

# Noise Parameter Measurement Verification by Means of Benchmark Transistors

By Cesar A. Morales-Silva, University of South Florida, and  
Lawrence Dunleavy, Rick Connick, Modelithics, Inc.

This paper examines the technique of comparing different measurement methods using actual devices, rather than relying on traditional calibration, which may differ between the methods used.

Test systems used for noise parameter measurements are known to involve complex setups and calibration procedures. The absolute accuracy of calibration techniques for noise parameter measurements systems is not

easily determined and alternative methods are needed for routine system validation. Among the different methods that have been proposed to test the accuracy of the noise characterization systems, both passive and active test structures have been explored as verification paths [1, 2]. Previous work was reported by V. Adamian analyzing the Available Gain of a two port device by different methods [3], this procedure does not include a benchmark device measured repeatedly, just the validity of the noise parameter instrumentation against the VNA measurements [3].

Passive structures, based on Lange couplers were used by Ali Boudiaf et al. [5]. Common-gate cold FETs were implemented to test the accuracy of the Noise Parameter test set by L. Escotte et al. [6]. These methods also provide a check where noise parameters are calculated independently from measured  $S$ -parameters, however, errors due to ENR source calibration uncertainties and malfunction are not determined. Also, any accuracy issues that may be related to high gain DUTs causing receiver dynamic range related nonlinearities (usually alleviated by adding IF or RF attenuation to the system), for example, would not be tested with passive verification devices.

As a somewhat more direct validation method explored in this work, suitably prepared transistor samples can be effectively utilized as a means by which to validate noise parameter test system calibration, including addressing dynamic range related inaccuracies, as well as establishing benchmark data for interpreting data acquired from different test systems or software methods. As part of this work, measurement comparisons were made by the authors using three such “benchmark transistors” with widely different performance characteristics. For the sake of brevity, results for one of these transistors are shown in this paper. Various metric differences are proposed for use in combination with such benchmark transistors for relative comparison of noise parameter test results with historical benchmark data.

## Description of the System and the Benchmark Devices

Generally, noise characterization measurement systems implement manual or automated tuners on each end of the device under test (DUT). By means of the tuners, input and output matching networks of a low-noise amplifier stage can be simulated so that the noise figure and gain can be measured directly. For this paper, the system used corresponds to what we will refer to as a “NP5 system,” this one implement automated tuners and is originally manufactured by ATN Microwave Inc., now sold and supported by Maury Microwave Corporation. The NP5 system is based on the original method published by Adamian and Uhler [7]. Two different NP5 Systems available locally have been utilized in the present work (2 to 26 GHz and 0.3 to 6 GHz systems).

All results in this paper are focused in one particular chip transistor type, the MWT-1 from Microwave Technologies Inc. [11]. The bias condition used for this component in the present study is  $I_{DS} = 50\text{mA}$  and  $V_{DS} = 3.5\text{V}$ . Using this transistor with the previously mentioned bias conditions, the Minimum Noise Figure,  $F_{\min}$ , starts from 0.4 dB at 2 GHz and ends at 3.5 dB at 26 GHz. Also  $R_n$  remains between 1 and  $145\Omega$  in all the range of frequency from 2 to 26 GHz.

**Metrics Used to Compare Noise Parameter Results**

When analyzing repeated measurements of the same benchmark device, one thing to compare is the Minimum Noise Figure measurement  $F_{\min}$ . It was decided to utilize the following expression:

$$\Delta F_{\min}(f) \text{ dB} = |F_{\min_i}(f) \text{ dB} - F_{\min_j}(f) \text{ dB}| \tag{1}$$

A comparison of  $R_n$  measurement results is enabled by the following expression:

$$\Delta R_n(f) \Omega = |R_{n_i}(f) \Omega - R_{n_j}(f) \Omega| \tag{2}$$

It should be noted this is not the only possible expression that could be used as a metric, and further exploration might involve some form of normalization of this expression to arrive at a unit-less metric for  $R_n$ .

