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Design, implementation and evaluation of Broadband Low Noise Amplifier (LNA) for radiometer

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Abstract

The two major applications of microwave remote sensors are radiometer and radar. Because of its importance and the nature of the application, much research has been made on the various aspects of the radar. This paper will focus on the various aspects of the radiometer from a design point of view and the Low Noise Amplifier will be designed and implemented. The paper is based on a study in radio Frequency Communications engineering and understanding of electronic and RF circuits. Some research study about the radiometer and practical implementation of Low Noise Amplifier for Radiometer will be the main focus of this paper. Basically the paper is divided into two parts. In the first part some background study about the radiometer will be carried out and commonly used types of radiometer will be discussed. In the second part LNA for the radiometer will be designed.

Keywords: Radiometer, Sensors Low Noise Amplifier, ADS, Radar, Bandwidth

1 Introduction

Some of the major types of Radiometers will be discussed in this paper. The major applications and advantages of using them will also be the focus of this work. The main focus will be on the design of a low noise amplifier. A Low Noise Amplifier will be designed in the Advanced Design System (ADS) and will be also implemented for practical use in the selected Radiometer. Section 1 is based on the general overview of the radiometer and radiometer types will be discussed. Section 2 is based on a Low noise amplifier and general overview about low noise amplifiers, s-parameters and noise factor will be discussed. Section 3 discusses the design of low noise amplifier. It describes design specifications, design steps, flowchart for the design as well. Design parameters such as, chip selection, substrate selection and biasing of the IC is also discussed in this section. The section 4 and 5 are based on the software selection and the simulation of the design. In these sections some simulation strategies have been mentioned. Two stages of design have been discussed in this section; single stage and 2-stage design. The waveforms of the simulated results have been shown in this section. A comparison between the two stages of design is made in order to justify the differences and for selection of the particular design for any particular application. Section 6 is based on implementation and testing part of the project. Both the designs simulated above will be implemented and their results will be tested. In the end a comparison between the two designs in terms of physical implementation will be made. The last section of the paper is based on the conclusion and future work.

1.1 INTRODUCTION TO RADIOMETER

By definition a basic Radiometer is a device which produces an output which is proportional to the radiation received at antenna input. A practical Radiometer should be very sensitive and accurate in nature. The reason for having a very sensitive Radiometer is that, the sensitivity will make the Radiometer able to detect very weak emissions from the emitting device or object or the surface [1]. Whenever describing a Radiometer the following characteristics must be kept in mind:

- 1) Spectral Range
- 2) Sensitivity (Sensitivity against the wavelength)
- 3) Directional response
- 4) Field of view

Radiometer receiver

To understand about what a radiometer receiver is consider the figure given below.

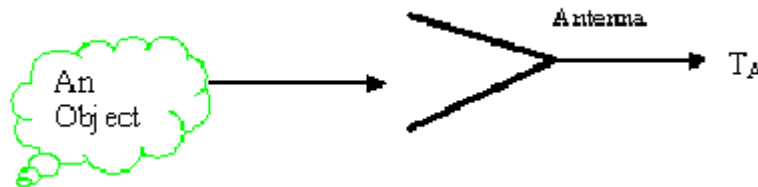


Figure1.1 Measurement situations

The task is to measure the brightness temperature of the object as shown in the above figure. “ T_A ” is the power or temperature to be measured. It can be seen that to measure the brightness of the object, an antenna is used. The direction of the antenna is pointing towards the object. In this case assume that the antenna is lossless, which of course would not occur in the real world but this is just for understanding at this point. The power emitted by the object is collected or sensed by the antenna. The output terminal of the antenna will give output power, which is T_A . The required task which must be performed is to measure this output from the antenna with enough accuracy and resolution. So, by definition the Radiometer itself is a microwave receiver which is used to determine the relation between the output of an antenna and value of input of an object or attribute [2].

Sensitivity of the Radiometer

The power received by the antenna is generated as the output of the antenna. The antenna output becomes the input to the radiometer. Below is the figure showing the relationship.

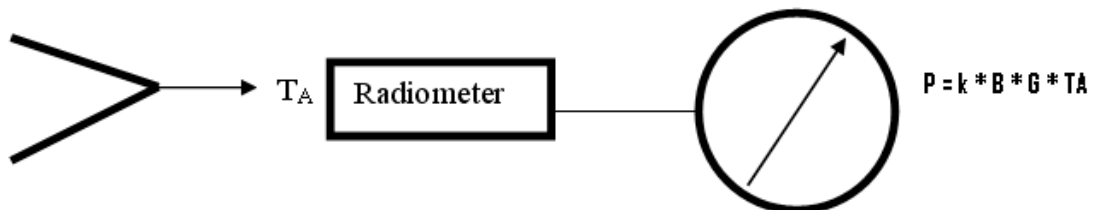


Figure1.2 Idealized radiometer [2]

The radiometer selects the portion of the available bandwidth from the antenna at a given central frequency. The power is amplified and is then given to an output medium as an input. The meter measures the power by the following formula [1].

$$P = k \cdot B \cdot G \cdot T_A$$

Where

K = Bolt man’s constant.

B = Bandwidth.

G = Amplification

T_A = Power received from the antenna.

The formula given above takes only ideal conditions into account, meaning that it does take into account any noise. In an ideal world this is not possible as there will be some noise existing, either from the antenna or from the passive components of the radiometer front end. This noise will be added as an input. The modified formula can be written as

$$P = k \cdot B \cdot G \cdot (T_A + T_N).$$

Where, T_N is the noise temperature added by radiometer and antenna noise.

Accuracy of the Radiometer

Absolute accuracy is another problem which is associated with the radiometer. According to the power equation [3]

$$P = k \cdot B \cdot G \cdot (T_A + T_N)$$

It can be seen from the equation that all these quantities k , B , G and T_A are real constant values. As the bandwidth of the radiometer is determined by the band pass filter so, if the filter is made with care then it should be very much a constant value which means stable bandwidth can be achieved. When designing a radiometer or even working with it, the problem occurs when the signal travels through the path and noise is added to the signal. This problem lies only with the radiometer, but it is associated with any RF device. For an efficient design of radiometer accuracy is a key factor that needs to be considered. To understand how the path loss occurs consider the figure given below:

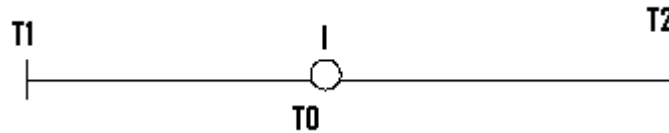


Figure1.3 Lossy path

The letter 'l' denotes the loss. T_0 is the physical temperature, T_1 is the input temperature and T_2 is the output temperature which can be calculated as:

$$T_2 = T_1 (1-l) + T_0 \cdot l$$

The difference between the input and the output temperature can be calculated as:

$$T_D = T_2 - T_1 = l \cdot (T_0 - T_1)$$

As an example let us say

$$T_1 = 100k$$

$$T_0 = 300k$$

$$l = 0.01dB$$

$$T_D = 0.5k$$

This shows that the physical temperature needs to be measured and used for the correction of measured brightness temperature. In the real world the values of losses can be much bigger, for accuracy of the device these factors need to be measured.

Types of Radiometer

There are several types of radiometers, but three of them are most widely used. These are:

- 1) total power radiometer
- 2) dicke radiometer
- 3) noise injection radiometer

Now each of these will be discussed one by one.

Total power radiometer

This is one of the simplest types of radiometer. It can be seen from the block diagram given below (in figure 1.0.4) that the first element is the amplifier, used to amplify the signal. The gain is denoted by 'G'. Band pass filter is used for frequency selectivity which is denoted by the letter 'B'. To find the measure of its mean, microwave power needs to be detected. In most of the types of the radiometer a detector is used. A square law detector is used in this case. From the detector signal is smoothed by an integrator and output fluctuations are reduced. The output can be expressed by the following equation.

$$V_{out} = c \cdot (T_A + T_N) \cdot G$$

Where V_{out} is the output power

C is the constant

T_N and G are noise temperature and Gain respectively. It can be seen from the equation that V_{out} mainly depends upon the noise temperature and the gain. As discussed earlier it is very important for a radio meter to be accurate, this may be disturbed by these factors and the device may not fulfil the absolute accuracy requirements.

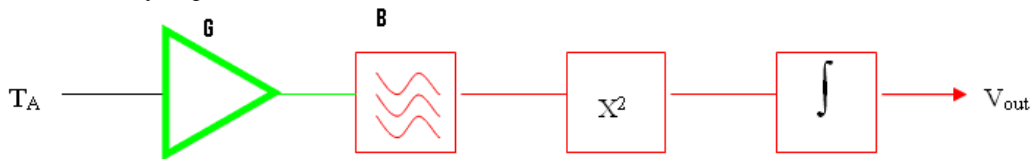


Figure1.4 Total power radiometer [4]

Dicke radiometer

In a total power radiometer it is seen that radiometer measures the power directly from the antenna. This direct measurement may cause unstable measurements. R.H Dicke in 1946 found a way to solve the stability problem in radiometers. Dicke proposed that instead of measuring the power directly from the antenna, there should be some reference temperature and the difference between reference and the antenna temperature should be measured. By employing this technique the sensitivity of measurement to gain and noise temperature instabilities are reduced. The radiometer input is switched by the reference temperature and the temperature of the antenna. The frequency of the switch is denoted by ' F_s ' which is typically 1KHz. depending upon the position of the switch the output of the square law detector is multiplied by +1 or -1 before integration is performed. The equation for input to integration will be

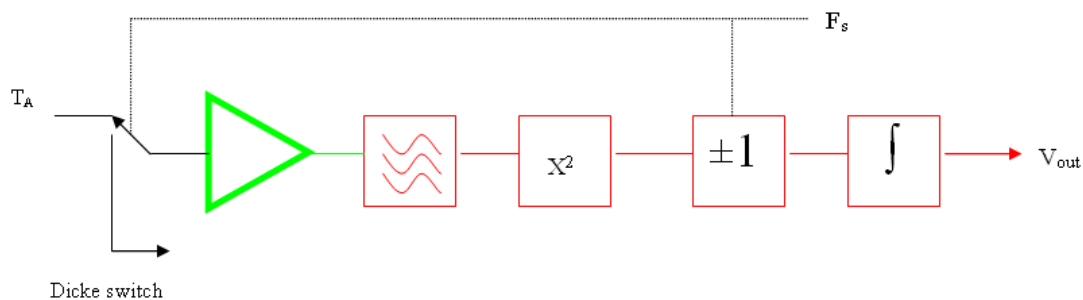


Figure1.5 Dicke Radiometer

In the first half period of switch frequency F_s

$$V_1 = c. (T_A + T_N). G$$

In the second half period of switch frequency F_s the voltage will be:

$$V_2 = c. (T_R + T_N). G$$

So,

$$V_{out} = V_1 + V_2$$

$$V_{out} = c. (T_A + T_N). G - c. (T_R + T_N). G$$

$$V_{out} = c. (T_A - T_R). G$$

The Dicke principle has proven to be very useful and dicke radiometers are the most widely used radiometers.

Noise injection radiometer

The noise injection radiometer is an extension of Dicke radiometer. It is the final step toward the accuracy of radiometer. It means that the noise and gain fluctuations are both affecting in this case.

According to the equation [5]

$$V_{out} = c. (T_A - T_R). G$$

It can be seen from the equation that if

$$T_A = T_R \text{ then}$$

$$V_{out} = 0$$

This is the condition which noise injection radiometer tries to satisfy. To understand the working of noise injection radiometers consider the figure shown below.

