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Full Length Research Paper

Performance analysis, design and assessment of broadband low noise amplifier (LNA) for radiometer

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The two major applications of microwave remote sensors are radiometer and radar. Lots of researches have been conducted on the various aspects of radiometer and radar but internal logical design is mostly ignored by researchers because of its digital logic and complex nature. This paper focus on radiometer from a design point of view and a low noise amplifier is designed and proved mathematically to ensure the high performance and working. The paper is based on a study of radio frequency communications and engineering, as well as an understanding of the radio frequency (RF) circuits. Moreover, practical implementation and performance analysis of low noise amplifier for radiometer is also discussed in this paper. Scientifically, the paper is divided into two parts. In the first part, some background study about the radiometer and its types was carried out so that a basic understanding can be developed by the reader. And in the second part low noise amplifier (LNA) for the radiometer was designed.

Key words: Radiometer, sensors low noise amplifier, advanced design system (ADS), radar, bandwidth.

INTRODUCTION

Some of the major types of radiometers, major applications and advantages of using them is also among the focus of this work. The main focus of this study is on the design of a low noise amplifier. A low noise amplifier was designed in the advanced design system (ADS) and was implemented for practical use in the selected radiometer. This study presents a general overview of the radiometer and radiometer types, followed by an overview of low noise amplifier. It discusses the design of low noise amplifier, and depicts the design specifications, design steps and flowchart. Design parameters, such as, chip selection and biasing of IC's was discussed, followed by software selection and simulation of design, where some simulation strategies have also been mentioned. Two stages of design have been discussed here; single stage and double stage design.

The waveforms of the simulated results have been shown, after which a comparison between the two stages of design is made in order to justify the differences and selection of a particular design for any particular application. Implementation and testing of the project was done in which both designs simulated were implemented and their results were tested. Finally, a comparison between the two designs in terms of physical implementation was made, and conclusion was drawn.

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 to be able to detect very weak

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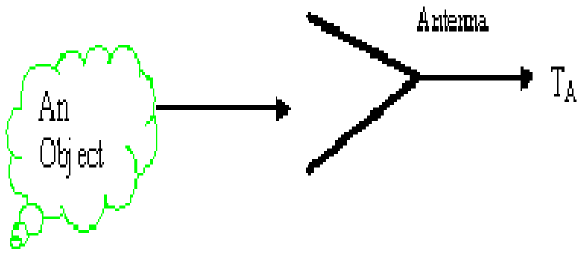

Figure 1. Measurement situations.

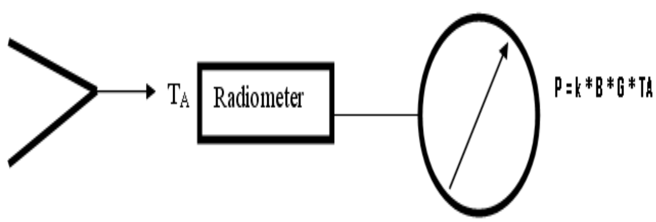

Figure 2. Idealized radiometer (Ulrich and David, 2006).

emissions from the emitting device or object or the surface (Neils, 2007). Whenever a radiometer is been describe, 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

The Figure 1 illustrates what a radiometer is. The task is to measure the brightness temperature of the object shown in the Figure 1. "T_A" is the power or temperature to be measured. It can be seen that, to measure the brightness of the object, an antenna need to be used. The direction of the antenna is pointing towards the object. In this case, if we assume that the antenna is lossless, which of course would not occur in the real world, but the assumption is just for an 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 (Ulrich and David, 2006).

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; this relationship is shown Figure 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 (Neils, 2007).

$P = k. B. G. T_A$

Where, K = Bolt man's constant; B = bandwidth; G = amplification; T_A = power received from the antenna.

The given formula takes only ideal conditions into account, meaning that it does not take into account any noise. In the real 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

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

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 (Neil et al., 2007),

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

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, 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. Figure 3 gives understand on how path loss occurs.

The letter 'l' in Figure 3 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:

$T_2 = T_1 (1-l) + T_0 * l$.

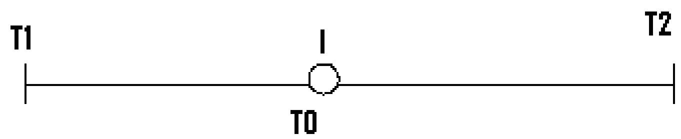

Figure 3. Lossy path.

