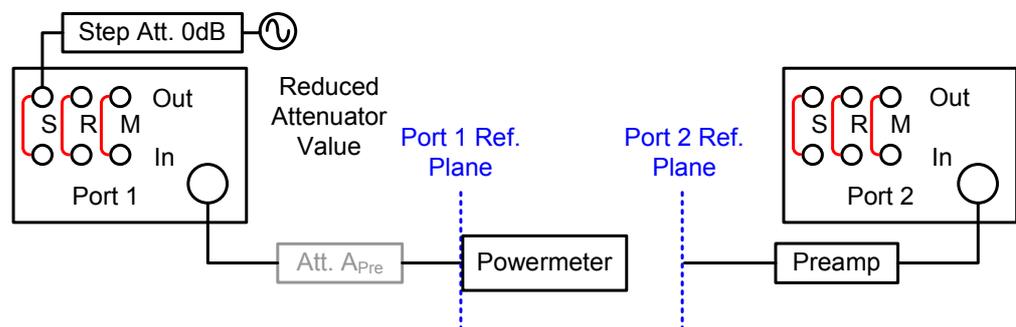
Because the power meter is a broadband device the broadband noise from the VNA source influences the accuracy of the power measurement, especially at low signal levels. For best signal to noise ratio the step attenuator should be set to 0 dB and the port output power should be set to 0 dBm for source power calibration.

However, in case an external attenuator is used at the port, it has to be ensured, that in this and the following receiver power calibration step the same external attenuator value is used. Using different external attenuator values will result in a wrong receiver power calibration. In this case, as a rule of thumb, reduce the attenuator value by the gain of the DUT to the value

$$A_{\mathrm{Pr}e} = \frac{A_{DUT}}{G_{DUT}},$$

since the DUT is not present during the power calibration steps.

Connect a power meter to the source port and perform a source power calibration by [Channel] → [Calibration] → [Start Power Cal] → [Source Power Cal]. For noise figure measurement only a calibration of the reference receiver is needed to know the exact source output power at each measurement point. A flat output power is not required. Therefore, to reduce the calibration time, the checkbox "Flatness Cal" in the menu [Modify Settings …] can be deselected.

1.5.3   Step 3: Receiver Power Calibration

For the receiver power calibration, set the internal step attenuator to the value $A_{\mathrm{Pr}e}$, to prevent compression of the preamp. Connect the driving port with the receiving port and perform a receiver power calibration on the receiving port by [Channel] → [Calibration] → [Start Power Cal] → [Receiver Power Cal]. Select the "b" wave of the receiving port to calibrate. As source enter the source port calibrated in the previous step.
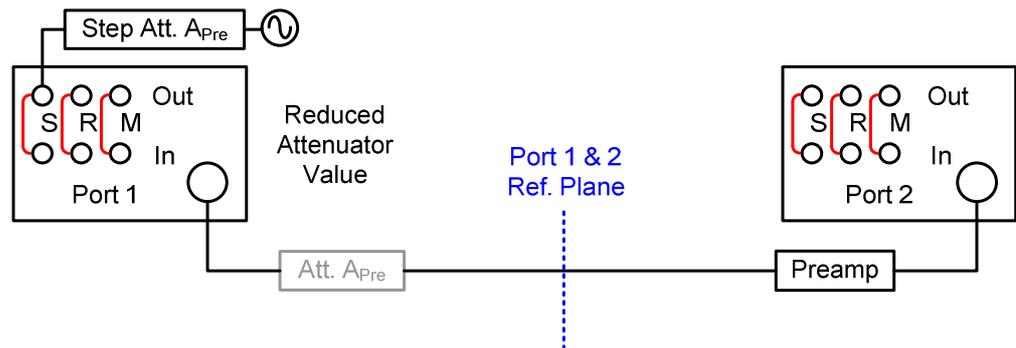
1.5.4   Step 4: Define Noise Figure Measurement

Set and activate noise figure specific settings by [Channel] → [Mode] → [Noise Figure] [Meas] → [Define Noise Figure Meas …]. In most cases accept the default settings by pressing [OK].
In the following a more detailed explanation of the possible settings is given.

1.5.4.1   Detector Meas Time

The "Detector Meas Time"[1] determines the number of samples M used for the AVG and RMS detectors from equation (1) and (2). The relation between the number of samples M and the detector measurement time T_{Meas} is

$$M = T_{\mathrm{Meas}} / T_{\mathrm{Sample}},$$

where $T_{\mathrm{Sample}} = 12.5\,\mathrm{ns}$ is the analog to digital converter sample interval.

Due to the random nature of noise the measured noise power value itself contains fluctuations which lead to trace noise. The longer the detector measurement time, the lower the trace noise is. The following figure shows the trace noise for the noise power measurement depending on the detector measurement time.

---

[1] Can be entered in the "More Wave Quantites" dialog or the "Define Noise Figure Measurement" dialog and is a channel specific setting which means it is equal for all traces.

measurement uncertainty intervall for 95% confidence interval
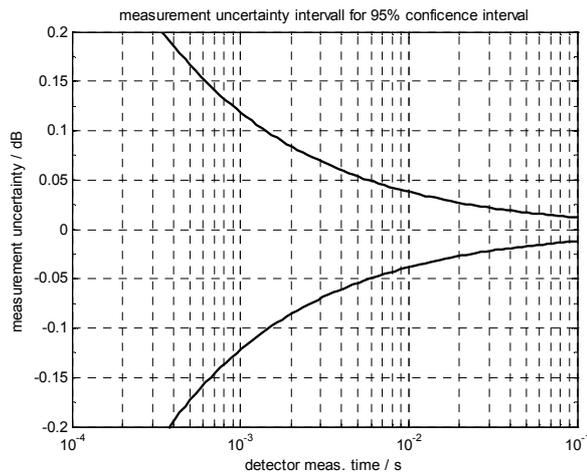
A detector measurement time of 40 ms, with respect to the given figure above, leads to a trace noise of 0.02 dB for the noise power (with 95% confidence interval). If trace noise is not an issue, the detector measurement time can be reduced to smaller values like 10 ms or 5 ms which increases the measurement speed by a factor of 4 or 8 respectively.

1.5.4.2   Simultaneous and Sequential Mode

As discussed in section 1.1.2 and 1.1.3 the AVG and RMS detectors can be used to measure the noise power, even if the carrier for the normal gain measurement is present. In this case the noise power is determined by the difference of the AVG and RMS detector and the carrier power by the AVG detector value. Exactly this is done in the "Simultaneous" mode. The advantage of this measurement mode is, that the noise and gain data is obtained in a single measurement step and that the noise properties of the DUT are determined under normal operating conditions operation.

The "Simultaneous" mode however also has some limitations. One of them is that the generator noise is higher when the generator is active. Furthermore, variations or noise of the carrier amplitude can not be separated from the broadband noise and therefore can cause inaccuracies during measurement. In addition the noise power is usually much smaller than the signal power, so the dynamic range of the receivers analog to digital converter or the floating point number format used to represent the detector results can have an influence on the measurement results.

By measuring the gain (carrier) and noise power in two steps, referring to as "Sequential" mode, the previous mentioned limitations can be overcome. In the first step a normal gain measurement is performed. In the second one the generator level is reduced and only the noise power is measured using both the AVG and RMS detector values. Compared to the "Simultaneous" mode the measurement time increases by a factor of two. However, due to the increased accuracy the "Sequential" mode is recommended and offered by default.

1.5.4.3 Assume Ideal Source Noise

As will be discussed in the following section 1.5.5.4 the measurement of the source noise figure can be difficult, if the effective receiver noise figure is much higher than the source noise figure. In this case the determined values for the source noise figure can be affected by high uncertainties and hence causes errors in the measured noise figure of the DUT. If the source noise figure is known to be very low, e.g. due to high source attenuator values, and the noise figure of the DUT is not too small, large errors in the measured noise figure can be reduced to assume that the source noise figure is equal to 0 dB.

A more accurate and recommended solution in such a case is however, to use a preamp to reduce the receiver noise figure. So the correct source noise value can be determined and so a precise noise figure of the DUT obtained.

1.5.5 Step 5: Noise Figure Calibration

The unknown parameters G_A, F_R and F_S of the noise figure system model are determined in the noise calibration procedure. It consists of two or three measurement steps, depending on the chosen setup. The order in which the steps are executed is arbitrary. The calibration dialog is opened using the menu command [Channel] → [Mode] → [Noise Figure Meas] → [Noise Figure Cal …].
Before performing the calibration steps, a number of settings have to be made.

1.5.5.1 Generator and External Attenuator Settings

Usually the generator noise figure is much smaller than the receiver noise figure. In case of a low noise power from the generator compared to the receiver noise, the generator noise figure cannot be measured accurately. The solution to the problem is to use a reduced attenuator value of $A_{\mathrm{Pr}e}$ during the source noise calibration step, while during the measurement the attenuation value of A_{DUT} is used.

The described uncertainty in the measurement of the source noise figure is included in the error estimation tool. The actual values for the source and receiver noise figure which are needed for the error estimation are shown in the diagram areas during the calibration steps.

So if the internal step attenuator is available, enter the value of $A_{\mathrm{Pr}e}$ in the field "Gen Atten for Src NCal" and the value of A_{DUT} in the field "Gen Atten for DUT Meas". The R&S ZVAB-K30 option then automatically sets the correct internal step attenuator values during the calibration steps. In case external attenuators are going to be used, activate the checkbox "Additional External Attenuator" so the firmware knows that user interaction is required before the attenuator calibration step. Connect the right attenuator values manually during the calibration steps, as described below. In special cases the external attenuators can also be combined with the internal step attenuators if necessary.

1.5.5.2 IF Gain Settings

The IF gain settings in the "Noise Figure Calibration" dialog, which can also be accessed via [Channel] → [Mode] → [Port Config …] and the button [Displayed Columns …], in most cases can be left at their default values.

The IF gain setting determines if an additional internal amplifier in front of the analog to digital converter is turned on or off to adjust the dynamic range of the IF signal. For the reference receiver "IF Gain a" the default value is "Low Dist" which turns the amplifier off and allows higher input powers without going into compression. Only if high attenuator values above 40 dB are used in generator option 1 (usage of the internal step attenuators) or 2 (external attenuator in the source path) the setting should be changed to "low noise" to reduce the trace noise.

For the measurement receiver "IF Gain b" the setting "Low Noise" is chosen by default, which turns the amplifier on and results in a lower receiver noise figure. Only if the receiver port input power is larger than 0 dBm or -10 dBm for receiver setup option 3 (direct connection to receiver path) the setting should be changed to "low distortion".

1.5.5.3 Receiver Noise Calibration
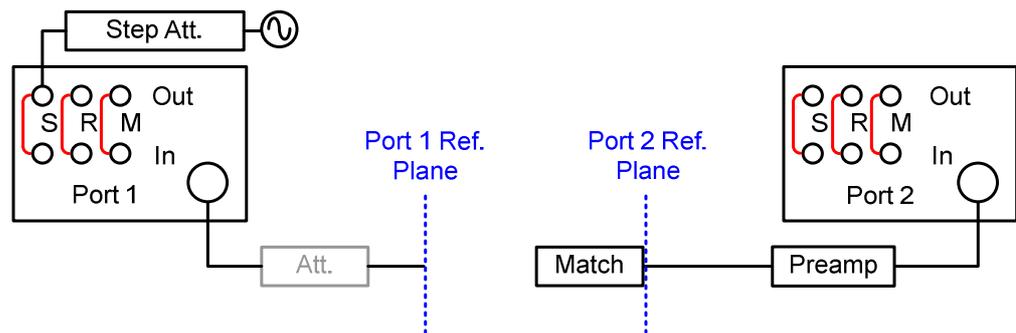
The inherent noise of the receiving port itself is determined during the receiver noise calibration with a 50Ω match connected to the receiving port. By measuring the absolute power, the VNA directly calculates the receiver noise factor F_R. After the calibration step is finished, the receiver noise figure is displayed in the calibration dialog diagram area.

### 1.5.5.4 Generator Noise Calibration
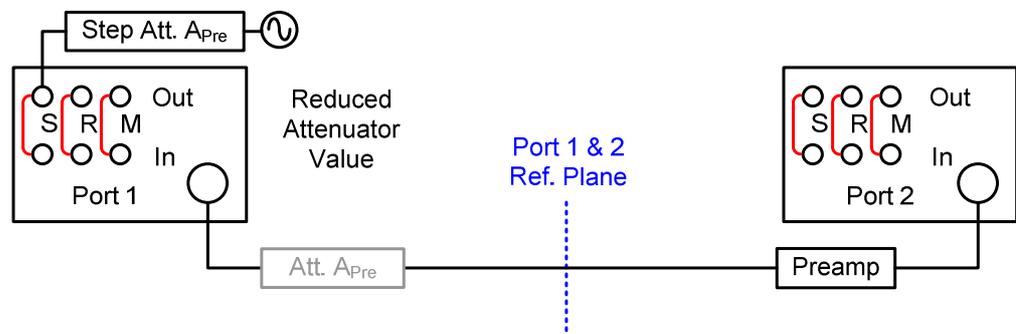
To calculate the noise figure of the DUT correctly, it is necessary to know the noise power, that is applied to the DUT. It is described by the source noise factor F_S and is measured by connecting the source port with the receiving port without the DUT. In case an external attenuator is applied, use the attenuator value $A_{\mathrm{Pr}e}$ in this calibration step.

