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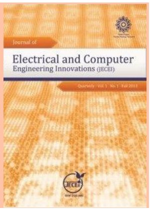

Design of an S-Band Ultra-Low-Noise Amplifier with Frequency Band Switching Capability

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ABSTRACT

In this paper, an ultra-low-noise amplifier with frequency band switching capability is designed, simulated and fabricated. The two frequency ranges of this amplifier consist of the 2.4 to 2.5 GHz and 3.1 to 3.15 GHz frequency bands. The designed amplifier has a noise figure of less than 1dB, a minimum gain of 23 dB and a VSWR of less than 2 in the whole frequency band. The design process starts with increasing the stability factor in the source through manipulating the inductor placement technique. Then, the input and output matching circuits for the first frequency band are designed. This process is completed by utilizing two similar stages placed successively in order to achieve the desired gain level. Since no degradation of the noise figure is observed and acceptable values are also obtained for other parameters, switching the elements in the output matching circuit can be a good idea for avoiding the use of a similar circuit for the second frequency band. The optimum secondary values for the mentioned elements are obtained through the analyses performed using the ADS software. For changing the values of the mentioned elements two MOSFETs are used for adding capacitance and inductance to the matching circuit. In the next step, the designed amplifier is finalized and optimized after adding a suitable bias circuit to it. Moreover, The designed amplifier is fabricated and a good agreement between the measurement, analysis, and simulation results is observed.

1. INTRODUCTION

The low noise amplifier (LNA) is the most important part of a radio receiver. Since, it must amplify the low input signal of the receiving antenna to the desired level and also the noise must be low because it has a larger contribution in the noise figure of the receiving system. However, in many cases it is not possible to simultaneously achieve the maximum gain and the minimum noise figure. So, we have to compromise between the high gain and low noise. Among other important parameters in a low noise amplifier, we can mention the standing wave ratio and 1dB compression point.

In the design of low noise amplifiers, depending on the frequency band, type of application and the importance of each parameter, different designs have been done. The general principles of the amplifier design are given in [1], [2]. In [3], a one-stage low noise amplifier at a frequency of 2.3GHz is designed for mobile communications applications. The method of design is such that after choosing a suitable transistor and stabilizing it with a shunt resistor, by using the ADS software design tool, the Input and output matching circuits are calculated with the selection of suitable values of Γ_S and finally, an amplifier gain in the 2.3GHz frequency equal to 17dB and a noise figure of 0.73dB are obtained. Also, in [3], for the design of low noise amplifier one of the ATF family transistors is used. This amplifier is designed for S-band frequency and in the 2-stage structure.

By selecting Γ_S, the appropriate matching circuit is designed and using ADS software for input and output have appeared in the form of two L-shaped matching. In frequency of 3.1GHz, a 30dB gain, a noise figure of 1.25 dB and input and output VSWR of 2.1 and 1.43 respectively have been obtained. Likewise, in [4], an S band low noise amplifier with the technique of switching in the input matching circuit is designed. The circuit works in both 2.4GHz and 3.5GHz frequency and a maximum gain of 21dB and a minimum noise figure of 2.6 dB were obtained.

In this paper, the design process is commended by the selection of the ATF-34143 transistor from Agilent company that has the optimal characteristics of noise and gain in the given frequency band. The stabilization of the transistor with the technique of placing an inductor in the source at 2GHz to 4GHz frequency range is done. The main design goal is to design low-noise amplifier in the first frequency range (2.4GHz to 2.5GHz) and the second frequency range (3.1GHz to 3.15GHz) with a noise figure below 1dB, a minimum gain of 23dB and a VSWR less than 2. According to the specifications, a two-stage amplifier with input and output matching networks for each stage is used. First, the design is performed for the first frequency range and is simulated, then by merely changing the values of the inductor and the capacitor of the second stage output matching network is achieved by the switching technique. The specifications will be realized in the second frequency band. Finally, the simulation results together with the power circuit, all done by the ADS, are presented.

