# A COMPUTER CONTROLLED NOISE PARAMETER MEASUREMENT SYSTEM

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## Abstract

**A novel, computer controlled, noise parameter measurement system utilizing a new programmable load, is presented. Both signal and noise measurements are possible using only two transfer switches. A thorough mathematical treatment and accuracy calculations are presented. The performance of the system is verified by measurements (4–8GHz).**

## Introduction

The noise factor ($F$) of a two-port is a function of the source admittance ($Y_s$). This can be written as [1]

$$F = F_{min} + \frac{R_n}{G_s}|Y_s - Y_{opt}|^2 \qquad (1)$$

where $F_{min}$, $R_n$ & $Y_{opt}$ are the noise parameters. The noise parameters can be determined by fitting $F(Y_s)$ to at least four measured $(F, Y_s)$ pairs [2].

## System description

A block diagram of the noise parameter measurement system is shown in Fig. 1. Only two switches (S1 & S2) are needed for calibration reconfiguration and to make the automatic network analyzer (ANA) a part of the system. Full signal and noise characterization is possible if using a modern ANA (ie HP-8510 or Wiltron 360).

Noise factor measurement for different source admittances is made possible by injecting noise power via a coupler and by using a new programmable load. The programmable load [3] consists of a cascade of PIN-diodes, see Fig. 2. The reverse bias capacitances of the diodes together with the interconnecting bondwires, form a transmission line with a characteristic impedance close to 50Ω. Partial forward biasing of any diode pair along this line enables the system to synthesize any reflection coefficient within the coverage area of the programmable load.