> **Application Hint:** It is advantageous to perform the source noise calibration step directly after the receiver power calibration step, because the setup usually is unchanged.

To calculate the source noise figure, the receiver noise figure has to be known in advance. So, if the receiver noise calibration has been performed before the generator noise calibration, the source noise figure is displayed in the diagram area. If the receiver noise calibration has not yet been performed, only the system noise figure N_R / N_0 is displayed.

1.5.5.5 Attenuator Calibration
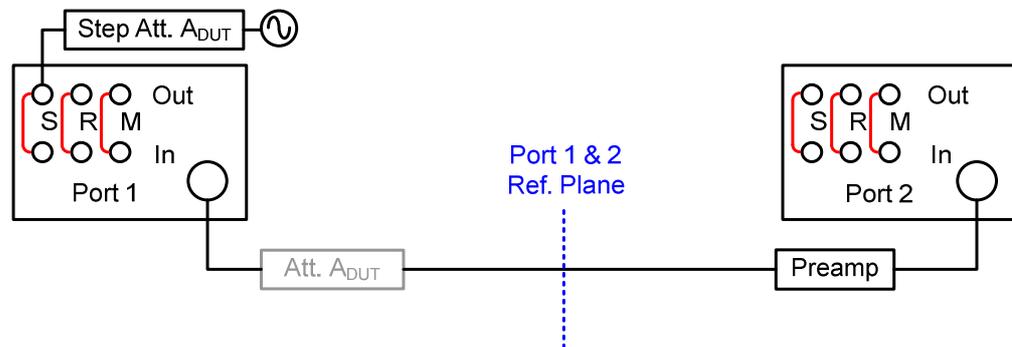
If the source noise calibration is performed with a lower attenuator value than during the actual measurement, the difference of the attenuator values has to be known to calculate the noise power at the DUT input port correctly. This attenuator difference is measured during the attenuator calibration step. If internal step attenuators are used, the calibration step is directly performed in a second sweep following the source noise calibration without user interaction. If external attenuators are used, user interaction is required and a separate calibration step is performed. At the end of the attenuator calibration, the measured external attenuator difference is displayed in the diagram area.

After the last noise calibration step press the [Apply] button to close the dialog.

1.5.6 Step 6: Activate Noise Figure Trace

Activate a noise figure trace by selecting [Trace] → [Measure] → [Noise Figure …].

To get a more stable trace and reduce spurious effects like interference discussed in chapter 1.8, trace smoothing with a aperture of 5% is automatically enabled. Trace smoothing is equivalent to the video bandwidth (VBW) which is employed by default for noise measurements on a spectrum or noise figure analyzer.

The checkbox [Adjust Channel Settings to Noise Cal] can be useful when the channel settings have been changed after the noise calibration procedure, for example when a noise calibration is loaded from the calibration pool in the calibration manager. When the checkbox is marked, the channel settings are adjusted to the settings present, when the noise calibration was performed.

The validity of the power and noise calibrations is displayed in the trace list area using the symbols "PCal" and "NCal".

1.6 Validity of the Noise Calibration

The NF measurement and calibration is sensitive to a change of the systems noise and gain properties. Subsequently a list of settings that will have an influence on the validity of the noise calibration and therefore the accuracy of the noise figure measurement:

- Frequency range
- Step attenuator values
- Noise measurement mode ("Simultaneous" or "Sequential")
- IF gain
- Power calibration
- Filter bandwidth or selectivity
- Connector line impedance (defined by connector type)
- Detector meas time
- Channel base power or port offset
- Low phase noise mode

In all of the listed cases a questionable or invalid noise calibration will be signaled by the symbols "NCa?" or "Nal Inv" in case they are modified between calibration and the actual measurement.

1.7 Noise Measurement Limits

When doing noise figure measurements with the ZVA network analyzer family, some boundary conditions should be kept in mind.

1.7.1 Low Frequency Considerations

Additional considerations have to be made when microwave network analyzers (>8 GHz) are used to perform noise figure measurements below 700MHz. Due to the naturally increasing coupling factor of directional couplers at low frequencies the receiver noise figure below 700MHz increases as well. Therefore, for NF measurements in this low frequency range, either a ZVA8 or the direct receiver access option, referring to as ZVAxy-B16, is suggested to bypass the microwave directional coupler.

1.7.2 Narrow Bandwidth DUT

Due to the double sideband mixing concept mentioned in section 1.1.3 the introduction of the factor "2" in equation (4) is only valid if the noise power in the two sidebands (with a distance of two times the intermediate frequency) is equal. Therefore the measured noise figure of a DUT with a bandwidth lower than 50MHz will contain inaccuracies.

1.7.3 High Frequency Considerations

For measurements above 24 GHz the R&S ZVA uses a harmonic mixing concept. For the noise figure measurement this implies that the noise floor of the fundamental and higher mixer frequency bands are both converted to the same intermediate frequency and can't be separated anymore. As a solution a high pass filter with a 20 GHz cutoff frequency, or a suitable band pass filter if applicable, is suggested.

1.8 Common Pitfalls

1.8.1 Interference from Mobile Communication Networks

Due to the small power of the noise signals the noise figure measurement is very sensitive to interference from mobile communication networks or other external signals. This interference signal can cause non repeatable spikes in the noise figure trace. For high accuracy noise figure measurements it is recommended to perform the measurements in a screened room or chamber.

1.8.2 Compression Effects

In case any part of the setup is in compression, wrong noise figure results are obtained. A simple check for detecting such conditions, consists of reducing the channel base power [Channel]→[Power Bandwidth Average]→[Power ...] to -10 dBm during the DUT measurement. Only small changes on the noise figure trace should be observed.

1.8.3 DUT Input and Output Match

An input and output reflection of the DUT better than 10 dB is required for accurate noise figure measurements. If strong ripples are visible on the noise figure trace, check the match of the DUT by a normal S-Parameter measurement, possibly in a separate measurement setup.

If the match of the DUT is not good enough, improve the matching by setup option 8, from chapter 1.3, using attenuators between 3 dB and 10 dB.

1.9 Simultaneous Measurement of Scattering Parameters

As discussed in the previous chapters, for certain measurement setups a simultaneous measurement of the scattering parameters of the DUT like gain or input and output reflection is possible. However the 5 MHz IF bandwidth required for noise figure measurements is to high for scattering parameter measurements, resulting in a high trace noise and calibration inaccuracies.

The solution to the problems is to set up a separate channel for the scattering parameter measurements. So after configuring the noise figure measurement as described above, follow these steps to set up a new channel.

► Remove the DUT from the setup.

► Create a new channel via [Channel]→[Channel Select]→[Add Channel + Trace].

► Set IF Gain for a and b waves to "Auto"

► Set the IF bandwidth to 1kHz or lower via [Channel]→[Power Bandwidth Average]→[Meas Bandwidth].

► Adjust the base power [Channel]→[Power Bandwidth Average]→[Power …] and internal step attenuator [Channel]→[Power Bandwidth Average]→[Meas Bandwidth] with respect to setup and consider pre-amp if applicable

Application Hint: If the step attenuator settings differ for S-parameter and NF channel you will have switching during the measurement.

► Select the desired S-Parameters.

► Perform a calibration via [Channel]→[Calibration]→[Start Cal]

► Connect the DUT an perform the measurement.

2 Measurement Uncertainty Considerations

The noise figure measurement uncertainty calculation is based on 13 input values, which can be sorted in five groups:

1. **Source Parameters**
   a. NWA Source Match
   b. Source Noise Figure
   c. Source Attenuator Gain

2. **DUT Parameters**
   a. Noise Figure
   b. Gain
   c. Isolation
   d. Input Reflection
   e. Output Reflection

3. **Receiver Parameters**
   a. NWA Receiver Match
   b. Receiver Noise Figure

4. **Power Meter Parameters**
   a. Power Meter Match
   b. Power Meter Accuracy

5. **Measurement Temperature**

Each group of parameter contains relevant inputs which has to be considered in order to calculate the overall RMS error respectively the absolute uncertainty value of the measurement result. The RMS error describes a tolerance window around the "real" value in which the measured result is with a probability of 95%.
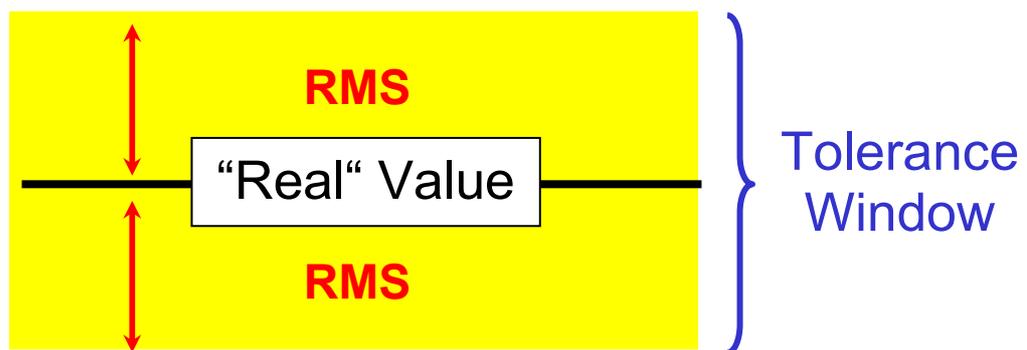
Application Hint: In a similar manner tolerances of a noise source (± 0.2 dB) used for measurement or calibration has to be considered.

2.1 Error Estimation

After the setup has been chosen, the measurement uncertainty and respectively the choice of the setup can be verified using the ZVAB-K30 Noise Figure Error Estimation Tool available as download from the R&S product and application homepage.
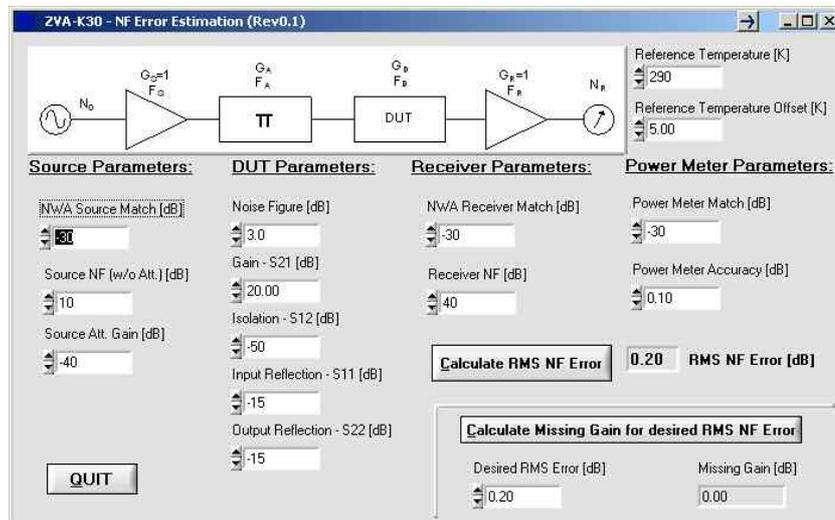
Figure 5: ZVAB-K30 Noise Figure Error Estimation Tool

For most parameters typical values are already entered. For the chosen setup usually only the following parameters have to be adjusted:

1. Enter the typical DUT parameters in the group of DUT parameters
2. Adjust "Source Att. Gain [dB]" to the used attenuator value during measurement.
3. Adjust the "Receiver NF [dB]" to the values obtained from Table 1 and Table 2.

Pressing the button "Calculate RMS NF Error" calculated the typical noise figure error.

In case the calculated error doesn't meet the measurement requirements in terms of accuracy, the missing gain of the pre-amplifier can be calculated. Therefore define the "Desired RMS Error [dB]" and press [Calculate Missing Gain for Desired RMS NF Error]. The calculation takes the other settings into account and derives the missing gain of the pre-amplifier in order to meet the desired maximum uncertainty. As a cross-check the calculated number can be used and subtracted from the previous used receiver noise figure. After calculating the RMS error again the desired RMS error should be reached.

> **Application Hint:** The gain of the pre-amplifier lowers in a first approximation the receiver noise figure of the analyzer in a one to one relation.