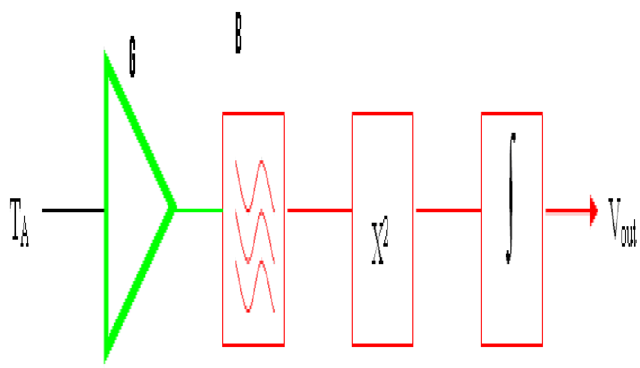

Figure 4. Total power radiometer (Carr, 2002).

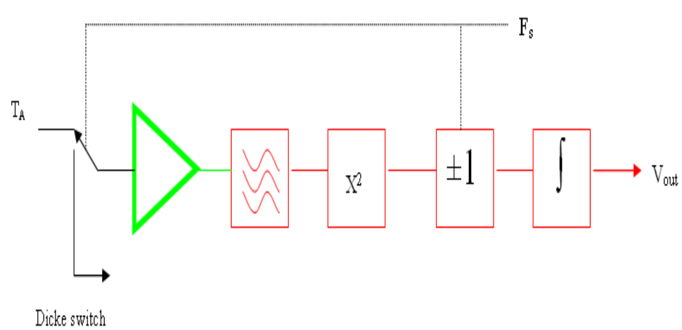

Figure 5. Dicke radiometer.

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

$T_D = T_2 – T_1 = l * (T_0 –T_1)$

As an example, let us say

$T_1 = 100$ k
$T_0 = 300$ k
l = 0.01 dB
$T_D = 0.5$ k

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, and for accuracy of this device, those 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 is discussed one by one.

Total power radiometer

This is one of the simplest types of radiometer. It can be seen from the block diagram (Figure 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. The detector signal is smoothed by an integrator and output fluctuations are reduced. The output can be expressed by the following equation.

$V_{out} = c. (T_{A +} T_N). G$

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.

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'

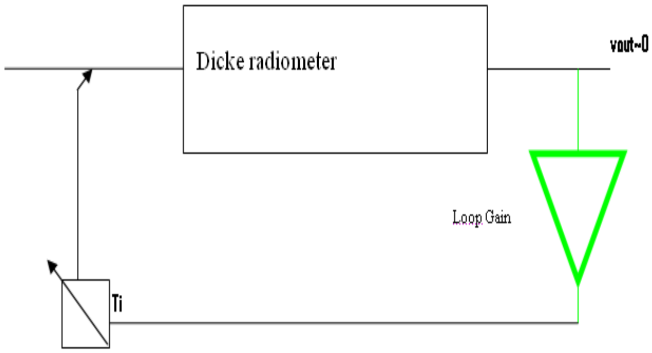

Figure 6. Noise injection radiometer (Losee, 1997).

which is typically 1 KHz. 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 was 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 was:

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

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 (Figure 5).

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 affected in this case.

According to the equation (Losee, 1997),

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

It can be seen from the equation that if

$T_A = T_R$ then

$V_{out} = 0$

This is the condition which noise injection radiometer tries to satisfy. To understand the working of noise injection radiometers, consider Figure 6. It can be seen from Figure 6 that 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.

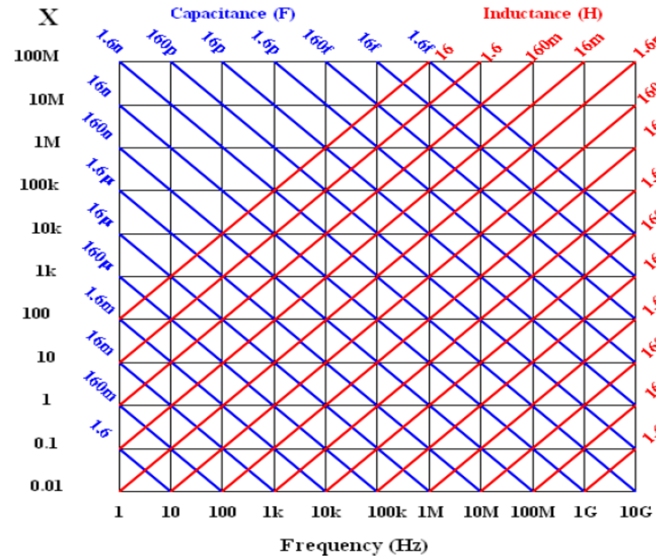

Figure 7. Reactance versus frequency (Clarke and McEwanl, 2006).

