LOW-NOISE AMPLIFIER DESIGN FOR POLAR WEATHER SATELLITE RECEIVER

Oleh

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<u>ABSTRAK</u>

Satu penguat hingar rendah untuk sistem komunikasi satelit telah dibina. Sistem penguat hingar rendah ini direkabentuk supaya ia boleh digunakan sebagai bahagian depan kepada satu penerima satelit yang beroperasi dalam jalur UHF. Sistem penguat ini akan menguatkan isyarat UHF lemah yang diterima dari satelit dengan gandaan tinggi disertai angka hingar rendah sebelum menyalurkannya ke sistem yang berada di bahagian belakang. Rekabentuk penguat hingar rendah ini bermula dengan pemilihan komponen diskret aktif serta pasif yang betul sebelum melakukan penyelakuan dalam perisian *Advanced Design System* (ADS2005A) untuk mengetahui ciri-ciri pindah komponen aktif tersebut dan seterusnya melakukan pemadanan galangan. Seterusnya, papan litar bercetak juga direkabentuk melalui penggunaan perisian yang sama dan parameter-parameter litar yang terhasil akan diukur, direkodkan dan dibandingkan dengan keputusan yang didapati dengan penyelakuan. Keputusan yang didapati menunjukkan bahawa pemilihan komponen diskret pasif dan rekabentuk papan litar bercetak yang betul memainkan peranan yang penting dalam memastikan ciri-ciri litar yang dibina adalah hampir menyerupai prestasi litar yang diselaku. Pengukuran IP3, OIP3, angka hingar serta titik mampatan gandaan menggunakan penganalisis rangkaian, sumber hingar dan penganalisis spektrum juga dipersembahkan dalam laporan ini.

ABSTRACT

For undergraduate program, a low-noise amplifier for satellite communication system was designed. This low-noise amplifier would play the role as a front end of a satellite receiver that operates in the UHF band. The low-noise amplifier would perform amplification with reasonable gain on the weak signal received from the satellite while maintaining a low noise figure. The amplified signal would then be passed on to the succeeding stages. The design of the amplifier commences with the selection of the discrete components that will be used. After making the suitable passive and active component selection, the chosen microwave transistor model is then simulated in Advanced Design System (ADS2005A) to get the scattering parameters and stability figure. After impedance matching is done, the printed circuit board is designed with the same software. Finally, the resulting actual circuit performance are recorded down and then compared with the results obtained from simulation. The fabricated low-noise amplifier showed that choosing the right passive components and proper printed circuit board design plays an important role in ensuring that the fabricated circuit specification closely resembles the simulated counterpart. The measurement of IP3, OIP3, noise figure, gain and gain compression point (P_{1dB}) utilizing the network analyzer, noise source and spectrum analyzer are also presented here.

ACKNOWLEDGEMENTS

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CHAPTER 1: INTRODUCTION

1.1 Project Overview

The system block of a basic satellite receiver must be understood first in order to gain more insight into this project. A basic satellite receiver is composed of various stages as depicted in Figure 1.1. Usually a bandpass filter is placed after the antenna to allow a certain bandwidth of signal to pass through. Notice that the low-noise amplifier serves as a front end to any receiver design. That is because the low-noise amplifier (LNA) would amplify the weak signal received by the antenna. The noise figure of the LNA plays an important factor in specifying the bit error rate (BER) performance of the receiver [1]. The gain provided by the LNA must also be taken into consideration during the design process. A LNA with a high gain but low noise figure is more preferred as the noise contributed by the succeeding stages will be divided by the high gain of the first stage. The amplified signal is then passed to the mixer and then to the demodulator. The fairly crowded UHF band necessitates the usage of a bandpass filter (BPF) with low loss and high selectivity.

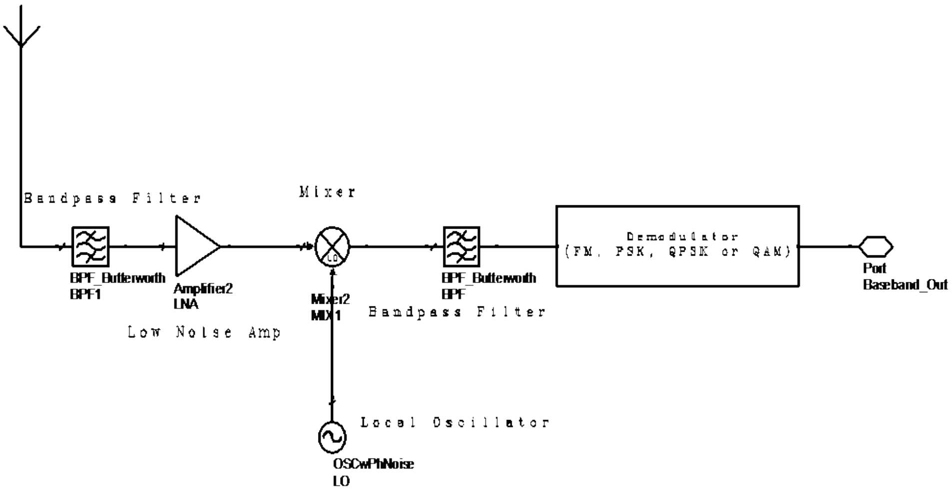


Figure 1.1: System block of a simple satellite downlink model

Meanwhile, the LNA system block is represented in Figure 1.2. The basic amplifier consists of the microwave transistor. Matching networks are used to transform the transistor impedance to the input and output impedance. Incorporating the bandpass filter network into the matching circuit is advantageous. This would help to alleviate the input losses as well as minimizing the number of components.

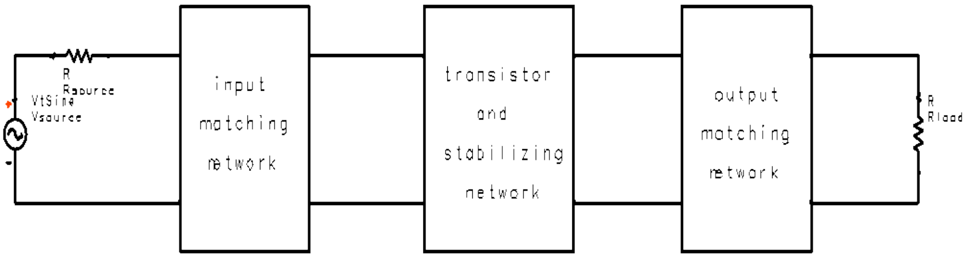


Figure 1.2: System block of a low-noise amplifier with matching network

The active device used in the LNA must also be considered properly since the type of transistor used will determine the gain and most importantly the noise figure. Since there are many types of active devices in the market, they are evaluated for the given specifications. Then the transistor operating point is used for the design of the biasing network. The biasing point must also be chosen properly to allow sufficient gain.

