# A WIDEBAND AUTOMATED MEASUREMENT SYSTEM FOR ON-WAFER NOISE PARAMETER MEASUREMENTS AT 50-75 GHZ

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## ABSTRACT

A wideband automated on-wafer noise parameter measurement system has been built. Using measurement system developed here, noise parameters of a chip device can be determined over entire 50-75 GHz range in an automated manner. As an example, measured noise parameters of an InP HEMT are shown over 50-75 GHz.

## INTRODUCTION

Noise parameters are used to describe noise behaviour of a linear two-port and they are essential information in designing low noise amplifiers (LNA). Usually, noise parameters at mm-wave frequencies are not given by the manufacturer or they have been derived by extrapolation from values measured at microwave frequencies. Therefore, accurate noise parameter measurements at mm-wave frequencies are needed in device characterisation as well as in the development and verification of device dependent equivalent circuit models.

Wideband on-wafer noise parameter measurements have so far been carried out only up to about 40 GHz. At 50-75 GHz range, measurements with manual input tuner and covering only part of the V-band has been shown previously by Lahdes, *et al.* (1, 2) and Tuovinen, *et al.* (3). Above 75 GHz, results only on a single frequency and for passive components have been reported by Alam, *et al.* (4).

## NOISE PARAMETERS

Noise parameters are unmeasurable quantities, which are determined indirectly by measuring noise figure of a linear two-port with different source impedances connected to the device under test (DUT). Noise figure of a linear two-port varies as a function of source reflection coefficient as

$$F = F_{\min} + 4r_n \frac{\left|\Gamma_S - \Gamma_{opt}\right|^2}{\left(1-\left|\Gamma_S\right|^2\right)\left|1+\Gamma_{opt}\right|^2} \qquad (1)$$

where $F_{\min}$ is the minimum noise figure, $r_n$ is the normalised noise resistance, $\Gamma_{opt}$ is the optimum reflection coefficient, with which minimum noise figure is achieved and $\Gamma_S$ is a reflection coefficient of a network connected to the input of the two-port. Parameters $F_{\min}$, $r_n$ and $\Gamma_{opt}$ are called noise parameters. Because $\Gamma_{opt}$ is a complex quantity, at least four noise figure measurements using different source reflection coefficients $\Gamma_S$ have to be made in order to solve noise parameters of the DUT. Usually, more than four measurements are made and noise parameters are solved using mathematical fitting routines.

## MEASUREMENT SETUP

Figure 1 shows a measurement setup for a wideband automated noise parameter measurements at 50-75 GHz. Setup can be divided in five functional blocks which are a noise source, a tuner, DUT, a noise receiver, and a S-parameter measurement setup. A solid-state noise source is used as a hot/cold noise reference needed in the noise figure measurement. A commercial automated waveguide tuner is used to change reflection coefficient of the network connected to the input of the DUT. Reflection coefficient at the DUT input plane is controlled by changing position and insertion of a moveable probe in a standard rectangular waveguide. Probe motions are controlled using stepper motors. Maximum magnitude of a realisable source reflection coefficient at DUT input is about 0.8. The noise receiver to measure noise power includes a LNA to increase receivers sensitivity and a mixer to downconvert the noise power from mm-wave frequencies to 30 MHz, which is suitable for a standard noise figure meter. The 50-75 GHz band LNA has been obtained through the Planck Surveyor development work, Tuovinen, *et al.* (5). The noise figure meter is used only to measure noise power levels. S-parameter measurement setup is included for DUT characterisation purposes. Transition from S-parameter measurements to noise measurements can be made without reconfiguration of the measurement setup using waveguide switches. A computer is used to control measurement setup and to perform noise parameter calculations.

Prior to actual noise measurements passive network between the noise source and the noise receiver must be carefully characterised. Also, a *kBG*-constant as well as noise parameters of the noise receiver are determined during calibration measurements using an on-wafer thru calibration standard. In the measurement method described by Adamian and Uhlir (6) and Meierer and Tsironis (7), only one hot noise power measurement with at least four cold noise power measurements are needed during noise figure measurements. After calibrations, a thru standard is replaced by a DUT and at least four noise power measurements are made using different values for source reflection coefficient at DUT input. Overall noise figure of a cascade of the DUT and the noise receiver can be determined from measured noise power levels using the *kBG*-constant of the noise receiver. Noise figure of the DUT is extracted removing the noise contribution of the noise receiver with help of noise parameters obtained during calibration. Noise parameters of the DUT are calculated from a set of noise figure and source reflection coefficient pairs.

