Evaluation of Noise Parameter Extraction Methods

Laurent Escotte, Robert Plana, and Jacques Graffeuil

Abstract—**The influence of the algorithm used for noise parameter fitting on the accuracy of the microwave noise parameter measurements is investigated. Five different commonly used algorithms are compared by statistical analysis including instrument accuracy specifications. Some of these algorithms are found to be more efficient in terms of available accuracy and computer-time. The best predicted available accuracies reported between 4 and 20 GHz for each noise parameter compare well with observed accuracies on noise parameter measurements performed with a dedicated test-set on a noise standard made of a passive two-port. The accuracy on minimum noise figure is found to be 0.1 dB maximum.**

I. Introduction

NOISE PARAMETER measurements of active microwave devices up to 26 GHz and beyond are now routinely performed. The "multiple impedance" technique which is best suited for appropriate automatic characterization and therefore most commonly used, derives noise parameters from noise figure data taken with various source admittances.

This technique is based on the relationship between the noise figure F of a linear two-port at a given frequency f and the source admittance $Y_s = G_s + jB_s$ given by the following equation [1]:

$$F = F_{\min} + \frac{R_n}{G_s}[(G_s - G_o)^2 + (B_s - B_o)^2] \qquad (1)$$

where the minimum noise figure $F_{\min}$, the equivalent noise resistance R_n and the optimum source admittance $G_o + jB_o$ yielding a minimum noise figure are referred to as the four noise parameters at frequency f. Therefore at least four noise figure data F_i values and the associated source admittances $G_{si} + jB_{si}$ are required at each frequency to compute the four noise parameters with an appropriate extraction software based on (1).

Several factors affect the accuracy of this technique [2]–[4]. Among them are uncertainties on noise measurements (noise source and noise figure meter accuracies [5]) which are more prone to errors than other microwave measurements and uncertainties on vector measurements which affect the accuracy of source admittance data and losses before and after the Device Under Test (DUT). More than four source impedances must therefore be used to do some averaging and to improve accuracy.

Many papers have already addressed the issue of noise parameter extraction from an over-dimensioned set of data and several different techniques have been proposed [6]–[12].

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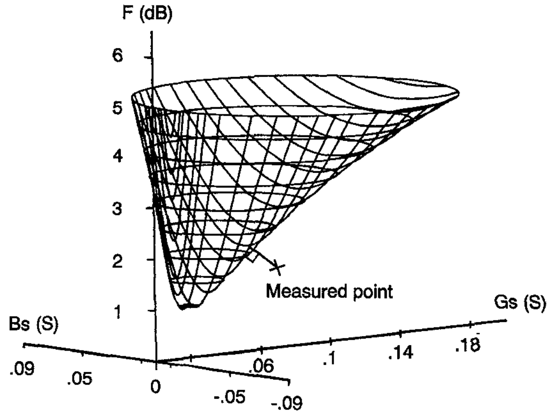

Fig. 1. Noise surface of a linear two-port. $F_{\min} = 1$ dB, $R_n = 15\,\Omega$, $|\Gamma_o| = 0.53$, arg $(\Gamma_o) = 67$ degrees.

However these various methods have not been systematically compared yet. This paper addresses this issue and compares the results of noise parameters extracted by five different extraction techniques either from computer simulated data or measured data. Section II describes the different extraction techniques. Section III compares the accuracies of each of these procedures from a computer-based investigation. Section IV presents experimental data substantiating our conclusions.

II. Different Extraction Procedures Under Test

Fig. 1 is the 3-D plot of (1): each set of four noise parameters defines a noise surface which is a quasi-elliptic paraboloid. Each point defined by a measured F_i and the corresponding $Y_{si} = G_{si} + jB_{si}$ must be located on this noise surface. As a result, any fitting algorithm must furnish suitable values of the four noise parameters to enable the measured points to be as close as possible to the noise surface.

