NOVEL 4-POINTS INPUT PATTERN
FOR LARGE BAND NOISE MEASUREMENTS

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ABSTRACT
Four parameters are necessary for a complete characterization of the noise behavior of a linear device. The parameters can be experimentally determined by a minimum set of four equations, which can be obtained by an equal number of synthesized reflection coefficients at the input of the DUT, forming a *pattern* on the Smith chart. To increase the accuracy in the determination of the noise parameters, it is a common procedure to implement an heavily redundant pattern, with a random selection of more than the strictly necessary four points, so forcing the adoption of an expensive tuner. This paper introduces a novel *ad hoc* selected 4-points pattern, and demonstrates how it can simplify the measurement system without appreciably affecting the measurement accuracy. The proposed pattern is synthesized by easily realizable transmission lines, and a study has been performed to determine lines characteristics for use in wideband noise measurements.

INTRODUCTION
Heavily redundant patterns can result in uncertainty values on the four noise parameters as low as 0.2% [1, 2]. In spite of this result, important drawbacks resides on measurement time and complexity, standing the necessity to synthesise a large number of impedances at the DUT's input port, with an electromechanical tuner. The possibility of synthesizing only the strictly necessary number of impedance values may result in a major improvement, since it avoids the use of the tuner, above all without an appreciable worsening in measurement uncertainty. For this purpose, a novel impedance pattern is reported, easily obtained by simple transmission lines, suitable for wideband noise measurements.

4-POINTS IMPEDANCE PATTERN
The linearised form of the paraboloid noise representation [3] can be expressed as:

$$F = A + B\frac{G_s^2 + B_s^2}{G_s} + C\frac{1}{G_s} + D\frac{B_s}{G_s} \qquad \text{(eq. 1)}$$

with:

$$\begin{cases} F_{\min} = A + \sqrt{4BC - D^2} \\ R_n = B \\ G_{opt} = \sqrt{4BC - D^2}\Big/2B \\ B_{opt} = -\dfrac{D}{2B} \end{cases} \qquad \text{(eq. 2)}$$

The system to be solved is therefore of the form:

$$\begin{bmatrix} 1 & \dfrac{G_{s,1}^2 + B_{s,1}^2}{G_{s,1}} & \dfrac{1}{G_{s,1}} & \dfrac{B_{s,1}}{G_{s,1}} \\ 1 & \dfrac{G_{s,2}^2 + B_{s,2}^2}{G_{s,2}} & \dfrac{1}{G_{s,2}} & \dfrac{B_{s,2}}{G_{s,2}} \\ \bullet & \bullet & \bullet & \bullet \\ 1 & \dfrac{G_{s,4}^2 + B_{s,4}^2}{G_{s,4}} & \dfrac{1}{G_{s,4}} & \dfrac{B_{s,4}}{G_{s,4}} \end{bmatrix} \begin{vmatrix} A \\ B \\ C \\ D \end{vmatrix} = \begin{vmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{vmatrix} \qquad \text{(eq. 3)}$$

where, as it can be easily noted, the coefficient matrix depends on the admittance values presented at the input of the DUT only (i.e. $G_{s,i}$ and $B_{s,i}$ values, with i=1..4). The sensitivity of the solutions of the solving system with respect to measurements errors, is strictly related to the coefficient matrix; it is crucial therefore the determination of the four admittances values ensuring the best matrix conditioning. To this purpose a statistical approach has been adopted, taking into account 4 measures at a time over all the possible combinations of an highly redundant input pattern of 330 points, that guarantees a uniform coverage of the Smith chart. For all the 4-point sets, the matrix conditioning has been evaluated, accounting for its determinant value after a proper row normalization. An *ad-hoc* routine revealed, for all the

