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Design of 10 to 12 GHz Low Noise Amplifier for Ultra-wideband (UWB) System

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ABSTRACT

Balanced amplifier is the structure proposed in this article, it provides better performance. In fact, the single amplifier meets the specification for noise figure and gain but fails to meet the return loss specification due to the large mis-matches on the input & outputs. To overcome this problem one solution is to use balanced amplifier topography. In this paper, a wide-band and high-gain microwave balanced amplifier constituted with branch line coupler circuit is proposed. The amplifier is unconditionally stable in the band [9-13] GHz where the gain is about 20dB. The input reflection (S11) and output return loss (S22) at 11 GHz are -33.4dB and -33.5dB respectively.

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1. INTRODUCTION

The low noise amplifier (LNA) is the first level of amplification of the incoming signal in almost all RF and microwave receivers and could be used in civil and military communications systems. Therefore, it is necessary to improve its performance. Various configurations are possible to design low noise amplifiers. But to obtain an average bandwidth, two structures are possible: the first unbalanced structure consists of having a multi-stage amplifier with inter-stage matching circuits, the second balanced structure is the one adopted in this work. It is characterized by the balanced amplifier and is generally used to limit the phenomenon of saturation of the transistors. Balanced approach employing hybrid couplers is used to improve the matching over wider bandwidth [1] and is also capable to meet high input and output return loss as well as high stability.

This paper proposes a [9-13] GHz low noise amplifier (LNA) for ultra-wideband applications. In the design, specific architecture has been selected for LNA implementation based on the branch line devices. The LNA involves simultaneous requirement such as noise figure (NF), enough gain and good impedance match. Thus, the matching network used to adapt the impedance adopted the technique of quarter wave transformers. The main objective of this study is to characterize the performance of the amplifier by determining the important parameters, including gain, noise figure and stability. The simulation and optimization are performed using ADS (Advanced Design System) software. The paper is organized as follows: Section1 introduce the utility of the low noise amplifier. The design of the broadband LNA and circuit diagram are reported in section 2. Sections 3 and 4 give the simulated results. The last section presents the conclusion of this work.

2. BALANCED AMPLIFIER CONFIGURATION AND THEORY

The balanced amplifier has been widely used in wireless communication systems due to its excellent performance in low noise figure, optimum gain and better stability comparing to a single amplifier. The LNA structure suggested comprises two transistors, and an impedance matching networks which are located in the input and the output. We opted for the HEMT transistor (AFP 02 N2-00) of Alpha Industries. AFP 02 N2-00 is a low noise enhancement mode HEMT designed for use in low cost commercial applications in the 2GHz to 26GHz frequency range.

The circuit consists of a pair of identical quadrature devices which is specific to balanced amplifiers. There are many types of 3dB couplers, some of them are lange coupler, directional coupler and branch line coupler. Generally, microwave transistors used to design broadband amplifiers are not well matched. In fact, a wider bandwidth can be obtained to the detriment of the gain and the complexity. Thus, the conception of a circuit based on two amplifiers having a coupler at their input and output provide a good adaptation over a wideband frequency. The balanced amplifier topology is shown in Figure 1.

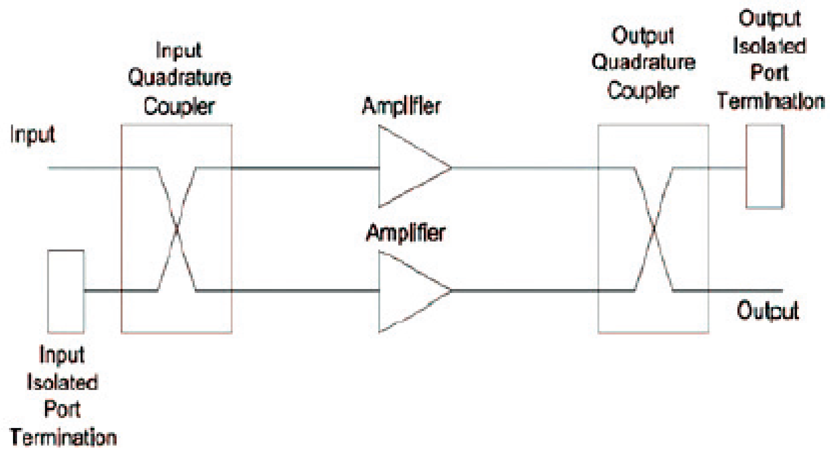

Figure 1. Circuit topology of the balanced LNA

2.1. Design of 3-dB Quadrature Couplers

For the balanced amplifier topology, the 3dB quadrature couplers used here are branch line couplers. The 90° hybrids use directly connected circuit elements and can be implemented either using a distributed approach or lumped elements [2]. These 3dB hybrid couplers divide the input RF signal into two signals having same power and 90° phase shift [3]. Directional couplers are characterized by three parameters:

