Design and Fabrication of C-band Low Noise Amplifier for Satellite Communication System

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***Abstract* - In this paper, the aim is to design, simulate and fabricate a two-stage low noise amplifier circuit (LNA) with high gain and low noise figure using GaAs FET for frequency from 3.7 GHz to 4.2 GHz, which is used for C band satellite receiver systems. The most important thing in the design of the LNA is to require the trade-off many important characteristics such as: Gain, noise figure, stability, and bandwidth. The LNA uses a diagram of the two-stage cascade to create high gain and noise figure as lower as possible. All of the designed, simulated and fabricated processes were done using Agilent' ADS 2009 package and machine LPKF Promomat C40. The LNA has successfully been fabricated on Rogers FR4 type with following specifications: Maximum overall gain of 25.4 dB, operating frequency: 3.7 GHz to 4.2 GHz, noise figure is less than 1.1dB, good impedance input-and-output matching, input impedance: 50 ohm.**

Keyword- Low noise amplifier, C band, noise figure, sattelite receiver, Advance Design System.

I. INTRODUCTION

Satellite communications played an important role not only in civilian communications but also in military purposes. It is also known such as the way of communication provides broadband and Internet services and will continue to play an important role in the future generation networks. To amplify the very small received signals in satellite receiver systems, a low noise amplifier, which is placed right after the antenna, is required. This stage has an important role in quality factor of the receiver, due to the signal to noise ratio of the receiver has the dominant effect on the noise of the first amplifier stage.

Figure 1 indicate the low-noise block downconverter (LNB) diagram. In C-band low-noise block downconverters (LNB), the received signals from satellite are amplified by a LNA, then go through bandpass filter, only allowing the intended band of microwave frequencies to pass through after that go to the mixer. At the mixer, output produces consisting of the sum and difference frequencies and multiples of the wanted input signal and the local oscillator frequencies. Output signal of mixer are amplified by a intermediate frequency amplifier. All that has come through the second bandpass filter and feeds them to the IF amplifier and into the cable.

There were many studies on designing and manufacturing LNA performed in different frequency bands [2-3], [5-9] and solving issues such as: increasing gain [3], [5-6], [8], increasing bandwidth of circuits and reducing noise figure [2], [7], [9].

The goal of this paper is to design a wideband LNA with the lowest noise figure, gain as high as possible. In order to abtain the demand of the system consisting of gain, noise figure, bandwidth, we have deal with the design of two-stage LNA. The first stage will be optimize the noise figure, bandwidth and the second stage will be increase overall gain. The transistor amplifier used here to design is spf-2086. which was fabricated in pHEMT GaAs FET technology with low noise figure, high gain and operating frequencies to 12 GHz.

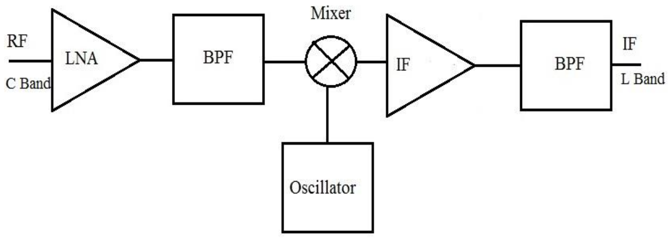

Figure 1: Low noise block downconverter diagram

II. DESIGN AND SIMULATION RESULTS

A. *Analysis of the low noise amplifier*

The configuration of the LNA in the paper is a two-stages cascade amplifier based on the design of single-stage one. The block diagram of two-stage cascade LNA illustrated the Fig.2.

