Application Note

MEASUREMENTS ON DEVICES WITH VERY HIGH NOISE FIGURE

Products:

- ► R&S®FSW
- ► R&S®FSWP
- ► R&S®FSW-K30
- ► R&S®FS-SNS

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Contents

1 Overview

Measurements of very high noise figure components are performed for a number of reasons. For instance, in a wide range of applications, devices under test (DUT) are characterized within a complex test setup that includes high losses before or after the low noise DUT. In case of high frequencies, the switch matrix with complex signal routing and cables might have a very high loss. In other cases, the device might be embedded in a test setup where direct access is physically impossible, on-wafer probing is one example for this case. Using conventional measurement equipment, the noise figure measurement of such a device is very unstable if not impossible at all.

This application note describes a technique to perform the noise figure measurement on lossy devices like attenuators, or on devices embedded into in test setups with high loss in front of the low noise amplifiers. The R&S®FSW-K30 noise figure measurement application performs this important measurement with a signal and spectrum analyzer using the Y-factor method. Key for this technique is a modified noise source with high level noise output signal that stimulates the device under test, 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 modified noise source this allowing precise measurements. The next sections will give further details.

2 Noise Figure Measurement

2.1 Fundamentals of Noise Figure Measurements

The measurement described in this application note uses the Y-factor technique to measure noise figure 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.

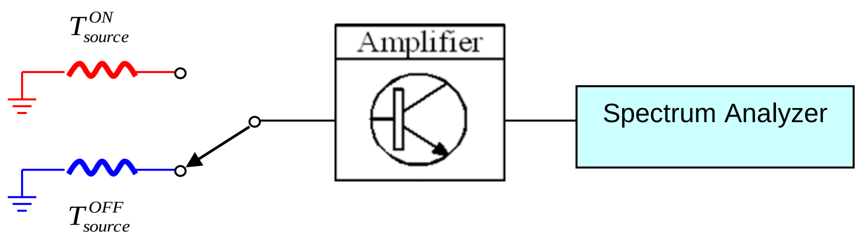

Figure 1: Principal Configuration window for making noise figure measurements

Noise sources are commonly specified by their excess noise ratio (ENR), which is expressed in dB. The ENR value describes the additional noise output signal when the noise source is active. The calibrated ENR values supplied by the noise source manufacturer are generally referenced to 290 K (T_0). Typical values for common noise sources are 6 dB and 15 dB ENR.

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.

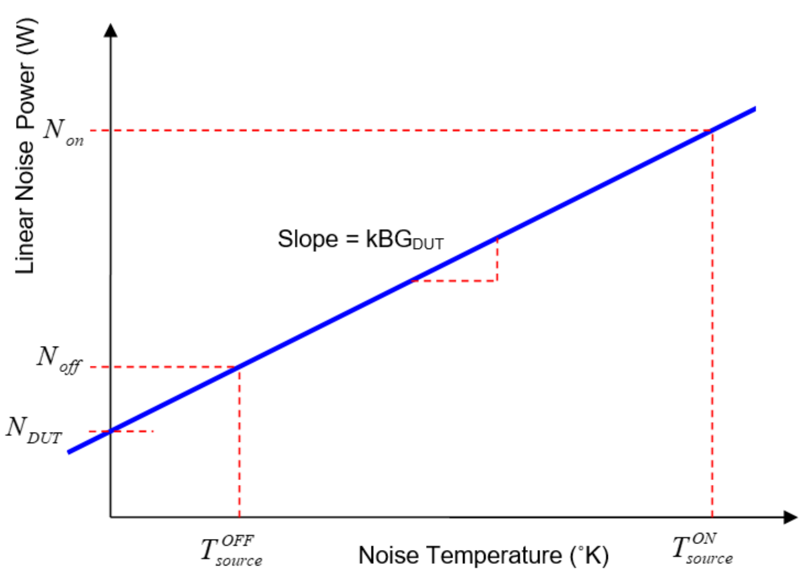

Figure 2: Diagram showing the Y factor variables

These two measurements establish a line (see figure above) from which the DUT gain G_{DUT} can be determined. The Y-intercept indicates the noise N_{DUT} added by the DUT. Noise figure and gain are calculated from these measurements. Further details about the fundamentals of noise figure measurements are explained in the application note 1MA178 available on the Rohde & Schwarz website.