For comparison of the different values of  $\Gamma_{opt}$  obtained during the noise parameter measurements, the following expression magnitude of vector difference is proposed:

$$\Delta \Gamma_{opt} = |\Gamma_{opt_i} - \Gamma_{opt_j}| \tag{3}$$

**Summary of Experiments and Results**

Table 1 illustrates the relevant measurement conditions. Three samples of the MWT-1, over a metallic Kovar carrier, were used for the analysis of this transistor as a Benchmark Device. Several experiments were performed as follows:

MWT1		
Setup Conditions	Value or Description	Units
Frequency Range	2-26	Gigahertz (GHz)
Drain Voltage (Vd)	3.5	Volts (V)
Drain Current (Id)	50	milliamperes (mA)
Text Fixture	Copper Heat Sink, 5mils Below Level of Microstrip over a Kovar carrier	N.A.
Probes used	150 pitch	microns ( $\mu\text{m}$ )
Probes that can be used	100, 150 and 200 (pitch)	Microns ( $\mu\text{m}$ )
Temperature	25	Celsius( $^{\circ}\text{C}$ )
Number of Samples	1	Unit(s)
Number of measurements on same component (MWT1)	3	Unit(s)
Observations	4 experiments developed, changing samples, days (calibrations and measurement conditions) and systems	Unit(s)

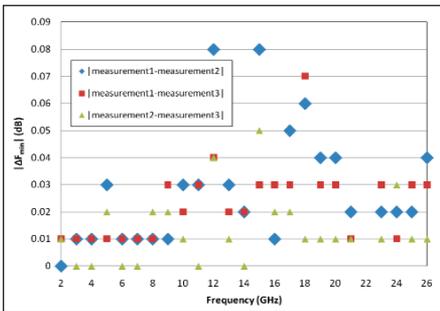
**Table 1 · Measurement conditions for MWT-1.**

1. Using same sample and calibration during the same day of measurements (Experiment 1),
2. Using different samples on the same day and calibration (Experiment 2),
3. Using the same sample on different days (Experiment 3), and
4. Measuring the same sample in two different systems (Experiment 4).

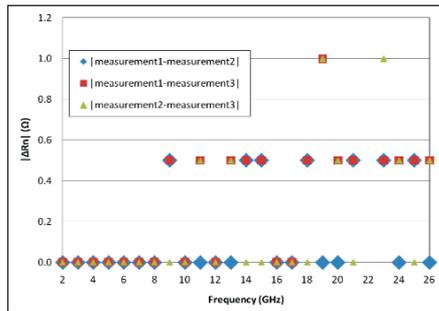
Figures 1 to 3 illustrate the comparisons developed over the obtained results from experiment 1.

From obtained results, it is possible to state that experiment 1 represents the best scenario for system repeatability measurements as it indicates only system repeatability. With all other measurement conditions (e.g. averaging) the same this should be the best attainable comparison.

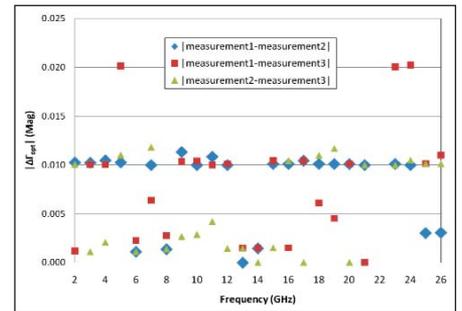
The set of comparisons developed from the obtained results of Experiment 2 are illustrated in Figures 4 to 6. Experiment 2 shows that using different samples results in the largest differences obtained. The principal reason, this experiment measures the repeatability between samples which turns out to be larger than measurement repeatability in this case. Hence, relying on prior mea-



**Figure 1 ·  $|\Delta F_{\min}|$  for MWT1, measuring same sample using the same calibration (Experiment 1).**



**Figure 2 ·  $|\Delta R_n|$  for MWT1, measuring same sample using the same calibration (Experiment 1).**



**Figure 3 ·  $|\Delta \Gamma_{opt}|$  for MWT1, measuring same sample using the same calibration (Experiment 1).**

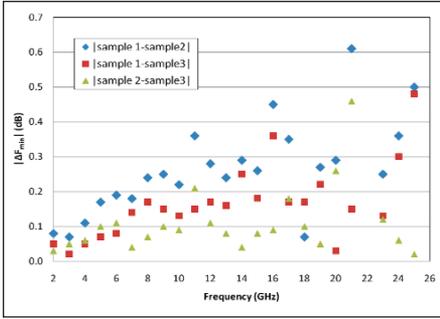


Figure 4 ·  $|\Delta F_{\min}|$  for MWT1, measuring different samples using the same calibration (Experiment 2).