examined devices at all the bias conditions and for all the considered working frequencies, that almost the same results of noise parameter values obtained by the reference case of highly redundant input pattern, are obtained when the normalized matrix determinant value is sufficiently close to its maximum (see fig. 1 as an example).
The maximum normalized determinant value has been obtained, in all the examined cases, with the 4-points well spaced over the Smith chart, i.e. three points located on a circle, 120° in phase apart, and the fourth point located at the center of the chart (fig.2). This input admittance pattern assures the elimination of singular loci as requested to prevent errors on the noise parameter evaluations [4, 5]. This optimal pattern condition can be easily realized by three transmission lines and a matched load. In any case, since the optimal situation of three points 120° apart can be realized only at a single measurement frequency, the noise parameter error percentage variation with respect to the angular movement of the points when the frequency is varied has been analyzed in detail. For this purpose three 50Ω transmission lines have been realized, synthesizing three values spaced 120° away at f_0=14.4 GHz. The input admittance of the three lines are subject to a *rotation* on the Smith chart with frequency, and the *rotation speed* is different for the different lines, as in fig.3. For our purpose, an error percentage on the noise parameters of 1.2% is assumed to be acceptable. This is equivalent to a minimum normalized determinant value of 70 (see fig. 1) and a minimum angular distance between each pair of the three points 60° apart (*fig. 4*). As a consequence, the acceptable operating frequency range, with the adopted transmission lines, relies in the range $f_0 \pm \Delta f$: 7.2-18GHz (fig.3), being $\Delta f = \frac{c}{2\pi \cdot \sqrt{\varepsilon_r}} \cdot \frac{\Delta\varphi}{l}$ hence $f_0 - \Delta f = \frac{f_0}{2}$ and $f_0 + \Delta f = \frac{5 f_0}{4}$ with l: transmission line physical length, c: light speed in vacuum, ε_r : effective dielectric constant of the substrate on which the lines have been realised. A different center working frequency changes the usable frequency range as shown in *fig. 5*, where the latter is plotted for the abovementioned error percentage on the noise parameters (1.2%).

EXPERIMENTAL VERIFICATIONS

The 4-lines pattern has been experimentally tested by accurate on-wafer noise measurements. For this purpose three different δ-doped Alenia Marconi System HEMT devices have been tested, featured by a 0.25µm gate length and different gate width namely 100µm (*H100*), 200µm (*H200*) and 300µm (*H300*); for each device three different bias conditions were selected: 10%, 25%, 50% I_{dss}. The results demonstrate a very good agreement between the noise parameter values obtained with the proposed 4-lines system with respect to the reference case of a highly redundant input admittance set (330 points) previously reported [1]. Fig.6 shows the F_{min} value reported in the 7-18GHz frequency band, while the fig. 7a,b,c,d show the relative percentage errors obtained with the proposed pattern. To increase the measurement frequency range using the same lines previously realized, a simple procedure consists in the adoption of a new (fourth), *ad hoc*, transmission line. In particular it is possible to extend the frequency range from 7.2-18GHz to 3.5-18GHz, considering the angular separation between the three lines of the outer circle at f=8GHz (fig.8) and replacing one of the lines (*B'*) with a new one ($\overline{B}'$) in order to guarantee that for the mentioned frequency value the lines return with the maximum angular separation (120°). Generalizing the basic idea, starting with a new central working frequency, the substitution of a transmission line at the lowest frequency of the range, generally guarantee the extension of the initial frequency band. As an example starting from an f_0=16GHz, the frequency range can be extended from 8-20GHz to 4-20GHz, while with f_0=32GHz it is possible to change from a possible range of 16-40GHz to 8-40GHz. The idea can be iterated and a new line added, the sixth, assuring even larger frequency band.

CONCLUSIONS

A new impedance pattern composed by easily realizable transmission lines has been proposed. It allows a DUT's noise parameter determination with an associated low percentage error. The proposed pattern has been tested in the case of three different HEMT devices at different bias conditions and for different working frequencies. Modified patterns allow an enlargement of the frequency range, maintaining low percentage errors on the four noise parameters.

