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Modeling of a Microwave Amplifier Operating around 11 GHz for Radar Applications

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ABSTRACT

The low noise amplifier is one of the basic functional blocks in communication systems. The main interest of the LNA at the input of the analog processing chain is to amplify the signal without adding significant noise. In this work, we have modeled a LNA for radar reception systems operating around 11 GHz, using the technique of impedance transformations with Smith chart utility. The type of transistor used is: the transistor HEMT AFP02N2-00 of Alpha Industries®. The results show that the modeled amplifier has a gain greater than 20 dB, a noise figure less than 2 dB, input and output reflection coefficients lower than -20 dB and unconditional stability.

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1. INTRODUCTION

For all countries, telecommunications have become an unavoidable priority. Rapid developments in research and industrialization have enabled of a wide public to access modern means of communication. The development of civil and military communications systems is reflected in their rise in power, the rise in frequency, or noise figure. This evolution appears for the designers as a new constraint on the amplification stages and therefore more particularly on the transistors which will constitute them [1].

The Figure 1 illustrates a typical situation in which a transistor, in order to provide a maximum power to a load of 50 Ω, must have adequate terminations Z_s and Z_L [2], [3].

The reflection coefficients Γ_S, Γ_L, Γ_{in} and Γ_{out} are defined by the following equations:

$$\Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0} \quad (1)$$

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (2)$$

$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\,\Gamma_L}{1-S_{22}\,\Gamma_L} = \frac{Z_{in}-Z_0}{Z_{in}+Z_0} \quad (3)$$

$$\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\,\Gamma_s}{1-S_{11}\,\Gamma_s} = \frac{Z_{out}-Z_0}{Z_{out}+Z_0} \quad (4)$$

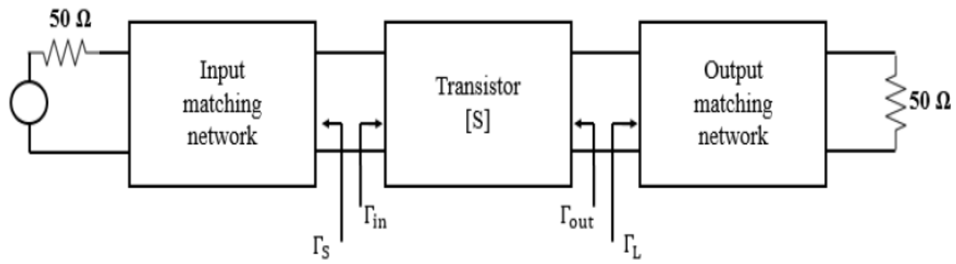

Figure 1. Block diagram of a microwave amplifier [2]

The matching technique used for the modeling of this microwave amplifier is the technique of impedance transformations with the Smith chart utility.

The aim of this modeling is, of course, to obtain a minimum noise figure, but also, with the compromise of having a gain with acceptable value and variation over the entire band of interest.

Our approach will be initiated by a selection of the transistor around which we plan to build this circuit. Then, we will calculate all the necessary parameters for the design to go after to the simulation of the circuits using the simulation software ADS®. Finally, we present the different found results for the modeled amplifier.

2. IMPEDANCE MATCHING WITH SMITH CHART UTILITY

Analysis of transmission lines problems and matching circuits in microwave frequencies can be difficult in analytical form. The Smith chart provides a very useful graphical aid for the analysis of these problems. The matching circuits that provide optimum performance for a microwave amplifier can be easily and quickly designed by using normalized impedance and admittance Smith chart [4], [5].

The ZY Smith chart can be used for the design of matching networks. The effect of adding an element with series reactance to an impedance or an element with parallel susceptance to an admittance, in ZY Smith chart, is illustrated in the following example [5].

Example:

A load $\boldsymbol{Z_{LOAD} = 10 + j10}$ Ω must be adapted to a line of 50 Ω. We design a matching network and we specify the values of $\boldsymbol{L}$ and $\boldsymbol{C}$ at the frequency 500 MHz.

