International Journal of Computer Applications (0975 – 8887)
Volume 71– No.22, June 2013

An Unconditionally Stable Front End Low Noise Amplifier Design for 2.4 GHz ISM Band

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ABSTRACT

This paper presents the design and simulation of a 2.4 GHz ISM band front end single stage Low Noise Amplifier (LNA) for wireless transceiver system. This amplifier uses AVAGO ATF-54143 transistor which is a low noise and high dynamic range Pseudomorphic high electron mobility transistor. The proposed method is addressed to optimize noise performance and power efficient while maintaining good input and output matching. The design simulation has been performed using Advance Design Simulation (ADS) software. The designed LNA offers minimum noise figure less than 0.38 dB, forward gain (S_{21}) greater than 15 dB, input return loss less than -15 dB and output return loss (S_{22}) less than -10 dB at frequency 2.4 GHz. The Designed LNA can be used in various applications like Bluetooth, WI-FI, RFID, digital cordless telecommunication.

Keywords

Advance Design System, Pseudomorphic high electron mobility transistor, Forward Gain, Low Noise Amplifier, Noise Figure, Stability, Wireless LAN.

1. INTRODUCTION

The fast progress of wireless communications emerges consumer equipment in low-cost and high-performance requirements, especially for portable devices such as handsets, Bluetooth devices. Light weight and long working time under limited battery capacity are major concerns, pushing the circuit designs to low power operations. In addition, some special demands from wireless sensor applications require the circuits working at very low supply voltage conditions.

Among the circuits of wireless communication equipment, the low noise amplifier plays an important role in the overall performance of a RF receiver. It is the first component in any RF receiver. The function of low noise amplifier (LNA) is to amplify low-level signals coming from antenna with as low as possible noise added by circuit, provides enough amplification and minimum degradation of signal-to-noise ratio. Additionally, for large signal levels, the low noise amplifier will amplified the received signal without introducing any noise, hence eliminating channel interference. LNA is located at the first stage of microwave receiver and it has dominant effect on the noise performance of the overall system. In LNA design, it is necessary to compromise its simultaneous requirements for high gain, low noise figure, stability, good input and output matching. The proposed LNA design is carried out with a systematic procedure and simulated by Advanced Design System (ADS) designed by Agilent. In the LNA circuit designing, IEEE 802.11 stand-art is used as references. The low noise amplifier system should meet this standard requirement and should operate properly for wireless applications.

2. SELECTION OF TRANSISTOR

In this design Agilent's ATF-54143 PHEMT has been used [1]. It is a high dynamic range, low noise, Pseudomorphic HEMT (High Electron Mobility Transistor) housed in a surface mount plastic package. Based on its featured performance, ATF-54143 is suitable for low noise amplifier application in cellular and personal communication service (PCS) base stations, low earth orbit(LEO) systems, Bluetooth devices and other systems requiring super low noise figure with good intercept in the 450 MHz to 10 GHz frequency range. Based on S-parameters of the transistor and certain performance requirements, a systematic procedure is developed for the design of LNA. In LNA design, the most important factors are low noise, moderate gain, matching and stability [2-3]. Besides these factors, power consumption and layout design size also need to be considered in designed works.

3. CIRCUIT ANALYSIS USING ADS

To design an amplifier, the input and output matching network are considered to achieve the required stability, noise-figure, and a bandwidth. Super high frequency amplifier is a typical active circuit used to amplify the amplitude of radio frequency signal. Using active or passive biasing, the basic amplifier design is shown in Fig 1.

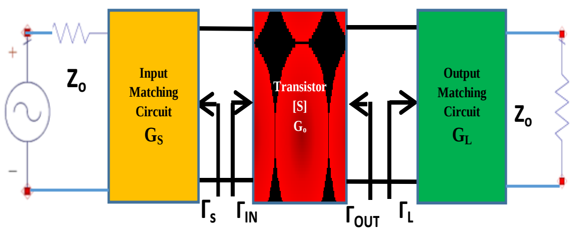

Fig.1. Block diagram of a single stage two port LNA model

Fig.1 shows a process for single-stage amplifier design including input/output matching networks. Analog integrated circuit designers accustomed to working with lower frequency circuits tend to have only a passing familiarity with two staples of traditional RF design as Smith charts and S parameters.

$$\Gamma_s = \frac{Z_s - Z_0}{Z_s + Z_0}, \Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad (1)$$

The relationship between the normalized load impedance, source and load reflection coefficient are given by equation (1). The LNA design formula and equation were referred to [4]. Input/output matching circuit is essential to reduce the unwanted reflection of signal and to improve efficiency of the transmission from RF source to load.

