

# Design, Analysis and Optimization of Multistage LNA at KU-Band

Mujeeb Ahmed, Noshawan Shoaib, Iftekhhar Mahmood  
Institute Of Space Technology, Islamabad

[mujeeb.ch@gmail.com](mailto:mujeeb.ch@gmail.com), [noshawan@live.com](mailto:noshawan@live.com), [iftekhhar\\_m2000@yahoo.com](mailto:iftekhhar_m2000@yahoo.com)

*Abstract*— This paper presents the design and analysis of a multistage low-noise amplifier (LNA) using Pseudomorphic High Electron Mobility Transistor (PHEMT). The LNA is designed at the center frequency of 12.7GHz with a gain of 30dB, bandwidth of 72MHz and noise figure of less than 3 dB. This paper is an extension of the author's previous work related to design of single stage LNA [1]. The matching design is carried using Narrowband amplifier design technique. The design methodology required the analysis of the transistor, stability check and proper matching network selection for input and output. Ideal microwave amplifier equations are used to carry out the analytical treatment for the design. The required gain and other parameters are achieved by a three stage Low Noise Amplifier. The most important task in the design is to establish a tradeoff between the noise figure and gain of the amplifier. Advanced Design Software (ADS) is used to carry out simulations for the design and to see how the design is comparable to the specifications. The design is optimized using stub matching resulting in reduced noise figure and minimizing the standing wave ratio. The DC and AC simulations for the LNA are presented in the paper [1].

*Key Words*— Multistage Low Noise Amplifier at Ku band, LNA, Designing of LNA, Analysis of LNA

## 1 INTRODUCTION

Low noise amplifier (LNA) is one of the basic building blocks of a communication system. The purpose of the LNA is to amplify the received signal to acceptable levels while minimizing the noise it adds. The low noise amplifier is used in communication systems to amplify very weak signals captured by an antenna. It is often located very close to the antenna thereby making losses in the feed-line less critical [1]. LNA is placed at the front-end of a radio receiver circuit. Using an LNA reduces the noise at all the subsequent stages. Thus, it is necessary for an LNA to boost the desired signal power while adding as little noise and distortion as possible so that the retrieval of signal is possible in the later stages in the system. For low noise, the amplifier needs to have a high amplification in its first stage. Therefore High Electron Mobility Transistor

(HEMT) is used; which are not energy efficient, but reduce the relative amount of shot noise [2] [3]. Input and output matching circuits are used for the device matching using the values of load and source reflection coefficients. Biasing is designed using large resistors, because energy efficiency is not of primary concern, and a large resistor prevents leakage of the weak signal out of the signal path or of noise into the signal path.

The matching network design is important part of the whole design. The important performance parameters of LNA's are gain, Noise Figure [4] [5] and impedance matching [6]. Achieving a high gain at microwave frequencies may result in instability, and mismatch can cause various drawbacks such as power loss and, hence, signal-to-noise reduction [6]. For typical applications Gain ranging from 12 to 25 dB and a better than 10-dB return loss must be provided.

To design an efficient and stable impedance matching network, different concerns are taken care for the input and output. The matching network at the input of the LNA greatly determines the noise figure while output matching network has a negligible effect on noise-figure performance. The noise figure can be minimized by designing the optimum matching network by selecting the optimum source impedance [7]. [8] [9] have presented extensive analysis on design of broadband matching techniques. The microstrip circuits highly depend on the frequency and their response is different at low frequencies as compared to high frequencies [10]. There are many options on designing a circuit using microstrip at high frequency. The design of matching networks using microstrip stubs need a very careful look into discontinuity affects at high frequencies; the authors in [11] [12] present a very good study for these issues

The remainder of this paper is organized as follows. In section 2, we present the analytical framework that addresses the design technique and analysis. Section 3 shows simulation results for the single stage design. Detailed three stage design simulations and results are presented in section 4 followed by the Conclusion in section 5.

## 2 DESIGN AND ANALYSIS

In electronic receiver system, the maximum power gain and minimum noise figure are equally important. However, from design practices, maximum power gain and minimum noise figure cannot be achieved simultaneously in most cases. Therefore, there is a tradeoff between high gain and low noise figure.

The block diagram of LNA is shown in figure 1 [1].

