High-Efficiency Low Noise Amplifier Design for Enhanced Receiver Sensitivity in S- and C- band Frequencies

C. R. Ravinthiran

Srilanka Institute of Advanced Technological Education (SLIATE), Advanced Technological Institute, Jaffna
Email: *crravi2002[at]yahoo.com*

Abstract: ***This research paper focuses on the design and implementation of a Low Noise Amplifier (LNA) with the objective of achieving a gain greater than 28 dB, a noise figure less than 0.4 dB and a receiver sensitivity better than -123 dBm in the S and C band ranges (between 2 GHz to 8 GHz frequency range).The amplifier is intended to operate at a low voltage supply of 1.8V, making it suitable for power-constrained applications. The paper presents a comprehensive analysis of the literature, discusses the methodology employed in the design, presents simulation results using Multisim-14.3 software and testing and experimental results of prototype circuit and concludes with a discussion of the findings and potential future work.***

Keywords: Low Noise Amplifier (LNA), Gain, Noise Figure, Receiver Sensitivity, Voltage Supply

1. Introduction

Nowadays wireless technology in communication keeps changing our everyday life because in this communication, electrical conductors or cables are not necessary to transfer the information over a very long distance. Therefore, these wireless communications are used in many applications from weather observation to guidance systems and law enforcement. Radar (Radio Detection and Ranging System) is one of the instruments used in wireless communication in the space to detects and locates of objects which are in far away from the radar system. Currently, the radar has been widened to numerous civilian applications including traffic control, remote sensing, velocity estimation, imaging, car cruise control and collision avoidance.

In RADAR system, a low noise amplifier (LNA) is placed at the front-end of radio receiver in order to provide first stage of amplification in the receiver, prior to the signal being down converted. Therefore, it plays vital importance in receiver design to amplify extremely low power signals without adding noise in the manner to preserve the required signal to noise ratio (S/N) of the system at extremely low power levels whereas for high signal levels, the LNA amplifies the received signal without introducing any distortions, hence eliminating channel interference.

In today's digital communications, complexity of the signals is high. Therefore, additional design consideration in LNA design procedure is to be addressed in terms of power gain, noise, sensitivity and stability. In addition to that wireless communications are very lossy, so signals travelling from far away commonly suffer from a lot of degradation. Hence LNA is to be located very close to the antenna because the first component after the antenna for reception is the LNA. Therefore, LNA used in the radar system should be designed with the combination of low noise, high gain, high sensitivity and stability over the entire range of operating frequency range for an effective and efficient reception.

Communication devices in the world are currently used in many areas for the transmitting and reception of the information between two or more different locations which are situated far away, through space wave, sky way or microwave links through satellite. In the aerospace research areas, unmanned aerial vehicle and surveillance of the sky or space, radar communications are widely used all over the world. So further studies in the area of radar communication devices are carried out to improve their performance.

The main objective of the research is to study the efficient detection of extremely low power signal ***with high Gain, Low Noise and high sensitivity*** in Radar System in order to detect the very far objects or signals from the Radar Station clearly without any ambiguity within the frequency range between 2 GHz to 8 GHz. In here, signals received by the radar antenna are always very weak in power for very far objects. So, the receiver in this system should be very sensitive to receive the greatest range of frequencies being transmitted by the transmitter in the radar system without introducing excessive noise.

Beside to the smallest possible signals' reception, the largest power signals are also possible to receive by the same antenna. In this situation the receiver should establish an upper power level limit that can be handled by the system while preserving signal quality. Then the dynamic range of the receiver between the highest possible received signal level to the smallest possible received signal level defines the quality of receiver chain.

2. Literature Review

The research works carried out in Radar Systems until now will be collected and studied as follows:

1) In the publication of "Design of High Frequency and Highly Sensitive Low Noise Amplifier" by A.O. Fadamiro and E.O. Ogunti in the Asian Journal of Engineering and Technology (ISSN 2321 -2462) Volume-1 Issue-2, June 2013, the LNA designed for a frequency range of 1.80 GHz to 2.5 GHz using BFR193

BJT transistor satisfies the gain of the amplifier as 16.6 dB with the noise factor of < 1dB and the receiver sensitivity of -123.95 dBm

2) In the publication of "Radar theoretical study: minimum detection range and maximum signal to noise ratio (SNR) equation by using MATLAB simulation program" by Sulaiman H.M Al Sadoon and Badal H. Elias in American Journal of Modern Physics 2013: 2(4) – 234 – 241 in online, July 20, 2013, the LNA designed for minimum detection range verses maximum signal to noise ratio for several choice parameters like antenna gain, peak power percent, radar cross section, coherently pulses and duty cycle by using MATLAB simulation program to make for easier evaluation, faster and more convenient selection of radar system.
3) In the publication of "Design and Realization of an S-Band Microwave Low-Noise Amplifier for Wireless RF Subsystems" by Ardavan Rahimian and Davood Momeni Pakdehi in the ResearchGate article, September, 2014, the reliable microstrip LNA is developed and realized to operate in wireless RF system within S-band (3 GHz frequency range) with high performance.
4) In the study of "Design of a Low-Noise Amplifier for Radar Application in the 5 GHz Frequency Band" by Javier Alvaro Rivera Suaña, June 2017, the LNA designed to operate in 5 GHz an unconditionally stable frequency range by using ATF-34143 transistor in two stages satisfies the maximum gain of the amplifier as 12.425 dB with the noise figure of 1.35 dB.
5) In the publication of "Design Concept of Low Noise Amplifier for Radio Frequency Receivers" by Sumathi Manickam in the ResearchGate article, November, 2018, an innovative single-stage design structure of LNA is introduced to achieve high performance as maximum gain of 28.754 dB and low noise factor of 2.709 at 2.4 GHz frequency range under low operating voltage of 1.8 V.
6) In the publication of "Design of Low Noise Amplifier for Optimum Matching between Noise Figure and Power Gain" by S. Jarallah Al-Jawadi and A. A. Ismail in International Journal of Computer Applications (0975 – 8887) Volume 178 – No. 44, August 2019, a single stage LNA circuit designed with high gain and low noise using PHEMT transistor at frequency 2.4 GHz satisfies the forward gain as 16.29 dB with the noise figure of 0.382 dB and good stability at this frequency.
7) In the publication of "Simulation and Design of Low Noise Amplifier" by N. NazeeyaAnjum, M.Akshaiya and G.Alagulakshmi in International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-9, Issue-1, November 2019, it proposesthe LNA designed with ATF-21170 to operate in 2.4 GHz with a maximum Gain of 18.453 dB and minimum Noise Factor 1.346.

From the above literature survey, factors influencing the engineering trade-offs in low power detection by LNA are listed for Gain, noise figure/noise factor, stability, receiver sensitivity and supply voltage. These factors will be considered to improve the performance of LNA design further for low cost at low voltage supply in the Radar System. So, in this research project, the target of designing the LNA with the gain > 28 dB, Noise figure < 0.4 dB and receiver sensitivity < -123 dBm at low voltage supply of 1.8V is considered as the objective of the research.