3 Difficulties with high Noise Figure Devices

As described in the chapter fundamentals of noise figure measurements, the main part is to acquire accurate power readings for the two states of the noise source. The linear ratio between the two power values N_{on} and N_{off} is also called the Y-factor ($Y = N_{on} / N_{off}$). With the knowledge of the ENR and the measured Y-factor the noise figure can be estimated with the following simplified formula: $F_{dB} = ENR_{dB} - 10 * \log(Y-1)$.

The accuracy of the noise figure measurement depends on the stability of the power readings and on the relative difference between N_{on} and N_{off}. This difference itself depends on the ratio between the measured noise figure and the ENR of the noise source. For a DUT with high loss at the input (or with high noise figure, which is similar) the signal from the noise source is attenuated in the loss in front of the DUT. This leads to a very small measured difference between the noise source on-state and the off-state power readings. As the measurement itself is a noise power measurement, the readings will show high fluctuations from measurement to measurement, and these fluctuations will lead to noise figure results that are extremely unstable.

For a better understanding the effect of the level variation is illustrated in the following Y-factor diagram:

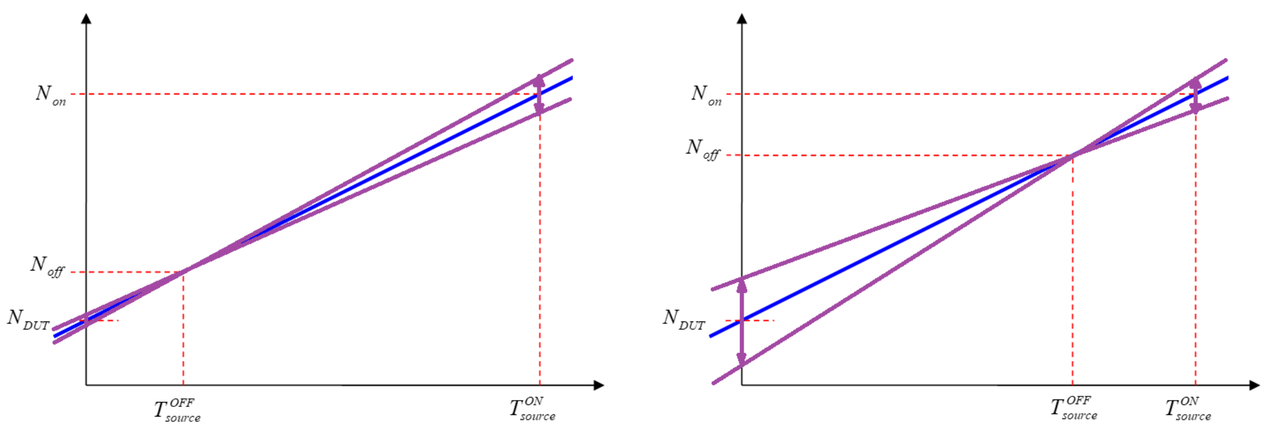

Figure 3: Comparing measurements with high and low ENR to NF ratio

In practice both measurements of N_{on} and N_{off} will vary to a certain extend due to the fact that we are measuring noise. The measurement bandwidth, measurement time and number of averages influence the variation of the power reading. For simplicity and visibility the above diagrams only display one variation of the measurement, in practice both measurements are suffering from the same effect.

In a measurement case with medium or high ENR (5 to 15 dB) and low noise amplifier (< 5 dB) as illustrated on the left side, the fluctuations of the power readings (as shown for the N_{on} case) will lead to small variations of the calculated N_{DUT}. This is the typical case of noise figure measurements on low noise amplifiers with noise figure below 5 dB and direct connection of the noise source.