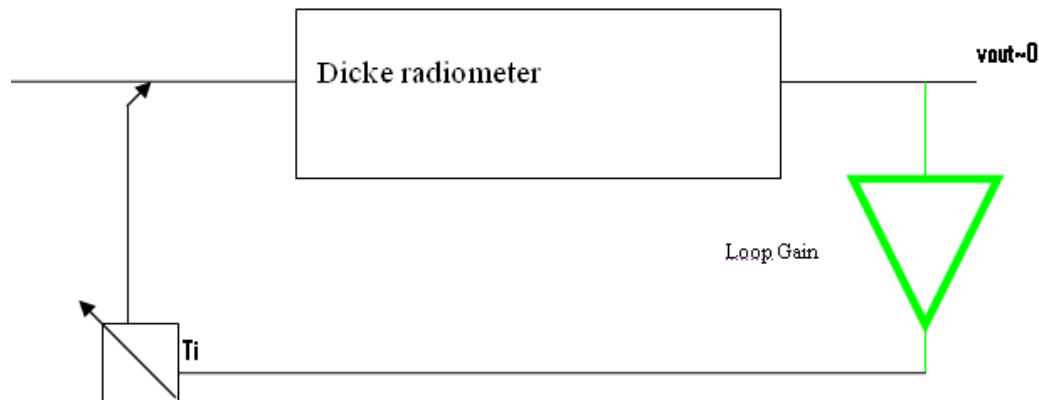


Figure1.6: Noise injection radiometer [5]

It can be seen from the figure that how the value of T_i is added to the antenna signal T_A , so that the resultant input to the radiometer is equal to T_R which must result in zero output voltage. The job of the loop is to adjust T_i to make it equal to T_R to get the zero output.

2 LOW NOISE AMPLIFIER DESIGN

A low noise amplifier (LNA) is a device used in communication systems which amplifies very weak signals captured by the antenna. Almost in any communication device the LNA is located very close to the antenna, in fact the first component after the antenna is the low noise amplifier. An LNA is the combination of low noise, high gain and stability over the entire range of operating frequency. Wireless communications are very Lossy, so signals travelling from far away normally suffer from a lot of degradation. When these signal are received at the antenna they are very weak, that is why the LNA is used very near to the antenna. In radiometer cases where the temperature is sensed by the antenna and from the antenna output received signal is amplified and purified from noise. The design of the LNA is a rather challenging task compared with other RF components.

Any electronic component design involves the use of lumped components. By the word lumped component one means either capacitors or inductors. These components are frequency dependent, meaning that their reactance values will change as the frequency increases or decreases. The figure below shows the relationship between the reactance and the frequency.

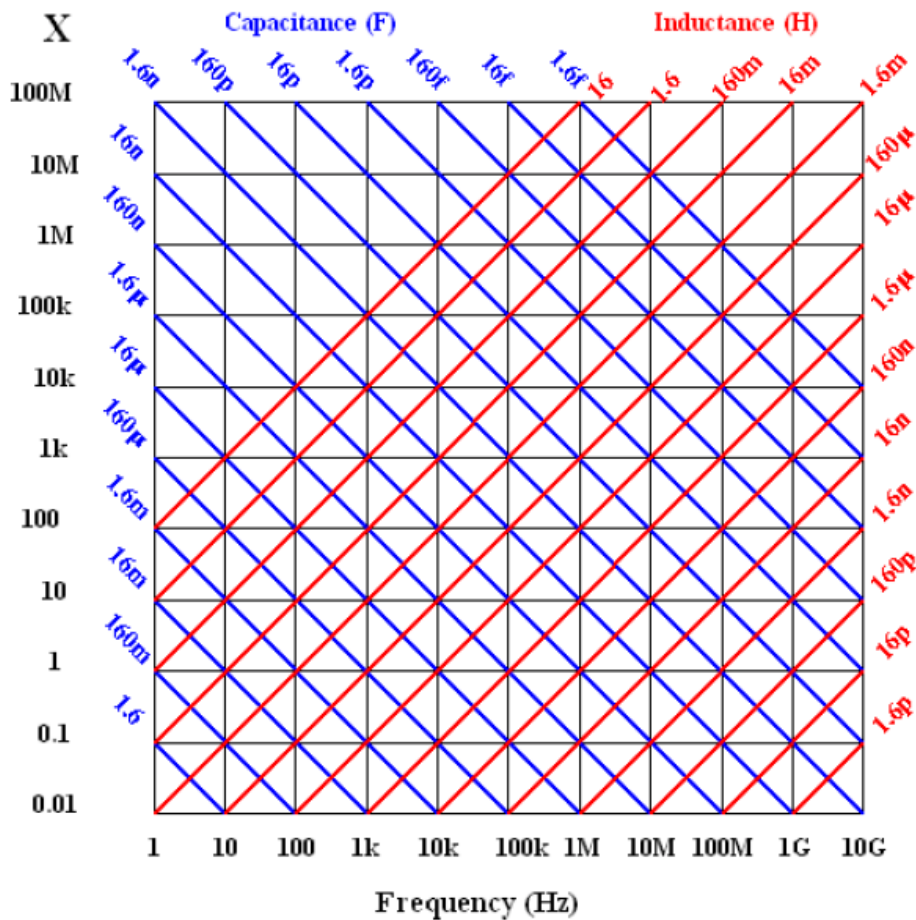


Figure 2.7 Reactance Vs Frequency [6]

It can be seen from the above figure that as frequency changes values for inductors and capacitors also change.

LNA design block diagram

The overall block diagram of LNA is shown in the figure below.

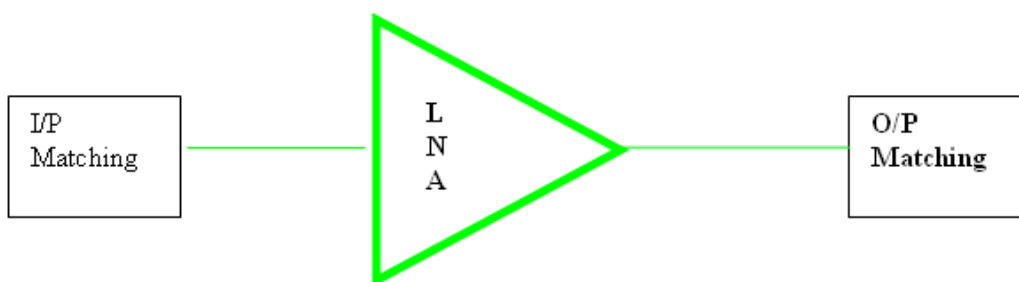


Figure2.8 LNA block diagram [7]

It can be seen from the block diagram that, there is an input and output matching circuit on the two ends of the amplifier. Theoretically input and output impedances are considered to be 50Ω [7]. In practical conditions it is not necessary that these are 50Ω , but may be closer to this value.

S-parameters

For an RF design S-Parameters are an extremely useful tool, specifically in the amplifier design. S-parameters were originally introduced in 1950, since then they have become a very powerful tool in RF design. Most of the manufacturers characterize RF transistors by their S-parameter values. S-parameters or scattering parameters provide all the information required to design a Low noise amplifier.

For a two port network as in this case the following S-parameters need to be considered

- S_{11} ———▶ Input reflection co efficient.
- S_{22} ———▶ Output reflection co efficient.
- S_{12} ———▶ Forward transmission co efficient.
- S_{21} ———▶ Reverse transmission co efficient.

Scattering parameters describe the concept of a travelling wave in order to describe a network having n number of ports. A wave generated by a source travels through the transmission line and drives the load where it becomes the incident wave. If there is any mismatch by the wave then it will cause a reflection. Then the wave will be known as the reflected wave. The reflected wave will travel back towards the source or generator.

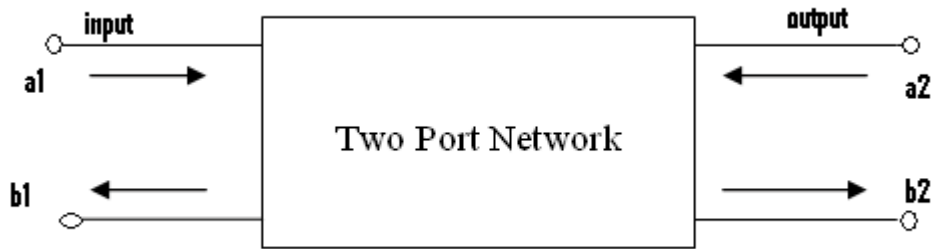


Figure2.9 S-parameters of 2-port network [8]

It can be seen from the above two port network how the travelling wave travels from the source and the reflected waves are shown as well. It can be seen that a1 is the input wave b1 is the reflected wave due to mismatch. Similarly b1 is the wave emerging from the output port and b2 is the reflected wave due to mismatch.

Noise factor

Noise factor is the measurement of degradation of signal to noise ratio. In telecommunications this term is used to measure the degradation of the signal. When the signal reached the amplifier, it does not know which one is the actual and which one is the noise. It just amplifies the signal. If, for instance the signal strength is lower then the noise then instead of actual signal noise will dominate. So it is very important that a signal is purified from the noise. The term noise figure is used some times which is referred to as noise factor expressed in dB.

According to the formula for noise factor

$$\text{Noise factor} = F = (S/N)_{IN} / (S/N)_{OUT}$$

Noise figure = F dB.

Noise Parameters

To describe the characteristics of the noise, one must consider the following parameters

1. NFmin
2. Rn
3. Γ_{opt}

These are the three basic parameters need to be considered.

NFmin is the minimum possible noise figure which a transistor can give

Rn is the noise resistance of the transistor

Γ_{opt} is the optimum reflection co-efficient.

So, these are some of the terms need to keep in mind before an amplifier is designed.

3 Design of LNA

The design of a low noise amplifier is a step by step procedure. Before designing an amplifier the following parameters need to be kept in mind.

- Gain and Gain flatness
- Bandwidth
- Centre frequency
- Input reflection co-efficient
- Output reflection co-efficient
- Stability
- Biasing of the circuit

So these are few important parameters which need to be measured in design of a low noise amplifier. The design will be done by following the steps given below.

Steps for LNA design

The following steps can be performed for the design of LNA [9]

1. On the basis of application and S-parameters select a transistor
2. Calculate the stability factor 'K'.
3. Check the value of 'K'. Depending upon the value of K calculate Gain
4. If $K > 1$, then design input and output matching networks.
5. Plot input and out reflection co-efficient and associated gain and noise and stability of the transistor.
6. If $k < 1$, then add some resistive components to stable the circuit on the entire range of frequency at the expense of gain. Do this step unless the circuit is stable over the entire range of frequency.
7. Perform step 5
8. Add Dc biasing and again check the stability of the circuit
9. Generate layout of the circuit
10. Generate the mask file
11. Implement the hardware

These are the steps need to be performed to generate a low noise amplifier.

The flow chart showing the logical design is shown in the below figure.