LOW NOISE AMPLIFIER

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 signals are received at the antenna, they are very weak, that is why the LNA is used very close 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. Figure 7 shows the relationship between the reactance and the frequency.

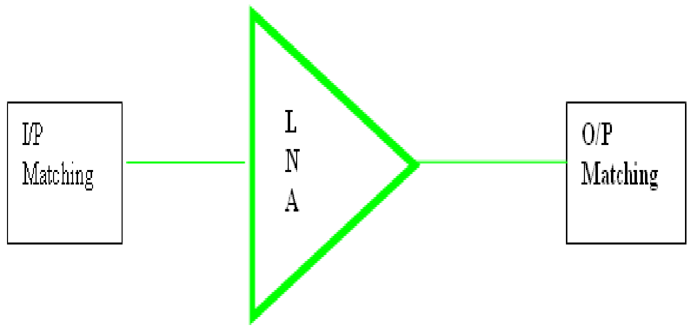

Figure 8. LNA block diagram (Gonzalez, 1984).

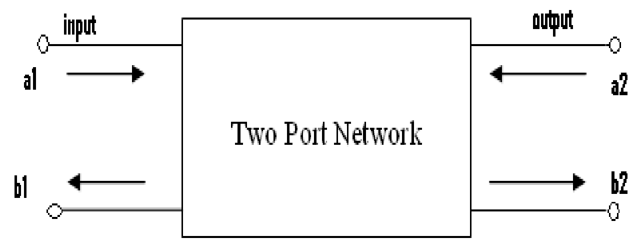

Figure 9. S-parameters of 2-port network (Wolf and roger, 1988).

It can be seen from Figure 7 that as frequency changes values, simultaneously changes also occur in the inductors and capacitors.

LNA design block diagram

The overall block diagram of LNA is shown in Figure 8. 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 50 Ω (Gonzalez, 1984). In practical conditions, it is not necessary that these are 50 Ω, but may be closer to this value.

S-parameters

The RF design S-parameters is 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 and the wave will be known as the reflected wave. The reflected wave will travel back towards the source or generator.

It can be seen from the two port network how the travelling wave travels from the source and the reflected waves are shown as well (Figure 9). 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 than the noise, then instead of actual signal the 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,

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 to keep in mind before designing an amplifier.

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.

(1) Gain and Gain flatness
(2) Bandwidth
(3) Centre frequency
(4) Input reflection co-efficient
(5) Output reflection co-efficient
(6) Stability
(7) Biasing of the circuit

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

Steps for LNA design

The following steps can be performed for the design of LNA (Norm and Helge, 1993)

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.

Flow chart for LNA design

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 to 3.6 GHz. The particular chip package for this application is MGA-72543.

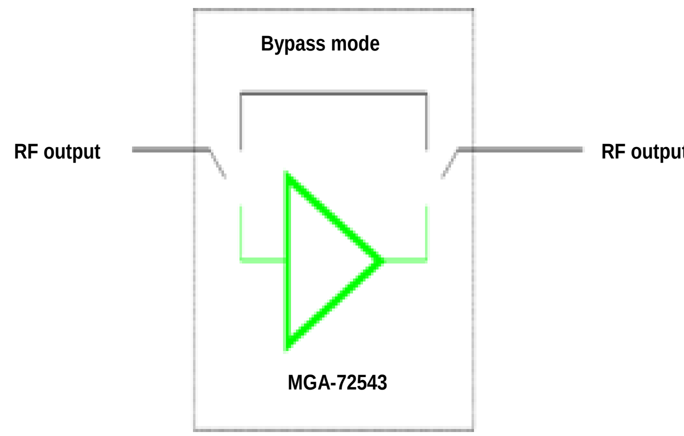

Figure 10. MGA-72543 functional diagram.

Chip specifications

Agilent's MGA-72543 is economical easy to use with Gas monolithic microwave integrated circuit (MMIC) low noise amplifier. The input is internally matched to the lowest noise figure into 50 Ω. The output is internally matched to 50 Ω. It is single stage amplifier with an integrated by pass switch. Below is the functional diagram of the MGA-72543 (Figure 10).