Methodology of Low Noise Amlifier Circuit Design and Simulation

The most important performance parameters of an LNA are the gain and the noise factor (F) or noise figure (NF). The level of the unavoidable noise generated by any two-port network is specified by the noise figure which is a comparison of the SNR at the input port of the network to the SNR at the output port as shown in Fig. 1.

$$\text{Noise Figure} = \frac{\left(\frac{Signal}{Noise}\right)\ at\ input}{\left(\frac{Signal}{Noise}\right)\ at\ output}$$

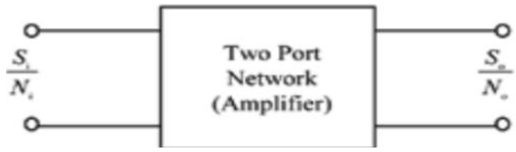


Figure 1: A two port network

The noise figure of two-port amplifier can also be expressed as:

$$F = F_{min} + \frac{R_N}{G_S}\left|Y_s - Y_{opt}\right|^2$$

Where Y_S = Source admittance presented to transistor
Y_{opt} = Optimum source admittance to get minimum noise figure
F_{min}= Minimum noise figure of transistor
R_N = Equivalent noise resistance of transistor
G_S= Real part of source admittance.
Thus, in order to achieve the minimum noise in an LNA design, it must be applied that

$$Y_s = Y_{opt}$$

Then the noise figure of cascaded amplifiers receiver system as shown in Fig. 2, according to Friiss' formula [6], is given by equation:

$$NF_{sys} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + .. + \frac{NF_n - 1}{G_1 G_2 \ldots G_{n-1}} \quad (1)$$

Where Gn ,i = 1, 2, 3, . . . are the gain parameters in each stages of the receiver. The noise figure (NF) of a system is simply expressed in decibel, that is:

$$NF = 10*log_{10} F \quad (2)$$

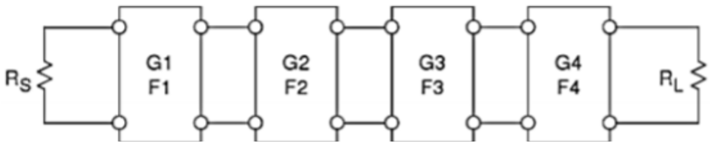


Figure 2: Cascaded Transistor Amplifier

Equation (1) shows that the first stage of the receiver will be the most significant contributor to the overall NF of the system. This means that the LNA must be designed for a minimum NF as well as a high gain so that the amplitude of the signal is maximized while adding as minimal amount of noise as possible. The quest for the simultaneous attainment of a high gain and a low NF in the design of a LNA poses a dilemma for the designer, as these are conflicting and mutually exclusive performance requirements. Hence, a trade-off and subsequent compromise between these two performance parameters is necessary in the design of LNA.

Further, sensitivity of LNA is normally taken as minimum input signal (S_{min}) required to produce a specified output signal having a specified signal-to-noise (S/N) ratio and is defined as the minimum signal-to-noise ratio times the mean noise power, see equation [2].

$S_{min} = (S/N)_{min}\, kT_0\, B(NF)$ receiver sensitivity [2]
where: $(S/N)_{min}$ = Minimum signal-to-noise ratio needed to process (vice just detect) a signal
NF = Noise figure/factor
k = Boltzmann's Constant = 1.38 x $10^{(-23)}$ J/K (Joule/Kelvin)
T_o = Absolute temperature of the receiver input (Kelvin) = 290K
B = Receiver Bandwidth (Hz)

The acceptable minimum Signal-to-Noise ratio (or think of it as Signal above Noise) for a receiver depends on the intended use of the receiver. For instance, a receiver that had to detect a single radar pulse would probably need a higher minimum S/N than a receiver that could integrate a large number of radar pulses (increasing the total signal energy) for detection with the same probability of false alarms.

Gain (Conjugative Matching)
To get the maximum gain between the Source and Load impedances of the transistor, it must be realized when the Source and Load reflection coefficients provide a conjugate matching on them. Thus, the maximum power transfer from the input matching network to the transistor will occur when reflection coefficient at the input of transistor (Γ_{in}) is equal to the reflection coefficient at the source terminal ($\Gamma_S{}^*$).

$$\Gamma_{in} = \Gamma_S{}^*$$

And the maximum power transfer from the transistor to the output matching network will occur when reflection coefficient at the output of transistor (Γ_{out}) is equal to the reflection coefficient at the load terminal ($\Gamma_L{}^*$).

$$\Gamma_{out} = \Gamma_L{}^*$$

With assumptions for lossless matching networks, the overall transducer gain for maximum gain will be given by

$$G_{Tmax} = \frac{1}{1-|\Gamma_S|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2}$$

And, the necessary equations to get the maximum gain in a bilateral case is as follows:

$$\Gamma_S^* = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L}$$

$$\Gamma_L^* = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1-S_{11}\Gamma_S}$$

where S_{11} , S_{12}, S_{21} and S_{22} are the stability parameter of two port network in Ω.

Then the solution of Γ_S and Γ_L are given as

$$\Gamma_S = \frac{B_1 \pm \sqrt{B_1^2 - 4|C_1|^2}}{2C_1}$$

$$\Gamma_L = \frac{B_2 \pm \sqrt{B_2^2 - 4|C_2|^2}}{2C_2}$$

where variables B_1, C_1, B_2 and C_2 are defined as

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2$$

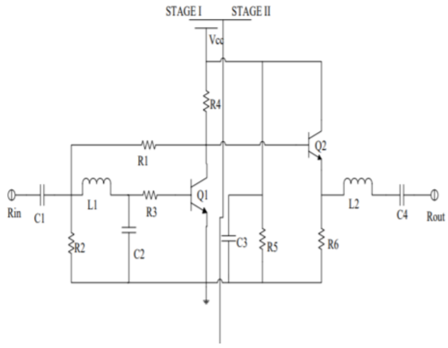
$$B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2$$

$$C_1 = S_{11} - \Delta S_{22}^*$$

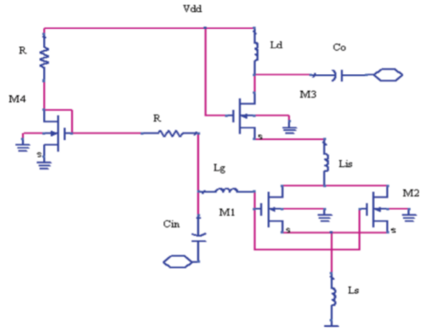
$$C_2 = S_{22} - \Delta S_{11}^*$$

where $\Delta = S_{11}.S_{22} - S_{12}.S_{21}$

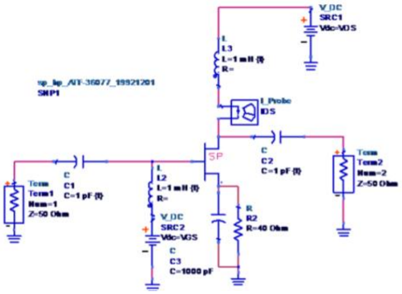
To compromise the trade-off between these two performance parameters, initially two stage and single stage amplifier circuits as shown in Fig. 3 will be selected with input and output matching network from the literature review [1] and they will be analyzed by simulation using CAD tool under the direct current and alternating current conditions (Fig. 4) to confirm the functionality of circuit performance in terms of measuring the gain, noise sensitivity, signal to noise ratio and stability factor over the range of operating frequency from 2.0 GHz to 5 GHz which range is relatively economical and potential for system on-chip integration. In this frequency range, circuit parameters will be adjusted according to the frequencies used in practice in order to obtain design goals of noise figure (= Signal to Noise ratio at the input to output in dB) of < 0.4 dB under unconditionally stable with the gain > 30 dB and optimum receiver sensitivity < -123 dBm. Thereafter each LNA circuit of given frequency will be implemented using discrete passive components (lumped element model) and using microstrip transmission lines (distributed element model) and simulated by using CAD tool.