Flow Chart for LNA design

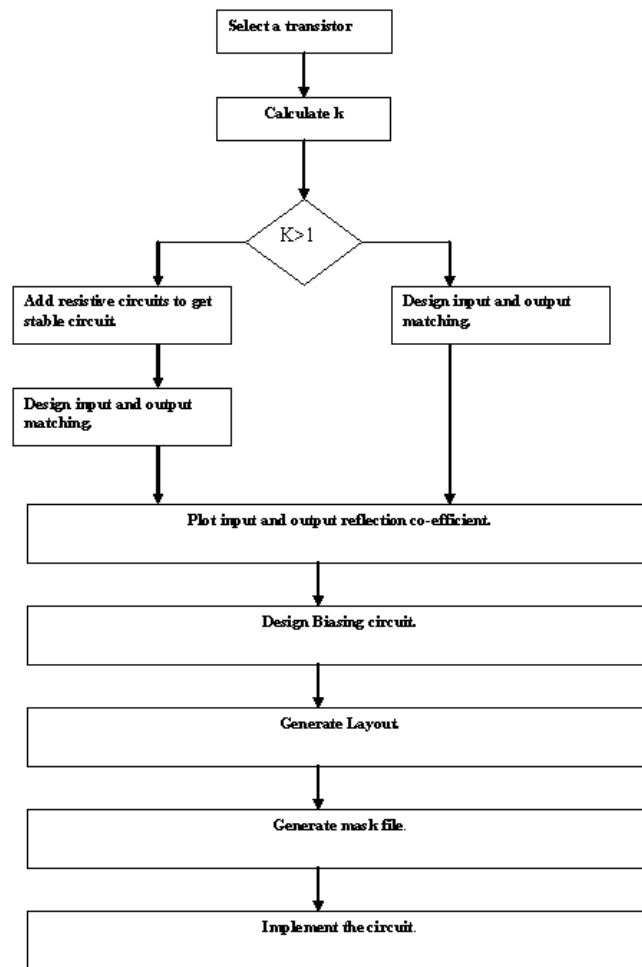


Figure3.1 Flow chart for LNA design [8]

This is just the simplified design procedure. Graphical representation gives an idea of how to perform the design in the lab.

Amplifier design parameters

Selection of Chip

The design task is to design an amplifier which can work from the frequency range of 2.44 GHz to 3.6 GHz. The particular chip package for this application is MGA-72543

Chip Specifications.

Agilent's MGA-72543 is an economical easy to use GAs MMIC low noise amplifier. The input is internally matched to the lowest noise figure into 50Ω. The output is internally matched to 50Ω. It is single stage amplifier with an integrated by pass switch. Below is the functional diagram of the MGA-72543.

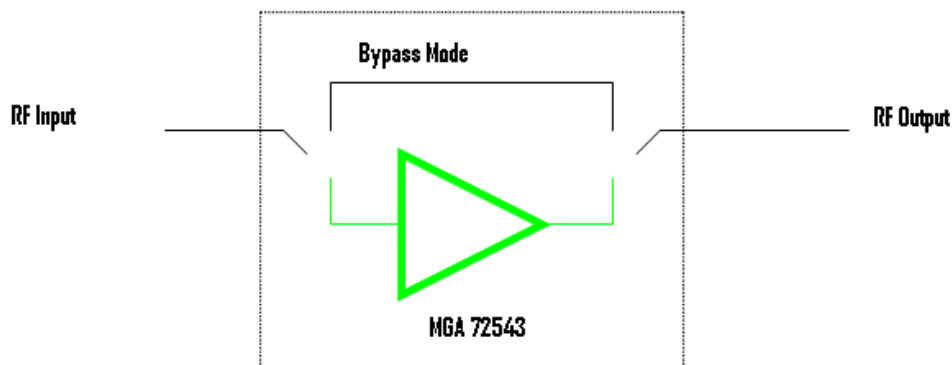


Figure3.2 MGA-72543 functional diagram

The purpose of the switch feature is to prevent distortion of high signal levels in receiver applications by bypassing the amplifier altogether. Here are some of the specifications of MGA-72543

- Operating frequency $F = 0.1 \text{ GHz to } 10 \text{ GHz}$
- $V_d = 3 \text{ v.}$
- $I_d = 20 \text{ mA}$
- $S_{11} =$
- $S_{22} =$
- $S_{12} =$
- $S_{21} =$
- Very small surface mount package

Substrate Selection

Amongst various choices available for substrate to implement the circuit, Fibre glass is used. FR4 is used with the specifications given below

Relative permittivity $\epsilon_r = 4.5$

Thickness $H = 0.8 \text{ mm}$

Dielectric loss $\text{TanD} = 0.017$.

These were some of the specifications related to the substrate which will be used for the implementation of the circuit.

Transducer gain

Transducer or power gain is denoted by G_t it is defined as the total power delivered to the load divided by the power available from generator. The equation which is used to calculate the transducer gain is given as below [10].

$$G_t = (S_{21})^2 * (1 - |\Gamma_s|^2) * (1 - |\Gamma_L|^2) / (1 - S_{11} \Gamma_s) * (1 - S_{22} \Gamma_L) - S_{12} S_{21} \Gamma_s \Gamma_L^2$$

Where Γ_L and Γ_s are output and input reflection co-efficient respectively.

How to extract maximum gain

There are various topologies which can be used to extract the maximum amount of gain. Depending upon the parameter requirement, as an example if NF is not a primary concern then conjugate match can be used to extract the maximum gain. When designing RF amplifier; especially LNA, there is trade-off between different parameters. Gain, stability and noise figure all these parameters are really important. It will be seen in the simulation that what can be done to get maximum gain, unconditional stability and minimum noise figure

Bias Circuit

Biasing of RF circuitry is very important. The term biasing is used in electronic circuits to set predetermined voltages and /or current to set a desired operating point. A bias point is a point which when applied to a device it causes the device to operate in a desired fashion. For linear circuits, which involve transistors and diodes require specific junction to operate correctly; this can be achieved by

using the biasing circuit [11]. The purpose of the amplifier is to amplify a weak signal into a strong signal without making any alteration in the shape of the signal. Before applying an AC circuit it is very important to properly bias the transistor.

MGA-72543 can use different biasing techniques. Biasing of MGA-72543 is similar to GAs FET. Passive biasing of MGA-72543 can be accomplished by two methods.

1. gate bias
2. Source resistor bias.

Both these techniques will be discussed one by one and one of them will be selected for the current application.

Gate Bias

MGA-72543 is a four pins IC. By using this technique the two pins 1 and 4 are DC grounded. As, it can be seen in the figure below:

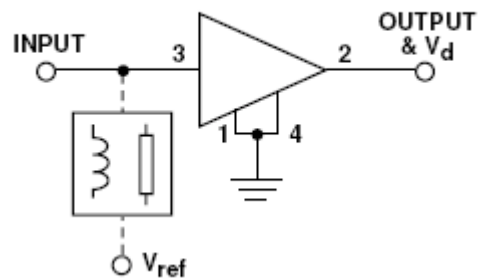


Figure3.3 Gate biasing [12]

The advantage of using this method is that it gives RF grounding of both the ground pins and also the DC. The major disadvantage of using this method is that it needs a negative input voltage. For applying the gate bias DC access to the input terminals can be made by using a high impedance transmission line as indicated in the above figure.

Source resistor bias

Although not used in the current application, but it still worth discussing this type biasing for MGA-72543. It is the simplest way of biasing MGA-72543 using a single positive supply. This method needs the ground pins to be RF bypassed. The input pin RF input at DC ground. The figure below will show the biasing using source resistor method.

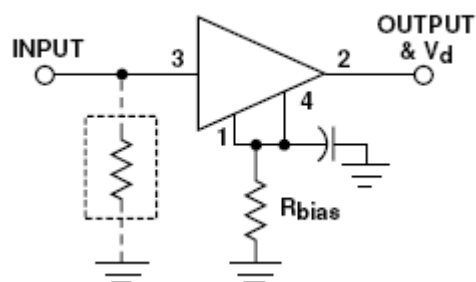


Figure3.4 Source resistor biasing [12]

The affect of the biasing circuit will be discussed in the design stage of the LNA. At this point it is just to discuss in perspective of the biasing required for RF circuit designs especially for a Low Noise Amplifier.

4 Software Selection and Simulation

The Smith chart is a powerful tool to design the RF circuit and for impedance matching. However as advancements in technology have been made, classical methods have been replaced by computer aided design. The modern system demands are very complex and there are varieties in terms of components available to use for building the circuits. To overcome these problems there was a need of computer aided design. There are various soft ware packages available for designing RF circuits; the software which has been selected for the simulation is Advance System Design (ADS). It is specifically designed to build RF circuits. ADS has been found very helpful during the design of LNA. There are a range of models existing in the ADS library to describe the amplifier components. ADS have built in library where a number. of components can be found. MGA-72543 is also available in ADS library. The design of the amplifier is carried out by following design guide feature of ADS. By using this feature an RF device can be designed. This is one of the most powerful features of this software. The ADS will be used to find the exact s-parameter values. It will be used to plot the noise, gain, stability and return loss parameters. Now the simulation circuit for MGA-72543 will be done step by step.

Single Stage design

The design will be presented has two types

- Single stage design
- Double stage design

In the case of single stage design, the topology will consist of one amplifier and all the parameter values will be recorded using single amplifier. Whereas using two amplifiers a two stage topology will be built and the comparison will be made. The two stage topology is an extension of single stage. Let us now consider the design of single stage LNA.

S-Parameters for MGA-72543

The simulation circuit below will show the S-Parameter values of the chip. These values are described by using the design guide in ADS.

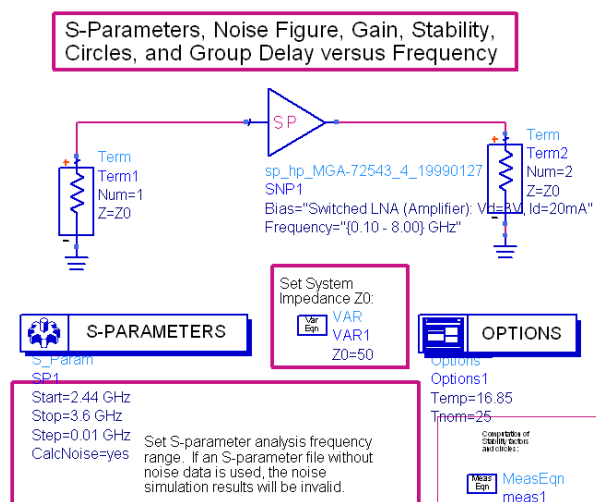


Figure 4.1 S-parameters simulation

The chip is selected from the library and put in the design guide circuit to check the values. Input and output termination is shown on both sides of the LNA they are both 50Ω in value. The value of S-parameters are shown in the table below at 2.44 GHz.

Table 4.1: S-Parameter Values

Frequency	S ₁₁	S ₁₂	S ₂₁	S ₂₂
2.44 GHz	-5.417 dB	-23.173 dB	12.97 dB	-9.63 dB

These values will vary at different frequencies. The design is supposed to work from any frequency range from 2.4 to 3.6GHz; S-parameter values can be obtained at any frequency and can be shown. As discussed earlier ADS will be used to plot the values of different parameters. The figure shown above also used to get the values of noise, stability and the gain circles.

Matching for Noise figure

Table will show the matching values for the noise figure.

Table 4.2: Matching values for Noise Figure

NFmin	Z ₀ for NFmin	Conjugate match load impedance Z _L *	Power gain with source and load coefficients.
1.43 dB	49.7 + j20.4	51.9 + j33.8	14.19

It can be seen from the above table that NFmin is 1.43dB at 2.44 GHz. With the conjugate matched impedance values are shown. The power gain is 14.19 dB is quite a reasonable value. Let us now design the circuit to get the maximum possible values of the specified parameters.

