A METHOD FOR COMPUTING THE NOISE FIGURE IN MATRIX DISTRIBUTED AMPLIFIER

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ABSTRACT

A method for the evaluation of the noise figure in matrix amplifiers has been developed. The amplifier noise figure is derived as a function of the noise characteristics of the active devices and circuit parameters. A simple expression in closed form is obtained. The results of the model are in good agreement with experimental data.

INTRODUCTION

In the last years, considerable interest has arisen in the characterization of microwave distributed amplifiers and a theory has been developed which describes the noise performances of these devices [1].
The matrix amplifier (Fig. 1) has been recently proposed as an extension of the distributed amplifier [2]. The comparison with a distributed amplifier employing cascade-connected devices shows that:

(a) the gain of the two circuits is comparable,

(b) the matrix amplifier has better input and output matching with a lower noise figure [3],

(c) the monolithic version of the matrix amplifier is more compact than the distributed one and hence it costs less to be produced,

(d) the matrix amplifier has a phase delay roughly halved with respect to the distributed one; this is an important feature when a good phase tracking is required such as in phase array applications.

A first theory for the matrix amplifier noise was presented in [3]: it permits the computation of the amplifier noise figure as a function of the active devices and circuit parameters. However because of the huge complexity of the resulting formulas its utilization in CAD programs is quite difficult.
In the present work a new theory is developed, which leads to a much simpler formulation for the matrix amplifier noise figure. The theory can even be used for simple distributed amplifier.

NOISE PARAMETERS OF FETs

The problem of noise in active devices is becoming more and more important, due to the wide bands necessary in today's technology. Almost two decades ago Van der Ziel [4, 5] developed a model for the noise evaluation in FETs, introducing two noise sources: i) a gate current generator $\sqrt{i_g^2}$ and ii) a drain current generator $\sqrt{i_d^2}$.

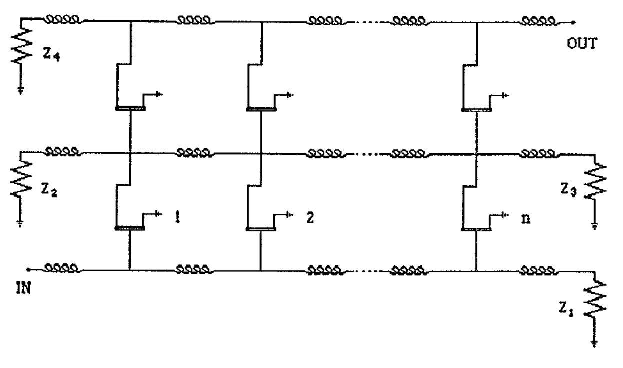

Fig. 1 Structure of the matrix distributed amplifier. Two tiers for n-elements. Input is in low-left side, output is in upper-right side.

The RMS values of these currents are given by:

$$\overline{i_g^2} = 4kT_0B\,\frac{C_{gs}^2 R\,\omega^2}{g_m} \qquad (1)$$

$$\overline{i_d^2} = 4kT_0Bg_m\,P \qquad (2)$$

where P and R are two dimensionless coefficients depending on the biasing conditions and on the technological parameters of the device.

Cappy [6] has recently presented a more suitable model for high-frequency noise analysis of both MESFETs and HEMTs. Referring to this work the drain current can be written as:

$$\overline{i_d^2} = 4kT_0Bg_m\,P\left[1+\left(\frac{f}{f_0}\right)^2\right] \qquad (3)$$

where f_0 is:

$$f_0 = \frac{g_d}{2\pi C_{gd}}\,. \qquad (4)$$

The two noise current $\sqrt{\overline{i_g^2}}$ and $\sqrt{\overline{i_d^2}}$ have the same origin, therefore a correlation coefficient can be evaluated as :

$$\gamma = \frac{\overline{i_g^*\,i_d}}{\sqrt{\overline{i_g^2}\;\overline{i_d^2}}} \qquad (5)$$

In the following analysis we can neglect this correlation coefficient because the currents (1) and (2) feed purely real impedances and the correlation coefficient is purely immaginary [7].

Hence a model with only two uncorrelated current generators is used to evaluate the noise figure of a microwave matrix amplifier.

THE NOISE THEORY

The model for the noise figure of the matrix amplifier derived in this work considers only the noise contribution due to the active devices and to the loads of all the idle ports.