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.

1- Operating frequency F = 0.1 to 10 GHz
2- V_d = 3 V.
3- I_d = 20 mA
4- S_{11} =
5- S_{22} =
6- S_{12} =
7- S_{21} =
8- 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 as follows:

Relative permittivity, ε_r = 4.5
Thickness, H = 0.8 mm
Dielectric loss, TanD = 0.017.

These were some of the specifications related to the substrate which was 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 follows (Reinhold and Pavel, 2000).

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

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

Extraction of maximum gain

There are various topologies which can be used to extract the maximum amount of gain. Depending upon the parameter requirement, for 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. These parameters (gain, stability and noise figure) are really important. However, how to get maximum gain, unconditional stability and minimum noise figure will be seen in the simulation.

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 (Chris, 1997). 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 of these techniques were discussed one by one and one of them was selected for the current application.

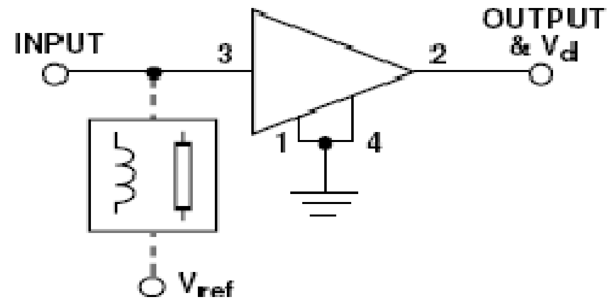

Figure 11. Gate biasing (PHEMT, 2004).

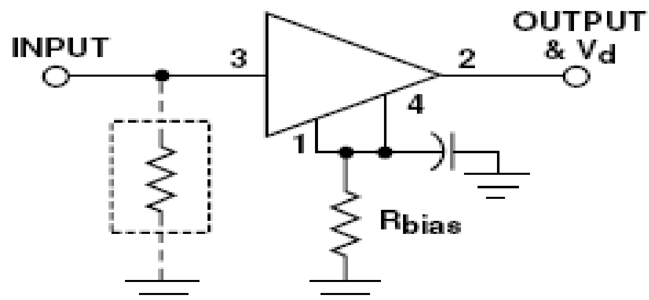

Figure 12. Source resistor biasing (PHEMT, 2004).

Gate bias

MGA-72543 is a four pins IC. By using this technique, the two pins 1 and 4 are DC grounded, as shown in the Figure 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. Applying the gate bias DC access to the input terminals done using a high impedance transmission line as indicated in Figure 11.

Source resistor bias

Though, source resistor bias was not used in the current application, but it still worth discussing this type of 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) is input at DC ground. Figure 13 shows biasing using source resistor method.

The effect of the biasing circuit was discussed in the design stage of the LNA. At this point, the focus is on how to discuss the perspective of the bias required for RF circuit designs especially for a low noise amplifier.

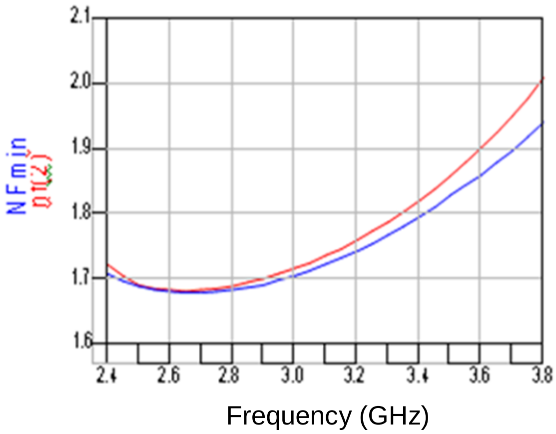

Figure 13. Noise Figure for 2-stage LNA

S-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 is a need for computer aided design. There are various soft ware packages available for designing RF circuits; the software which has been selected for the simulation is ADS. It is specifically designed to build RF circuits. ADS have 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 was used to find the exact s-parameter values. It was used to plot the noise, gain, stability and return loss parameters. Now, the simulation circuit for MGA-72543 was done step by step.