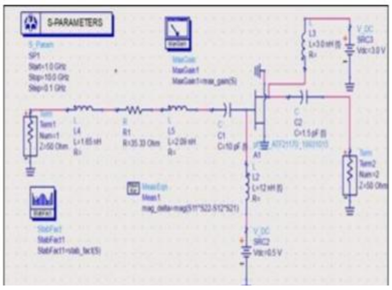
(a) Two stage BJT LNA design



(b) Two stage MOSFET LNA design

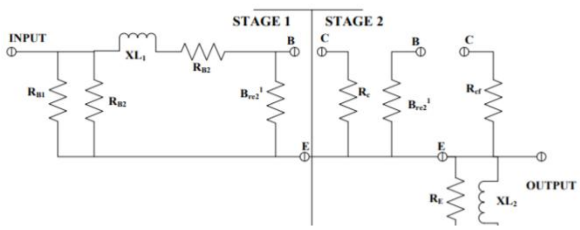


(c) Single stage FET LNA design

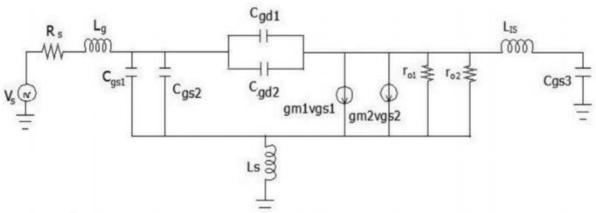


(d) Single stage MOSFET LNA design

Figure 3: LNA Design



(a) AC equivalent circuit of for two stage BJT LNA design



(b) AC equivalent circuit of for two stage MOSFET LNA design

Figure 4: AC Equivalent Circuit for LNA Design

Selection of Transistors

HEMTs are currently used to replace conventional MOSFET in many applications that require low noise figures and high gain at high frequencies. Though MOSFET and HEMT have the same functional structure, they contain different layers in order to optimize and extend their performance. In MOSFET, charge transport occurs in a highly doped material which results in high energy losses as a result of scattering. In HEMT, the conduction channel is a two-dimensional electron gas (2DEG) bounded at the interface between two materials with different band gap instead of a three-dimensional structure as in the conventional FETs. The 2DEG occurs in a lightly doped material and therefore it has a reduced Coulomb scattering and as result a high mobility device structure [2].

For an example, in this design, ATF-36163 PHEMT may be used based on its featured performance because it is suitable for low noise amplifier applications. Then three parts of design parameters such as d.c. biasing of transistor, matching network of input and output ports and stabilization of operation of LNA will be analyzed as follows.

D.C. Biasing

Each transistor in this design has its minimum noise figure and also the maximum available gain after adding the matching circuit and biasing circuit. The ATF-36163 has maximum saturated drain current as 100mA. The biasing point should be 10% of the saturated drain current I_{dss} to avoid any increase in the noise. The drain-source voltage V_{DS} = 2.5 V
at I_{DS} = 10mA as shown in fig. 5.

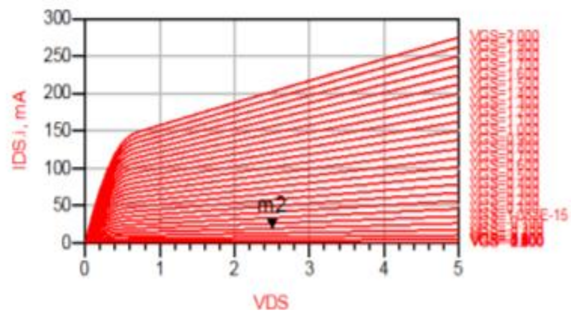


Figure 5: Drain Characteristic of ATF-36163 at Room Temperature

Impedance Matching Circuit

Impedance matching network is the most important circuit in the LNA. If the generator impedance and the load impedance are matched in the amplifier circuit, maximum power will be delivered to the load and as a result the power loss minimised. The impedance matching of the sensitive components such as antenna, low noise amplifier and mixer may improve the signal to noise ratio of whole system. There are two methods to design a matching network such as the analytic solution method and smith chart method. In my analysis ADS smith chat method is adopted in designing the LNA as shown in Fig. 6.

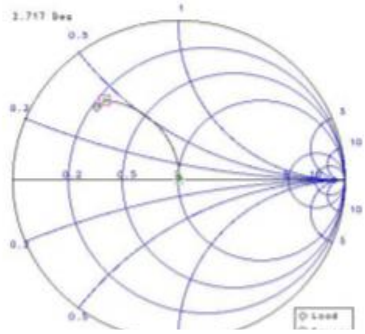


Figure 6: ADS Smith Chart for designing matching network

Stability Analysis

For a two port two stage amplifier circuit shown in Fig. 7, the amplifier is unconditionally stable at a given frequency if the following inequalities must be satisfied as specified in [6]

$$|\Gamma_{in}| = S_{11} + \frac{S_{21}S_{12}\Gamma_L}{1-S_{22}\Gamma_L} < 1 \quad (1)$$

$$|\Gamma_{out}| = S_{22} + \frac{S_{21}S_{12}\Gamma_L}{1-S_{11}\Gamma_L} < 1 \quad (2)$$

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{21}S_{12}|} \quad (3)$$

$$|\Delta| = S_{11}S_{22} - S_{21}S_{12} \quad (4)$$

Where:Δ is the determinant of the S-parameter matrix

S_{11} , S_{12}, S_{21}, S_{22} are the stability parameter of two port network in Ω.

In the above stability equations, if K-factor is greater than 1, then the amplifier is unconditionally stable at a given frequency. Otherwise, the design is not stable.

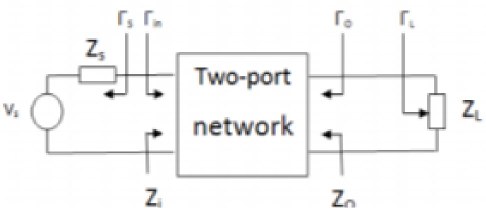


Figure 7: Stability of two port network

Radio frequency Filter

The radio frequency filter which is referred as RF choke, provides high impedance but at the same time a very low resistance. Micro-strip band stop filter is used to make the choke due to its stability to maintain a good RF isolation at higher frequency circuits. The radial stub and the butterfly stub are the most common methods to design the RF chock. The butterfly stub can provide broader bandwidth while the radial stub provides a narrow bandwidth. In this LNA design, a radial stub RF choke is used as a narrow bandwidth is needed for this application.

