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Design of a Wide Band Low Noise Amplifier [9.5-12.5] GHz

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ABSTRACT

In this paper, we have modeled a low noise amplifier LNA based on HEMT transistors adapted by band pass filters. Different design constraints have been treated to achieve the performances of the amplifier (S-parameters, gain, noise and stability). This amplifier is double stage circuit. It is unconditionally stable in the band [9.5-12.5] GHz with gain greater than 21 dB, noise figure less than 0.8 and the reflection coefficients at the input and at the output (S_{11}, S_{22}) lower than -20 dB and -26 dB respectively. The designed amplifier can be integrate in satellite reception systems.

Keywords : **LNA, Adaptation, Stability, Noise Factor**

1. INTRODUCTION

This paper will be devoted to the study of the low noise amplifier, the component used to amplify the signal while maintaining the noise level; this means that the signal is amplified with the least possible noise. The low noise amplifiers are widely used in communication systems and sensing. The adaptation networks of these amplifiers are manufactured from lumped elements (inductors and capacitors) or from distributed elements (transmission lines) or from the combination of both, this is due to economic and technological constraints [1, 2].

The main objective of this study is to model a low noise amplifier having an architecture that is as simple as possible based on HEMT transistors for multistandard applications. The transistors used have the advantage of operating frequencies higher than MOS transistors. The parameters that are essential to take into consideration are noise, gain and stability. We must have a minimum of noise, high gain and unconditional stability all along the frequency range of interest [9.5-12.5] GHz.

2.DIMENSIONING OF LNA

The general structure of an amplifier. It includes an active device (usually a transistor), characterized by its S-parameters and surrounded on both sides by impedance adaptation networks [1, 2]. The study of this structure allows us to determine the important parameters for characterizing an amplifier, including gain, noise figure and stability.

The power at the input of a system is determined by calculating the link budget. It is therefore important to maximize the gain of the amplifier stage in order to minimize the number of stages of the amplifier chain. This allows us to find the impedances $Z_1 = Z_{in}{}^*$ and $Z_2 = Z_{out}{}^*$ to present at the input and output of the transistor, in order to ensure maximum transfer of power from the source to the load [1-2].

Are the two impedances Z_G and Z_L of the figure 1.a. If $jX_G - jX_L = 0$, the scheme of figure 1.a can be simplified and summarized in the scheme of figure 1.b. [3].
In order for the power transfer is maximum, the simple equality $R_G = R_L$ must be verified. This simple example can be generalized by a law just as easy.
On the scheme of figure 1.a, the impedance seen from point A to the source is Z. The impedance seen from point A to the load is Z_1 [1-3].
If Z_1 is equal to the conjugate value of the impedance Z the circuit is adapted. $Z_1 = Z^*$.

The role of the adaptation circuit is to transform the value of the complex impedance Z_L so that this impedance, seen from entry of the adaptation circuit is equal to the conjugate value of the impedance Z, is Z * [1-3].

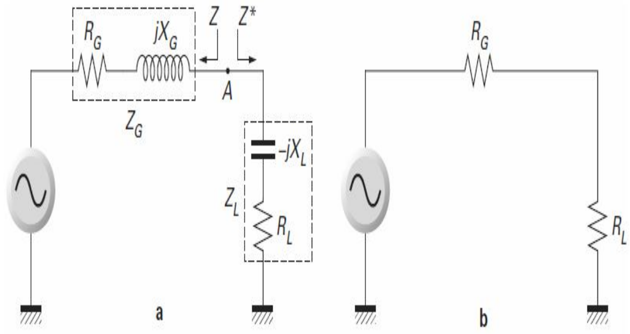

Figure 1. Equivalence of the adapted network

3.ADAPTATION CIRCUIT

The choice of a configuration of the matching networks results from the choice of the bandwidth on which the

adaptation must be made, which sets the overvoltage coefficient Q.
If the matching cell comprises two reactive elements, the overvoltage coefficient Q is completely defined by the ratio of the real parts of the impedances of the source and load. This overvoltage coefficient is the minimum overvoltage coefficient Q_{min}, corresponding to the maximum bandwidth in which the adaptation is effected.
Regardless of the configuration, the number of circuits and their association, any resulting overvoltage coefficient can not be less than Q_{min}.
If the cell contains three reactive adaptation, the overvoltage coefficient Q can be chosen with the restriction $Q > Q_{min}$. As a result, circuits in L, in condition they have at least three reactive elements are to be used when the adaptation is narrowband.
If adaptation is broadband, the circuits in L should be used with the restriction given by Q_{min}.

Is the circuit of figure 2. This is to adapt two resistors R_1 and R_2 by a filter in L. [2-3].