Coupling: $C_{dB} = 10\ \mathrm{Log}(\frac{P_1}{P_3})$ (1)

Directivity: $D_{dB} = 10\ \mathrm{Log}(\frac{P_3}{P_4})$ (2)

Isolation: $I_{dB} = 10\ \mathrm{Log}(\frac{P_1}{P_4})$ (3)

Single section branch line coupler has a short bandwidth [10-20%]. In order to increase the bandwidth, several sections can be cascaded [4]. By using multisection coupler, the performance of the coupler can be improved [5]. In this design, the two-section branch line coupler is adopted for the convenience of design and implementation. As can be seen in Figure 2, the key dimension of the presented hybrid coupler is composed of three uniform impedances Z_a, Z_b, Z_c and electrical lengths.

Those parameters could be calculated based on computed values of the even- and odd-mode impedances and effective dielectric constants using the assumption of coupled micro-strip lines. The simulated results of the branch line coupler are shown in Figure 3. Over the band [9-13] GHz it is observed that the isolation and reflection coefficient show better performance with S parameters amplitude below –28 dB. The amplitude of the coupled coefficient is on the order of -3.5 dB [6].

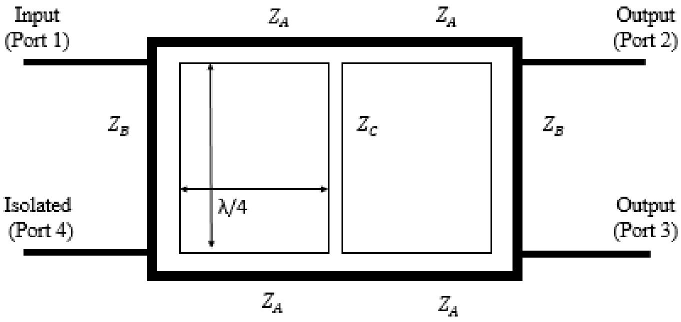

Figure 2. Schematic of the presented branch-line coupler

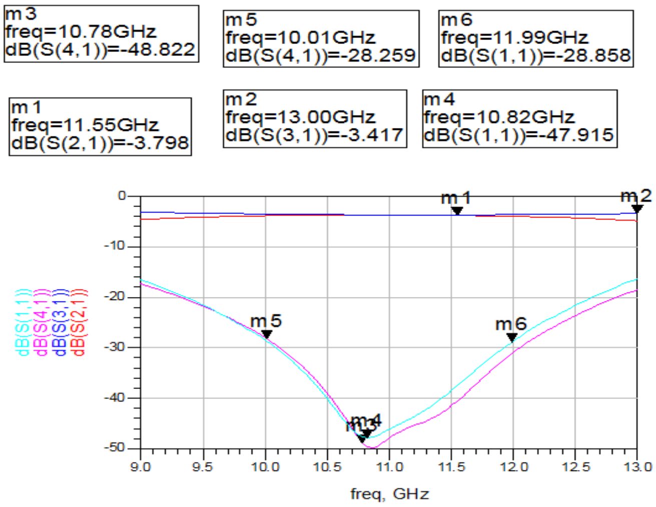

Figure 3. S-parameters of the proposed wide-band coupler: S11, S21, S31 and S41

2.2. The Impedance Matching Network

The purpose of adding the matching network to the system is to provide an optimum return loss and a better noise figure. Being a low-noise high gain stage, extreme care is needed to stabilize the device without compromising NF. Matching network was placed between the microwave transistor and coupler to maximize power transference as it is represented on Figure 4. The matching block was designed by the quarter wave transformer and will have a lot to stay for the bandwidth [7].

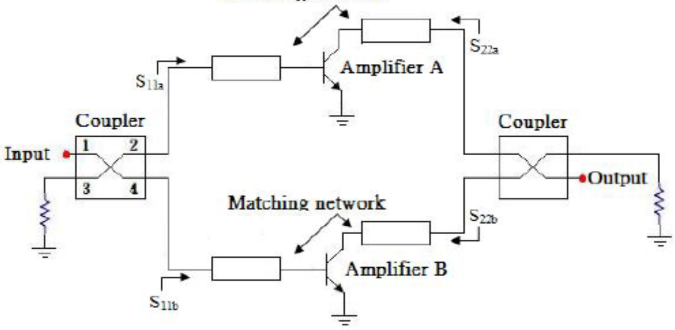

Figure 4. Balanced LNA configuration

2.3. Stability Design

There are two types of stability namely unconditional stability and conditional stability. Conditional stability in amplifier occurs when K<1 and stability depends on source and load termination. It can keep the system stable for a certain range of source and load impedances [3]. To the contrary, the unconditional stability in amplifier occurs when K>=1, ensures the network to be stable for all source and load impedances. For proper working of low noise amplifier, the designer should have an unconditional stability [3]. The stability factor, `K' is calculated over a frequency band by using the equation:

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

3. SIMULATION OF THE PROPOSED UWB LNA

The final circuit is shown in Figure 5 and analyzed using the ADS software relying on the S-parameters of the transistor. The selected device for this design is the HEMT transistor (AFP 02 N2-00) of Alpha Industries ®. The input and the output matching networks were optimized for 50-Ω matching and have been implemented using transmission line transformers. Also an inter-stage matching network was designed between the first and the second stages. The complete balanced LNA design consists of adding branch line couplers (BLC) on the input and output of the amplifier. Table 1 shows the LNA's design specification to be achieved.

Table 1. Design Specification of LNA

Parameters	Value
Operating frequency	11 GHz
Gain, S21 (dB)	>10
Noise figure (dB)	<2
Input return loss, S11(dB)	>-10
Output return loss, S22(dB)	>-10
Stability factor, K	>1

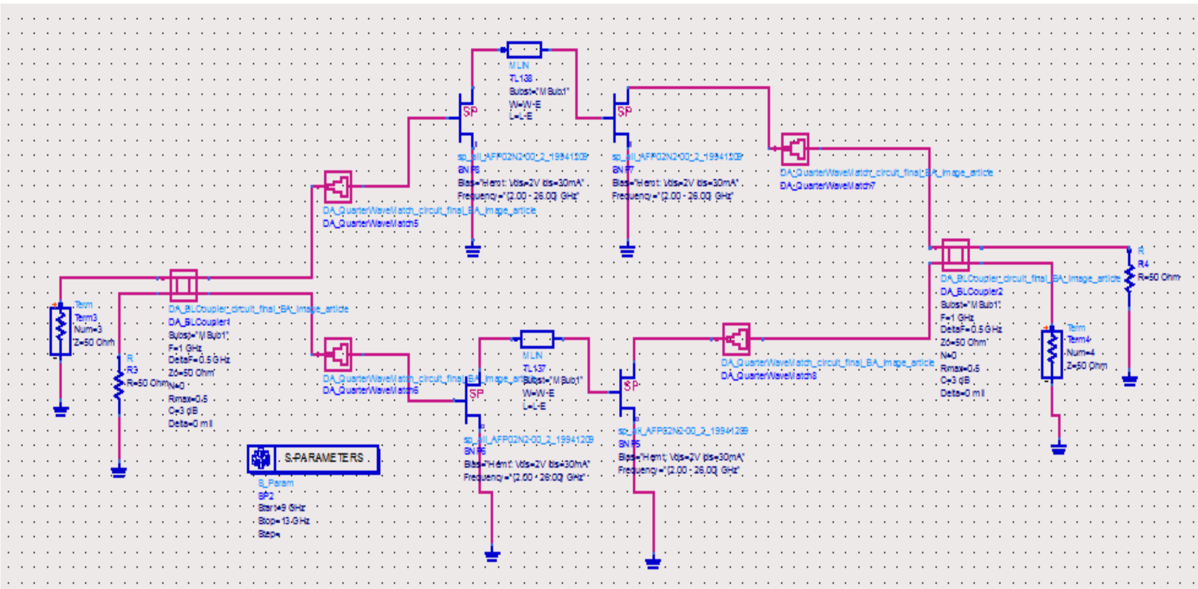

Figure 5. Structure of the proposed circuit

4. RESULTS AND ANALYSIS

The various simulation iterations are performed on the proposed LNA circuit to meet design requirements. The simulation was done at 11GHz frequency and we obtained various results which are shown in the below figures. The experimental characterization results for gain, input and output reflections of amplifier, and the stability factor are depicted in Figures 6, 7 and 8, respectively.

4.1. Gain (S21) and Reverse Isolation (S12)

The LNA's gain is an important factor, it allows signal to not be affected by noise contribution of subsequent stages in the receiver chain. In our circuit the value of the gain S (2 ,1) obtained after simulation is about 20 dB. It is achieved over the entire bandwidth of [9-13] GHz while the peak power gain of 22 dB is achieved at 9 GHz as shown in Figure 6. The input–output isolation (S1,2) is very important parameter to ensure better stability. The value of (S1,2) obtained after the simulation is -39.27dB at 11GHz.