The low-noise amplifier is designed to amplify signal in the 130-140MHz range. This is the frequency range for the weather satellite specified by the NOAA (National Oceanic and Atmospheric Administration). The satellite receiver is supposed to decode the data into images. The images transmitted by NOAA satellites are in analog mode and called Automatic Picture Transmission (APT). The NOAA satellite itself operates on many bands. Operating band for these satellites can be found on the website of many amateur radio hams. Recently launched satellites also transmit data in a digital format but the carrier frequency is much higher at 1.70GHz. The operating bands are as of now for the year 2005 for these satellites are given in Table 1.1.

Table 1.1: List of operating band for NOAA satellites [22]

FREQUENCY	OPERATING SATELLITE
137.350	NOAA K, L, & M
137.500	NOAA 10, 12, K, L & M
137.620	NOAA 9, 11, 14, K, L & M
137.770	NOAA K, L & M
137.850	METEOR 3-5, METEOR 2-21

NOAA satellites have two types of orbit. Some are satellites with polar orbit while others geostationary or geosynchronous. Geostationary satellites have an orbital time of 24 hours and appear almost static in the sky. A polar satellite passes the South and North Pole and thus can cover the whole Earth. The satellites transmit data of the surface below them as they pass through. The transmission in UHF frequency allows the use of reasonable VHF to UHF receiver to decode the signal. For NOAA polar satellites, they will rotate the Earth two times in 24 hours.

This project also must take into consideration the power supply to the LNA. Keeping the LNA close to the receiver and connecting a long coaxial cable to the antenna will cause tremendous loss of the input signal. The antenna is a passive system and cannot provide mush gain to overcome the attenuation when the signal passes through the coaxial cable. The amount of electromagnetic interference will also increase. The capability of the amplifier to work with a remote and low power supply is important.

1.2 Objectives and Scope of Project

First and foremost, the objectives of designing this low-noise amplifier are:

- Design a front end amplifier with good input and output matching that will complement the back end that will consist of the receiver.
- Provide an optimized gain without sacrificing noise figure for various impedances of the antenna and gives a good output match to the receiver.
- If possible, design of an amplifier with two stages of amplification with band-pass matching circuits to provide a narrow bandwidth for the required frequency of 130MHz to 140MHz.

The important specifications of the LNA must be defined first before the design stage begins. All LNA are characterized generally by a few important things such as possessing a high gain and low noise figure. Designing at the relatively low frequency for this project also necessitates the consideration of the LNA’s stability. The amplifier specifications that will be used for this project are similar in requirements to other microwave amplifiers but more emphasis is placed on the stability of the amplifier since the tendency to oscillate becomes greater at lower frequency.

This LNA should also possess good input and output return loss. This is to make sure there are no reflections of the already weak input signal to the antenna and also to make matching to the filter and receiver after the LNA less lossy. Table 1.2 shows all the specifications that have been set for this LNA design and the amplifier would be designed to meet these parameters.

Table 1.2: Specifications of the low-noise amplifier

SPECIFICATIONS	**VALUES**
Gain	≥ 15dB
Noise Figure	< 1.5dB
Input Return Loss	≥ 15dB
Output Return Loss	≥ 15dB
Input Third Order Interference Point	≥ 3dBm
Current Consumption	≤10 mA
Supply Voltage	≤10V

After the performance of the LNA has been specified, the physical aspect of the LNA must be considered. This LNA would be placed very close to the antenna to prevent attenuation of the signal. The antenna is placed on the rooftop where it is subject to moisture, rain and extreme sunshine. The LNA must be designed for outdoor use and withstand high levels of moisture and heat. Components especially resistors and capacitors that possess low temperature coefficient must be used to ensure the LNA's stability. The power supply to the LNA must also be provided remotely to the LNA through the coaxial cable and that places a limit on how much current that can be supplied through it. Hence the isolation in the output matching network must be good to prevent leakage of bias current into other parts of the circuit and the circuit must be of a low power type. The size of the LNA is also important and the printed circuit board must be placed in a water and moisture proof insulated aluminium box.

1.3 Structure of Report

This report will follow a certain procedure during the progress of the design. Basically this report will be divided into a few segments as given below:

- Chapter 2: A description of a low-noise amplifier followed by explanation about scattering parameter, gain, noise figure and impedance matching.
- Chapter 3: Simulation of microwave transistor for stability and scattering parameters for frequency of interest. Also design of stabilization network and impedance matching network is presented here.
- Chapter 4: Layout and fabrication of the designed circuit. This also includes the mounting of components on the printed circuit board and also the inclusion of the onboard voltage regulator with bias tee.
- Chapter 5: Measurement of the resultant fabricated circuit using specialized equipment like network analyzer and spectrum analyzer. Performance of LNA is then compared with the one obtained from simulation.
- Chapter 6: Conclusion about the progress of this project is made and ideas are suggested to improve the performance of the LNA or proceed with more advanced design methods.

CHAPTER 2: LITERATURE SURVEY

2.1 Low-Noise Amplifier

A low-noise amplifier is a class A amplifier that operates in the linear region to provide gain at a very low noise level. That also means that the amplifier is actually designed for small signal amplification. Class A amplifiers are very inefficient but this disadvantage is offset by the low harmonic distortion it offers. The noise figure of the amplifier is determined by the type of active device used for the amplification and also the loss or quality factor of the matching network components. The gain of the amplifier is determined by the active device since the passive components used for matching can only contribute a gain value of less than 1 but the loss of the passive components used must be taken into account as Figure 2.1 below shows:

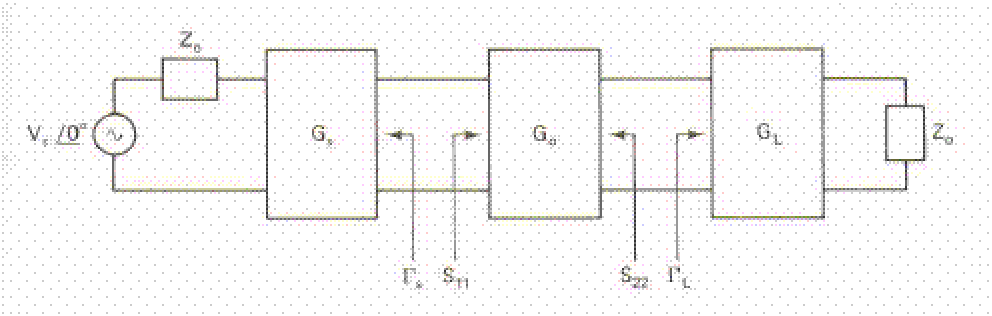


Figure 2.1: Three distinct gain block in a low-noise amplifier [15]

where the total gain can be given as the multiplication of the separate gain from the three stages [15].

$$\text{Total Gain, } G_{TOTAL} = G_S G_O G_L$$

Designing a LNA requires deep understanding of s-parameter concepts and impedance matching using the Smith chart.