Following the noise figure definition, if P_Z is the thermal noise power available from an impedance Z and P_I is the noise power dissipated in the load by the FETs noise generators, we obtain:

$$F = \frac{\Sigma P_Z + P_I}{kT_0BG} \qquad (6)$$

where G is the total power gain of the amplifier.

The noise figure definition requires the evaluation of the available noise power dissipated in the external load R_L.

The intrinsic noise sources in the matrix amplifier are identified, as shown in Fig. 2, as:

A) Noise from impedances Z_i, which, in accordance with the noise figure definition, are at standard temperature T_0,

B) Noise associated with each FET.

The noise associated with the generic impedance Z_i is:

$$F(Z_i) = \frac{G_i}{G_M^2} \qquad (7)$$

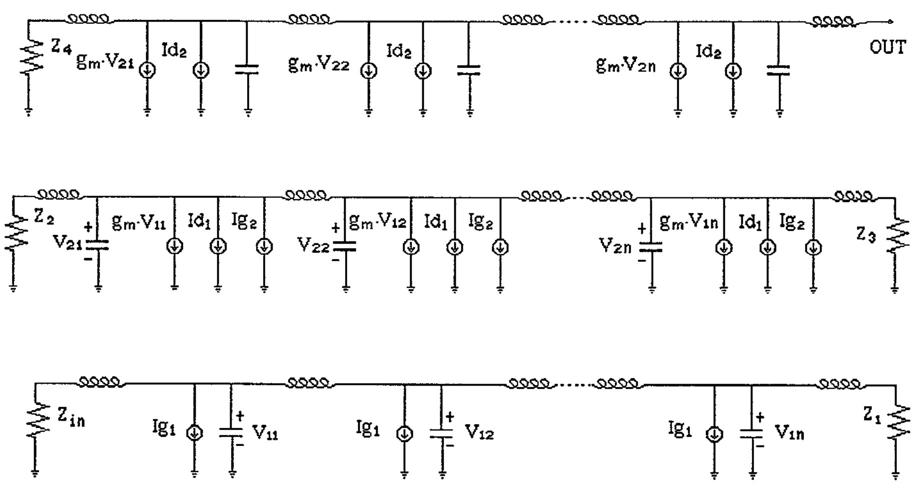

Fig. 2 Equivalent circuit of the matrix amplifier with noise sources.

where G_M^2 is the power gain of the matrix amplifier and G_i is the power gain calculated from the impedance Z_i to the output.
The noise figure due to all the impedances is:

$$F_Z = 1 + \frac{G_r^2}{G_M^2} + \frac{1}{G_M^2} + \frac{G_r}{G_M^2} + \frac{1}{G_M} \qquad (8)$$

where G_r^2 is the reverse power gain of the matrix amplifier. We have found that:

$$G_r = \frac{G_M}{n^2}\left(\frac{\sin n\beta l}{\sin \beta l}\right)^2 \qquad (9)$$

where β is the phase propagation coefficient of the line linking two devices and n the number of the FET in the tier (Fig. 1).
The noise power dissipated in the external load from each FET can be obtained by combining vectorially every contribution of the current generators $\overline{i_g^2}$ and $\overline{i_d^2}$.
With a simple procedure it is possible to move the gate noise generators of the first tier to the second one (Fig. 2). This approach simplifies the solution of the circuit and the evaluation of the output current.
Therefore it is easy to obtain:

$$F_I = F\left(\overline{i_g^2}\right) + F\left(\overline{i_d^2}\right) \qquad (10)$$

Finally we can write: $F = F_Z + F_I$.

RESULTS

From this classical approach and using only circuit theory concepts we were able to derive an expression of the noise figure of a matrix amplifier as a function of the FET small signal equivalent circuit as:

$$F = \left\{ \frac{1}{4} g_m^2 Z_\pi^2 \left[g_m \omega^2 C_{gs}^2 R Z_\pi^2 + \frac{\omega^2 C_{gs}^2 R}{g_m} + g_m P \left(1 + \left(\frac{f}{fo}\right)^2\right) \right] \sum_{k=1}^{n} g(k,\beta) + n\, g_m P \left(1 + \left(\frac{f}{fo}\right)^2\right) \right\} \frac{Z_\pi}{G_M^2} + F_Z \qquad (11)$$

where $g(k,\beta)$ is a function that takes in account the phase differences between noise generators.