To answer this question; select the network ***L* series - *C* parallel** indicated in the Figure 2(a), the matching network is designed as shown in Figure 2(b) (See Figure 2(b) on the inside cover). The displacement of point $\boldsymbol{A}$ [i.e., $\boldsymbol{Z_{LOAD} = (10 + j10)/50 = 0.2 + j0.2}$] to point $\boldsymbol{B}$ is along a circle of constant resistance, and we obtain for the inductance impedance $\boldsymbol{z_L = j0.4 - j0.2 = j0.2}$. Notice that the point $\boldsymbol{B}$ is along the unit circle with constant conductance. Admittance in the point $\boldsymbol{B}$ is $\boldsymbol{y_B = 1 - j2}$. Moving from point $\boldsymbol{B}$ to point $\boldsymbol{C}$ (i.e., origin) is along a constant conductance circle, and we get admittance capacity $\boldsymbol{y_C = 0 - (-j2) = j2}$ (or $\boldsymbol{z_C = 1/j2 = -j0.5}$).

Consequently, at the point $\boldsymbol{C}$, $\boldsymbol{y_{IN} = z_{IN} = 1}$ (or $\boldsymbol{z_{IN} = 50}$ Ω) and the network is matched to a line of 50 Ω. At 500 MHz, the value of $\boldsymbol{L}$ is

$$L = \frac{10}{2\pi(500\times10^6)} = 3.18 \text{ nH} \quad (5)$$

and the value of $\boldsymbol{C}$ is

$$C = \frac{1}{25(2\pi)500\times10^6} = 12.74 \text{ pF} \quad (6)$$

The matching network at 500 MHz is shown in Figure 2(c).

In conclusion, the addition of a series reactance produces a displacement along a constant resistance circle in the ZY Smith chart, and the addition of a parallel susceptance produces a displacement along a constant conductance circle in the ZY Smith chart. The types of displacements are illustrated in the Figure 3 [5].

The design of a matching network with the ZY Smith chart consists of moving along a constant resistance or constant conductance circle from one impedance or admittance value to another. Each displacement along a circle with constant resistance or constant conductance gives the value of the appropriate element [4]-[6].

