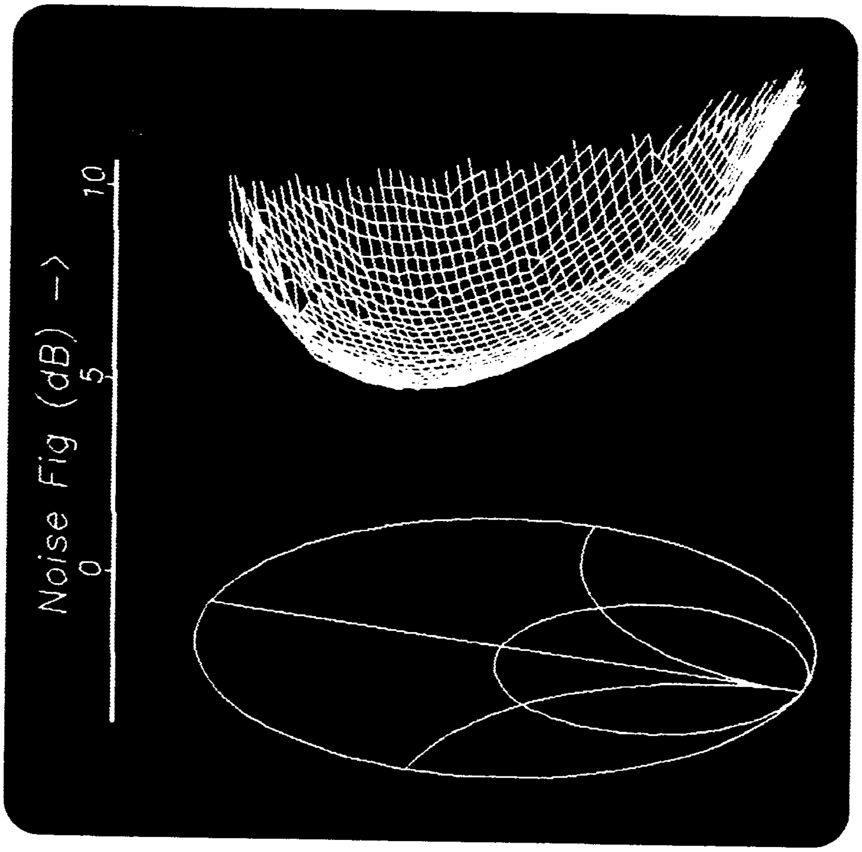
Application Note 1-90

FOCUS
MICROWAVES
INC.

Noise Measurements Using the Computer Controlled Microwave Tuner (CCMT) System



Source Pull Noise Figure measurement at 180 impedance points ($F_{min} \approx 1.2$ dB).

Summary

The COMPUTER CONTROLLED MICROWAVE TUNER (CCMT) and the application software package NSOFT permit to install, characterize and operate a full Noise Measurement Setup based on GPIB controllable instruments in the frequency range 1.6 to 18 GHz. Using Phase Extender and waveguide Tuners from FOCUS MICROWAVES the frequency range can be extended from 800 MHz to 60 GHz and beyond.

The 4 Noise and Gain Parameter of any twoport can be determined using one of three available automatic or manual measurement routines. The Noise Figure or Gain Contours can also be mesured using Source Pull and processed to 2D or 3D plots. This Note explains the techniques applied in Noise Measurement by the CCMT system, summarizes the formulas used for corrections and presents a random error analysis for theoretical comparison of the different measurement routines.

1. Introduction

The CCMT application software for noise parameter measurements NSOFT requires only one tuner connected at the input port of the DUT, while the output port is loaded with a wideband 50 Ohm load (isolator). This permits double side band and oscillation-free operation without additional precautions (Figure 1). The relations used for computing the exact DUT noise figure from the measured uncorrected data of the noise analyzer are given in the appendix to this note. They show that for accurate consideration of the output mismatch factor the 'S' parameters of the DUT for the actual frequency, test fixture and bias conditions together with the 'S' parameters of the twoports included in the measurement setup need to be known. These data can be produced automatically using the SETUP program of FOCUS MICROWAVES and an automatic Vector Network Analyzer .