2. DESIGN METHOD FOR THE FIRST FREQUENCY RANGE

In order to design, it is necessary to first stabilize the transistor in the required frequency band. Then, with the proper selection of the reflection coefficient, Γ_S for the input and output, the L- shaped matching circuits are designed for the first frequency band and then is analyzed. To achieve the required gain, the similar 2-stage method is used and the results of the simulations are presented.

A. Stability

The transistor stability is analyzed according to Equations (1) and (2). The results of the stability analysis show that due to the lack of obtaining k>1 & $\delta<1$, this transistor in the S-band frequency range is not stable. One way to stabilize is the insertion of an inductor at the transistor source.

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2*|S_{12}S_{21}|^2} \qquad (1)$$

$$\Delta = S_{11}S_{22} - S_{12}S_{21} \qquad (2)$$

With the addition of inductors with different values within the acceptable range, calculation of the S-parameters, and the stability analysis is achieved by the value of 0.6nH for the inductor. Figure 1 shows values of K versus the frequency, after the stabilizing the transistor.

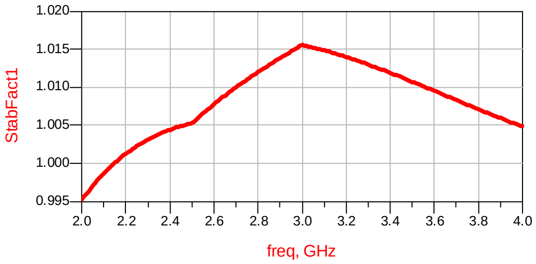


Figure 1: K values after stability.

B. Circles of constant noise and gain

In order to design the input matching circuit and to choose an appropriate value for Γs, the circles of constant noise and gain can be plotted according to Figure 2. In this figure, the bold and light lines respectively show the constant gain and constant noise circles for 2.4GHz frequency. To select an appropriate Γ_S, we have to establish a compromise between the gain and noise so that for having a low noise figure, the value of Γ_S is chosen from the circle with a lower noise figure. Hence, inevitably a higher gain will not be achieved.

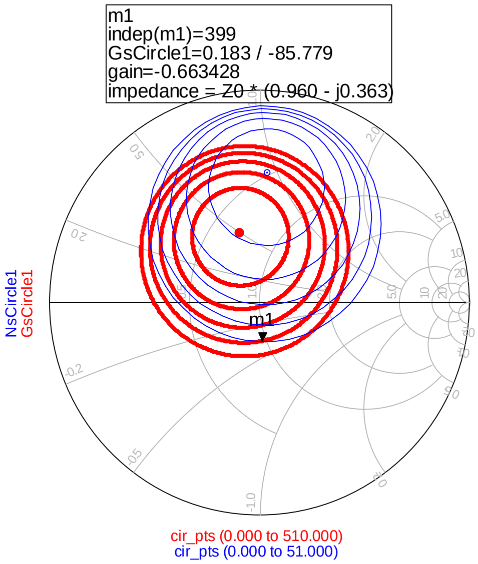


Figure 2: The circles of constant noise and gain.

A value of Γ_S equal to 0.18∢:-85.7 °, (the m1 point in Fig. 2) is chosen. The Γ_L parameter (the output reflection coefficient) value for the design of the output matching circuit is obtained according to Equation (3). The value is obtained equal to 0.38∢ 31.37 °.

$$\Gamma_L = \left(S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1-S_{11}\Gamma_S}\right)^* \qquad (3)$$

C. Input and output matching networks

The input matching network is used for source impedance matching and the output matching network is used for load impedance matching with the transistor. The matching networks with the lumped elements can be implemented by three structures: L-shaped network, π and T.

In designing the network input matching circuit in frequency of 2.4GHz, for compensation, Γ_S, an L-shaped inductive-capacitive matching circuit is used. Similarly, for the output matching circuit, the value of Γ_L should be compensated by the L matching circuit. The input and output matching circuits values for the elements in the 2.4GHz frequency design are given in Figure 3.