3.1 Power Gain

The power gain is the ratio of power actually delivered to some load and the power actually delivered by source. Three widely used definitions for the power gain of the two-port network are the transducer power gain G_T, the available power gain G_A, and the power gain G_P, also called the operating gain. The two-port network is shown in Fig. 2

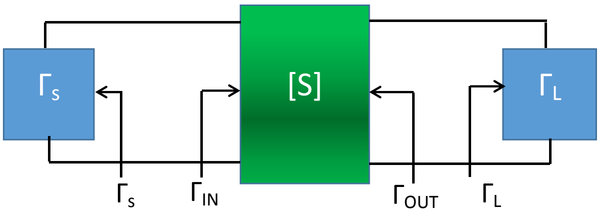

Fig.2. General two-port network

The matrix elements are S_{11}, S_{12}, S_{21} and S_{22} which are referred to as the scattering parameters. Γ_S, Γ_L will lead to a stable input and output impedances.

3.2 Transducer Power Gain

Transducer Power Gain is the ratio of the power delivered to the load (P_L) to the power available from the source (P_{avg}). This depends both on source and load impedance [4-7].

$$G_T = \frac{\text{Output power of network}}{\text{max input power}} = \frac{P_L}{P_{avg}}$$

$$G_T = \frac{1-|\Gamma_s|^2}{|1-S_{11}\Gamma_s|^2} \; |S_{21}|^2 \; \frac{1-|\Gamma_s|^2}{|1-\Gamma_{out}\Gamma_L|} \tag{2}$$

3.3 Available Power Gain

Available power gain is the ratio of the power available from the two-port network (P_{avn}) to the power available from the source (P_{avs}). This assumes conjugate matching of both the source and the load, and depends on source impedance but not load impedance.

$$G_A = \frac{\text{Output power of network}}{\text{max.input power}} = \frac{P_{avn}}{P_{avg}}$$

$$G_A = \frac{1-|\Gamma_s|^2}{|1-S_{11}\Gamma_s|^2} \; |S_{21}|^2 \; \frac{1}{1-|\Gamma_{out}|^2} \tag{3}$$

3.4 Operating Power Gain

Operating power gain is the ratio of power dissipated in the load (P_L) to the power delivered to the input of the two port network (P_{in}). The gain is independent of source impedance.

$$G_P = \frac{\text{Output power of network}}{\text{input power of network}} = \frac{P_L}{P_{in}}$$

$$G_p = \frac{1}{|1-\Gamma_{in}|^2} \; |S_{21}|^2 \; \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|} \tag{4}$$

3.5 Noise Figure

Every device is a source of internally generated noise. The noise entering the device and the internal noise must be added to obtain the total input system noise. If the device is an amplifier, the total system noise power will be amplified the output by the gain of the device. If the output load is matched, this gain will be the available gain. The signal to noise ratio of input port to that of output port is referred as noise figure and is larger than 1 dB [2].

$$F = F_{Min} + \frac{4r_n|\Gamma_s - \Gamma_{opt}|^2}{\left(1-|\Gamma_s|^2\right)|1+\Gamma_{opt}|^2} \tag{5}$$

Transistor noise factor F is a function of Γ_S, F_{min}, R_n, and Γ_{Opt}, where F_{min}, R_n, and Γ_{Opt} are known as the transistor noise parameters and are usually known.

3.6 Simultaneous Conjugate Matching

The transducer, available, and operating power gains become equal to the maximum available gain (G_{max}) when both the generator and the load are conjugate matched to the two-port, i.e. $\Gamma_{in} = \Gamma^*_S$ and $\Gamma_L = \Gamma^*_{out}$.

$$\Gamma^*_s = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L} \tag{6}$$

$$\Gamma^*_L = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1-S_{22}\Gamma_S} \tag{7}$$

4. CIRCUIT ANALYSIS USING ADS

Transistor must be biased at appropriate operating point before used. So that, transistor can works under values required and achieve less power consumption. In this project, passive biasing method is adopted. The component readings are determined with reference from datasheet. By referring datasheet, data of V_{DS} = 3V and I_{DS} = 60mA had be chosen because it is believed that it can give optimum values in gain and noise figure, with V_{GS} = 0.52V, I_{BB} = 2mA, V_{DS} = 3V and I_{DS} = 60mA.