2.2 Measurement uncertainty examples

This chapter illustrates the measurement uncertainty of a device for different setups. A DUT with a NF of 3 dB to 4 dB across the frequency band of 1 GHz to 3 GHz is measured with a ZVA40 with internal step attenuators and direct receiver access.

a) NF measurement with "Basic Setup"

NF_{DUT} ~3.5dB
$NF_{Receiver}$ ~35dB

1) Uncertainty calculation

→ **calculated RMS NF Error: 2.14 dB**

2) Noise figure measurement
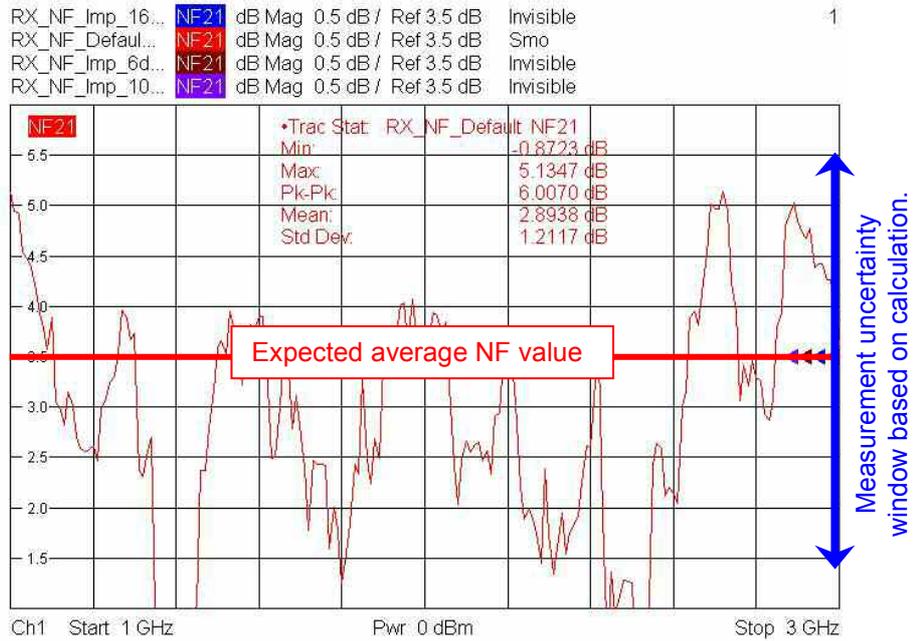
Even if the measurement result looks odd at the first sight, with respect to the previous estimated uncertainty of 2.14 dB it is still in a reasonable range.

b) NF measurement with improved receiver NF by 6dB

NF_{DUT} ~3.5dB
$NF_{Receiver}$ ~29dB

Comment: *The receiver NF is improved with a 6 dB pre-amplifier inserted into the measurement receiver loop of the direct receiver access option, referring to as ZVAxy-B16.*
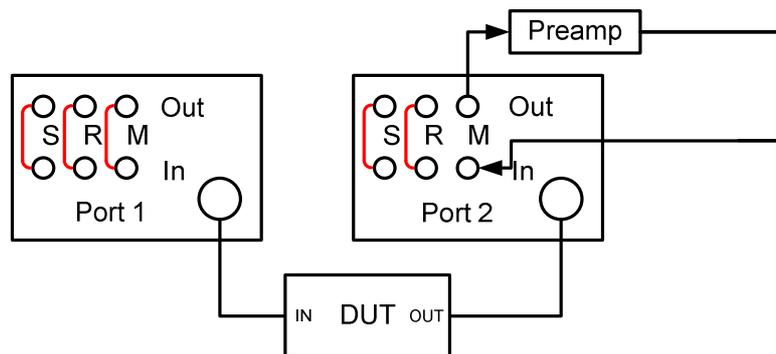
1) Uncertainty calculation
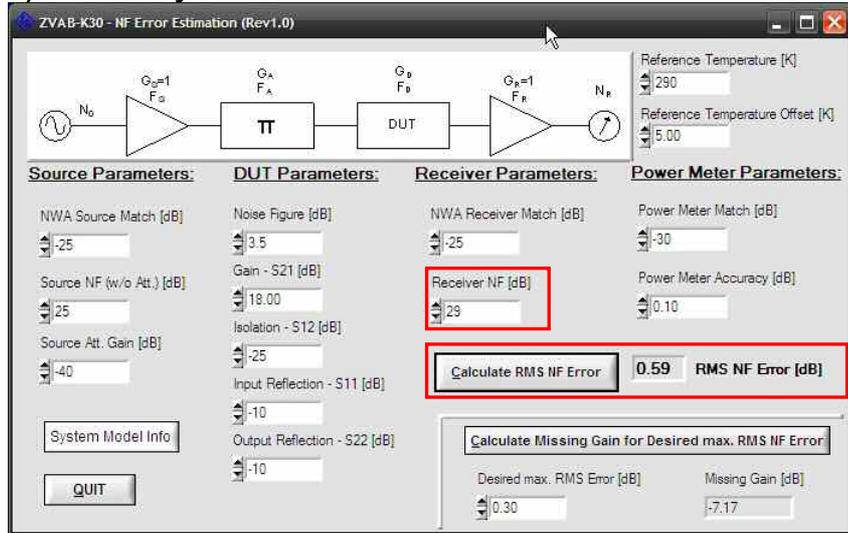
→ **calculated RMS NF Error: 0.59 dB**

2) Noise figure measurement
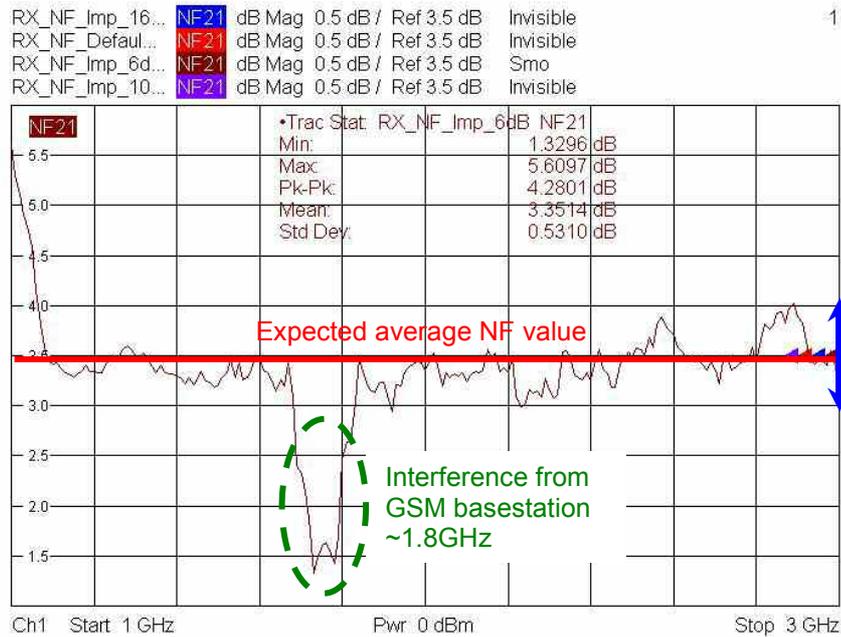
c) NF measurement with improved receiver NF by 10dB

NF_{DUT} ~3.5dB

$NF_{Receiver}$ ~25dB

Comment: *The receiver NF is improved with a 10 dB pre-amplifier inserted into the measurement receiver loop of the direct receiver access option, referring to as ZVAxy-B16.*

1) Uncertainty calculation
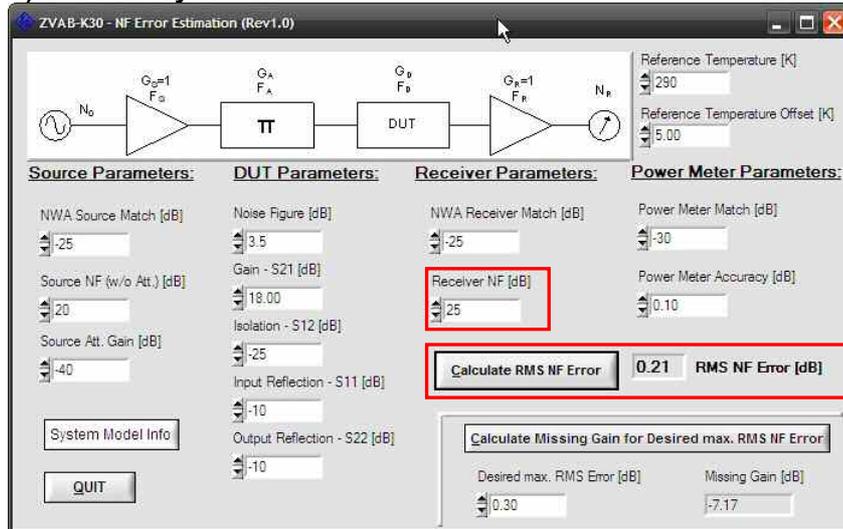

→ **calculated RMS NF Error: 0.21 dB**

2) Noise figure measurement
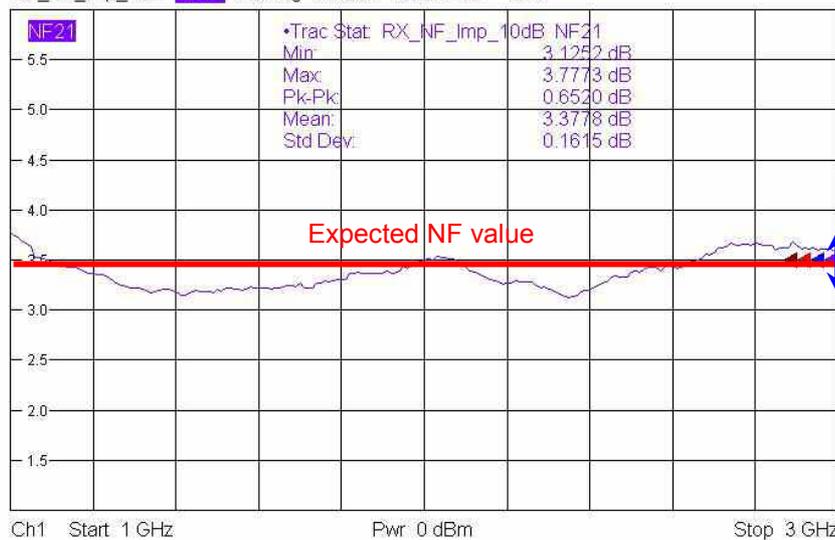
d) NF measurement with improved receiver NF by 16dB

NF_{DUT} ~3.5dB
$NF_{Receiver}$ ~19dB

Comment: *The receiver NF is improved with a 16 dB pre-amplifier inserted into the measurement receiver loop of the direct receiver access option, referring to as ZVAxy-B16..*

1) Uncertainty calculation
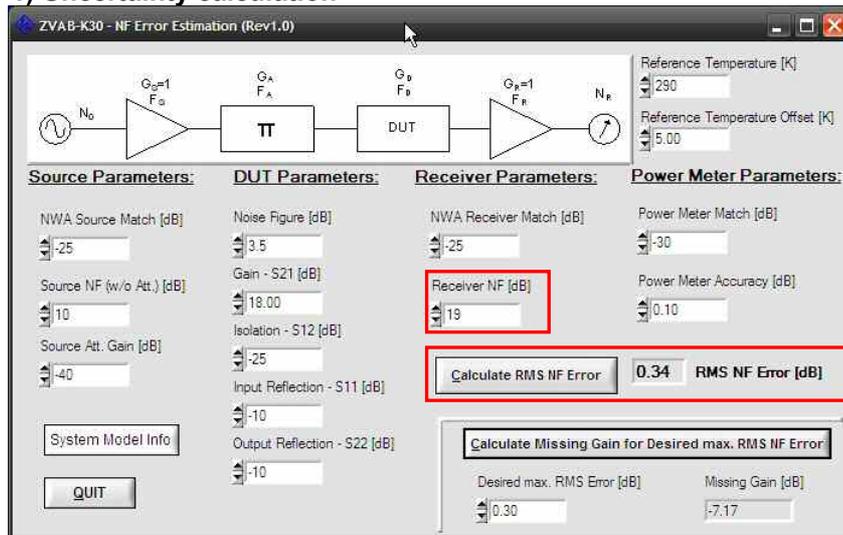
→ **calculated RMS NF Error: 0.34 dB**