2.2 Scattering Parameter or S-Parameter

Any small signal microwave amplifier design starts with modeling the microwave transistor in high frequency. As we know, there are z, y, h and ABCD parameters to describe an n-port network at low frequency. Each parameter is defined as shown in Table 2.1.

Table 2.1: List of parameters and their actual representation

PARAMETER	**TYPE OF REPRESENTATION**
Z-parameter	Impedance
Y-parameter	Admittance
H-parameter	Hybrid
ABCD-parameter	Chain or ABCD

A two-port network can be defined in many parameters. While the equations given are a representation of a two-port network, they can be easily expanded to accommodate more than two ports. A simple two-port model is shown in Figure 2.2.

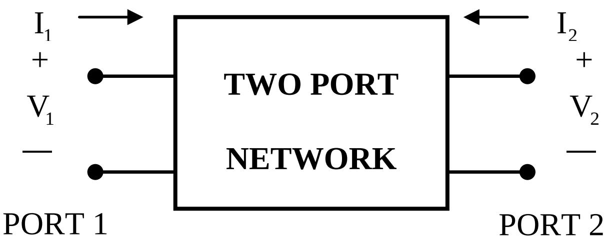


Figure 2.2: Two-port network model to derive the parameters [13]

The two-port can be represented by applying open and short circuit testing at the ports. Note that these methods apply at low frequencies since inductors and capacitors do not really behave like inductors and capacitors at high frequency. From the figure above, the impedance and admittance parameter can be defined as

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \tag{2.1}$$

Meanwhile the admittance parameter can be represented as

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \tag{2.2}$$

The s-parameter can be derived from the chain or ABCD parameter. The details of the derivation will not be shown here. Instead each s-parameter coefficient is explained in detail here.

S-parameter is a parameter more suitable for high frequency design and it can be easily derived from other parameters. S-parameter will be fully used during the design and characterization of this LNA. We must understand that s-parameter is used to design this LNA because they are easily measured for high frequency and they can be used to characterize the linear relationship of an n-port network for a small signal transistor model. As mentioned earlier, s-parameter only represents the linear behavior of a two-port network that is the LNA. Figure 2.3 gives a basic two-port s-parameter network.

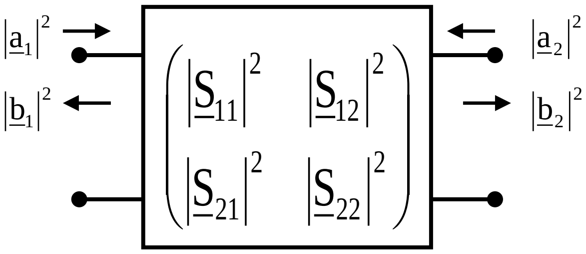


Figure 2.3: A two-port network with s-parameter defined in matrix form [13]

Defining the s-parameter in the form of power,

$$\begin{pmatrix} |\underline{b}_1|^2 \\ |\underline{b}_2|^2 \end{pmatrix} = \begin{pmatrix} |\underline{S}_{11}|^2 & |\underline{S}_{12}|^2 \\ |\underline{S}_{21}|^2 & |\underline{S}_{22}|^2 \end{pmatrix} \times \begin{pmatrix} |\underline{a}_1|^2 \\ |\underline{a}_2|^2 \end{pmatrix} \tag{2.3}$$

where each component can be denoted as

$|\underline{a}_i|^2$ =power wave traveling towards the two-port gate

$|\underline{b}_i|^2$ =power wave reflected from the two-port gate

$|\underline{S}_{11}|^2$ =power reflected from port 1

$|\underline{S}_{21}|^2$ =power transmitted from port 2 to port 1

$|\underline{S}_{12}|^2$ =power transmitted from port 1 to port 2

$|S_{22}|^2$ =power reflected from port 2

Going further, the parameter S_{11}, S_{12}, S_{21} and S_{22} represent the reflection and transmission coefficients and they can also be represented in matrix form as given in Equation 2.4 which is called the scattering matrix

$$[S] = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \tag{2.4}$$

The s-parameter coefficients are defined as

$S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2 = 0}$ =input reflection coefficient with output terminated

$S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1 = 0}$ =reverse transmission coefficient with input terminated

$S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2 = 0}$ =forward transmission coefficient with output terminated

$S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1 = 0}$ =reverse reflection coefficient with input terminated

The meaning of input and output terminated means that the measurement of the coefficient is taken by terminating the ports with the characteristic impedance, which would usually be either $50\,\Omega$ or $75\,\Omega$. The reflection and transmission coefficient can also be written in decibel (dB) as

$$S_{ij} = 20\log_{10}|S_{ij}| \tag{2.5}$$

The reflection coefficient is also defined in Equation 2.6

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \tag{2.6}$$

where Z_L is equal to the load impedance and Z_0 is the characteristics impedance of the transmission line. Z which is capitalized means impedance that is not normalized to the characteristics impedance [14]. The characteristics impedance is usually set in a circuit. If Equation 2.6 is normalized then

$$\Gamma = \frac{\frac{Z_L}{Z_0} - 1}{\frac{Z_L}{Z_0} + 1} \tag{2.7}$$

this is done by substituting $\frac{Z_L}{Z_0} = z_l$ and this is actually the normalized impedance.

$\Gamma = \frac{z_l - 1}{z_l + 1}$ now can be used to show the reflection coefficient and this is the equation that will be used to represent the s-parameter reflection coefficients on the Smith chart. Before we go further, Z is also a complex value such as

$$Z = R + jX$$

$$z_l = \frac{R_L + jX_L}{R_0 + jX_0} \tag{2.8}$$

The characteristic impedance has no complex value and only has a real value and this can be simplified to

$$z_l = \frac{R_L + jX_L}{R_0} \tag{2.9}$$

and the reflection coefficient can also be shown in a phasor form which is

$$\Gamma = |\Gamma| e^{j\theta} = |\Gamma| \angle \phi \tag{2.10}$$

The equation given above is very important. Applying this to the s-parameter starting with S_{11} which is the input reflection coefficient, it can be seen that the ranges of values are

$$0 \le |S_{11}| < 1$$

where 0 represents the best match and no waves are reflected back and the worst when $|S_{11}|$ approaches 1 where almost all the waves are reflected back. This is also shown as

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{2.11}$$

The equation above represents voltage standing wave ratio (VSWR) or simply standing wave ratio (SWR) and this shows the mismatch in the transmission line. It is also shown that if $|\Gamma|$ =1 then VSWR would be infinity. VSWR=1 indicates the load and source is perfectly matched and an increasing VSWR denotes increasing mismatch in the line. This also holds true for the load reflection coefficient S_{22} . For a properly matched network, the value of VSWR should approach the value 1 which means there is almost no reflected wave.