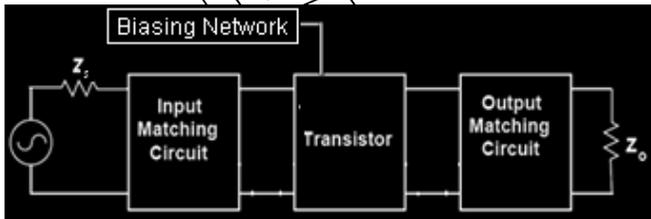


Figure 1 - Block Diagram of LNA

Transistor selection is the first and most important step in a LNA design. The designer should carefully review the transistor selection keeping the most important LNA design tradeoffs in mind. The transistor should exhibit high gain, low noise figure, at the lowest possible current consumption, while preserving relatively easy matching at frequency of operation. Examination of a datasheet is a good starting point in a transistor evaluation for LNA design. The factors of gain, noise and stability were taken into consideration for all the devices and finally the device chosen was the ATF36077, because this device has high gain and low noise figure at the frequency of operation.

After selection of the device, the next step is its stability check. Stability or resistance to oscillation in a microwave circuit can be determined by the S-parameters of the device, and the source and load impedances. The datasheet does not provide S-parameters and noise figure values exactly at 12.7 GHz to obtain the device S-parameters at 12.7 GHz, the interpolation is used. Touch stone file is a data file which is used to interpolate the device parameters between two points of the variable. S-parameters are swept between 10 GHz to 15 GHz with a step of 100 MHz to get required data at 12.7 GHz.

Table 1 - Device Parameters at 12.7 GHz using Touchstone file

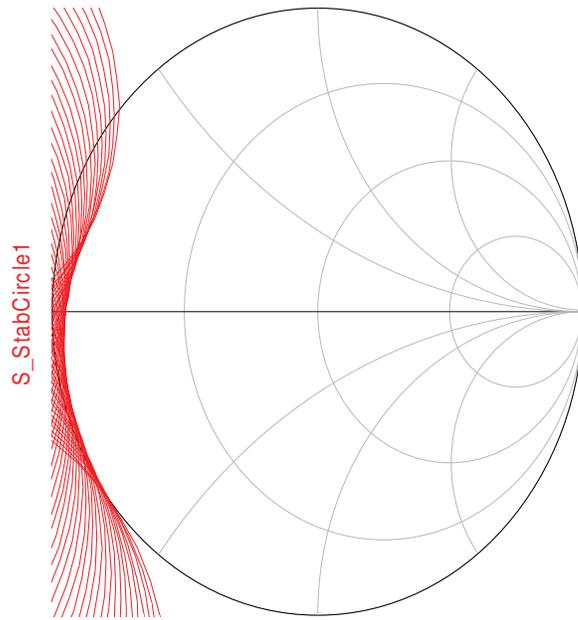
	S <sub>11</sub>	S <sub>12</sub>	S <sub>21</sub>	S <sub>22</sub>	F <sub>n</sub>	r <sub>n</sub>
Mag.	0.577	0.194	2.899	0.262	.50	.03
Phase	175.446	-38.48	-1.136	-129.74		

The stability of device can be checked by two stability factors K and |Δ|. The mathematical equations for K and |Δ| are [13]:

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

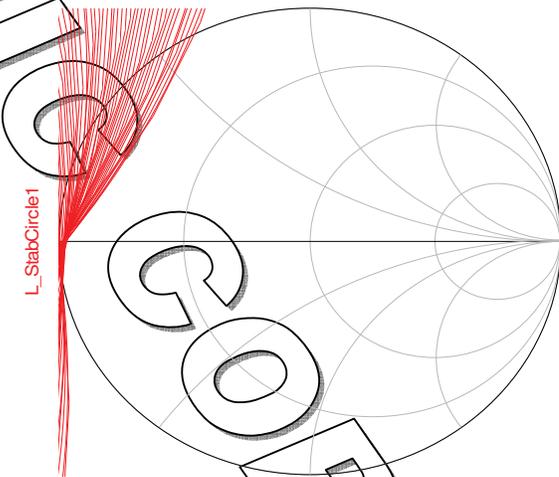
$$\Delta = S_{11}S_{22} - S_{12}S_{21} \dots \dots \dots (2)$$

Putting the values of S-parameters in equation (1) and (2) gives K=0.823 and |Δ|=0.572. Since K<1 and also |Δ|<1, therefore the device is potentially unstable. The input and output stability circles are shown for all the frequencies from 10 GHz to 15 GHz with a step of 100 MHz, in figure 2 and 3 respectively. The circles show that the entire smith chart except the intersection of stability circles with smith chart is a stable region and any point can be selected in that region for design of LNA.