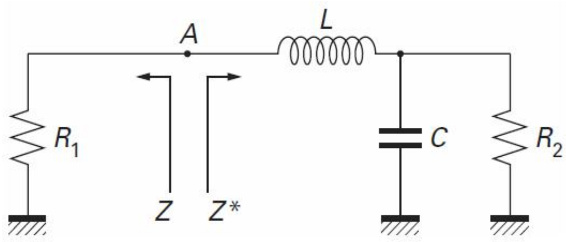

Figure 2. Adaptation with filter in L

The impedance Z seen from point A to the source is:

$$Z = R_1 + j0 \tag{1}$$

The impedance Z_1 seen from point A to the load is:

$$Z_1 = \frac{R_2}{R_2{}^2C^2w^2+1} + j\left[LW - \frac{R_2{}^2CW}{R_2{}^2C^2w^2+1}\right] \tag{2}$$

By equating real and imaginary parts and after the resolution of the resulting system we find:

$$C = \frac{1}{R_2W}\sqrt{\frac{R_2-R_1}{R_1}} \quad \text{and} \quad L = \frac{R_1}{W}\sqrt{\frac{R_2-R_1}{R_1}} \tag{3}$$

Note: A broadband adaptation can be obtained by shifting, in frequency, many adaptation networks in cascade [3].In fact the addition of adaptation networks for input and output can sometimes introduce stability problems and the amplifier may start to oscillate, hence it is important to study the stability of the system [1, 4].

An amplifier is unconditionally stable if the real parts of input impedances and output of the amplifier are greater than zero at a frequency, whatever the impedance of the source and charge is. We define the stability coefficient μ by the following expression [1].

$$\mu = \frac{1-|S_{11}|^2}{|S_{22}-S_{11}{}^*\Delta|+|S_{12}S_{21}|} \tag{4}$$

This criterion allows to reach the same conclusion with the criteria K>1 and $|\Delta| < 1$ when μ>1 [1-2].
With

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2.|S_{12}|.|S_{21}|} \tag{5}$$

$$\Delta = S_{11}\,S_{22} - S_{12}\,S_{21} \tag{6}$$

One of the performances of a receiver or particular an amplifier is its noise figure; it is defined by [4].

$$F = \frac{(\frac{S}{B})_E}{(\frac{S}{B})_S} = 1 + \frac{B_a}{B_E} \tag{7}$$

The input noise, B_E is modeled by an input noise source v_S associated with an impedance $Z_S = R_S + jX_S$. The additional noise, B_a, provided by the quadrupole is modeled by two noise sources, one voltage and one current. By developing, we obtain the expression [4].

$$F = 1 + \frac{R_n}{R_S} + \frac{G_p}{R_S}(R_S{}^2+X_S{}^2) + 2RcoG_p + 2X_{co}G_p\frac{X_S}{R_S} \tag{8}$$

With R_n and G_p, resistance and conductance equivalent of noise of the quadrupole.
Differentiating the function F in relation to X_S and R_S, we show that there is an optimum value of Z_S to obtain the minimum noise figure. This impedance is called the optimum impedance Z_{opt} ($Z_{opt} = R_{opt} + jX_{opt}$) [2, 4].

$$F_{min} = 1 + 2G_p\left(R_{co} + \sqrt{\frac{R_n}{G_p} - X_{co}{}^2}\right) \tag{9}$$

With R_{co} and X_{co} are the real and imaginary parts of impedance of correlation Z_{co} such that $Z_{co} = R_{co}+jX_{co}$.

For modeling the low noise amplifier we have used the simulation software ADS (Agilent Device System) developed by Agilent®, this software is considered among the most powerful software at the level of design and simulation of electronic systems for microwave and radiofrequencies. After a theoretical study, we modeled our system as shown below (figure 3). It is composed of two transistors in cascade, bias circuits and impedance matching networks for input and for output, in the form of band-pass filters with 4 elements.