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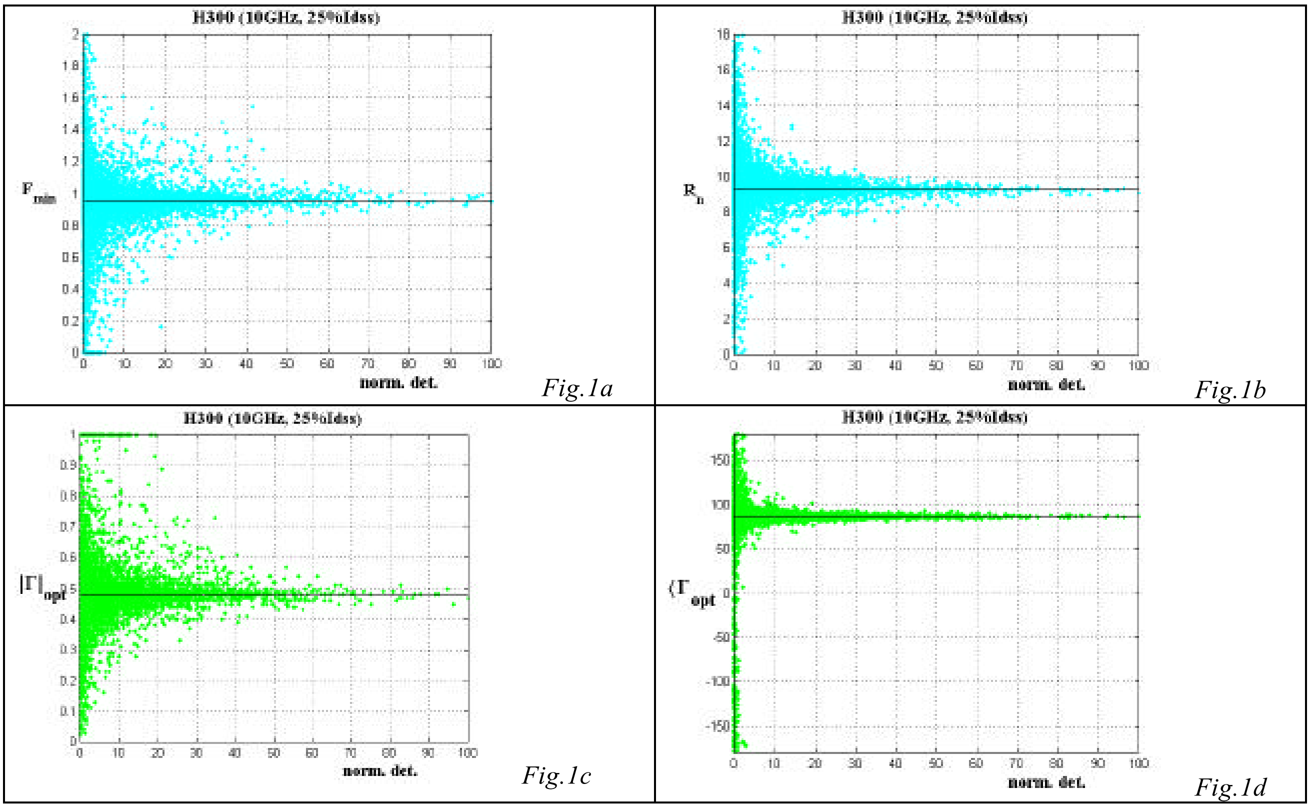

fig. 1: Results of a 10000 iteration routine: noise parameters vs the normalized determinant for the H300 devices, 10GHz, bias: 25%Idss, 10GHz working frequency. A stright line indicates the reference values.