Matching for Gain

Table below will show the values for gain

Table 4.3: Gain values

Maximum available power gain	Z _S	Z _L	Z ₀	Stability factor k
15.462	14.826 + j35.052	27.674 + j39.981	50	1.186

The values of load and source impedances can be seen from the table above. For the matching to achieve the gain of 15.462 the stability factor is 1.186. This value of k satisfies the condition of being k > 1, to avoid any oscillation. The reference impedance of the system is 50Ω. Now the input/output matching network design carried out in ADS will be discussed.

Input/output impedance matching

The matching circuit for the amplifier is the most important part of the design. The impedance matching is very important in terms of building efficient circuit and to extract the maximum gain without having any oscillations [13]. LNA design is a complicated process, not only for LNA design, but any RF circuit. It is not expected that at first the best results will be achieved. Simulations take considerable time not for topology connections, but for the dimensions and to meet the required specifications changing and trade-off need to be made. The matching circuit which is built for the first time will be shown. This is very important to mention the first simulated result achieved; the whole design will be based on the first circuit. Below is the figure showing the topology.

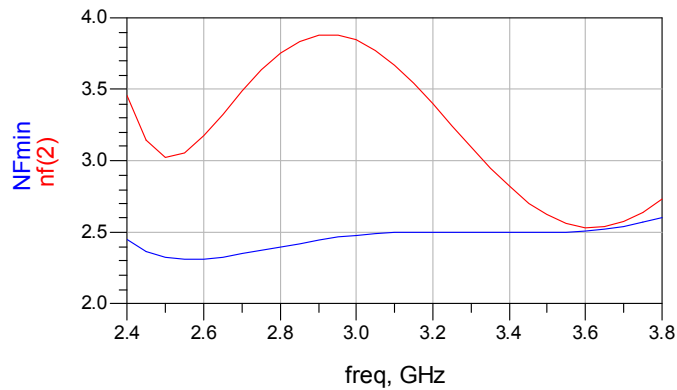


Figure 4.4 Noise figure

It can be seen from the figure that both NFmin and nf (2) are not quite satisfactory. If the comparison is made between the simulated waveforms of gain and noise figure, it can be seen that both of them are going in the opposite direction. If the gain is increasing then the noise is decreasing and vice versa. It is not possible to get gain and forget other parameters. This kind of behaviour in RF design makes things bit complicated. Also this does not only involve gain and noise but also other parameters. The next one is Stability. Let us look at the stability waveform.

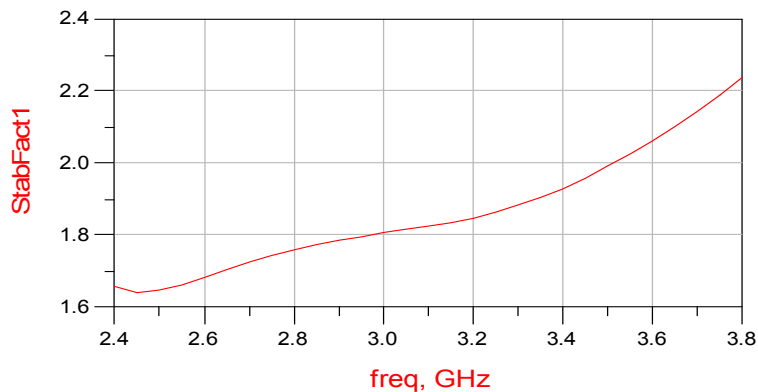


Figure 4.5 Stability

The stability value is quite satisfactory, right above the required value of > 1 . Which means that the device will not oscillate as far as simulation is concerned on these matching values. It is also important to consider the values of input and output return loss at this stage. The figure given below shows the return loss.

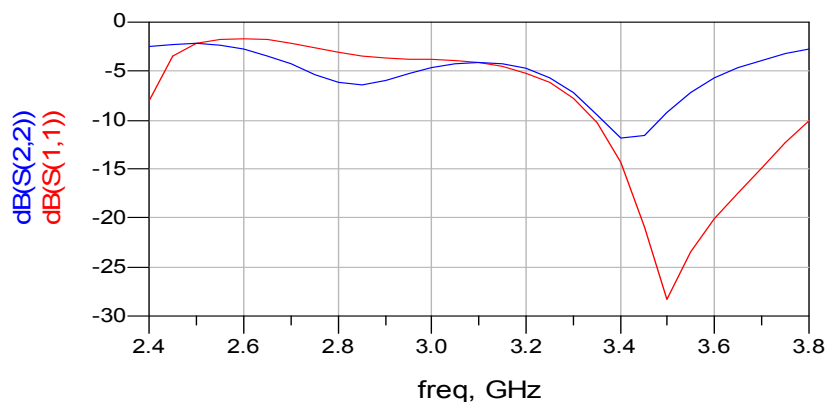


Figure 4.6 I/O return loss

It is shown in the figure that, return loss is not very good as far as both input and out put values are concerned. The values are less than 0 which is good but still the loss should be minimised in all the way through on the operating band.

From the above circuit simulation the conclusion arises is that two parameters need be adjusted; gain and noise figures.

By using ADS that is not a big problem. Optimisation function will used to get the optimum values of gain and noise. On the other hand care must be made in terms of stability because gain and stability are inversely proportional to each other. One of the problems faced in designing this circuit was that; design is not on just one frequency it is on the band of frequency which is quite challenging task itself. To maximize the gain, minimize the noise figure and keep the circuit stable there was no need to change the topology of the circuit. The only factor which needs to be changed is the dimensions of the transmission lines used in the circuit design. The simulation for an optimised version of the above circuit is shown is given in the figure below.

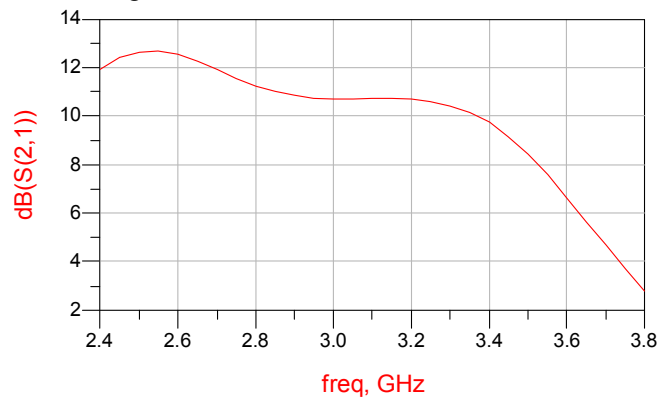


Figure 4.7 Optimised gain

It can be seen from the above figure that the gain is not better and flatter then the one for the previous waveform. As discussed earlier that topology of the circuit remained the same, the only thing which is changed is the dimension of the circuit. These dimensions are optimised by ADS to get the best possible results. To see the difference between the dimensions consider the figure below which shows the comparison between the dimensions.

Table 4.4: dimensions comparison of two simulations

Dimensions for simulation1	Dimensions for simulation2
TL2.L = 23.6423e-03	TL2.L = 42.8818e-03
TL2.W = 5.15459e-03	TL2.W = 2.95885e-03
TL8.L = 37.25e-03	TL8.L = 20.4264e-03
TL8.W = 1.34861e-03	TL8.W = 2.93541e-03
TL7.L = 38.8576e-03	TL7.L = 25.2131e-03
TL7.W = 4.66473e-03	TL7.W = 2.05843e-03
TL1.L = 31.2328e-03	TL1.L = 20.9886e-03
TL1.W = 1.84689e-03	TL1.W = 2.2629e-03
TL5.L = 21.5545e-03	TL5.L = 22.9147e-03
TL5.W = 4.70074e-03	TL5.W = 2.02954e-03
TL6.L = 22.1305e-03	TL6.L = 26.4241e-03
TL6.W = 4.43415e-03	TL6.W = 3.60708e-03

It can be seen from the table that by keeping the same topology two different versions of the results has been achieved due to the fact that the size of the transmission line has been changed. This gives a clear idea of the sensitivity of the RF circuit design. A very small change in dimensions can lead to a big change in the output of the circuit.

What about the other parameter measurements? Have they got any changes as well? Let us now see the noise figure of the optimised circuit.

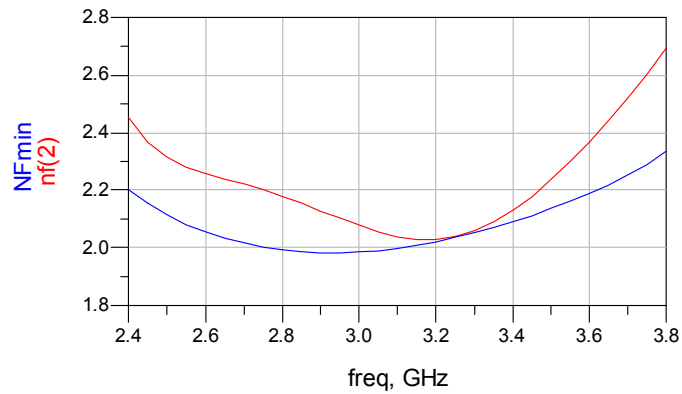


Figure 4.8 Optimised noise figure

The difference is very clear. By comparing it with the simulation1 it can be seen that this time the noise figure is lower. This time both NFmin and nf(2) are better than the previous case. It means that optimisation has worked for this topology and results have improved this time. The stability and input/output return loss have improved as well. Below are the figures for both of them.

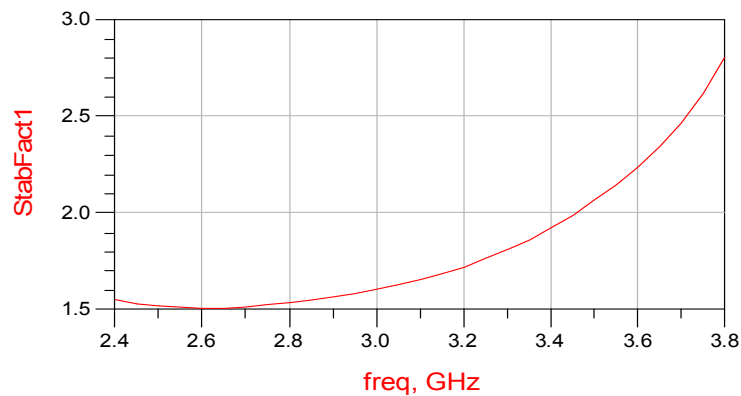


Figure 4.9 Stability for optimised circuit

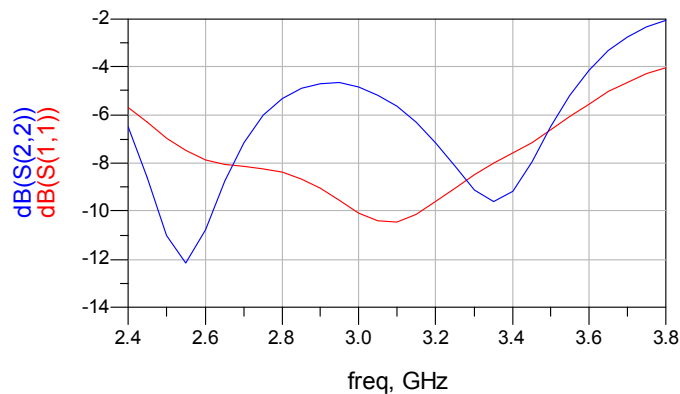


Figure 4.10 I/O return loss for optimised circuit

The above topology still can be optimised. These are not the final measurements. The maximum potential values on frequency range of 2.44GHz to 3.6GHz are shown in the figures below. Maximum available gain for this particular circuit is:

Final design of single Stage Amplifier

The waveform below shows the gain value of the single stage LNA design.

