A NEW AUTOMATED NOISE AND GAIN PARAMETER MEASUREMENT SYSTEM

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ABSTRACT

This paper describes an automated noise and gain parameter measurement system which operates to 26.5 Ghz. A new test set configuration and thorough measurement techniques are employed to minimize errors. The noise and gain parameters for an 0.3 µm gate GaAs FET at 10 and 22 Ghz are presented.

INTRODUCTION

The accurate determination of the gain and noise parameters of FET's is required for developing high performance and high yield monolithic low noise amplifiers. The noise characterization of GaAs FET's by traditional methods has been replaced by more accurate techniques involving noise and gain measurements for more than four arbitrary source admittances and then fitting the data by a least squares method to the linear two-port noise equation given by

$$F = Fmin + \frac{Rn}{Gs} \mid Ys - Yon \mid^2 \qquad [1]$$

where
F = noise factor,
Ys = Gs + jBs source admittance,
with noise parameters:
Fmin = minimum noise factor,
Yon = Gon + jBon = optimum source admittance for minimum noise figure,
Rn = equivalent noise resistance(1).

The gain parameters are obtained using an equation similar to [1]:

$$\frac{1}{Ga} = \frac{1}{Ga_{max}} + \frac{Rg}{Gs} \mid Ys - Yog \mid^2 \qquad [2]$$

where
Ga = available gain,
with gain parameters:
Ga_{max} = maximum available gain,
Yog = Gog + jBog source admittance for maximum available gain,
Rg = equivalent gain resistance.

Manual and automated noise and gain parameter test systems employing least squares fitting algorithms have been reported and are available commercially(1,2,3). These test systems have brought about significant improvements in determining the noise and gain parameters with speed, accuracy, and repeatability. However, these test systems have several limitations. Electronic tuners are used in some cases having a fixed number of available unique source reflection coefficients(2,3). The available set may not be adequate for all desired measurement frequencies or all test devices. Often, pre-measured input tuner losses are substituted for more accurate in-place S-parameter measurements at each reflection coefficient setting(4). This approach introduces subtle errors since changes in the tuner due to temperature, non-repeatable connections, and source mismatch are not considered. The use of an output tuner is also avoided to simplify the measurement procedure, hence the accuracy of the available gain measurement is sacrificed.

An automated noise and gain parameter measurement system has been designed to overcome these limitations and to reduce other sources of error. The system is composed of commercially available components and is configured to perform noise and gain measurements to 26.5 Ghz. The principal system components including several key features of the software are described. Noise and gain parameters for an NE71000 GaAs FET chip at 10 and 22 Ghz are presented.

THE SYSTEM CONCEPT

System Features

A block diagram depicting the principal components of the automated noise and gain parameter measurement system is shown in Figure 1.

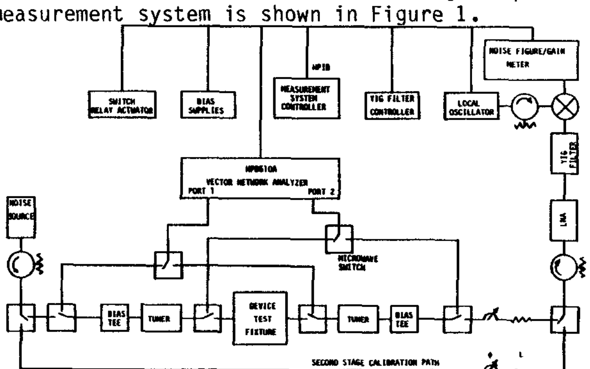

Figure 1. Block Diagram of the Measurement System

The system incorporates a number of unique features to minimize errors and to decrease the time needed to determine both noise and gain parameters without sacrificing measurement flexibility. These features are:

1. Microwave SPDT coaxial switches which exhibit excellent repeatability and well-matched transmission characteristics are used to eliminate the errors and delays associated with off-line measurements.
2. An HP8510A network analyzer is used as an integral part of the system to obtain tuner network S-parameters in near real time and display reflection coefficients during the process of making tuner adjustments.