For decades various methods using a least-squares fitting procedure have been proposed. Lane's method [6] reduces the derivation of the noise parameters to the solution of a four linear equation system. Equation (1) is transformed into (2):

$$F = A + BG_s + \frac{C + BG_s^2 + DB_s}{G_s} \qquad (2)$$

where A, B, C and D depend on the noise parameters $F_{\min}, R_n, G_o$ and B_o, and are obtained by minimizing the following estimated error ϵ_1:

$$\epsilon_1 = \frac{1}{2}\sum_{i=1}^{N} w_i \left[A + B\left(G_{si} + \frac{B_{si}^2}{G_{si}}\right) + \frac{C}{G_{si}} + D\frac{B_{si}}{G_{si}} - F_i\right]^2 \qquad (3)$$

where w_i is a weighting factor and N the number of different measured noise figures and source admittances. Unfortunately this technique entails small data perturbations due to unavoidable measurement uncertainties and may produce strong variations of computed noise parameters [2] leading to inaccurate results. To circumvent this a widely used technique referred to as Mlane (for Modified Lane) chooses a weighting factor w_i equal to $1/F_i^2$: thus high values of F_i, which are known to be less accurately measured than smaller F_i, contribute less to the total estimated error.

Another method proposed by Katoh and Mitama [7] considers noise figure and source admittance errors. It consists of minimizing the distance between the estimated data, which must be located on the noise surface, and the measured ones not located on it due to measurement uncertainties. This distance is the length of a segment of a line normal to the noise surface projected from the measured point (F_i, G_{si} and B_{si}) as shown in Fig. 1. Assuming small estimated errors, (1) is extended in a Taylor series and a set of linear equations is obtained. It is solved with the help of initial values of $F_{\min}, R_n, G_o$ and B_o derived from Lane's technique.

Another method proposed by Vasilescu, Alquie and Krim [8] consists of directly solving a system of four nonlinear equations instead of using a least-squares fit. The procedure begins by making all the possible M combinations of four data sets among the N measured data sets (F_i, G_{si}, B_{Si}) and solving each of them for $F_{\min j}, R_{nj}, G_{oj}$ and B_{oj} ($j = 1$ to M and $M = N!/4!(N-4)!$).

For each M computed noise parameter sets, the noise figures Fc_{ij} are calculated at each source admittance (G_{si}, B_{si}) and the retained noise parameter set is the one which minimizes an error function ϵ_3 given by:

$$\epsilon_3 = \sum_{i=1}^{N} \frac{|Fc_{ij} - F_i|}{F_i}. \tag{4}$$

This technique yields satisfactory results but, in some cases, up to 50% of the computed solutions may be meaningless. We therefore modified the algorithm so as to delete any noise parameter set yielding an error function greater than 10%. The noise parameter sets returned at the end of the procedure are finally averaged. Thus all the results obtained are meaningful and the algorithm used to evaluate the different methods is referred to as Vasilescu although it is in fact the modified one.

An alternative technique is proposed by Boudiaf *et al.* [9] by extending Williamson's method [10] to noise parameter determination. Equation (1) is transformed into a straight line:

$$y_i = F_{\min} + R_n x_i \tag{5}$$

where

$$y_i = F_i$$

and

$$x_i = \frac{1}{G_{si}}[(G_{si} - G_o)^2 + (B_{si} - B_o)^2].$$

The weighted distance between adjusted (x_i, y_i) and measured values (X_i, Y_i) is defined as:

$$d_i = \frac{(x_i - X_i)^2}{u_i} + \frac{(F_{\min} + R_n x_i - Y_i)^2}{v_i} \tag{6}$$

where u_i and v_i are called "variances" and correspond to accuracies in noise figure and admittance measurements. The error function ϵ_2 is defined as:

$$\epsilon_2 = \sum_{i=1}^{N} d_i \tag{7}$$

Setting $\delta d_i/\delta x_i = 0$ leads to minimizing each distance. Equation (8) is then obtained:

$$\epsilon_2' = \sum_{i=1}^{N} w_i (a + bX_i - Y_i)^2 \tag{8}$$

where

$$w_i = \frac{1}{v_i + R_n^2 u_i}. \tag{9}$$

The R_n slope and the $F_{\min}$ intercept of the straight line are derived by setting $\delta\epsilon_2'/\delta R_n = \delta\epsilon' 2/\delta F_{\min} = 0$. This method requires initial values of noise parameters to fit R_n and $F_{\min}$. G_o and B_o are then obtained by straightforward combinations of Y_{si}.