Calculation of Designed Low Noise Amplifier Circuit

As per the existing transistors in the current market, ATF-36077 is selected because it has an ultra-low noise GaAs Pseudomorph High Electron Mobility Transistor (pHEMT) with the Gain of 28 - 31 dB and Noise factor of 0.3 dB at 2 - 4 GHz frequency range of operation. The ATF-36077 has very low noise resistance, reducing the sensitivity of noise performance to variations in input impedance match, making the design of broadband low noise amplifiers much easier. The premium sensitivity of the ATF-36077 makes this device the ideal choice for use in the first stage of extremely low noise cascades. To increase the gain of this amplifier, cascading of another transistor ATF-36163 which has low noise-resistance and ideal for the use in the 2nd or 3rd stage of low noise cascades. ATF-36163 provides maximum gain of 17 dB with Noise factor of 0.6 dB at 4 GHz of operating frequency. These two transistors are able to operate at the supply voltage of 1.5V as expected in the research objective.

Further, stability parameters for ATF-36077 and ATF-36163 were obtained from their datasheets as follows:

(1) For ATF-36077 at 4 GHz frequency with Z_O = 50Ω, V_{DS} = 1.5V, I_D =10mA as

$S_{11} = 0.97\angle{-33°}$; $S_{21} = 4.904\angle{147°}$; $S_{12} = 0.03\angle{66°}$; $S_{22} = 0.59\angle{-28°}$

Then maximum gain was calculated as G_{max} = 31.75 dB.

(2) For ATF-36163 at 4 GHz frequency with Z_O = 50Ω, V_{DS} = 1.5V, I_D =10mA as

$S_{11} = 0.87\angle{-83°}$; $S_{21} = 4.12\angle{97°}$; $S_{12} = 0.10\angle{23°}$; $S_{22} = 0.40\angle{-71°}$

Then maximum gain was calculated as G_{max} = 16.38 dB.

By cascading above two transistors, possible maximum gain can be achievable at 4GHz frequency as (31.75 + 16.38) = 48.13 dB. This means that overall gain of cascaded circuit will be 48 dB in the frequency range of 2 GHz to 8 GHz.

In cascading situation, noise figure of overall system as calculated is 0.321 dB when ATF-36077 is at front stage of the cascaded low noise amplifier.

Further stability analysis was carried out in the selected front end transistor, ATF-36077 at the frequency of 4 GHz, $\Delta = 0.521\angle{268.9°}$; K = 0.323 <1 ; $|\Gamma_{in}|$ = 1.0001 > 1 and $|\Gamma_{out}|$ = 0.869 < 1.

In this transistor, K is less than 1 for the operating frequency between 2 GHz to 8 GHz. This provides potentially unstable condition for the low noise amplifier circuit. Hence the transistor would be stabilized. To do that, impedance matching network has been implemented using the Z – Y plot available in the ADS smith chart as follows:

(a) Design of input matching network

At maximum stable gain condition, impedance values of input of LNA circuit (at ATF-36077 input) has been obtained from the reflection coefficient as Z_{in} = (11.27 + j150.44) Ω to match the source impedance to 50 Ω. By using this input impedance, L_1 and C_1 can be calculated from Z_{input} as L_1 = 0.18 nH at the quality factor, Q = 22.5 and C_1 = 0.3 pF.

This input impedance of the LNA is matched by connecting series capacitor and parallel inductor at the input source. This value of capacitor and inductor are obtained by using Smith Chart as 0.19 pF and 7.18 nH respectively.

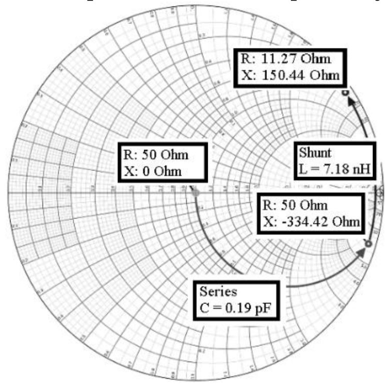


Figure 8: Smith's Chart Plot for Input Matching Network of LNA

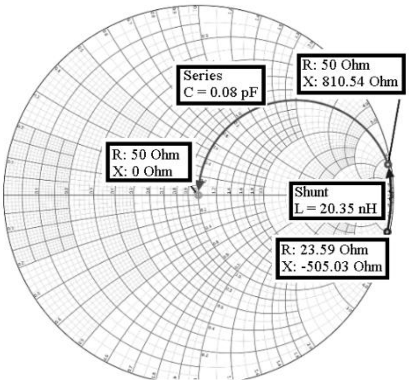


Figure 9: Smith's Chart Plot for Output Matching Network of LNA

(b) Design of output matching network

Output load of 50 Ω is matched to the output impedance of the LNA at ATF-36163, which can be obtained from the reflection coefficient at maximum stable gain condition as Z_{out} = (23.59 + j505.03) Ω. This output impedance of the LNA is matched by connecting series capacitor and parallel inductor at the output of LNA to the 50 Ω load. This value of capacitor and inductor are obtained by using Simith Chart as 0.08 pF and 20.35 nH.

In addition to above analysis, Noise Figure and Sensitivity analysis are performed as follows:

- Noise Figure of ATF-36077 = 0.3 dB whereas Noise Figure of ATF-36163 = 0.57 dB.

When both transistors are cascaded, System Noise Figure is 0.321 dB as expected in this research objective.

- In case of sensitivity, ATF-36077 provides minimum operational sensitivity (MOS) as -116.65 dBm whereas ATF-36163 provides minimum operational sensitivity (MOS) as -101.31 dBm.

This sensitivity also for each transistor satisfies the research objectives.

Designed Low Noise Amplifier Circuit

The complete circuit for LNA designed is used as shown below with the designed parameters of input and output matching circuit.

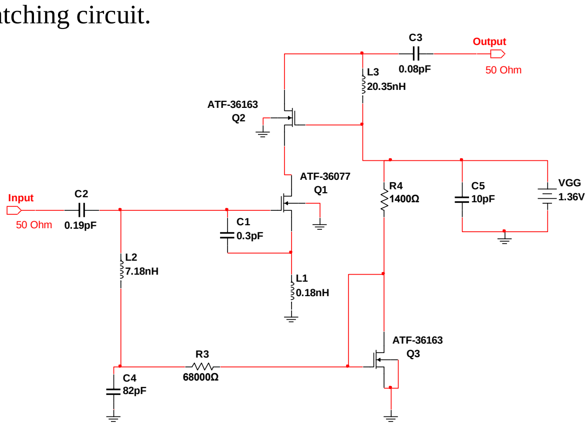


Figure 10: Completely Designed Low Noise Amplifier Circuit

The designed circuit was initially simulated with multisim software to see their performance in respect to maximum gain, minimum noise figure and minimum sensitivity. Further, above circuit was costructed with the available facilities and tested in Ccommunication Laboratory.