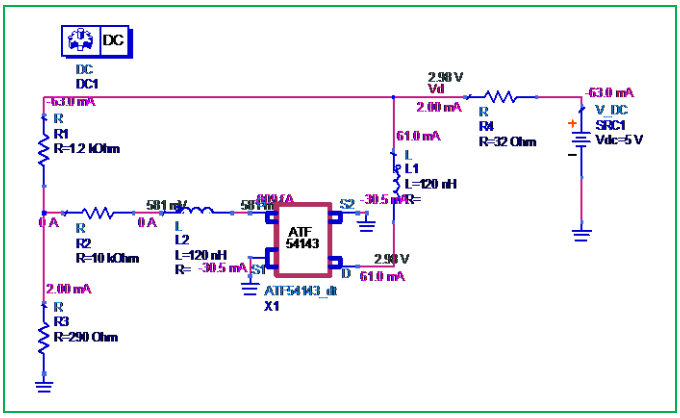

Fig.3. DC Biasing circuit

The Values of resistance R_1, R_3 and R_4 can be calculated as:

$$R_3 = \frac{V_{GS}}{I_{BB}} = 260\,\Omega$$

$$R_4 = \frac{V_{DD} - V_{DS}}{I_{DS} + I_{BB}} = 32.26\ \Omega$$

$$R_1 = \frac{(V_{DS} - V_{GS})\,R_3}{V_{GS}} = 1.24\,k\Omega$$

The R_1, R_3 and R_4 in circuit are slightly adjusted from calculation readings in order to obtain better V_{DS} and I_{DS} reading in the simulation.

4.1 Stability Consideration

The stability of an amplifier or its resistance to oscillate is an important consideration in a design. It can be determined from the S parameters. Oscillation occurs when $|\Gamma_{In}| > 1$ or $|\Gamma_{Out}| > 1$.This is due to the dependence of and on the source and load matching networks. By using S-parameters of ATF-54143 PHEMT for V_{DS} = 3V and I_{DS}= 60 mA, Stability Factor K and Δ can be calculated. For unconditionally stable LNA,

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2\,|S_{12}\,S_{21}|} > 1 \qquad (8)$$

$$|\Delta| = |S_{11}S_{22} - S_{21}S_{12}| < 1 \qquad (9)$$

For the frequency range 2 GHz to 3 GHz, it can be shown that

$K > 1$ and $|\Delta| < 1$

The designed LNA with matching network and DC- biasing network is shown in Fig.4. It has L-type matching networks at input and output which have been designed at 2.4 GHz using Quick Smith software and tuned for the frequency range 2 GHz to 3 GHz. The DC-biasing network has been designed using RF chokes and dc-blocking capacitors.

5. SIMULATION RESULTS

For the proposed LNA shown in Fig.4, simulation results are shown in Fig. 5 to 10. The designed low noise amplifier offers forward gain S_{21} > 15 dB, input return loss S_{11} < - 15 dB, output return loss S_{22} < -10 dB and minimum noise figure NF_{min} < 0.38 dB, for the frequency range of 2 GHz to 3 GHz which are shown in Fig.5, Fig.7, Fig.9 and Fig.10 respectively . The Stability Factor plot is shown in Fig.8. The Stability Factor K > 1 for 2 GHz to 3 GHz which indicates that LNA is unconditionally stable in this frequency range.