2) Noise figure measurement
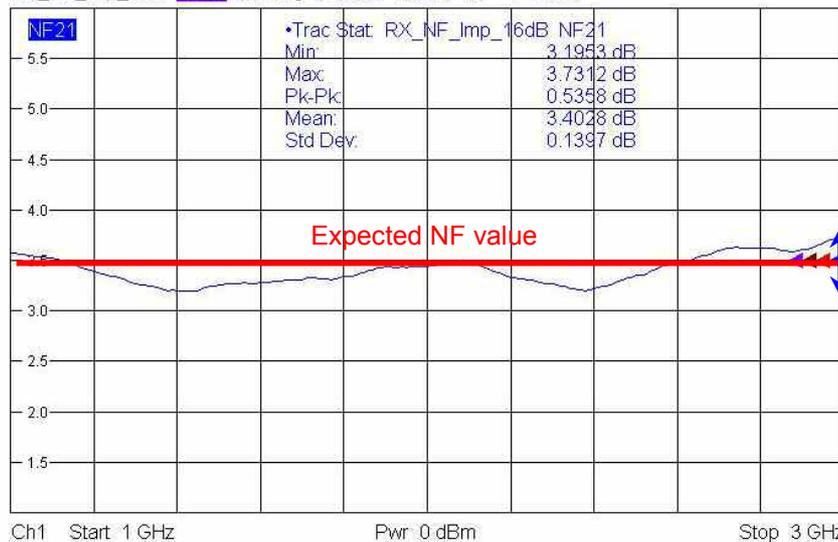
e) NF measurement result comparison versus receiver noise figure
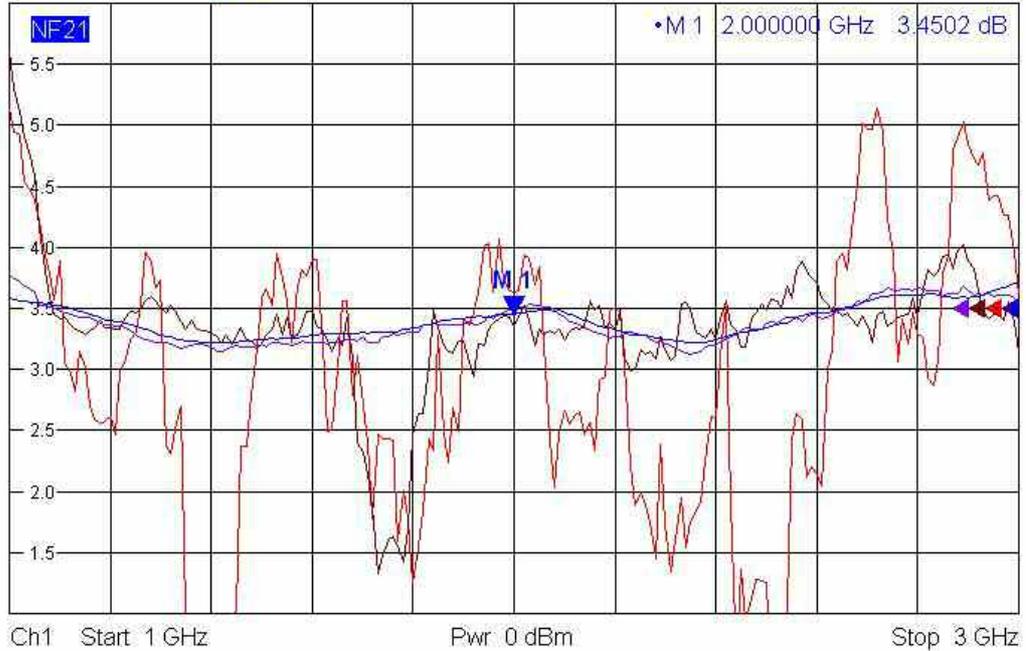
Application Hint: If you want to measure the NF of a simple THRU adapter with a loss resp. NF for instance of < 0.2 dB one can calculate the same way the uncertainty:
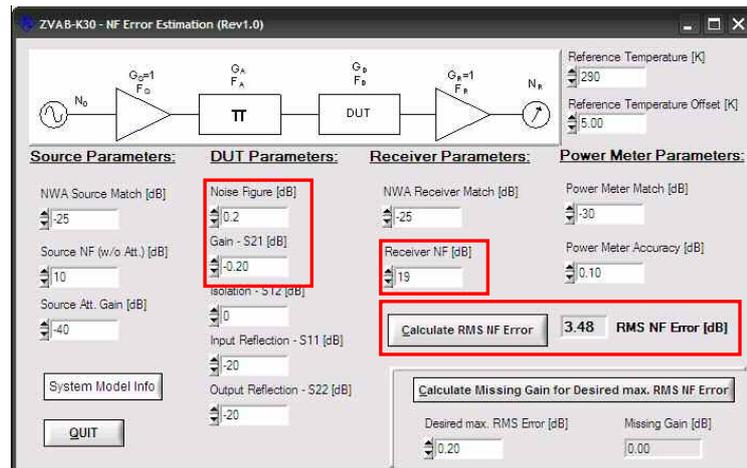
As a matter of fact the expected NF reading for a THRU adapter and a ZVA sensitivity as given in example d) will not show a straight line around 0 dB due to the uncertainty in the measurement setup.

3 Measurement Examples

This chapter describes a step-by-step measurement approach for different settings and devices. The required settings and configurations are illustrated by screenshots.

All measurements are performed on a 4-port R&S ZVA40 with direct-receiver access (option ZVA40-B16) and step attenuators in the generator and receiver paths (option ZVA40-B2x/B3x) unless otherwise stated. For the power calibrations a thermal power sensor R&S NRP-Z55 with a passive USB adapter (NRP-Z4) was used.

For a simplified navigation thru the VNA menu the following syntax, shown on selecting the source power calibration menu, is used:
► [Channel] → [Calibration] → [Start Power Cal] → [Source Power Cal …]
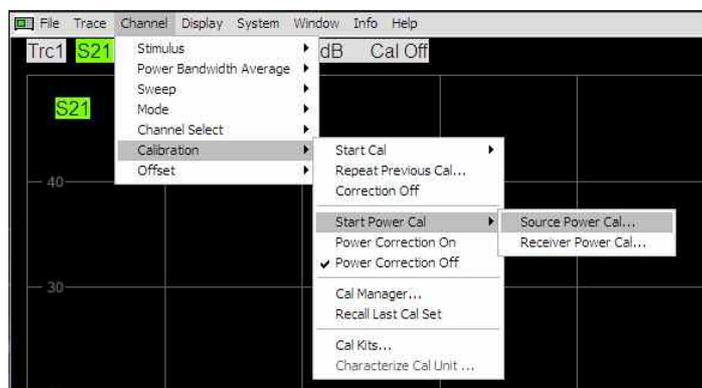
If pressing further buttons is required, it's illustrated the same way by naming the button in squared brackets, e.g.
► [Modify Settings…]

Subsequently some typical measurements are shown on the following devices:
1. Mini-Circuit amplifier ZJL-3G+
   a) Measured with a ZVA40 (with internal step attenuators)
   b) Measured with a ZVA8 (without internal step attenuators and no direct receiver access)
2. Infineon LNA BFP740F for DAB-L, GPS-L1 and PCS applications
3. Production (parallel) testing of Mini-Circuit amplifiers

3.1 Mini Circuit Amplifier ZJL-3G+

3.1.1 Device Under Test

Datasheet :   http://www.minicircuits.com/pdfs/ZJL-3G+.pdf
Characteristic: - Wideband amplifier: 20 to 3000 MHz
                 - Gain (typical): 19 dB
                 - Gain Flatness (typical): ±2.2 dB
                 - Noise Figure (typical): 3.8 dB

3.1.2 Measurement Setup a) - ZVA40 with internal step attenuators

3.1.2.1 Choosing the Setup

As the first step, the characteristic properties of the ZVA40 can be taken from Table 1 and Table 2. The receiver noise figure is about 35 dB and the 1 dB compression point about 3 dBm.

The second step consists of choosing the receiver setup. Since no direct receiver access option is available, the choice that remains is whether a preamp is needed or not. With the gain of the DUT of approximately 20 dB the receiver noise figure relation (RNF) results in

$$35dB < 20dB + 10dB = 30dB .$$

As discussed previously the RNF relation is at it's limit, but a measurement without preamp is still possible. Therefore in the following the receiver setup option 1 is used.

The next step is to choose an appropriate attenuation value. Since the 1 dB compression point of the ZVA40 is 3 dB, the attenuation in this example has to be 30 dB in contrast to the previous example to prevent any compression effects. With a source power of 0 dBm the power level will be -30 dBm at the DUT Input and -11 dBm at the receiver input. In both cases the power levels are sufficiently below the 1 dB compression points of -10 dBm of the DUT and 3 dBm of the analyzer.

For the generator setup the step attenuator option is available and therefore will be used in generator setup option 2. The final setup is shown in the figure below.

The chosen setup can be checked with the R&S NF error estimation tool, which yields a measurement uncertainty of 0.4 dB for the chosen setup.

Frequency range: 1 to 1.5 GHz
No of Points: 201
Power: 0 dBm
Measurement Ports: DUT input @ Port1
                      DUT output @ Port2

3.1.2.2   Step 1: Source Power Calibration

► Connect a power meter to the port 1 reference plane.

► [CHANNEL] → [Calibration] → [Start Power Cal] → [Source Power Cal …]

► [Modify Settings…]
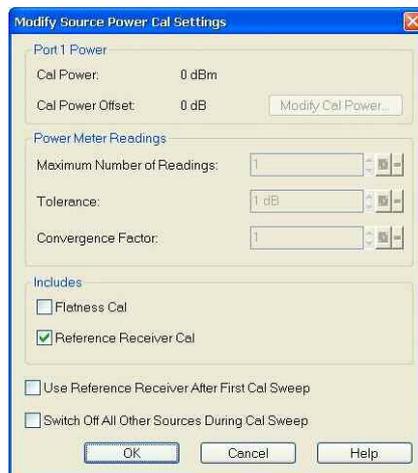
⇨ A reference receiver calibration is sufficient.
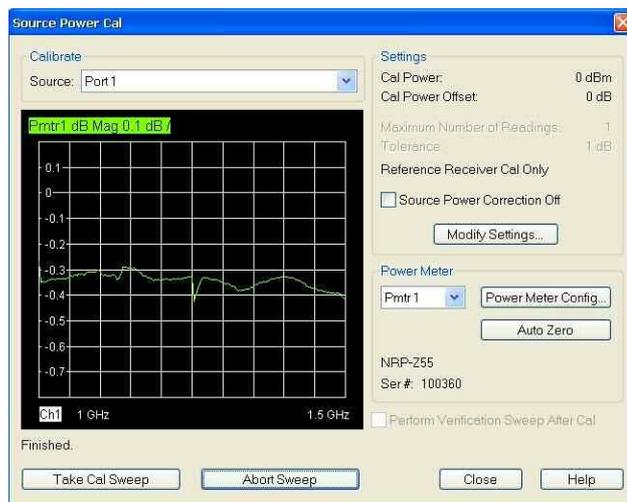
► [Take Cal Sweep]

► [Take Cal Sweep]

⇨ A flat and smooth curve is not required after calibration – only the exact power levels must be known.

⇨ Performing a power calibration at low power levels, e.g. -30 dBm, might reduce the NF measurement accuracy later on. The reason for that is the limited accuracy of power meters at low power levels. **The suggested power level for the power calibration is 0 dBm.**

3.1.2.3 Step 2: Receiver Power Calibration

► Directly connect the port 1 and 2 reference plane.

► [CHANNEL] → [Calibration] → [Start Power Cal] → [Receiver Power Cal …]

► Select wave quantity b2 and port 1 as source port.

► [Take Cal Sweep]

3.1.2.4 Step 3: Define Noise Figure Measurement

► [CHANNEL] → [Mode] → [Noise Figure Meas] → [Define Noise Figure Meas …]
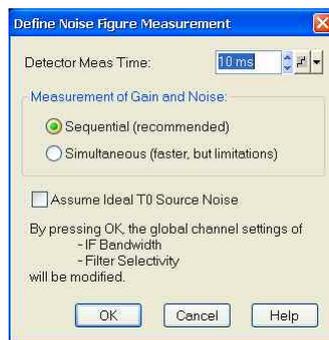
⇨ 10 ms Detector Meas Time are set by default. A reduced number would reduce the measurement time but also the accuracy

⇨ For most applications the sequential mode is recommended. For a detailed explanation of the two modes refer to chapter 1.5.4.2.

3.1.2.5 Step 4: Noise Figure Calibration Settings

► [CHANNEL] → [Mode] → [Noise Figure Meas] → [Noise Figure Cal …]
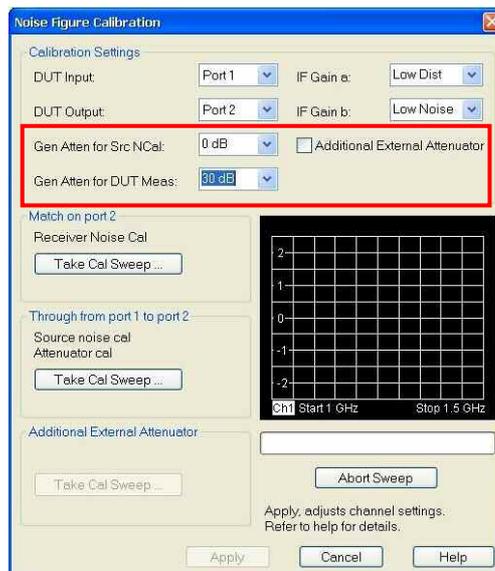
⇨ The [Gen. Atten. for Src NCal] and [Gen. Atten. for DUT Meas] settings are defining the possibly different source step attenuator levels for the source noise calibration step and the measurement later on. For the source noise calibration the power has to be reduced only if a preamp is inserted in order to avoid compression of the receiver front-end during calibration. The attenuation for the measurement depends on the system (DUT + pre-amp) gain as discussed in chapter 1.4.