Testing and Results:

The above designed circuit was implemented in the Multisim 14.3 software for simulation studies. In the simulation, RF input signal was applied with the voltage of 0.01 mV r.m.s., the carrier frequencies varied between 2 to 8 GHz in the step of 0.25 GHz increase and the signal bandwidth of 10 MHz with different thermal noise input and the voltage and current readings at the input and output were taken. From those reading, power gain in dB was calculated by using the following method.

$$Current\ Gain = \frac{Output\ Current}{Input\ Current}$$

$$Voltage\ Gain = \frac{Output\ Voltage}{Input\ Voltage}$$

$$Power\ Gain = 10\log_{10}(Current\ Gain\ \times Voltage\ Gain) \quad (10)$$

The calculated power gain for different carrier frequency, ranges between 2 GHz to 8 GHz were plotted without noise and for different noise figure as follows.

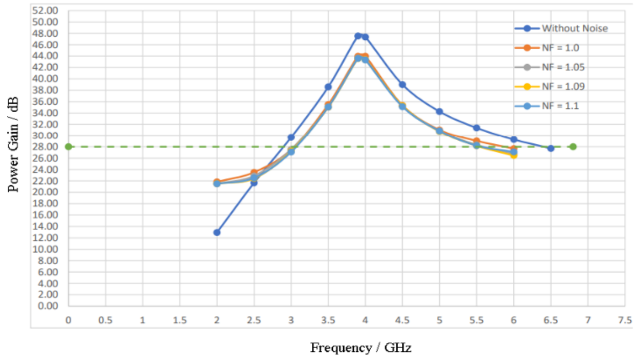
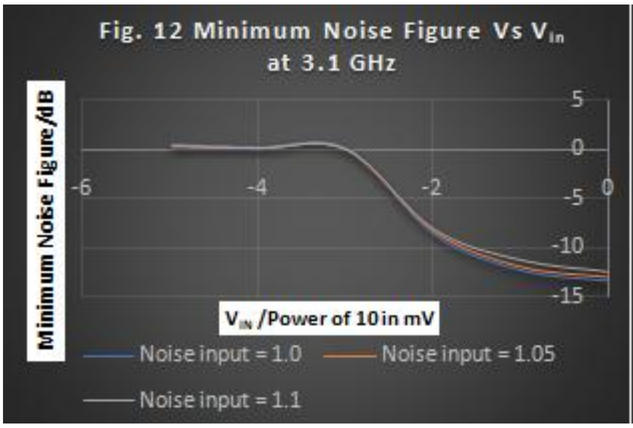
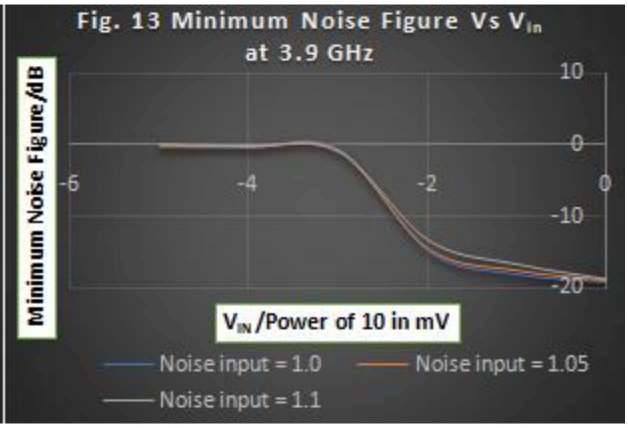


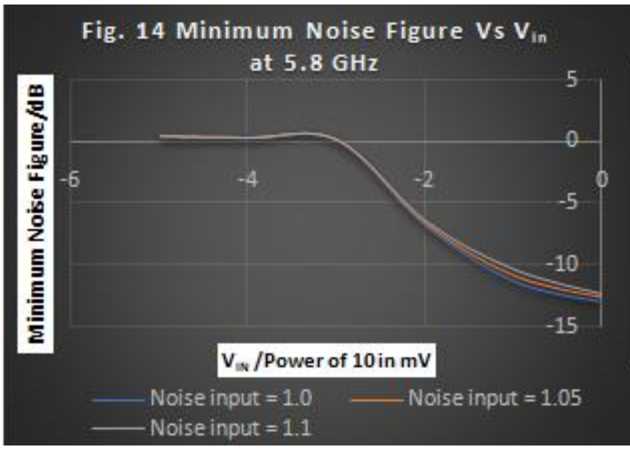
Figure 11: Power Gain in dB Vs Frequency in GHz plots

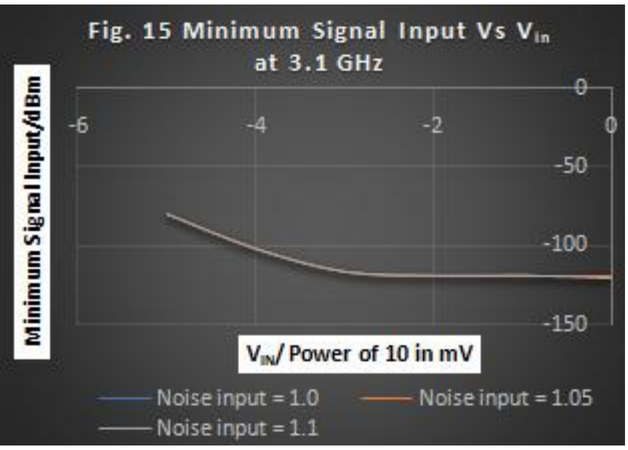
As per simulation result, power gain of Low Noise amplifier within the frequency band of 3.1 GHz to 5.8 GHz is above 28 dB with noise figure up to 0.394 dB or noise factor of 1.095. Then the possible signal detection bandwidth is 2.7 GHz.

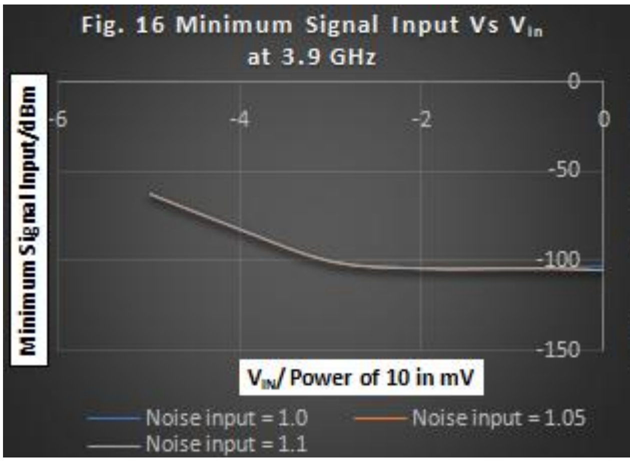
Further, simulation test for minimum noise figure of LNA and needed minimum input signal of LNA for detecting the object without ambiguity were carried out with the circuit in Fig. 8 at 3.1 GHz, 3.9 GHz and 5.8 GHz carrier frequencies with input noise factor of 1.0, 1.05 and 1.1. From above tests following plots as shown in Fig. 12, Fig. 13, Fig. 14, Fig. 15, Fig. 16 and Fig. 17 were obtained respectively. These plots indicate minimum noise figure of LNA for gain greater than 28 dB is below 0.394 dB as expected from our research object (< 0.4 dB) and the minimum input signal power needed for good detection of signal is below -119.93 dBm as expected from our research object (< -123 dBm).

