Application Note

OUTPUT POWER MEASUREMENT ON NOISE SOURCES

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Contents

1 Overview

Noise sources are used as a wideband source for white gaussian noise signals in many applications. Noise sources are not only used to measure noise figure and gain in the field of test and measurement, but they are also an important device to generate an AWGN (additive white gaussian noise) signal in carrier-to-noise ratio measurements or BER test scenarios. Another important application is found in BITE (build in test equipment) where they are used as a simple test signal with known output power.

Noise sources used for noise figure and gain measurements are typically controlled by the spectrum analyzer or noise figure meter instruments and are calibrated with their ENR value (Excess noise ratio). While this external control and the use of ENR values is common in noise figure test, it may be difficult in system applications where the noise source control is not available, and the use of ENR values is replaced with the values for the noise output power of the noise source. The calculation of the output power for the noise source requires to know the P_hot value (hot power) which is not a common specification for noise sources used in test and measurement applications.

This application note describes a technique to perform a calibrated noise power measurement (P_hot) with spectrum analyzers and noise sources. The next sections will give further details.

2 Noise figure measurement

2.1 Introduction

Measurements with noise sources are performed for a number of reasons. For instance, in a wide range of applications devices under test (DUT) are characterized for noise figure and gain by using broadband noise sources together with spectrum analyzers or noise figure meter using the Y-factor method. Key for this technique is a noise source with known noise output signal level that stimulates the device under test, and a sensitive receiver that captures the signal from the device. The noise figure and amplitude gain are derived from the measured Y-factor, which is the difference between the noise source ON and OFF states. More details on the noise figure measurement are explained in the next chapter.

In other applications like jamming, carrier to noise ratio tests or build in test applications, noise sources are used as wideband signals with precisely known RF level. By turning on the noise source and measuring the output level with a calibrated test system it is possible to derive precise values for system gain, noise figure or sensitivity. This application note describes a technique to perform the output power measurement for a noise source. The R&S®FSW-K30 noise figure measurement application performs this measurement using the Y-factor method. Key for this technique is a modified test process that allows separate measurements with the device under test for the hot and cold states of the noise source, and a sensitive spectrum analyzer that captures the signal from the device. Besides evaluating the noise figure, amplitude gain or Y-factor, the measurement application allows to measure the ENR of the noise source thus allowing a calculation of the output power in the hot state of the DUT. For a better understanding of the hot power measurement the next section will give further details on the noise figure and gain measurement principles.

2.1.1 Fundamentals of Noise figure measurements

The measurement described in this application note uses the Y-factor technique to measure noise figure and gain with a spectrum analyzer. This technique utilizes a characterized broadband noise source that contains two temperature states: A high temperature state T_{on}, with a higher output of noise power, and a low temperature state T_{off}, with reduced noise output (typically at room temperature). The noise source is connected to the DUT input.

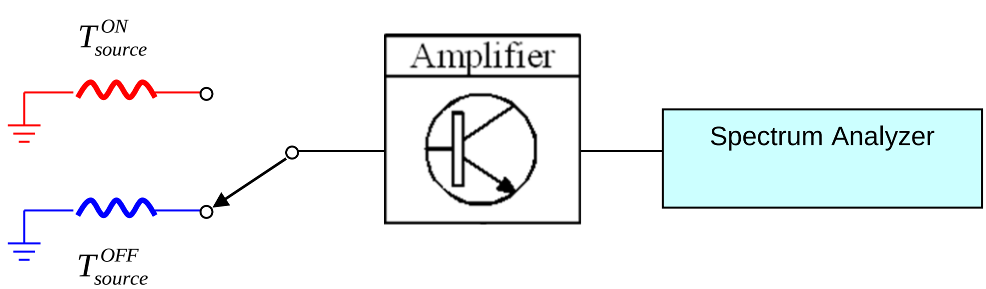

Figure 1: Principal Configuration for noise figure measurements

For the practical noise figure measurement with the spectrum analyzer, the noise source is switched On and Off and the noise power at the output of the DUT is measured for each of the two input noise states.