indep(S\_StabCircle1) (0.000 to 51.000)

Figure 2 - Input Stability Circle [1]



indep(L\_StabCircle1) (0.000 to 51.000)

Figure 3 - Output Stability Circle [1]

The DC biasing requirement for the device is  $V_{ds}$ (Drain to source voltage)=1.5V,  $V_{gs}$ (Gate to drain voltage)=0.2V and  $I_{ds}$ (Drain to source current)=10mA. The biasing technique used for DC biasing of device is Active biasing rather than Passive biasing because Active biasing provides a stable operating point as compared to the Passive biasing technique [14]. The biasing circuit is simulated on ADS. The biasing circuit is shown in figure 4.

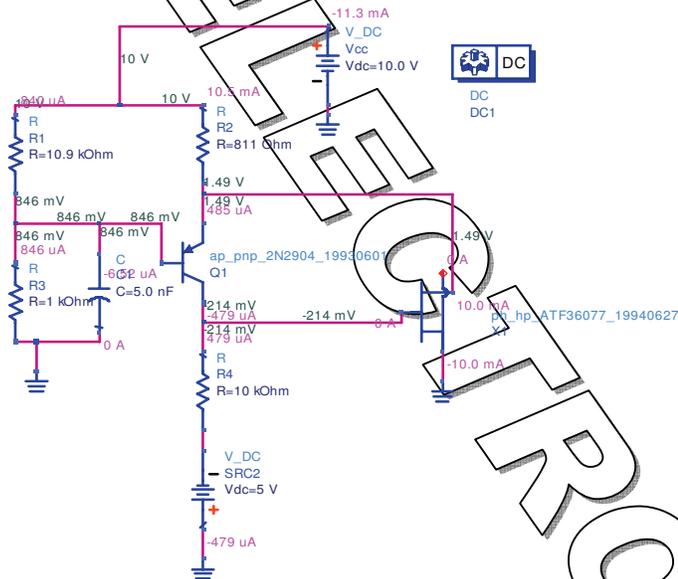


Figure 4 - DC Biasing Network [1]

The DC biasing circuit must be protected from the high frequency effects of the termination ports so that the S-parameters should not change due to the biasing of the active device. The inductors are inserted between the termination port and DC biasing circuit to protect the biasing circuit from the effects of the termination ports. Another important task is to protect termination ports from the DC voltages and currents used to bias the device, therefore DC blocking capacitors are used [15].

The next step in the designing of LNA is to draw constant gain and noise circles on Smith chart [16] as shown in figure 5. The purpose of drawing constant gain and noise circles is to find a point on smith chart that gives a high gain and low noise figure because in the design of LNA, the major concern is to minimize the noise and maximize the gain of the input signal. For this purpose some optimum values of  $\Gamma_s$  (source reflection coefficient) and  $\Gamma_L$  (load reflection coefficient) are selected to design the matching network for which the noise figure is up to a tolerable level and the gain set to the required value. For the matching Network design, the intersection of noise and gain circle has to be located, as shown in figure 5

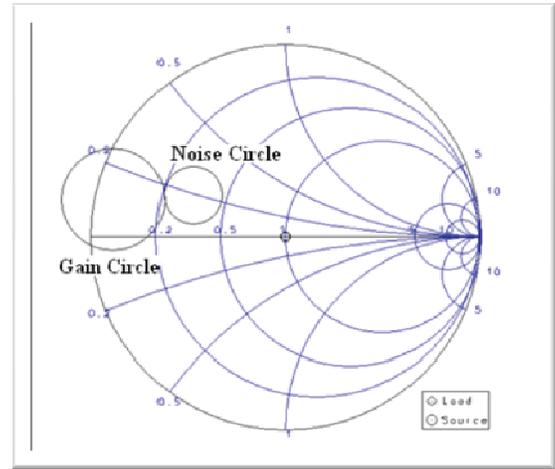


Figure 5 - Intersection of Gain and Noise Circle [1]

Since the device is potentially unstable so we have to mismatch either at the input or the output port. From the intersection of the Noise and Gain circles, the value of  $\Gamma_s$  is chosen to design the matching network. Then  $\Gamma_s$  is used to determine  $\Gamma_{out}$  (output reflection coefficient) using the following equation [14]:

$$\Gamma_{out} = S_{22} + \frac{S_{12} S_{21} \Gamma_s}{1 - S_{11} \Gamma_s} \dots \dots \dots (3)$$