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3. The user can select a set of source reflection coefficients known to optimal for the particular test device.
4. An output tuner is used for conjugately matching the test device output impedance for each selected source reflection coefficient. This minimizes the error introduced by mismatching an output isolator at the input to the receiver and allows the noise figure meter to measure the available gain accurately(5).
5. A built-in self-calibration scheme allows a second stage noise figure and gain calibration at any time without disconnecting the noise source from the input tuner.

The System Hardware

The automated measurement system consists of three major components in addition to the HP8510A network analyzer and system controller. An equipment rack houses the power supplies, switch relay actuators, YIG-tuned filter and controller, 1 to 26.5 Ghz low conversion loss mixer, local oscillator, and the HP8970A automatic noise figure meter. The remaining system components are two test platforms consisting of coaxial switches, slide-screw tuners, bias tees, flexible cables, isolators, a low noise amplifier, and a device test fixture. These platforms were constructed to perform measurements from 2 to 18 Ghz and from 18 to 26.5 Ghz. A photograph of the complete measurement system configured with the 18 to 26.5 Ghz test platform is shown in Figure 2. Photographs of the two test platforms are shown in Figure 3.

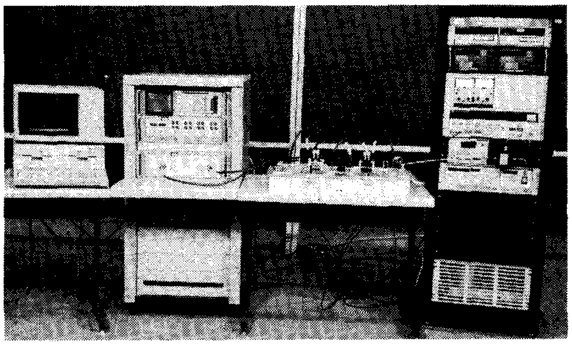
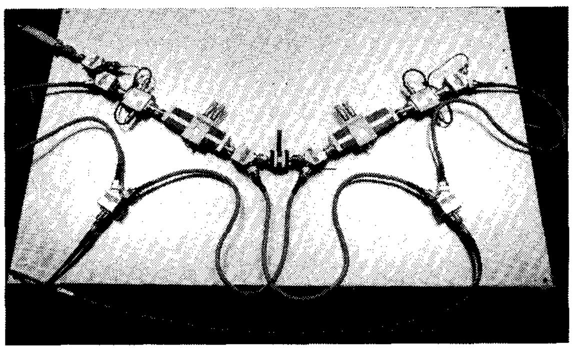
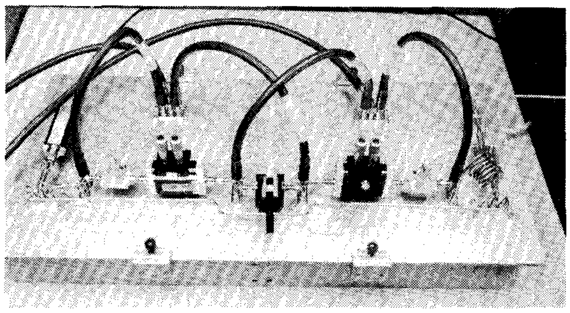


Figure 2. The complete automated noise and gain parameter measurement system



a. The 2 to 18 Ghz test platform



b. The 18 to 26.5 Ghz test platform

Figure 3. The coaxial test platforms

The test platforms use low loss, well-matched, and highly repeatable microwave coaxial switches. Typical measured transmission characteristics for the K-Band switches are shown in Figures 4 and 5. The switches used in the 2-18 GHz test set exhibit transmission characteristics with even less deviation. Flexible coaxial cables are used to extend the network analyzer measurement ports to the input and output tuner networks.

