Efficient Noise Extraction Algorithm and Wideband Noise Measurement System from 0.3 GHz to 67 GHz

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***Abstract*— An efficient and accurate noise parameter statistical extraction algorithm is proposed and validated experimentally using a high performance Silicon MOSFET transistor. The proposed algorithm is applicable to most devices with high input reflection coefficients and operating over wide bandwidth. Measured data agree well with theoretical expectation.**

***Index Terms*— noise parameter extraction, noise figure measurement, tuner, PNA-X.**

I. INTRODUCTION

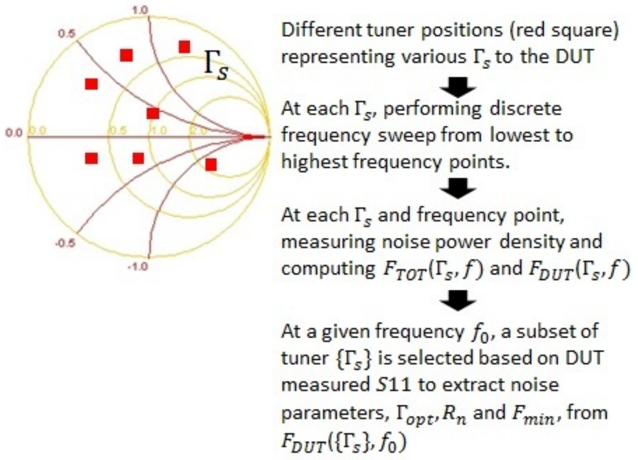
Traditional noise parameter extraction techniques rely mainly on the measurement of noise figure at several impedance points and a least square fitted solution based on an algebraic decomposition of the basic noise parameter formula. However, given current generation of devices with very high input Γ and operating over multi octave bandwidth, traditional techniques are no longer sufficient [1], [2]. The traditional method can fail due to measurement inaccuracies, as is common with very low noise figure, high input reflection devices. Additionally, the practical use of traditional techniques is limited when trying to extract noise parameters over an ultra-wide frequency range.

This summary presents an efficient noise parameter extraction algorithm suitable for most devices operating over ultra-wide band. Measured data of a Si MOSFET transistor is given to validate the proposed algorithm.

II. NOISE PARAMETER EXTRACTION ALGORITHM

Fig. 1 illustrates main steps of the proposed noise parameter extraction algorithm. The idea is to perform a new type of impedance pattern distribution using a programmable tuner, as well as a statistical extraction technique that is based on combinations of appropriately selected tuner's impedances Γ_S presenting to the device under test (DUT) at each frequency of extraction, i.e. f_0. In order to ensure that there will be always be appropriate subset of noise parameter data (Γ_{opt}, R_n, and F_{min}) on each frequency sweep, an appropriate set of tuner's impedances Γ_S is first generated and pre-optimized for the frequency range of interest.

Next, at each tuner's impedance point, a discrete frequency sweep is performed (often using a vector network analyzer) and the noise power density (P) is recorded for each discrete frequency point. The total noise figure of the noise measurement setup (as depicted in Fig. 2) is given by Eq. 1.



Different tuner positions (red square) representing various Γ_s to the DUT

At each Γ_s, performing discrete frequency sweep from lowest to highest frequency points.

At each Γ_s and frequency point, measuring noise power density and computing $F_{TOT}(\Gamma_s, f)$ and $F_{DUT}(\Gamma_s, f)$

At a given frequency f_0, a subset of tuner $\{\Gamma_s\}$ is selected based on DUT measured $S11$ to extract noise parameters, Γ_{opt}, R_n and F_{min}, from $F_{DUT}(\{\Gamma_s\}, f_0)$

Fig. 1. Proposed noise parameter extraction algorithm.