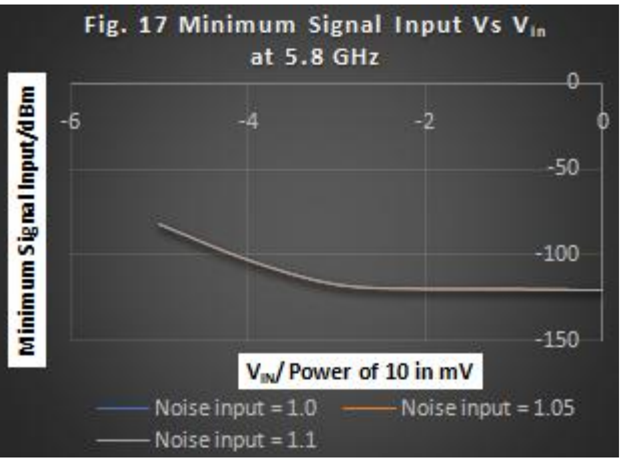












The above circuit in Fig. 10 was implemented with the necessary component in Vero Circuit Board as prototype model and tested with network analyzer as in fig. 18 shown below in the Communication Laboratory.

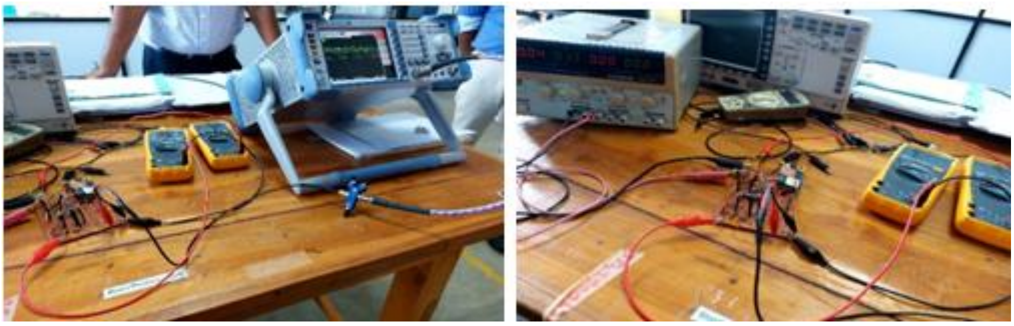
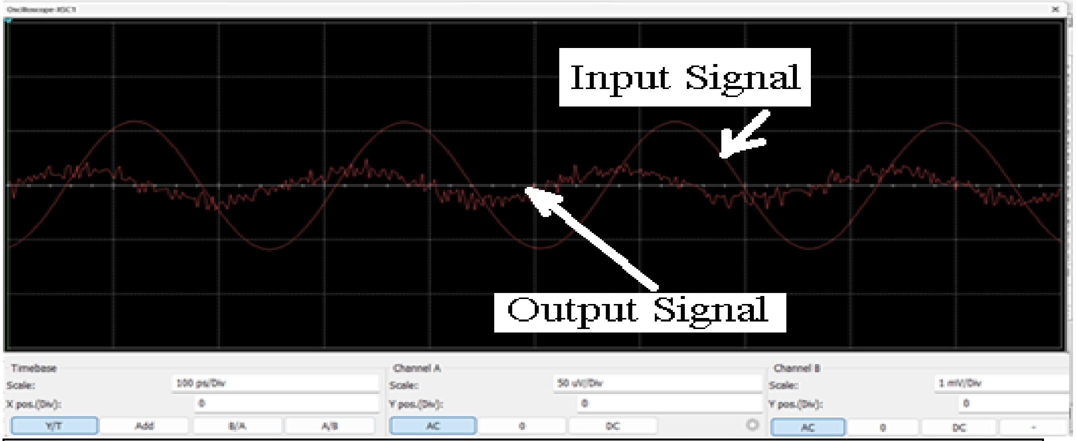


Figure 18: Circuit connected with Network analyzer

Here input and output signals of the LNA circuit were observed in the oscilloscope as shown in Fig. 19. Further, as in simulation, input and output voltage and current readings were taken at 0.01mV r.m.s. input of RF signal for different

International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

input carrier frequency ranges between 2 to 8 GHz in the step of 0.25 GHz at the signal bandwidth of 10 MHz without noise and for different input noise figure as shown in Fig. 20 below.



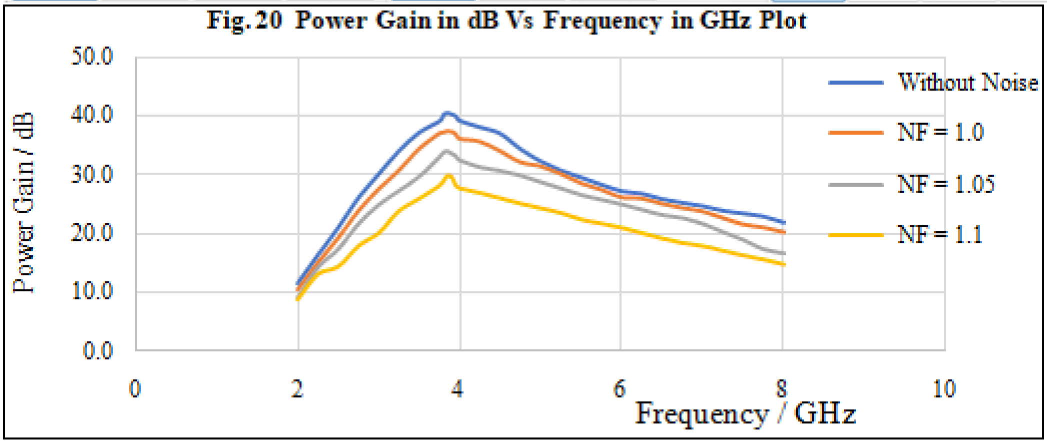
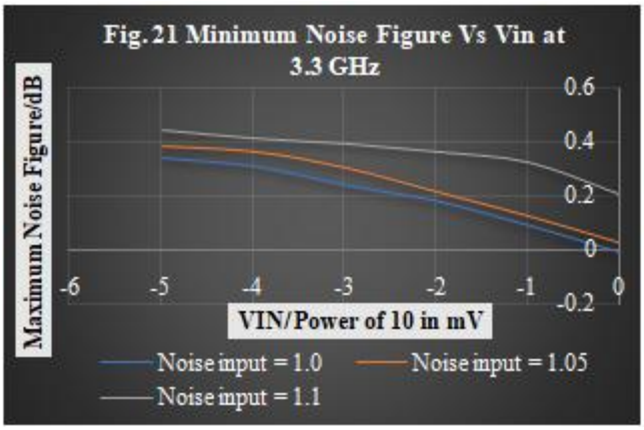
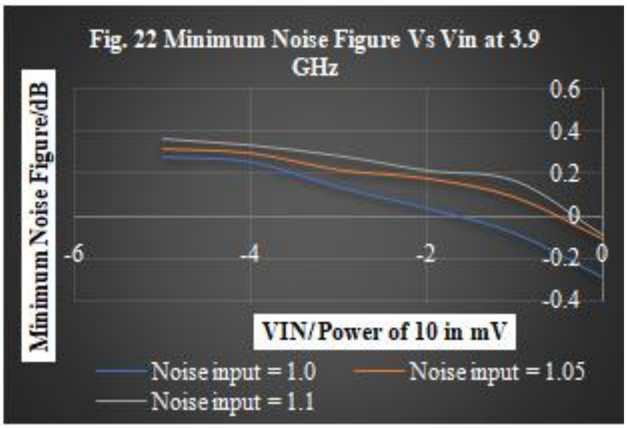