$\Gamma_{out}$  is conjugate matched with  $\Gamma_L$ . The value of  $\Gamma_L$  is used to determine  $\Gamma_{in}$  (input reflection coefficient) using the following equation [1]:

$$\Gamma_{in} = S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22} \Gamma_L} \dots \dots \dots (4)$$

After the selection of  $\Gamma_s$  and  $\Gamma_L$ , the input and output matching networks are designed using ADS Smith Chart utility. The Open Stub matching technique is used in designing of matching networks [17]. The lengths and widths for the stub and microstrip line of the matching networks are calculated using the Line Calculator utility in ADS.

### 3 SIMULATIONS OF SINGLE STAGE LNA

Once the matching network has been designed and implemented, the single stage LNA can be simulated. The simulation results often differ from what was designed, the next step is to optimize the results. The optimization tool of the ADS is used for the optimization of matching networks [17]. Housing effects are also included while doing simulations. There are different types of losses in microstrip like dielectric loss, radiation loss and conductor loss [18], however, in simulations the Ideal

Transmission lines are used. The schematic of single stage LNA is shown in figure 6.

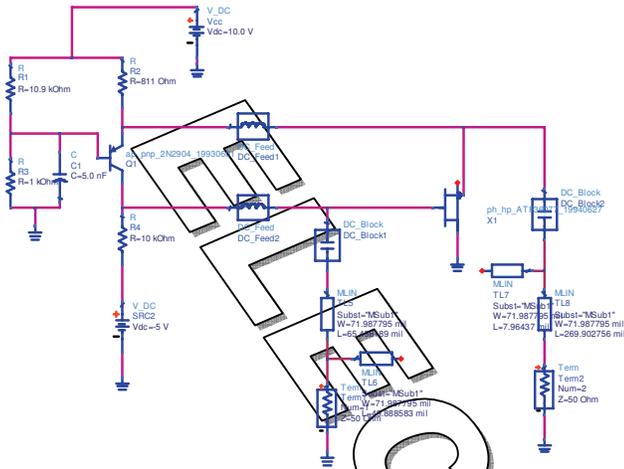


Figure 6 - Schematic of Single Stage LNA [1]

The simulated results are shown in the following figures.

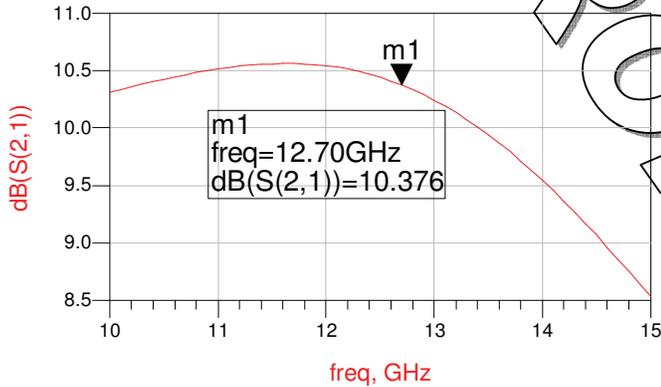


Figure 7 - Gain curve of Single Stage LNA [1]

A gain of 10.376dB is obtained at 12.7GHz which satisfies design requirements of 10dB so it means the gain of 30 dB can be achieved using three stages.

Another parameter which dictates the performance of the low noise amplifier is the noise figure. The noise figure of 0.614dB is obtained at 12.7GHz which also satisfies design requirements of 3 to 4dB.

Voltage Standing Wave Ratio (VSWR) is calculated at the input and at the output of the amplifier. This factor is important as it specifies phenomenon of standing waves due to reflections on the transmission line.

