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Low Power RF Transceivers

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Abstract: **This paper presents the work done about the Low Power RF Transceivers. This paper includes both theoretical and practical part. In the theoretical part it covers Receiver Architectures and Digital Modulation Schemes. On the other hand the practical part covers the design simulation Low Noise Amplifier (LNA) that includes the analysis, design, simulation and fabrication.**

The purpose of LNA is to amplify the received RF signal by keeping the noise factor as low as possible. The design simulation of this paper involves the analysis of GaAs field effect transistor stability and matching network selection.

The aim of this paper is to design and fabricate an LNA with the gain of 5-12 dB over the frequency of 2.4GHz. To achieve this goal the software used is industry standard Advanced Design System (ADS). Low Noise Amplifier is working on the desired frequency of 2.4 GHz and giving an acceptable gain of 9.593dB.

Keywords: **LNA, Receiver Architectures and Digital Modulation Schemes.**

1. INTRODUCTION

The main objective of this paper is to carry out a thorough study Low Power RF Transceiver, that includes theory about receiver architectures and digital modulation schemes whereas on the other hand design and simulation of Low Noise Amplifier (LNA). Furthermore, to prototype the circuit in micro-strip technology using commercially available transistor and other components.

There are always some parameters that should be kept in mind while designing a microwave circuit, it could be bandwidth efficient, cost efficient or power efficient. This paper is about power efficient as we are talking about 'Low Power RF Transceivers'. Now what does a transceiver means? A transceiver is something that can transmit and receive at the same time for example a mobile phone. There are two types of transceivers.

- Analogue Transceivers
- Digital Transceivers

In digital transceiver where the transmitter and receiver are again working together, the voice signal is first of all digitalized by using an 'Analogue to Digital Converter' (ADC) and then compressed to reduce the bit rate as shown in figure 1.3. Next the data undergoes 'coding' and 'interleaving' [1].

1.2 Analogue Transceivers:

In the analogue transceivers as there are both transmitter and receiver at the same time shown in figure 1.1. In transmitter the signal from microphone is modulated with a high frequency carrier, the result is then amplified by using a power amplifier and transmitted via antenna.

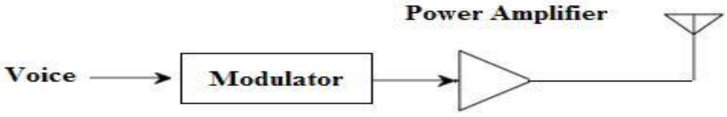

Fig 1.1: Block Diagram of Analogue RF Transmitter

On the other hand in receiver path the signal received is first of all amplified by a Low Noise Amplifier (LNA), the spectrum is then translated to a lower frequency by down converting it and before getting the output on the speaker it is demodulated. This architecture is shown in figure 1.2.

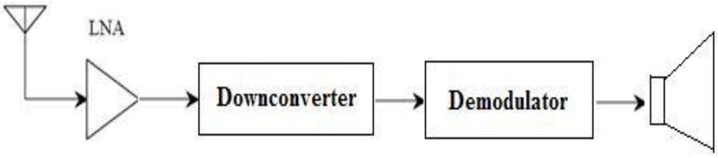

Fig 1.2: Block Diagram of Analogue RF Receiver

1.3 Digital Transceivers:

In digital transceiver where the transmitter and receiver are again working together, the voice signal is first of all digitalized by using an 'Analogue to Digital Converter' (ADC) and then compressed to reduce the bit rate as shown in figure 1.3. Next the data undergoes 'coding' and 'interleaving' [1]. These two functions format the data such that the receiver can detect and minimize errors by performing reverse action. Since rectangular pulses are not optimum for modulation so it is then shaped before it applies to the amplifier.

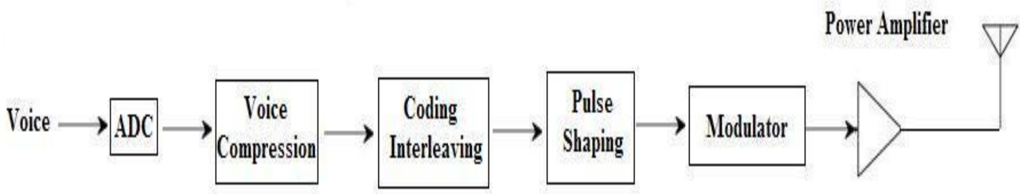

Fig 1.3: Block Diagram of Digital RF Transmitter.

In the receiver path the signal is amplified again by using an LNA, down converted and digitized. Subsequently, demodulation, equalization, decoding, deinterleaving and decompression are performed in the digital domain. The digital data is converted back to analogue by using a 'Digital to Analogue Converter' (DAC) as shown in figure 1.4.

