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IMPLEMENTATION OF Y-FACTOR METHOD FOR NOISE FIGURE MEASUREMENT USING EMI MEASURING RECEIVER

NENAD MUNIĆ
Technical Test Center, Belgrade, nenadmunic@yahoo.com

ALEKSANDAR M. KOVAČEVIĆ
Faculty of technical sciences, University of Kragujevac, Čačak, aleksandarkovacevic1962@yahoo.com

NENKO BRKLJAČ
Technical Test Center, Belgrade, brkljacnenko@gmail.com

LJUBIŠA TOMIĆ
Technical Test Center, Belgrade, ljubisa.tomic@gmail.com

MIROSLAV JOVANOVIĆ
Technical Test Center, Belgrade, jovanovic.miroslav.77@gmail.com

Abstract: *This paper presents the implementation of the Y-factor method for noise figure measurement using the EMI measuring receiver. The measurement results of the new method were compared with the results obtained using noise figure meters. Measurement results were compared using z-score criteria. The comparison of results was performed in order to confirm the accuracy of the new method.*

Keywords: *Noise figure, Y-factor method, Noise figure meters, z-score, Intercomparation.*

1. INTRODUCTION

Different measuring equipment can be used during the tests. Their accuracy can significantly affect the reliability of the measurements. Therefore, “Ensuring the validity of results,” is a wonderful tool for laboratories confirming their end data is accurate and reliable [1]. In doing so, each laboratory must establish a program and procedure for validate its measuring procedures. Due to all the above, the Technical Test Center (TTC) [2], a specialized military scientific research institution, in accordance with the requirements of the quality management system [3], can develop and use a new measuring method procedure [4].

One of the ways to determine and review measuring accuracy for new development method is interlaboratory comparisons. Participation in intercomparison is one of the requirements for laboratories that are entering the accreditation process or have already been accredited [5]. Positive results of intercomparison are confirmation of the accuracy of measurements performed in the laboratory and the competence of that laboratory.

Intercomparison is performed at the request of the user. In doing so, the intercomparison is performed by the laboratory user of the measuring equipment, and if necessary, other laboratories and the competent metrological laboratory can also participate [4]. Measurement intercomparison means the comparison of metrological characteristics of meters of the same type and approximately the same measurement uncertainty under established conditions.

Due to the need to validate the accuracy of the implemented Y-factor method of measuring the noise figure using an EMI measuring receiver (in general, a spectrum analyzer), the Department for Electromagnetic Compatibility and Environmental Impacts in the TTC initiated and organized an intercomparison of the noise figure and gain measurement for the amplifier devices. A total of four meters from two laboratories, were used in this intercomparison. Three meters (one EMI receiver and two spectrum analyzers) were provided by TTC, while the noise figure meter was provided by the Military academy [6].

The intercomparison was made in two measurement variants: the first variant using a noise figure meter, while in the second variant software written in Matlab [7] was developed, which enables automated measurement of the noise figure by implementing the Y-factor method [8, 9]. It should certainly be noted that the noise figure meter itself uses the Y-factor method for measurement [10]. Measurement results were compared using the z-score criterion.

The goal of the intercomparison is to validate implementation of Y-factor method for noise figure measurement using EMI measuring receiver. Namely, the aim of processing the results of intercomparison of these measures is to analyze the results according to the criteria for measures of the same type and approximately the same measurement uncertainty, under established conditions, then to determine the acceptability of results, and thus confirm their applicability to measure noise figure and gain of RF amplifier.

2. INTERCOMPARISON CONDITIONS

The intercomparison was performed in the Laboratory for electromagnetic compatibility of Technical Test Center. The subject of the intercomparison is the implemented Y-factor method of measuring the noise figure and the gain level of the RF amplifier on the EMI measuring receiver with the corresponding values obtained using the noise figure meter and the spectrum analyzers.

