Paper

Lowering the uncertainty in fast noise measurement procedures

Gianluca Acciari, Franko Giannini, Ernesto Limiti, and Giovanni Saggio

Abstract — To completely characterise the noise behaviour of a two port device, four noise parameters $F_{\min}$, R_n, G_{opt} and B_{opt} must be determined. This paper reports improvements in the uncertainty related to the above parameters, taking into account measurement errors due both to the limited instrument precision and connection repeatability. Results are reported for noise characterisation of 0.3 μm δ-doped HEMT devices by Alenia, demonstrating as the common hot-cold measurement procedure can result with an error confidence as low as 0.2% for all the noise parameters.

Keywords* — *noise, device characterisation, measurement errors, lowering uncertainty.

1. Introduction

The F50 method [1] is recognised as a well established procedure to determine the four noise parameters of a noisy two port. It allows simple and fast measurement procedures with respect to standard method characterisation, where a tuner is needed. Nevertheless, the F50 method has an important drawback since an equivalent circuit model of the DUT is necessary. It is therefore important an exhaustive investigation of the standard procedure also to establish the final obtainable measurement accuracy it can provide.

To overcome the overall measurement uncertainty problem it is necessary to maximise the measure repeatability and to compensate for systematic errors. In order to solve the Friis formula for the determination of the noise parameters, more than four measurements (corresponding to four different values of the source reflection coefficient Γ_S), are required for redundancy. The evaluation of the optimum number of measurements which are convenient to carry out is not an easy task, and many efforts have been spent to determine its minimum value, since the measurement procedure is quite time consuming.

Assuming the DUT as a two port device, its noise behaviour as a function of the source admittance $Y_s = G_s + jB_s$, can be expressed as:

$$F = F_{\min} + \frac{R_n}{Re\{Y_s\}} \left| Y_{opt} - Y_s \right|^2, \tag{1}$$

where $Y_{opt} = G_{opt} + jB_{opt}$ is the optimum source admittance which gives the minimum noise figure $F_{\min}$ for the DUT and R_n is the equivalent noise resistance.

Since the noise figure F value depends on the source admittance Y_s, its determination is consequently subordinated to random and/or systematic measurement errors. In order to evaluate the four unknown values $F_{\min}$, R_n, G_{opt} and B_{opt}, in principle the Y_s value can be experimentally varied until a minimum in the $F_{\min}$ value is obtained. From a practical point of view, four different values of source admittance could be enough in order to solve, a linearised system [2] of four equations. Nevertheless, to minimise the errors due to measurement inaccuracy, is commonplace to consider more than four Y_s values for redundancy.

It has been previously reported how the accuracy increases with the redundancy of experimental data [3], but at the same time, different criteria may help in the reduction of the needed experimental data to the order of tens [4]. These criteria come from the necessity of a simple algebric manipulation for a few measurement points but exhibit the drawback of the time consuming search for particular Γ_S values varying the position of the tuner's probe. Thanks to modern computer-controlled mechanical tuners and to efficient and adequate equipment, heavy procedures in terms of calculus can be implemented with no particular computing overhead. So it appears common sense to increase the number of redundant measurements since the effort established in reducing it can be generally paid just in terms of accuracy.

Taking advantage of the fact that all the measurement set-up is computer-controlled via GP-IB, the measurement procedure here adopted is fully automated and completely optimised so that, to collect a data set in the order of hundreds, both the S parameter characterisation and the noise measurements need only few minutes per frequency.

2. Experimental set-up

The proposed experimental set-up is optimised for on-wafer measurement. To characterise each block of the measurement chain a preliminary standard SOLT calibration has been performed, while a TRL procedure has been adopted to de-embed the contribution of the probes by a home-made software algorithm. The source admittance is varied by a slide screw computer controlled mechanical tuner. The set-up is fully controlled via a GP-IB bus.

Before noise measurements, a S parameter characterisation has been performed for all parts of the measurement chain, by a HP8510C vector network analyser.