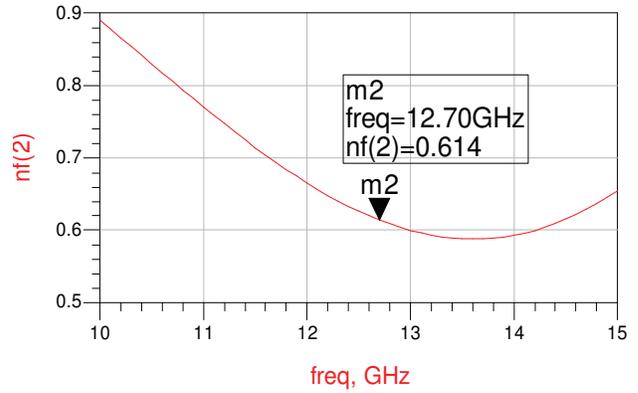


Figure 8 - Noise Figure curve of Single Stage LNA [1]

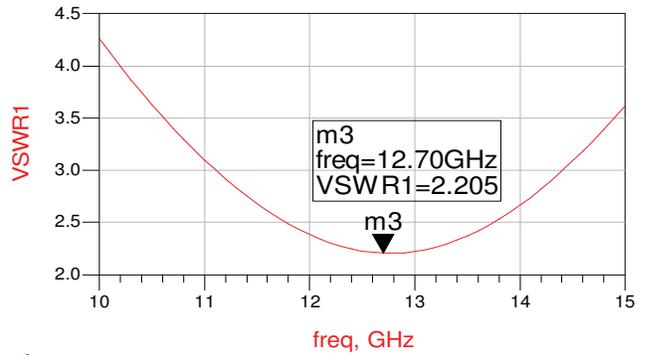


Figure 9 - Input VSWR curve of Single LNA [1]

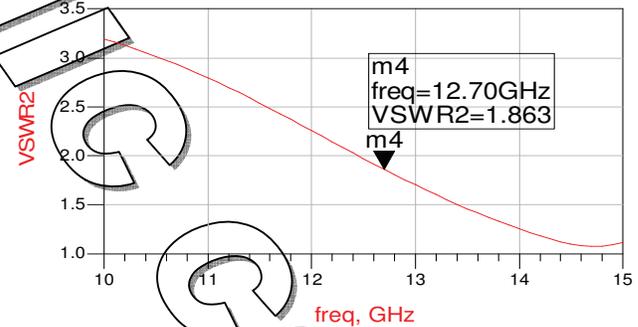


Figure 10 - Output VSWR curve of Single LNA [1]

#### 4 SIMULATIONS OF THREE STAGE LNA

The first step in the design of multi stage LNA is to design the single stage first and if it accomplishes the design goals then you may use that to design multistage LNA for your desired specifications. Three-stage LNA can be designed by cascading

three single stage LNAs. There can be several ways to achieve the design; three different active devices (transistors) can be used if same device is not able to handle the signal level in progressive stages. As the LNA under consideration is a small signal amplifier, all the three stages use the same transistor device. No inter-stage matching network is required because this design is a narrowband amplifier and the input and output impedance of each stage is matched to  $50\Omega$ .

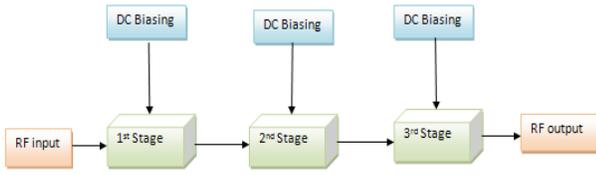


Figure 11 - Three Stage LNA Block Diagram

The Schematic of three-stage LNA is implemented in ADS with separate DC biasing for each stage and matching networks as shown in figure 12.

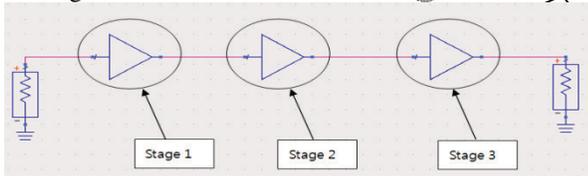


Figure 12a - Three Stage LNA: System Level Schematic

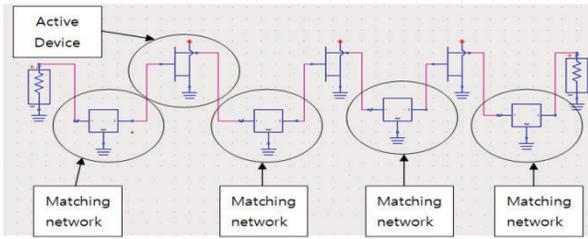


Figure 12b - Component Level Schematic

The optimization of three-stage LNA is done. Initially the design was giving VSWR's more than two at input and output ports, but by using the ADS optimization tools VSWR's are reduced to less than two to minimize the reflections at the input and output ports. For an amplifier the gain is the most important factor. The following graph is drawn by taking the gain on the Y-Axis and frequency on the X-Axis. Three-Stage LNA is simulated in ADS to obtain the desired results. A gain of 30.553dB is obtained at 12.7GHz. The marker in above graph shows the gain at the frequency of interest. The gain is found to be nearly same as was calculated during the design procedure. Another parameter which dictates the performance of the low