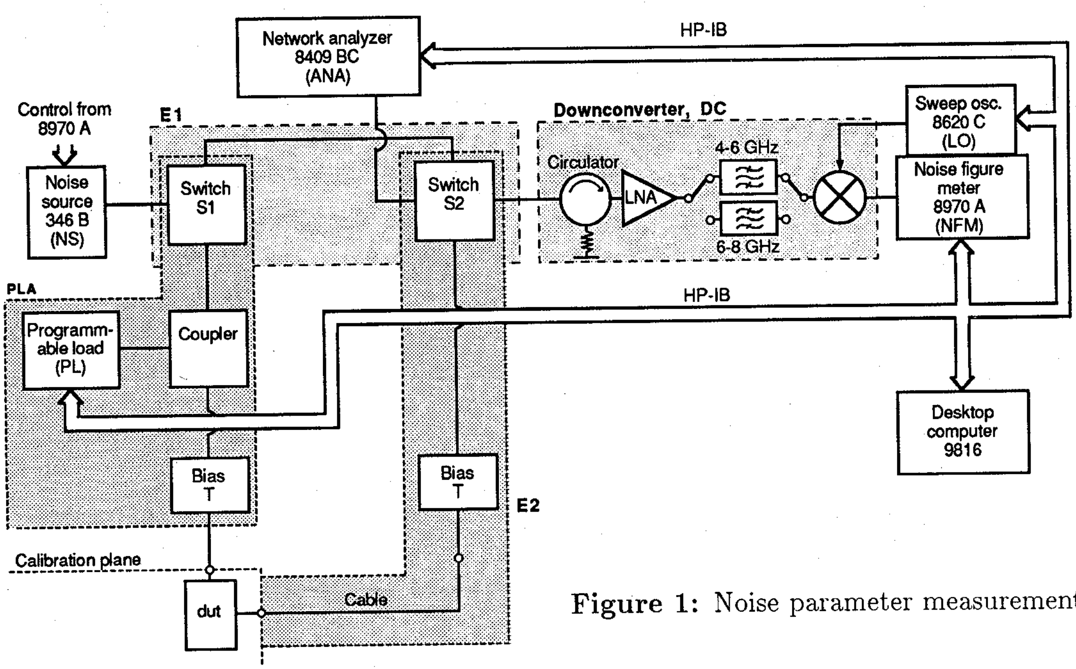


**Figure 1:** Noise parameter measurement system

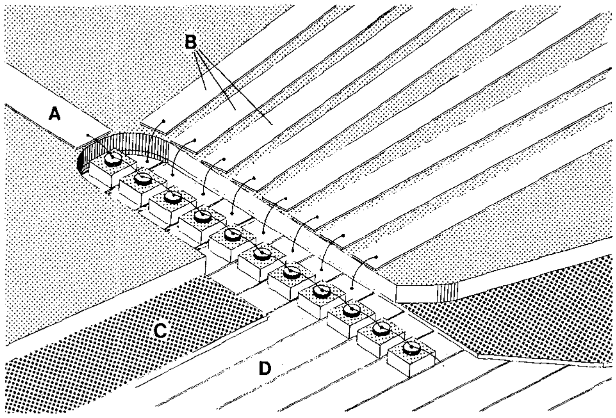


**Figure 2:** Programmable load realization: (A) 50Ω microstrip RF-feed; (B) DC supply lines; (C) combined microstrip and stripline ground plane; (D) virtual RF ground for the PIN diodes.

The noise factor meter is used in its SSB external LO mode. The 4–8GHz band is covered by using only two band-pass filters. This is achieved by alternating between upper and lower sideband. A low noise amplifier (LNA) is preceding the filters to improve the noise factor of the down converter (DC) block. The corrections made for this block are simplified by the circulator at the input.

## Measurements

The measurements can be divided into three groups: instrumentation calibrations, measurement calibrations and DUT measurements. The configurations for the last two measurement groups are shown in Fig. 3

The instrumentation calibrations are S-parameter measurements of subsystems E1 and E2. Measured quantities are $S_{21}^{E1}$, $S_{11}^{E2}$ and $S_{21}^{E2}$. Remeasurement is only needed if the hardware has been changed.

The measurement calibrations are done at beginning of each measurement session. Included in this group are:

- ANA reflection calibration at the reference plane where the output reflection coefficients of the programmable load assembly ($\Gamma_{out}^{PLA}$) and the *dut* ($\Gamma_{out}^{DUT}$) will later be measured.
- Second stage noise factor ($F^{m,2nd}$) measurement and insertion gain ($G_i$) reference level measurement.
- Programmable load calibration which is needed for the source admittance synthesis procedure [3].
- Programmable load assembly (PLA) noise factor ($F^{m,PLA}$), insertion gain ($G_i^{m,PLA}$) and output reflection coefficient ($\Gamma_{out}^{PLA}$) measurements. $\Gamma_{out}^{PLA}$ is the source reflection coefficient presented to the input of the *dut*. $F^{m,PLA}$, $G_i^{m,PLA}$ and $\Gamma_{out}^{PLA}$ are measured for all PL-settings used.

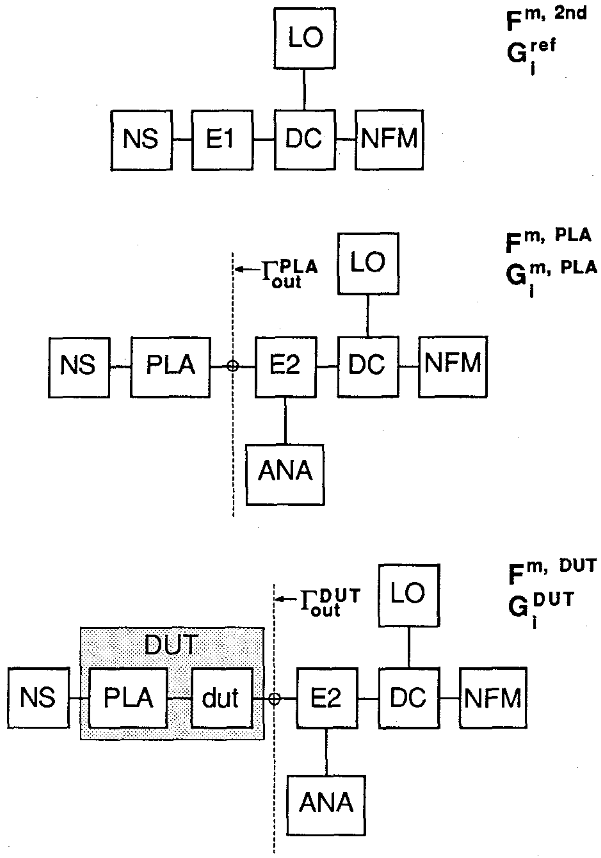


**Figure 3:** Measurement configurations. Note the distinction between dut and DUT=PLA+dut.

The DUT measurements are essentially the same measurements as for the PLA but with the *dut* inserted after the PLA. Measured quantities are $F^{m,DUT}$, $G_i^{m,DUT}$ and $\Gamma_{out}^{DUT}$. These quantities are the only ones measured for every *dut*.