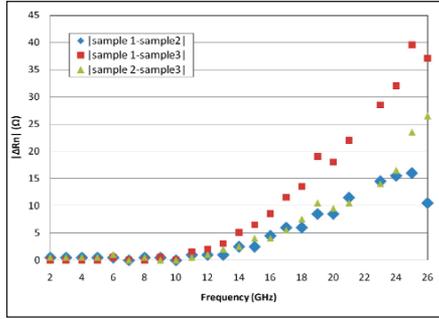


Figure 5 ·  $|\Delta R_n|$  for MWT1, measuring different samples using the same calibration (Experiment 2).

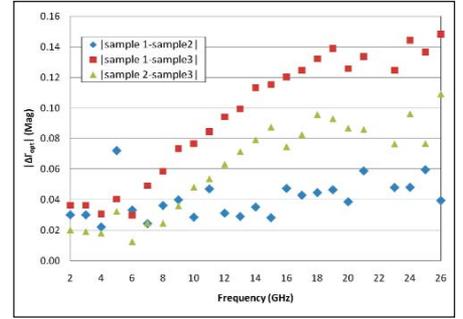


Figure 6 ·  $|\Delta \Gamma_{opt}|$  for MWT1, measuring different samples using the same calibration (Experiment 2)

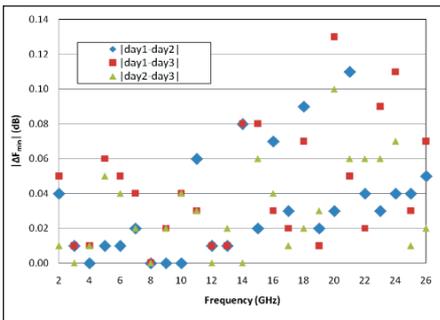


Figure 7 ·  $|\Delta F_{\min}|$  for MWT1, measuring same sample on different days (Experiment 3).

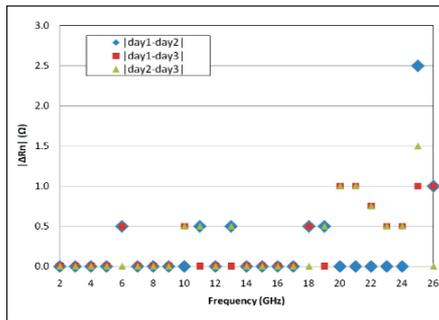


Figure 8 ·  $|\Delta R_n|$  for MWT1, measuring same sample on different days (Experiment 3).

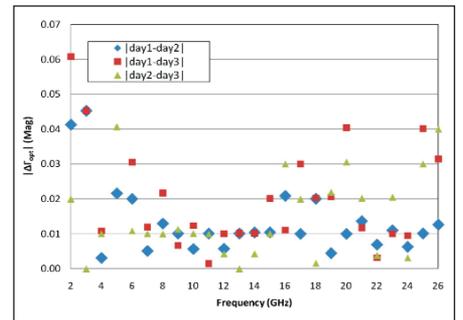


Figure 9 ·  $|\Delta \Gamma_{opt}|$  for MWT1, measuring same sample on different days (Experiment 3).

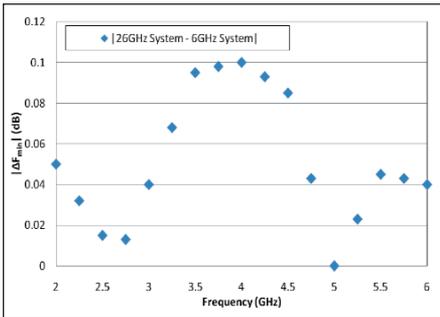


Figure 10 ·  $|\Delta F_{\min}|$  for MWT1, measuring same sample on different systems, 6 GHz and 26 GHz (Experiment 4).