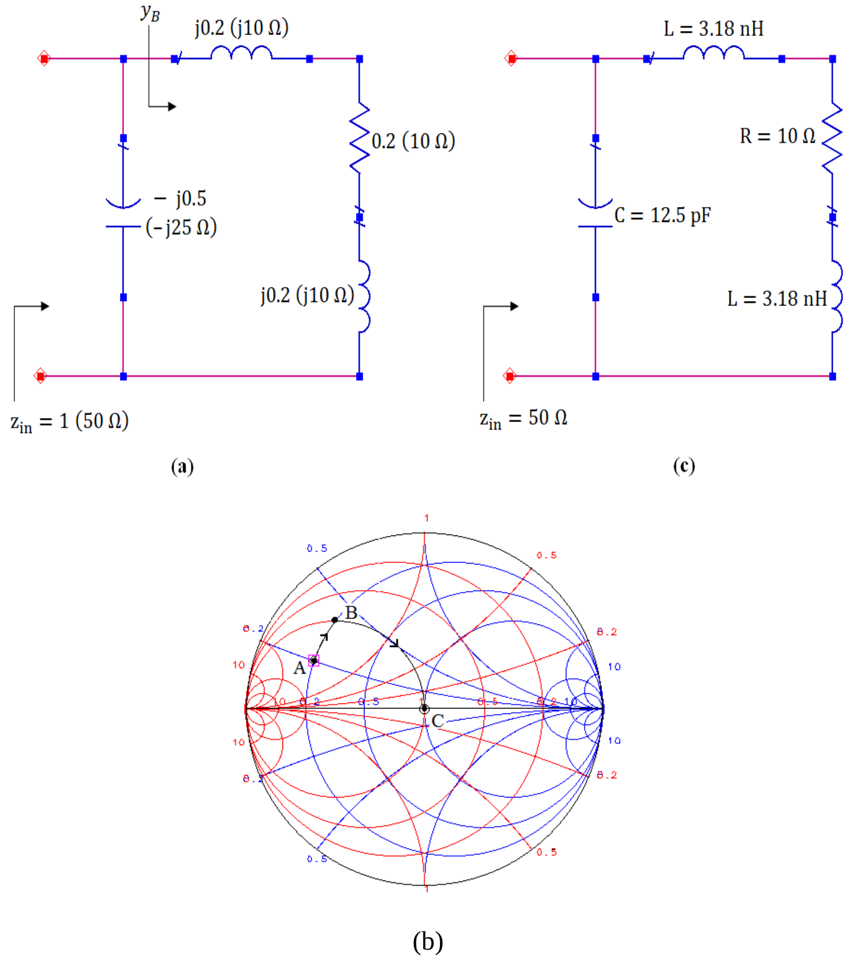

Figure 2. Design of a matching network *L* series *C* parallel

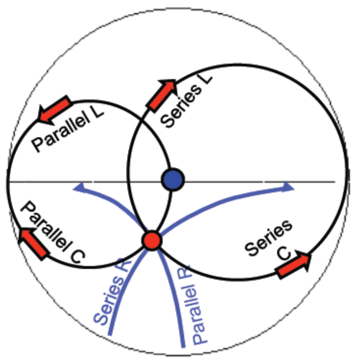

Figure 3. Effect of addition of series and parallel elements in the ZY Smith chart [5]

3. MODELING OF THE LOW NOISE AMPLIFIER

Among the proposed architectures in the scientific literature [7]-[11], we have chosen the structure represented in the Figure 4. It is composed of an amplification block and input and output impedance matching networks.

We have modeled our amplifier according to the following procedure using the simulation software of the radiofrequency circuits ADS®:

a. Choice of the transistor (the transistor HEMT AFP02N2-00 of Alpha Industries®),
b. Transistor biasing,
c. Determination of the input and output matching circuits of the amplifier,
d. Simulation of the final circuit.

We have modeled the input and output impedance matching circuits by *L-circuits* (A parallel capacitor and a series inductor) as shown in the Figure 4.