noise amplifier is the noise figure. The design is carried out to achieve a noise figure as low as possible. Figure 14 shows the noise figure in a two stage LNA. Comparatively, this is a quite low noise figure with a gain of 30.553dB at 12.7GHz. Voltage Standing Wave Ratio (VSWR) is calculated at the input and at the output of the amplifier. This factor is important as it specifies phenomenon of standing waves due to reflections on the transmission line.

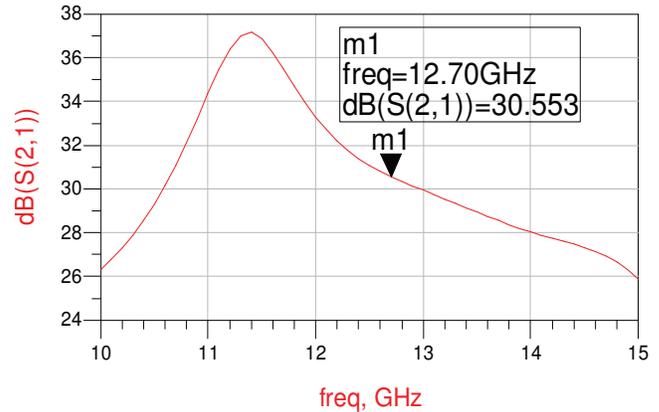


Figure 13 - Gain Curve three-Stage LNA

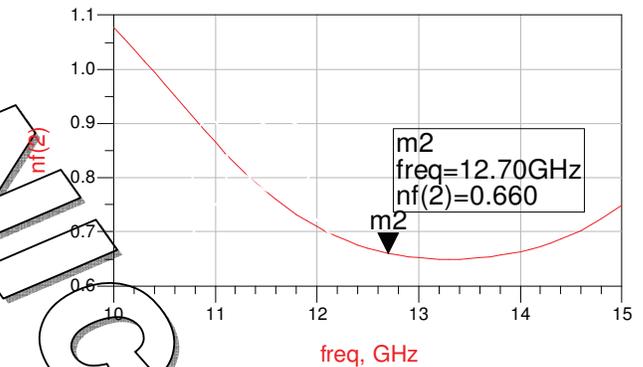


Figure 14 - Noise Figure Curve three-Stage LNA

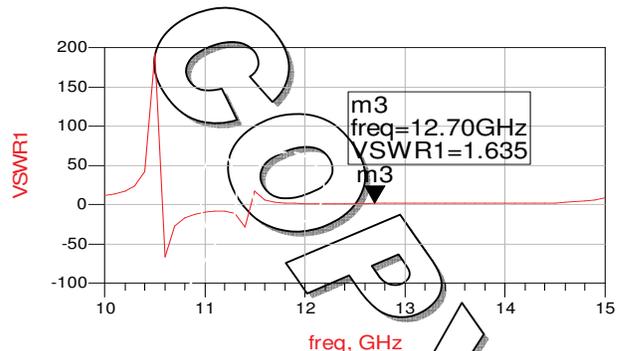


Figure 15 - Input VSWR Curve three-Stage LNA

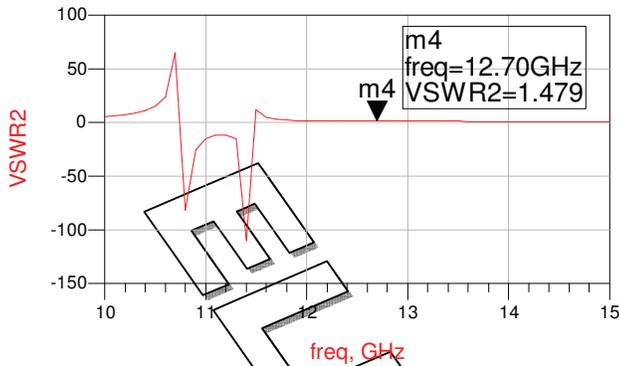


Figure 16 - Output VSWR Curve three-Stage LNA

The VSWR1 and VSWR2 curves are showing the Output and Input Voltage Standing Wave Ratio respectively. Both the standing wave ratios are found to be same as were calculated during the design procedure.