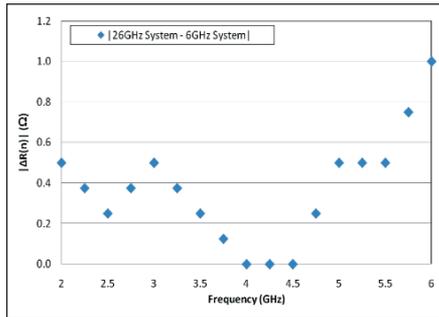


Figure 11 ·  $|\Delta R_n|$  for MWT1, measuring same sample on different systems, 6 GHz and 26 GHz (Experiment 4).

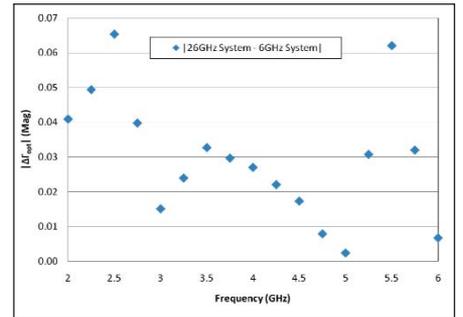


Figure 12 ·  $|\Delta \Gamma_{opt}|$  for MWT1, measuring same sample on different systems, 6 GHz and 26 GHz (Experiment 4).

surement data on a different sample of the same device type is not the best benchmarking strategy.

Figures 7 to 9 illustrate the results obtained from Experiment 3. In this experiment, the results generally maintain lower differences compared with Experiment 2. Also, as expected, differences are slightly larger than the ones obtained in Experiment 1 because of the implementation of different calibrations and variation of conditions

day by day.

Figures 10 to 12 illustrate the comparisons developed from the results obtained from Experiment 4. Repeatability of results in the overlapping region confirms good (comparable) performance of both systems in this band.

A summary of maximum differences for MWT-1, presented in Table 2, is used for the analysis of the results.

Summary of Maximum Differences for MWT-1				
[] Up to 26GHz		{ } Up to 18GHz	{ } 2-6GHz inter-systems	
Parameter	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Description	System repeatability	Different samples same day	Same sample different days	Same sample, different test systems
$\Delta F_{min}$	{0.08}{0.08}	{0.6}{0.45}	{0.13}{0.09}	{0.10}
$\Delta R_n$	{1.00 $\Omega$ }{0.5 $\Omega$ }	{38 $\Omega$ }{13 $\Omega$ }	{2.5 $\Omega$ }{0.5 $\Omega$ }	{1 $\Omega$ }
$ \Delta \Gamma_{opt} $	{0.02}{0.02}	{0.15}{0.13}	{0.06}{0.06}	{0.065}

**Table 2** · Summary of maximum differences for MWT-1 in the four experiments.

### A Possible Strategy for Noise Parameter Validation

To create a data base for benchmarking purposes, the next 3 steps can be followed:

1. Classify benchmark devices depending of noise level and/or technology of the possible DUTs, also test fixture and probe size.
2. Measure multiple samples of a given benchmark device as many times as practical under different conditions (varying calibration, days and samples) and perform the noise parameter comparisons.
3. Create a data base with these results that is updated with each new session. They will be the baseline used to judge the accuracy of future noise system calibrations. During this process also start formulating guidelines based in the collected information, they include the margin of differences permitted for benchmarking purposes. Data on multiple samples will allow for having backup pre-characterized devices in case of failure of the primary benchmark device.

To determine the accuracy of the calibration, before and after new DUT measurements the following actions are suggested:

1. Select the benchmark device to use for calibration and setup verification depending of component similarities: expected noise level and/or technology of the DUT, also test fixture and probe size.
2. After system setup and calibration, but before new DUT measurements, measure the selected benchmark device and compare measurements with historical benchmark data and acceptable margins for metrics like those of equations (1) through (3).
3. Save the result of new measurements and add it to the benchmarking data set for future use and statistical analysis.
4. Finally, after you have completed DUT measurements, or periodically during long sessions, re-measure

the benchmark device to check for potential degradation in the calibration or test system drift. If a recalibration is performed, do not forget to measure the benchmark device again.