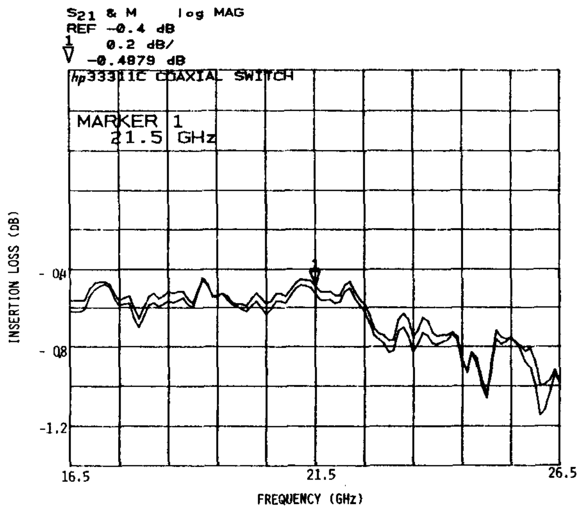


Figure 4. Insertion loss for both switch states

The System Software

The software controls the measurement system components, acquires and corrects the measured data and outputs the results. Some of the activities performed are as follows:

1. Swept frequency network analyzer calibrated measurements are converted to single frequency calibrated measurements. This shortens the measurement of the tuner networks to a few seconds.
2. Tuner reflection coefficients are instantaneously displayed for use during the tuning process by recalling the appropriate calibration set.

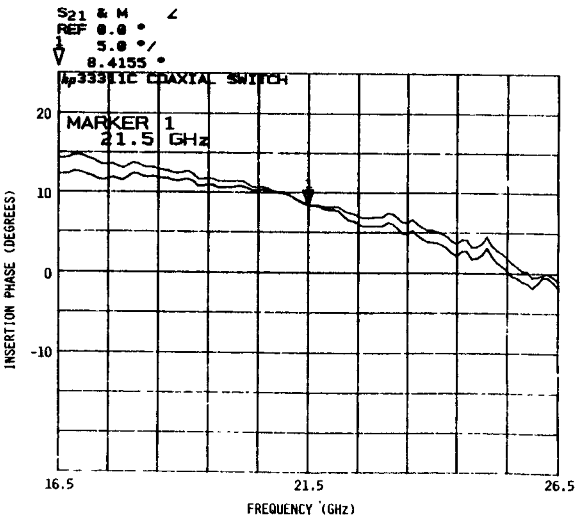


Figure 5. Insertion phase for both switch states

3. Before initiating a second stage calibration or performing a noise and gain measurement, the network analyzer operating frequency, which is the same as the noise measurement frequency, is attenuated and shifted far out of band.
4. Accurate and repeatable noise figure and gain measurements are made using a special routine which allows the completion of an averaged second stage calibration or noise figure and gain measurement before acquiring data. The software performs the following tasks:

- Measures the input tuner source reflection coefficient
- Corrects the measured noise figure and gain
- Computes the noise and gain parameters
- Checks the consistency of the measured data by performing a least squares fit using the computed noise parameters

The Measurement Sequence

A computer-controlled measurement begins after the automatic initialization and calibration of the system and the insertion of a device in the test fixture. A minimum of seven noise figure and gain measurements are then performed for a set of user selected source reflection coefficients. The process of making these measurements is completely automated with the exception of the tuner adjustments. After selecting a source reflection coefficient, the output tuner is adjusted to conjugately match the test device to 50 ohms. This is easily accomplished since both tuner reflection coefficients are displayed in real time on the network analyzer. Noise figure and gain (Fm,Gm) are subsequently measured along with the tuner network S-parameters. The noise match is measured separately and includes the effect of the noise source mismatch. The input and output tuner available gains (Gavi,Gavo) are computed and used to determine the corrected device noise figure and gain using:

$$Gdut = \frac{Gm}{(Gav_i)(Gav_o)} \qquad [3]$$

$$Fdut = [\ Fm - \frac{(1 - Gav_o)}{Gm}\ ]\ Gav_i \qquad [4]$$

where

$$Gav_x = |\ S_{21}\ |^2 \frac{1 - |\Gamma_s|^2}{(1-|\Gamma_2|^2)(|1-S_{11}\Gamma_s|^2)} \qquad [5]$$

$$\Gamma_2 = S_{22} + \frac{S_{12}\ S_{21}\ \Gamma_s}{1 - S_{11}\Gamma_s} \qquad [6]$$

Γ_s = source reflection coefficient.