Another parameter that is important is the forward transmission coefficient S_{21} . This represents the actual forward gain of the amplifier after the mismatch has been taken into account. It is lower than the maximum gain value unless the load and source has been conjugately matched for maximum gain. The reverse transmission coefficient S_{12} would be much smaller for any amplifier since all amplifiers only amplify in one direction. Usually it is around 30-40dB below S_{21} .

2.3 Smith Chart And Impedance Matching

Smith chart is a tool to represent complex resistance in a graphical way. A Smith chart is made up of constant resistance and reactance circles. Figure 2.4 below shows how the Smith chart transforms complex resistance into graphical form.

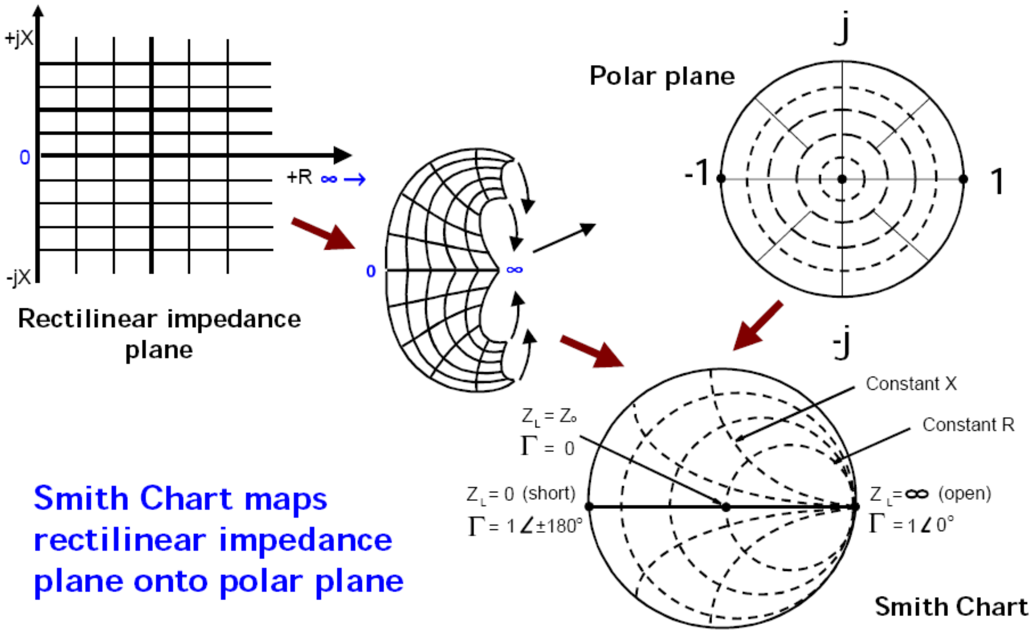


Figure 2.4: Diagram showing how Smith chart transforms complex resistance plane into graphical form [13]

The point in the center of the Smith chart represents the characteristics impedance and is equal to 1 if the load impedance is equal to the characteristics impedance. Using Equation 2.11, we see that $|\Gamma| = 0$ and the circuit will be perfectly matched. The horizontal line on the Smith chart represents the resistance. The far left of the Smith chart, the resistance is zero and that means $Z_L = 0$ or short circuit. The far right is $Z_L = \infty$ and that means open circuit.

The Smith chart can also be used to find the length of transmission line. Each $360°$ rotation around the Smith chart is equal to the distance of $\frac{\lambda}{2}$ or half the wavelength of the wave. If the Smith chart is rotated to around the center for $\frac{\lambda}{4}$ or $180°$, we come to a new type which is called the admittance Smith chart. Any point in the impedance Smith chart can be transformed into admittance by turning the point$180°$. Notice that the area above the center line for the admittance Smith chart represents negative susceptance and the area below it is positive susceptance. This can be proven from Equation 2.12 that inductance is actually negative susceptance while capacitance is positive.

$$Y = G + jB \tag{2.12}$$

where

Y =admittance

G =conductance

B =susceptance

For the impedance Smith chart, the area above the center line represents positive reactance and that would be inductive load. Meanwhile the area below the center line represents negative reactance, which is capacitive load. The impedance Smith chart is actually a representation of reactance placed in series with resistance. The figure below shows the effect of adding or decreasing reactance to the series or shunt resistance. SWR circles can also be drawn on the Smith chart. By using a compass to draw a circle with the radius of the distance from the center to a point, the SWR is the value where the drawn circle intersects with the center line on the right half of the chart.

Matching is done by moving from the load to the characteristic impedance or the center of the Smith chart. The load can be matched either by moving through constant impedance or conductance line.

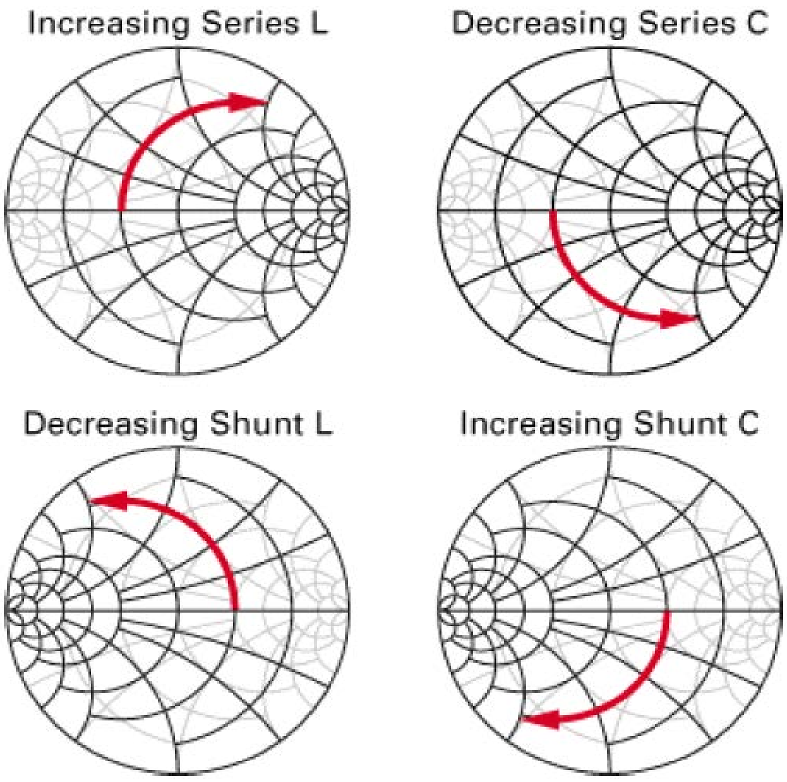


Figure 2.5: Figure showing the effect of series and shunt reactance [13]