Other methods involving optimization algorithms [11], [12] are time-consuming. So they are not well-suited for automatic measurements and statistical analysis and have therefore been discarded. As a result only five methods have been retained for consideration in this paper, each one being named after its first author.

III. Computer-Based Comparison Between Extraction Techniques

In order to evaluate each one of the previously described techniques, a computer simulation was performed according to the flow-chart of Fig. 2. Initial noise parameter values of a typical HEMT (Table I) and an experimental distribution over the Smith chart of ten different source impedances are supposed to be given. As shown in Fig. 3 source impedances are fairly well distributed over the Smith chart as it describes noise surface more accurately than points around the optimum source impedance [2]. Another reason lies in that the synthesis of source impedances around the minimum is impractical for measurements since the minimum is not known at the time of measurements. The given number of ten impedances was also found to be a good tradeoff between accuracy and measurement time according to [13].

In order to simulate errors in noise figure and reflection coefficient measurements, random perturbations were performed for each pair $(F_i, \Gamma_{si} = (1 - Z_0 Y_{si})/(1 + Z_0 Y_{si})$ where Z_0 is the normalization impedance). Gaussian distribution is assigned for noise figure and magnitude of reflection coefficients Γ_{si}, and uniform distribution for the phase of Γ_{si}. The relative standard deviation for reflection coefficients corresponds to the

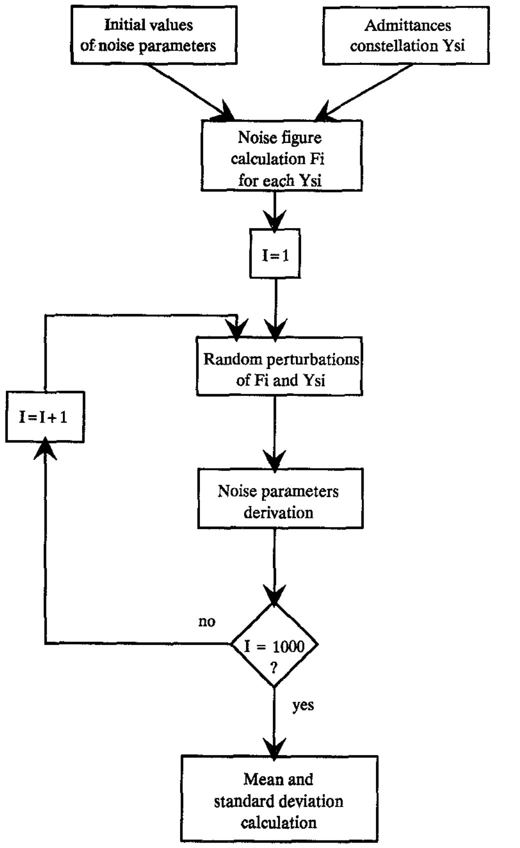

Fig. 2. Flow-chart for evaluating noise parameter values extraction methods.