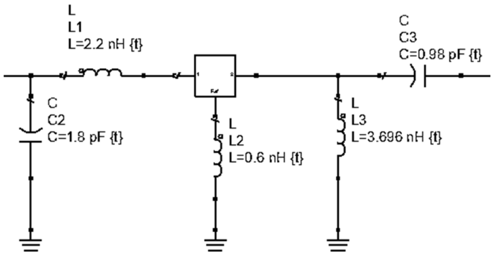
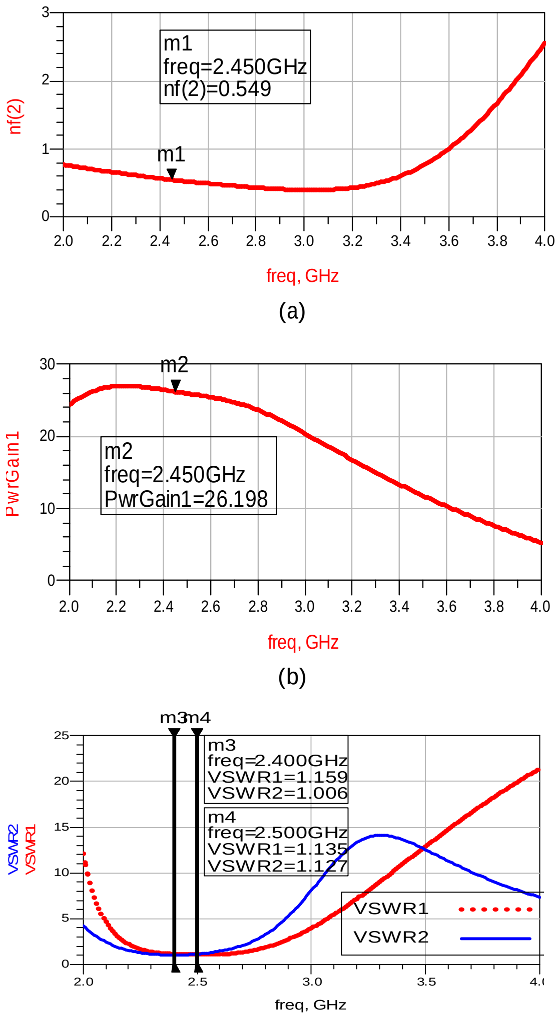


Figure 3: Lumped elements in the matching circuits.

3. THE DESIGN METHOD FOR THE FIRST AND SECOND FREQUENCY RANGES

Regarding the required operations in the two frequency ranges of interest for the ultra-low-noise amplifier and the difficulty of using to two separate amplifiers due to the bulkiness of the final circuit, there is a need to provide a suitable method for the design. In this section, a method is proposed whereby by the minimum amount of changes to the design elements, the required results for the optimal performance in both frequency ranges are obtained. This is possible by doing the switching operation between the matching circuit elements. To initiate the design procedure and in order to minimize the amount of changes that can be involved in the process, we have based the design of the proposed amplifier on the requirements of the first amplifier frequency range (2.4GHz to 2.5GHz). The overall proposed plan is to make minimal changes in the first amplifier circuit elements, and then, one can exploit this amplifier circuit for the purpose of the second frequency range (3.1GHz to 3.15GHz).



(a)

(b)

(c)

Figure 4: The results of the simulation for 2-stage LNA in the first frequency range. a) Noise figure, b) Gain, c) VSWR.

Since, in the two-stage amplifier, the first stage will have a major impact on the overall system noise, therefore, once the first stage is fully designed, the designed values remains unchanged throughout the entire design procedure.