It is quite clear that the gain has improved a lot. There are certain reasons for that. Change in the dimensions of transmission lines off-course had significant affect, but the capacitors used in the circuit have replaced by the moarata components. This shows that not only the size of the components affects but also the type of the components significantly affects the circuit performance.

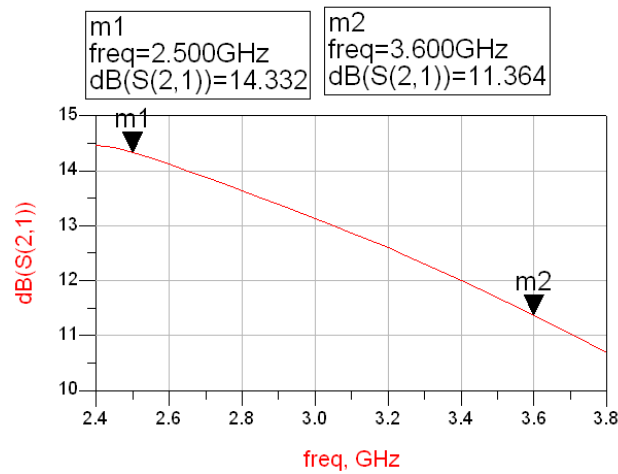


Figure 4.11: Maximum gain

Gain start at maximum value of 14.45dB and the minimum value is at 3.6GHz which is 11.364, quite acceptable. To check the noise figure of this circuit below is the attached waveform.

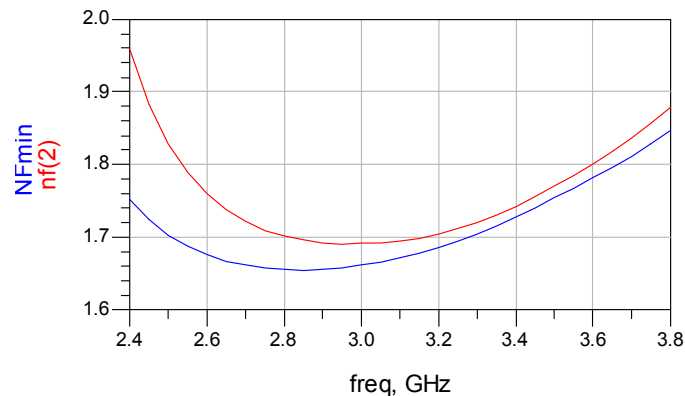


Figure 4.12 Minimum noise figure

Like gain noise the figure improved equally as well. In this case NFmin and actual noise figure both are kept under 2dB over the whole operating band which is a big achievement. As noise figure and gain are inversely proportional to each other, the improvement in both the parameters show that replacement of components had good affect on the circuit performance.

The next waveform is the stability of the circuit. The stability waveform is shown in the figure below.

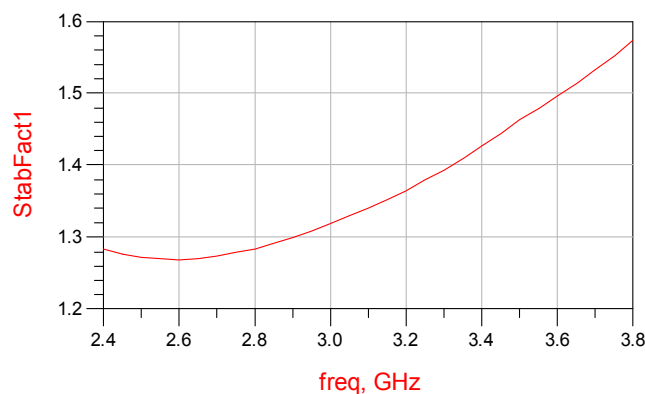


Figure4.13: Maximum stability

It is clear from the stability waveform that it is quite above the minimum condition for the circuit to avoid any oscillation. Although the stability factor is a little bit lower than in the previous case, where it was above 1.45, this is not important either as it is >1 .

Return loss values have improved with quite remarkable margin. Both input and output return losses are below -10dB , which is very much acceptable.

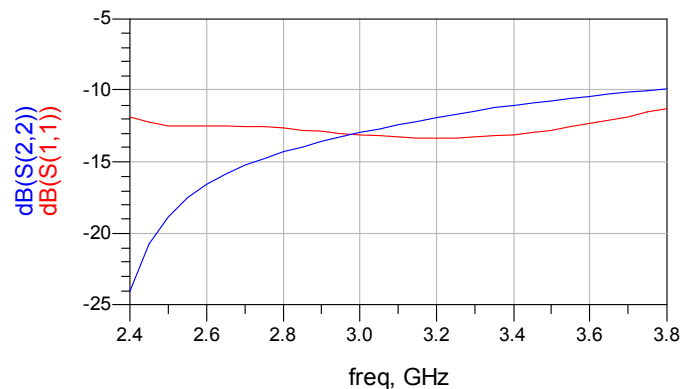


Figure 4.14 Best return losses available

From the waveforms the conclusion can be made that all the parameters have improved. Their values have changed with a significant ratio. But still the potential is there to get better results. In practical applications gain > 10 and also input/output return losses should be $< -5\text{dB}$. Stability should be > 1 and noise figures should be kept at minimum [13]. So keeping in view some adjustments have been made and below are final single stage amplifier design for MGA-72543 at frequency range from 2.4 to 3.6 GHz.

This was all about the simulation of single stage LNA design using MGA-72543. These results are satisfactory and acceptable for any application in the frequency band for which the amplifier has designed.

The next step is the design of a two stage amplifier. The two stage amplifier is an extension of single stage one. It gives more gain than single stage one [14]. It can be used for the applications where there is need of higher value of gain. The design topology of the two stages LNA is given in the next section.

5 Two Stages LNA Design

As discussed earlier as well that second stage design is just the extension of the one stage. The difference between the two is that in two stage one two chips of MGA-72543 will be used in cascaded. This will provide more gain and the stability as well. The schematic diagram of the two stage design is shown in the figure 5.1.

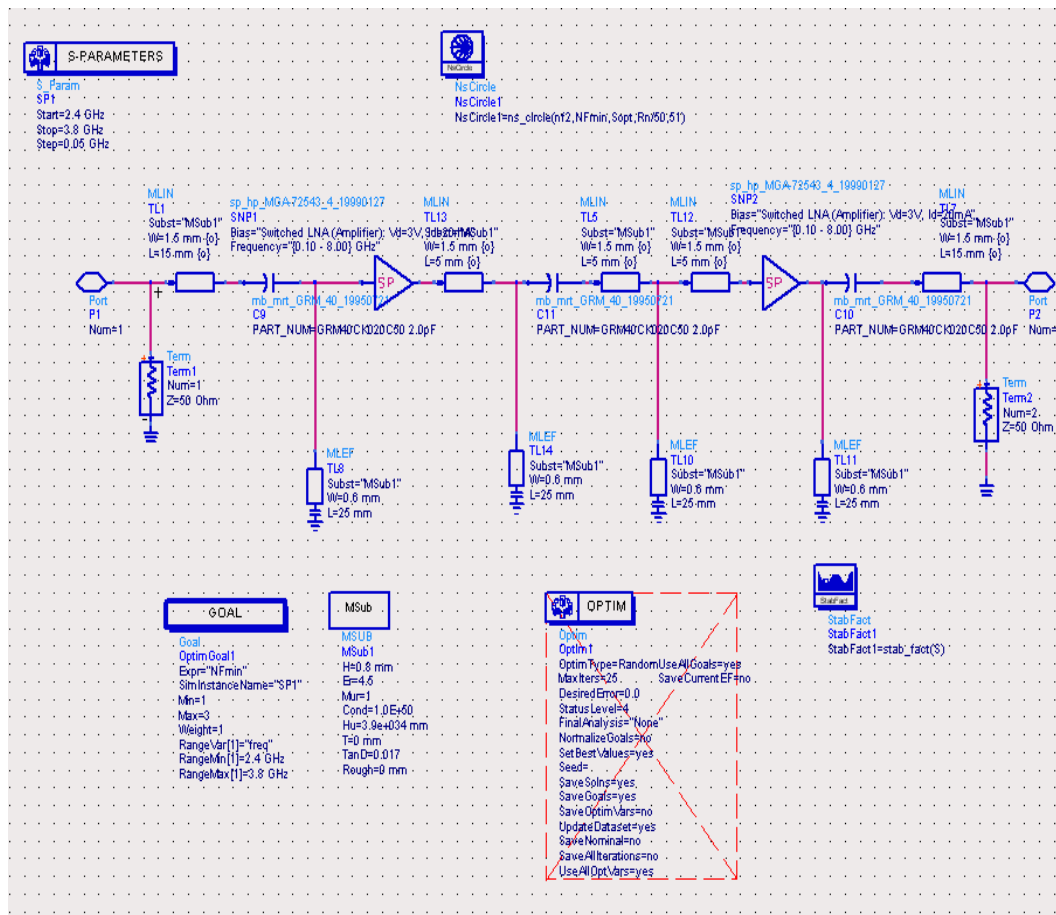


Figure 5.1 Two stage LNA circuit diagram

It can be seen from above circuit diagram that two are two chips cascaded. The matching circuit is based on the same idea as the one for the single stage design.

The topology shows three capacitors attached to block the DC. The point to be noted is that the biasing applied is the gate biasing. So at every junction voltage needs to be blocked. That is why there is a capacitor attached in input and output matching and also between the two chips. Results obtained after simulations are very good again and well within the required specifications. Let us now discuss them one by one.

Parameters for 2-stage design

The simulated result for the gain of 2-stage design is shown below

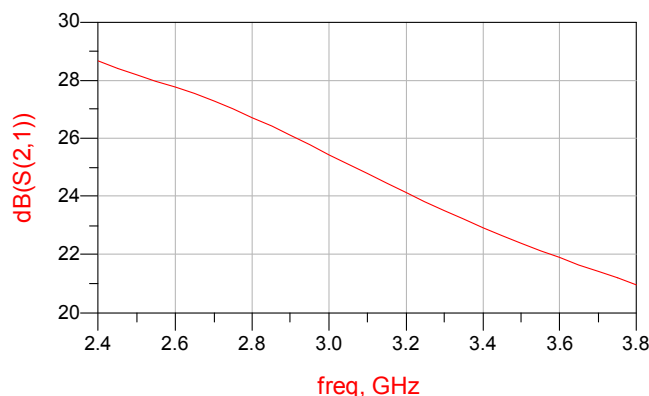


Figure 5.2 Gain for 2-stage LNA

It is very clear from the waveform above that the gain is of quite a high value compared to the single stage amplifier design. It starts at about 28.9 at 2.4GHz and at 3.6 GHz the value is about 21.9. This is a big improvement in the circuit design. The improvement is because of the 2- chips used. This design is very useful for those applications where the gain requirements are high. Other parameters are also equally important as well as the gain. The waveform for the noise figure is shown below:

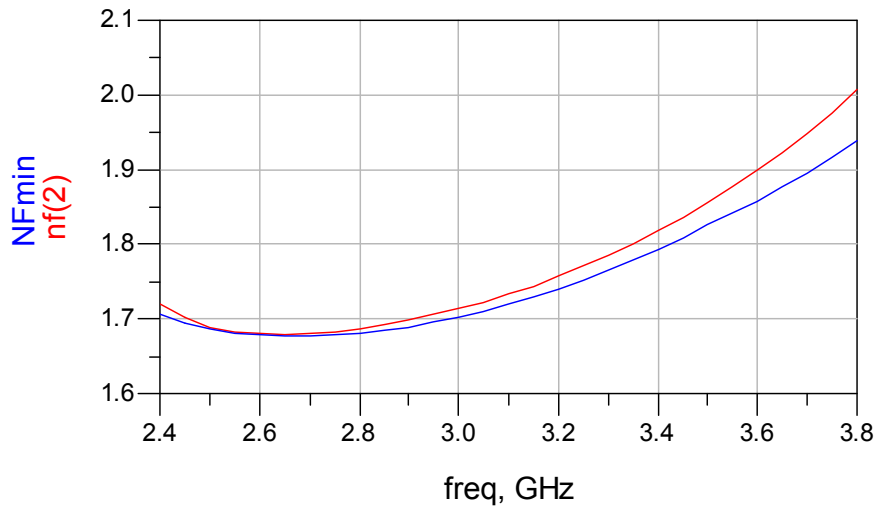


Figure 5.3 Noise figure for 2-stage LNA

The noise figure waveform shows very good results. On the entire operating band it is < 2dB which is very much acceptable. The stability is also important at this stage, so the waveform below will show the stability measurement.