The required equipment for this task is a spectrum analyzer and a noise source. An integrated noise source control port (28 V supply for the noise source) in the spectrum analyzer is used to supply the noise source, switching it between its hot and cold states.

There are three primary steps for making the measurement:

– Calibration where the noise figure of the test equipment is measured
– Measurement of the DUT cascaded with the test equipment.
– Calculate of the DUT's parameters by using the cascaded noise figure equation.

Most modern spectrum analyzers offer a personality that will make the noise figure measurement automatically. The R&S®FSW-K30 Noise Figure measurement determines the noise figure and gain of the DUT within the user-defined frequency range. The noise source is switched on and off at every point and the average power is measured with the spectrum analyzer. Noise figure and gain are calculated from these measurements.

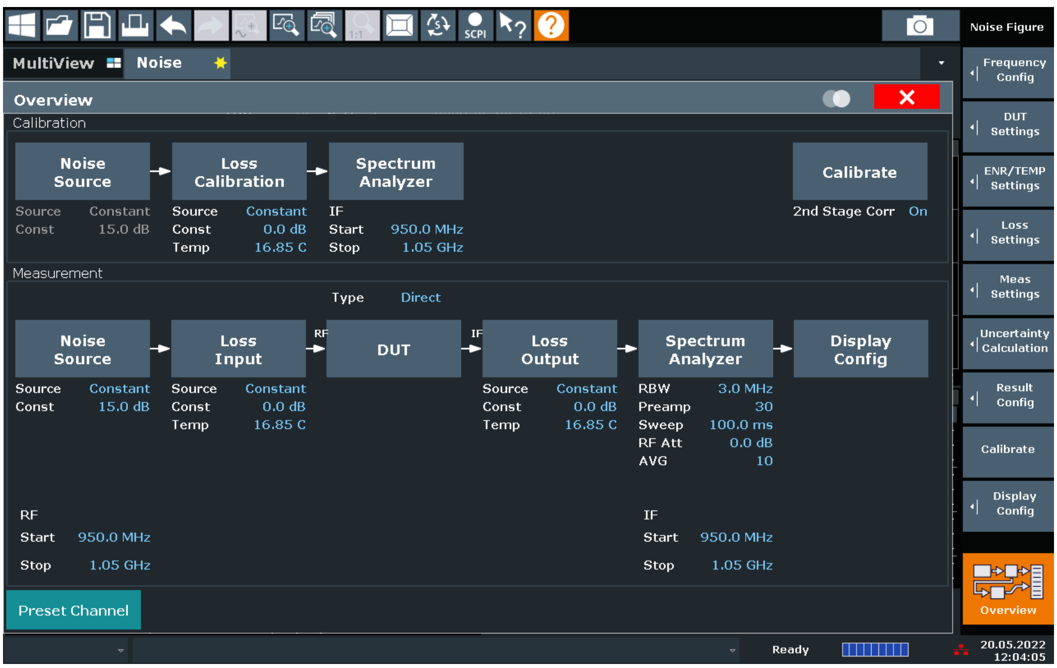

Figure 2: Overview window for noise figure application FSxx-K30

The above figure shows the measurement overview screen in the R&S®FSW-K30 Noise Figure application. The Noise Figure application also factors in any losses at the input and output of the DUT, compensating for items such as matching pads, isolators or attenuators. The impact of the temperature of the noise source on the measurement is automatically compensated. Measurements on frequency converting devices such as a mixer or a receiver (RF to IF) front end are possible as well.

Further details about the fundamentals of noise figure measurements are explained in the application note 1MA178 available on the Rohde & Schwarz website.

3 Noise Source measurement

Most Noise Sources designed for noise figure and gain measurements generate a very low level of noise power over a wide frequency range. The output signal is often generated by a simple noise diode followed by an attenuator and is specified as the ENR value (Excess Noise Ratio), which is:

$$ENR = 10 * \log\left(\frac{T_{hot} - T_{cold}}{290K}\right)$$

This is roughly the ratio of the noise power for the enabled noise source to the thermal power at room temperature. The ENR values of noise sources for noise figure tests range from 6 to 25 dB ENR. The noise source with 15 dB ENR is very common and available in most labs that perform noise figure measurements. In the next section the measurement of the ENR value for an unknown noise source is explained.