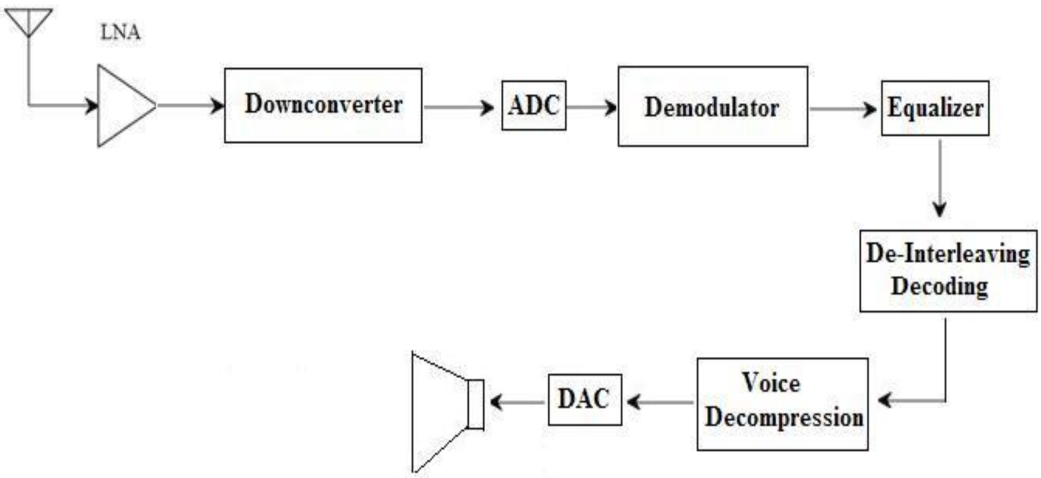

Fig 1.4: Block Diagram of Digital RF Receiver.

It can be seen from both analogue and digital transceiver there is atleast one thing common in both the architectures that in receiver right after receiving the signal from antenna it is first of all amplified by using an LNA without introducing noise. So amplification without noise is the major part of this paper.

2. LOW NOISE AMPLIFIER

Microwave amplification is one of the critical circuit functions in modern RF and microwave wireless systems. The advancement of the microwave amplifiers required the employment of microwave active and passive circuits and resulting in a significant improvement in the active circuit deployment in the system applications. [2]. These amplifiers are used in the wireless communication transceivers to boost the power of the modulated RF signal without introducing the noise, Low Noise Amplifier (LNA) is one of the example of these amplifiers. Microwave amplifiers were designed by using Field Effect Transistor (FET) as a main building block of Microwave Integrated Circuit (MIC) in 1970s. These transistor got a very high demand because of their reliability, cost and availability in both monolithic and hybrid circuitry [3].

There are so many types of amplifiers are available in the market but one of the main types of amplifier and the focus of the paper is Low Noise Amplifier (LNA). Microwave amplifiers were introduced in the market as soon as there was some advancement in GaAs FET and MOSFET technologies. This direction was also supported with the possibility of having microwave amplifiers because of their small size, low noise figure and low power consumption [4].

An LNA can amplify RF signal of a particular frequency or a range of frequencies by introducing noise as low as possible. As it is described first that our RF signal is very weak, to amplify this weak RF signal normally an LNA is used. It will be discussed in more details later in the 2^{nd} chapter that why LNA is attached very next to antenna? LNA is discussed more precisely in the next section to illustrate its performance, strengths and limitations.

This part of the paper describes the designing and simulation of Low Noise Amplifier (LNA). During the design of an LNA combination of few things is required that includes low noise figure, reasonable gain and stability without oscillation over entire useful frequency range. The smallest signal that can be received by a receiver defines the receiver sensitivity. The largest signal can be received by a receiver establishes the upper power level limit of what can be handled by the system while preserving voice or data quality.

The dynamic range of the receiver, the difference between the largest possible received signal and the smallest possible received signal, defines the quality of the receiver chain. The LNA function, play an important role in the receiver designs. Its main function is to amplify extremely low signals without adding noise, thus preserving the required Signal-to-Noise Ratio (SNR) of the system at extremely low power levels. Additionally, for large signal levels, the LNA amplifies the received signal without introducing any distortions, which eliminates channel interference.

Transistor selection is the first and most important step in an LNA design. The designer should carefully review the transistor selection, keeping the most important LNA design trade-offs in mind. Carefully selecting a transistor and understanding parameter trade-offs can meet most of these conditions. Unconditional stability will always require a certain gain reduction because of either shunt or series resistive loading of the source.

An LNA design presents a considerable challenge because of its simultaneous requirement for high gain, low noise figure, good input and output matching and unconditional stability at the lowest possible current draw from the amplifier. Although Gain, Noise Figure, Stability, Linearity and input and output match are all equally important, they are interdependent and do not always work in each other’s favor. So starting from the selection of the transistor all the steps are given below.

2.1 Transistor Selection:

The decision was made to use an NE76038 transistor to build a Low Noise Amplifier which is available in Glasgow University’s Electronics Lab. In addition, NE76038 is a high performance GaAs FET that has low noise figure (1.8dB at 12GHz) allowing operation in the range of 1-14GHz frequency range and it also has a high associated gain (7.5dB) typically at 12GHz [12].

2.2 S-Parameter Measurements:

The next step was to measure the S-parameter of NE76038 and the biasing points by doing different tests in the lab over the frequency of 2.4GHz, the decision was made to use V_{GS}=-0.5V and V_{DS}=2.5V.

2.3 Stability Design:

After measuring the S-Parameters and biasing points the next step was to measure the stability of the transistor at 2.4GHz that should be greater than ‘1’. If it is the case then the transistor is stable otherwise there will have to be done something to stable the transistor at 2.4GHz frequency. To check the stability a schematic was designed with the DC block and DC feedback components, which is shown in figure 2.1.

