OPTIMIZATION OF THE NOISE RESISTANCE OF MESFET's AND HEMT's FOR CAD OF MICROWAVE LOW-NOISE AMPLIFIERS

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Abstract - Among the noise parameters expressed in the reflection coefficient form (F_o, $|\Gamma_o|$, $/\Gamma_o$ and r_n), the noise resistance r_n is of critical importance to the design of low-noise receivers. Very low values of r_n allow for optimizing the performance of broad-band amplifiers in receiver front-ends.
We here present an analysis performed on typical circuit models of FET's which was aimed at assessing the key elements influencing the behavior of r_n at microwave frequencies.
We found that the noise performance can be improved by tuning the value of the input (gate, source) inductances which are responsible of the U-shaped curves typically observed for r_n in MESFET's and HEMT's.

INTRODUCTION

At microwave and millimeter wave frequencies, the noise performance of any linear two-port is more conveniently expressed in the reflection coefficient form by the following equation

$$F(\Gamma_S) = F_o + 4\, r_n \frac{|\Gamma_S - \Gamma_o|^2}{|1 + \Gamma_o|^2 (1 - |\Gamma_S|^2)} \qquad (1)$$

where F_o (minimum noise figure), $|\Gamma_o|$ and $/\Gamma_o$ (optimum value of Γ_S) and r_n (noise resistance normalized to standard 50 Ω) are the four noise parameters, whereas F and Γ_S are the noise figure and the relevant source termination reflection coefficient of the device, respectively.
So far, the main concern of device technologists in developing low-noise microwave transistors has been the reduction of the minimum noise figure F_o, being such parameter responsible for the lowest signal level detectable by a low-noise receiver.
Next to F_o, we think that great care has to be devoted to another noise parameter for its inherent importance to the design of broad-band low-noise amplifiers (LNA), i.e. r_n which is a measure of the noise figure degradation as Γ_S deviates from Γ_o.
The noise resistance of low-noise FET's and HEMT's exhibits a typical behavior in the microwave range (2-20 GHz) with distinguished features that have been presented and discussed in a previous work [1]. Such devices have been tested during the last ten years in our lab with a unique automated system which performs the complete microwave characterization of transistors by means of noise figure measurements only [2].
From these experimental data, several circuit models have been extracted to reproduce the typical performance of the tested series (usually 5 to 10 devices each).
In the present work, the circuit models have been employed for a sensitivity analysis aimed at determining the major factors influencing the performance of r_n .

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From such analysis, a key role played by the input (gate, source) inductances has been brought out. Therefore, by tuning the values of the above inductances a desired performance of r_n in a given device can be taylored specifically for low-noise applications.

TYPICAL PERFORMANCE OF r_n IN MESFET's AND HEMT's

Differently from the monotonic trend seen for bipolar devices, the noise resistance of FET's reported in Fig.1 shows a characteristic U-shaped curve as a function of frequency which is broader and lower for updated pHEMT's as compared with older MESFET's. The reader will note that in such diagrams the noise resistance is plotted as $R_n = r_n * 50\ [\Omega]$.

Such frequency dependence is mainly due to the inductive component of the gate and source terminals since the performance of r_n for the bare *chip* device is almost flat with frequency.

It is to be noted that the inductive behavior is caused essentially by the presence of the wires connecting the FET *chip* to external circuitry (or package) since the inductance due to the contact metallization is negligible even for the small gate stripes.

To realize competitive LNA's the input matching network has to be designed for minimizing the noise figure by making $\Gamma_s = \Gamma_o$. Since both the noise parameters and the distributed-element network performance vary with frequency, the optimum low-noise condition can be theoretically obtained at a single frequency which represents the basic drawback in the realization of broad-band LNA's. In addition, the first stage of a low-noise front-end has to be optimized also from the viewpoint of the available gain. As it is well known from the Friis' formula, a high value of the gain of the input stage allows for minimizing the overall noise contribution due to the multistage chain.