## RESULTS FOR HEMT DEVICE

Operation of the wideband automated on-wafer noise parameter measurement system was verified by measuring noise parameters of both passive and active chip devices. Noise parameters were determined by performing cold noise power measurements using nine different source reflection coefficient values generated by the tuner. Noise parameters were calculated from measured data using noise parameter extraction technique described by Vasilescu *et al*. (8) with similar modifications as suggested in Escotte, *et al*. (9). With passive devices, a good agreement between values obtained by the automated measurement system and noise parameters calculated from S-parameter data was found, as can be seen in Figure 2. Typical results obtained for HEMT device are presented in Figure 3. Gate length and width of the HEMT device are 0.18 μm and 2 x 40 μm, respectively. Drain voltage 1.0 V and drain current 10 mA were used in the measurements.

Measurement uncertainty was studied with help of a Monte Carlo analysis. In the analysis random statistical errors were added to all measured values and noise parameters were re-calculated 1000 times. Resulted noise parameter sets were examined statistically. As an example, measured noise parameters with 95.5 % confidence boundaries at 57 GHz were $F_{\min} = 2.65 \pm 0.5$ dB, $r_n = 0.25 \pm 0.06$, $|\Gamma_{opt}| = 0.57 \pm 0.1$, $\angle\Gamma_{opt} = 121° \pm 8°$. Deviations of the minimum noise figure and the optimum source reflection coefficient are illustrated in Figure 4. Confidence boundary of individual noise parameter depends heavily of device as well as values of the other noise parameters.

## CONCLUSIONS

A unique wideband automated on-wafer noise parameter measurement system has been built and its performance has been demonstrated by measuring noise parameters of both passive and active device. System provides noise parameter data over entire 50-75 GHz range. The wideband automated on-wafer noise parameter measurement system will be an important tool in the development and verification of device models as well as in device characterisation.