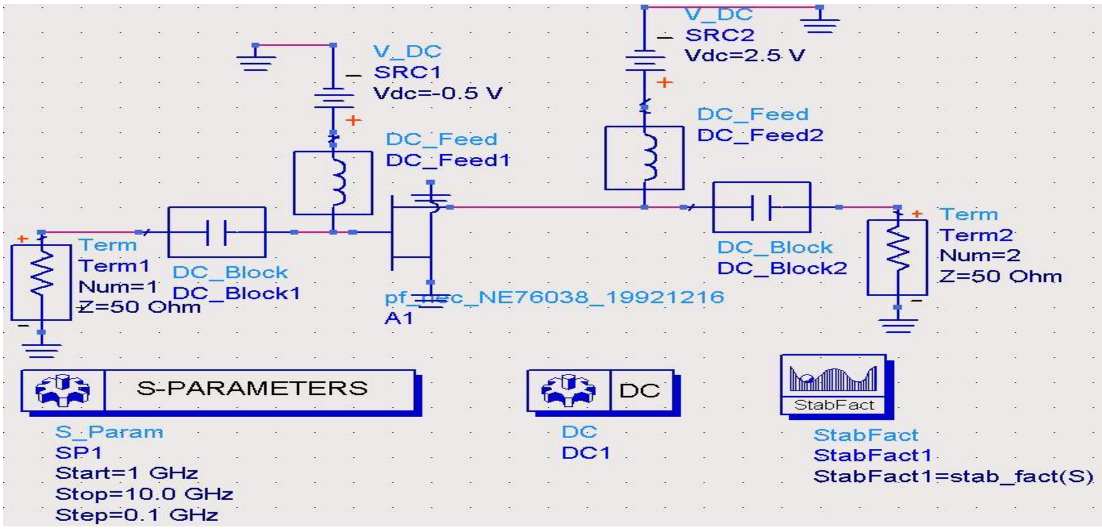

Fig 2.1: Stability Test

After the simulation of this schematic it was found that the transistor was not stable at the frequency of 2.4GHz, that means the value of stability factor 'K' was less than '1', which can be seen in the figure 2.2.

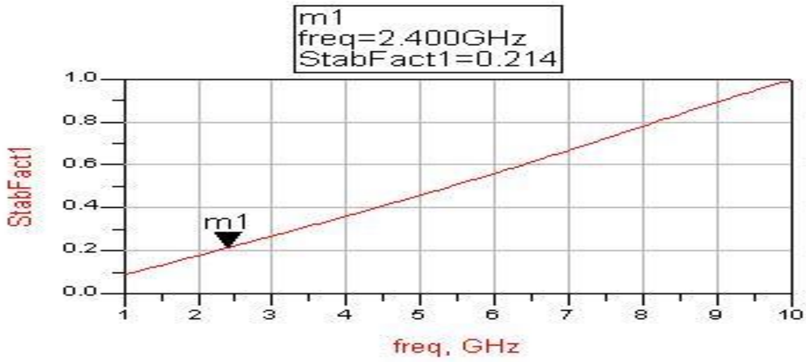

Fig 2.2: Stability Test

To solve this problem a resistor of 100Ω was introduced at the drain of the transistor to make the circuit stable. There are some other methods to stale as well but it was one of the easiest methods. The modified schematic is shown in figure 2.3 with a resistance of 100Ω.

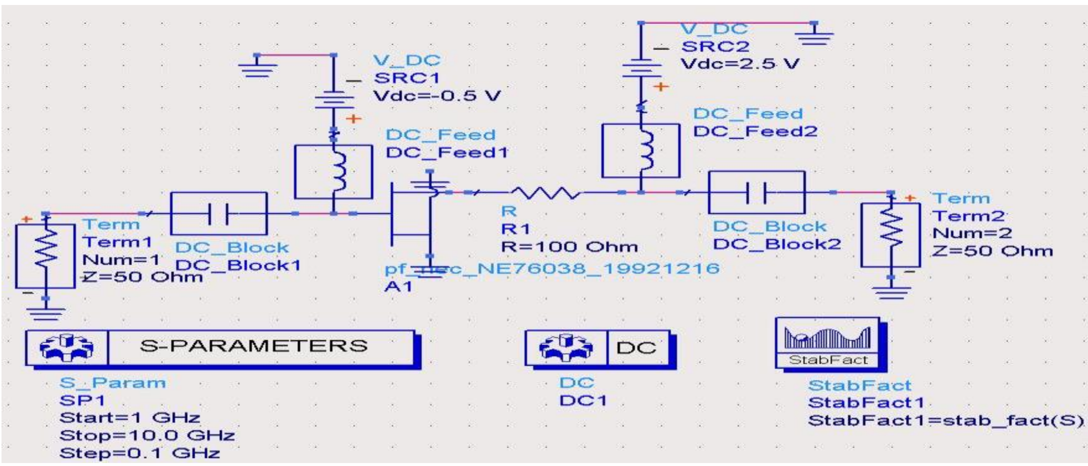

Fig 2.3: Modified Schematic for the Stability.

After this modification the circuit stability was greater than '1' at 2.4GHz frequency which means that the transistor is stable at given frequency. The graph of the stability factor with modified schematic is shown in figure 2.4.

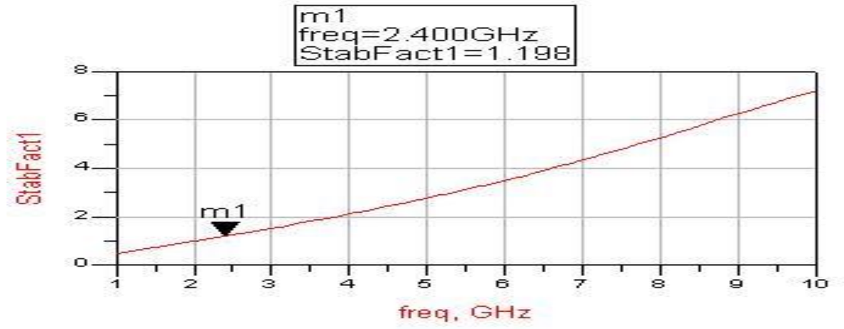

Fig 2.4: Stability Factor with Modified Schematic.