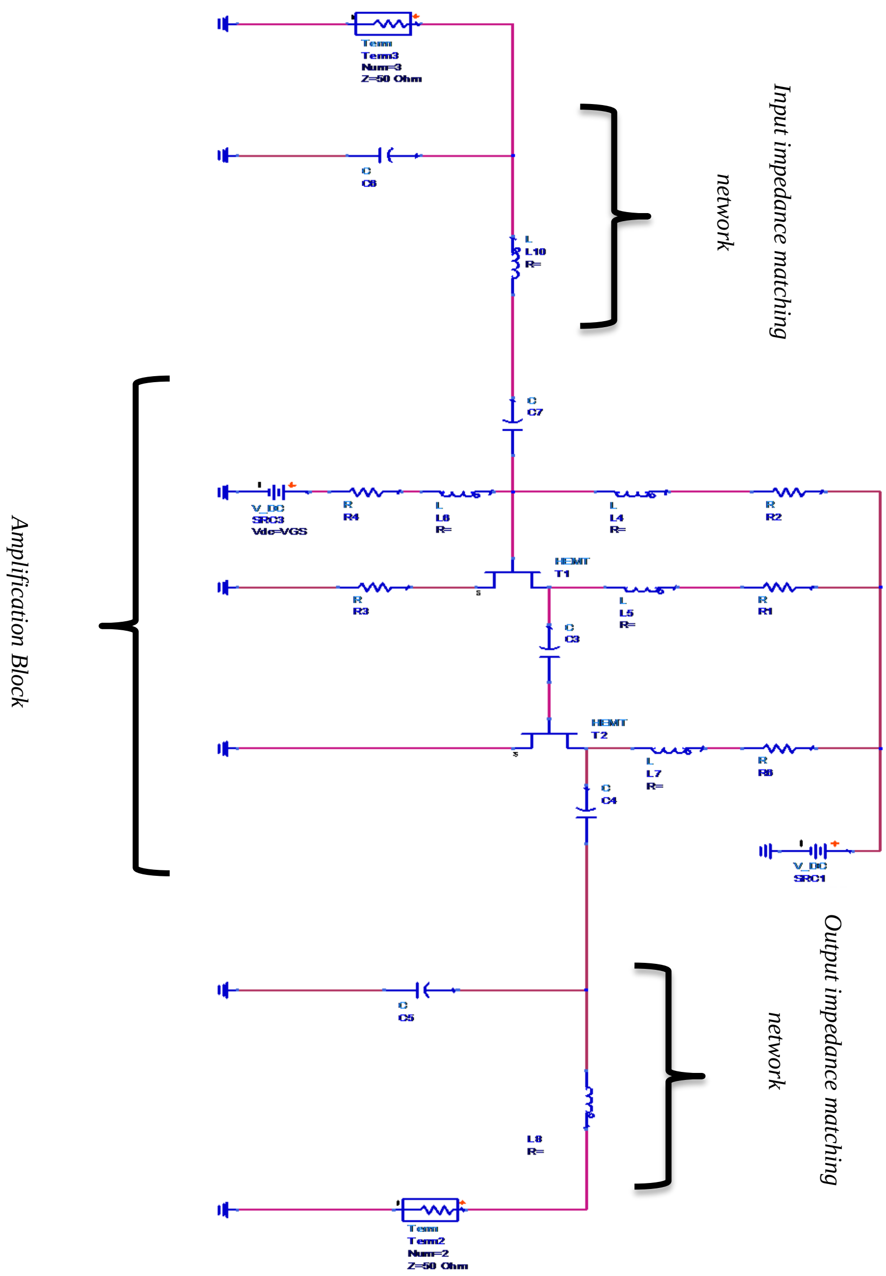

Figure 4. General structure of the modeled amplifier

4. RESULTS AND DISCUSSION

Finally, once the various stages of the amplifier are realized, we simulate its overall performances, as well as a number of additional analyzes, such as stability analysis it should be noted, however, that, for these studies to be effective and in particular the stability analysis of the amplifier, they should not be construed as final analyzes, but must be implemented and monitored throughout the design, in order to correct a problem as soon as possible without resuming the entire design process.

The circuit of the modeled amplifier shows the following simulation results:
For the reflection coefficients, the Figure 5 and Figure 6 show that S_{11} = - 67.985 dB and S_{22} = - 64.67dB at the frequency of 11 GHz. The input and output reflection coefficients (S_{11} and S_{22}) are very satisfactory.