Figure 19: Input and Output RF signal observed in Oscilloscope

From fig. 20, it is noticeable that gain of the LNA is reduced with the increase of noise at the input. Due to that bandwidth of the detectable signal above 28 dB gain is reduced. The minimum possible detectable output signal bandwidth with the gain above 28 dB is 0.35 GHz (3.75 GHz to 4.1 GHz) at the input noise factor of 1.1. For the noise figure of 1.05, detectable signal above 28 dB gain at the output is between 3.3 GHz to 5.2 GHz which provides 1.9 GHz bandwidth. For noise figure of 1.0, detectable output signal bandwidth is 2.1 GHz which is between 3.1 GHz to 5.2 GHz. So, when the noise at the input increases, detectable signal bandwidth at the output above 28 dB gain is reduced in experimental circuit.

Further, practical test on prototype circuit for minimum noise figure of LNA and needed minimum input signal of LNA for detecting the object without ambiguity were carried out with the circuit in Fig. 8 at 3.3 GHz, 3.9 GHz and 5.2 GHz carrier frequencies with input noise factor of 1.0, 1.05 and 1.1. From above tests following plots as shown in Fig. 21, Fig. 22, Fig. 23, Fig. 24, Fig. 25 and Fig. 26 were obtained respectively. The plots of Fig. 21, Fig. 22 and Fig. 23 indicate that minimum noise figure of LNA for gain greater than 28 dB is below 0.401 dB which is slightly greater than our research object (< 0.4 dB) and the plots of Fig. 24, Fig. 25 and Fig. 26 indicates that minimum input signal power needed for good detection of signal is below -123.8 dBm which is slightly lower than our research object (< -123 dBm).





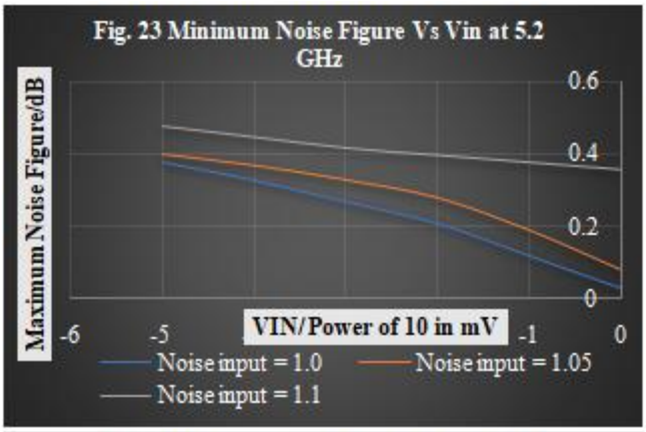


Fig. 23 Minimum Noise Figure Vs Vin at 5.2 GHz

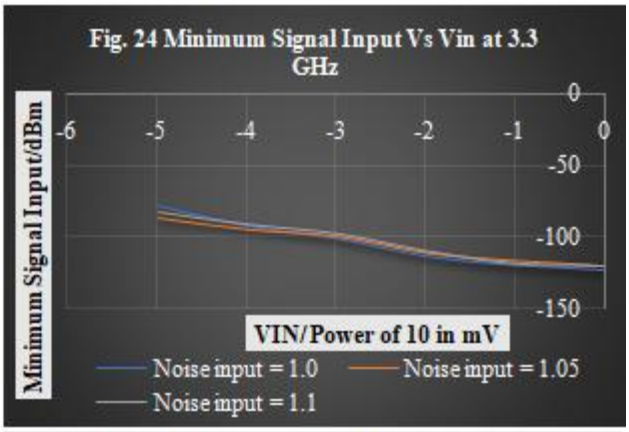


Fig. 24 Minimum Signal Input Vs Vin at 3.3 GHz

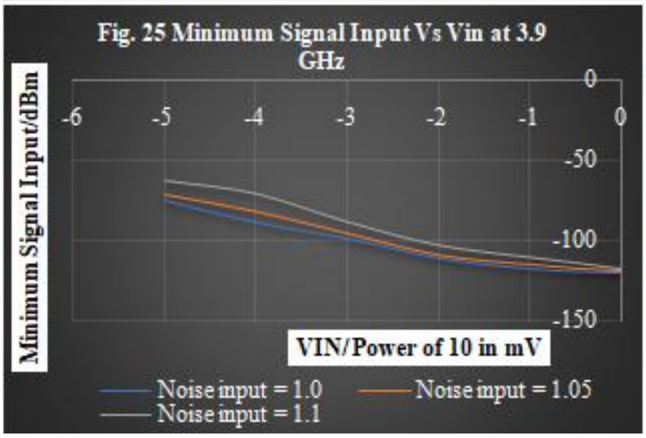


Fig. 25 Minimum Signal Input Vs Vin at 3.9 GHz

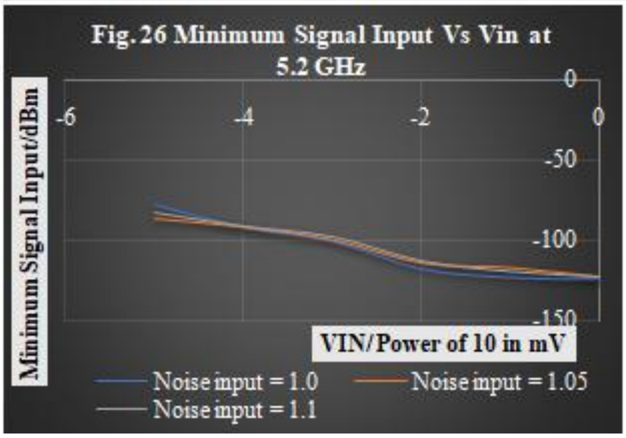


Fig. 26 Minimum Signal Input Vs Vin at 5.2 GHz

From the above tests results of simulation and prototype model circuit, it is possible to observe the following scenarios of the LNA design:

1) The input noise level increases, overall noise figure of LNA increases. In same time overall noise figure increases with the decrease of RF signal input voltage.
2) The minimum input signal power increases with the increase of input noise level as well as decrease of RF input signal voltage.