2.4 Measurement and Matching for Z_{opt}:

After the stability the next step is to measure the Optimum Impedance (Z_{opt}) for the circuit which can be done by adding a Zopt1 parameter in the schematic. The measured values of Z_{opt} are shown in figure 2.5.

freq	Zopt1/50
1.000 GHz	1.716 + j6.988
1.100 GHz	1.561 + j6.338
1.200 GHz	1.432 + j5.795
1.300 GHz	1.323 + j5.335
1.400 GHz	1.229 + j4.939
1.500 GHz	1.148 + j4.594
1.600 GHz	1.078 + j4.292
1.700 GHz	1.015 + j4.025
1.800 GHz	0.960 + j3.786
1.900 GHz	0.911 + j3.571
2.000 GHz	0.866 + j3.377
2.100 GHz	0.826 + j3.201
2.200 GHz	0.790 + j3.040
2.300 GHz	0.757 + j2.893
2.400 GHz	0.727 + j2.757

Fig 2.5: Z_{opt} Measurement

From the figure it can be evaluated that the value of Z_{opt} at 2.4GHz is (0.727+j 2.757). Now moving forward, the next step is to match for this value of Z_{opt}, which can be done by adding another parameter called as Smith Chart Matching Network. By using this parameter transmission lines designed for Z_{opt} will be added which is shown in figure 2.6.

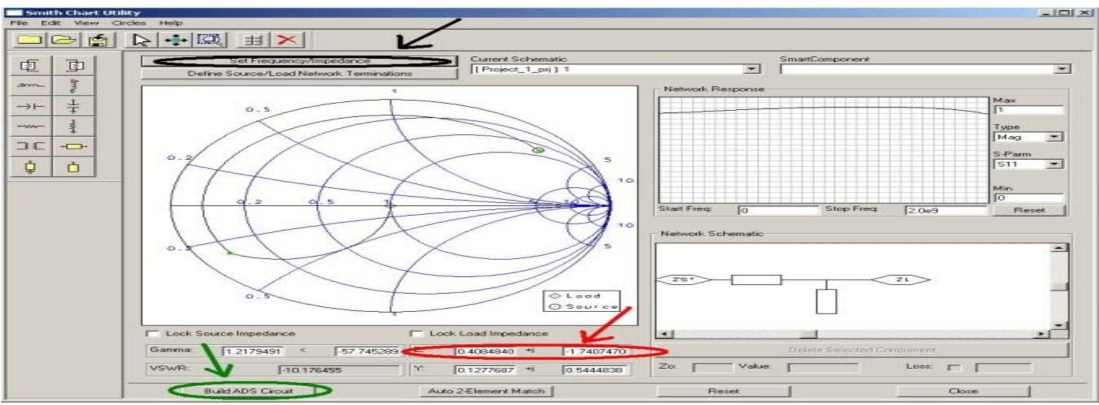

Fig 2.6: Smith Chart Utility for Z_{opt}.

In the given diagram the very first step is to set the frequency and impedance shown in black arrow that is 2.4GHz and 50Ω respectively, next is to select a node and enter the value of Z_{opt} measured above and enter in the box shown in red arrows and match to the selected point and at the last building the ADS circuit shown in green. This designed circuit will be added at the source of the schematic. Modified schematic can be seen in figure 2.7.

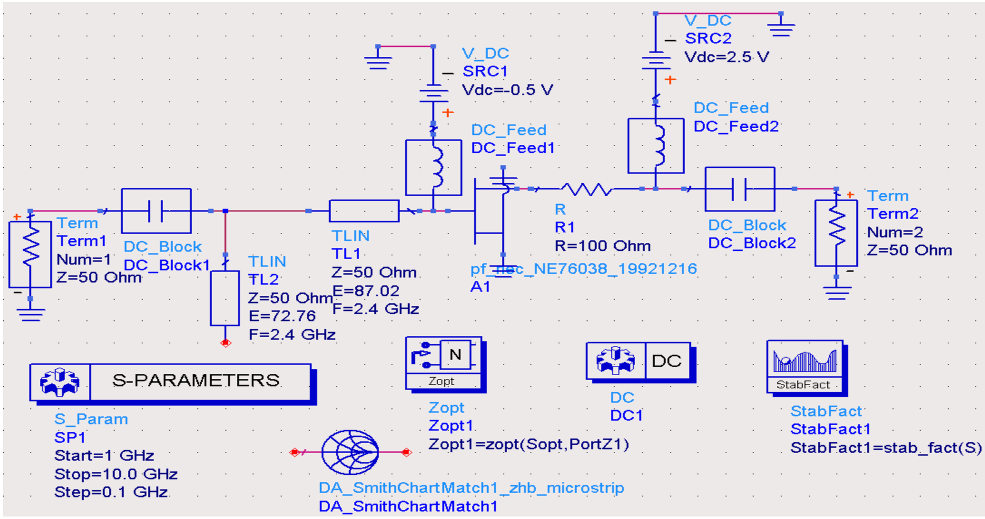

Fig 2.7: Schematic with Transmission Lines at Source End.