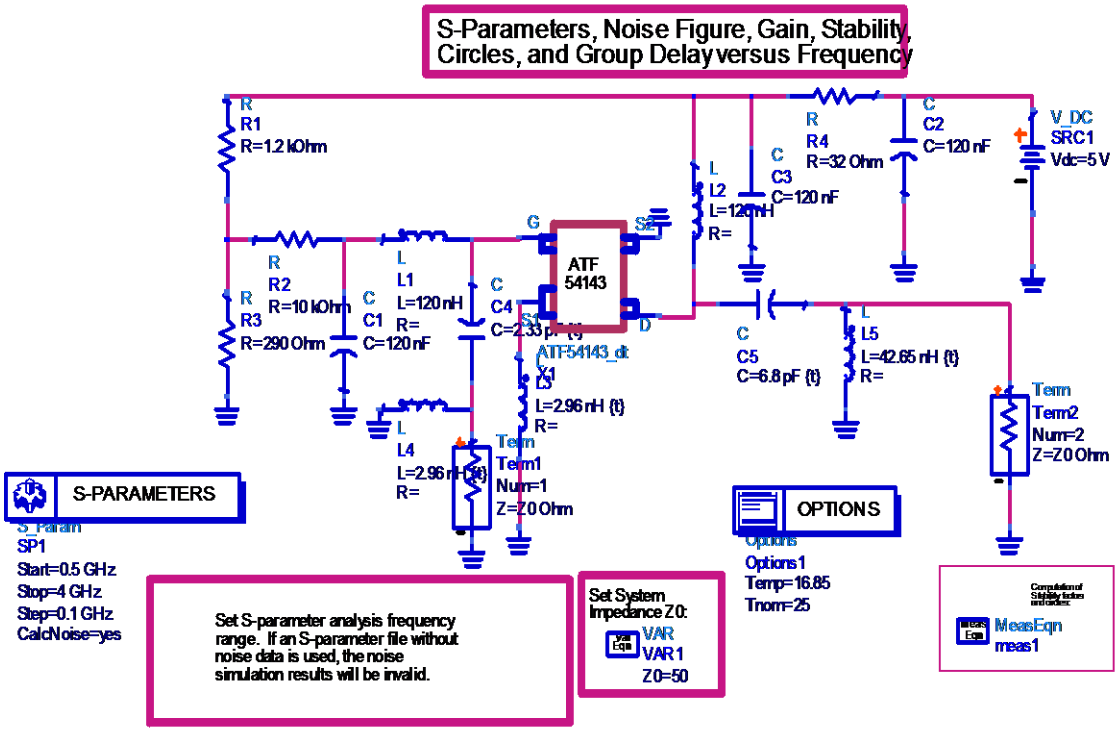

Fig 4: Complete LNA circuit after input and output matching

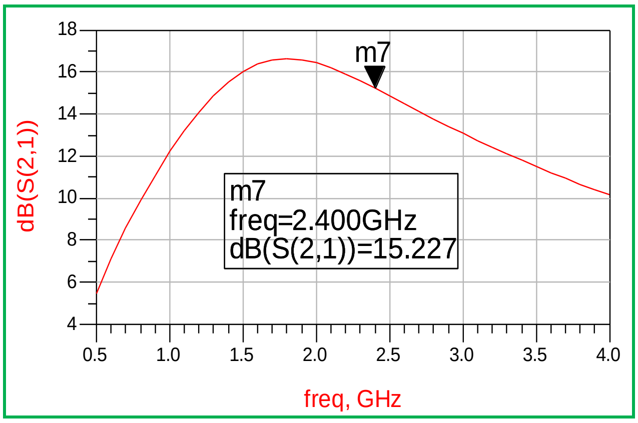

Fig.5. Forward Gain (S_{21})

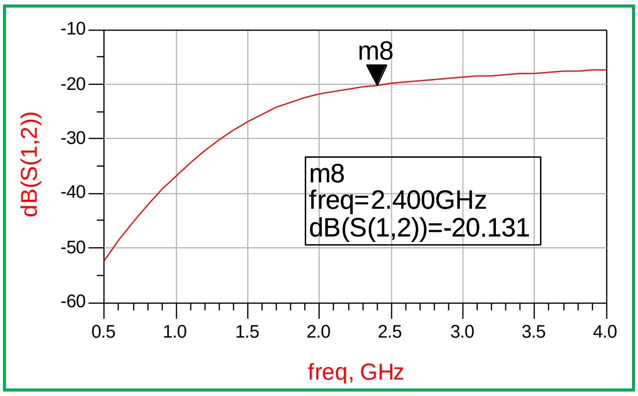

Fig.6. Isolation (S_{12})

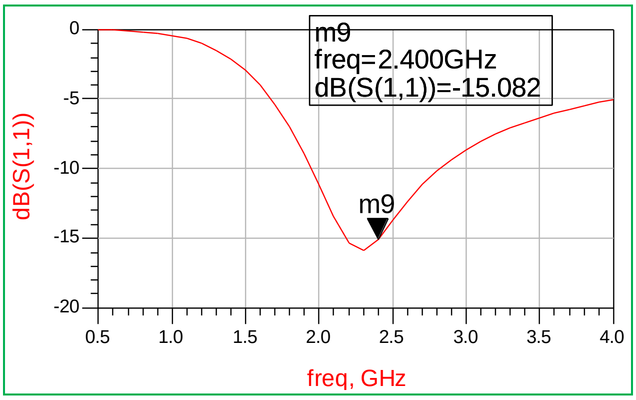

Fig.7. Input Reflection Coefficient (S_{11})