## 5 CONCLUSION

The main aim was to design, simulate and analyze a three-stage LNA at Ku band. Before explaining the design, basic concepts related to the microwave are discussed which paved the way to a good design. The important parameters related to microwave amplifiers are described including gain and noise figure circles. Tradeoff between noise figure and gain is also considered in detail for a low noise amplifier. Selection of device was done after of comparisons between different devices and the decision was made on the gain and noise figure parameters of the ATF 36077 device. A detailed investigation of the stability of the device is made. This led to a better understanding of the device characteristics and performance. The fundamentals and design of DC biasing circuit is elaborated. The most important part in microwave circuits is matching network design; matching techniques are mentioned along with their design procedures. The matching network optimization is done to achieve maximum gain for a comparatively low noise figure.

## REFERENCES

[1] Noshawan Shoaib, Mujeeb Ahmad and Iftekhar Mahmood, "Design, Fabrication & Testing of Low Noise Amplifier at Ku band" IEEE International Conference on Advances in Space Technology 2008.  
 [2] Streit, D.C. Kobayashi, K.W. Oki, A.R. Umemoto, D.K., "A monolithic HBT-regulated HEMT LNA by selective MBE," IEEE Microwave and Guided Wave Letters, Apr 1995

[3] Kobayashi, K.W., Streit, D.C., Oki, A.K., Umemoto, D.K.; Block, T.R., "A novel monolithic linearized HEMT LNA using HBT tuneable active feedback", IEEE Microwave Symposium Digest, Jun 1996  
 [4] T. T. Ha, *Solid-State Microwave Amplifier Design*, Wiley, N.Y., 1981  
 [5] C. Gentile, *Microwave Amplifiers and Oscillators*, McGraw-Hill, N.Y., 1987  
 [6] Giovanni Girlando and Giuseppe Palmisano, *Associate Member, IEEE*, "Noise Figure and Impedance Matching in RF Cascode Amplifiers", IEEE transactions on circuits and systems, vol. 46, no. 11, November 1999  
 [7] P. R. Gray and R. G. Meyer, *Analysis and Design of Analog Integrated Circuits*, 3rd ed.ch 11, New York: Wiley, 1993.  
 [8] Poes, H.F. Van de Capelle, "An impedance-matching technique for increasing the bandwidth of microstrip antennas," IEEE Transactions on Antenna and Propagation, Nov 1989  
 [9] Aly Ismail and Asad A. Abidi, *Fellow, IEEE*, "A 3–10-GHz Low-Noise Amplifier With Wideband LC-Ladder Matching Network," IEEE Journal of Solid-state Circuits, vol. 39, no. 12, December 2004  
 [10] Jia-Sheng Hong, M. J. Lancaster, *Microstrip filters for RF/microwave applications*, John Wiley & Sons INC., USA  
 [11] Pisti b. Katehi and nicolaos g. Alexopoulos, Senior Member, IEEE, "Frequency-Dependent Characteristics of Microstrip Discontinuities", IEEE Transactions on Microwave Theory and Techniques, vol. Mtt-33, no. 10, October 1985  
 [12] Drissi, M.; Hanna, V. Fouad; Citerne, J., "Theoretical and Experimental Investigation of Open Microstrip Gap Discontinuities," IEEE 18<sup>th</sup> European Microwave Conference, 1988  
 [13] Samuel Y. Liao, *Microwave Circuit Analysis and Amplifier Design*, Prentice-Hall, INC., New Jersey, 1986.  
 [14] Guillermo Gonzalez, *Microwave Transistor Amplifiers*, Prentice-Hall, INC., Englewood Cliffs, N.J., 1996.  
 [15] Inder Bahl and Prakash Bhartia, *Microwave Solid State Circuit Design* 2<sup>nd</sup> Edition, John Wiley & Sons, Inc., Hoboken, New Jersey, 2003.  
 [16] H. Fukui, "Available Power Gain, Noise Figure and Noise Figure measure of Two-Ports and their Graphical Representations," IEEE Transactions on Circuit Theory, June 1966  
 [17] Tahir Abbas and Mujeeb Bin Ihsan Design of a two stage Low Noise Amplifier at Ku Band, 17<sup>th</sup> International Conference on Microelectronics, pp. 40-45, Dec. 2005.  
 [18] David M. Pozar, *Microwave Engineering*, 2<sup>nd</sup> Edition, John Wiley & Sons INC., USA