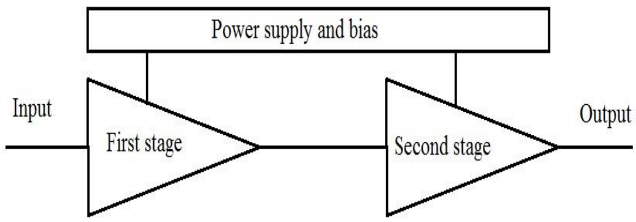

Figure 2: Diagram of two-stages cascade LNA

This two-stages amplifier have the same structure, however they were provided the different bias voltage. In order to achieve bandwidth 500 MHz, we suppose the design of the center frequency at 4.0 GHz.

A single-stage amplifier with matching networks at the input and output terminals of the transistor spf-2086 are shown in Fig.3. To delivere the maximum power from source to load, the input and output impedances of transistor have to match to the source and load impedances Z_S and Z_L. In this case, Z_S and Z_L is equal 50 Ω.

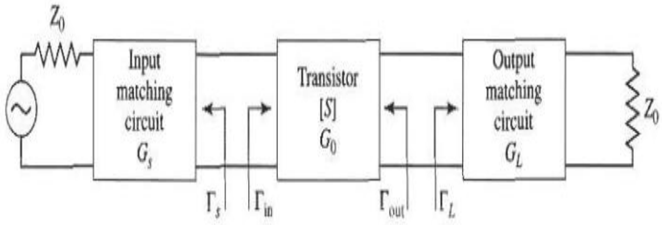

Figure 3: The diagram of a single stage amplifier stage.

The most useful gain definition for amplifier design is the transducer power gain, which accounts on both source and load mismatch. Thus from [4], we can define separate effective gain factors for the input (Source) matching network, the transistor itself and the output (Load) matching network as follows:

$$G_S = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2} \quad (1)$$

$$G_0 = |S_{21}|^2 \quad (2)$$

$$G_L = \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \quad (3)$$

The overall transducer gain is $G_T = G_S.G_0.G_L$. The effective gains from G_S and G_L are due to the impedance matching of the transistor to the impedance Z_0.

The stability of an amplifier, or its resistance to oscillate, is a very important consideration in a design and can be determined from the S parameters, the matching networks, and the terminations. The stability condition of an amplifier circuit is frequency dependent.

Another parameter must take into account the stability factor K [4], defined as:

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|S_{11}S_{22}-S_{12}S_{21}|^2}{2|S_{12}S_{21}|} \quad (4)$$

Along with the auxiliary condition that

$$\Delta = S_{11}S_{22} - S_{12}S_{21} \quad (5)$$

The stability of an amplifier is K>1 and |Δ| <1.

B. Design of the matching networks

The first stage has an important rule in quality factor of the receiver. Because any noise injected by components in a system is amplified by later gain stages along with the signal, it is essential that the signal be amplified early in the receiver chain while adding as little noise as possible. Therefore, important to optimize characteristics to trade-offs between gain, stability, and noise figure.

From the S parameters and noise parameters at 4.0 GHz is provided as follows: Minimum noise factor F_{min} = 0.57 dB, $\Gamma_{opt} = 0.64e^{28j}$, the noise resistance $R_N/50$ = 0.32. Then the noise figure at this frequency is calculated to be as follows:

$$F = F_{min} + \frac{4R_N}{Z_o}\left(\frac{|\Gamma_{opt}-\Gamma_s|^2}{|1+\Gamma_{opt}|^2(1-|\Gamma_S|^2)}\right) \quad (6)$$

In order to abtain the minimum noise figure, the reflection coefficient Γ_S look into the source is matched to Γ_{opt}.

With Γ_{in} is set to be the conjugate of Γ_S, the reflection coefficient looking into the load is shown below:

$$\Gamma_L^* = \frac{S_{22}-\Delta\Gamma_S}{1-S_{11}\Gamma_S\Delta} \quad (7)$$

In the second stage, we will design for maximum gain. The overall transducer gain is $G_T = G_S.G_0.G_L$. Since G_0 is fixed for a given transistor, the overall gain of the amplifier will be controlled by the gains, G_S and G_L of the matching sections.

