

ROY MONZELLO
RF/Microwave Design Engineer
E-mail: roy.monzello@gmail.com

Measure Noise Without A Calibrated Source

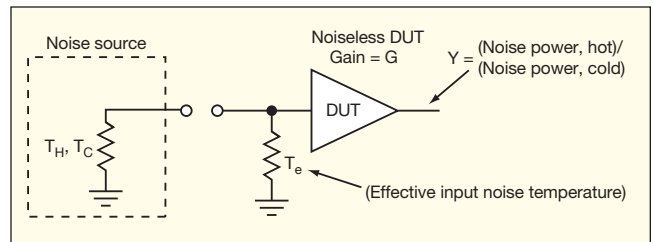
This new technique is based on a variation of the Y-factor method to achieve accurate noise-figure measurements without the need for a calibrated noise source.

MANUAL NOISE-FIGURE measurements are often necessary when automated measurement systems are not available. One of the more popular techniques for making noise-figure measurements is the Y-factor method, which is accomplished with the aid of a hot/cold noise source to provide two different noise power levels (for this article, cold will be assumed at 290K). The difference between the two noise power levels is the excess noise ratio (ENR), which is given numerically by $(T_H - T_C)/T_C$, where T_H represents the hot temperature and T_C is the cold temperature. Under true impedance-matched conditions, the actual available noise power would be equal to kTB , where k is Boltzmann's constant ($1.3806503 \times 10^{-23} \text{ m}^2\text{kg/s}^2\text{K}$), T is the temperature (in degrees Kelvin) or S/B (in Kelvin), and B is the bandwidth of the circuit under test.

The Y-factor is the ratio of output noise power from a device under test (DUT) with the noise source set to hot, divided by the output noise power with the noise source set to cold. Using the Y-factor approach, the noise figure of a DUT can be calculated by using Eq. 1:

$$\text{Noise figure of DUT} = 10\log_{10}[\text{ENR}/(Y - 1)] \tag{1}$$

where ENR is the numerical ratio of the ENR in dB, or $\text{ENR} = 10^{(\text{ENR}/10)}$. The ENR is defined as $(T_H - 290)/290$. **Figure 1** shows a typical setup for measuring the Y-factor. The resistor in the noise source is a fictitious component with a body temperature that can be changed to produce different levels of output noise power.



1. This basic circuit is used to evaluate the Y-factor of a DUT when using a calibrated noise source.

The resistor at the input of the DUT, T_E , represents a fictitious resistor at a temperature of T_E K that, when multiplied by the gain of the DUT, would produce the proper amount of noise at its output corresponding to its internally generated noise. The input noise temperature is related to the noise figure by Eq. 2:

$$T_E = 290(\text{NFac} - 1) \tag{2}$$

where NFac, the noise factor, is the numerical value of the noise figure—e.g., $\text{NFac} = 10^{[(\text{Noise Figure})/10]}$.

As shown in **Fig. 1**, the standard circuit for a noise figure measurement is simple and can provide an accurate measurement of the DUT's noise figure if one were able to accurately measure the output noise power of the DUT. Since an instrument must be used to make the noise power measurement at the output of

the DUT, the noise power measurement is a composite of the noise power coming out of the DUT, along with the internal noise generated by the measuring device (for manual measurements, the

Table 1: Noise figures measured for the spectrum analyzer, using standard and variation Y-factor methods.

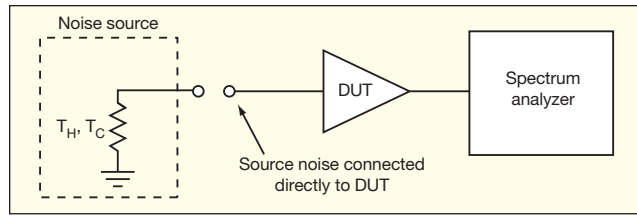
ENR (dB)	Noise temp.	Measured P ₀ (dBm)	T _i	dT _i	dENR	Y-factor	dY	dY/dENR	Nfac	Nfig	Standard Y-factor method Nfig
---	290 K	-131	6017.6								
15.30	10116.5 K	-126.9	15467.7	9450.1	32.59	2.57	---	---	---	---	13.34
20.15	30309.1 K	-123.3	35434.5	19966.8	68.85	5.89	3.32	0.048	20.75	13.17	13.26

measuring instrument is usually a spectrum analyzer).