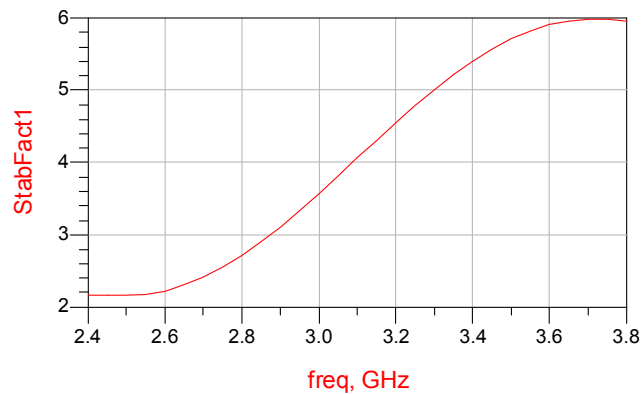


Figure 5.4 Stability for 2-stage LNA

The stability results seem to be above 2, which is far better than the required value. So the chances of any oscillation do exist in this circuit design. The input and output return loss is shown in the below waveform.

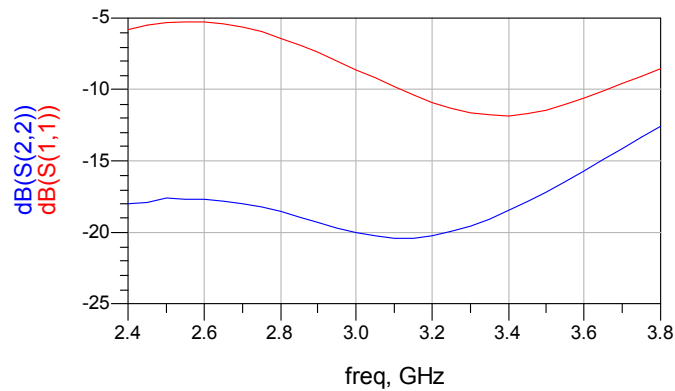


Figure 5.5 I/O return loss for two stage design

For this circuit the output return loss is always good. The value of input return loss is little higher than it could have been. It shows that at some initial frequencies the value is about -5dB; it is improving as the frequency is increasing. So the overall performance of the designed circuit is very much satisfactory as far as the simulation is concerned. At the end of this section a comparison will be shown between the two stages results in terms of gain, noise, and stability and return loss.

Table 5: Comparison between two design simulations

<u>Parameter Name</u>	<u>Single Stage Design</u>	<u>2-Stage design</u>
Maximum gain (dB)	11.364	21.892
Minimum Gain (dB)	14.459	28.654
Noise Figure (dB)	< 2.0 on entire band	< 2.0 on entire band
Stability	> 1.28	> 2.2
Input return loss (dB)	< -10	< -5
Out return Loss (dB)	< -10	< -15

On the basis of the above comparison the circuit can be used as required for any specific application. As discussed earlier for both of these designs the biasing scheme used is gate biasing. For this particular application some DC-DC conversion will be required to inject from the input port. This is the only disadvantage of this particular design, but this is not significant, since these days there are power supplies which are available which can do this task.

6 Implementation and Testing

The last part of the project is to implement the design carried out in ADS in the physical form. This was actually quite a satisfactory experience. It gives an idea of how the physical and simulated circuit differ from each other. This part of the project gave the chance to work with the equipments used for surface mount, and physically connect different components and put them in a way that they work properly. The implementation is done in steps which are given below.

- 1) Layout generation
- 2) Mask file generation
- 3) PCB manufacturing
- 4) Component connections

The first step is to generate the layout, which is quite simple. Beginning by ADS using 'layout' from the toolbar layout is generated. After the layout is generated the next thing to do was to generate the art work. From the file menu in layout window art work is generated. This gives the facility of generating different types of files from the layout. The mask file with the extension '.msk' is selected to generate the mask file. This mask file contains the dimensions of all the transmission lines. The mask file generated is used to generate the PCB. Once the PCB is generated the next thing to do was the component connections. This was the difficult task in the implementation part of the project.

The implementation of the circuit has been performed by using the surface mount technology. In the RF context it was new for the equipment to be used. This part of the project required much effort, but finally it was completed and quite satisfactory results were achieved although some parameters were not perfect.

The figure below will show the layout of the designed circuits in ADS.

Layout of single stage LNA

The layout for the single stage design is quite simple it is shown in the figure below

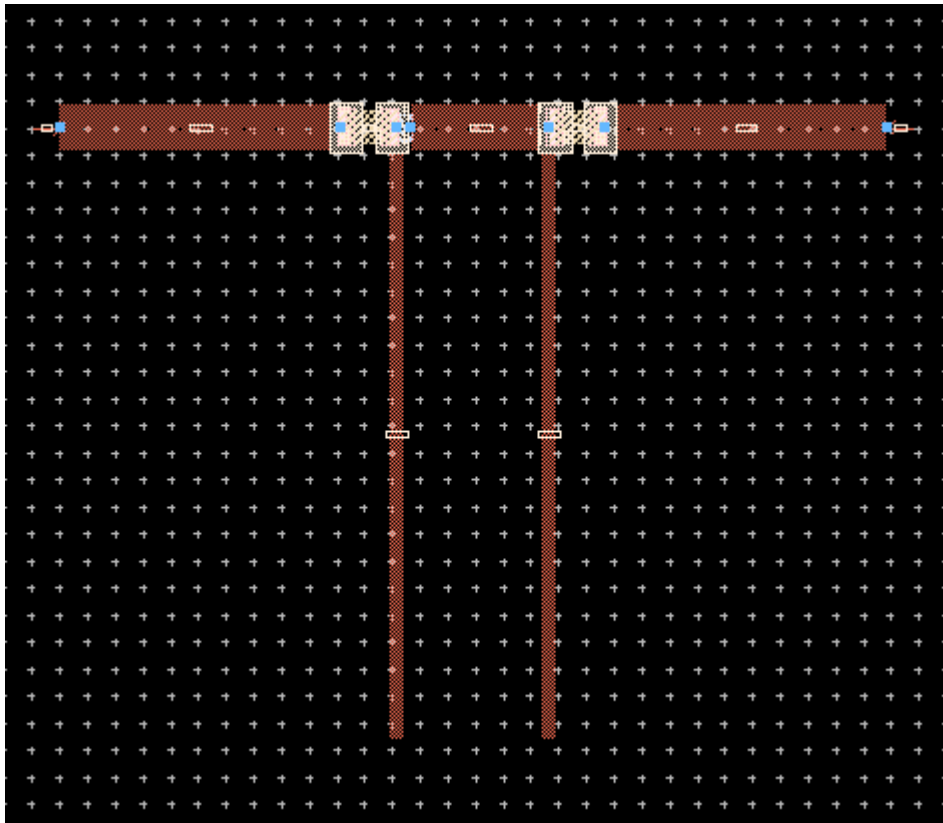


Figure 6.1 Single stage LNA gain

As it can be seen from the above figure that single stage LNA design having two ports attached with transmission lines. There are two transmission lines attached to the ground with the capacitors at the end to avoid any DC coupling.

Measurement results

Below are shown the measured actual results for the single stage LNA design. It can be said that results were satisfactory although not perfect as they were in the simulation. There can be certain factors for that, for example components used in simulation are ideal where as they behave differently when implemented physically in the real world.

The figure below will show the gain for this circuit.

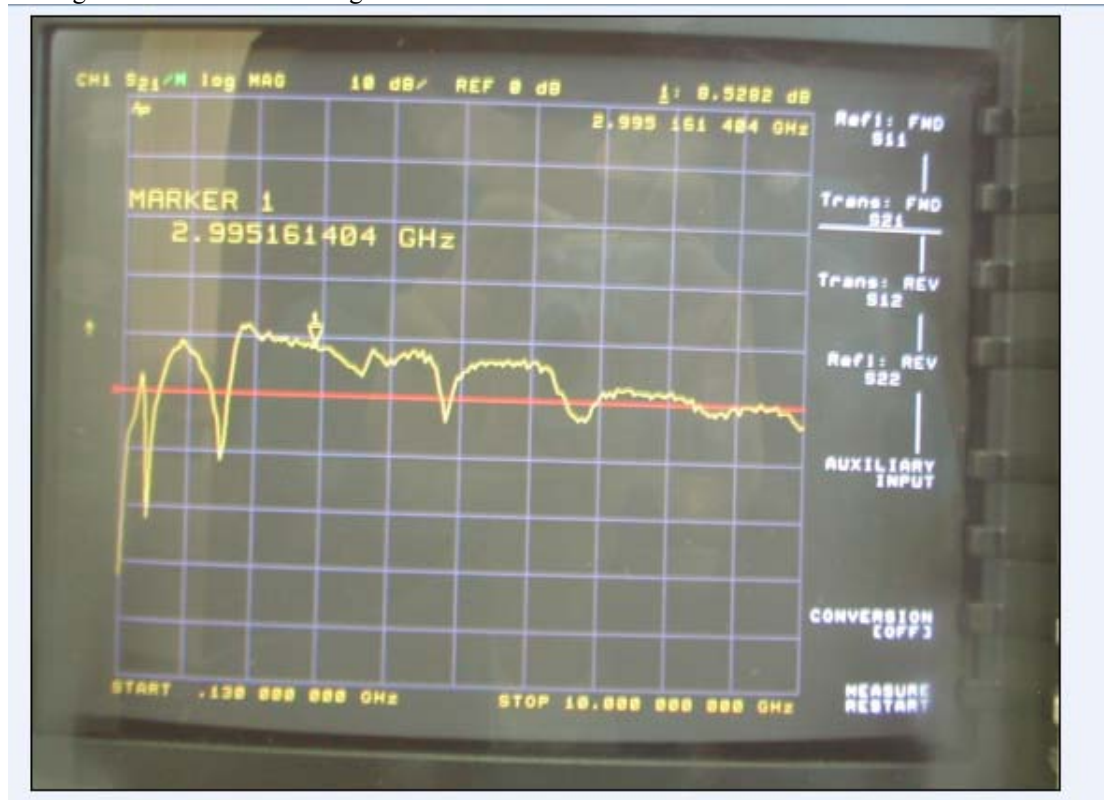


Figure 6.2 Gain Measurement

It can be seen from the waveform that gain is quite good; about 9.5282 dB at 2.99 GHz is a good value. The simulation was giving actually about 14-11 dB from 2.4-3.6 GHz. So it does not vary too much compared with the simulated results.