3.1.1 Fundamentals of Noise Source ENR measurements

The figure below shows the test setup for noise source measurements. It consists of the spectrum analyzer that performs and controls the noise source measurement, a commercial noise source with a known ENR and the unknown DUT noise source (DUT with unknown ENR or output power P_Hot). The spectrum analyzer controls (enables) the noise source control signal, in order to switch between the hot and cold states of the noise source.

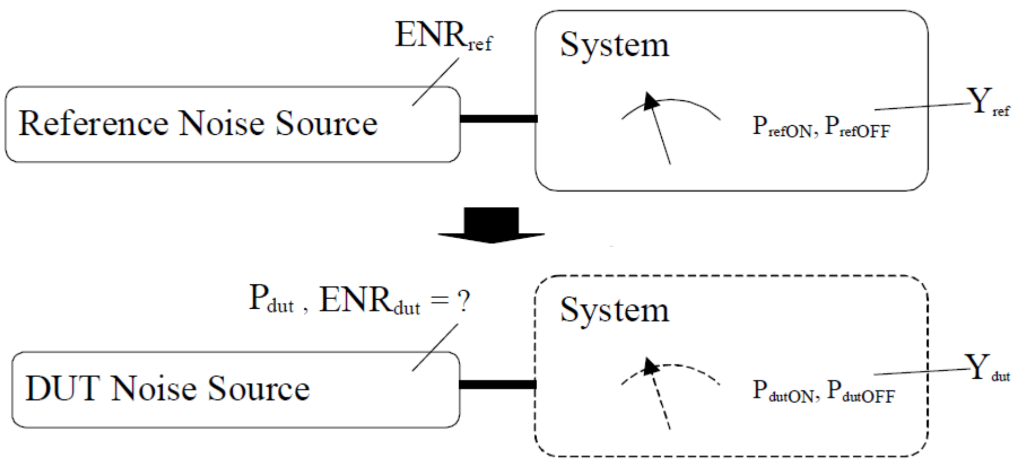

Figure 3: ENR measurement procedure

In a first step a calibration is carried out to determine P_{on} and P_{off} of the reference source. During the calibration measurement, a noise source (reference source with known ENR values) is connected directly to R&S®FSW.

When the calibration measurement is completed, the measurement is repeated to determine P_{on} and P_{off} of the unknown noise source (DUT). The ENR of the noise source can simply be calculated from the power readings and the ENR values from the reference source:

$$ENR_{dut} = ENR_{ref} + 10\log\left(\frac{Y_{dut} - 1}{Y_{ref} - 1}\right)$$

The ENR measurement of a noise source is possible with the R&S®FSW signal and spectrum analyzer. The ENR value is available as a measurement result in the R&S®FSW-K30 Noise Figure and Gain application software. In the noise figure and gain measurement, press the Display Config button and select ENR as measurement result.