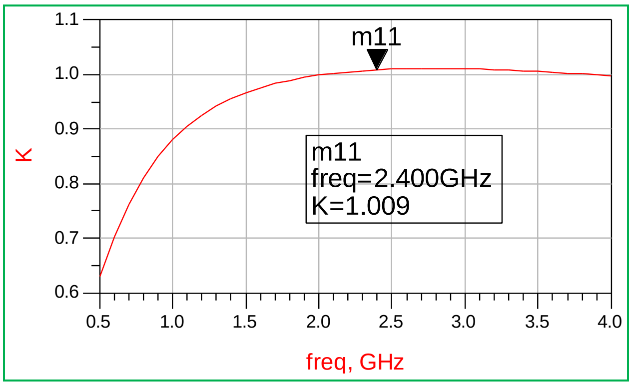

Fig.8. Stability Factor K

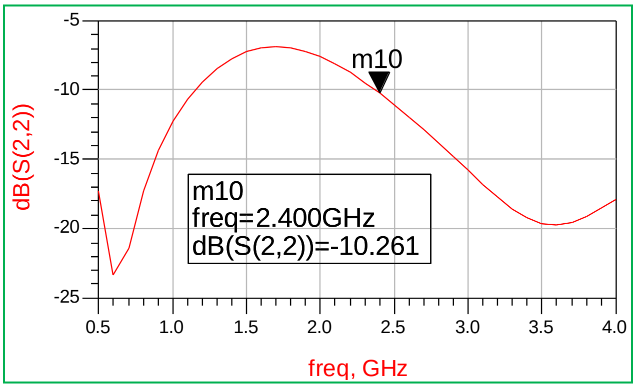

Fig.9. Output Reflection Coefficient (S_{22})

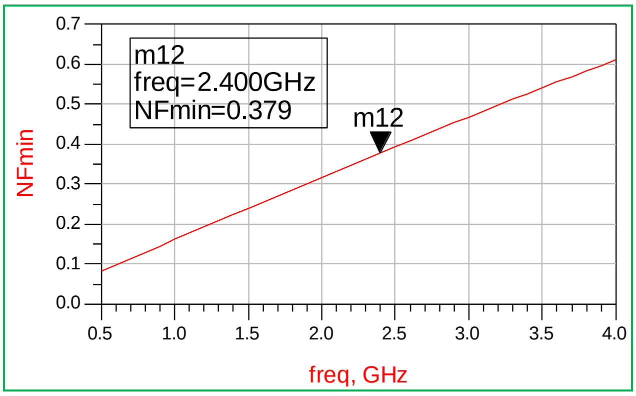

Fig.10. Minimum Noise Figure

Table 1. LNA performance summary with comparisons of published works

	[8]	[9]	[10]	Our Work
Frequency (GHz)	2.40	2.40	2.45	2.40
Supply Voltage (V)	1.2	1.5	0.9	3.0
Gain (dB)	13	21.4	15.3	15.2
Noise Figure (dB)	3.6	5.2	3.34	0.38
Input Reflection (dB)	-13.1	-19.0	-16.5	-15.1
Output Reflection (dB)	-11.5	--	--	-10.2
Isolation(dB)	--	--	--	-20.1

6. CONCLUSIONS

A 2.4 GHz single stage low noise amplifier is design and simulated. The input insertion loss S_{11} is -15 dB and the output insertion loss S_{22} is -10 dB. The better performance in NF of the amplifier is achieved. The synthesized LNA guided by the proposed methodology achieves up to 15 dB power gain with a suppressed NF as low as 0.38 dB and provides good input and output matching over 2 GHz to 3 GHz. A 2.4 GHz single stage low noise amplifier is used in IEEE 802.11b and 802.11g standards for wireless local area network (WLAN).Most popular application is Bluetooth. We can also use the designed LNA for the purpose of RF Transceiver systems [5-6, 11]. This can also suitable for the switching circuits.

7. ACKNOWLEDGMENTS

The authors would like to thank Dr. Priyanka Jain, Assistant Professor, Department of Electronics & Communication, Delhi Technological University, New Delhi for her support and encouragement.

8. REFERENCES

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