The next step is to check the reflection co-efficient. The waveform below will show the input reflection co-efficient:

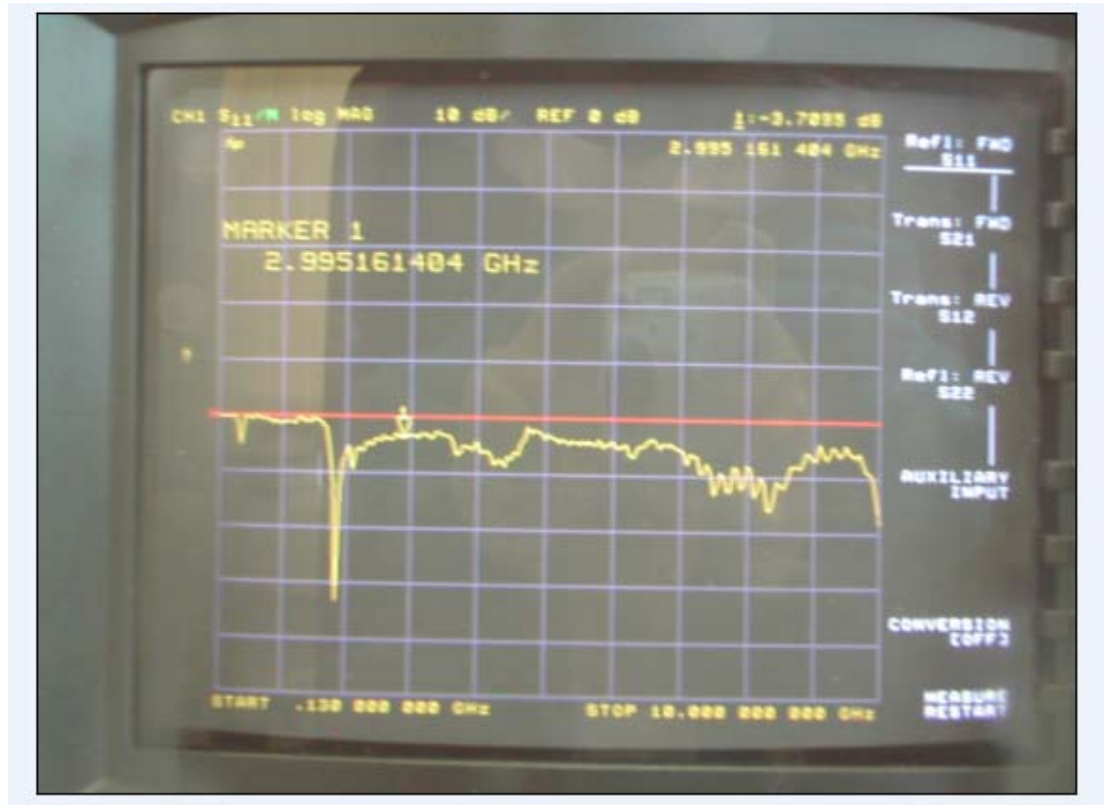


Figure 6.3 Input reflection co-efficient

The input reflection co-efficient S_{11} is less than -3 at all frequencies over the operating band. This is not perfect as an ideal result could be less than -5 dB but as mentioned earlier the physical implementation is quite different to the simulations. When simulated the above circuit, S_{11} was always less than -10 dB over the entire operating band. This shows that it varies with quite a big margin as compared to simulations, maybe other parameters have affected the implemented results. To see the S_{22} consider the below figure:

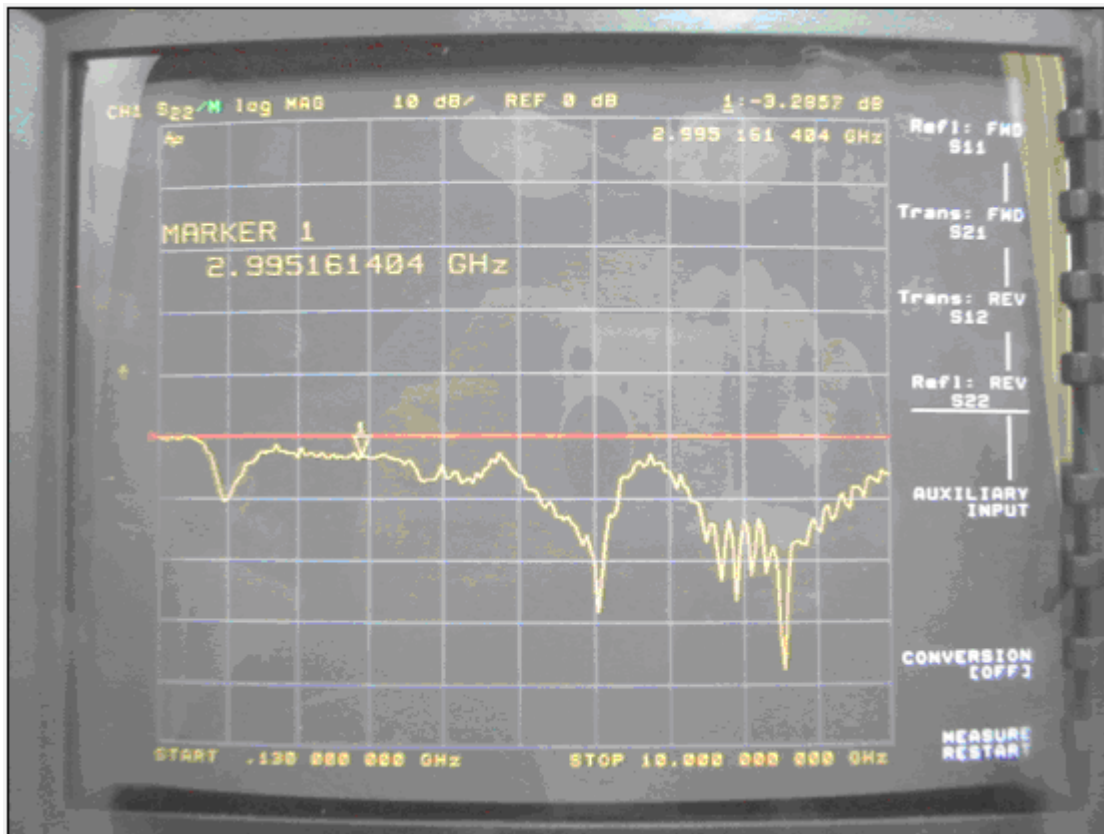


Figure 6.4 Output reflection co-efficient

Again like S11, the result varies as compared to the simulated results. However the important thing is that both input and output reflection co-efficient are less than -3 dB. These results could be made far better but the time limitations and the actual components used were not those planned for in the design, because almost all the companies were out of stock. If the actual components are used then these results could be much better than they appear in the analyser waveforms.

Single Stage LNA Circuit

The circuit implemented for the above layout is shown below.

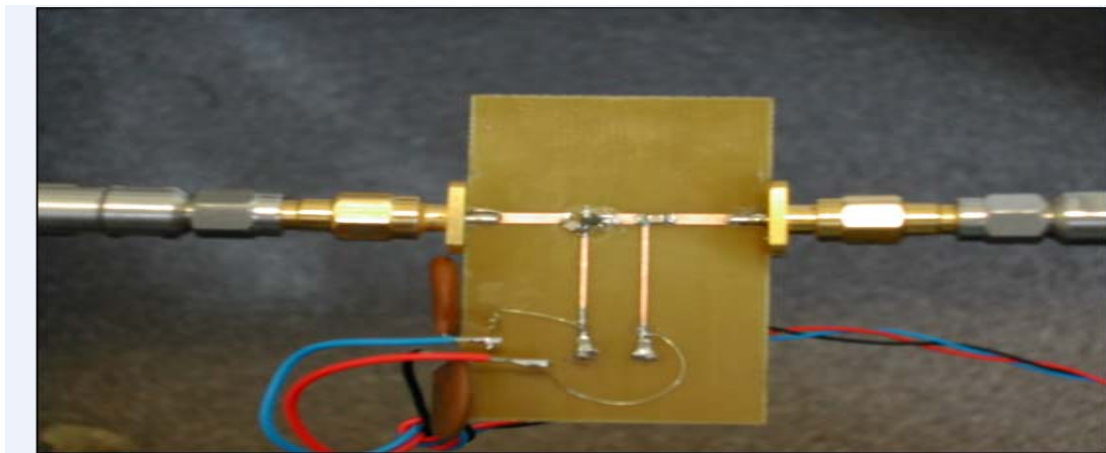


Figure 6.5 Implemented circuit for single stage LNA

The actual circuit board shows the single stage LNA implementation. As discussed earlier implemented results vary as compared to the simulated results the reason being is that capacitors used in the circuit were not the actual ones and also may be the fringing affect that could cause this. In summary this design was successful and results achieved were also satisfactory.

Two Stage LNA Design

As in the single stage design the two stage design was also satisfactory except few problems overall results achieved were good. The design of two stages LNA will be discussed step by step.

Layout for 2-stage LNA

The layout for 2-stage LNA is shown in the below figure:

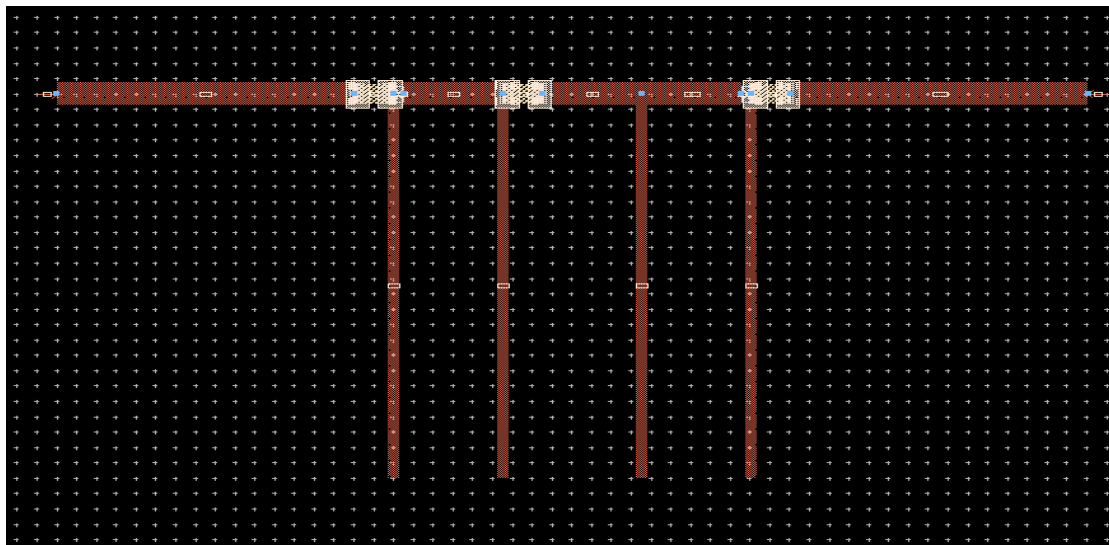


Figure 6.6 Two Stage LNA layout

It can be seen from the layout diagram that the 2-stage LNA is like an extension of single stage design. The design becomes complex in comparison to the single stage one. There are two MGA-72543 chips used this time instead of one, like in single stage design. Again transmission lines have been used as the transmission medium.