3. Discussion

The testing results for the Low Noise Amplifier (LNA) by simulation appear to be quite promising, indicating that it performs well within the specified frequency band of 3.1 GHz to 5.8 GHz. But in the practical prototype type model, the testing results shows that expected results for this project work within the frequency band of 3.3 GHz to 5.2 GHz up to the input noise level of 1.05. For the input noise level of 1.1, the output satisfies the expected results for very narrow band between 3.75 GHz to 4 GHz. Let's break down the key findings:

1) ***Power Gain of LNA:*** The power gain of the LNA by simulation within the frequency range of 3.1 GHz to 5.8 GHz is reported to be above 28 dB for the input noise level up to 1.1 as shown in Fig. 11. But as per prototype design, frequency range is reduced to 3.3 GHz to 5.2 GHz for the input noise level up to 1.05 and further reduced to 3.75 GHz to 4 GHz while input noise level increases to 1.1 as shown in Fig. 20. This means that the LNA amplifies the incoming signal by a significant factor, which is desirable in many RF (Radio Frequency) applications.
2) ***Noise Figure/Factor:*** The noise performance of the LNA is crucial, and the results from simulation indicate that the noise figure is as low as 0.394 dB or, equivalent, a noise factor of 1.095. But in prototype design, result indicates that the noise figure is 0.401 dB for the gain greater than 28 dB, or equivalent, a noise factor of 1.097. A lower noise figure/factor is better because it means that the LNA introduces very little additional noise into the signal it amplifies. This is especially important in application where signal quality is crucial.
3) ***Signal Detection Bandwidth:*** The simulation testing results suggest that the LNA's signal detection bandwidth is 2.7 GHz without significant degradation. But practical prototype design shows that the signal detection bandwidth as 1.9 GHz up to the input signal noise level of 1.05 and the input noise level increases up to 1.1, the bandwidth of signal detection is reduced to 0.25 GHz as shown in Fig. 20.
4) ***Minimum Input Signal Power:*** The minimum input signal power required to the LNA for reliable signal detection without ambiguity is another important parameter in this design. As per the simulation result, it is below -119.93 dBm and for the practical prototype design, it shows -123.8 dBm. This also aligns with the research objective of having a minimum input signal power better than -123 dBm for effective signal detection.

In summary, testing results from simulation as well as prototype circuit demonstrate that the LNA is performing well within specific parameters of research, meeting the requirements for low noise figure/factor, high gain and the ability to detect signals at the desired power levels. This is a significant achievement and is essential for applications in RF communication, radar systems, or any scenario where signal sensitivity and quality are critical.

4. Conclusion

The research successfully demonstrates a Low Noise Amplifier design with high gain, low noise figure and enhanced receiver sensitivity, suitable for S- and C- band applications. This LNA design, verified through simulation and prototype testing, presents a significant advancement in receiver technology, particularly for radar systems and wireless communication, meeting the set objectives of high performance under low voltage supply conditions.

Base on positive results obtained from simulation and prototype circuit test analysis of the Low Noise Amplifier (LNA), there are several directions for further work and consideration:

1) ***Optimization:*** This could involve fine-tuning parameters to achieve even better performance or exploring alternative circuit configurations to improve gain, noise figure, or bandwidth.
2) ***Robustness Testing:*** Assess the LNA's robustness under different environmental conditions, such as temperature variations, electromagnetic interference, and power supply fluctuations. This will help ensure its reliability in practical applications.
3) ***Applications:*** Explore potential applications for this high-performance LNA. Consider how it can be used in specific fields, such as wireless communication, radar systems, or radio astronomy. Customizing the LNA for specific applications may be necessary.
4) ***Power Efficiency:*** Evaluate the power consumption of the LNA and work on making it more power-efficient if necessary. Reducing power consumption is crucial for battery-powered devices and environmentally friendly applications.
5) ***Manufacturability:*** To bring this LNA circuit to market, consider manufacturability aspects. Work on a design that is cost-effective and can be produced in quantity while maintaining consistent performance.
6) ***Regulatory Compliance:*** If applicable, ensure that the LNA complies with relevant regulations and standards, particularly in industries like telecommunications and aerospace.

In summary, further work can involve a combination of optimization, practical applications, and collaboration to maximize the potential of this high-performance Low Noise Amplifier. The aim is to ensure that it not only meets the stated research objectives but also addresses real-world challenges and requirements in the field of RF electronics and signal processing.

References

[1] “Design of High Frequency and Highly Sensitive Low Noise Amplifier” by A.O. Fadamiro and E.O. Ogunti in the Asian Journal of Engineering and Technology (ISSN 2321 -2462) Volume-1 Issue-2, June 2013.

[2] “Radar theoretical study: minimum detection range and maximum signal to noise ratio (SNR)equation by using MATLAB simulation program” by Sulaiman H.M Al Sadoon and Badal H. Elias in American Journal of Modern Physics 2013: 2(4) – 234 – 241 in online, July 20, 2013.

[3] “Design and Realization of an S-Band Microwave Low-Noise Amplifier for Wireless RF Subsystems” by Ardavan Rahimian and Davood Momeni Pakdehi in the ResearchGate article, September, 2014.

[4] “Design of a Low-Noise Amplifier for Radar Application in the 5 GHz Frequency Band” by Javier Alvaro Rivera Suaña, June 2017.

[5] “Design Concept of Low Noise Amplifier for Radio Frequency Receivers” by Sumathi Manickam in the ResearchGate article, November, 2018.

[6] “Design of Low Noise Amplifier for Optimum Matching between Noise Figure and Power Gain” by S. Jarallah Al-Jawadi and A. A. Ismail in International Journal of Computer Applications (0975 – 8887) Volume 178 – No. 44, August 2019.

[7] “Simulation and Design of Low Noise Amplifier” by N. NazeeyaAnjum, M.Akshaiya andG.Alagulakshmi in International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-9, Issue-1, November 2019.

[8] “A Novel Design and Optimization Approach for Low Noise Amplifiers (LNA) Based on MOST Scattering Parameters and the gm/ID Ratio” by Juan L. Castagnola, Fortunato C. Dualibe Agustín M. Laprovitta and Hugo García-Vázquez, published on 11 May 2020 in the Electronics 2020, 9, 785 publications.

[9] “Design of Low Power Wideband Low Noise Amplifier for Software Defined Radio at100MHz to 1GHz A” by Salleha, K. S. Yonga, M. Z. A. Abd Aziza, M. H. Misrana, N. R. Mohamada in Malaysian Technical Universities Conference on Engineering & Technology 2012, MUCET 2012.

[10] “Design of X-Band Low Noise Amplifier for Radar Applications “ by M M Abdel hakem et al 2020 Journal of Physics.: Conference Series 1447 012036.

[11] ”Design and Realization of an S-Band Microwave Low-Noise Amplifier for Wireless RF Subsystems” by Ardavan Rahimian1 , Davood Momeni Pakdehi in ResearchGate, September, 2014.

[12] “Low Noise Amplifier Design and Performance Analysis of RF Front-End for Narrow Band Receivers” by Amgothu Laxmi Divya et al 2021 J. Phys.: Conf. Ser. 1817 012007.