2.5 S_{22} Measurement for Input Matching Network:

In this step S_{22} will be measured for input matching network. After the simulation of this schematic 'S_{22}' can be measured by using smith chart. Measured S_{22} is shown below.

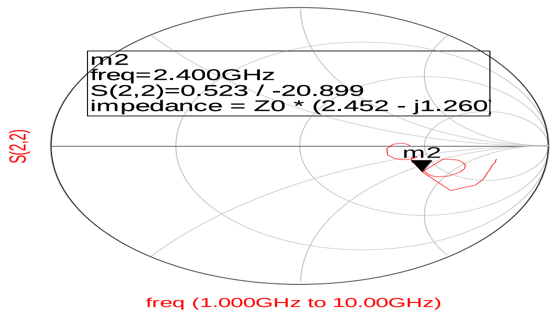

Fig 2.8: Measurement of S_{22}

By doing the same thing as we did in the Smith Chart Utility of Z_{opt} now will be done by using S_{22}, this time instead the value of Z_{opt}, conjugate of S_{22} will be inserted in the box shown by red arrow. After building the ADS circuit it will be attached at the output terminal of the schematic. New schematic is shown in figure below.

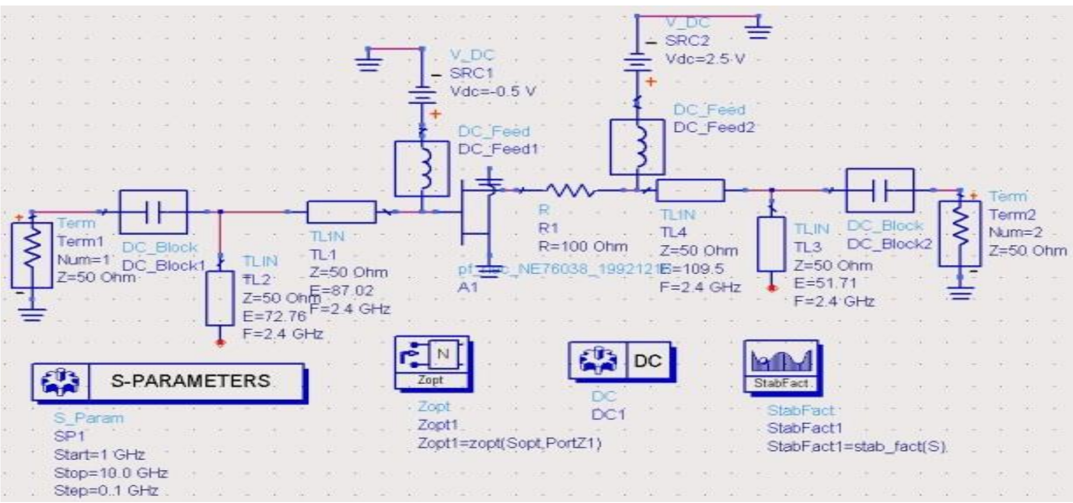

Fig 2.9: Schematic with Transmission Lines at Load End.

After the simulation of this schematic S_{21}, S_{11}, S_{12} and S_{22} are shown in the following figure.

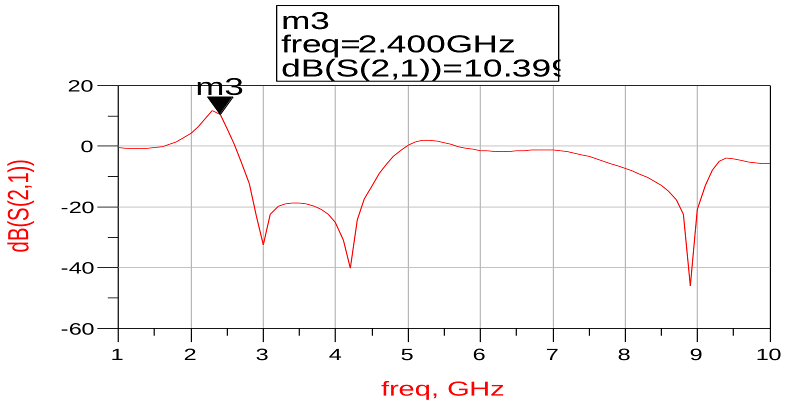

Fig 2.10: Gain (S_{21}) of LNA.

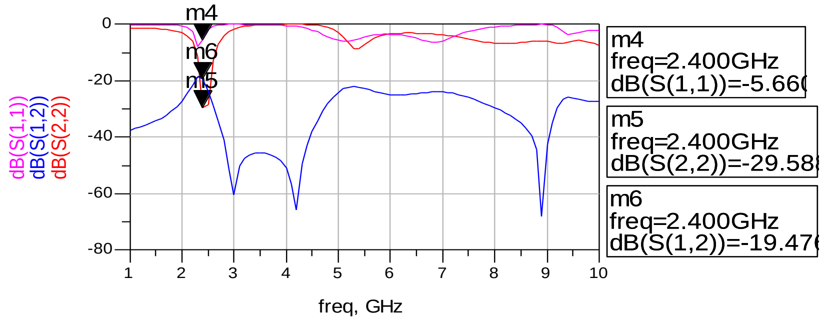

Fig 2.11: S_{11}, S_{12} and S_{22} of LNA

2.6 Measurement of Noise Factor:

Previous figures and graphs are acceptable because the values of all S-Parameters are fine but now next step is measure the noise factor to see that either the LNA is amplifying the signal without amplifying the noise. To measure noise factor another graph which is shown in figure 2.11 will be added to the results. It should be noted that the value of noise factor should be less than '1' if it is greater than '1' it means that LNA is amplifying the noise as well which is not a good sign. To overcome this problem again some changes will have to be done in the schematic.