A total of four laboratory values of noise figure and gain level were obtained using the following measuring instruments:

- HP 8970B, Noise Figure Meter (Lab 1);
- Agilent E4447A, PSA Spectrum Analyzer (Lab 2);
- Rohde&Schwarc, ESR26, EMI test receiver (Lab 3):
- HP 8568B Spectrum Analyzer with RF Preselector (Lab 4);

When using the noise figure meter (Lab 1), the Y-factor measurement method was implemented in the software of the instrument [10], while in the other three cases (Lab 2-4) a same method for automation of measurement and processing of measured values is implemented.

Intercomparison was performed by comparing the measured noise figure and gain values using Noise Figure Meter and spectrum analyzer/EMI receiver. The device under test (DUT) was a pulse RF amplifier, MINI-CIRCUITS, model: ZPUL-30P, s/n: 15542.

Noise Figure measurements with consist of two main tasks:

- Calibration of the setup,
- Measurement of the DUT.

In both tasks, the noise level values are measured by the instrument and calculate the Y-factor values. Finally, the Noise Figure and Gain of the DUT are calculated.

2.1. Calculation (Y-factor method)

The Y-factor method is a widely used technique for measuring the gain and noise figure of the amplifiers [9]. It is based on the Johnson–Nyquist noise of a resistor at two different, known temperatures [11] (Fig 1).

The Y-factor method uses the measured noise power of the DUT output with a room temperature noise source (noise source off) at the input, and with a high temperature noise source (noise source biased with 28 V) at the input. Noise sources are commonly specified by their excess noise ratio or ENR value, which is expressed in dB. The relationship between noise temperature and ENR is shown in equation (1). The calibrated ENR values supplied by the noise source manufacturer are generally referenced to T_o=290 K.

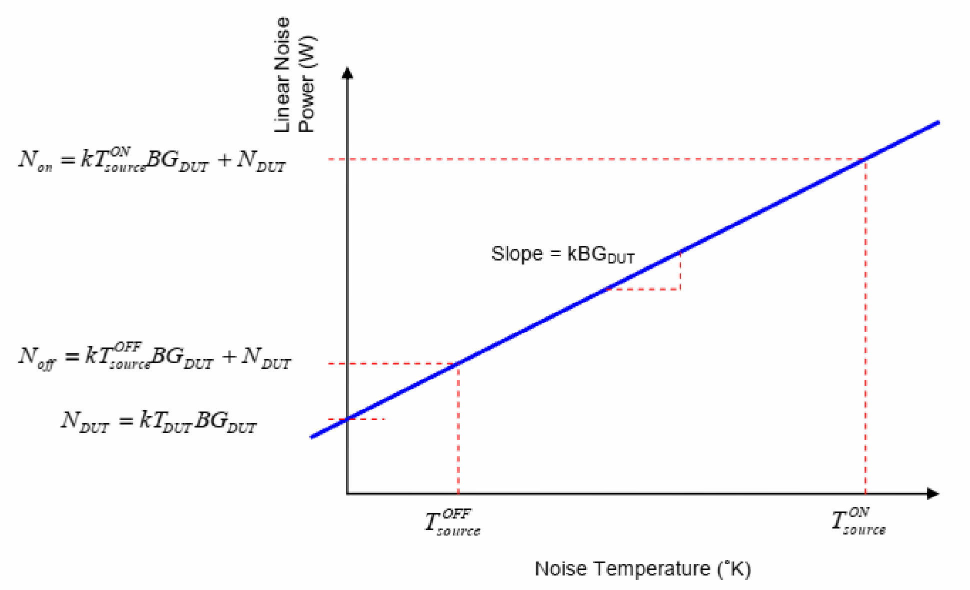

Figure 1. Diagram showing the Y factor variables.

$$ENR_{dB} = 10\log\left(\frac{T_{sourse}^{ON} - T_{sourse}^{OFF}}{T_0}\right) \qquad (1)$$

The Y-factor (2) is the ratio of the measured (linear) noise power at the DUT output when the noise source is "on" and "off" (fig 2).

$$Y_{dB} = \frac{N_{on}}{N_{off}} \qquad (2)$$

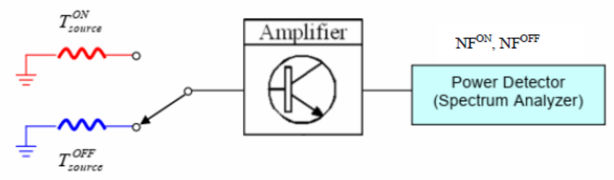

Figure 2. Diagram showing the Y factor noise figure variables.