Hence, the overall noise figure of the entire system undergoes minimum changes. Design of the second stage amplifier circuit is done by changing the output elements. Using the ADS software, the effects of any increase or decrease in the output matching circuit elements i.e. the inductor and capacitor, can be observed. For example, the input and output VSWR results as well as the gain results for different values of inductor and capacitor can be seen in Figures 5 and 6.

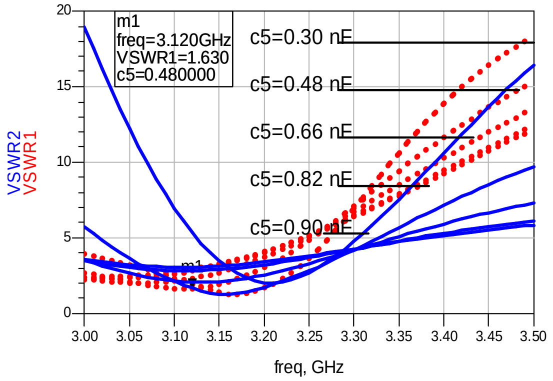


Figure 5 : The input and output VSWR results for different values of capacitors with the inductor value being 1.8nH.

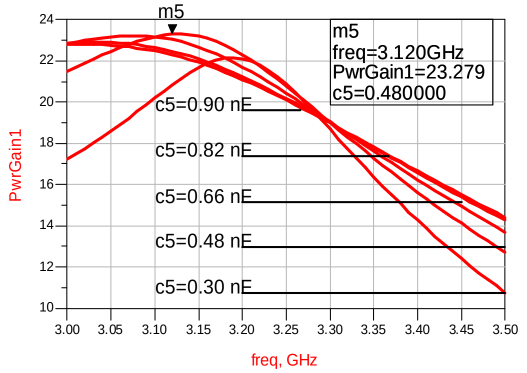


Figure 6 : The gain results for different values of capacitor with the inductor value being 1.8nH.

As can be seen, by the decreasing the values of the inductor and capacitor to about half of their values in the frequency range of the first amplifier, ultimately the optimal parameters of the amplifier design for the second frequency range is achieved. Thus, the values for the inductor and capacitor are considered to be 1.8nH and 0.48nF.

By using a MOSFET switch, it is possible to change the values of the inductor and capacitor at the output of the second stage, for use in both the first and second frequency ranges. The proposed final low noise circuit with MOSFET switches, power circuit and the coupling capacitors is shown in Figure 7.

The results of the final circuit simulation are shown in Figure 8. From the results, it can be seen that our amplifier operates well in both the first and the second frequency bands.

For this amplifier, the maximum noise figure equals to 0.55dB, the minimum gain value is 23 dB and the maximum VSWR is equal to 2. The P1dB parameter simulation results for the first and the second frequency bands are shown in Figure 9.