In order to transfer the maximum power from the input matching networks to the transistor will occur when $\Gamma_S = \Gamma^*_{in} = S^*_{11}$ and the maximum power transfer from the transistor to the output matching network will occur when $\Gamma_L = \Gamma^*_{out} = S^*_{22}$.

The value of Γ_S and Γ_L is then used for the design of the input and output matching networks using smith chart. The matching networks can be designed by some methods such as using lumped components, stubs, quarter-wave transformer or using general transmission line. However, in this paper the design of the LNA using opened stubs matching networks.

The completed LNA with two stages was shown in Fig.4.

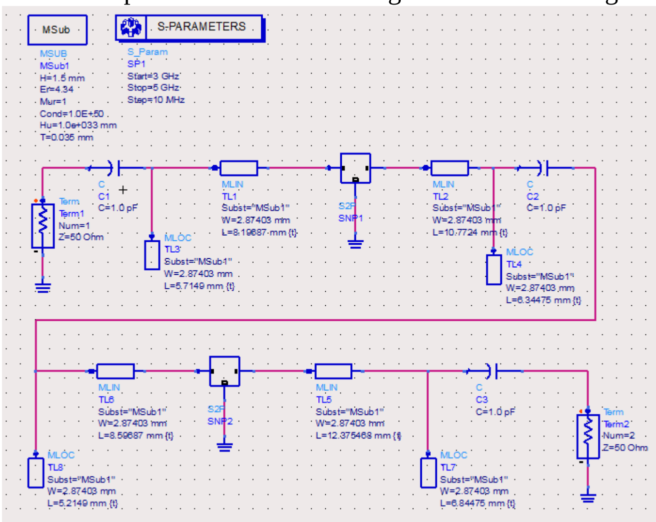

Figure 4: Schematic of the two-stages cascade LNA

C. Simulation of the LNA

The initial simulations to test the LNA performance were done with the S-Parameter file of the transistor. The results were shown in the bellow Figs.

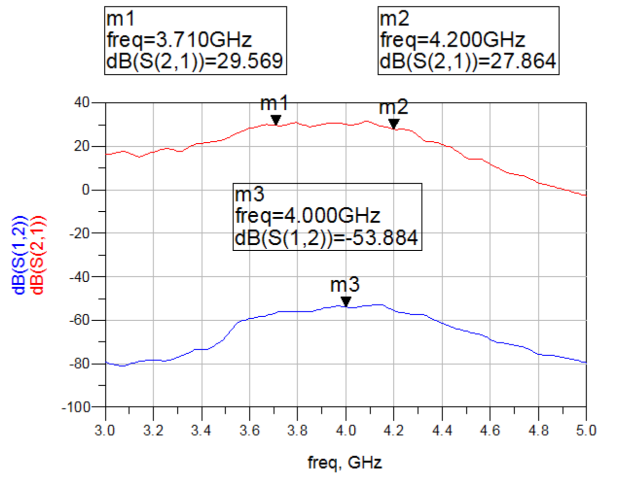

Figure 5: The S_{21} and S_{12} of the LNA.

The Fig.5 indicates the overall gain (S_{21}) and reverse transmission (S_{12}) parameter which have been achieved: overall gain is greater than 27.864 dB from 3.7 GHz to 4.2 GHz and the maximum gain obtains 29.569 dB at 3.7 GHz. The value of reverse isolation (S_{12}) is very good in working band.