The noise figure is given in simplified form in equation 3, using equations 1 and 2. The noise figure (*NF*) is defined as the noise factor (*F*) in units of decibels (4).

$$NF_{dB} = ENR_{dB} - 10\log(Y-1) \tag{3}$$

$$NF_{dB} = 10\log(F) \tag{4}$$

2.2. Calibration

Connect the equipment as shown in Figure 3. (No DUT)

- Connect the output of the noise source to the RF input of the spectrum analyzer/receiver.
- Connect the noise source control of the spectrum analyzer/EMI receiver to the noise source (for HP 8568B Spectrum Analyzer noise source was driven manually by using external power supply).
- Set the spectrum analyzer to the desired test frequency.
- Set the RBW to be less than the BW of the DUT (For EMI receiver: 1 MHz).
- Enable the preamplifier.
- Set the minimum RF attenuator (For EMI receiver: 0 dB).
- Set the Reference level to a fairly low value (For example: -80 dBm.).
- Set the Log range to a fairly low value (For EMI receiver: 30 dB.).
- Select the RMS detector.
- Select a slower sweep time to RMS average the results (For example: 1 second.).
- Turn the noise source on or off and measure the noise power of the trace.
- Calculate the linear Y factor using equation (2).
- Finally, calculate a noise figure by using equation (3).

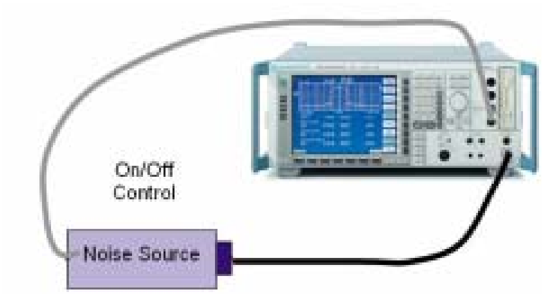

Figure 3. Connection diagram for the calibration step.

HP 346B noise source was used for these measurements. ENR value of the noise source is printed directly on the source in a table.

2.3. Measurement of the DUT

In this step the cascaded noise figure of the device under test and the spectrum analyzer are measured. The DUT is connected between the noise source and the spectrum analyzer/EMI receiver as shown in Figure 4. All settings and measuring are the same as during calibration. Finally, in this step we got noise figure for measuring step.

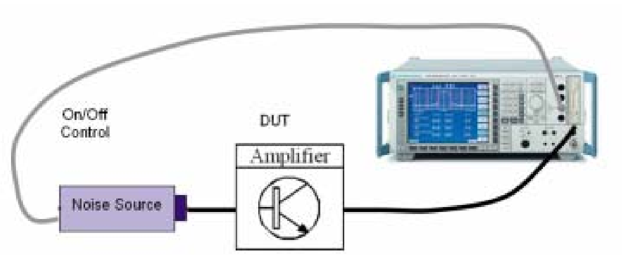

Figure 4. Connection diagram for the measurement of the DUT's noise figure.

In the final step calculate the gain and the noise figure of the DUT by applying the cascaded noise figure equations. Use equation (5) to calculate the linear gain of the DUT and equation (3) for noise figure.

$$G_{DUT} = \frac{N_{on}^{meas} - N_{off}^{meas}}{N_{on}^{cal} - N_{off}^{cal}}) \tag{5}$$

At the same time, the characteristics of the measuring equipment meet the prescribed standards [12, 13].

Environmental conditions:

- temperature: 24 °C ± 2 °C,
- relative humidity: 50 % ± 15 %.