2.4 Amplifier Parameter And Their Definition

2.4.1 Gain

Gain is a common thing for any active device. For a microwave transistor, gain comes in many versions. The forward transmission coefficient discussed above is a gain parameter. Large signal or maximum available gain will be discussed here. Maximum available gain (MAG) is the highest gain that can be provided by that transistor for a certain biasing point [12]. Maximum gain is given by the equation

$$\text{MAG}=\left|\frac{S_{21}}{S_{12}}\right| * \left(K-\sqrt{K^2-1}\right) \tag{2.13}$$

where

MAG=maximum available gain

K=Rollett stability figure

Equation 2.13 can only be used if the Rollett stability figure is equal to or higher than 1. All microwave transistors are unstable at low frequency and they are certainly very unstable at the design frequency as shown later. Hence the actual value plotted by the ADS software when K<1 is actually not maximum available gain but maximum stable gain (MSG). Also like mentioned earlier, S_{21} is usually lower than maximum available gain and this actually means that the gain can be improved by correct impedance matching.

Gain of an amplifier is usually compared to a reference power and expressed in dB. If the reference power P_2 is set to 1mW, the power of a system can be expressed in dBm [12]. Equation 2.14 is commonly used due to the low power of the carrier signal.

$$\text{P}_{\text{dB}} = 10\log_{10}\frac{P_1}{P_2} \tag{2.14}$$

$$\text{P}_{\text{dBm}} = 10\log_{10}\frac{P_1}{1\times10^{-3}}$$

2.4.2 Noise Figure

All electronic devices emit noise. Noise is produced due to random movement of electron. Not all types of noise are random. Some are created by external source while some are intrinsic of nature like shot noise and flicker or $\frac{1}{f}$ noise. Noise is generated not only in the amplifier but also from external source.

Having a low noise allows the sensitivity of the receiver to increase. In other words, there will be an increase in the amplifier's signal to noise ratio (SNR). The capability to detect smaller signal is much higher for an amplifier with a lower noise floor [5].

SNR can also be improved by increasing the gain but if the external circuit is very noisy, the input noise will also be amplified to a very high value. Noise figure (NF) is related to noise factor [1], N where

$$\text{Noise Figure, NF} = 10\,\log_{10}\text{N} \tag{2.15}$$

Noise figure can also be represented as

$$\text{NF} = 10\,\log_{10}\frac{\text{SNR}_{\text{IN}}}{\text{SNR}_{\text{OUT}}} \tag{2.16}$$

where

SNR_{IN} = Input signal to noise power ratio

SNR_{OUT} =Output signal to noise power ratio

CHAPTER 3: DESIGN AND SIMULATION

3.1 Selection of Active and Passive Components

The components that will be used for this project must be chosen first. The circuit will be constructed on a double layer FR4 fiberglass board. Since this project does not involve millimeter wave amplification and the use of Duroid board is deemed unnecessary, as this amplifier will not be matched using transmission lines. The selection process starts with the active device or microwave transistor. Active device means the discrete component that will provide amplification or biasing. There are many types of microwave transistors around. The most popular ones are SiGe, Si-BJT, HEMT, CMOS and GaAs type transistors. Each one has their advantages and disadvantages. Table 3.1 shows the comparison between different microwave transistors.

Table 3.1: Comparison between different types of transistor [12]

	SIGE	**BJT**	**CMOS**	**HEMT**
Gain (dB)	10-15	10-25	10-25	10-30
Noise Figure(dB)	0.6	1.0-2.0	0.6	0.3-0.5
Cost	Medium	Low	Low	High
Frequency Range(GHz)	20	10	20	More than 50

Gain of a transistor must be taken into account. Notice that all modern microwave transistors are designed for DECT, GSM900-1800 and higher frequency. Most transistors above exhibit very high gain at the frequency of interest. Too much gain is also a bad thing since this means that the tendency for the transistor to oscillate would be high. Some special techniques are necessary to stabilize the HEMTs before adding in the matching network. HEMTs need relatively higher current to operate. The advantages of HEMTs are the noise figure does not change significantly when drain current is increased. The bipolar junction transistor can easily be obtained and they provide reasonable gain at a slightly higher noise figure. Bipolar junction transistor also uses less current. This is also because the increase in collector current will cause the generated noise inside the device to increase. Lower current consumption also means that Third Order Interference Point (IP3) is smaller. CMOS based transistor are out of the picture since they require complex biasing method. The chosen transistor should possess a gain of 20-25dB after stabilization while having a noise figure lower than 1dB. The Si-BJT was chosen as a good candidate due to its high gain and moderate noise figure value. Also, Si-BJT only needs simple matching stabilizing and matching circuits as compared to HEMT.

After choosing the type of device, the correct transistor model must now be chosen. There are many manufacturers of BJT microwave transistor such as NEC, Siemens, Vishay and Agilent Technologies. Some are designed for the pager and mobile phone market while others are for medium power amplifiers. The chosen transistor must be able to work at supply voltages below 10V and current below 10mA. Agilent's AT-41511 is chosen due to its low noise level and excellent gain at the given bias conditions above. Figure 3.1 and 3.2 shows the characteristics of AT-41511 transistor for various bias conditions.

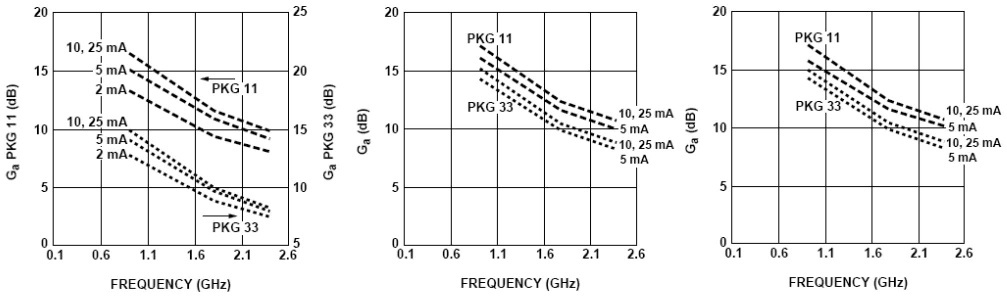


Figure 4. AT-41511 and AT-41533 Associated Gain vs. Frequency and Current at V_{CE} = 2.7 V.

Figure 5. AT-41511 and AT-41533 Associated Gain vs. Frequency and Current at V_{CE} = 5 V.

Figure 6. AT-41511 and AT-41533 Associated Gain vs. Frequency and Current at V_{CE} = 8 V.