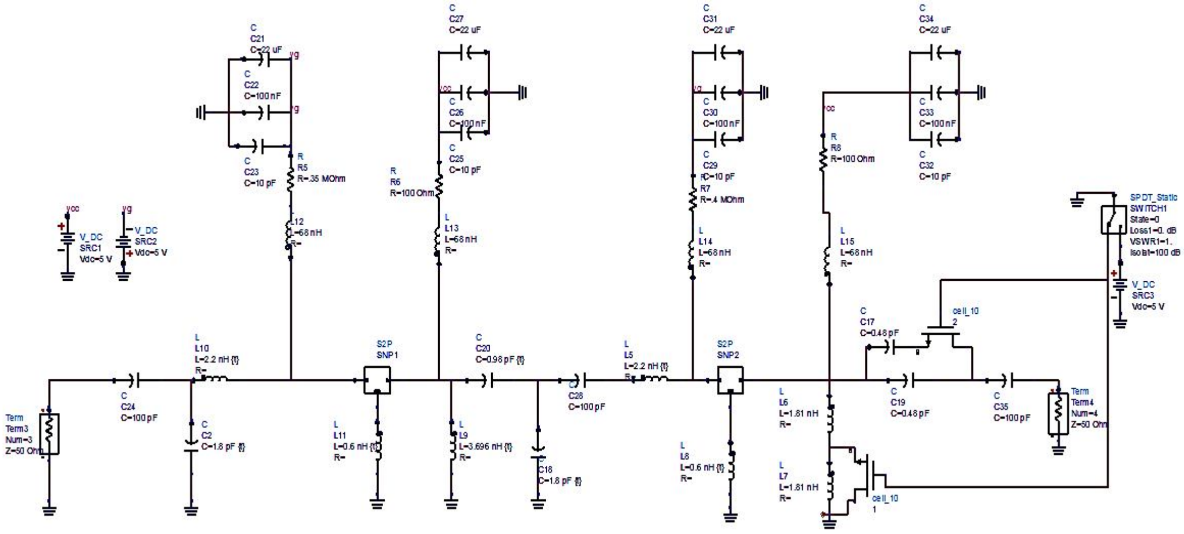


Figure 7 : The proposed final circuit for the LNA.

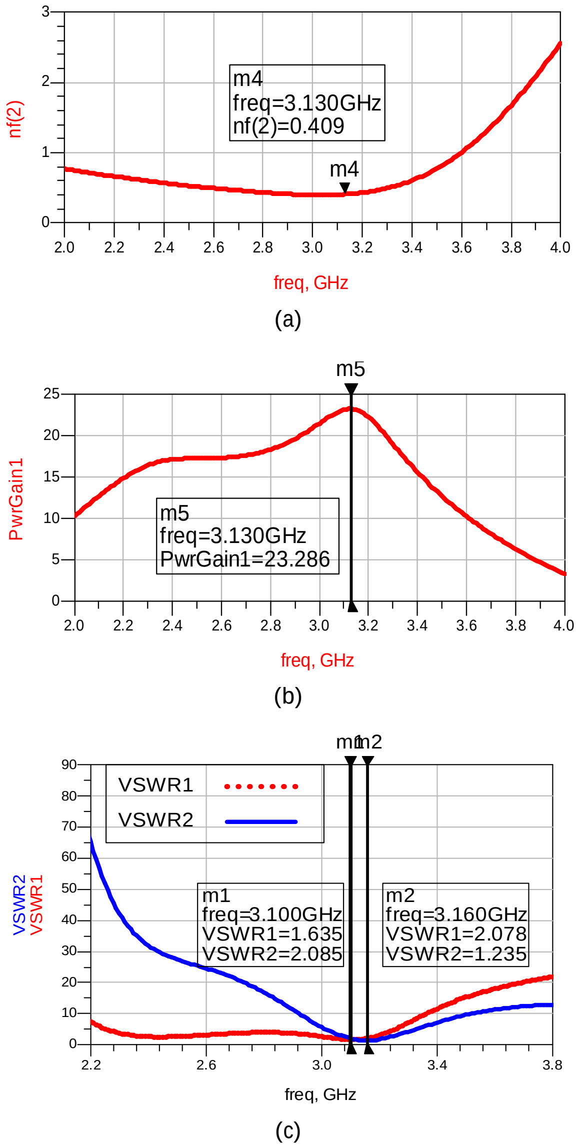
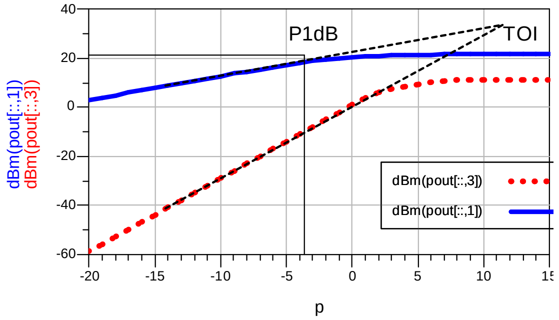


Figure 8 : The simulation results of the proposed LNA in the second frequency. a) Noise figure, b)Gain, c)VSWR.