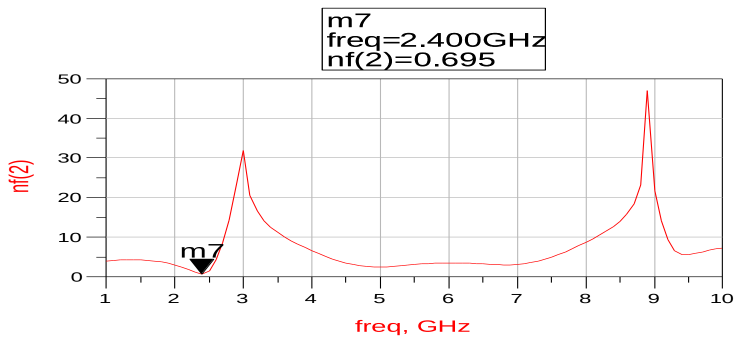

Fig 2.12: Noise Factor Measurements

Noise factor is less than '1' that means amplifier is not amplifying the noise with original signal.

2.7 Microstrip Lines:

Next step is to add the Microstrip line in the schematic, for this purpose a substrate will be added in the schematic. After this change now next step is to add the Microstrip lines in the schematic. It can be done by using the LineCalc.

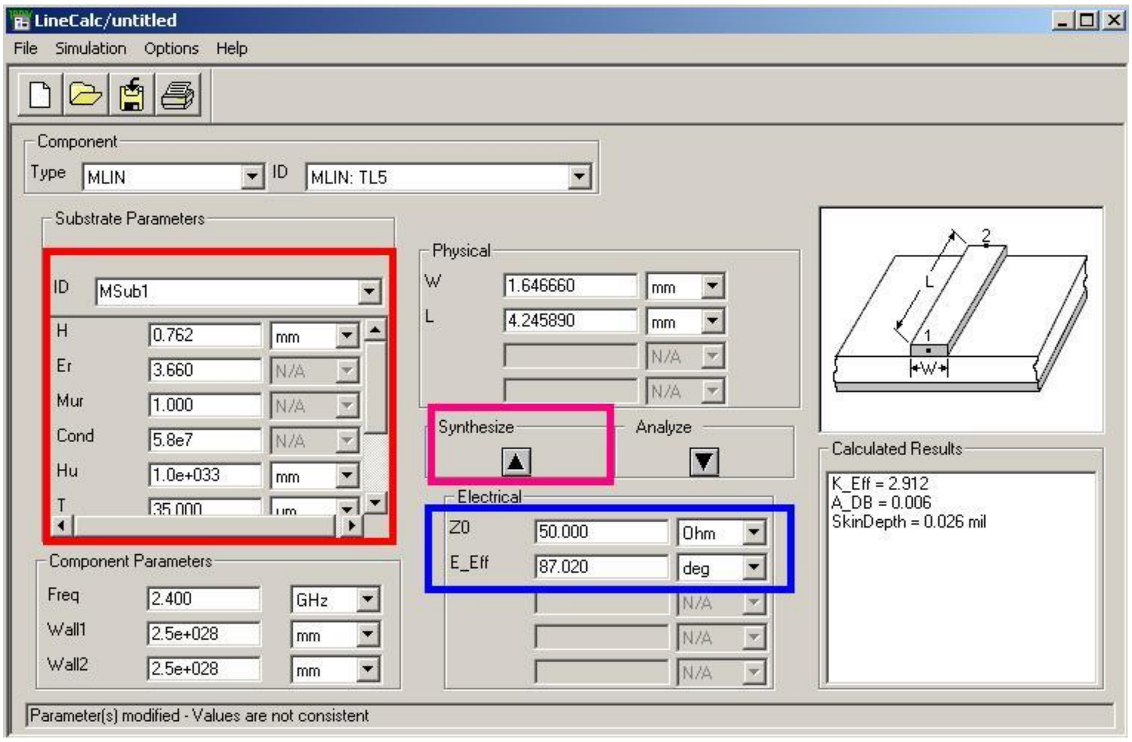

Fig 2.13: LineCalc

In above figure LineCalc is shown in which red box shows the values of substrate which is being used, blue box shows the impedance and E_Eff that is the value of transmission line which is already there in LNA schematic and at the end pink box shows synthesis by which width and length of Microstrip line will be obtained. It should be noted that the width for all the lines will be same just the length will be changed. By applying different values of E_Eff Microstrip lines will be obtained and transmission lines will be replaced by these Microstrip lines. LNA schematic after Microstrip lines is shown in figure 2.13.