Single stage LNA design

The design that was presented has two types, viz:

1. Single stage design
2. Double stage design

In the case of single stage design, the topology will consist of one amplifier and all the parameter values were recorded using single amplifier, whereas by using two amplifiers, a two stage topology was built and the comparison was 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 shows the S-parameter values of the chip. These values are described by using the design guide in ADS. 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 50 Ω in value. The value of S-parameters is shown in Table 1 at 2.44 GHz. These values will vary at different frequencies. The design is supposed to work from any frequency range from 2.4 to 3.6 GHz; S-parameter values can be obtained at any frequency. As discussed earlier, ADS was used to plot the values of different parameters. Figure 14 is used to get the values of noise, stability and the gain circles.

Matching for noise figure

Table 2 shows the matching values for the noise figure. It can be seen from Table 2 that NFmin is 1.43 dB at 2.44 GHz. The conjugate matched impedance values are shown in this study. The power gain (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 3 shows the values for gain. The values of load and source impedances can be seen from Table 3. For the matching to achieve the gain of 15.462, the stability factor must be 1.186. This value of k satisfies the condition of being $k > 1$, to avoid any oscillation. The reference impedance of the system is 50 Ω.

Now the input/output matching network design carried out in ADS is 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 (Lawrence, 1996). LNA design is a complicated process, not only for a LNA design, but for 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 is shown in this study. This is very important to mention the first simulated result achieved; the whole design was

Table 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

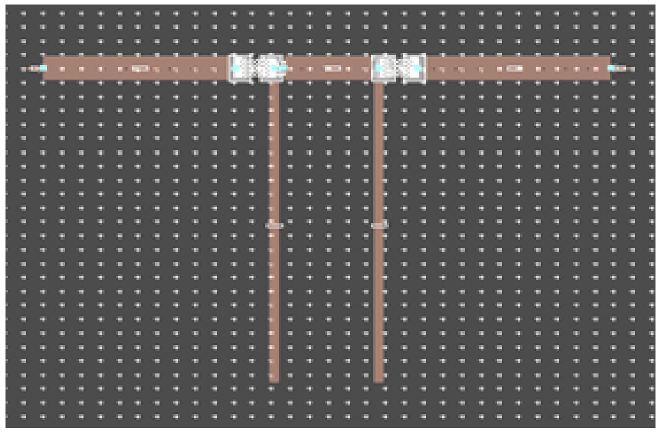

Figure 14. Single stage LNA gain.

Table 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

Table 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

based on the first circuit.

For the circuit designed in ADS, the simulation was done (Figure 15). Simulated results show the parameter values of gain, NFmin, actual noise, stability, input and output return loss. An input port connected with the transmission line (carry on describing the circuit by looking at the actual topology).

It can be seen that gain is not quite flat, and also, at its peak value. It starts at about 9 dB, and then goes up and down. The maximum value for the gain is about 10.8 dB at 3.4 GHz. The topology needs some dimensional adjustments and some more value of gain. It is all to play with the transmission line. For most of the applications, the minimum gain at any frequency should be > 10 for the circuit to be use in practical applications. Of course some dimensions will be changed to get maximum gain. Also, there are other parameters in the simulation to be paid attention to, for the device to meets all the requirement specifications. The next thing to check is Noise figure for this circuit.

It can be seen from that both NFmin and nf (2) are not quite satisfactory. When comparison is made between the simulated waveforms of gain and noise figure, it was 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.

The stability value is quite satisfactory, right above the required value of > 1, which means that the device will

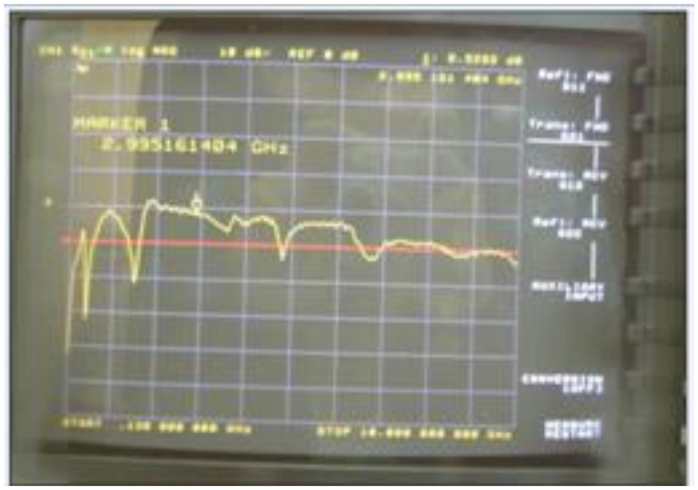

Figure 15. Gain measurement.

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.