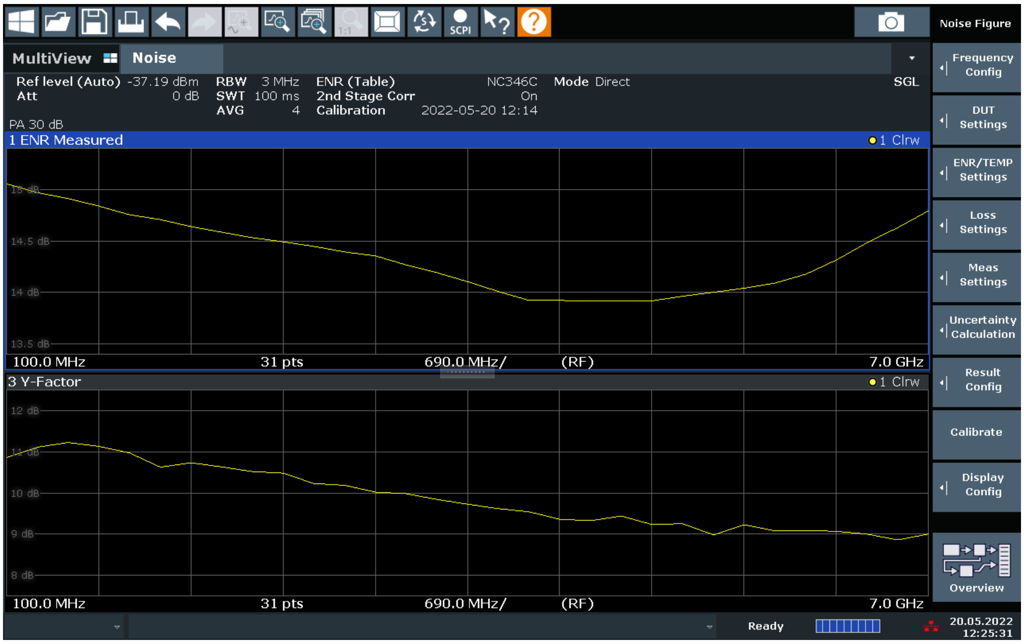

Figure 4: ENR measurement on a noise source

The above plot shows the ENR and Y-factor results of a noise source. The difference between the measured ENR and the measured Y-factor is the noise figure of the preamplifier in the R&S®FSW.

4 Output Power of a Noise Source

This chapter describes a test solution that derives the output power P_hot of a noise source from the ENR measurement. It is based on a commercial noise source for the calibration and an unknown wideband noise signal from any noise source or device under test. The tested noise signal does not need to be switched ON and OFF like the normal noise source in order to determine the P_hot value.

Values for noise power can be specified either as absolute power in dBm or Watt, or more common in values of power density like dBm/Hz as the total power depends on the measurement bandwidth. A value that most RF engineers know is the noise power density at room temperature (noise source off) in a 50 Ohm system, which is -174 dBm/Hz. The output power value of a noise source for the on state is typically given as the ENR in dB, this number can be converted in a noise density as well. With the definition of ENR as 10 log ({T_hot - T_cold} / 290 K) we can calculate the value for P_hot from ENR:

$$P_{hot} = -174\ dBm(Hz) + 10 * \log\left(10^{\frac{ENR}{10}} + 1\right)$$

Another common way to describe the output power P_hot from any noise source is to refer its power value to the noise power at the room or reference temperature of 290 K. As the measurements of noise power for hot and cold states are performed with the same bandwidth, this simplifies the handling of noise power values. The calculation from ENR to P_hot then becomes:

$$P_{hot} = 10 * \log\left(10^{\frac{\text{ENR}}{10}} + 1\right)$$

With the above formula it is possible to calculate the relative noise output power of the noise source for some ENR values in the range from -30 dB to +30 dB:

ENR	Power Density	P_Hot
+30 dB	-144 dBm/Hz	30 dB
0 dB	-171 dBm/Hz	3 dB
-30 dB	-174 dBm/Hz	0 dB

Figure 5: ENR, Noise power density and hot power values of a noise source

From this table we can observe that an active(hot) noise source with an ENR of 0 dB leads to a 3 dB increase in noise floor, something that is not expected by most engineers.

In the next chapter the setup to determine the hot power P_hot of any noise signal is explained.

4.1 Setup for noise power measurements of a noise source

The measurement of an unknown noise source is possible with the R&S®FSW signal and spectrum analyzer and the R&S®FSW-K30 Noise Figure and Gain application software. The normal operation of noise figure and gain measurements requires a control of the noise source states. The spectrum analyzer controls (enables) the noise source control signal, in order to switch between the hot and cold states of the noise source. In some cases, this control is not possible and the measurement for the hot and cold state of the noise source must be performed individually with manual control of the noise source states.

In a first step a calibration is carried out, in order to determine the noise figure and gain of the spectrum analyzer. During the calibration measurement, a reference noise source with known ENR values is connected directly to the analyzer RF input.