3.1.2.6   Step 5: Noise Figure Calibration

⇨ As mentioned in chapter 1.5.5 the order of the noise figure calibration steps is arbitrary. Since the THRU connection of the port 1 and 2 reference plane is already in place, the source noise calibration step can be performed before the receiver noise cal step to speed up the calibration process. However in that case the source noise figure is not displayed in the diagram area. For that reason the receiver noise calibration is performed first in the following description.
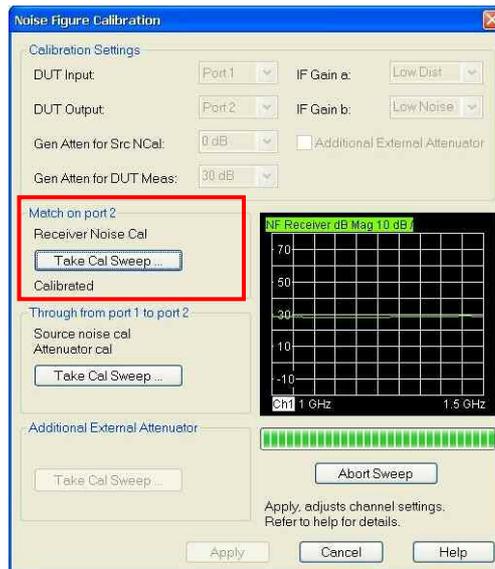
► Terminate the receiver reference plane with a match

► [Take Cal Sweep]

⇨ Receiver Noise is measured and displayed in the diagram
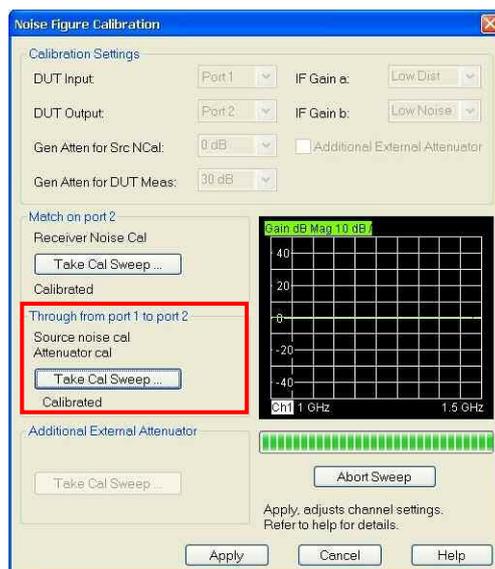

► Establish a THRU connection between source and receiver reference plane

► [Take Cal Sweep]

⇨ If the attenuator settings for source noise calibration and DUT measurement are different two calibration sweeps are performed.

⇨ The source noise is measured and displayed in the diagram (1st sweep). The 2nd sweep would measure the attenuation difference and normalize it.

⇨ In case external attenuators are used and selected in the settings, the attenuator calibration sweep is performed in a separate step, so the user can add an additional external attenuator after the source noise calibration. This way two different attenuator values can be chosen for the source noise calibration step and the DUT measurement, as with the internal step attenuators.

► Press [Apply] to leave the dialog.

3.1.2.7 Step 6: Activate Noise Figure Trace

► [TRACE] → [Meas] → [Noise Figure …]
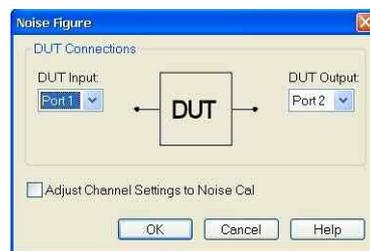
► Select the measurement quantity NF21 with respect to the measurement ports

3.1.3 Noise Figure Measurement Result

After setting up and calibrating for the noise figure measurement according Step 1 to 6, the analyzer is ready to measure the NF of the DUT. Additionally, as shown in the following screenshot, limit lines can be configured and the trace statistic displayed.

For a complete amplifier characteristic, one might also be interested in parameters like gain, 1 dB compression point or the input or output matching of the device. In a single connection and different channels (see chapter 1.9) the amplifier is characterized in a single shot:

3.1.4 Measurement Setup b) - ZVA8 without internal step attenuators and without direct receiver access

3.1.4.1 Choosing the Setup

The setup and settings for the measurement can be determined by the procedure described in section 1.4.

As the first step, the characteristic properties of the ZVA8 can be taken from Table 1 and Table 2. The receiver noise figure is about 35 dB and the 1dB compression point about 10 dBm.

The second step consists of choosing the receiver setup. Since no direct receiver access option is available, the choice that remains is whether a preamp is needed or not. With the gain of the DUT of approximately 20 dB the receiver noise figure relation (RNF) results in

$$35\text{dB} < 20\text{dB} + 10\text{dB} = 30\text{dB}.$$

The equation indicates that the sensitivity of the analyzer is most likely not sufficient in order to characterize the DUT in terms of noise figure that's why a pre-amplifier should be considered. Since the relation is only a rule of thumb the measurement can also be tried without preamp. Subsequently the receiver setup option 1 is used.

The next step is to choose an appropriate attenuation value. To compensate the gain of the DUT a 20 dB attenuator is reasonable. With a source power of 0 dBm the power level will be -20 dBm at the DUT Input and -1 dBm at the receiver input. In both cases the power levels are sufficiently below the 1 dB compression points of -10 dBm of the DUT and 10 dBm of the analyzer.

Since no direct receiver access option or internal step attenuator option are available, the generator setup option 1 has to be used. The final setup is shown in the figure below.

The chosen setup can be checked with the R&S NF error estimation tool, which yields a measurement uncertainty of 0.4 dB for the chosen setup.
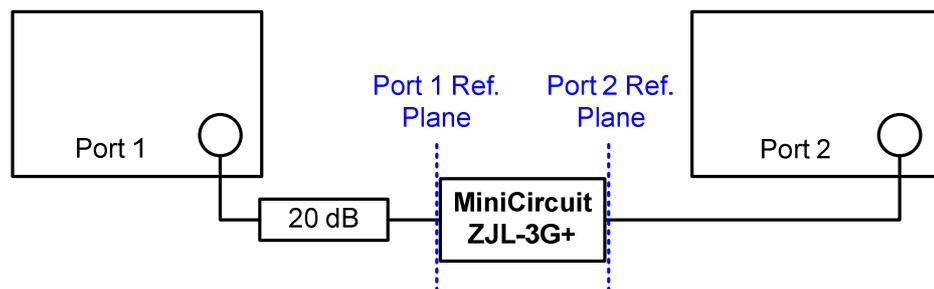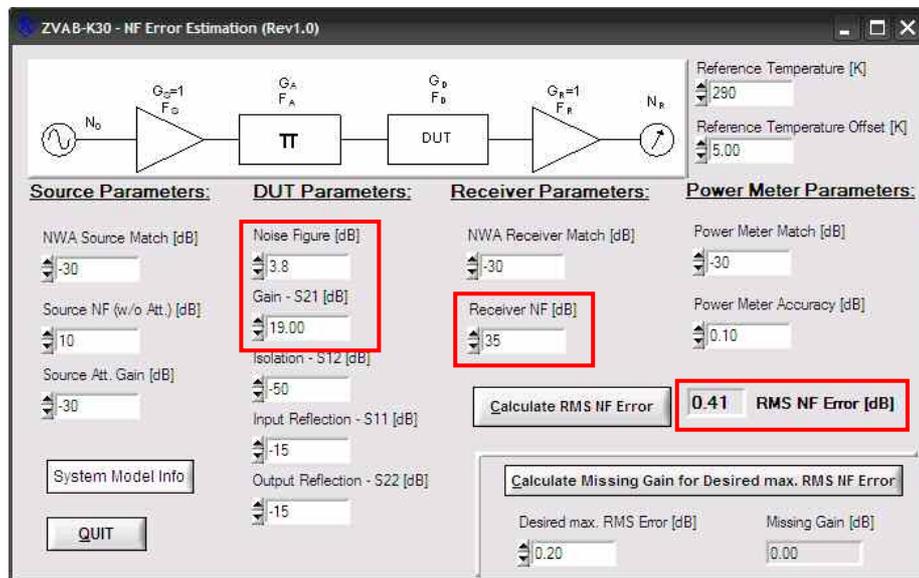

Frequency range: 0.1 … 3 GHz
No of Points: 201
Power: 0 dBm
Measurement Ports: DUT input @ Port1 with ext. attenuator (20 dB)
                        DUT output @ Port2

3.1.4.2 Step 1: Source Power Calibration

► Connect a power meter to the port 1 reference plane, but without the external attenuator.

► [CHANNEL] → [Calibration] → [Start Power Cal] → [Source Power Cal …]

► [Modify Settings…]
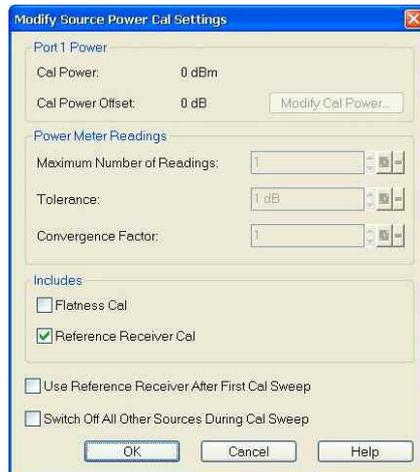
⇨ A reference receiver calibration is sufficient.

► [Take Cal Sweep]
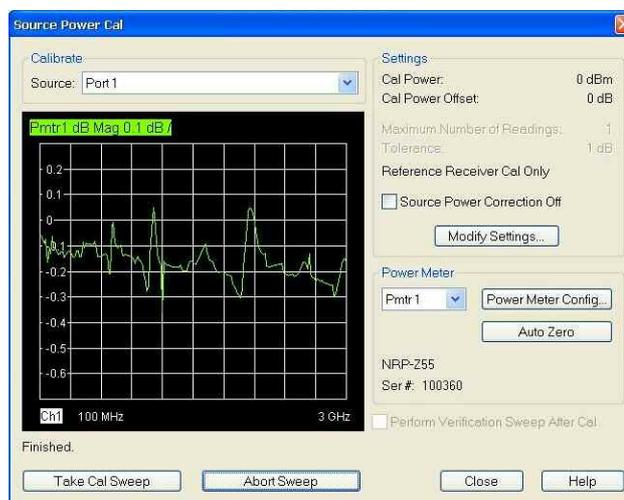
⇨ A flat and smooth curve is not required after calibration – only the exact power levels must be known.

⇨ Performing a power calibration at low power levels, e.g. -30 dBm, might reduce the NF measurement accuracy later on. The reason for that is the limited accuracy of power meters at low power levels. **The suggested calibration power level is 0 dBm.**

3.1.4.3 Step 2: Receiver Power Calibration

► Directly connect the port 1 and 2 reference plane, again without the external attenuator.

► [CHANNEL] → [Calibration] → [Start Power Cal] →[Receiver Power Cal …]
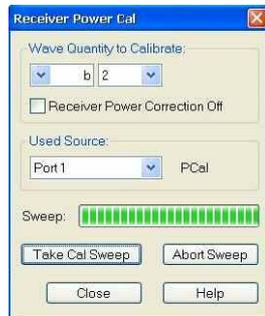
► Select wave quantity b2 and port 1 as source port.

► [Take Cal Sweep]

3.1.4.4 Step 3: Define Noise Figure Measurement

► [CHANNEL] → [Mode] → [Noise Figure Meas] → [Define Noise Figure Meas …]
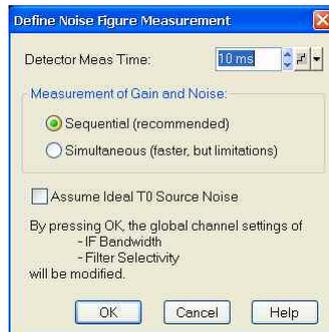
⇨ 10 ms Detector Meas Time is set by default. A lower value reduces the measurement time but also increases the trace noise.

⇨ For most applications the sequential mode is recommended. For a detailed explanation of the two modes refer to chapter 1.5.4.2.