The illustration on the right side shows the measurement case with a low ENR to noise figure ratio. This is a very common scenario in noise figure measurements. One typical example is a test system with a lot of switches, cables or other loss devices in front of the low noise amplifier that shall be tested. Another example is the measurement of a passive device with attenuation, or a power amplifier with high noise figure. In these situations the difference between the measurements of N_{on} and N_{off} becomes small, and the variations of these readings lead to a very high variation of the calculated noise figure of the device.

If the attenuation or noise figure is above the ENR value, the noise figure measurement becomes very unstable and impractical. The best possibility to solve this task is to use a noise source with high ENR.

3.1 The effect of ENR and DUT Noise Figure

The absolute value of the ENR and the DUT noise figure have a direct impact on the measurement accuracy. The noise figure measurement in the R&S®FSW signal and spectrum analyzer has a built-in uncertainty calculator that supports the user to decide whether the setup will produce reliable measurement results. The following measurement guidelines help to make reliable measurements:

► (ENR) – (NF of SA) > 3 dB

► (ENR) – (NF of DUT) > 5 dB

► (NF of DUT) + (Gain of DUT) – (NF of SA) > 5 dB

These guidelines ensure that the instrument will make accurate noise figure measurements. The first item in the list ensure that the ENR of the noise source is above the noise figure of the spectrum analyzer. Noise figure measurements are typically performed with a so called second stage correction, which takes out the effect of the test instrument on the DUT noise figure result. This first item makes sure that the second stage calibration is performed with sufficient accuracy. The second item in the list verifies that the ENR is sufficient higher than the DUT noise figure, which has a direct impact on the measurement accuracy and therefore uses a bit more margin as the first item. The last item verifies the cold power measurement of the DUT to be sufficient higher than the noise floor of the spectrum analyzer. This test is easy to fulfill in most cases when the DUT has gain above 15 dB.

The guidelines are not stringent rules that "must" be fulfilled and shall only be used to prevent the users from extremely wrong results. The effect of the ENR to noise figure ratio on the accuracy of the noise figure calculation is visualized in the following plot:

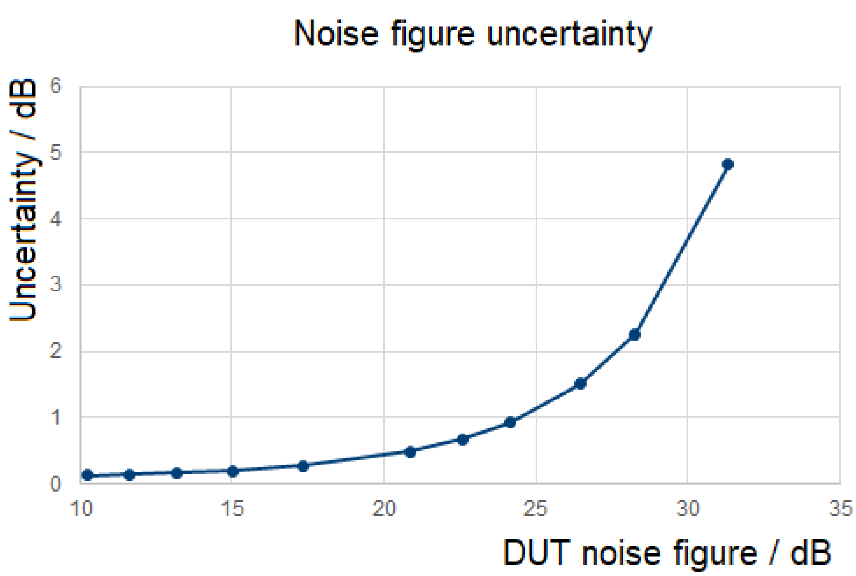

Figure 4: Noise Figure uncertainty versus NF for a given ENR of the noise source

The calculation used in this plot is based on a noise source with 15 dB ENR and 0.1 dB measurement repeatability for the Y-factor due to noise in the readings (variation of subsequent power readings). For low noise figure DUTs we can find the 0.1 dB variation in the noise figure, there is a direct, proportional behavior between the readings and the results.

Once the noise figure exceeds the ENR of the noise source, the uncertainty rises very fast. For noise figures 5 to 10 dB above the ENR measurements are possible, but require an increased amount of averages to produce reliable results. For measurements above these values a noise source with increased ENR is needed.