TABLE I
INITIAL VALUES OF NOISE PARAMETERS OF A TYPICAL HEMT AT 4, 10 AND 18 GHz

Frequency (GHz)	4	10	12
F_{min} (dB)	0.35	1	1.7
R_n (Ω)	20	15	8
$\|\Gamma_o\|$	0.75	0.53	0.24
phase(Γ_o) (°)	27	67	130

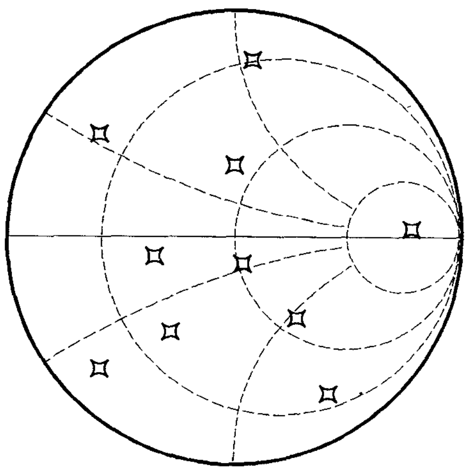

Fig. 3. A typical source impedance constellation.

accuracy of the network analyzer (curve fit [14]). Hence for the noise figure it is fixed at ±5% representing a mean value that

TABLE II
THREE STANDARD DEVIATIONS OF NOISE PARAMETER VALUES AT $f = 4$ GHz

4 GHz	Lane	Mlane	Mitama	Vasilescu	Boudiaf
$3\sigma(F_{min})$ dB	.64	.31	.48	.32	.30
$3\sigma(R_n)$ Ω	3.3	2.2	2.2	2.2	2.3
$3\sigma(\|\Gamma_o\|)$	.21	.16	.27	.16	.16
3σ(phase(Γ_o)) (°)	6	4	7	5	4

TABLE III
THREE STANDARD DEVIATIONS OF NOISE PARAMETER VALUES AT $f = 10$ GHz

10 GHz	Lane	Mlane	Mitama	Vasilescu	Boudiaf
$3\sigma(F_{min})$ dB	.45	.24	.30	.22	.21
$3\sigma(R_n)$ Ω	3.6	2.2	1.9	1.9	2.2
$3\sigma(\|\Gamma_o\|)$	.09	.07	.15	.07	.07
3σ(phase(Γ_o)) (°)	11	6	10	6	7

TABLE IV
THREE STANDARD DEVIATIONS OF NOISE PARAMETER VALUES AT $f = 18$ GHz

18 GHz	Lane	Mlane	Mitama	Vasilescu	Boudiaf
$3\sigma(F_{min})$ dB	.25	.16	.16	.17	.14
$3\sigma(R_n)$ Ω	2.9	2.4	2.4	2.1	2.4
$3\sigma(\|\Gamma_o\|)$	.12	.08	.11	.08	.08
3σ(phase(Γ_o)) (°)	19	15	25	14	18

can be worse for certain values of source impedance where D.U.T. exhibits a poor gain and a large noise figure.

For a given extraction technique, the ten values of F_i, and (G_{si}, B_{si}) of (1) $(G_{si} + jB_{si} = (1 - \Gamma_{si})/Z_0(1 + \Gamma_{si}))$ are randomly altered around their mean value, a set of noise parameters is then extracted and the process is continued for 1000 runs. Assuming a gaussian distribution for these 1000 runs, the mean and relative standard deviations are computed for $F_{\min}, R_n$ and modulus and phase of Γ_o. The values of three standard deviations (3σ) which correspond to a worst-case error (the relevant noise parameter will be, within this limit, 99 times out of 100) are also computed. This has been successively done for three frequencies (4 GHz, 10 GHz and 18 GHz). The corresponding results are reported in Tables II, III and IV.

Comparing the accuracies on the determination of $F_{\min}$ at the three different frequencies it is found that an accuracy worse than 0.3 dB is obtained at the lowest frequency (4 GHz). These poor results can be accounted for by the small $F_{\min}$ value (0.35 dB i.e. similar to the noise measurement accuracy) associated with the high value of $|\Gamma_o|$.