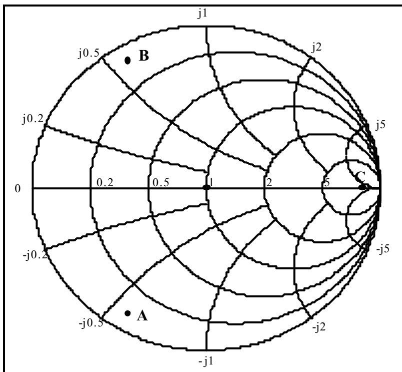

fig.2: 4-points input admittance values

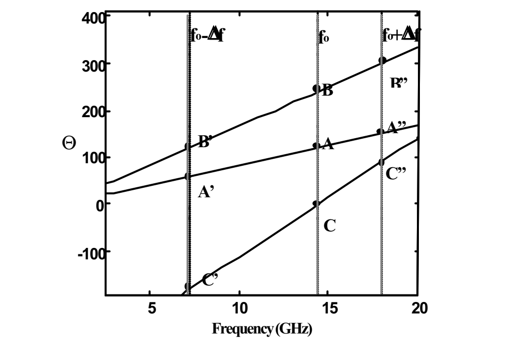

fig.3a: Angular rotation of the impedance values for the transmission lines with freq.

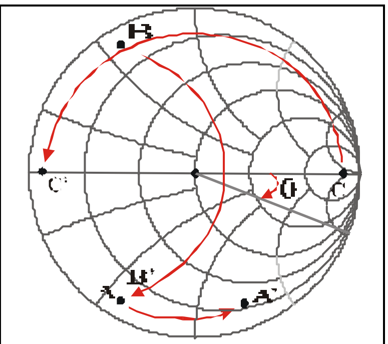

Fig.3b Angular rotation for a frequency variation from 14.4GHz to 7.4GHz

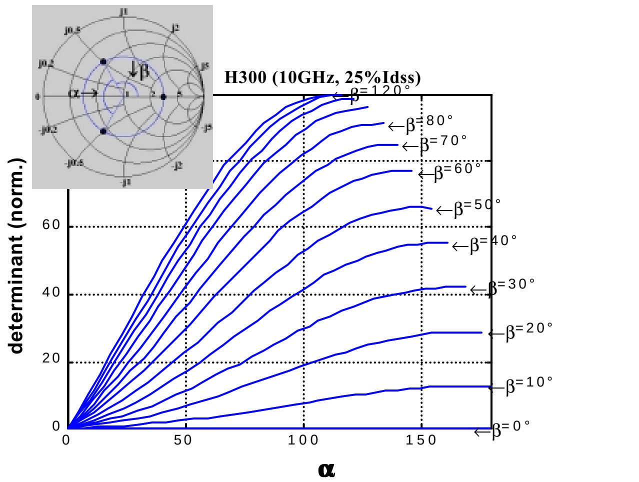

fig. 4: Angular rotation for two points of the outer circle with respect to the fixed third

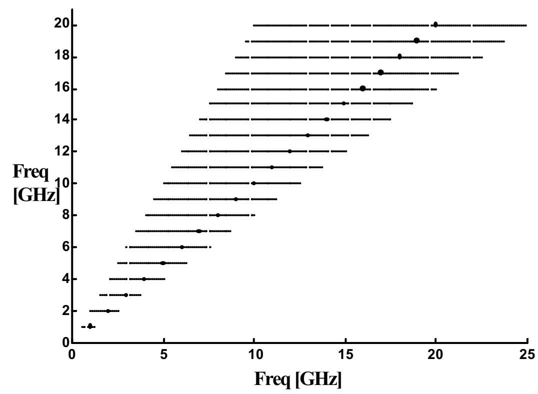

fig. 5: Possible frequency measurement range for noise measures with 1.2% error percentage