Figure 3.1: Associated gain for different bias conditions [4]

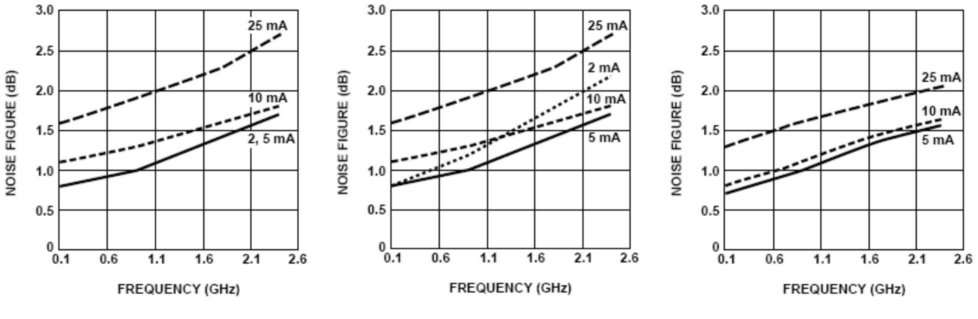


Figure 1. AT-41511 and AT-41533 Minimum Noise Figure vs. Frequency and Current at V_{CE} = 2.7 V.

Figure 2. AT-41511 and AT-41533 Minimum Noise Figure vs. Frequency and Current at V_{CE} = 5 V.

Figure 3. AT-41511 and AT-41533 Minimum Noise Figure vs. Frequency and Current at V_{CE} = 8 V.

Figure 3.2: Noise figure for different bias conditions [4]

From Figure 3.2, increasing the collector current only increases the noise figure while increasing the collector voltage does not provide any real benefit. In addition, the gain is dependent on the type of transistor package used. For low parasitics, SOT-143 package with two emitter leads will be used. Figure 3.3 shows a typical SOT-143 package and its dimension.

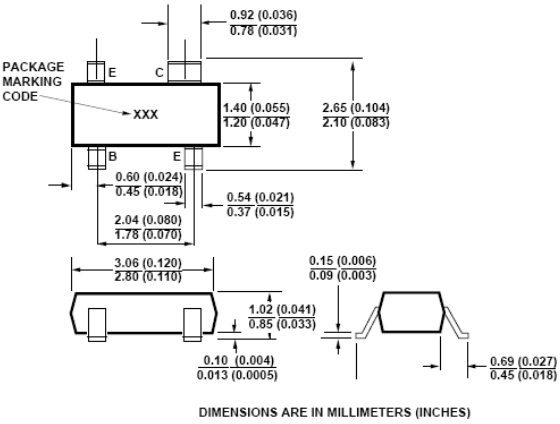


Figure 3.3: SOT-143 package and the associated dimension [4]

Having a higher current also has its advantages as the OIP3 and IP3 will be higher but that is a secondary consideration. The biasing current is chosen to be 5mA at a voltage of 5V. A little bit of introduction on the AT-41511, this transistor is designed for optimum matching at 900MHz at a bias voltage of 2.7,5 and 8V. After choosing the right transistor, the passive components for the circuit will now be considered. Transmission line based inductors and capacitors are not feasible for this project since the design frequency is very low. The maximum design frequency is 140MHz. The wavelength for a signal with this frequency can be found by

$$v = f * \lambda \tag{3.1}$$

when

$f = 137\text{MHz}$

$v = 3\times 10^{8}\text{m}$

which results in

$$\lambda = \frac{3\times 10^{8}}{137\times 10^{6}}$$

$$\lambda = 2.1897\text{m}$$

The wavelength is $\lambda = 2.1897\text{m}$ and this is very long when compared to microwave frequency transmission line standards. Transmission line effects can be ignored if the length of the circuit is less than $\frac{\lambda}{10}$ which is true in this case [15]. Hence the use of transmission line is not convenient here as the length will be very long.

Instead, discrete based components will be used. While air wound inductor and high Q variable capacitor are more preferred, the circuit was designed using surface mount devices (SMD) to minimize space. Air wound inductor offer much superior Q values than their SMD counterpart. Tunable capacitors like those from Vishay are also mush better since they drift very little with varying temperature while maintaining very high Q's, Despite this, SMD based circuit are much smaller in size and this is the main advantage of surface mount technology (SMT). To minimize losses, SMT inductors and capacitors must be chosen properly to make sure they are of the correct type. SMT inductors generally are designed for frequencies above 900MHz and tend to have dismal Q values for lower frequency such as 100MHz. Nevertheless, they provide a compact circuit design. SMT capacitors tend to have many types of dielectric such as NPO, XR7, Z5U and Y5V. NPO class dielectrics are class 1 dielectrics with negligible dependence of capacitance with frequency, time or temperature. X7R based dielectrics are general purpose and have higher capacitance than NPO dielectric. All matching network capacitors use NPO based dielectric while those for coupling are X7R based. Inductors are basically chosen from Murata due to the availability of their design kit and the fact that they do offer wire wound high-Q SMT inductors.

Q or quality factor referred here is actual the ratio of the average energy stored to the energy lost in the network [12]. The equation for quality factor is

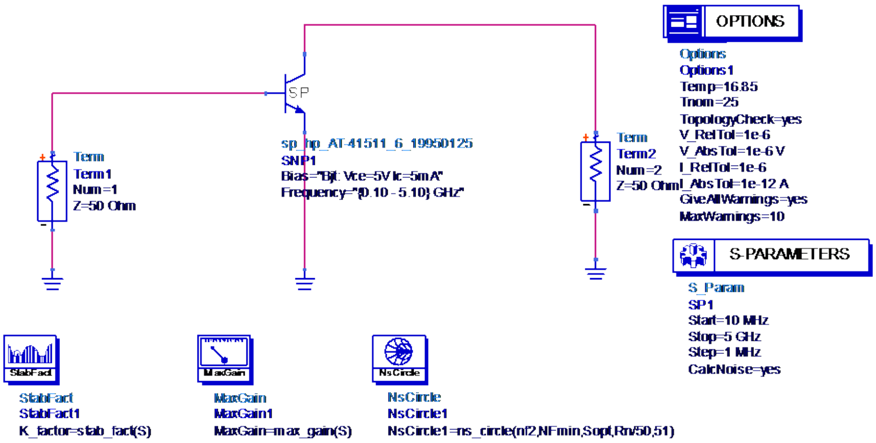
$$\text{Quality Factor, Q=}\omega\frac{\text{average energy stored}}{\text{energy lost/second}} \tag{3.2}$$

Biasing and stabilization resistors are basically from thin film type that possess very low temperature coefficient and this is to ensure that their values drift little with temperature variation. Since this LNA will be employing an active biasing scheme for transistor stabilization, the bias transistor must have a high transition frequency f_T with low noise. The bias transistor must be capable of providing negative feedback that deviates little from the specified bias point. The bias transistor must be of a PNP type and Philips Semiconductor BC559 is chosen since it has a medium forward current gain h_{FE} coupled with low noise figure.