Results obtained at high frequencies (10 and 18 GHz) are reported in Tables III and IV and suggest the following comments:

i) better accuracies on $F_{\min}$ and $|\Gamma_o|$ are due to the larger $F_{\min}$ (or smaller $|\Gamma_o|$)

ii) whatever the frequency, accuracy on R_n is observed to be constant (less than 3 Ω)

iii) accuracy obtained on the phase of Γ_o worsens at higher frequencies probably because of the smallest values of $|\Gamma_o|$

and of the enhanced inaccuracies of vector measurements at higher frequencies, especially for low reflection coefficient.

Comparing the different extraction techniques shows the Lane and Mitama methods to provide poor results whatever the frequency. Moreover we have also observed that these techniques sometimes provide results that are meaningless from a physical viewpoint. On the other hand Mlane, Vasilescu and Boudiaf techniques similarly provide best accuracies. The Vasilescu method however is time-consuming since M different impedance configurations have to be considered and M is very large for more than 6 impedances ($M = 210$ for $N = 10$). The Boudiaf extraction technique therefore provides the best tradeoff between computation time and accuracy. This technique should provide an accuracy on the measurement of $F_{\min}$ up to 18 GHz in the 0.1 dB range (one standard deviation). It should be noted that this technique is sensitive to initial values of noise parameters.

An experimental validation of the previous statements necessitates an appropriate test set based on the multiple impedance technique and a noisy two-port featuring well defined noise parameters as reported in the next section.

IV. Experimental Verification

In this section, experimental evaluation of the different methods is performed and is based on the comparison between the noise parameters of a passive two-port, computed from measured S parameters, and those directly measured with a dedicated noise test-set.

A. Noise Parameters of a Passive Two-Port

The chain representation of a noisy linear two-port which uses two dependent voltage and current noise sources is illustrated in Fig. 4 [15]. The corresponding correlation matrix is given by [16]:

$$(C_A) = \frac{1}{2\Delta f}\begin{pmatrix} \overline{e^2} & \overline{ei^*} \\ \overline{ie^*} & \overline{i^2} \end{pmatrix} \tag{10}$$

where noise sources are characterized by their mean fluctuation in bandwidth Δf centered on frequency f and related to the noise parameters by the following relationships:

$$\overline{e^2} = 4kT_0R_n\Delta f \tag{11}$$

$$\overline{i^2} = 4kT_0R_n|Y_o|^2\Delta f \tag{12}$$

$$\overline{ei^*} = 4kT_0\left[\frac{F_{\min}-1}{2} - R_nY_o^*\right]\Delta f \tag{13}$$

where k is the Boltzmann's constant, T_0 the standard temperature (290 K) and z^* the complex conjugate of z.

Consider a passive two-port at temperature T. Its correlation matrix in parallel (admittance) representation is given by [16]:

$$C_Y = 2kT\,\mathrm{Re}\{Y\} \tag{14}$$

where $\mathrm{Re}\{Y\}$ represents the matrix made up of the real part of each of the admittance matrix coefficients. The transformation formula given in [16] relating the chain to admittance correlation matrices yields the following values for the chain correlation matrix coefficients:

$$C_{A11} = kT(A_{11}A_{12}^* + A_{11}^*A_{12}) \tag{15}$$

$$C_{A12} = kT(A_{11}A_{22}^* + A_{12}A_{21}^* - 1) \tag{16}$$

$$C_{A21} = C_{A12}^* \tag{17}$$

$$C_{A22} = kT(A_{21}A_{22}^* + A_{22}^*A_{21}) \tag{18}$$

where the coefficients A_{ij} are chain matrix elements derived from S parameter measurements, and A_{ij}^* their complex conjugates. Therefore noise parameters of any passive two-port can be easily deduced from measured S parameters by using (15)–(18) and (10)–(13).

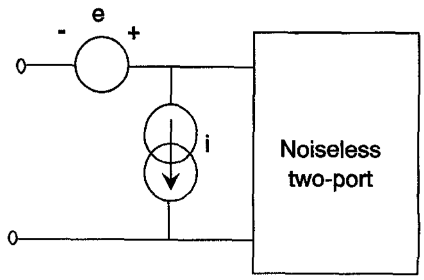

Fig. 4. Chain representation of a noisy two-port.