Fixture De-embedding

Fixture de-embedding can also be added to the computations to move the noise and gain parameters to the test device reference plane. The absence of fixture embedding will be evident in the measured data at 22 Ghz presented in the following section. Fixture effects can be removed by cascading the input and output test fixture launcher S-parameters with those of the tuner networks to obtain corrected available gain and source reflection coefficients. Accurate launcher models or measured S-parameters which include the effects of bond wires and parasitics are necessary to avoid the introduction of additional significant errors.

TEST RESULTS

A NE71000 GaAs FET was characterized at 10 and 22 Ghz to evaluate the measurement system. A series of noise and gain measurements at 10 GHz along with computed noise and gain parameters are shown in Table 1. To examine the system repeatability, seven separate independent measurements were performed. Table 2 summarizes the results of this exercise.

Table 1.
Computed Noise and Gain Parameters at 10 GHz

NOISE AND GAIN PARAMETER CALCULATION

19 Feb 1987 10:00:29

WAFER/LOT: 5ZU2-159M
DEVICE ID: NE71000 #2 (5)

TEST FREQUENCY (MHZ): 10000

Vds: 3 00 V
Ids: 10 00 mA
Vgs: -.53 V

***** MEASURED DATA *****

POINT	NF (dB)	GAIN (dB)	Gs (MAG)	Gs (ANG)	Gavi (dB)	Gavo (dB)
1	1 3033	9.7201	6043	-109.700	-2 2655	- ?926
2	1.2911	9.6887	5069	-110.338	-1.7841	- 8246
3	1 3690	9.5587	.4026	-109 823	-1 4706	- 8521
4	1.4985	9.3180	.3030	-109 289	-1.2336	- 8684
5	1 6766	8.9122	1999	-111 396	-1 0452	- 8980
6	1 8688	8.5405	.1042	-110.617	-.8920	- 9004
7	2.4455	7.4982	.1034	68.566	- 6260	- 9171
8	2 7941	6.8849	.2003	70 970	-.5077	- 9292
9	3.2219	6.2026	.3010	71.032	-.3872	- 9394
10	3.7994	5.4800	4006	70 584	-.2530	-.9570

***** CALCULATED NOISE PARAMETER VALUES *****
MINIMUM NOISE FACTOR = 1.3390
MINIMUM NOISE FIGURE (DB) = 1.268
NOISE RESISTANCE (OHMS) = 9.721
OPTIMUM NOISE SOURCE ADMITTANCE = .017528 + j .024527
OPTIMUM NOISE SOURCE REFLECTION COEFFICIENT = 5499 AT -117 41 DEGREES
***** CALCULATED GAIN PARAMETER VALUES *****
MAXIMUM GAIN FACTOR = 18 2243
MAXIMUM GAIN (dB) = 12.606
EQUIVALENT GAIN RESISTANCE = 3.729
MAXIMUM GAIN SOURCE ADMITTANCE = 001707 + j 014580
MAXIMUM GAIN SOURCE REFLECTION COEFFICIENT= .8946 AT -72 45 DEGREES

Table 2
Measurement System Repeatability

MSMT	NF(dB)	Rn(Ω)	Γs(MAG)	Γs(ANG)
1	1.144	10.24	0.569	-113.61
2	1.194	10.70	0.557	-111.95
3	1.224	10.70	0.560	-112.25
4	1.203	10.10	0.589	-112.98
5	1.268	9.72	0.550	-117.41
6	1.204	10.11	0.588	-112.99
7	1.301	9.98	0.539	-114.25
MEAN	1.220	10.22	0.546	-113.63
STD. DEV.	0.048	0.34	0.017	1.70

The measured noise figure and noise resistance are comparable to the typical data given by the manufacturer at this frequency since the fixture losses are small (<0.2 dB). Using the computed noise parameters, a two-variable least squares fit to the measured data was performed to examine the consistency of the data (Figure 6).