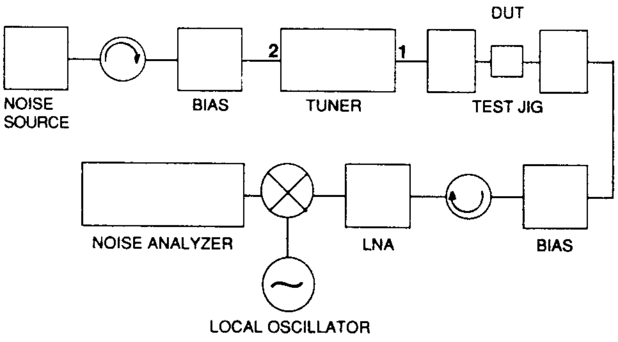


Fig. 1 - Typical Noise Measurement Setup using the CCMT

2. Instruments and components supported

The following GPIB programmable instruments can be used in order to prepare and carry out exact noise parameter measurements over a wide frequency range:

1. Network Analyzer: HP8510, Wiltron 360, HP8720.
2. Noise Analyzer: HP 8970A and -B, EATON 2075A and -B and HP 8971B single sideband noise test set.
3. Local Oscillator: Wiltron 6600 and 6700, HP 8350 with serie 83 and 86 plug ins, HP 8672 frequency synthetizer, as well as any fixed or manually tuneable signal source.

Furtheron microwave components available in most microwave laboratories can be used to compose the setup in any specific frequency range. As can be seen from fig. 1 other components required include isolators, bias tees, a mixer and a good test fixture. For noise figure measurements of less than 1dB it is recommanded to use a low noise preamplifier in front of the mixer. The quality of the test fixture used is very important for the measurement accuracy. The insertion loss and residual mismatch of the test fixture affect the precision of the measurement since it can be strongly mismatched by the tuner (see section 5, 'Accuracy Considerations').

3. Measurement Preparation

In order to carry out accurate and time effective noise parameter measurements a dedicated setup should be installed and thouroughly characterized using the SETUP program of FOCUS MICROWAVES and a Vector Network Analyzer.

SETUP gives the option of measuring 'S' parameters of all setup building blocks (isolators, bias tees and DUT). It characterizes the test fixture using TRL (*) or TDL (**) and uses those to deembed 'S' parameters of any DUT. It also offers the possibility to enter manually the 'S' parameters of any test fixture that cannot be characterized using TRL / TDL. Figure 2. shows the options offered by the program SETUP.

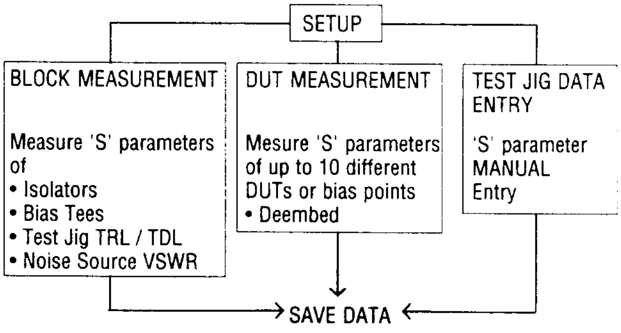


Fig. 2: Structure and options of the SETUP program.

The measured data are saved in binary files on the hard-disk ready to be retrieved automatically from the CCMT measurement routines at the time of operation.

(*) TRL: Thru-Reflect-Line calibration method [1]
(**) TDL: Thru-Delay-Line calibration method [2]

Appendix: Methodology of Noise Measurements.

This Appendix describes the method of Calibration and Measurement of Noise Factor used by the CCMT Applications Software NSOFT.

1. CALIBRATION

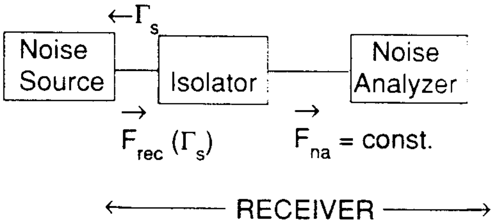


Figure A1: Measure: $F_{rec}(\Gamma_s)$

2. MEASUREMENT

(Valid both for single and double sideband operation)

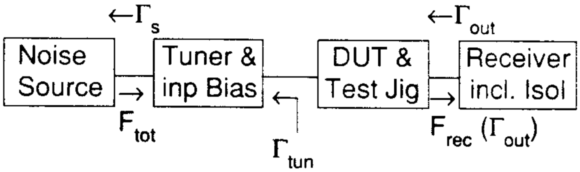


Figure A2: Measure: F_{tot}, G_{ins}, F_{corr}

hereby

$$\Gamma_{out} = S_{22} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_{tun}}{1 - S_{11} \cdot \Gamma_{tun}} \quad \text{(Sij are DUT parameter)} \qquad \text{(A1)}$$

hereby Γ_{tun} refers to the DUT, not the Test Jig plane.