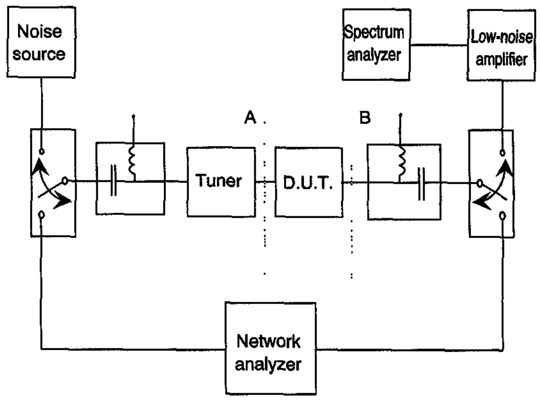

Fig. 5. Noise parameter test set block diagram.

B. Experimental Investigation

The passive two-port used for our investigations is a common-gate cold FET (unbiased FET). The advantages of this passive device are described elsewhere [17]. The major benefit over other passive two-ports such as attenuators is that it easily fits into the same test-jig to be used for DUT and features a large optimum source reflection coefficient close to that observed in FETs.

Fig. 5 shows our automatic dedicated test-set used for noise parameter measurements. Ten different carefully selected positions of a slide-screw computer-controlled mechanical tuner provide well distributed source impedances over the Smith chart from 4 to 18 GHz.

TRL calibration is performed at the planes A and B, allowing measurement at each frequency of the different source reflection coefficients Γ_{si} if a "thru" is substituted for the D.U.T. Noise figures of the second stage (also called

TABLE V
"EXACT" NOISE PARAMETER VALUES OF COLD FET OBTAINED FROM S PARAMETERS MEASUREMENTS

Frequency (GHz)	4	10	18
F_{min} (dB)	0.6	2.65	7.6
R_n (Ω)	14	8	64
$\|\Gamma_o\|$	0.63	0.46	0.73
phase(Γ_o) (°)	44	132	-140

receiver) at each source admittance are determined in a first step, from a single measurement of output power with noise source on and several measurements of output power (noise source off) for each position of the tuner [18]. In the second step, the D.U.T. is inserted between the planes A and B, and the noise figures of the D.U.T. and receiver assembly are determined from noise power measurements (noise source off) for the same positions of the tuner. The noise parameters of the D.U.T. are then obtained by de-embedding the noise contribution of the receiver with correlation matrix relations [16].

S parameters of the passive common-gate unbiased FET are also measured in the second step, the corresponding noise parameters are calculated and compared to the ones extracted from the data provided by the noise test-set.

The noise parameter values calculated from S parameter measurements are supposed to be exact (since the inaccuracies of modern network analyzers are far less than noise measurement inaccuracies) and reported in Table V. The deviation expressed in dB between the "exact" minimum noise figure and the measured one is shown in Fig. 6. The methods proposed by Lane and Mitama present higher irregularities than the other. The maximum deviation reaches 0.5 dB at 13 GHz for Mitama's method while it does not exceed 0.2 dB with Boudiaf's. An interesting example of Mitama's technique can be emphasized at two particular frequencies (4 and 9 GHz), where the source admittance configurations are clearly different. In one case (f = 4 GHz), the highest deviation is observed while it is the smallest one at 9 GHz. Therefore it can be stated that this technique is very sensitive to the source impedance constellation and not appropriate for very broadband measurements where good results must be obtained at each frequency even with very different source impedance constellation. On the other hand, it has been observed in Fig. 6 that Vasilescu and Boudiaf techniques, and to a lesser extent the Mlane technique, provide the most constant deviations.