3.1.4.5 Step 4: Noise Figure Calibration Settings

► [CHANNEL] → [Mode] → [Noise Figure Meas] → [Noise Figure Cal …]
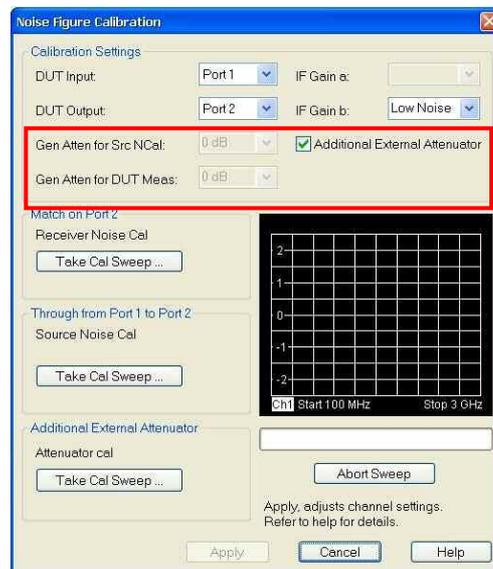
⇨ [Additional External Attenuator] has to be checked due to missing internal step attenuators.

3.1.4.6 Step 5: Noise Figure Calibration

⇨ As mentioned in chapter 1.5.5 the order of the noise figure calibration steps is arbitrary. Since the THRU connection of the port 1 and 2 reference plane might be already in place from the previous receiver power calibration, the source noise calibration step can be performed before the receiver noise cal step to speed up the calibration process. However in that case the source noise figure is not displayed in the diagram area. For that reason the receiver noise calibration is performed first in the following description.
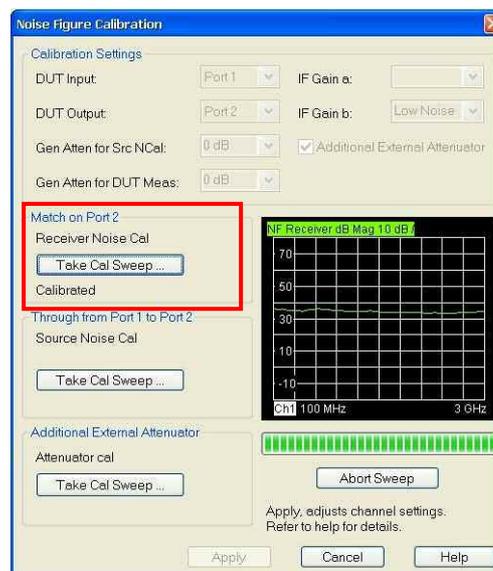
► Terminate the receiver reference plane with a match

► [Take Cal Sweep]

⇨ The receiver noise figure is measured and displayed in the diagram.
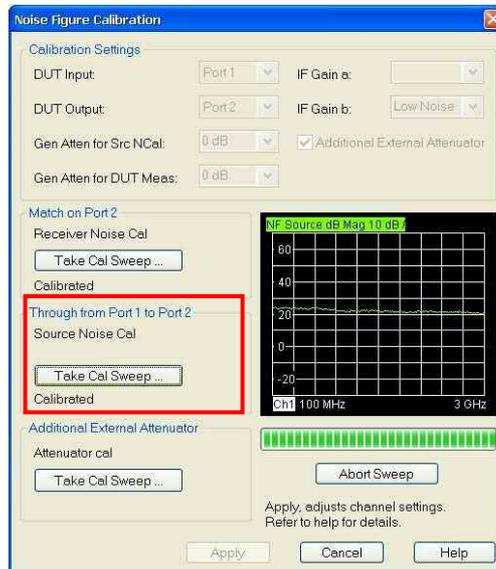
► Establish a THRU connection between source and receiver port.

► [Take Cal Sweep]
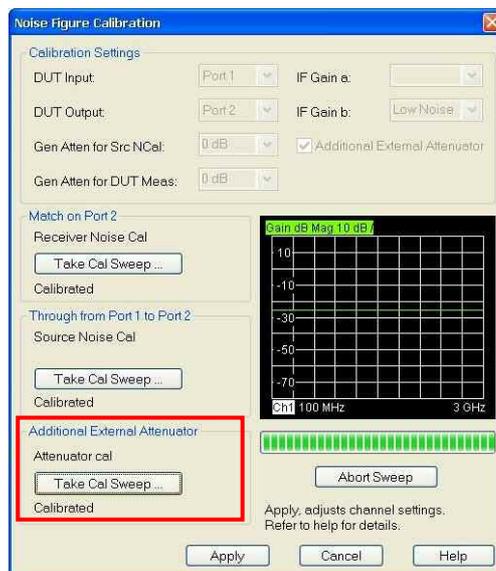
► Connect external attenuators at source port and establish a THRU connection between source and receiver reference plane.

► [Take Cal Sweep]

⇨ The inserted attenuation is measured and displayed in the diagram.

► Press [Apply] to leave the dialog.

3.1.4.7 Step 6: Define Noise Figure Meas

► [TRACE] → [Meas] → [Noise Figure …]
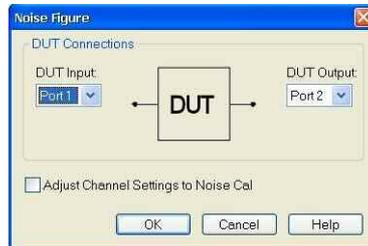
► Select the measurement quantity NF21 with respect to the measurement ports

3.1.5 Noise Figure Measurement Result

After setting up and calibrating for the noise figure measurement according to step 1 to 6, the analyzer is ready to measure the NF of the DUT. As shown in the screenshot, a second measurement channel for the gain is activated and displayed as described in chapter 1.9.

3.2 Ultra Low Noise Amplifier BFP740F

3.2.1 Device Under Test

Type: Ultra Low Noise RF Amplifier
Manufacturer: Infineon Technologies
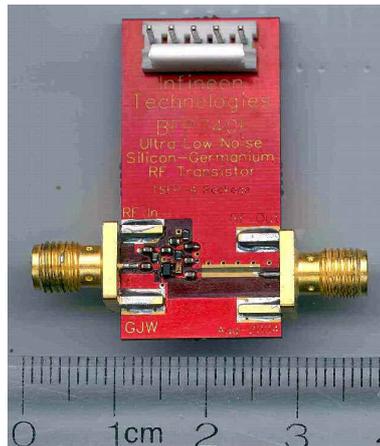
Datasheet: http://www.infineon.com/.../BFP740F
Applications: - Digital Audio Broadcasting DAB-L (1452.960 MHz to 1490.624 MHz)
                  - GPS "L1" Frequency (1575.42 MHz)
                  - 1900 MHz PHS and PCS
Characteristic: - Noise Figure @ 1.4 GHz to 2 GHz: ~0.7 dB
                  - Gain @ 1.4 GHz to 2 GHz: > 18 dB

3.2.2 Measurement Setup

3.2.2.1 Choosing the Setup

Again as the first step, the characteristic properties of the ZVA40 can be taken from Table 1 and Table 2. The receiver noise figure is about 35 dB and the 1 dB compression point about 3 dBm at the port connector and -10 dBm at the B16 "Meas In" connector.

The second step consists of choosing the receiver setup. With the gain of the DUT of approximately 18 dB the receiver noise figure relation (RNF) results in

$$35\,\text{dB} < 18\,\text{dB} + 10\,\text{dB} = 28\,\text{dB}.$$

Since the difference between the left and right side is getting bigger and the DUT has a small noise figure, this time the receiver setup option 1 is not considered. For this example the direct receiver access option of the ZVA is utilized. Since a parallel measurement of the NF and the S-parameters of the DUT is desired, in this case the receiver setup option 4 has to be chosen, with a preamp located in the "Meas" path.

As preamp the ZJL-3G+ from the previous examples could be used, if the relation

$$NF_R - L_{G_{\mathrm{Pre}}} < L_{G_D} + 10\,\mathrm{dB}$$

is true. Entering the values for the preamp Gain G_{Pre} and noise factor F_{Pre}, the ZVA receiver noise factor F_M and the gain of the DUT G_D, the following relation is obtained.

$$35\,\mathrm{dB} - 19\,\mathrm{dB} < 18\,\mathrm{dB} + 10\,\mathrm{dB}$$

$$16\,\mathrm{dB} < 28\,\mathrm{dB}$$

Since the relation is true, the selected preamp can be used.

The next step is to choose an appropriate attenuation value. Following the procedure described in chapter 1.4.3, with the values $L_{P_{1dB,DUT}} = -17.5\,\mathrm{dBm}$,

$L_{P_{1dB,\mathrm{Pre}}} = 10\,\mathrm{dBm}$ and $L_{P_{1dB,ZVA}} = -10\,\mathrm{dBm}$ at the direct receiver access connector the following attenuator values are obtained.

- $L_{A_1} = 27.5\,\mathrm{dB}$
- $L_{A_2} = 8\,\mathrm{dB}$
- $L_{A_3} = 38\,\mathrm{dB}$

The maximum value is 38 dB. To be on the safe side, an attenuation value of 50 dB will be used in the setup.

For the generator setup the step attenuator option is available and therefore will be used in generator setup option 2. The final setup is shown in the figure below.

The chosen setup can be checked with the R&S NF error estimation tool, which yields a measurement uncertainty of <0.2 dB for the chosen setup.

Frequency range: Channel1:   1.45 to 1.50 GHz   → DAB-L Band
                    Channel2:   1.57 to 1.58 GHz   → GPS L1
                    Channel3:   1.93 to 1.99 GHz   → PCS DL
                    Channel4:   1 to 3 GHz   → Broadband Gain
No of Points: 201 for each channel
Power: 0 dBm
Measurement Ports: DUT input @ Port1
                    DUT output @ Port2 with pre-amplifier in MEAS path

3.2.2.2   Step 1: Source Power Calibration

► Connect a power meter to the port 1 reference plane.

► [CHANNEL] → [Calibration] → [Start Power Cal] → [Source Power Cal …] →

► [Modify Settings…]

⇨ A reference receiver calibration is sufficient

Source Power Cal

Calibrate

Source: Port 1

Pmtr1 dB Mag 0.1 dB /

0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7

Ch1   1 GHz   1.5 GHz

Finished.

Settings

Cal Power: 0 dBm
Cal Power Offset: 0 dB

Maximum Number of Readings: 1
Tolerance: 1 dB

Reference Receiver Cal Only

☐ Source Power Correction Off

[Modify Settings...]

Power Meter

Pmtr 1   [Power Meter Config...]
          [Auto Zero]

NRP-Z55
Ser #: 100360

☐ Perform Verification Sweep After Cal

[Take Cal Sweep]   [Abort Sweep]   [Close]   [Help]
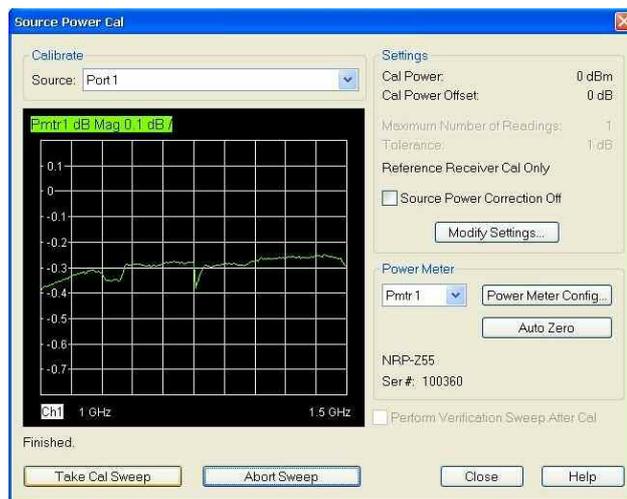
► [Take Cal Sweep]

⇨ A flat and smooth curve is not required after calibration – only the exact power levels must be known.

⇨ Performing a power calibration at low power levels, e.g. -30 dBm, might reduce the NF measurement accuracy later on. The reason for that is the limited accuracy of power meters at low power levels. **The suggested calibration power level is 0 dBm.**

### 3.2.2.3   Step 2: Adjust Source Power and Perform Receiver Power Calibration

► [CHANNEL] → [Power Bandwidth Average] → [Step Attenuators …]

Step Attenuators

Rec Wave	Atten	Gen Wave	Atten (Electronic Range)	Src Pwr Result
b1	0 dB	a1	30 dB (-60 dBm...-20 dBm)	-30 dBm
b2	0 dB	a2	30 dB (-60 dBm...-20 dBm)	-30 dBm

[Close]   [Help]

⇨ Due to the pre-amplifier in the receive path the source signal of port 1 and port 2 have to be reduced for the receiver power calibration to avoid compression effects.

► Directly connect the port 1 and 2 reference plane.

► [CHANNEL] → [Calibration] → [Start Power Cal] → [Receiver Power Cal …]

Receiver Power Cal

Wave Quantity to Calibrate:

b 2

☐ Receiver Power Correction Off

Used Source:

Port 1   PCao

Sweep: ▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮

[Take Cal Sweep]   [Abort Sweep]

[Close]   [Help]

► Select wave quantity b2 and port 1 as source port.