The overall measured Noise Factor is

$$F_{tot} = F_1 + \frac{F_{rec}(\Gamma_{out}) - 1}{G_{ins}} \qquad \text{(A3)}$$

At this point we need the relations

$F_{rec}(\Gamma_{out})$ = function ($F_{rec}(\Gamma_s)$) and G_{av} = function (G_{ins})

If $|S_{12}(\text{isol})| \to 0$ (example < -25 dB) then the assumption 'F_{na} = const' is correct and we get

$$F_{rec} = \frac{1}{G_{av}.\text{isol}} + \frac{F_{na}(S_{22}.\text{isol}) - 1}{G_{av}.\text{isol}} = \frac{F_{na}}{G_{av}.\text{isol}} \qquad \text{(A4)}$$

For the Receiver Noise Factor we therefore obtain

a) In CALIBRATION

$$F_{rec}(\Gamma_s) = \frac{F_{na}}{G_{av}.\text{isol}(\Gamma_s)} \qquad \text{(A5)}$$

b) In MEASUREMENT

$$F_{rec}(\Gamma_{out}) = \frac{F_{na}}{G_{av}.\text{isol}(\Gamma_{out})} \qquad \text{(A6)}$$

By dividing these two equations we get

$$\frac{F_{rec}(\Gamma_s)}{F_{rec}(\Gamma_{out})} = \frac{G_{av}.\text{isol}(\Gamma_{out})}{G_{av}.\text{isol}(\Gamma_s)} \qquad \text{(A7)}$$

The general formula for Available Gain of a twoport which sees 'Γ_s' at its input port is

$$G_{av}(\Gamma_s) = |S_{21}|^2 \bullet \frac{1 - |\Gamma_s|^2}{|1 - \Gamma_s \bullet S_{11}|^2 \bullet (1 - |\Gamma_2|^2)} \qquad \text{(A8)}$$

where

$$\Gamma_2 = S_{22} + \frac{S_{12} \bullet S_{21} \bullet \Gamma_s}{1 - S_{11} \bullet \Gamma_s} \qquad \text{(A9)}$$

By applying this relation to the Isolator for the Calibration and the Measurement cases and dividing we get

$$\frac{G_{av}.\text{isol}(\Gamma_s)}{G_{av}.\text{isol}(\Gamma_{out})} = \frac{(1 - |\Gamma_s|^2) \bullet |1 - \Gamma_{out} \bullet S_{11}.\text{isol}|^2}{|1 - \Gamma_s \bullet S_{11}.\text{isol}|^2 \bullet (1 - |\Gamma_{out}|^2)} = \frac{F_{rec}(\Gamma_{out})}{F_{rec}(\Gamma_s)} \qquad \text{(A10)}$$

We define the mismatch correction factor M as

$$M = \frac{(1 - |\Gamma_s|^2) \bullet |1 - \Gamma_{out} \bullet S_{11}.\text{isol}|^2}{|1 - \Gamma_s \bullet S_{11}.\text{isol}|^2 \bullet (1 - |\Gamma_{out}|^2)} \qquad \text{(A11)}$$

Using M we can express the first of the requested relations as

$$F_{rec}(\Gamma_{out}) = m \cdot F_{rec}(\Gamma_s) \qquad \text{(A12)}$$

The Insertion Gain of the Tuner and DUT chain in Fig. A2, when loaded by the Isolator can be expressed as:

$$G_{ins} = |S_{21}.\text{chain}|^2 \bullet \frac{1 - |S_{11}.\text{isol} \bullet \Gamma_s|^2}{|1 - \Gamma_s \bullet S_{11}.\text{chain}|^2 \bullet |1 - S_{11}.\text{isol} \bullet \Gamma_2|^2} \qquad \text{(A13)}$$

The relation between the G_{av} and G_{ins} of the Tuner-DUT chain is

$$\frac{G_{av}}{G_{ins}} = \frac{(1-|\Gamma_s|^2)\cdot|1-S_{11}.isol\cdot\Gamma_{out}|^2}{(1-|\Gamma_{out}|^2)\cdot|1-S_{11}.isol\cdot\Gamma_s|^2} = M_1 \qquad (A14)$$

It can be seen that $M_1 = M$.