4 Test setup for a DUT with high Noise Figure

The availability of noise sources with ENR above 15 dB is very limited. There are some models available with 25 dB ENR, but they are not very common. The noise source with 15 dB ENR is very common and available in most labs that perform noise figure measurements.

This chapter describes a test solution that overcomes the ENR limitations. It is based on a commercial noise source with ENR values of 6 to 15 dB and a commercial wideband amplifier to boost the wideband noise signal from the noise source to higher levels required for passive devices like attenuators, power amplifiers with high noise figure and other scenarios.

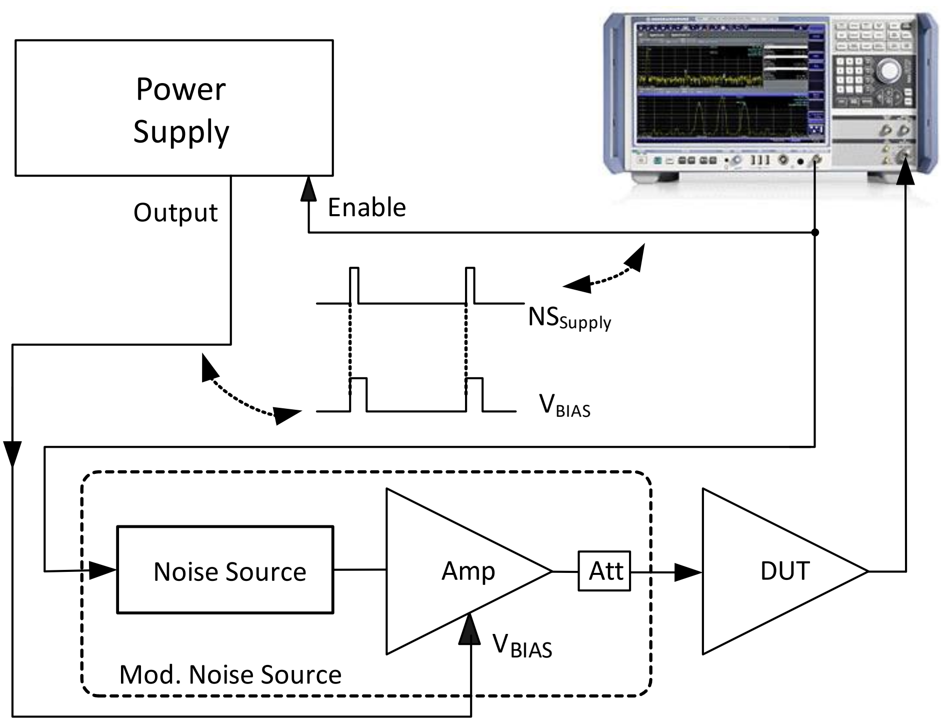

Figure 5: Test setup for DUT with high noise figure

The figure above shows the test setup for high noise figure measurements. It consists of the spectrum analyzer that performs and controls the noise figure measurement, the DUT, a power supply, a commercial noise source with low or medium ENR, a wideband amplifier connected to the noise source output and an attenuator for matching purposes. The power supply generates the required bias for the wideband amplifier that boosts the noise signal. The spectrum analyzer controls (enables) the power supply output synchronous to the noise source control signal, in order to activate the noise source and the amplifier at the same time interval. The matching pad behind the amplifier ensures a good matching of the DUT for the cold power measurement, as the amplifier is not biased at this time and may present a bad matching to the DUT.

The control of the amplifier bias is a very important feature of the setup. If the amplifier operates in continuous mode and only the noise source is controlled by the spectrum analyzer, the cold power at the DUT RF input would be defined by the amplifiers noise figure and gain. For accurate noise figure measurements it is required that the cold temperature (cold power) is equal to room temperature set in the measurement application.