## Calculations

It is possible to derive equations for $F^{dut}$ expressed in measured quantities only. If the circulator at the input of the DC is ideal, this can be written as

$$F^{dut} = G_a^{PLA}\left[F^{m,DUT} - \frac{F^{m,2nd}}{G_i^{m,DUT}}\right] + \frac{1}{G_a^{dut}} \qquad (2)$$

where

$$G_a^{PLA} = \frac{|S_{21}^{E1}|^2}{|S_{21}^{E2}|^2}\frac{|1 - S_{11}^{E2}\Gamma_{out}^{PLA}|^2}{(1 - |\Gamma_{out}^{PLA}|^2)} \qquad (3)$$

$$G_a^{dut} = \frac{G_i^{m,DUT}}{G_i^{m,PLA}}\frac{|1 - S_{11}^{E2}\Gamma_{out}^{DUT}|^2}{|1 - S_{11}^{E2}\Gamma_{out}^{PLA}|^2}\frac{(1 - |\Gamma_{out}^{PLA}|^2)}{(1 - |\Gamma_{out}^{DUT}|^2)} \qquad (4)$$

The obtained ($Y_s$,$F^{dut}$) pairs can now be used to determine the noise parameters of the *dut*. This is done by least square fitting of the linear noise factor equation presented by Lane [2].

## Accuracy

The accuracy of $Y_s$ is depending on the network analyzer accuracy. The error propagation from measurement accuracy to $F^{dut}$ accuracy was studied by numerically perturbing Eq. 2. This study showed that the measurement of passive devices is much more sensitive to measurement errors than the measurement of active devices. The reason for this is the product $F^{dut}G_a^{dut}$. It is equal to unity for passive devices and much greater than unity for active devices. The influence of this is illustrated by the algebraic differentiation of Eq. 2:

$$\begin{aligned}\Delta F^{dut}(dB) &= \Delta G_i^{m,PLA}(dB) \\ &- \frac{(1-QF^{m,2nd})}{F^{dut}G_a^{dut}}\cdot\Delta G_i^{m,DUT}(dB) \\ &+ \frac{QG_i^{m,DUT}F^{m,DUT}}{F^{dut}G_a^{dut}}\cdot\Delta F^{m,DUT}(dB) \\ &- \frac{QF^{m,2nd}}{F^{dut}G_a^{dut}}\cdot\Delta F^{m,2nd}(dB) \\ &+ \frac{2(F^{dut}G_a^{dut}-1)}{F^{dut}G_a^{dut}}\cdot\Delta|S_{21}^{E1}(dB)| \\ &- \frac{2(F^{dut}G_a^{dut}-1)}{F^{dut}G_a^{dut}}\cdot\Delta|S_{21}^{E2}(dB)| \\ &+ \Re \end{aligned} \quad (5)$$

where

$$Q = \frac{|S_{21}^{E1}|^2}{|S_{21}^{E2}|^2}\cdot\frac{|1-S_{11}^{E2}\Gamma_{out}^{DUT}|^2}{(1-|\Gamma_{out}^{DUT}|^2)} \quad (6)$$

$$\Re = \frac{\partial F^{dut}}{\partial S_{11}^{E2}}\Delta S_{11}^{E2} + \frac{\partial F^{dut}}{\partial \Gamma_{out}^{PLA}}\Delta\Gamma_{out}^{PLA} + \frac{\partial F^{dut}}{\partial \Gamma_{out}^{DUT}}\Delta\Gamma_{out}^{DUT} \quad (7)$$

The accuracy of the noise parameters is not only depending on the accuracy of $Y_s$ and $F^{dut}$. It is also depending on where the $Y_s$-points are located [4], [5] and on the way in which the parameter fitting is performed [6]. In this system we have placed the $Y_s$-points according to Davidson et al. [5] and monitored the condition number of the linear equation system of the least square fitting routine.