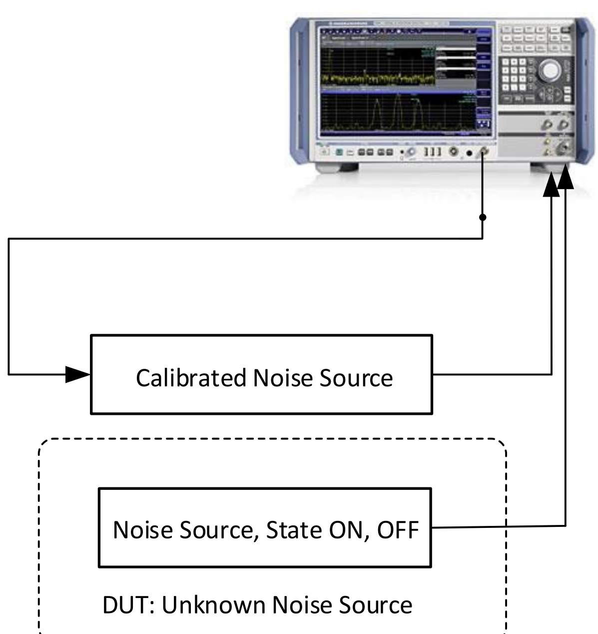

Figure 6: Manual ENR or P-hot measurement procedure

After the calibration it is recommended to perform a quick check of the calibration in order to verify the measurement results before making the measurement on the DUT. The next step is to disconnect the calibrated noise source and connect the DUT (i.e. noise source, noise generator, etc.). In case of a DUT that requires an external or manual control of the ON and OFF states for the noise signal, the operating mode of the R&S®FSW-K30 Noise Figure and Gain application software must be set at this time.

All required steps and a typical result are explained in the next section.

4.1.1 Calibration of the Noise figure measurement

Perform the following settings in the R&S®FSW-K30 Noise Figure and Gain application software:

- Set the measurement range and number of points (FREQUNCY SETTINGS).
- Select the ENR table from the reference Noise Source. (ENT/TEMP SETTINGS)
- Set the RBW, measurement time and averages according to your accuracy requirements
- Connect the reference source to the RF input and start the calibration (MEAS CONFIG).
- Replace the Noise Figure Result with the Measured ENR result (DISPLAY CONFIG).
- Press Run Single after the calibration is completed.

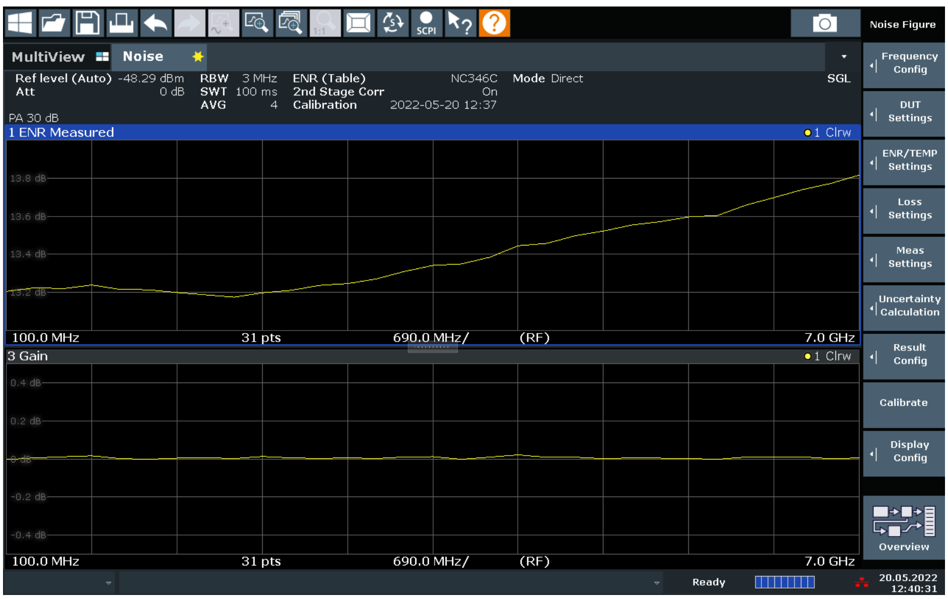

Figure 7: Measured ENR and Gain after the calibration

The results screen now shows the ENR values from the reference or calibration noise source. After a successful calibration the gain result shall be around 0 dB with very little trace noise. The calibration of a noise source with automatic control of the ON and OFF states from the analyzer is now possible with the same settings. Connect the DUT noise source and perform a single sweep, the measured ENR of the DUT is displayed on the screen. For noise sources with manual control of the state follow the procedure in the next chapter.