In the case of a perfect Isolator ($|S_{11}| \rightarrow 0$) and a Noise Source with $\Gamma_s \rightarrow 0$, M can be simplified to

$$M = \frac{1}{1-|\Gamma_{out}|^2} \qquad (A15)$$

Using '$G_{av} = M \cdot G_{ins}$' and '$F_{rec}(\Gamma_{out}) = M \cdot F_{rec}(\Gamma_s)$', equation (A2) can be written as

$$F_1 = F_{tot} - \frac{F_{rec}(\Gamma_s)\cdot M - 1}{G_{ins}\cdot M} \qquad (A16)$$

after some algebraic manipulations we get

$$F_1 = \underbrace{F_{tot} - \frac{F_{rec}(\Gamma_s)-1}{G_{ins}}}_{\text{'}F_{corr}\text{' as shown by Noise Analyzer}} - \frac{G_{av}-G_{ins}}{G_{av}\cdot G_{ins}} = F_{corr} - \frac{1-1/M}{G_{ins}} \qquad (A17)$$

F_1 is the Noise Factor of the chain 'Input Bias + Tuner + Test Jig + DUT + Output Bias' corrected for **Receiver Noise Contribution including Mismatch.**

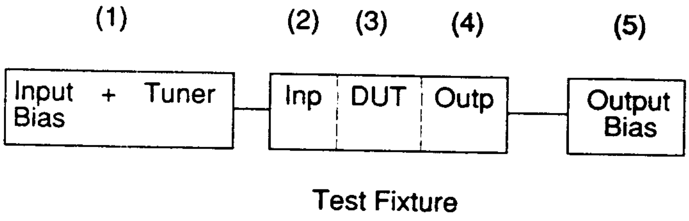


Figure A3:

For the complete setup of Fig. A3 we obtain:

$$F_1 = \frac{1}{G_{av1}} + \frac{1/G_{av2}-1}{G_{av1}} + \frac{F_{dut}-1}{G_{av1}\cdot G_{av2}} + \ldots. \qquad (A18)$$

We abbreviate $G_{av1}\cdot G_{av2} = G_{av}.inp$, $G_{av4}\cdot G_{av5} = G_{av}.out$ and get

$$F_{dut} = F_1\cdot G_{av}.inp - \frac{1}{G_{av}.dut \cdot G_{av}.out} + \frac{1}{G_{av}.dut} \qquad (A19)$$

F_1 from equation (A6) is now used in (A7)

$$F_{dut} = \left(F_{corr} - \frac{G_{av}-G_{ins}}{G_{av}\cdot G_{ins}}\right)\cdot G_{av}.inp - \frac{1}{G_{av}.dut\cdot G_{av}.out} + \frac{1}{G_{av}.dut} \qquad (A20)$$

which finally delivers

$$F_{dut}(\Gamma_{tun}) = F_{corr}\cdot G_{av}.inp - \frac{G_{av}.inp}{G_{ins}} + \frac{1}{G_{av}.dut} \qquad (A21)$$

From these quantities F_{corr} and G_{ins} are measured by the Noise Analyzer, $G_{av}.inp$ is calculated from the Setup and Tuner calibration data and $G_{av}.dut$ from the DUT's 'S' parameter and Γ_{tun} (fig A2).

References:

[1]: Product Note 8510-8, Hewlett Packard, Oct. 1987.

[2]: Application Note Measurement and Modelling of GaAs FET chips, AVANTEK, 1983.

[3]: M. Sannino, On the determination of Device Noise and Gain Parameters, Proceedings of the IEEE, Vol. 67, Sept. 1979.