3. Experimental results

The overall measurement accuracy can be affected by many potential errors, generally classified into a first group evaluated by statistical methods and a second group evaluated by manufacturer specifications [5]. Statistical methods can be applied to evaluate the error amounts which can be due, for instance, to mismatch problems, to EM susceptance of the set-up or to connection repeatability. Manufacturer specification accuracies can be adopted for the standards when the calibration procedure is performed, for the factory tabled ENR values of the noise source, for the tuner position repeatability, and in general for the instrumentation uncertainty.

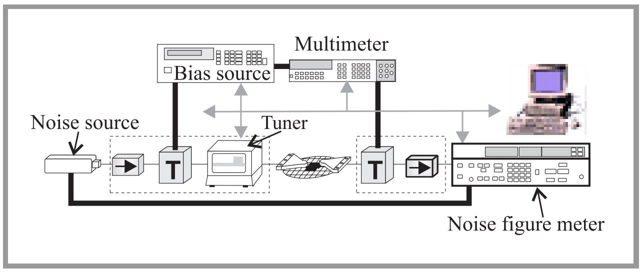


Fig. 1. Measuring system scheme. It is based on the HP346C noise source, home-designed wafer probe station, HP8970B noise figure test set and on the Focus 1808 mechanical tuner. The input block (isolator, bias tee, tuner) and the output block (bias tee, isolator) are highlighted.

Given their large number, it is practically impossible to account for all the possible error sources but, in our experience, the influence of all of them on the final results can be summarised in a percentage variation both on the measured S parameters (for each block in the measurement chain), and on the overall insertion gain G_{ins} and noise figure F_{tot}. In particular for the measured S parameters a ±4% error has been assumed for the DUT and for the block before DUT it in the measurement chain (first **isolator, bias tee** and **tuner** in Fig. 1), and an error of ±0.3 dB has been assumed for the insertion gain G_{ins} measured by the noise figure meter and for the measured noise figure F_{tot} of the entire chain. With such error adoptions, a Monte Carlo analysis has been performed based on 3000 iterations, adopting a gaussian parameter variation. Several investigations for different devices and for different bias conditions have been carried on, in the aim of determining how the resulting noise parameters can be affected in the sense of percentage errors. For comparison purpose, different data analysis have been adopted, such as the Mitama-Katoh evaluating method [5] (for which an integrated microstrip tuner was adopted), and the Boudiaf-Laporte recursive fitting procedure [6]. However the most suitable method has been demonstrated to be a least-squares fitting procedure proposed by Lane [2] who reduced the noise figure expression (1) to the following linearised expression:

$$F = A + BG_S + \frac{C + BB_S^2 + DB_S}{G_S}, \tag{2}$$

where the coefficients A, B, C and D are functions of the four noise parameters and are evaluated minimising the estimated error ε:

$$\varepsilon = \frac{1}{2} w_i \sum_{i=1}^{N_{TOT}} \left[A + B\left(G_{s,i} + \frac{B_{s,i}^2}{G_{s,i}} \right) + \frac{C}{G_{s,i}} + D\frac{B_{s,i}}{G_{s,i}} - F_i \right]^2, \tag{3}$$

where w_i is a weighting factor that we selected, after some optimisation, to be equal to $1/F^{1.5}$.

Figure 2 shows the $F_{\min}$ behaviour with frequency for the H300 device as an example, and in Fig. 3 is reported the experimental results and the evaluated corresponding errors for the same device, 50% I_{dss}. It is worth noting a meaningful improvement in accuracy with redundancy increasing.