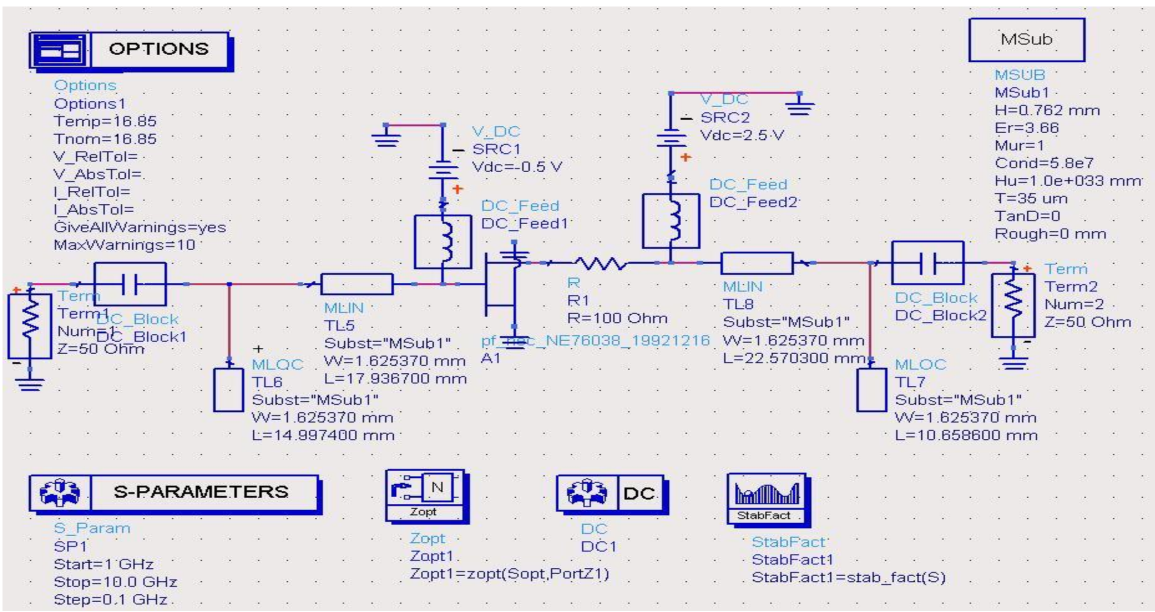

Fig 2.14: LNA with Microstrip Lines

The last step is to add the MRSTUB and MTEE in the LNA schematic, after the addition of these parameters the output of LNA will be slightly changed but it can be overcome by tuning the schematic. The final schematic is shown in figure 2.14.

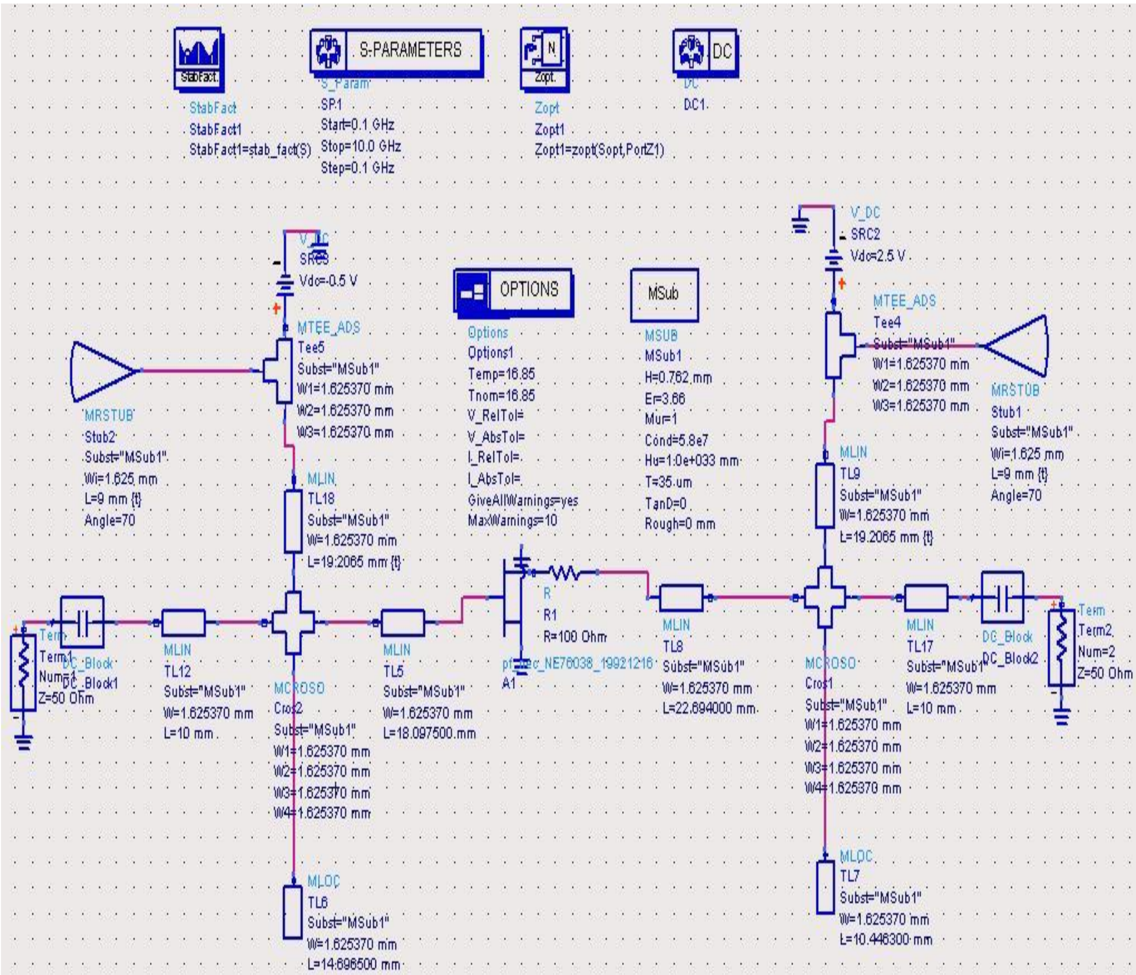

Fig 2.15: Low Noise Amplifier (LNA)

The final results of LNA are shown below that includes S_{21}, S_{11}, and S_{22} and Noise Factor respectively.