There might be cases where the supply voltage of the amplifier cannot be switched. One important reason is the temperature depending gain stability of the amplifier, that will have a direct impact on the achievable accuracy of the effective output ENR. In this case another possible solution is to use a RF switch behind the attenuator to switch between the hot signal (output of the active noise source and amplifier) and a cold signal, represented by a 50 Ohm termination on the switch Off-state connection. The RF switch can be directly driven from the noise source control signal that delivers 28 V and max 100 mA.

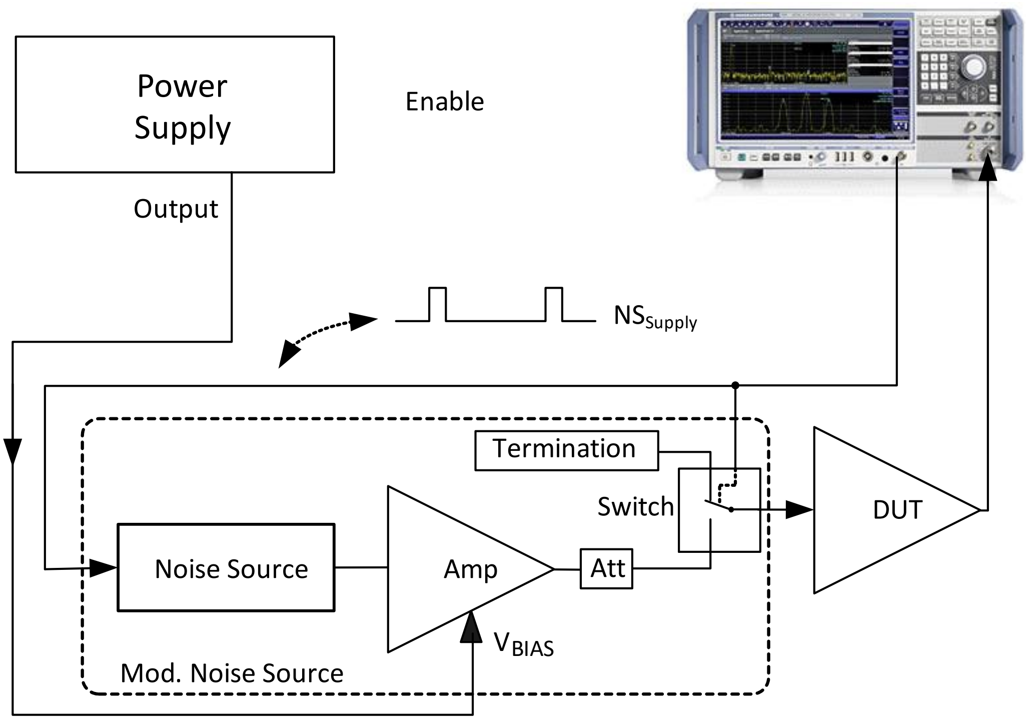

Figure 6: Test setup for DUT with high noise figure

In order to determine the effective ENR at the output of the "modified noise source" (noise source, amplifier and matching pad, maybe switch) the sum of the output noise power must be calculated. The output signal consists of the hot power from the noise source (defined by the ENR) and the additive part of the amplifier input noise power (defined by the noise figure). Both signals are amplified with the gain of the broadband amplifier and then attenuated at the output of the modified noise source. All these calculations must be done in the linear or power domain, it is not possible to just add the dB figures.

5 ENR Measurement of the Noise Source

In a first step a calibration without any device under test (DUT) 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 without the amplifier and the attenuator. This calibration step can be done with the same noise source that will be used for the modified noise source in the next step.

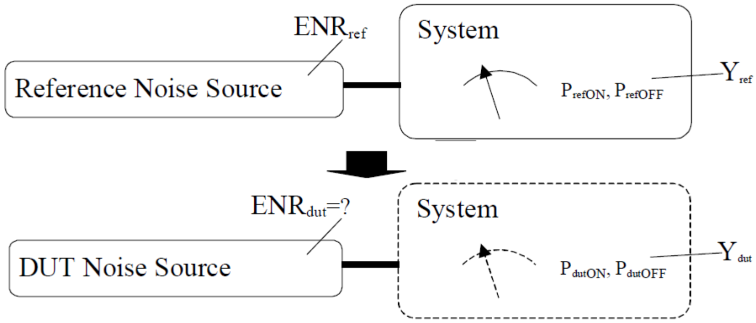

Figure 7: ENR measurement procedure

When the reference measurement is completed, connect the modified noise source and repeat the measurement to determine P_{on} and P_{off} of the modified noise source (DUT). The ENR of the new 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 measurement of the effective ENR is also possible with the R&S®FSW signal and spectrum analyzer. The ENR is available as a measurement result in the R&S®FSW-K30 Noise Figure and Gain application software.