3. INTERCOMPARISON CRITERIA

As a criterion for evaluating the results of intercomparison, taking into account all the specifics of the measurement, the z-score was adopted, in accordance with the standard ISO 13528: 2005 [12, 13]. As four test samples participated in the comparison, the mean value of the test results for all samples was taken as the assigned (reference) value X_{ref}. The z-score should indicate whether the measured value deviates significantly from the assigned value, in our case from the mean value of the test results, taking into account the standard deviation σ .

The z-score is calculated as follows [12]:

$$z_i = \frac{x_{lab_i} - X_{ref}}{\sigma}, i = 1, 2, \ldots, 4, \tag{6}$$

where:

x_{lab_i} test results for each sample (i = 1, 2, 3, 4),

X_{ref} the assigned (reference) value is the mean value of the test results of all samples,

$$x_{ref} = \frac{\sum_{i=1}^{n} x_{lab_i}}{n}, \text{n=4}, \tag{7}$$

σ standard deviation for non-repeat testing,

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_{lab_i} - x_{\mathrm{ref}})^2}{n}}, \text{ n=4.} \tag{8}$$

The z-score coefficient can be positive or negative and determines the number of standard deviations of the data set from the arithmetic mean. A negative result indicates a value less than the mean, and a positive result indicates a value greater than the mean, with the average of each z-score weighing to zero.

The value of z-score is interpreted as follows:

– A result that gives |z| ≤ 2,0 is considered to be acceptable;
– A result that gives 2,0 < |z| < 3,0 is considered to give a warning signal;

A result that gives |z| ≥ 3, 0 is considered to be unacceptable (or action signal) and the participants should be advised to check their measurement procedures following warning signals in case they indicate an emerging or recurrent problem [13].

4. RESULTS OF INTERCOMPARISON

The results of intercomparison the parameters gain (G) and noise figure (NF) of the pulse amplifier, for different frequencies are shown in Table I and represented in figures 5 and 6. Based on the results obtained from Table I and the calculation of mean and standard deviation, and using formula (6) obtained values of z-score coefficient, shown in Table II and Table III.

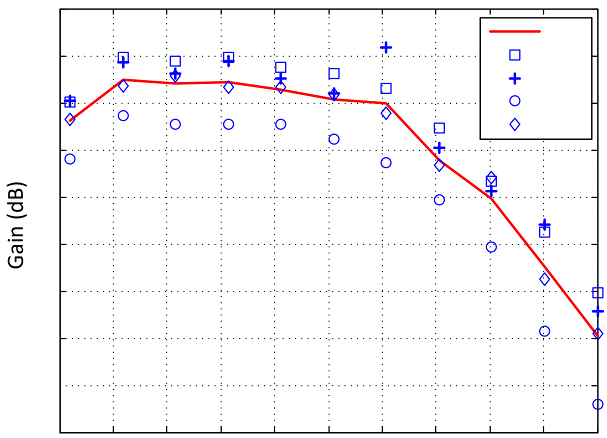

Figure 5. Results of gain (G) measurement of the pulse amplifier, for different frequencies.

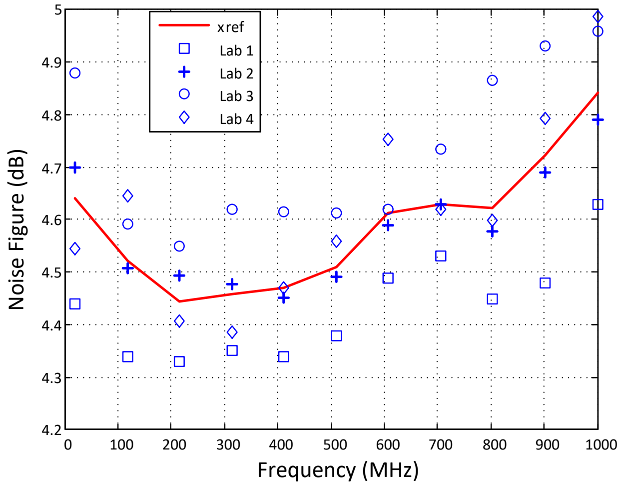

Figure 6. Results of noise figure (NF) measurement of the pulse amplifier, for different frequencies.