Fig. 7 confirms the results previously described, where the deviation between $|\Gamma_o|$ obtained from S parameter and noise figure measurements is reported from 4 to 18 GHz. The deviation decreases with increasing frequency (a similar result could be observed on minimum noise figure when a relative deviation is taken into account). On average, the smallest deviation on Γ_o (about .02) is obtained from Boudiaf's method. Note that the weighting factor $w_i = 1/F_i^2$ introduced in (3) provides better results. Concerning the equivalent noise resistance and the phase of optimum reflection coefficient, the maximum deviations are approximately in the order of 2 Ω and 5° (1 Ω and 2° in average) with Boudiaf's method.

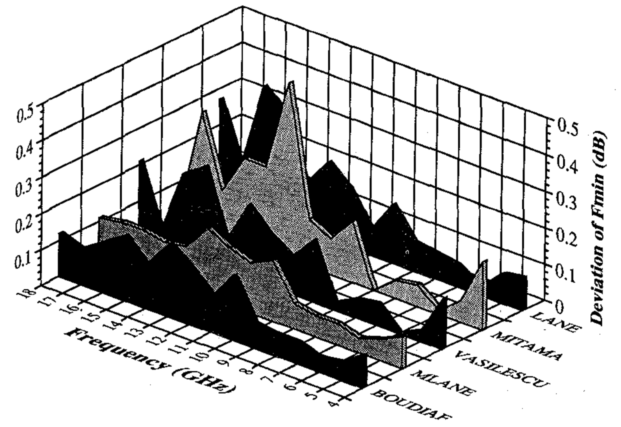

Fig. 6. Deviation between minimum noise figure value obtained from S parameters and minimum noise figure value obtained from noise parameter value measured from 4 to 18 GHz.

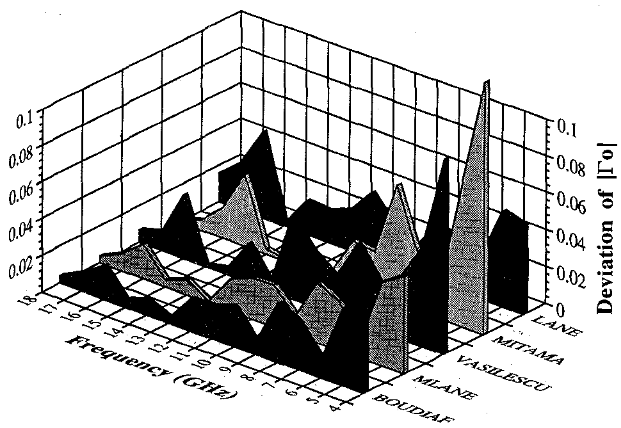

Fig. 7. Deviation between the magnitude of optimum reflection coefficient obtained from S parameters and the magnitude given by noise parameter values measured from 4 to 18 GHz.

V. CONCLUSION

Methods of noise parameter values extraction have been evaluated. Computer simulation has been performed to provide worst-case error on noise parameter, due to innacurate noise figure and admittance measurements. Experimental investigation has also been carried out with passive two-port allowing comparison of the noise parameter values from S parameter and noise figure measurements. Experimental results are in good agreement with our simulations and allow conclusions to be drawn.

With respect to Vasilescu's extraction technique, the error criterion has been modified to avoid solutions with no physical meaning. This technique leads to a correct accuracy, but is time-consuming.

The methods proposed by Lane and Mitama are prone to measurement errors as shown in the third part of this paper. For certain source impedance configuration, they nevertheless provide good results and the use of a weighting factor in error criterion improves accuracy. This is done to obtain initial values of noise parameters in Boudiaf's method where fitting a straight line seems well adapted to noise parameter extraction.

Moreover, Boudiaf's technique has been found to be less sensitive to source impedance constellation without being time-consuming. It provides an accuracy similar to the best other techniques. With this technique we achieved an accuracy in excess of 0.2 dB (0.1 dB in average) on $F_{\min}$, and better than 10%, 0.05 and 5° (5%, 0.02 and 2° in average) on R_n, modulus and phase of Γ_o within the frequency range 4 to 18 GHz. Furthermore, this method has been improved recently [19] and the results seem to be better.