## ACKNOWLEDGMENT

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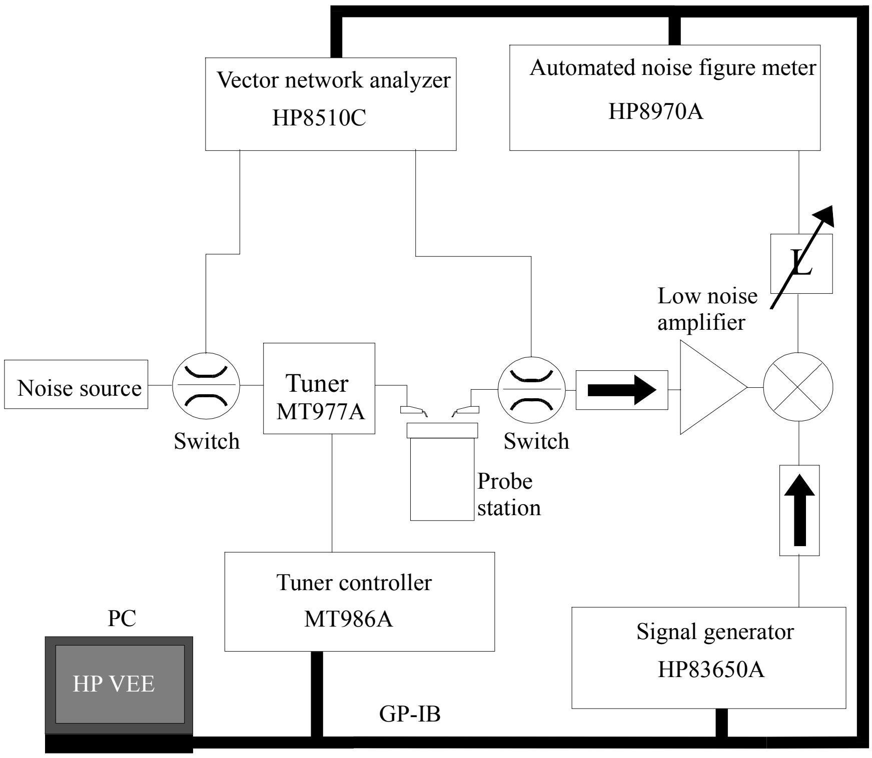
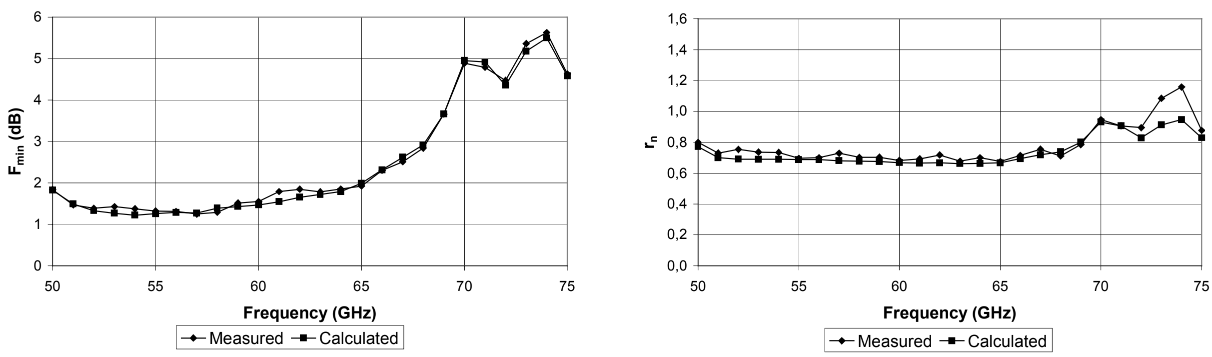



Figure 1: *Measurement setup for on-wafer noise parameter measurements at 50-75 GHz.*




*(a)* *(b)*

Figure 2: *Comparison between values measured with automated measurement system and values calculated from S-parameters: minimum noise figure (a) and normalised noise resistance (b) of a passive test device.*