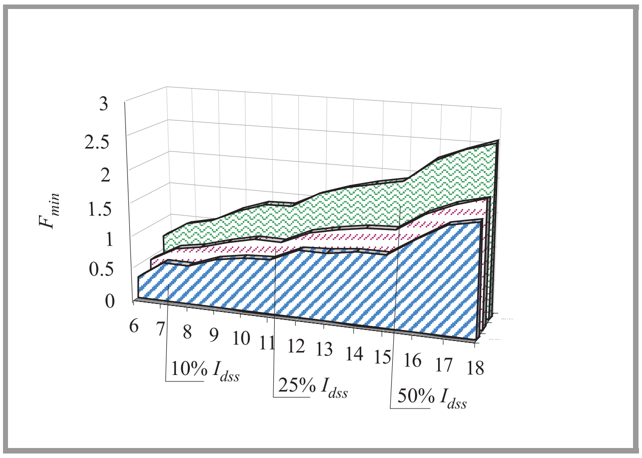


Fig. 2. The minimum noise figure $F_{\min}$ versus frequency for different biasing conditions for the H300 device.

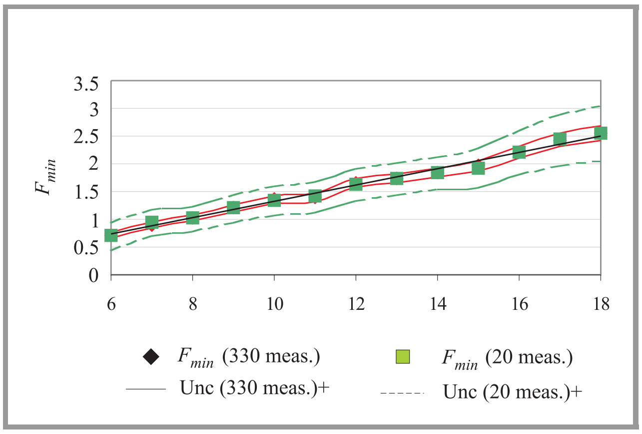


Fig. 3. $F_{\min}$ at the 50% I_{dss} versus frequency. Uncertainty range is reported for high redundancy (330) and low redundancy (20) measures.

For all the DUTs at all the bias conditions the equivalent noise resistance R_n decreases as frequency increases (e.g. Fig. 4), while its uncertainty can be considered neg-

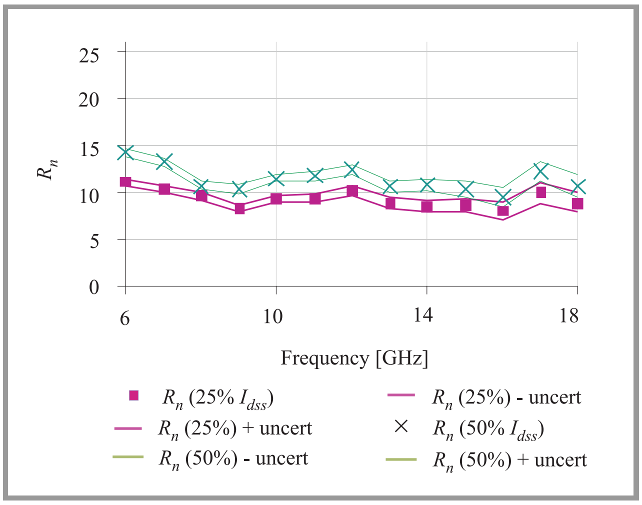


Fig. 4. Equivalent noise resistance R_n versus frequency for the H300 device at two bias condition: 25% and 50% I_{dss}.

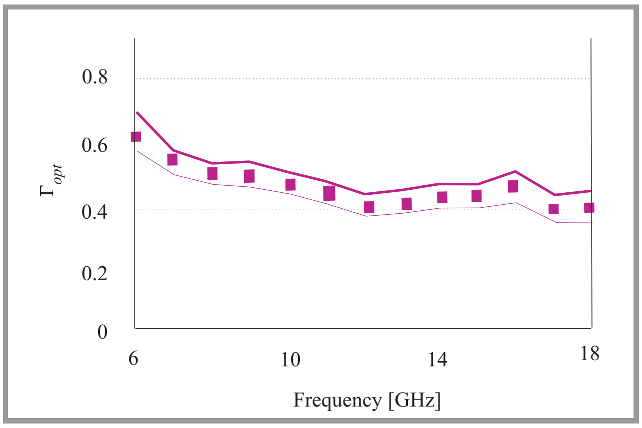


Fig. 5. $|\Gamma_{opt}|$ versus frequency for the H300 device at the 25% I_{dss} bias condition.