► [Take Cal Sweep]

3.2.2.4 Step 3: Define Noise Figure Measurement

► [CHANNEL] → [Mode] → [Noise Figure Meas] → [Define Noise Figure Meas …]
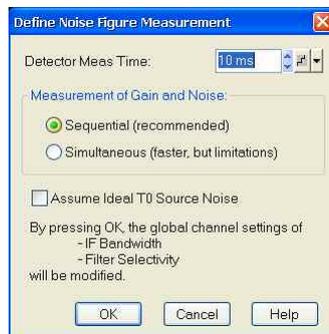
3.2.2.5 Step 4: Noise Figure Calibration Settings

► [CHANNEL] → [Mode] → [Noise Figure Meas] → [Noise Figure Cal …]
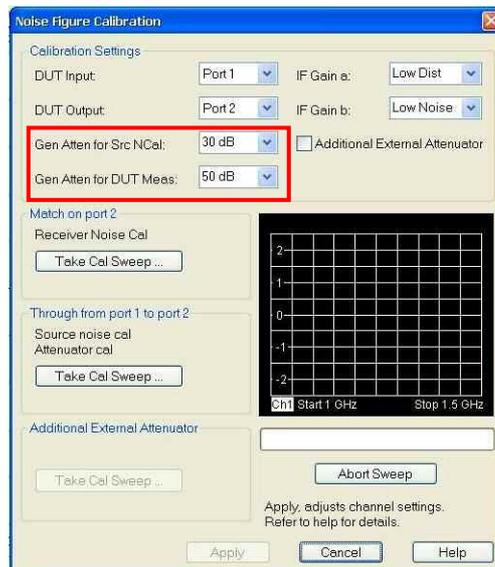
⇨ The [Gen. Atten. for Src NCal] and [Gen. Atten. for DUT Meas] settings are defining the possibly different source step attenuator levels for the source noise calibration step and the measurement later on. For the source noise calibration the power has to be reduced by 30 dB due to the installed preamp. For the measurement, due to the gain of the DUT, additional 20 dB attenuation are required.

3.2.2.6 Step 5: Noise Figure Calibration

⇨ As mentioned in chapter 1.5.5 the order of the noise figure calibration steps is arbitrary. Since the THRU connection of the port 1 and 2 reference plane might already be in place from the previous receiver power calibration, the source noise calibration step can be performed before the receiver noise cal step to speed up the calibration process. However in that case the source noise figure is not displayed in the diagram area. For that reason the receiver noise calibration is performed first in the following description.
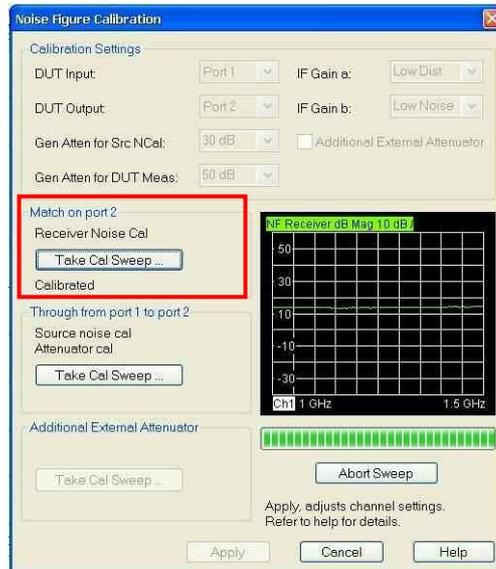
► Terminate the receiver reference plane with a match

► [Take Cal Sweep]

⇨ The receiver noise figure is measured and displayed in the diagram

⇨ Compared to the previous measurement without pre-amplifier the receiver noise figure is roughly lowered by the gain of the pre-amplifier.
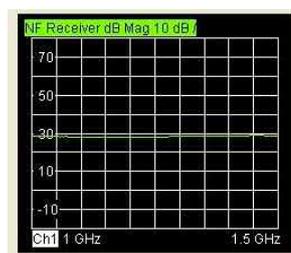
Result From Receiver Noise Calibration Without Pre-Amplifier
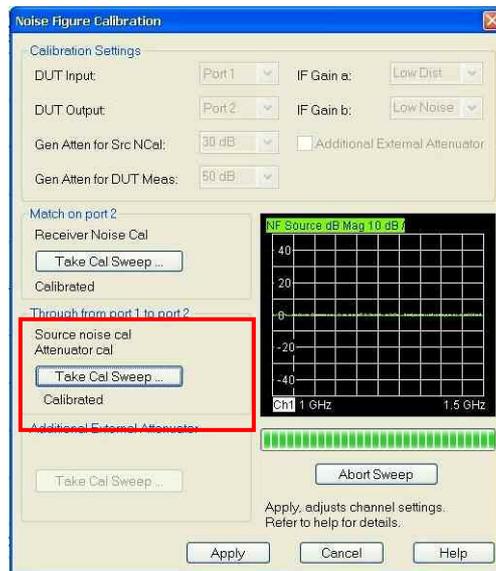
► Establish a THRU connection between source and receiver reference plane

► [Take Cal Sweep]

► Press [Apply] to leave the dialog.

3.2.2.7 Step 6: Define Noise Figure Meas

► [TRACE] → [Meas] → [Noise Figure …]
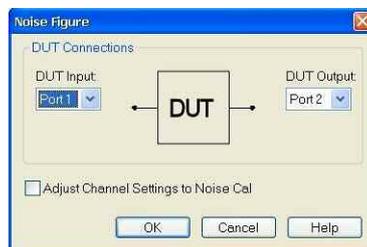
► Select the measurement quantity NF21 with respect to the measurement ports

3.2.3 Noise Figure Measurement Result

After setting up and calibrating for the noise figure measurement according Step 1 to 6, the analyzer is ready to measure the NF of the DUT. The result screenshot below shows the noise figure measurement in the 3 dedicated application bands (channels 1 to 3) and the broadband gain measurement (channel 4).
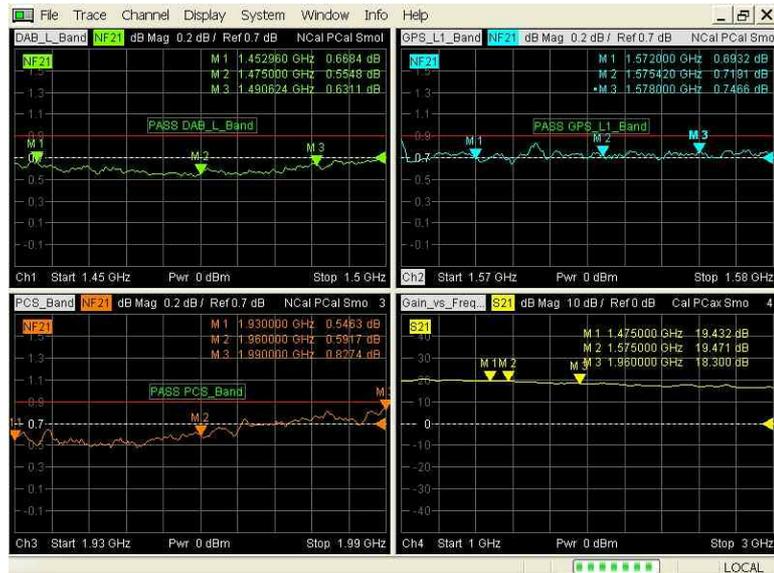
Noise figure measurement in the DAB-L band

Noise figure measurement around the GPS-L1 frequency 1575.42 MHz
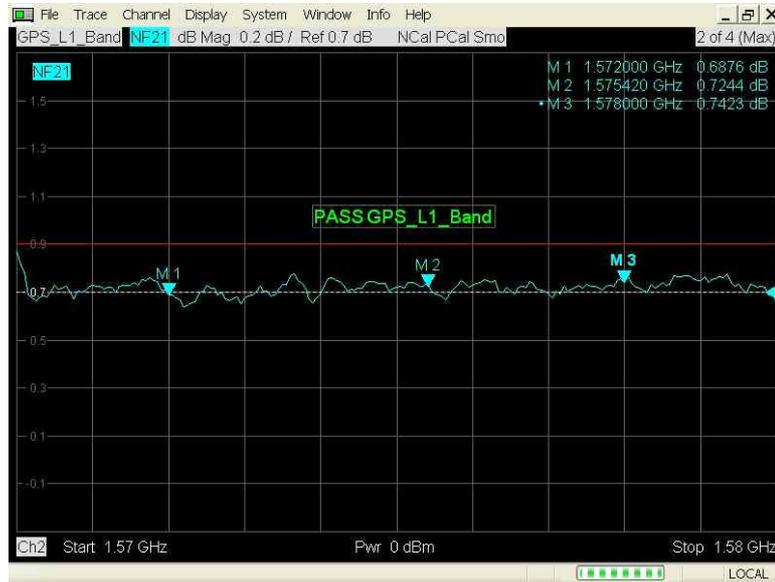
Noise Figure measurement in the PCS band

Broadband gain measurement from 1 to 3 GHz
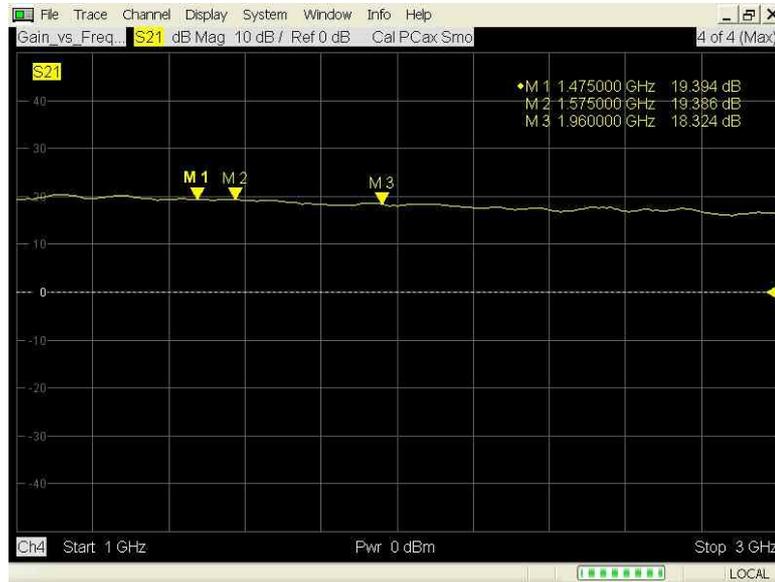
24h long-term stability measurement

3.2.4 Measurement Results with ZVA8 without Options

The same low-noise amplifier is measured with a ZVA8 without internal step attenuators and without direct receiver access. The setup and calibration is done with 26 dB external attenuation at the source port and a pre-amplifier (Mini-Circuit ZJL-3G+) in the receive path.
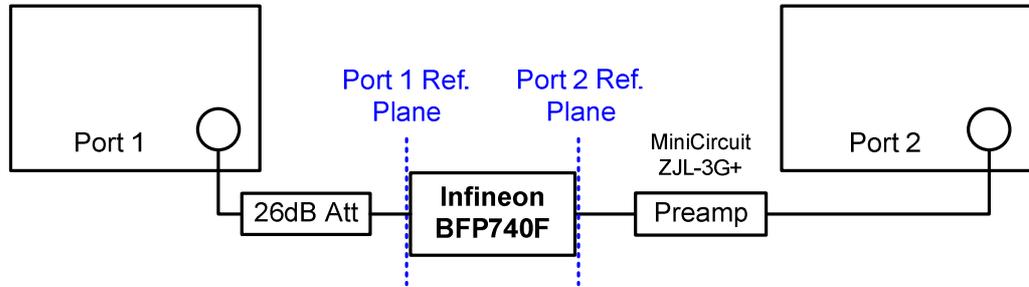
ZVA8 noise figure and gain measurement result from 1.2 to 3 GHz

3.3 Parallel Testing

For production lines parallel testing is essential in order to keep the throughput high and hence the testing time and finally the costs at a minimum. With a standard approach, utilizing the y-factor method, parallel testing of amplifiers is nearly impossible. However, one of the main application fields for the ZVAB-K30 option is the mass production line. While utilizing the direct receiver access of the analyzer, referring to as ZVAxy-B16 option, it is possible to measure one DUT per port which means basically up to 8 devices with a ZVT8.

The DUT is connected in such a setup between the normal measurement and the MEAS IN connector of the direct receiver access:
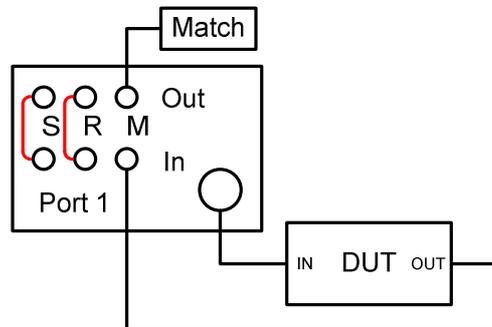
The noise figure setup and calibration is similar to the one shown in the previous measurement examples. The difference is the measurement quantity to be selected. Instead of a NF21 measurement a NF11 for instance has to be performed. In this case the noise figure of the device connected at port 1 and the corresponding MEAS IN connector as shown schematically above is measured.
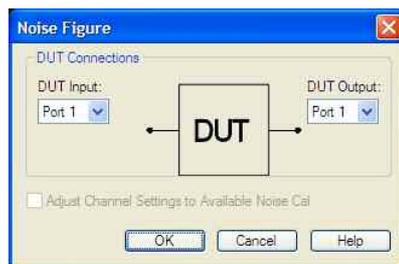
Additional ports have to be configured accordingly but can utilize the same measurement channel for instance if the frequency ranges etc. are equal.