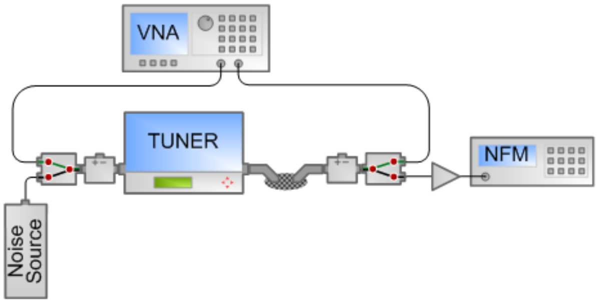


Fig. 2. Noise measurement setup. VNA: Vector Network Analyzer, NFM: Noise Figure Measurement, TUNER: Electromechanical tuner. Equipment from left to right: Noise source, switch, bias-tee, TUNER, DUT, bias-tee, switch, low noise amplifier (LNA), NFM.

$$F_{TOT}(\Gamma_s) = \frac{P}{T_0 kBG} \frac{|1 - S_{11}\Gamma|^2 \, |1 - \Gamma_{Rx}\Gamma_s|^2}{(1 - |\Gamma|^2)\, |S_{21}|^2} - \frac{T_C}{T_0} + 1 \quad (1)$$

In Eq. 1, S_{11}, S_{21} are S-parameter of the DUT, Γ_S is the source reflection coefficient seen by the DUT, Γ is the source reflection coefficient seen by the LNA, Γ_{Rx} is the input reflection coefficient of the LNA, T_c and T_0 are the actual and standard temperature (290K), respectively. The term kBG is the gain-bandwidth constant of the receiver and is given as:

$$kBG = \frac{P_H - P_C}{T_H - T_C}\left(\left|1 - \Gamma_{Rx}\Gamma_s\right|^2\right)\left(\frac{\left|1 - S_{11}\Gamma_{NS}\right|^2}{\left(1 - \left|\Gamma_{NS}\right|^2\right)\left|S_{21}\right|^2}\right) \tag{2}$$

with $T_H = T_0\left(1 + 10^{\frac{ENR}{10}}\right)$ is the hot noise source temperature, ENR is the excess noise ratio of the noise source, measured in dB. Γ_{NS} is the reflection coefficient of the noise source in OFF state. The term kBG is computed by measuring the noise power density in two different states of the noise source: state 1) the noise source is ON (P_H, T_H) and state 2) the noise source is OFF (P_C, T_C).

Once the total noise figure is computed, the noise figure of the DUT can be extracted by appropriately de-embedding and given as [3], [4]:

$$F_{DUT}(\Gamma_s) = F_{TOT} - \frac{F_{Rx}(\Gamma_s) - G_{OUT}}{G_{DUT}G_{OUT}} \tag{3}$$

where G_{DUT} and G_{OUT} are DUT's available gain and total available gain (loss) of the output network (bias-tee and switch), respectively.

At the final step when $F_{DUT}(\Gamma_s)$ is available for all tuner's impedances at f_0, the statistical extraction algorithm then selects an appropriate subset of the measured F_{DUT} and perform extractions using different combinations of the selected F_{DUT} data. The resulting extractions are then statistically analyzed to produce a final set of noise parameter data at f_0.

III. NOISE MEASUREMENT EXPERIMENTAL DEMONSTRATION

A high performance Silicon MOSFET transistor is used as a DUT to validate the proposed noise parameter extraction algorithm. Agilent PNA-X model N5247S (10 MHz to 67 GHz) with option S29 (built-in fully-corrected Noise Figure Measurement to 50 GHz) is used in the measurement setup. For frequency range from 50 GHz to 67 GHz, an external downconverter with a local oscillation frequency of 47 GHz is used in the output path to convert noise to an measurable frequency range (3 GHz to 20 GHz). Due to limits of tuner and PNA-X, the entire frequency band from 0.3 GHz to 67 GHz is broken into three sub-bands with band 1 from 0.3 GHz to 10 GHz, band 2 from 10 GHz to 50 GHz and band 3 from 50 GHz to 67 GHz. The results are subsequently combined to produce the data between 0.3 GHz to 67 GHz. Fig. 3 shows the extracted noise figure of the DUT upto 67 GHz. Additional measured data of the DUT and extracted noise parameters will be given at the conference.

Fig. 3. Measured NFmin of a Si MOSFET device from 0.3 GHz to 67 GHz using proposed noise parameter extraction algorithm. The Si MOSFET has NFmin of 4.841dB at 67 GHz.

IV. CONCLUSION

An efficient and accurate noise parameter statistical extraction algorithm has been proposed and validated experimentally. The extracted noise figure of the Si MOSFET device shows a upward trend versus frequency and agrees well with the expected theoretical result.

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