## Verification measurements

The noise parameters of passive circuits can be calculated from the their scattering parameters [7]. This makes them suitable for verification measurements. The measurements of two passive devices are presented here.

The first is a 3dB attenuator which measured results are presented in Fig. 4. The peaks in the measured $|\Gamma_{opt}|$ corresponds to high condition numbers for the linear equation system and hence to less well distributed $\Gamma_s$ patterns.

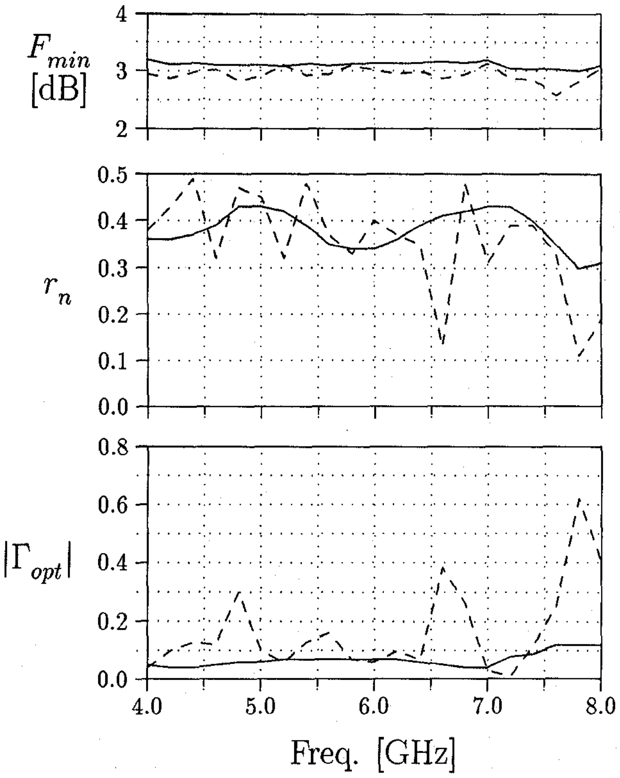


**Figure 4:** Noise parameters of a 3dB attenuator. Measured (dashed) and calculated from measured S-parameters (solid).

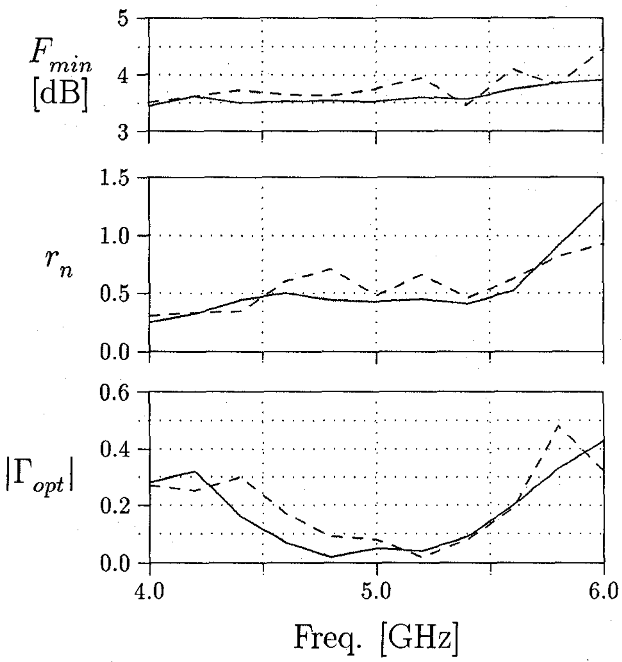


**Figure 5:** Noise parameters of a 3dB attenuator preceded by a stub. Measured (dashed) and calculated from measured S-parameters (solid).

The second is the same attenuator preceded by a stripline stub. The measured results for this device are shown in Fig. 5. The attenuation of this device was too high for the dynamic range of the instrumentation for frequencies above 6GHz.

## Conclusions

A novel configuration for a noise parameter measurement system has been presented. The methods and calculations used to determine the noise parameters are independent of frequency. A system designed for method verification over the 4–8GHz band has been built. Measurements demonstrates its abilities.

## References


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