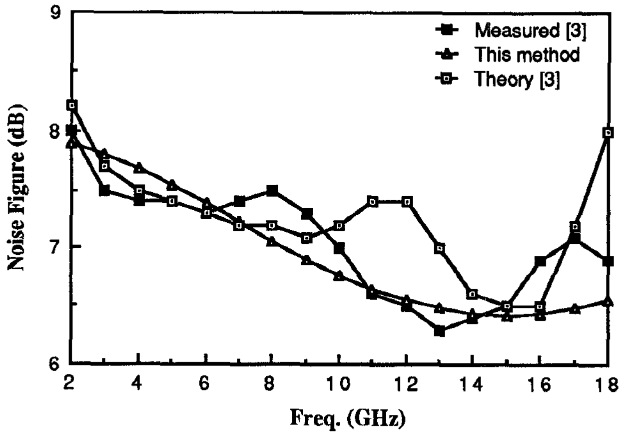

Fig. 3 Noise figure versus frequency according to [3], to our computing method and to mesurements.

Figure 3 shows the comparison between the noise figure behavior of a 2x4 matrix amplifier[3], and the results obtained from (11). The agreement between the computed and measured data is fairly good.
From the error analysis (between theories and experimental data) shown in Fig. 4 it results that our formulation gives a smaller error in the range 2-18 GHz than that obtained in [3] with a much shorter computational time.

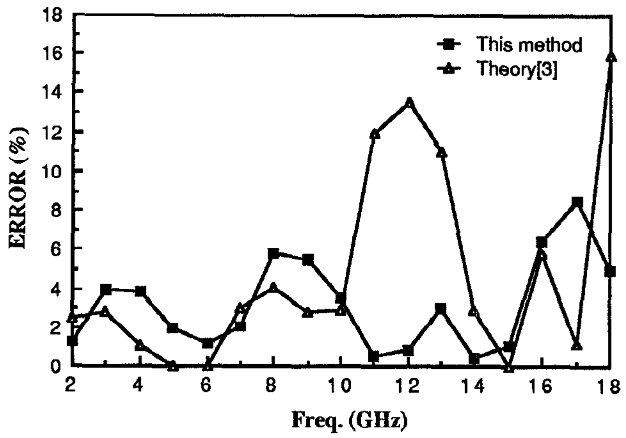

Fig. 4 Error respect to the experimernal data of noise figure versus frequency according to [3] and to our computing method.

The parameters of the FET small signal model used in [3] are :

C_{gs} = 0.1385 pF

g_m = 26.5 mS

C_{gd} = 0.015 pF

R_{ds} = 213 ohm

Typical values for FETs have been used in (11) as P and R.

Finally Figure 5 shows the comparison between our model and the measured noise figure of a monolithic matrix amplifier [8].

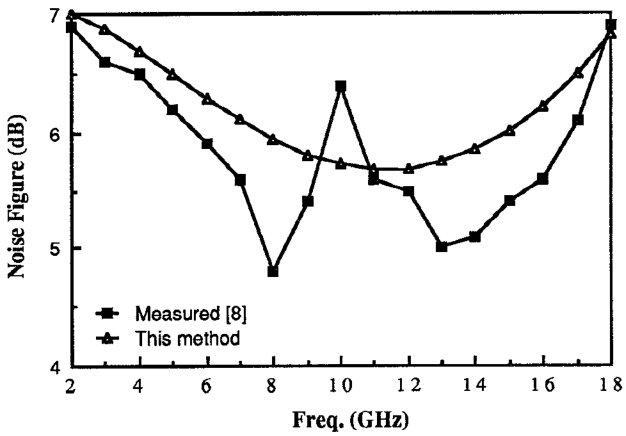

Fig. 5 Measured noise figure versus frequency according to [8] and results from present computing method.

This method can be easily used even to compute the noise figure of a simple distributed amplifier without moving the gate noise sources (see Fig. 2) and considering only three impedance noise generators.

CONCLUSION

This paper present a new approach to the modelling of noise behavior of a matrix distributed amplifier. A simple expression that permits the computation of the noise figure has been derived. The model uses only circuit theory concepts and therefore is very easy to be implemented in any CAD package.

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