3.2 Simulation of Microwave Transistor

3.2.1 Simulation For Stability

The simulation of the selected microwave transistor is carried out. Since this transistor basically amplify small signal and only operate in the linear region, simulation using s-parameter should suffice [8]. The s-parameter model for AT-41511 transistor can be obtained from Agilent Technologies (now Avagotech) website. The selected file has been characterized at the bias point of V_{CE} =5V and I_C =5mA. A two-port is then used in ADS to model the transistor. Figure 3.4 shows the setup of the s-parameter simulation. Another method would be to use the already provided library files in ADS. The S2P file used for the simulation is given in Appendix B.



Options
Options1
Temp=16.85
Tnom=25
TopologyCheck=yes
V_RelTol=1e-6
V_AbsTol=1e-6 V
I_RelTol=1e-6
I_AbsTol=1e-12 A
GiveAllWarnings=yes
MaxWarnings=10

Term
Term1
Num=1
Z=50 Ohm

sp_hp_AT-41511_6_19950125
SNP1
Bias="Bjt: Vce=5V Ic=5mA"
Frequency="{0.10 - 5.10} GHz"

Term
Term2
Num=2
Z=50 Ohm

S_Param
SP1
Start=10 MHz
Stop=5 GHz
Step=1 MHz
CalcNoise=yes

StabFact
StabFact1
K_factor=stab_fact(S)

MaxGain
MaxGain1
MaxGain=max_gain(S)

NsCircle
NsCircle1
NsCircle1=ns_circle(nf2,NFmin,Sopt,Rn/50,51)

Figure 3.4: Simulation for stability and gain using AT-41511 s-parameter model

Simulation is the carried out for stability and maximum available and stable gain. The sweep is done from 10MHz until 5GHz. This is shown in Figure 3.5. Stability of the microwave transistor is given by the Rollett stability figure [12]. Equation 3.3 defines Rollett stability figure.

$$K = \frac{1-|S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}S_{21}|} \quad (3.3)$$

$$\Delta = S_{11}S_{22}-S_{12}S_{21} \quad (3.4)$$

From the sweep simulation carried out, the Rollett stability figure is very low and almost approaching zero for 137MHz. It is only above 1 for frequencies above 1.7GHz. This amplifier can be extremely unstable for the design frequency and hence it might oscillate if the antenna impedance changes from the characteristics impedance.

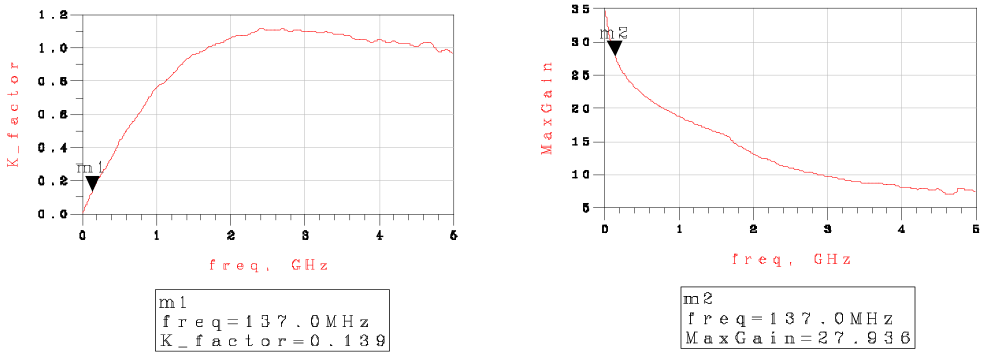


Figure 3.5: Simulation showing the Rollett stability figure and gain

An amplifier is said to be unconditionally stable if the Rollett stability figure is higher than 1 and it is conditionally stable if it is lower than 1. In other words, the condition for unconditional stability can be represented as $K > 1$ and $|\Delta| < 1$ where $|\Delta| = |S_{11}S_{22} - S_{12}S_{21}|$.

While the available gain can be very high, that means gain must be sacrificed to bring the transistor into stability. Before proceeding to make this amplifier unconditionally stable, the load and source stability circles must be plotted. Load and source stability circles are the place where $|\Gamma_{IN}| = 1$ or $|\Gamma_{OUT}| = 1$. The equations used to find the radius and centers of these circles are given below [12].

Load stability circle

Γ_L values for $|\Gamma_{IN}| = 1$

$$r_L = \left| \frac{S_{12}S_{21}}{|S_{22}|^2 - |\Delta|^2} \right| \text{ is the radius} \tag{3.5}$$

$$C_L = \frac{(S_{22} - \Delta S^*_{11})^*}{|S_{22}|^2 - |\Delta|^2} \text{ is the center} \tag{3.6}$$

Source stability circle

Γ_S values for $|\Gamma_{OUT}| = 1$

$$r_S = \left| \frac{S_{12}S_{21}}{|S_{11}|^2 - |\Delta|^2} \right| \text{ is the radius} \tag{3.7}$$

$$C_S = \frac{(S_{11} - \Delta S^*_{22})^*}{|S_{11}|^2 - |\Delta|^2} \text{ is the center} \tag{3.8}$$

A stable area on the Smith chart is represented by the region where $|\Gamma_L| < 1$ when $|\Gamma_S| < 1$. In ADS there are commands that allow us to plot the stability circles straight without calculation. This is very helpful if the stability circle has a very big radius or the center is very far away from the Smith chart. Both the source and load stability circles are shown in Figure 3.6.