Measurement results for 2-stage design

For this design again the results are quite satisfactory. The gain value is almost double of what was achieved in the single stage design. The problem with this design is that it behaves quite badly at 3.5 GHz of frequency. The problem is extracted already which is the decoupling capacitor used for the high impedance. Due to lack of time and also not having the exact component this problem can not be solved at this stage. On the rest of the frequency the design is very good and quite a high value of gain is available. The below figure from the network analyser will show the actual measured value of gain:

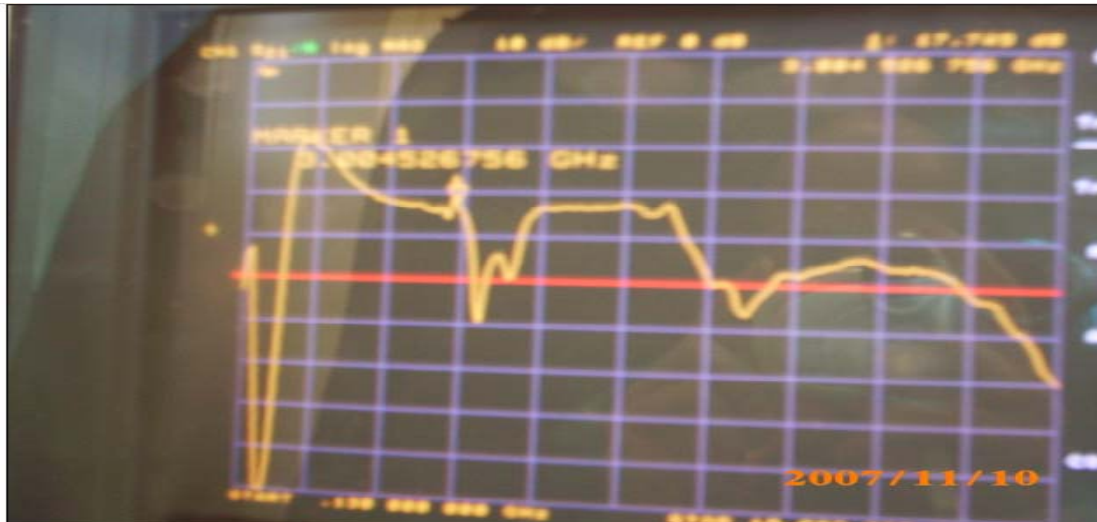


Figure 6.7 Two Stage LNA gain

Although not very clear picture because of the camera used to capture the picture was not very good, but still visible. One good thing about the design is that except at one frequency it gives quite tremendous value of gain right from 1 GHz to 6 GHz, which is very encouraging. As mentioned earlier the reason for the problem at 3.5 GHz is already been identified, but lack of time is again a problem to solve this problem straight away. The input and output reflection co-efficient are also shown in the below figures:

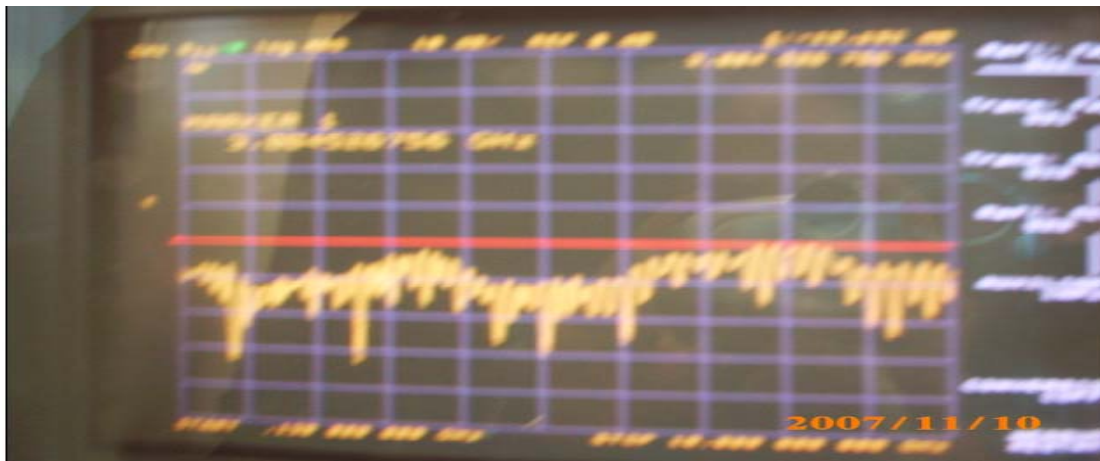


Figure 6.8 S11 for two stage LNA design

Again not quite visible, but the red line shows the zero value, so the Input reflection co-efficient like stage 1 is less the -3 dB at almost entire operating frequency band. The output reflection co-efficient is given by the figure

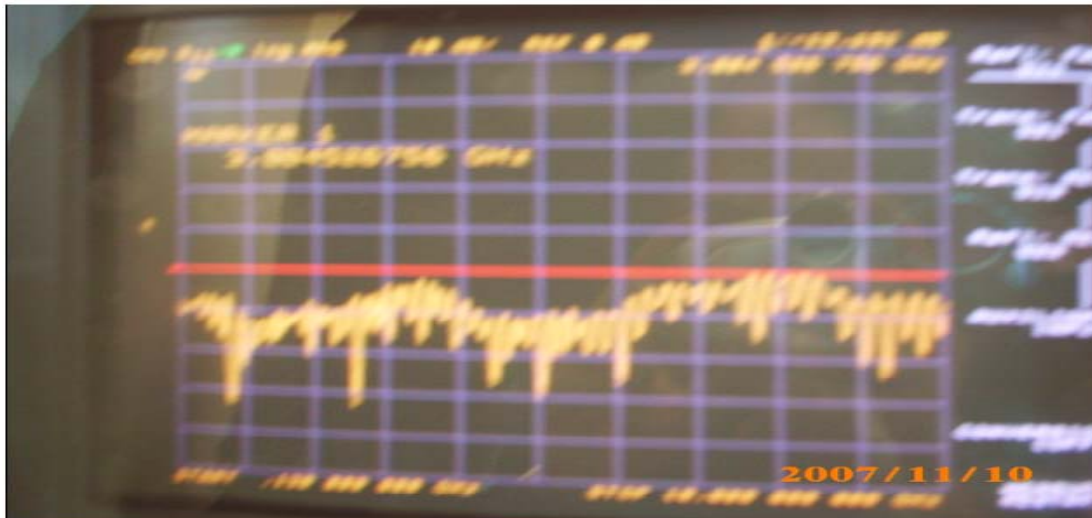


Figure 6.10 Output reflection co-efficient

Like S_{11} , S_{22} is < 0 over the entire frequency band. In conclusion it can be said that 2-stage design was quite successful and also gave satisfactory results except few problems which are mentioned earlier.

Two Stage LNA implemented circuit

The circuit implemented for two stage LNA design will be shown below. Unlike the single stage it was a little complicated. Some extra effort was put into the design this stage. Also surface mount technology was used for the first time, so it is obviously not very easy when using first time. In the end some useful results were achieved. So the figure below will show the physical topology of the 2-stage LNA design.

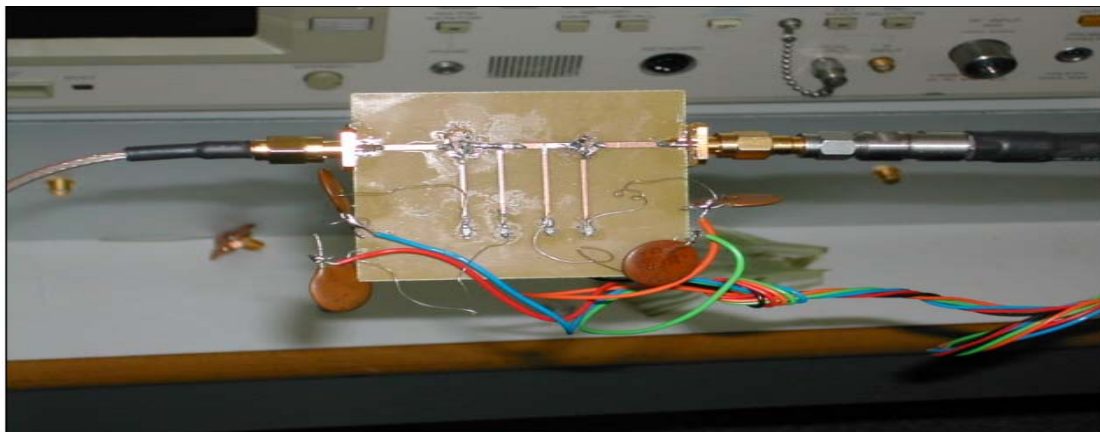


Figure 6.11 two Stage LNA physical circuit Diagram

Comparison between single stage and two stage design

The comparison between the single stage and 2-stage design will be shown in the form of a table. In conclusion it can be said that both designs were successful and the results achieved were also satisfactory. There were some problems in the 2-stage design which were identified as well. Now the table below will show the comparisons:

Table 6: Comparison table for both designs

Parameter	Single Stage	2-Stage
Frequency Range	2.4-3.6 GHz	2.4-3.6GHz
Minimum Gain	6 dB at 3.6 GHz	16 dB at 3.6 GHz
Maximum Gain	12 dB at 2.5 GHz	22 dB at 2.45 GHz
Noise	Not Measured	Not Measured
Stability	$\gt 1$	$\gt 1$
Input Return Loss	$< -2\text{dB}$	$< -3\text{dB}$
Output return loss	$< -3\text{dB}$	$< -2\text{dB}$

From the above table it can be concluded that both designs have parameters measured under the same conditions. The noise parameter for both designs could not be measured because of the lack of the right apparatus to measure the noise figure. Other parameters were very much satisfactory and acceptable.

7 Conclusion and Future Work

Using MGA-72543 process of LNA design for the radiometer was effective in that all the required goals were achieved successfully. The operating band is from 2.4 to 3.6 GHz. On the entire operating band noise figure was kept less than 2dB, and gain more than 11dB for the single stage design which is a major achievement. For the 2-stage design again the same results were achieved in terms of a noise figure but gain is almost double that at the single stage at every point. One of the important factors to consider was to make sure that there is no oscillation over the operating band, so the stability factor should be > 1 , which is achieved with a margin as well. In the case of a single stage design $K > 1.25$ and in the case of 2-stage design $K > 2$.

When designing LNA the emphasis is always put on the noise figure. Since LNA is a low noise and high gain component in the receiver chain, so keeping in mind this factor it was preferred not to use any noisy component like resistors. Also the Radiometer is a very sensitive receiver so, it is desirable not to use any inductive component, and so neither inductors nor resistors were used in this design.

The specifications were challenging in terms of frequency range because when designing RF devices there is always the trade-off between different parameters like gain, noise figure, stability and VSWR. The major achievements in this design were flat gain response, unconditional stability at entire operating band, small noise figure which is < 2 for both designs and broadband VSWR.

As far as future work is concerned the design can be extended from 0.5 to 10 GHz applications, which means a broadband design, can be made by using this chip. That can be used for any application on this operating band. Also the biasing scheme used in the design is the gate biasing; a special power supply can be made specially for this application to work in a way so that there is no need for an external power supply.

Finally the overall design can be regarded as successful and gave lots of exposure to learn and understand the RF circuit design. Also the surface-mount technology used during the design gave an opportunity to learn how to connect the components. Troubles shooting the circuit replacing the components these are all very important aspects which were learned in this work.

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