As far as both input and output values are concerned. The values are less than 0 which is good, but still the loss should be minimised the whole time on the operating band.

From the circuit simulation, the conclusion arises is that two parameters need be adjusted; gain and noise figures. Using ADS 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 just on 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.

It can be seen that the gain is not better and flatter than 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.

It can be seen from Table 4 that by keeping the same topology, two different versions of the results have 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. The difference is very clear. By comparing it with the simulation1, it can be seen

Table 4. Dimensions comparison of two simulations.

Dimensions for simulation 1	Dimensions for simulation 2
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

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.

These are not the final measurements. The maximum potential values for frequency range of 2.44 to 3.6 GHz. Maximum available gain for this particular circuit is:

Final design of single stage amplifier

The waveform 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 effect, but the capacitors used in the circuit have replaced by the moarata components. This shows that not only the size of the components is affected, but

Table 5. Comparison between two design simulations.

Parameter name	Single stage design	2-Stage design
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

also the type of the components significantly affects the circuit performance.

Gain start at maximum value of 14.45 dB and the minimum value is at 3.6 GHz which is 11.364, quite acceptable.

Like gain noise the figure improved equally as well. In this case, NFmin and actual noise figure both are kept under 2 dB 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.

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 little bit lower than 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 -10 dB, which is very much acceptable. 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 dB. Stability should be > 1 and noise figures should be kept at minimum (Lawrence, 1996). So keeping these in view, some adjustments have been made such as the 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 was 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 (Vizmuller, 1965). 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 next.

Two-stage LNA design

As discussed earlier, the second stage design is just the same as the extension of stage one. The difference between the two is that in two stage, one two chips of MGA-72543 is use in cascade. This will provide more gain and stability as well.

It can be seen from the circuit diagram that stage two has two chips cascade. 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

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 2.4 GHz and at 3.6 GHz, while the value is about 21.9. This is a big improvement in the circuit design. The improvement is as a result 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 in Figure 13.

The noise figure waveform shows very good results. On the entire operating band it is < 2 dB which is very much acceptable. The stability is also important at this stage, and thus, the waveform revealed the stability measurements.

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.

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 5 dB; 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. Table 5 shows a comparison between the two stages results in terms of gain, noise and stability, and return loss.

On the basis of the previous comparison, the circuit can be use as required for any specific application.

As discussed earlier for both 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.

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. Here, this project had the chance of working 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 as follow:

1) Layout generation
2) Mask file generation
3) Printed circuit board (PCB) manufacturing
4) Component connections

The first step is to generate the layout, which is quite simple. Beginning with 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 used for generating different types of files from the layout. The mask file with the extension 'mask' 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 is the component connections. This is the difficult task in the implementation part of the project. The implementation of the circuit was 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.

Layout of single stage LNA

The layout for the single stage design is quite simple. It can be seen from Figure 14 that single stage LNA design is having two ports attached to it 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

The measured actual results for the single stage LNA design are shown here. 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, whereas they behave differently when implemented physically in the real world. Figure 15 shows the gain for this circuit.

It can be seen from the waveform that gain is quite good; about 9.5282 dB at 2.99 GHz which is a good value. The simulation was given actually at about 14 to 11 dB from 2.4 to 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 in Figure 16 shows the input reflection co-efficient.

Figure 16. Input reflection co-efficient.

The input reflection co-efficient (S11) 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 from simulations. When the discussed circuit simulated, S11 was always less the -10 dB over the entire operating band. This shows that it varies with quite a big margin as compared to simulations, which may be fringing other parameters that have affected the implemented results. To see the S22, consider Figure 17.

Considering 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 previous layout is shown in Figure 18. The actual circuit board shows the single

Figure 17. Output reflection co-efficient.

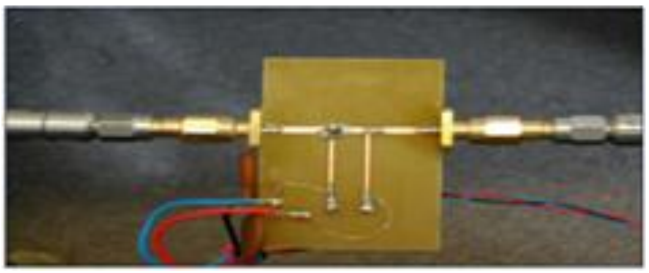

Figure 18. Implemented circuit for single stage LNA.