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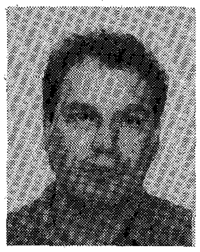
REFERENCES

[1] IRE Subcommittee on Noise, "Representation of noise in linear two-ports," *Proc. IRE,* pp. 69–74, Jan. 1960.
[2] A. Davidson, B. Leake, and E. Strid, "Accuracy Improvements in microwave noise parameter measurements," *IEEE Trans. Microwave Theory Tech.,* vol. 37, no. 12, Dec. 1989.
[3] A. McAmant, "Error analysis aids measurement of noise parameters," *Microwaves and RF,* June 1989.
[4] B. Byzery, "Précision de la détermination des 4 paramètres de bruit par la méthode des impédances multiples," *Journées Nationales Microondes de Montpellier,* pp. 21–23, June 1989.
[5] L. Colby, "Accuracy of noise figure measurement systems," *RF & Microwave Meas. Symp.,* Hp. Stanford Park Division, Apr. 1987.
[6] R. Q. Lane, "The determination of noise parameters," *Proc. IEEE,* pp. 1461–1462, Aug. 1969.
[7] M. Mitama and H. Katoh, "An improved computational method for noise parameter measurement," *IEEE Trans. Microwave Theory Tech.,* vol. 27, no. 6, June 1979.
[8] G. Vasilescu, G. Alquie, and M. Krim, "Exact computation of two-port noise parameter," *Electron. Lett.,* vol. 25, no. 4, Feb. 16, 1989.
[9] A. Boudiaf and M. Laporte, "Evaluation des méthodes d'extraction des paramètres de bruit," *IEEE French Chapter Meeting,* Carcassonne, Nov. 22–23, 1990.
[10] J. H. Williamson, "Least-squares fitting of a straight line," *Canadian Journal of Physics,* vol. 46, pp. 1845–1847, 1968.
[11] M. S. Gupta, "Determination of the noise parameters of a linear 2-port," *Electron. Lett.,* vol. 6, no. 17, Aug. 20, 1970.
[12] L. Chusseau, M. Parisot, and N. Jousseaume, "Mesure automatique des paramètres de bruit des MESFET hyperfréquences," *Annales des Télécommunications,* vol. 43, no. 5–6, 1988.
[13] G. Caruso and M. Sannino, "Computer-aided determination of microwave two-port noise parameters," *IEEE Trans. Microwave Theory Tech.,* vol. 26, no. 9, Sept. 1978.
[14] Hp8510B Network Analyzer, System Manual.
[15] M. Rothe and W. Dahlke, "Theory of noisy fourpoles," *Proc. IRE,* pp. 811–818, June 1956.
[16] H. Hillbrand and P. Russer, "An efficient method for computer aided noise analysis of linear amplifier networks," *IEEE Trans. Circuits Syst.,* vol. CAS-23, no. 4, pp. 235–238, Apr. 1976.
[17] L. Escotte *et al.,* "Using cold FET to check accuracy of microwave noise parameter test set," *Electron. Lett.,* vol. 27, no. 10, May 9, 1991.
[18] V. Adamian and A. Uhlir, "A novel procedure for receiver noise characterization," *IEEE Trans. Instrum. Meas.,* June 1973.
[19] A. Boudiaf *et al.,* "Accuracy improvements in two-port noise parameter extraction method," *IEEE MTT-S Int. Microwave Symp. Dig.,* June 1992, pp. 1569–1572.



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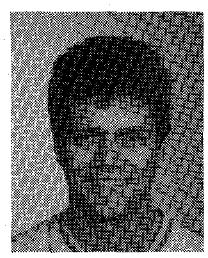

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Jacques Graffeuil , for a photograph and biography, see this issue, p. 374.