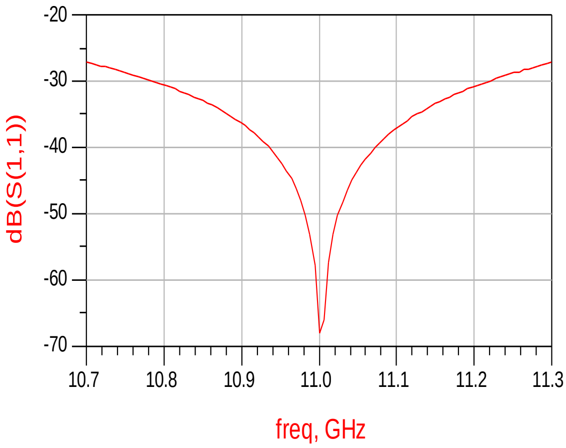

Figure 5. Reflection coefficient S_{11}

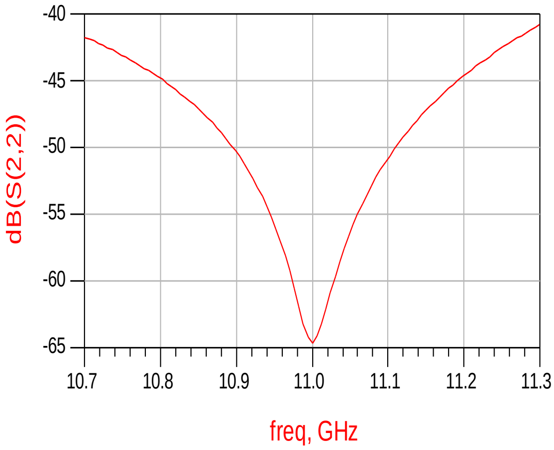

Figure 6. Reflection coefficient S_{22}

For the direct and inverse transmission parameters, the Figure 7 and Figure 8 show that S_{21} = 22.87 dB and S_{12} = - 36.82 dB at the same frequency (11 GHz). These coefficients are also satisfactory.

The circuit design requires taking into consideration the factor of stability. The aim objective is to avoid amplifier oscillation when we try to optimize the gain.

The quadrupole is unconditionally stable if: the Rollet factor K is superior to 1 ($K > 1$) and the factor Δ is inferior to 1($\Delta < 1$) [11], [12].
With

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{12}S_{21}|} > 1 \tag{7}$$

And

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| < 1 \tag{8}$$

Another stability coefficient is defined by the expression (9), if $\mu > 1$ the circuit is unconditionally stable [11]:

$$\mu = \frac{1-|S_{11}|^2}{|S_{22}-\Delta S_{11}^*|+|S_{12}S_{21}|} > 1 \tag{9}$$

The Figure 9 shows that the coefficient of stability (μ) at the input and at the output (Mu1 and MuPrime1) is strictly superior to 1, this shows that the circuit has no oscillations; it is therefore unconditionally stable.

For the noise figure: Signals and noises applied to the input port of amplifier were amplified by the gain of the amplifier and noise of amplifier itself is added to the output. Therefore, SNR (Signal to Noise Ratio) of the output port is smaller than that of the input port. The ratio of SNR of input port to that of output port is referred to as noise figure and is larger than 1. Typically, noise figure of 2-port transistor has a minimum value at the specified admittance given by formula [13]-[15]:

$$F = F_{min} + \frac{R_N}{G_s}\left|Y_s - Y_{opt}\right|^2 \quad (10)$$

For low noise transistors, manufactures usually provide F_{min}, R_N, Y_{opt} by frequencies. The noise figure of the modeled amplifier (F_dB) is equal to 0.96 dB at 11 GHz. The minimum noise figure (Fmin_dB) is equal to 0.8 dB at the same frequency (Figure 10).