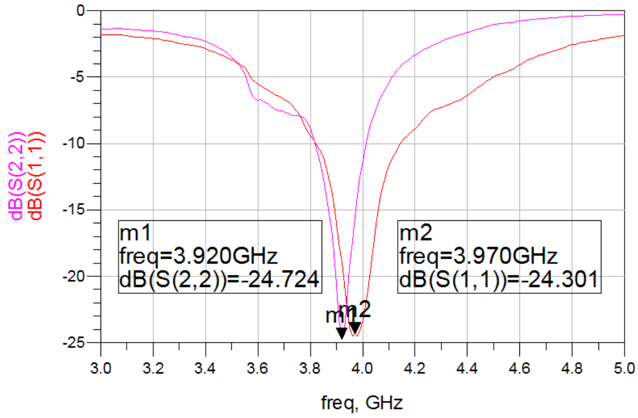

Figure 6: The S_{11} and S_{22} of the LNA

The result in Fig.6 shows the value of the input impedance matching (S_{11}) and output impedance matching (S_{22}). The intput and output impedance matching is quite good and minimum value is -24.3 dB at 3.9.2 GHz.

The noise figure of the LNA is plotted in Fig. 7 with maximum level reaches at 1.061 dB.

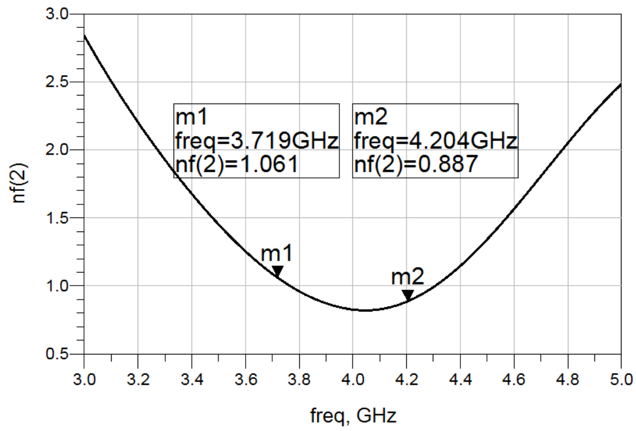

Figure 7: The noise figure of the amplifier

From the S2P data provided by Stanford Microdevices, we can check stability performance by calculating stability factor K using ADS package, the results shows in fig. 8:

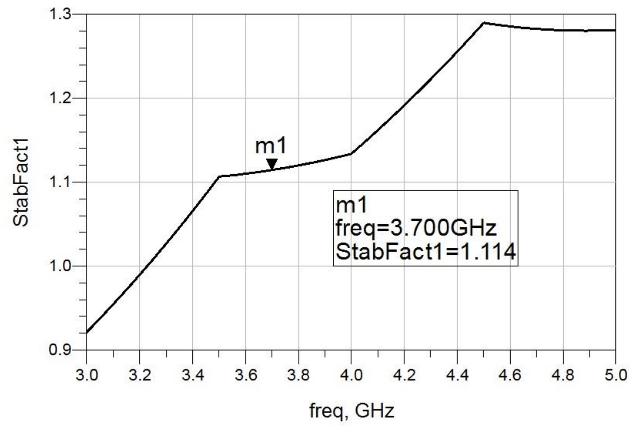

Figure 8: The stability factor K

III. EXPERIMENTAL RESULTS AND ANALYSES

The LNA circuit was successfully fabricated in Laboratory with the aid of the ADS package and machine LPKF Promomat C40. The result was shown in Fig.9.

Figure 9: The fabricated LNA

The circuit was supplied Vds of 5VDC/400mA and Vgs of -0.8 VDC through the DC pins at the top of the board. The drain current was measured to be about 20 mA. The testing results are measured on the vector network analyzer 37369D - Anritsu technology up to 40 GHz.