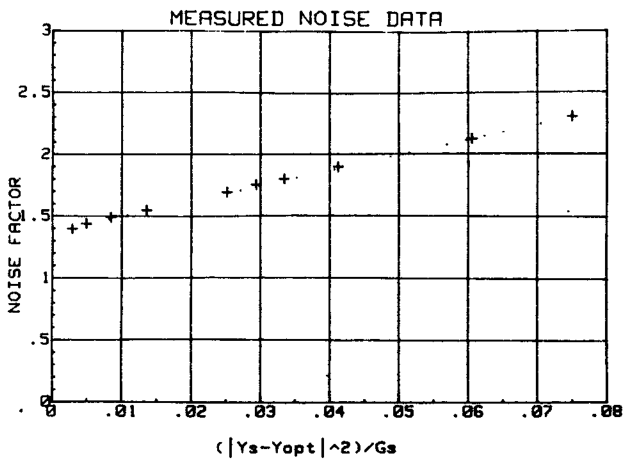


Figure 6. Two-variable least squares fit shows consistent measurements

A series of measurements were made at 22 GHz for an identical device. The results are summarized in Table 3. Unfortunately, the test fixture losses were excessive resulting in significantly degraded measured performance.

CONCLUSIONS

An automated noise and gain parameter measurement system capable of making highly accurate and repeatable measurements to 26.5 Ghz was developed for the purpose of determining GaAs FET noise and gain parameters. This system combines in-situ calibration and measurement of the tuner losses and noise match. No assumptions are made and the output is matched to 50 ohms for each source admittance. The measured data is fitted and then checked against the computed results to ensure the measurements are accurate and repeatable. The measurement system can accommodate a variety of test fixtures and can be configured with a microwave wafer probe for on-wafer noise measurements. Noise and gain measurements for a commercial GaAs FET are presented at 10 and 22 Ghz.

Table 3
A sequence of measurements at 22 Ghz

```
*****************************************************************
*                                                               *
*            NOISE AND GAIN PARAMETER CALCULATION               *
*                                                               *
*****************************************************************

                                      2 Mar 1900    03 19 21

        WAFER/LOT  5ZU-159M
        DEVICE ID  NE71000

TEST FREQUENCY (MHZ) 22000

            Vds   3 00 V
            Ids  12 70 mA
            Vgs   - 53 V

*****  MEASURED DATA  *****
POINT   NF (dB)   GAIN (dB)   Gs (MAG)   Gs (ANG)   Gavl (dB)   Ga m (dB)
  1     4.8649    1 0040      5292        61 044    -4 0493     -2 0046
  2     5 1238      3366      3773        61 545    -4 5271     -2 0125
  3     4 8644    1 1047      5504        63 347    -4 1236     -1 9931
  4     4 9000    1 1763      5898        61 501    -4 7694     -1 9819
  5     6 5017   -1 9102      0080       -11.247    -2 0627     -2 0091
  6     5 7377    -.8068      1691        59 844    -2 3601     -1 9341
  7     5 2914    - 0396      2979        61 556    -2 8094     -1 9690
  8     9 1654   -5 1891      4243      -118 527    -2 1244     -2 0536
  9     7 5739   -3 2580      1960      -112 301    -1 9347     -2 0533

*****  CALCULATED NOISE PARAMETER VALUES  *****
MINIMUM NOISE FACTOR =  2 9772
MINIMUM NOISE FIGURE (DB) =  4.738
NOISE RESISTANCE (OHMS) =  89.798
OPTIMUM NOISE SOURCE ADMITTANCE =   007887 + j - 013460
OPTIMUM NOISE SOURCE REFLECTION COEFFICIENT =   5848 AT   73 78 DEGREES
*****  CALCULATED GAIN PARAMETER VALUES  *****
MAXIMUM GAIN FACTOR =  1.3977
MAXIMUM AVAILABLE GAIN (DB) =  1 454
EQUIVALENT GAIN RESISTANCE (OHMS) =  42.542
MAXIMUM GAIN SOURCE ADMITTANCE =  .007887 + j - 013460
MAXIMUM GAIN SOURCE REFLECTION COEFFICIENT =   6998 AT   67 72 DEGREES
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