### Conclusions

This paper explores the use of benchmark transistors for noise parameters measurement system verification. The results suggest that:

- Suitably prepared transistors can be used as local reference standards for noise parameter measurement verification.
- Developing an inventory of “known good data” on different benchmark transistors, from different technologies and probe footprints, allows verification of the system in close coordination with the device to be measured.

An example was shown herein (Experiment 4) of using a benchmark device measurement to compare two different systems with overlapping frequency ranges the results provided a good means of verification of the one measurement system against another.

### References

1. S. van den Bosch & L. Martens, “Deriving Error Bounds on Measured Noise Factors Using Active Device Verification,” *54th ARFTG Conference Digest*, Spring, vol. 36, pp. 1-6, Atlanta, GA, USA, Dec. 2000.
2. A.C. Davidson, B.W. Leake, & E. Strid, “Accuracy improvements in microwave noise parameter measurements,” vol. 37, pp. 1973-1978, Dec. 1989.
3. V. Adamian & R.Fenton, “Verification of the Noise Parameter Instrumentation,” *49th ARFTG Conference Digest*, Spring, vol. 31, pp. 181-190, Denver, CO, USA, June 1997.
4. A. Boudiaf & A. Scavenec, “Experimental investigation of On-Wafer Noise Parameter Measurement Accuracy,” *A. Microwave Symposium Digest*, 1996., IEEE MTT-S International, vol 3, pp. 1277-1280, 17-21 Jun 1996.
5. A. Boudiaf, C. Dubon-Chevallier, & D. Pasquet, “Verification of on-wafer noise parameter measurements,” *IEEE Transactions on Instrumentation and Measurement*, vol 44, issue 2, pp. 332-335, Apr 1995.
6. L. Escotte, R. Plana, J. Rayssac, O. Llopis, & J. Graffeuil, “Using Cold FET to Check Accuracy of Microwave Noise Parameter Test Set,” *Electronic Letters*, 1991. vol 27, issue 10. pp. 833-835, 9 May 1996.
7. V. Adamian and A. Uhlir Jr., “Simplified noise evaluation of microwave receivers,” *IEEE Trans. On Instrumentation and Measurement*, Vol. IM-33, No. 2, pp. 136-140, June 1984.

## Author Information



Cesar A Morales-Silva, M.S.E.E. was a research assistant at University of South Florida supported under a Modelithics grant. He received the B.S.E.E. degree with honors as a distinguished student from Universidad del Norte (Barranquilla-Colombia) in 2004, and the M.S.E.E. degree in 2008 from the University of South Florida. Morales-Silva is a member of the RF-MEMS transducers group and is currently studying to pursue his Ph.D. in Electrical Engineering at University of South Florida. He can be reached by e-mail at: camorale@mail.usf.edu, or cmorales@modelithics.com.

Lawrence P. Dunleavy co-founded Modelithics, Inc. in 2001 to provide improved modeling solutions and high quality microwave measurement services for RF and microwave designers. Prior to this, Dr. Dunleavy co-developed the University of South Florida's innovative Center for Wireless and Microwave Information Systems (The WAMI Center). He maintains a part-time position as a

Professor within USF's Department of Electrical Engineering, where has been on the faculty since 1990. Prior to this he worked for Hughes Aircraft and E-Systems companies. Dr. Dunleavy received the B.S.E.E. degree from Michigan Technological University in 1982, and the M.S.E.E. and Ph.D. degrees in 1984 and 1988, respectively, from the University of Michigan. He is a Senior Member of IEEE, and is active in the IEEE MTT Society, and the Automatic RF Techniques Group (ARFTG).



Rick Connick received the B.S.E.E. degree from the University of South Florida, and joined Modelithics in 2002. He is currently working on his M.S.E.E and is an Engineering Group Leader at Modelithics, Inc., providing coordination of various measurement and modeling projects for active and passive microwave devices. His current research and development interests are in the areas of non-linear transistor modeling and behavioral modeling techniques for ICs.