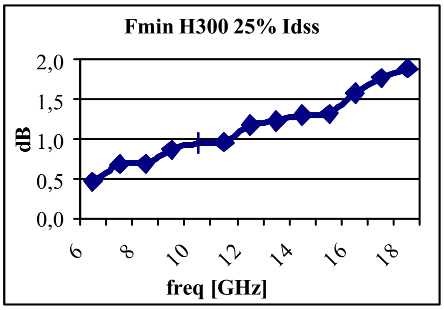

Fig.6a

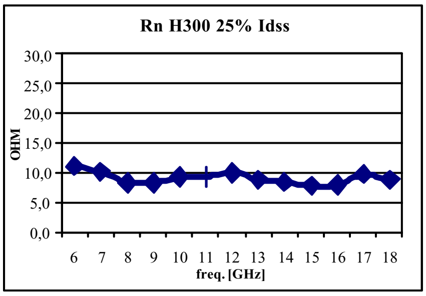

Fig.6b

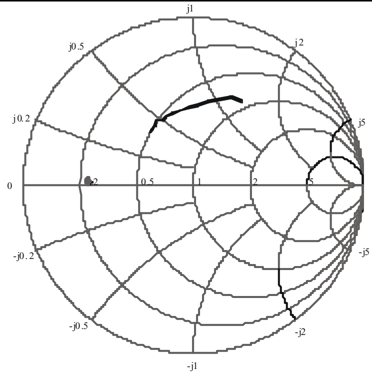

Fig.6c

fig. 6: (a) Fmin, (b) Rn, (c) Γopt values for the H300 device at 25%Idss

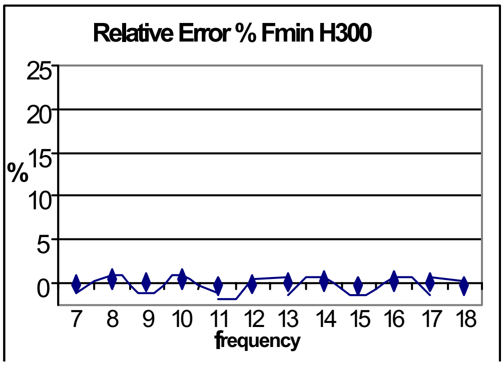

Fig.7a

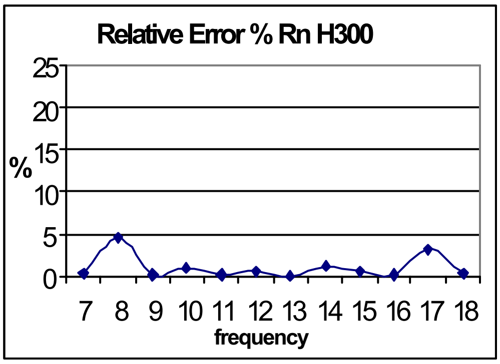

Fig.7b

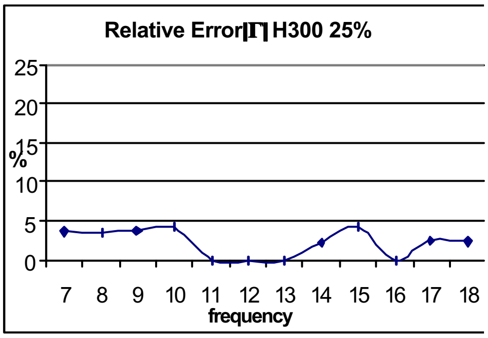

Fig.7c

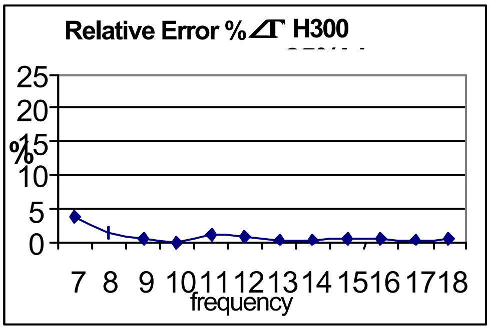

Fig.7d

fig. 7a,b,c,d: Relative percentage errors on the noise parameter values for the 4-points pattern with respect to the redundant one, for the H300 device at 25%Idss

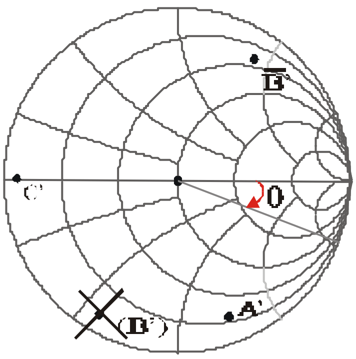

fig. 8: 4-points admittance pattern considered to extend the frequency range to 3.5-18GHz