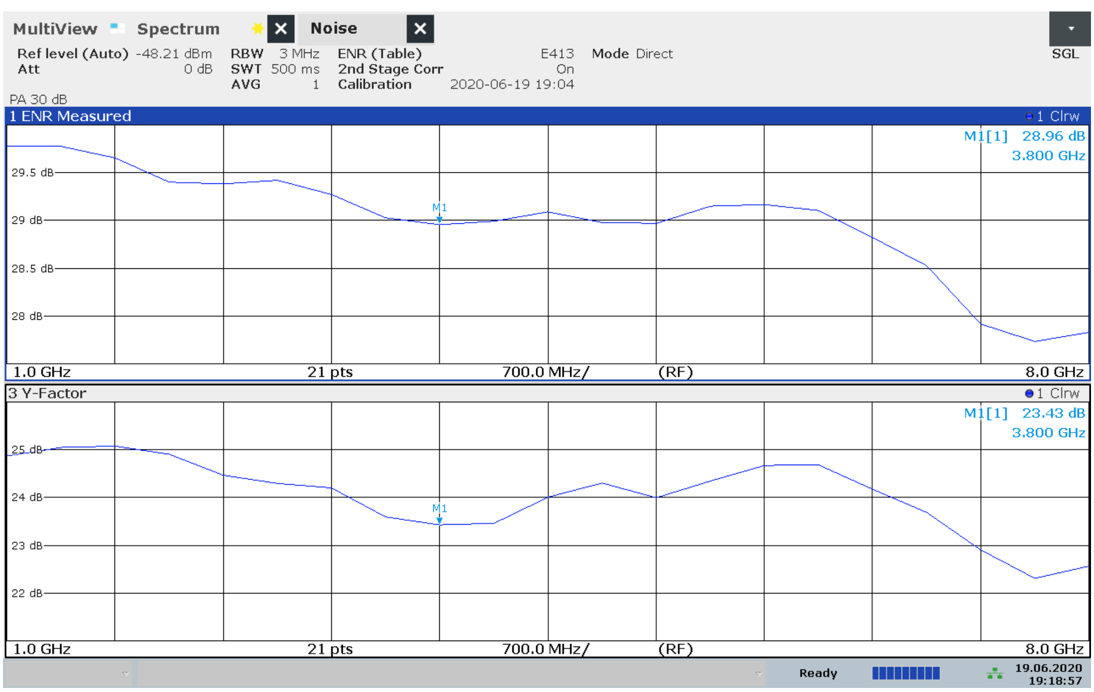

Figure 8: ENR measurement on the modified noise source

The above plot shows the ENR and Y-factor results of a modified noise source. In this test case the amplifier was biased along with the noise source. In the noise figure and gain measurement, press the Display Config button and select ENR as measurement result. The difference between the measured ENR and the measured Y-factor equals the noise figure of the preamplifier in the R&S®FSW.

6 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. The integrated uncertainty calculator is a powerful tool that takes into account all setup parameters such as VSWR, ENR uncertainty and additional attenuators and filters for error calculations.

With the new 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 create your own modified noise sources with higher ENR values, which are required for test scenarios including attenuators, power amplifiers and test systems. The same function can also be used to verify the ENR values of existing noise sources against a known reference noise source.

7 Literature

[1] R&S®FSW Signal and Spectrum Analyzer – Product Brochure

[2] R&S®FSW Signal and Spectrum Analyzer – Data Sheet

[3] R&S®FSW-K30 Noise Figure Measurement – Data Sheet

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

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