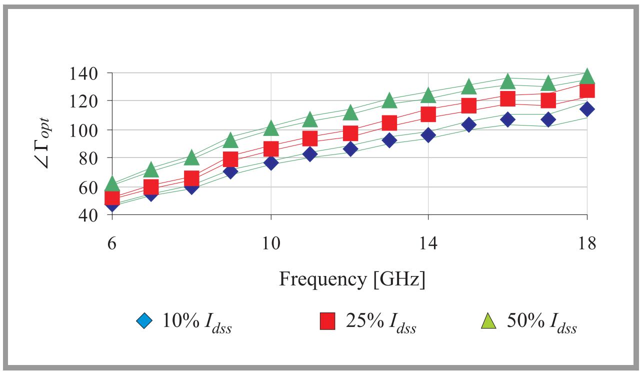
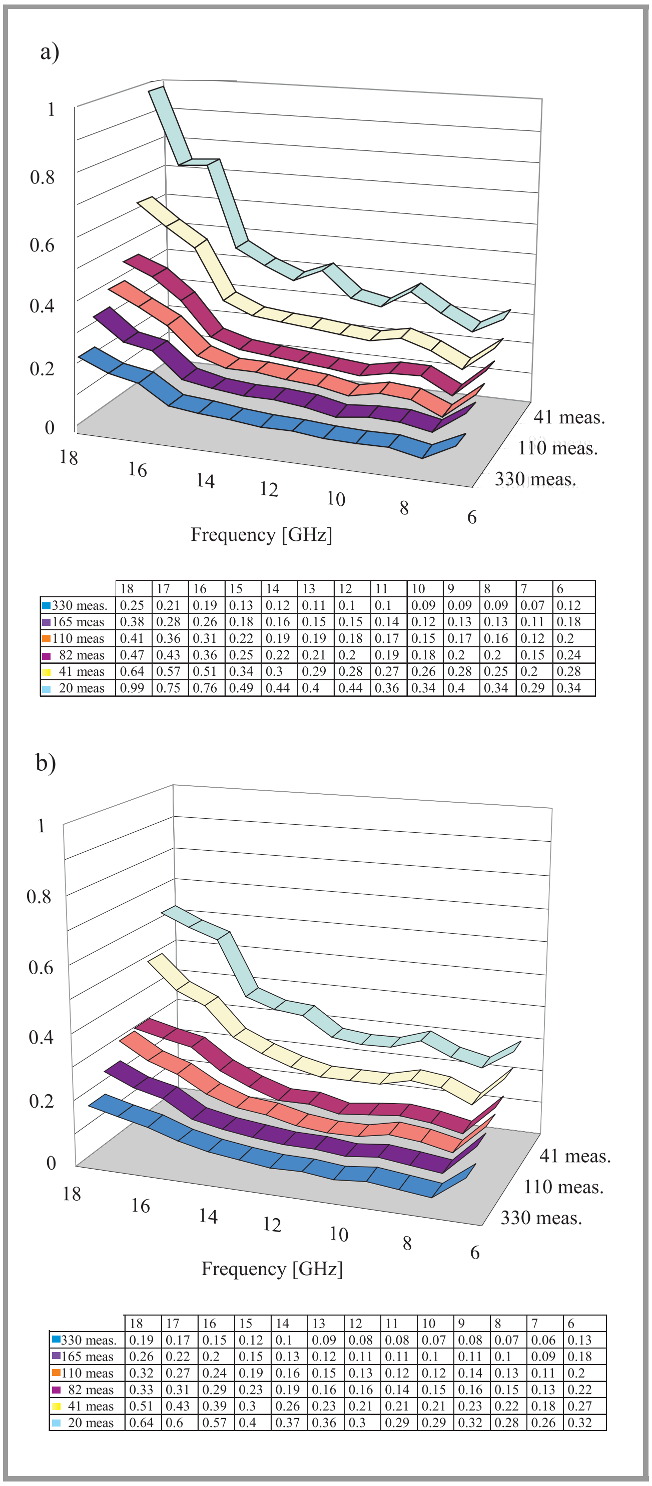


Fig. 6. $\angle\Gamma_{opt}$ versus frequency for the H300 device at three bias conditions.