1st band: P1dB(in)=-3 and P1dB(out)=18.887
2nd band: P1dB(in)=-6 and P1dB(out)=18.966

Figure 9 : The P1dB parameter simulation results for the first and second frequency bands.

4. IMPLEMENTAITION, TESTING AND COMPARISON OF THE RESULTS

After ensuring the correctness of the simulation results, an amplifier prototype is tested and evaluated. Figure 10 shows an overview of the assembled ultra-low-noise amplifier circuit.

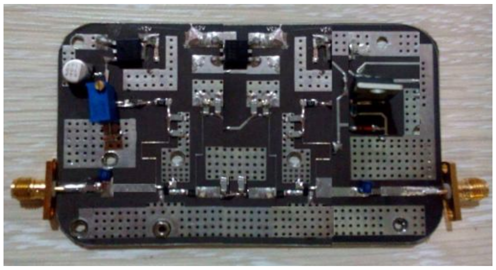


Figure 10 : Assembled LNA.

In Figure 11, the measured values for both the noise figure and the gain in both frequency ranges are compared with the corresponding simulation results. To measure the noise figure, a noise figure analyzer of type Agilent N8975A is used. According to this figure, despite a minimal difference between the measured and the simulated results, a good conformity between them is observed. Regarding the VSWR values, the experimental results agree well with those of the simulation results in both frequency ranges.

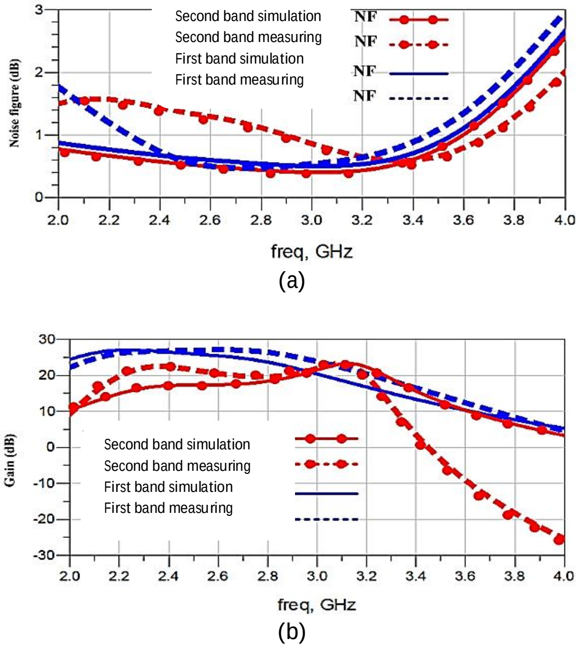


Figure 11 : Comparing the results of the simulations and the measurements for LNA. a) Noise figure, b) Gain.

In Table 1, the results of the proposed low-noise amplifier are compared with those of the other designs in the literature.

TABLE 1
COMPARING THE RESULTS OF THE PROPOSED LNA WITH THE OTHER WORKS

Reference	Parameters			
	Frequency band(GHz)	Gain (dB)	Noise figure (dB)	Input and output VSWR
[2]	2.3	17	0.73	-
[3]	2.9 to 3.1	30	1.25	≤ 2.1
[4]	and 3.2 2.4	21	2.6	≤ 2
This work	2.4 to 2.5, 3.1 to 3.15	23	0.55	≤ 2

5. CONCLUSION

In this paper, a 2-stage ultra-low-noise amplifier with the capability to switch between the first frequency range (2.4GHz to 2.5GHz) and the second frequency range (3.1GHz to 3.15GHz) was designed. This amplifier is compact and low cost. Moreover, both frequency bands were designed with a maximum noise figure 0.55dB, a minimum gain of 23dB and a maximum VSWR equals 2. The advantages of this circuit is to reduce the effects of noise and to increase the "signal to noise level" ratio at the output of the above mentioned communication system.

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BIOGRAPHIES

The Authors’ photographs and biographies not available at the time of publication.

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