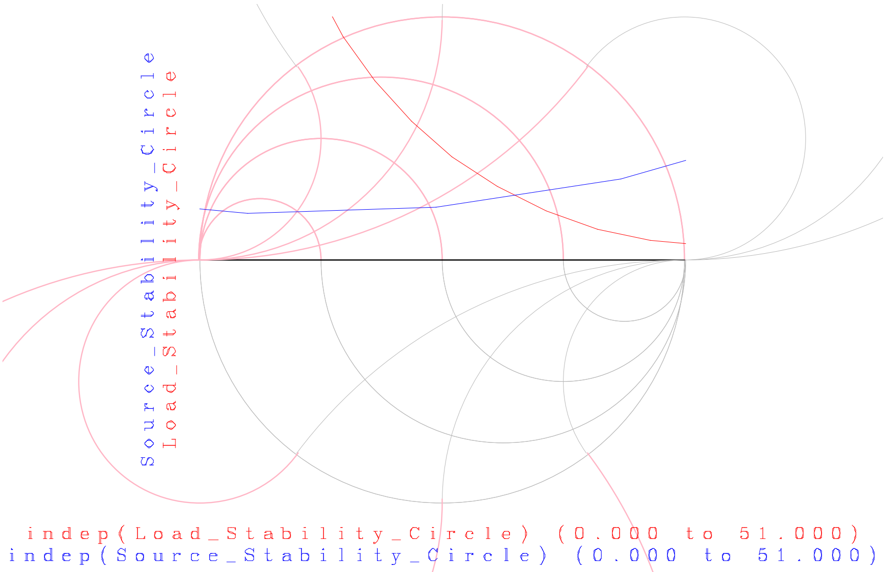
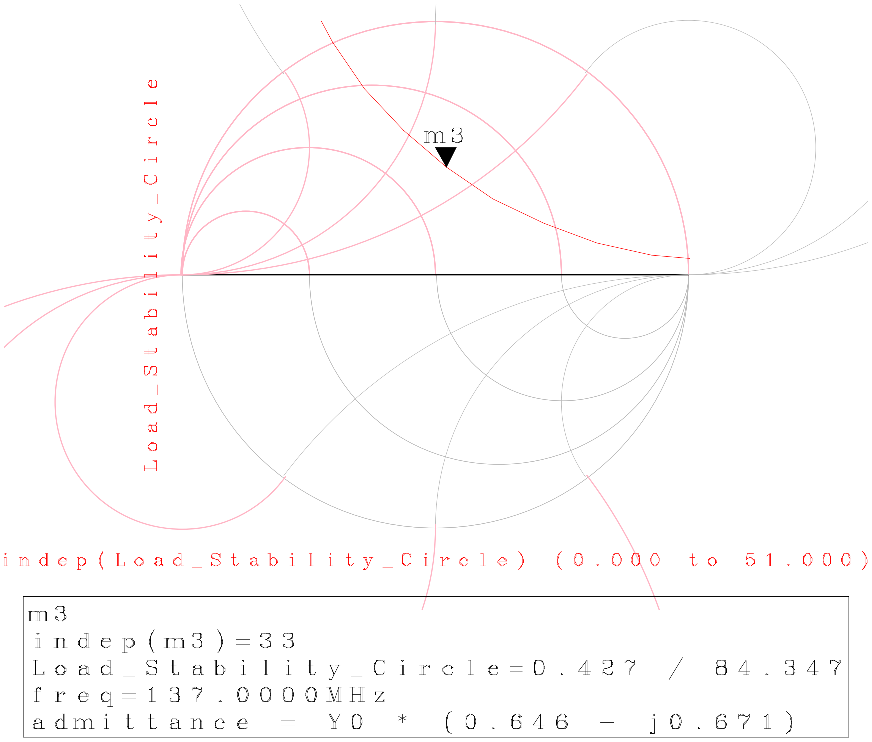


Figure 3.6: Source and load stability circle

Both the load and source stability circle are well into the Smith chart. That would make this amplifier conditionally stable and the source and load reflection coefficient must be chosen properly. A two port network can oscillate if either $|\Gamma_{IN}| > 1$ or $|\Gamma_{OUT}| > 1$. Unfortunately the stability circles are taking half of the smith chart and there are no points to choose for matching. The amplifier must be stabilized first before matching is done. An amplifier can be stabilized either by negative feedback methods or by resistively loading it. Resistive loading is simple but adds a little to the noise figure while lowering the gain [9]. The amplifier can be stabilized either by adding a resistor in series at the input port or a resistor in shunt at the output. Adding a resistor to the input will not only lower the input power but also causes the noise figure to increase by a great margin. Instead, a shunt resistor is added at the output port. The value is found out by finding out the point that would push the load stability circle out of the Smith chart. The area outside the Smith chart represents negative resistance. Now the value of the shunt stabilizing resistor can be calculated. This is done by placing an admittance marker on the load stability circle. Figure 3.7 shows the marker placement.



```
m3
indep(m3)=33
Load_Stability_Circle=0.427 / 84.347
freq=137.0000MHz
admittance = Y0 * (0.646 - j0.671)
```

Figure 3.7: Admittance marker on load stability circle

The goal is to push the load stability circle out of the Smith chart. The value of the shunt resistor is calculated from the marker value

$$R_{stab} = \frac{50\Omega}{0.646}$$

$$R_{stab} = 77.3\Omega$$

This resistor is then placed in shunt with the output port and coupled with a capacitor with a value of 10nF for DC bias blocking. This is done to prevent the current from flowing through the stabilizing network for DC conditions. Figure 3.8 shows the amplifier after stabilization.

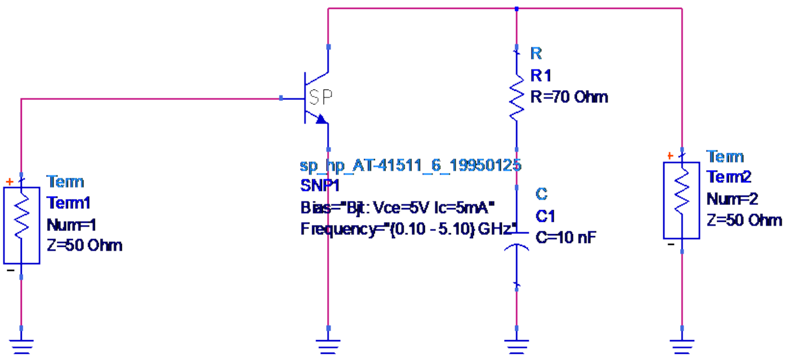


Figure 3.8: Transistor with stabilizing network in place

The value of 70 Ω was chosen to make sure the Rollett stability figure is safely above 1. This value was chosen after a couple of simulation. The Rollett stability figure is not set very high as gain decreases and noise figure increases. Another s-parameter simulation is carried out with stabilizing network in place.

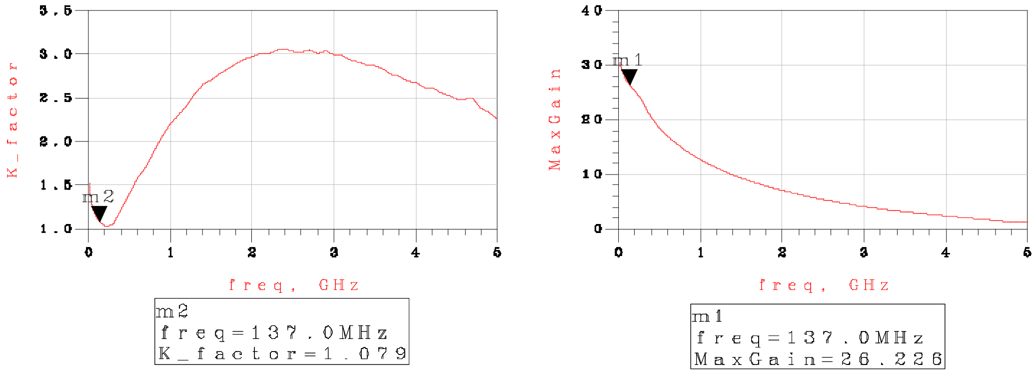


Figure 3.9: Rollett stability figure and gain after stabilization