Such trade-off requirements either at a fixed frequency between noise and gain performance, and over a broad frequency range for an acceptable degradation of the amplifier noise figure, are managed by the input impedance transforming network and are influenced by the values of the noise resistance.

If r_n were negligible, the noise figure would approach F_o while the input matching network is optimized for the maximum gain.

Anyway, if r_n takes on small values over the operating frequency range the design of the input amplifier section becomes less critical since the difference between Γ_s and Γ_o and their frequency dependence affects the noise performance to a reduced extent, thus making easier to obtain a satisfactory noise performance over a given frequency band.

We have therefore developed a specific interest in investigating the performance of r_n and analyzed the main factors affecting it. Such a study has been aimed at extracting useful information to be employed in CAD of broad-band LNA's.

SENSITIVITY ANALYSIS OF r_n

Starting from the noise performance of the chip, we have noted that even for modern devices like pHEMT's the values of r_n are moderately high (0.2 to 0.3), though frequency independent. When adding either the gate bonding inductance L_g or the (smaller) source bonding inductance L_s the values of r_n decrease markedly and become frequency dependent.

No major changes are attributable to the parasitic capacitances due to interelectrode (or pad-to-pad) coupling whose values are usually in the range of $10\text{-}10^2$ fF.

With reference to the computer noise analysis of the circuit model of a low-noise MESFET (NE71083 by NEC), we report in Fig.2 the performance of r_n over the 6-18 GHz frequency range as a function of the values of L_g. The flat line refers to the performance of r_n for the chip without any bonding and the relevant values are quite high.

By progressively increasing the values of L_g from 0 to 0.5 nH, we observe a profound influence on the performance of r_n which becomes strongly frequency dependent. In addition, its values lower markedly over a large middle frequency range.
By looking at the effects due to L_s separately, as shown in Fig.3, we note a similar behavior of r_n. We here remember that the values of L_s are usually less than 0.1 nH since this element is inserted into the grounded source feed-back path whose effects have to be carefully controlled.
By increasing the values of either L_g or L_s the curves of r_n sharpen and their peaks displace towards lower frequencies without changing their bottom values. When examining the combined effects of both inductances, we observed that the peak frequency reduces for $L_g = L_s = L_i$ with respect to the presence of a single inductance having value L_i, whereas it remains unchanged for $L_g = L_s = 2^* L_i$.
With reference to the device analyzed in Figs. 2 and 3, we found that an optimum performance exists for $L_g = 0.2$ nH and $L_s = 0.05$ nH. Both inductance values are quite reasonable and can be tuned by acting on the length and the number of the bonding wires.
The role played by either L_s and L_g therefore may help in improving CAD of LNA if optimized to this end since their presence minimizes the noise resistance over a frequency range which depends on the values of both inductances.
Anyway, since r_n is markedly influenced by the device transconductance g_m (∞ $1/g_m^2$)[3], the contribution arising from the input inductances will be less and less desirable by developing HEMT's characterized by very high values of g_m. In such high performance devices the values of r_n offered by the chip will represent the optimum condition to be achieved, being both low and frequency independent.

CONCLUSIONS

The noise resistance r_n is of critical importance to the design of low-noise amplifiers. Very low values of r_n allow for optimizing the performance of broad-band amplifiers.
We have here presented an analysis performed on typical circuit models of FET's which was aimed at assessing the key elements influencing the behavior of r_n at microwave frequencies.
We found that the noise performance can be improved by tuning the value of the input (gate, source) inductances which are responsible of the U-shaped curves typically observed for r_n in MESFET's and HEMT's. However, in new generation devices characterized by remarkable values of the transconductance g_m, the noise resistance offered by the chip is likely to exhibit very low and frequency-independent values thus making less acceptable the contribution due to the input inductances.