	18	17	16	15	14	13	12	11	10	9	8	7	6
330 meas.	0.25	0.21	0.19	0.13	0.12	0.11	0.1	0.1	0.09	0.09	0.09	0.07	0.12
165 meas	0.38	0.28	0.26	0.18	0.16	0.15	0.15	0.14	0.12	0.13	0.13	0.11	0.18
110 meas	0.41	0.36	0.31	0.22	0.19	0.19	0.18	0.17	0.15	0.17	0.16	0.12	0.2
82 meas	0.47	0.43	0.36	0.25	0.22	0.21	0.2	0.19	0.18	0.2	0.2	0.15	0.24
41 meas	0.64	0.57	0.51	0.34	0.3	0.29	0.28	0.27	0.26	0.28	0.25	0.2	0.28
20 meas	0.99	0.75	0.76	0.49	0.44	0.4	0.44	0.36	0.34	0.4	0.34	0.29	0.34

	18	17	16	15	14	13	12	11	10	9	8	7	6
330 meas.	0.19	0.17	0.15	0.12	0.1	0.09	0.08	0.08	0.07	0.08	0.07	0.06	0.13
165 meas	0.26	0.22	0.2	0.15	0.13	0.12	0.11	0.11	0.1	0.11	0.1	0.09	0.18
110 meas	0.32	0.27	0.24	0.19	0.16	0.15	0.13	0.12	0.12	0.14	0.13	0.11	0.2
82 meas	0.33	0.31	0.29	0.23	0.19	0.16	0.16	0.14	0.15	0.16	0.15	0.13	0.22
41 meas	0.51	0.43	0.39	0.3	0.26	0.23	0.21	0.21	0.21	0.23	0.22	0.18	0.27
20 meas	0.64	0.6	0.57	0.4	0.37	0.36	0.3	0.29	0.29	0.32	0.28	0.26	0.32

Fig. 7. Error percentage for F_{min} versus frequency and measurement number with (a) $\alpha = 0$ and (b) $\alpha = 1.5$.

ligible since it is in the $0.5-1.5\ \Omega$ range in the worst case of 10% I_{dss}. Being the R_n value a weighting factor for the mismatch of the measured source reflection coefficient Γ_s from its optimum value Γ_{opt}, its behaviour justifies that the device mismatch assumes less importance with frequency. In spite of that, the $|\Gamma_{opt} - \Gamma_s|$ value increases quite rapidly with frequency, reducing the positive smoothing effect that can be due to R_n with frequency.

The uncertainty for $|\Gamma_{opt}|$ values results to be higher when its value is near unity (Fig. 5 as an example). In any case, at all the biasing conditions and for all the devices under test, the same $\angle\Gamma_{opt}$ behaviour can be observed (Fig. 6 as an example). At low frequency it increases rapidly while tends to saturate for higher frequencies. Its uncertainty increases with frequency, remaining however almost negligible.

Figure 7 shows how the accuracy increases with redundancy, both for the least-squares fitting procedure (Fig. 7a) and for the same fitting considering the $1/F^{\alpha}$, with $\alpha = 1.5$, weighting factor (Fig. 7b). In addition it can be noticed as an error confidence as low as 0.2% can be obtained for all the determined noise parameters.

4. Conclusions

This work demonstrates how the accuracy in measuring the four noise parameters can be drastically improved collecting a data set with a certain redundancy. This consideration is to be associated with the reported criteria of choice the experimental points in certain regions of the Smith Chart [3, 4]. A method is also proposed to estimate the overall measurement accuracy taking into account measurement errors due to both the limited instrument precision and to connection repeatability.

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