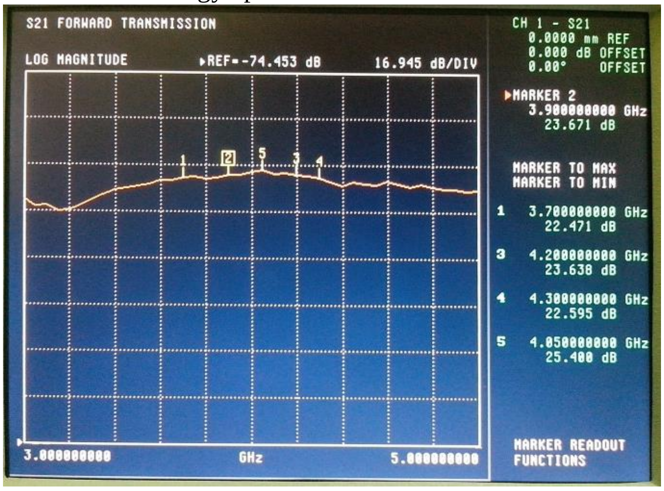

Figure 10: The gain of the LNA

The result in Fig.10 determines the maximum gain of 25.4 dB at 4.05 GHz and circuit amplifies wideband from 3.7 to 4.2 GHz with gain is greater than 22.47 dB.

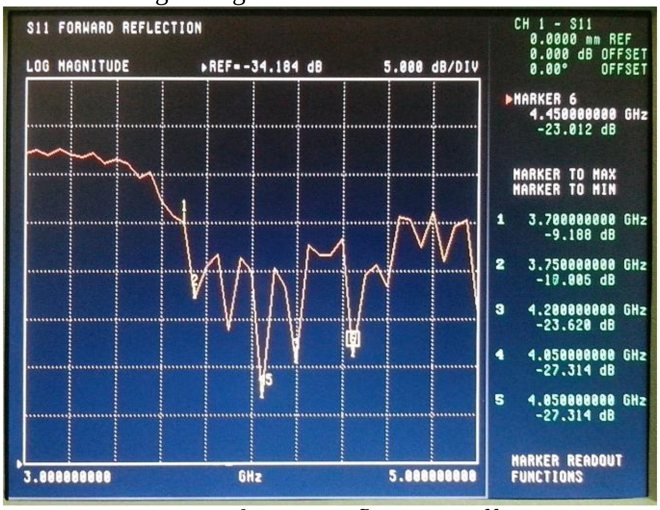

Figure 11: The input reflection coefficient S_{11}

The magnitude of S_{11} and S_{22} in Fig.11 and Fig.12 clearly illustrate the quite good impedance input-and-output matching of the cascade amplifier at C band. The S_{11} and S_{22} value are greater than the simulated value.

The reverse isolation observes above is good agreement between the simulated and measured result.