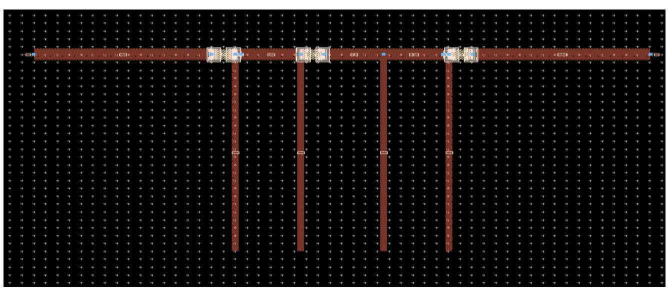

Figure 19. Two-stage LNA layout.

stage LNA implementation. As discussed earlier, the implemented results vary as compared to the simulated results; the reason is that capacitors used in the circuit were not the actual ones and may also be the fringing effect 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 satisfactory except few problems and the overall results achieved were good. The design of the two stages LNA is discussed step by step.

Layout for 2-stage LNA

The layout for 2-stage LNA is shown in Figure 19. 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 were used as the transmission medium.

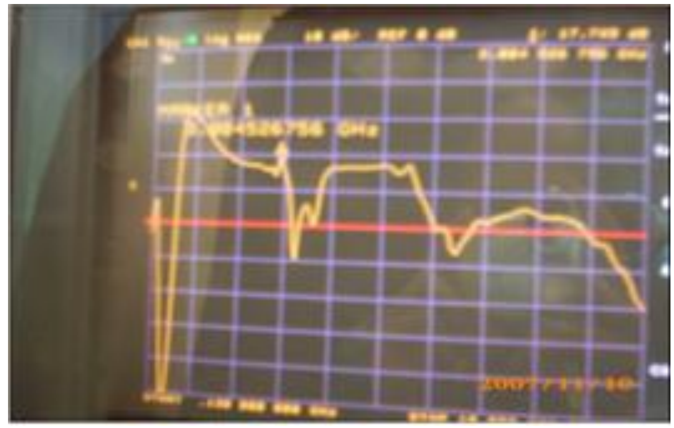

Figure 20. Two-stage LNA gain.

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 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 cannot be solved at this stage. On the rest of the frequency, the design was very good and quite a high value of gain was available. Figure 20 shows from the network analyser the actual measured value of gain. Though, not very clear picture, because 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 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 Figures 21 and 22.

The red line was not quite visible, but it shows the zero value, so the input reflection co-efficient like stage1 is less the -3 dB at almost the entire operating frequency band. The output reflection co-efficient is given in Figure 22.

Like S11, S22 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 were mentioned earlier.

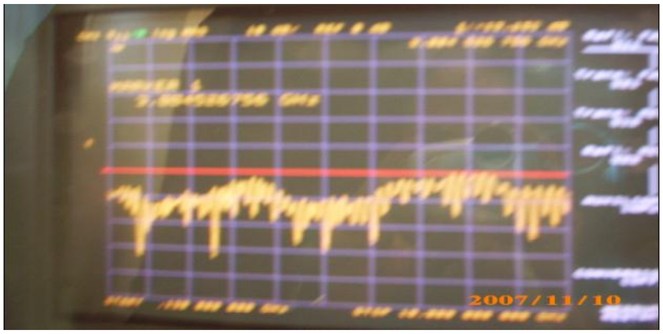

Figure 21. S11 for two stage LNA design.

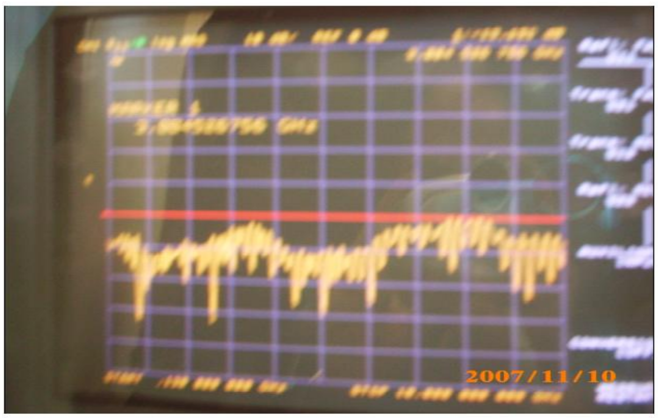

Figure 22. Output reflection co-efficient.