Parallel measurement setup for 4 devices
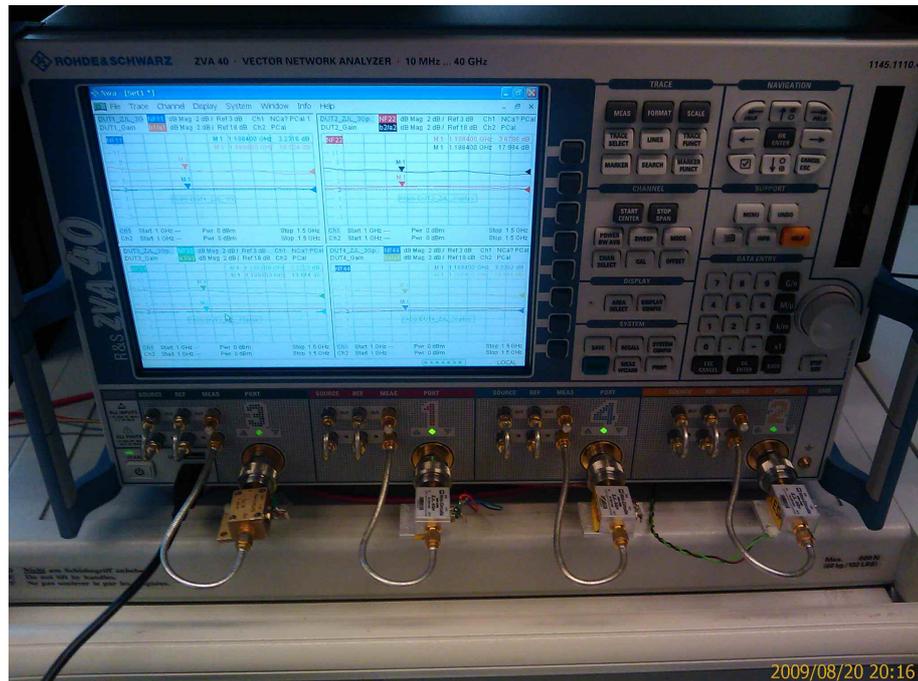
The setup also allows to measure the gain (e.g. b1/a1) of each DUT besides the noise figure.

Measurement result screen, NF and Gain for 4 devices in parallel

4 Ordering Information

Designation	Type	Frequency range	Order No.
Base Unit			
Vector Network Analyzer, 2 Ports, 8 GHz, N	ZVA8	300 kHz to 8 GHz	1145.1110.08
Vector Network Analyzer, 4 Ports, 8 GHz	ZVA8	300 kHz to 8 GHz	1145.1110.10
Vector Network Analyzer, 2 Ports, 24 GHz, 3.5 mm	ZVA24	10 MHz to 24 GHz	1145.1110.24
Vector Network Analyzer, 4 Ports, 24 GHz, 3.5 mm	ZVA24	10 MHz to 24 GHz	1145.1110.26
Vector Network Analyzer, 2 Ports, 40 GHz, 2.4 mm	ZVA40	10 MHz to 40 GHz	1145.1110.43
Vector Network Analyzer, 2 Ports, 40 GHz, 2.92 mm	ZVA40	10 MHz to 40 GHz	1145.1110.40
Vector Network Analyzer, 4 Ports, 40 GHz, 2.4 mm	ZVA40	10 MHz to 40 GHz	1145.1110.45
Vector Network Analyzer, 4 Ports, 40 GHz, 2.92 mm	ZVA40	10 MHz to 40 GHz	1145.1110.42
Vector Network Analyzer, 2 Ports, 50 GHz, 2.4 mm	ZVA50	10 MHz to 50 GHz	1145.1110.50
Vector Network Analyzer, 4 Ports, 50 GHz, 2.4 mm	ZVA50	10 MHz to 50 GHz	1145.1110.52
Vector Network Analyzer, 2 Ports, 67 GHz, 1.85 mm	ZVA67	10 MHz to 67 GHz	1305.7002.02
Vector Network Analyzer, 4 Ports, 67 GHz, 1.85 mm	ZVA67	10 MHz to 67 GHz	1305.7002.04
Options			
Direct Generator/Receiver Access, 2-Port Model, 8 GHz	ZVA8-B16	300 kHz to 8 GHz	1164.0209.08
Direct Generator/Receiver Access, 4-Port Model, 8 GHz	ZVA8-B16	300 kHz to 8 GHz	1164.0209.10
Direct Generator/Receiver Access, 2-Port Model, 24 GHz	ZVA24-B16	10 MHz to 24 GHz	1164.0209.24
Direct Generator/Receiver Access, 4-Port Model, 24 GHz	ZVA24-B16	10 MHz to 24 GHz	1164.0209.26
Direct Generator/Receiver Access, 2-Port Model, 40 GHz	ZVA40-B16	10 MHz to 40 GHz	1164.0209.40
Direct Generator/Receiver Access, 4-Port Model, 40 GHz	ZVA40-B16	10 MHz to 40 GHz	1164.0209.42
Direct Generator/Receiver Access, 2-Port Model, 50 GHz	ZVA50-B16	10 MHz to 50 GHz	1164.0209.50
Direct Generator/Receiver Access, 4-Port Model, 50 GHz	ZVA50-B16	10 MHz to 50 GHz	1164.0209.52
Direct Generator/Receiver Access, 2-Port Model, 67 GHz	ZVA67-B16	10 MHz to 67 GHz	1164.0209.67
Direct Generator/Receiver Access, 4-Port Model, 67 GHz	ZVA67-B16	10 MHz to 67 GHz	1164.0209.69
Generator Step Attenuator, Port 1, for ZVA8	ZVA8-B21	300 kHz to 8 GHz	1164.0009.02
Generator Step Attenuator, Port 2, for ZVA8	ZVA8-B22	300 kHz to 8 GHz	1164.0015.02
Generator Step Attenuator, Port 3, for ZVA8	ZVA8-B23	300 kHz to 8 GHz	1164.0021.02
Generator Step Attenuator, Port 4, for ZVA8	ZVA8-B24	300 kHz to 8 GHz	1164.0038.02
Generator Step Attenuator, Port 1, for ZVA24	ZVA24-B21	10 MHz to 24 GHz	1164.0109.02
Generator Step Attenuator, Port 2, for ZVA24	ZVA24-B22	10 MHz to 24 GHz	1164.0115.02
Generator Step Attenuator, Port 3, for ZVA24	ZVA24-B23	10 MHz to 24 GHz	1164.0121.02
Generator Step Attenuator, Port 4, for ZVA24	ZVA24-B24	10 MHz to 24 GHz	1164.0138.02
Generator Step Attenuator, Port 1, for ZVA40	ZVA40-B21	10 MHz to 40 GHz	1302.5409.02
Generator Step Attenuator, Port 2, for ZVA40	ZVA40-B22	10 MHz to 40 GHz	1302.5415.02
Generator Step Attenuator, Port 3, for ZVA40	ZVA40-B23	10 MHz to 40 GHz	1302.5421.02
Generator Step Attenuator, Port 4, for ZVA40	ZVA40-B24	10 MHz to 40 GHz	1302.5438.02
Generator Step Attenuator, Port 1, for ZVA50	ZVA50-B21	10 MHz to 50 GHz	1305.5616.02
Generator Step Attenuator, Port 2, for ZVA50	ZVA50-B22	10 MHz to 50 GHz	1305.5622.02
Generator Step Attenuator, Port 3, for ZVA50	ZVA50-B23	10 MHz to 50 GHz	1305.5639.02
Generator Step Attenuator, Port 4, for ZVA50	ZVA50-B24	10 MHz to 50 GHz	1305.5645.02
Generator Step Attenuator, Port 1, for ZVA67	ZVA67-B21	10 MHz to 67 GHz	1305.7077.02
Generator Step Attenuator, Port 2, for ZVA67	ZVA67-B22	10 MHz to 67 GHz	1305.7083.02
Generator Step Attenuator, Port 3, for ZVA67	ZVA67-B23	10 MHz to 67 GHz	1305.7090.02
Generator Step Attenuator, Port 3, for ZVA67	ZVA67-B24	10 MHz to 67 GHz	1305.7102.02

Designation	Type	Frequency range	Order No.
Receiver Step Attenuator, Port 1, for ZVA8	ZVA8-B31	300 kHz to 8 GHz	1164.0044.02
Receiver Step Attenuator, Port 2, for ZVA8	ZVA8-B32	300 kHz to 8 GHz	1164.0050.02
Receiver Step Attenuator, Port 3, for ZVA8	ZVA8-B33	300 kHz to 8 GHz	1164.0067.02
Receiver Step Attenuator, Port 4, for ZVA8	ZVA8-B34	300 kHz to 8 GHz	1164.0073.02
Receiver Step Attenuator, Port 1, for ZVA24	ZVA24-B31	10 MHz to 24 GHz	1164.0144.02
Receiver Step Attenuator, Port 2, for ZVA24	ZVA24-B32	10 MHz to 24 GHz	1164.0150.02
Receiver Step Attenuator, Port 3, for ZVA24	ZVA24-B33	10 MHz to 24 GHz	1164.0167.02
Receiver Step Attenuator, Port 4, for ZVA24	ZVA24-B34	10 MHz to 24 GHz	1164.0173.02
Receiver Step Attenuator, Port 1, for ZVA40	ZVA40-B31	10 MHz to 40 GHz	1302.5444.02
Receiver Step Attenuator, Port 2, for ZVA40	ZVA40-B32	10 MHz to 40 GHz	1302.5450.02
Receiver Step Attenuator, Port 3, for ZVA40	ZVA40-B33	10 MHz to 40 GHz	1302.5467.02
Receiver Step Attenuator, Port 4, for ZVA40	ZVA40-B34	10 MHz to 40 GHz	1302.5473.02
Receiver Step Attenuator, Port 1, for ZVA50	ZVA50-B31	10 MHz to 50 GHz	1305.5716.02
Receiver Step Attenuator, Port 2, for ZVA50	ZVA50-B32	10 MHz to 50 GHz	1305.5722.02
Receiver Step Attenuator, Port 3, for ZVA50	ZVA50-B33	10 MHz to 50 GHz	1305.5739.02
Receiver Step Attenuator, Port 4, for ZVA50	ZVA50-B34	10 MHz to 50 GHz	1305.5745.02
Receiver Step Attenuator, Port 1, for ZVA67	ZVA67-B31	10 MHz to 67 GHz	1305.7119.02
Receiver Step Attenuator, Port 2, for ZVA67	ZVA67-B32	10 MHz to 67 GHz	1305.7125.02
Receiver Step Attenuator, Port 3, for ZVA67	ZVA67-B31	10 MHz to 67 GHz	1305.7131.02
Receiver Step Attenuator, Port 4, for ZVA67	ZVA67-B32	10 MHz to 67 GHz	1305.7148.02
Oven Quartz (OCXO)	ZVAB-B4		1164.1757.02
Time Domain (TDR)	ZVAB-K2		1164.1657.02
Frequency Conversion Measurements	ZVA-K4		1164.1863.02
Vector Corrected Mixer Measurements	ZVA-K5		1311.3134.02
True Differential Measurements	ZVA-K6		1164.1540.02
Pulsed Measurements, 3 ms recording time, for all ZVA	ZVA-K7		1164.1511.02
Pulsed Measurements, 25 ms recording time, for all 2-port ZVA	ZVA-B7		1164.1492.02
Pulsed Measurements, 25 ms recording time, for all 4-port ZVA	ZVA-B7		1164.1492.03
Embedded LO Mixer Delay Measurements	ZVA-K9		1311.3128.02
Long Distance Group Delay Measurement	ZVA-K10		1164.1805.02
Cable Set for ZVA-K9	ZVA-B9		1311.3134.0x
5 MHz Receiver Bandwidth	ZVA-K17		1164.1070.02
Internal Pulse Generators	ZVA-K27		1164.1892.02
Noise Figure Measurement	ZVAB-K30		1164.1828.02
USB-to-IEC/IEEE Adapter	ZVAB-B44		1302.5544.02
Visa I/O Library	VISA I/O BIB		1310.0054.02

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Environmental commitment
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● Continuous improvement in environmental sustainability
● ISO 14001-certified environmental management system

Certified Quality System
ISO 9001

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