Spectrum analyzers usually have a large noise figure in the 20-to-30 dB range or, for more sophisticated instruments with an internal preamplifier, the noise figure may be reduced to the 10-to-15 dB range. The typical procedure for making a

noise-figure measurement is to first measure the noise figure of the spectrum analyzer by placing the noise source directly on the analyzer's input port. A measurement is then made with the DUT placed between the noise source and the input to the spectrum analyzer, as shown in Fig. 2. Once the two measurements have been made, the noise figure of the device is calculated from the following equations:

$$\text{Noise factor of spectrum analyzer} = \text{ENR}/(Y_{SA} - 1) = \text{NF}_{SA} \quad (3)$$



2. A spectrum analyzer can also be used for measuring the noise figure of a DUT.

Total noise factor of the DUT plus the spectrum analyzer:

$$\text{NF}_{\text{TOTAL}} = \text{ENR}/(Y_{\text{TOTAL}} - 1) \quad (4)$$

$$\text{Noise factor of the DUT} = \text{NF}_{\text{TOTAL}} - (\text{NF}_{SA} - 1)/G_{DUT} \quad (5)$$

where G_{DUT} is the gain of the DUT.

The novel noise-measurement approach about to be described follows the procedure for first characterizing the noise figure of a spectrum analyzer, and then evaluating the noise of a DUT in cascade

with the analyzer. One important difference is that results with the new method are obtained by means of the derivative of the Y-factor. Measurements are independent of the absolute value of the input excess noise level to the DUT and eliminate the need for a calibrated noise source.

The new method begins with the standard equation for the noise factor of a DUT, given the ENR of the noise source and a Y-factor measurement as detailed in Eq. 6:

$$\text{NF}_{\text{Fac}} = \text{ENR}/(Y - 1) \quad (6)$$

Rearranging terms results in Eq. 7:

$$Y = \text{ENR}/\text{NF}_{\text{Fac}} + 1 \quad (7)$$

Taking the derivative of each side with respect to the ENR yields Eq. 8:

$$dY/d\text{ENR} = 1/\text{NF}_{\text{Fac}} \quad (8)$$

which leads to Eq. 9:

$$\text{NF}_{\text{Fac}} = 1/(dY/d\text{ENR}) \quad (9)$$

What this shows is that the noise factor of a DUT can be determined without knowing the absolute ENR; only the difference in ENR, which results in a difference of the Y-factor measurement, is needed. This new noise factor approach consists of making two Y-factor measurements at two different noise power levels at the input of the DUT. These two Y-factor values, along with the corresponding source noise power values, provide the information needed to construct the ΔY and ΔENR values. These will produce the slope or $dY/d\text{ENR}$, producing the noise factor result according to Eq. 9.

The method used to vary the ENR involved using an arbitrary source of noise power (e.g., a high-gain amplifier) with its noise output level controlled by a step attenuator. This produces a range of ENR values based on the setting of the step attenuator. This method does not

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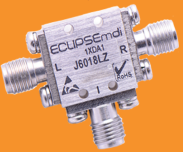
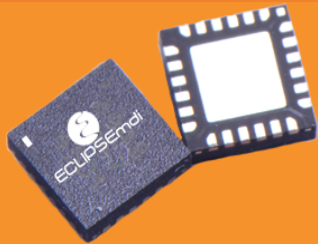
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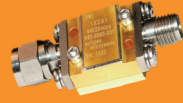
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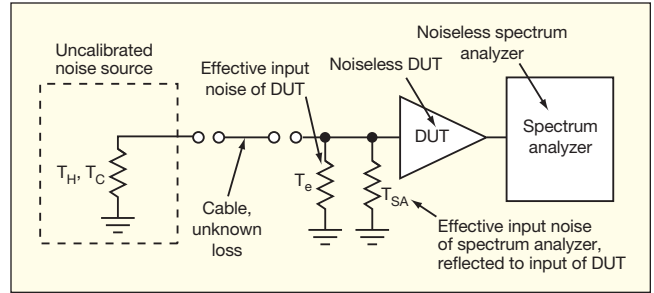


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NOISE FIGURE MEASUREMENTS

3. A spectrum analyzer can also be used when measuring the change in ENR of an uncalibrated noise source to check the noise figure of a DUT.



require knowledge of how much noise power is being generated, nor details about the attenuation characteristics of the step attenuator. The only purpose of the noise source/attenuator is to provide two different levels of noise power. This also means that a cable with unknown loss characteristics can be used to connect the noise source/attenuator to the DUT without impacting the noise-figure calculations.

The key to this new noise measurement approach is to determine the change in ENR at a DUT's input, using power readings from the spectrum analyzer translated to the input plane of the DUT. For example, if the spectrum analyzer reads -121 dBm, and the gain between the input to the DUT and the input to the spectrum analyzer is 15 dB, then the translated noise power at the input reference plane of the DUT would be -136 dBm. The noise temperature model of Fig. 3 shows how the internal noise power generated by the analyzer can be translated to the input reference plane of the DUT as an effective input noise temperature. The effective input noise power at the input to the DUT is a composite of three sources:

1. The input noise power (generated by the noise source);

2. The effective input noise power of the DUT (related to the noise figure of the DUT); and

3. The effective input noise power of the spectrum analyzer translated to the input of the DUT (related to the noise figure of the spectrum analyzer).