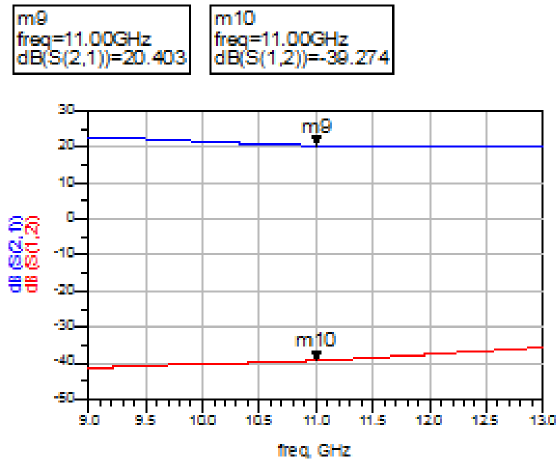

Figure 6. Simulated gain and reverse isolation of LNA

4.2. Input and Output Matching (S11/S22)

While designing LNA, it is also required to make sure that the input and output matching network is achieved. In our proposed LNA, good result are obtained S(1,1) and S(2,2) are less than -30 dB over the bandwidth of [10-12] GHz. Figure 7 shows that the value of S(2,2) is about -45dB at 11.7 GHz and S(1,1) obtained at 10.27 GHz is equivalent to -51.27dB.

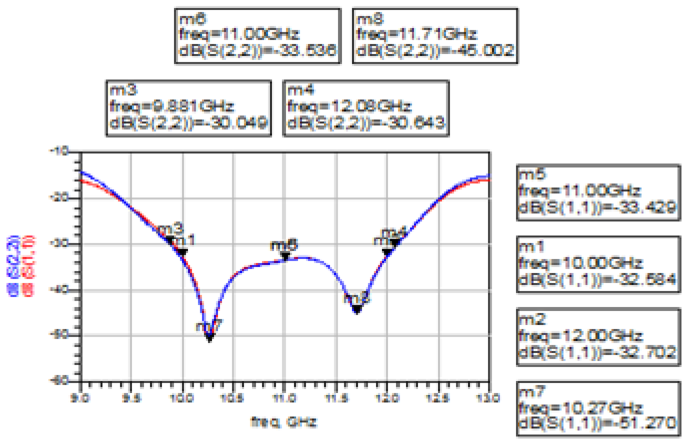

Figure 7. Input and output return loss for the balanced amplifier

4.3. Stability (StabFact)

The stability of this transistor is unconditionally stable at 11 GHz since its K constant is more than 1, which is 4.4 from the simulation result on Figure 8.

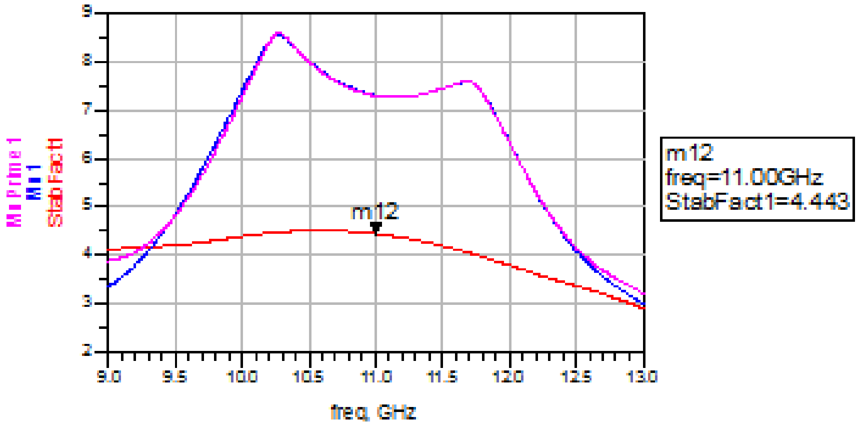

Figure 8. Stability factor

4.4. Comparison

Table 2 illustrate the summary of the simulation results for the LNA design. The performance of the designed LNA is compared with the performance of other low noise amplifiers circuit.

Table 2. Performance Summary of Balanced Amplifier

Published Works	Architectures	Gain (dB)	S(1,1) (dB)	S(2,2) (dB)
[8]	1 stage	> 7.5	< -12	< -10.2
[9]	Single stage	16.8	-17	-19
This work	2stages	20.4	<-33	<-30.6

5. CONCLUSION

The circuit presented in this article is designed with the balanced amplifier structure and simulated using Agilent's ADS tool to get high gain, low noise figure and unconditional stability. From above simulation results it is clear that LNA is unconditional stable, the results obtained have achieved the requirements that have been set. The gain is above 20 dB, input matching (S1,1) and output matching (S2,2) parameters are below -33dB. This low noise amplifier is capable of broadband performance between 9 GHz and 13 GHz that can be used across a wide spectrum of military and radar applications.

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