Table 1. Results of measurement the parameters gain (G) and noise figure (NF) of the pulse amplifier, for different frequencies.

f (*MHz*)	G_{lab1} (dB)	NF_{lab1} (dB)	G_{lab2} (dB)	NF_{lab2} (dB)	G_{lab3} (dB)	NF_{lab3} (dB)	G_{lab4} (dB)	NF_{lab4} (dB)
20	36.0	4.4	36.0	4.7	34.8	4.9	35.7	4.5
118	37.0	4.3	36.9	4.5	35.7	4.6	36.4	4.6
216	36.9	4.3	36.6	4.5	35.5	4.6	36.6	4.4
314	37.0	4.4	36.9	4.5	35.5	4.6	36.3	4.4
412	36.8	4.3	36.5	4.5	35.5	4.6	36.3	4.5
510	36.6	4.4	36.2	4.5	35.2	4.6	36.2	4.6
608	36.3	4.5	37.2	4.6	34.7	4.6	35.8	4.8
706	35.5	4.5	35.0	4.6	33.9	4.7	34.7	4.6
804	34.3	4.5	34.1	4.6	32.9	4.9	34.4	4.6
902	33.2	4.5	33.4	4.7	31.2	4.9	32.2	4.8
1000	32.0	4.6	31.6	4.8	29.6	5.0	31.1	5.0

Table 2. Results of z-score for gain (G) of the pulse amplifier, for different frequencies.

f (*MHz*)	z_{Glab1}	z_{Glab2}	z_{Glab3}	z_{Glab4}
20	0.77	0.83	-1.65	0.05
118	0.99	0.78	-1.53	-0.24
216	0.93	0.43	-1.69	0.33
314	0.92	0.82	-1.56	-0.19
412	1.03	0.49	-1.64	0.11
510	1.12	0.29	-1.62	0.21
608	0.34	**1.34**	-1.43	-0.25
706	**1.21**	0.47	-1.51	-0.18
804	0.64	0.29	**-1.70**	**0.77**
902	0.81	1.00	-1.50	-0.30
1000	1.02	0.57	-1.62	0.04

Table 3. Results of z-score for noise figure (NF) of the pulse amplifier, for different frequencies.

f (MHz)	$z_{NF\text{lab}1}$	$z_{NF\text{lab}2}$	$z_{NF\text{lab}3}$	$z_{NF\text{lab}4}$
20	-1.21	0.36	1.44	-0.58
118	**-1.57**	-0.12	0.61	1.07
216	-1.37	**0.57**	1.26	-0.46
314	-1.04	0.19	1.55	-0.70
412	-1.32	-0.18	1.49	0.01
510	-1.50	-0.22	1.18	0.55
608	-1.31	-0.25	0.07	**1.49**
706	-1.36	0.00	1.47	-0.10
804	-1.15	-0.30	**1.60**	-0.16
902	-1.48	-0.21	1.26	0.42
1000	-1.47	-0.36	0.82	1.01

5. CONCLUSION

Due to the need to validate the accuracy of the implemented Y-factor method of measuring the noise figure using an EMI measuring receiver (in general, a spectrum analyzer), the Department for Electromagnetic Compatibility and Environmental Impacts in the TTC initiated and organized an intercomparison of the noise figure and gain measurement for the amplifier. A total of four meters from two laboratories, were used in this intercomparison. Three meters (one EMI receiver and two spectrum analyzers) were provided by TTC, while the noise figure meter was provided by the Military academy.

The result of intercomparison (gain and noise figure) according to frequencies is represented by the numerical value of the z-score model in Tables 2 and Table 3. Based on the presented results, we conclude that the values of z-score, $|z| \leq 2$ and that the results are satisfactory (acceptable), and no corrective measures are needed. This shows that the deviations in the measurements, the values of the gain or noise figure between the four meters are acceptable in the entire frequency range of the meters.

The goal of the intercomparison is to validate implementation of Y-factor method for noise figure measurement using EMI measuring receiver is fulfilled. EMI measurement receiver can be used to measure noise figure and gain of amplifier.
For the further work was planned to calculate the budget of measurement uncertainly.

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