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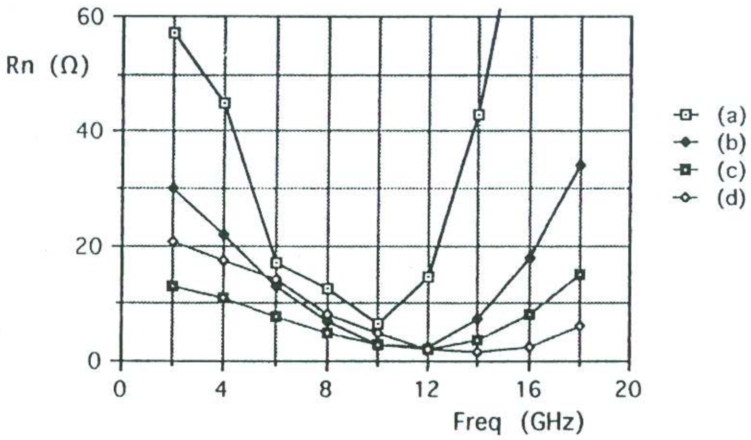

Fig. 1 - Performance of R_n for: a) 1 μm-gate MESFET (TX0061-2087 FA); b) 0.3 μm-gate MESFET (NE71083); c) sub-half μm-gate pHEMT (CFB001-03); d) 0.25 μm-gate pHEMT (ATF35076).

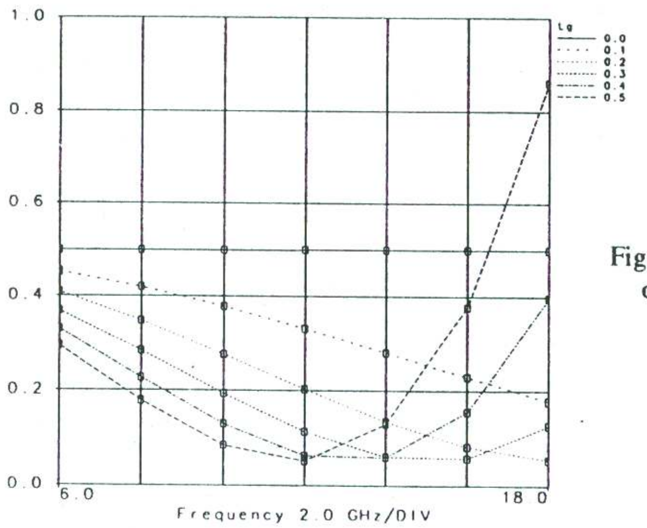

Fig. 2 - Performance of r_n vs. frequency as a function of the values of L_g from 0.0 to 0.5 nH @ L_s=0;

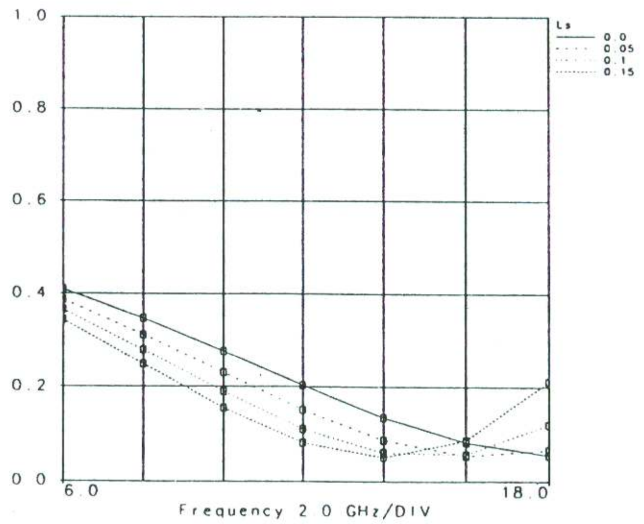

Fig. 3 - Performance of r_n vs. frequency as a function of the values of L_s from 0.0 to 0.15 nH @ L_g=0.2 nH.