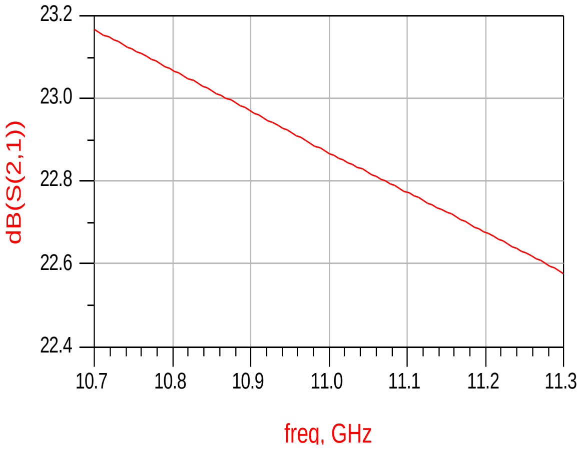

Figure 7. Direct transmission coefficient S_{21}

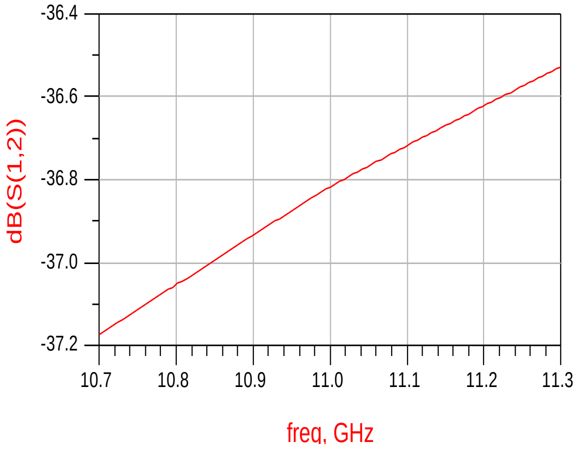

Figure 8. Inverse transmission coefficient S_{12}

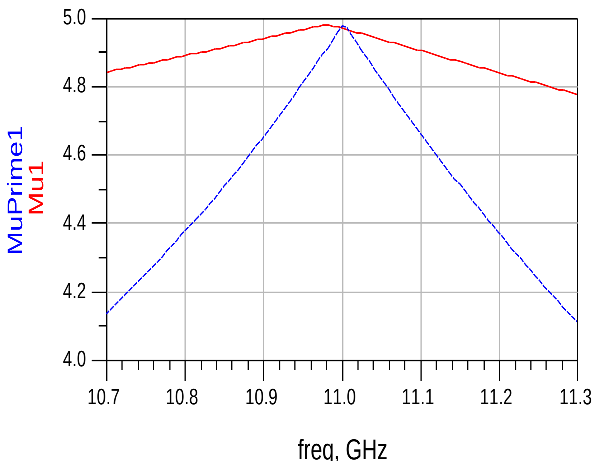

Figure 9. Stability coefficients

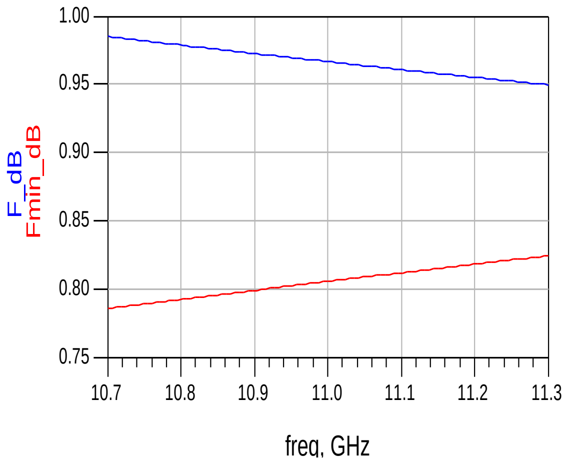

Figure 10. Noise figure

Table 1. Summary of the LNA Performances

	Band of interest	S_{11}(dB)	S_{22}(dB)	S_{21}(dB)	S_{12}(dB))	NF (dB)	Technology
This work	X	< -26	< -41.3	> 22.5	< -36.52	< 1	HEMT
[10]	X	< -18.93	< -19.10	> 20.37	< -36.29	< 3.2	HEMT
[11]	X	< -32	< -40	> 20	< -35	> 1.25	HEMT
[16]	X	< -15	< -0.4	> 7	*	< 2.4	HBT

5. CONCLUSION

In this work, we have presented a simple and complete impedance matching technique for the modeling of narrowband microwave amplifiers namely: Impedance transformations technique with Smith chart utility.

The type of transistor used is: the transistor HEMT AFP02N2-00 of Alpha Industries®. The found simulations results show that the modeled amplifier is unconditionally stable with satisfactory gain and good impedance matching throughout the band of interest. This amplifier can be integrated into radar and satellite reception systems operating around 11 GHz.

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