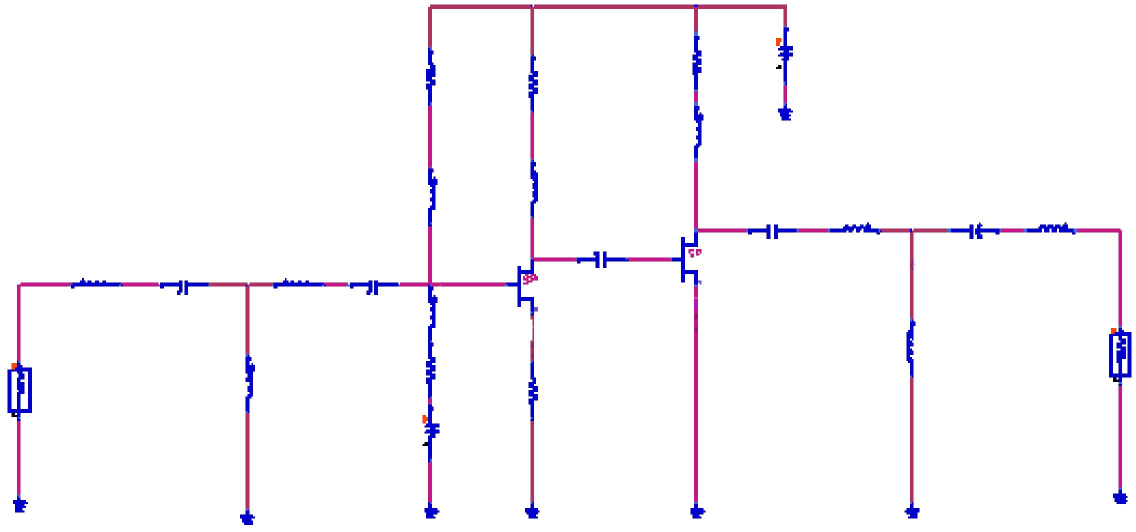

Figure 3. General structure of the modeled amplifier

4.RESULTS AND DISCUSSION

The reflection coefficient S_{11} is strictly less than -20 dB and can reach the value -62 dB at 10.8 GHz, S_{22} is less than -26 dB and can reach -60 dB at 11 GHz (figure 4). For direct transmission S_{21} varies between 21 and 24 dB and for inverse transmission S_{12} varies between -38 dB and -40 dB (figure 5).

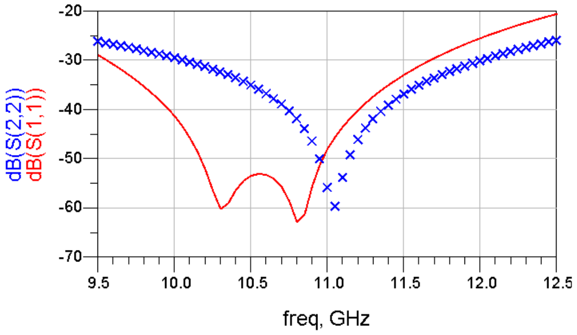

Figure 4. Reflection coefficients

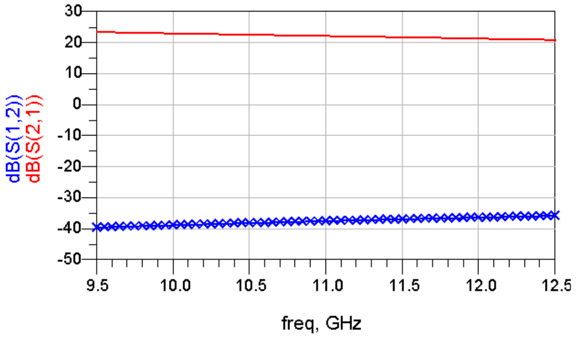

Figure5. Transmission coefficients

For the stability of the LNA, the stability coefficients at the input and at the output Mu1 and MuPrime1 are greater than 1 across the band of interest (figure 6).

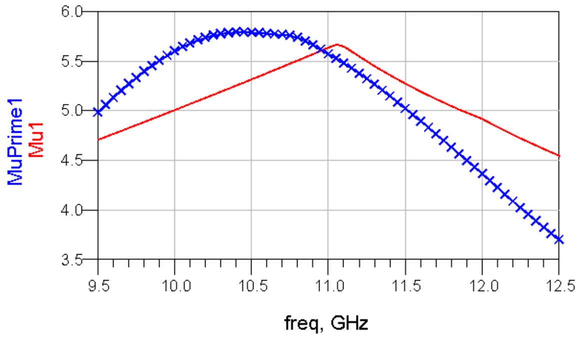

Figure 6. Stability coefficients

The noise of LNA varies between 0.4 and 0.8 dB. The minimum noise figure NF_{min} is of the order of 0.11 dB (figure 7).

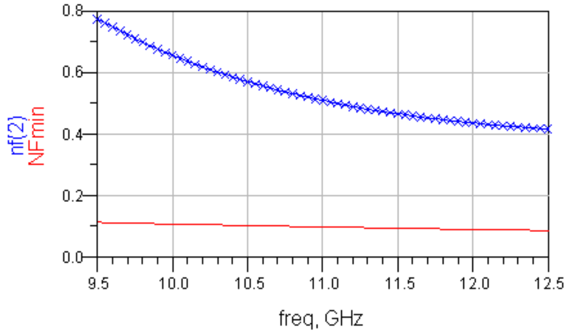

Figure7. Noise of LNA

5.CONCLUSION

We have established a thorough study of the performance optimizations in both stability, noise in each of the different matching circuits in order to satisfy our specifications.

The LNA modeled in this work presents very satisfactory results in terms of gain, stability and noise compared with other studies [5-8] and can be integrated into satellite reception systems.

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