This can be written as:

$$P_{n1} = KB(T_{H1} + T_{DUT} + T_{SA}) \quad (A)$$

and

$$P_{n2} = KB(T_{H2} + T_{DUT} + T_{SA}) \quad (B)$$

where $P(p)_{ni}$ is defined as the effective input noise power into the DUT for different values of hot input temperature, T_{Hi} , and is determined from the measurements by:

$$P(p)_{ni} = 10[(P_{dB \text{ MEASURED}} - \text{Gain}_{dB})/10]$$

and where parameter Gain_{dB} represents the small-signal gain (in dB) from the input of the DUT to the input of the spectrum analyzer.

Taking the difference of the two noise powers, $P(p)_{n2} - P(p)_{n1}$, yields Eq. 10:

$$\Delta P_n = KB(T_{H2} - T_{H1}) \rightarrow (T_{H2} - T_{H1} = \Delta P_n / KB) \quad (10)$$

Table 2: Noise figure of the spectrum analyzer determined by using the difference in ENR directly from calibrated noise source data.

ENR linear	Noise temp.	Measured P_0 (dBm)	dENR	Y-factor	dY	dY/dENR	Nfac	Nfig
---	290 K	-131						
15.30	10116.5 K	-126.9	---	2.57	---	---	---	---
20.15	30309.1 K	-123.3	69.63	5.89	3.32	0.05	20.99	13.22

At this point, it is necessary to solve for ΔENR by means of Eq. 11:

$$\text{ENR}_1 = (T_{\text{H1}} - 290)/290$$

and

$$\text{ENR}_2 = (T_{\text{H2}} - 290)/290 \rightarrow \Delta\text{ENR} = \text{ENR}_2 - \text{ENR}_1 = (T_{\text{H2}} - T_{\text{H1}})/290$$

and from Eq. 10,

$$\rightarrow \Delta\text{ENR} = \Delta P_n / (290KB) \quad (11)$$

Parameter dY can be calculated from Eq. 12:

$$Y_1 = 10^{(P_{n1} - P_{n0})/10}$$

and

$$Y_2 = 10^{(P_{n2} - P_{n0})/10} \quad (12)$$

where P_n is in dBm and P_{n0} is the noise power measured on the spectrum analyzer with an input noise power to the DUT of 290 K (the input of DUT terminated with a matched load at 290 K):

$$\rightarrow \Delta Y = Y_2 - Y_1 \quad (13)$$

To evaluate the new noise figure test method, measurements were made of a spectrum analyzer's noise figure (with the preamplifier turned on) using two calibrated noise sources. Using the standard Y-factor method for the two different ENR noise heads,

a noise figure of 13.34 dB was measured for the ENR head with 15.30 dB value. For the second calibrated noise source, with an ENR value of 20.15 dB, the standard Y-factor method yielded a spectrum analyzer noise figure of 13.26 dB. Using the new method detailed in this article yielded a noise figure of 13.17 dB for the two different ENR noise heads (Table 1).

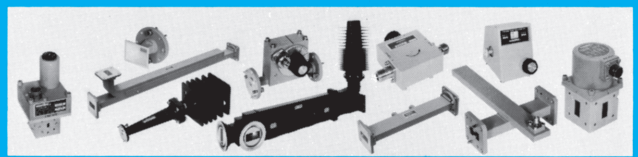
The noise figure of the spectrum analyzer was also evaluated by means of a method in which the difference of the two ENR noise heads is used with the calibrated noise source data. This is the new method detailed in this report, in which the difference in ENR is determined by taking the difference in the ENR values of the calibrated noise sources (Table 2). The value of the spectrum analyzer's noise figure from this approach, at 13.22 dB, was roughly between the values of the first measurement approach and the result from this new approach. Additional measurements were made [results available in the online version of this article (www.mwrf.com) as Tables 3, 4, and 5] to show the effectiveness of the new method using a model HP 8970A noise figure test set from Hewlett-Packard/Agilent Technologies (www.agilent.com), with results available for both the measurement equipment and the amplifiers under test.

In summary, a manual noise figure test method has been presented which eliminates the need for a calibrated noise source. The method is as accurate as the previous Y-factor method, while eliminating the expense and calibration routine associated with a calibrated noise source. The method allows the use of a lossy test cable to connect the noise source to the DUT without any need to account for the cable's loss in the noise figure calculations. The accuracy of this method will also depend upon such parameters as measured gain accuracy and ambient room temperature. MWRF

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