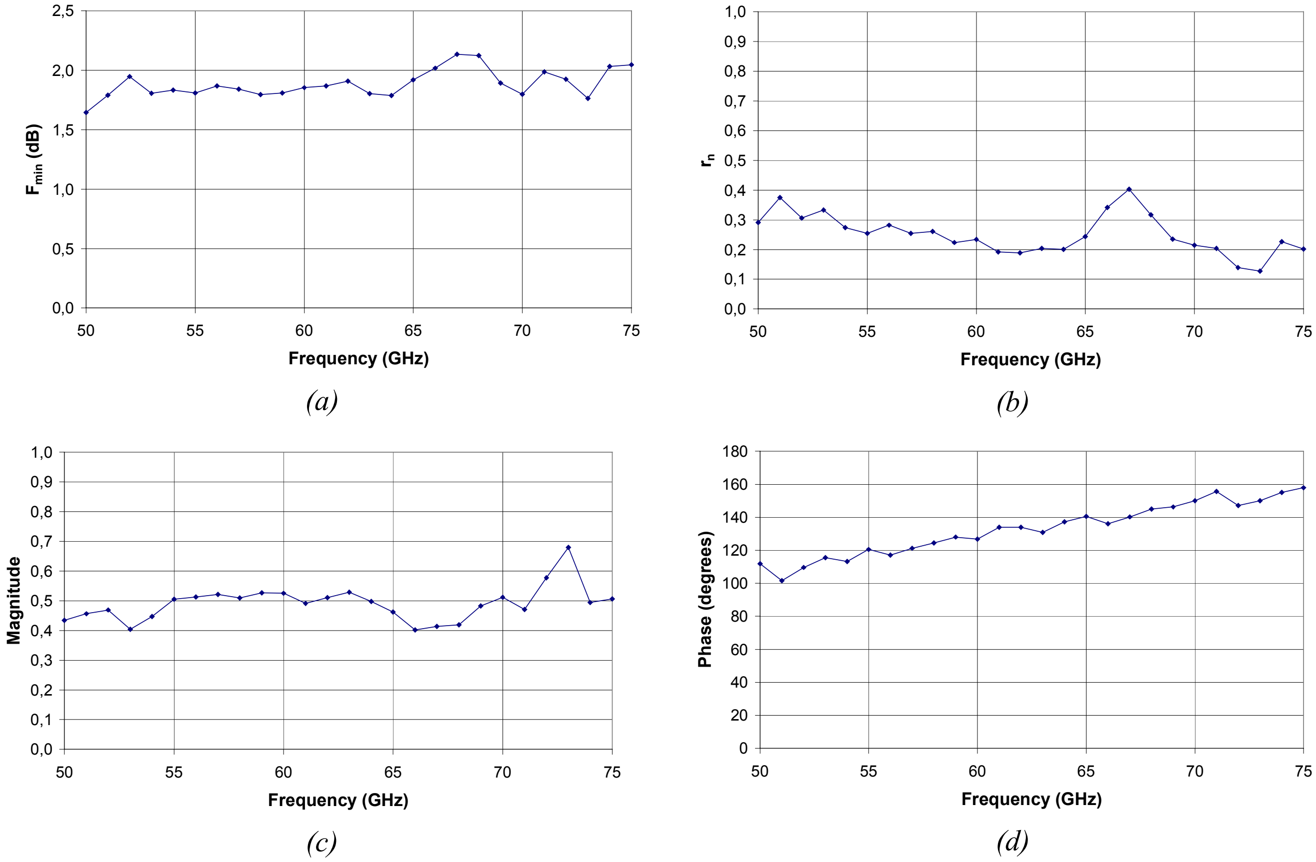



Figure 3: *Measured minimum noise figure (a), normalised noise resistance (b), magnitude of optimum source reflection coefficient (c) and phase of optimum source reflection coefficient (d) of a HEMT device. Values at 65-75 GHz range had some extra errors due to inaccurate calibrations*

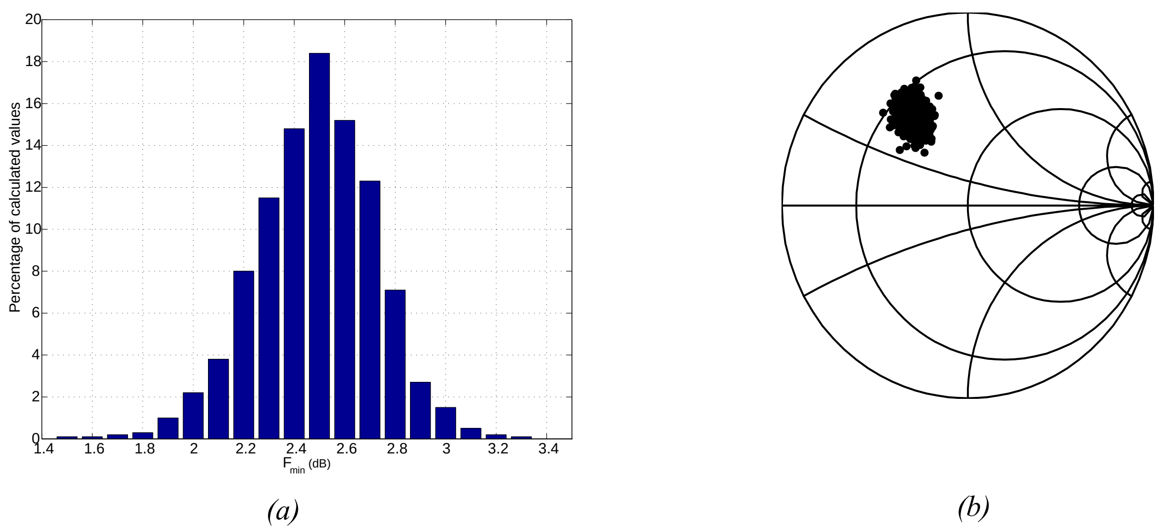



Figure 4: *Deviations of minimum noise figure (a) and optimum source reflection coefficient (b) obtained in Monte Carlo analysis at 57 GHz.*