4.1.2 Measurement with manual noise source control

In some cases the manual control of the noise source states ON and OFF is required. A typical example for such a situation is a noise source that is embedded inside a test system with no direct access to the noise source control. Another example is a BITE noise source that is typically controlled direct by the software inside the DUT. In these examples the direct control of the states is not possible for the R&S®FSW-K30 Noise Figure and Gain application software. The measurements are still possible with the use of the manual mode, where the K30 allows the operator to select the state of the noise source and start a measurement according to the selected state.

The measurement requires calibration as described in the previous chapter for standard noise sources. After the completion of the calibration, the control of the noise source must be changed from automatic (state controlled by the instrument) to a manual mode (control by the user). Keep the reference noise source connected.

– Set the manual mode in the sweep menu (HARD KEY SWEEP - MEAS MODE MANUAL).

– Perform the first single measurement in the manual mode (HARD KEY - SINGLE SWEEP).

Figure 8: Manual Sweep Mode dialog

When the measurement is started in manual mode, a dialog opens that allows the user to select the measurement mode according to the actual state of the DUT noise source.

Note: For all measurements in the R&S®FSW-K30 Noise Figure and Gain software it is required to perform a cold measurement and a hot measurement in order to calculate all results. The noise source control (28V control from the analyzer) is automatically enabled when Measure P_Hot is selected, or it can be done manually inside the DUT.

► *Perform both measurement MEASURE P_HOT and MEASURE P_COLD in the manual mode.*

When both measurements are completed you get the ENR results from the reference noise source as described in the previous chapter.

– Connect the DUT noise source and repeat the measurement for the P-Hot state.

Figure 9: Measured ENR and Result table of DUT noise source

Now the ENR results of the DUT are displayed. For a better visibility of the results the plots can be replaced with the Result Table (DISPLAY CONFIG - RESULT TABLE). This allows easier reading of the results.

4.1.3 Calculation of the P_Hot noise source output power

The noise output power from the DUT can now be calculated from the ENR in the above measurement:

$$P_{hot,density} = -174\ dBm(Hz) + 10 * \log\left(10^{\frac{ENR}{10}} + 1\right)\ ;\ P_{hot} = 10 * \log\left(10^{\frac{\mathrm{ENR}}{10}} + 1\right)$$

With the above formula it is possible to calculate the noise output power of the noise source. Some examples from the above result table:

ENR	P_hot,abs	P_hot
3.32 dB	-169,02 dBm/Hz	4,98 dB
3.08 dB	-169,18 dBm/Hz	4,82 dB
3.13 dB	-169,15 dBm/Hz	4,85 dB

Figure 10: ENR, Noise power density and P-hot values of a noise source

The table above shows the P-hot values for the DUT noise source measured in the ON (hot) state. It is possible to omit the OFF (cold) measurement and use the cold values from the calibration source, as both noise sources are presenting a match to the analyzer and the result of this measurement is similar.

5 Conclusion

A R&S®FSW signal and spectrum analyzer equipped with the R&S®FSW-K30 Noise Figure and Gain measurement application forms the basis of a solution to accurately measure noise figure and gain using the Y-factor method.

With the implementation of the ENR measurement result, the functionality of the noise figure and gain measurement is extended to cover measurements on noise sources. This function can be used to calibrate ENR values of noise sources and determine the values for the output power P_Hot, which are required for many test scenarios outside the traditional noise figure and gain test.

6 Literature

[1] Application Note 1MA178, The Y Factor Technique for Noise Figure Measurement

[2] Application Note 1EF103, Pulsed Noise Figure measurements

[3] Application Note 1EF110, Measurements on devices with very high noise figure

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