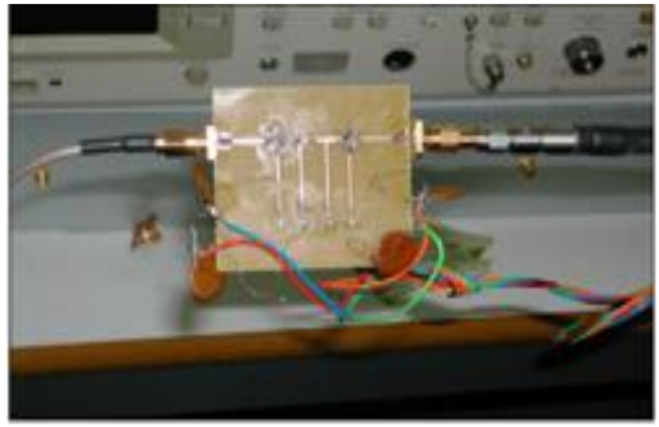

Figure 23. Two stage LNA physical circuit diagram.

Table 6. Comparison table for both designs.

Parameter	Single stage	2-stage
Frequency range	2.4 to 3.6 GHz	2.4 to 3.6 GHz
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	> 1	> 1
Input return loss	< -2 dB	< -3 dB
Output return loss	< -3 dB	< -2 dB

Two-stage LNA implemented circuit

The circuit implemented for two stage LNA design is shown in Figure 23. Unlike the single stage, it was a little complicated. Some extra effort was put into the design in this stage. Also, surface mount technology was used for the first time, so it is obviously not very easy when using it for the first time. In the end, some useful results were achieved. Figure 22 shows the physical topology of the 2-stage LNA design.

Comparison between single stage and two stage design

The comparison between the single stage and 2-stage design is shown in Table 6. 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.

From Table 6, 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.

Conclusion

Using MGA-72543 process of LNA design for the radiometer was effective in that all the required goals were achieved successfully as shown and proved mathematically to reduce noise factor. The operating band is from 2.4 to 3.6 GHz. In the entire operation band, noise figure was kept less than 2 dB, and gained more than 11 dB 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 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 factor. Keeping in mind the fact that LNA is a low noise and high gain component in the receiver chain, it was preferred not to use any noisy component like resistors. Also, the radiometer was a very sensitive receiver, so it is desirable not to use any inductive component, and thus 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.

Future works

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 which 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 especially for this application to work in a way so that there is no need for an external power supply.

REFERENCES

Carr JJ (2002). RF Components and Circuits. Radio Society of Great Britain, Oxford Newnes, ISBN 0750648449, p. 2.

Chris B (1997). RF circuits design. Oxford, p. 7.

Clarke RW, McEwan NJ (2006-2007). RF Cad & RF and microwave Design. University of Bradford, pp. 2-4.

Gonzalez G (c1984). Microwave Transistors Amplifiers: Analysis and Design. Englewood Cliffs London: Prentice Hall, p. 5.

Lawrence EL (1996). RF and microwave circuit design for wireless communications. Boston Artech House, pp. 10-13.

Losee F (1997). RF system, Components and Circuits handbook, Boston M.A London, Artech House, p. 4.

Neil JM, Raed A, Abd-Alhameed M, Nasir Z, Abidin A (2007). modified Radiometric Method for Measuring Antenna radiation Efficiency. Department of Electronics and Telecommunication, University of Bradford.

Neils S (2007). Microwave Radiometer Systems: Analysis and Design. Technical University of Denmark, Artech House, 685 Canton Street, Norwood, ISBN 0-89006-368-0, p. 2.

Norm D, Helge G (1993). Helge Granberg, Radio Frequency Transistors: Principles and Practical applications. Boston, London: Butterworth-Heinman, p. 6.

PHEMT (2004). Low Noise Amplifier. Agilent Technologies, p. 8.

Reinhold L, Pavel B (2000). RF circuit design theory and applications. Prentice Hall International London, p. 7.

Ulrich LR, David P (2006). Newkirk RF Microwave Circuit Design for Wireless Applications. John Wiley and Sons, Inc. NewYork USA. ISBN 0-417-29818-2, p. 2.

Vizmuller P (1965). RF Design Guide: Systems, Circuits, and Equations. Boston, London, Artech House, p. 13.

Wolf EA, Roger K (1988). Microwave Engineering Systems and Applications. John Wiley and Sons, ISBN 0-471-63296-4, pp. 5-10.