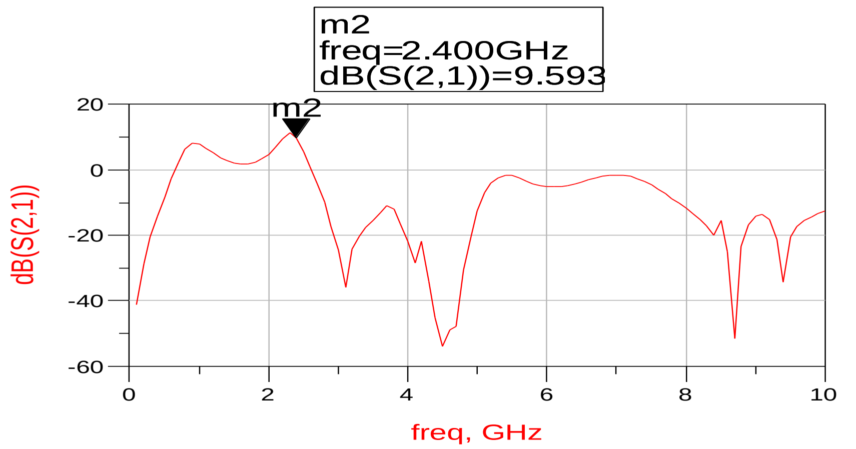

Fig 2.16: Gain (S_{21}) of LNA.

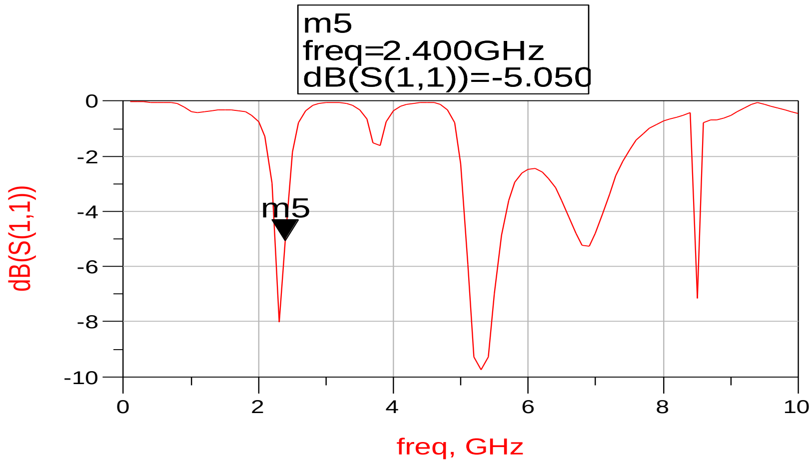

Fig 2.17: S_{11} of LNA

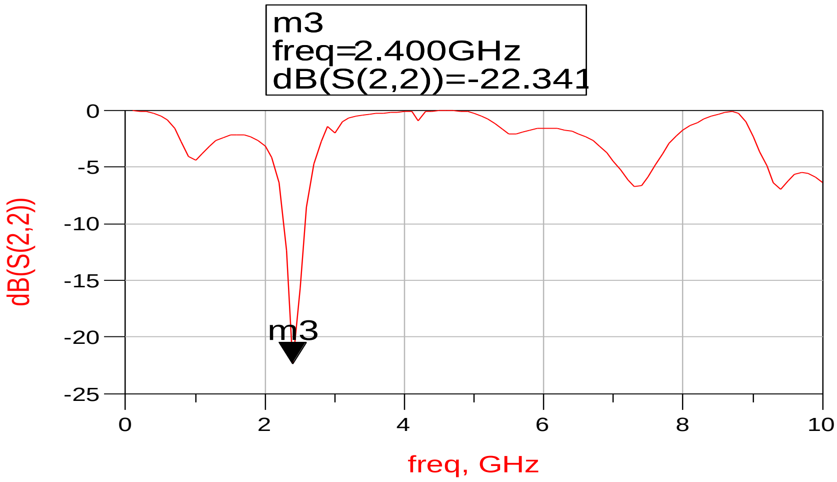

Fig 2.18: S_{22} of LNA

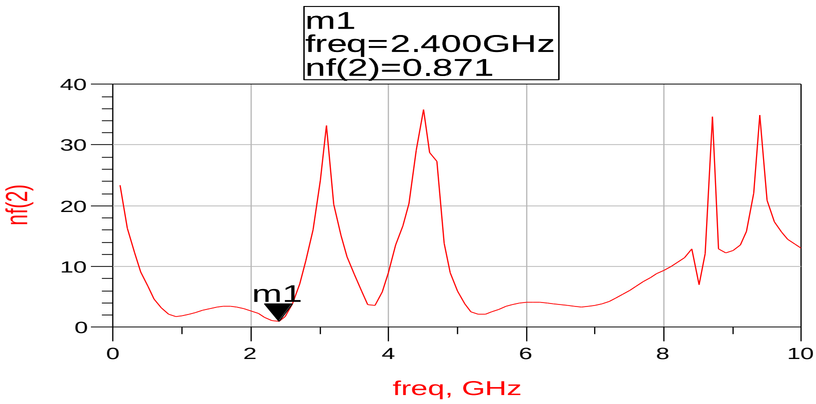

Fig 2.19: Noise Factor of LNA

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