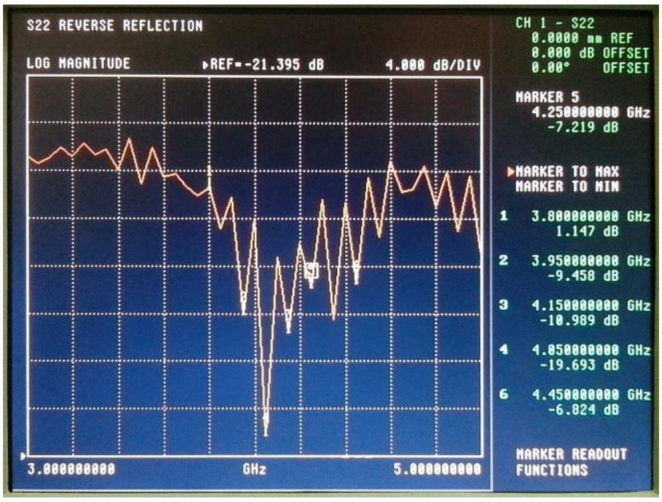

Figure 12: The output reflection coefficient

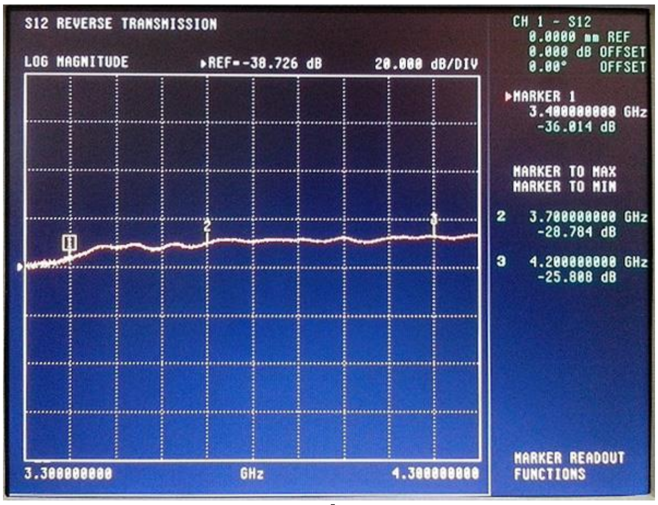

Figure 13: The S_{12} parameter

IV.CONCLUSION

A two-stage LNA with spf-2086 was designed and demonstrated with simulations in ADS package as well as tuning for the optimum gain, noise figure and bandwidth. The design was fabricated and the board was measured and analyzed together with the simulated results. In summary, the measurement results of wideband low noise amplifier circuit were compared to references with following parameters:

TABLE 1: COMPARISON BETWEEN MEASUREMENT RESULTS AND REFERENCES

Parameters	**Measured results**	**Ref. [5]**	**Ref. [7]**
Frequency	3.7 - 4.2 GHz	5.1 - 5.8GHz	3.4-4.2GHz
NF	1.06 dB	1.30 dB	1.17 dB
S_{21}	25.4 dB	18.5 dB	23.9 dB
S_{11}	- 27.3 dB	-11.5 dB	-32 dB
S_{12}	- 25.8 dB	-27.3 dB	-41 dB
S_{22}	- 19.6 dB	-12.3 dB	-15 dB

The benefits of this LNA design are the stability of its performances throughout the wideband frequency range, high gain, low noise and smaller PCB fabrication. Overall, this LNA could be used for C band satellite receiver systems or RF front end application working at 3.7 – 4.2 GHz.

REFERENCES

[1] Andrei Grebennikov, RF and Microwave Transistor Oscillator Design, John Willey & Sons, Ltd.

[2] A. F. Osman and N. Mohd. Noh, Wideband LNA Design for SDR Radio using Balanced Amplifier Topology, 2012 4th Asia Symposium on Quality Electronic Design, pp.86-90.

[3] Abhimanyu Athikayan, Aswathy Premanand, Athira Damodaran, Gayathry Girisan, Design Of Low Noise Amplifier At 4 Ghz, 2011 International Conference on Information and Electronics Engineering, pp 209 – 212.

[4] David M. Pozar, Microwave Engineering, 3nd Edition, John Wiley & Sons, Inc- New York, United State of America, chap 11, 2005.

[5] Othman A.R, Ibrahim A.B, Husain M.N, Ahmad M.T, Senon M., "High Gain Low Noise Cascode LNA Using T-Matching Network for Wireless Applications", IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE 2012), 2012, pp 383 - 387.

[6] Tran Van Hoi, Hoang Duc Long, Bach Gia Duong, "High Gain Low Noise Amplifier design used for RF Front End Application", The 2013 IEICE International Conference on Intergrated Circuits, Design, and Verification, pp. 243-247, 2013.

[7] Tran Van Hoi, Bach Gia Duong, "Study and design of wide band low noise amplifier operating at C band", VNU Journal of Mathematics – Physics, Vol. 29, No. 2, pp. 16-24, 2013.

[8] Zhihong Dai; Yongzhong Hu; Kunzhi Xu, "Two-stage Low Noise Amplifier for BD-II Receiver Application", 5th Global Symposium on Millimeter Waves (GSMM 2012), 2012, pp. 303-306.

[9] Z. Abolfazl, A. B. Masih, A. Jafar, D. Masoud, "A 3-5 GHz Ultra Wideband Common-Gate Low Noise Amplifier", 2012 IEEE International Conference on Circuits and Systems (ICCAS).

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