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Study and design of wide band low noise amplifier operating at C band

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Abstract: This paper reports on design and fabrication of wide band low noise amplifier (LNA) at C band, which is used for satellite receiver systems. The most important thing in the design of the LNA is to compromise importance characteristics such as gain, noise figure, stability, bandwidth. The results of this paper introduce an approach to design the LNA with gain as high as possible, bandwidth 800 MHz and the lowest noise figure. All the designed, simulated and fabricated processes were done using Agilent' ADS 2009 package. The LNA has successfully been fabricated using microtrip technology and pHEMT transistor amplifier with following specifications: Maximum overall gain is 23.9 dB, operating frequency from 3.4 GHz to 4.2 GHz, standing wave ratio is less than 1.9, the reverse isolation: -41dB, input and output impedance: 50 Ω.

Keywords: LNA, C band, noise figure, satellite receiver, ADS.

1. Introduction

Satellite communications played an important role not only in civilian communications but also in military purposes. It is moreover 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. Due to the signal to noise ratio in the receiver has the dominant effect of the noise of the first amplifier stage [3]. Therefore, the goal of the designer is to design the LNA with gain as high as possible, the lowest noise figure and required wide band. In order to obtain the demand on the system consisting of the gain, noise figure, bandwidth, we have to deal with the design of two-stage LNA. The first stage will optimize the noise figure, bandwidth and the second stage will increase an overall gain. The transistor amplifier used here to design is spf-3043,

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which was fabricated in pHEMT GaAs FET technology with low noise figure, high gain and operating frequencies to 10 GHz.

2. Design and simulation results

2.1. 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-stages cascade LNA illustrated the Fig.1.

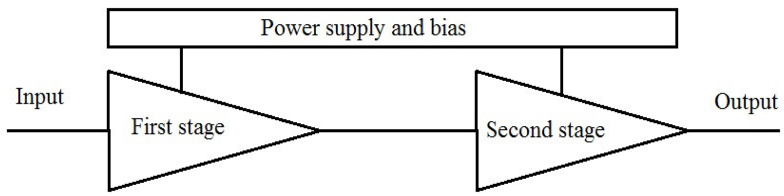

Fig.1. Diagram of two-stage cascade LNA.

This two-stage amplifier has the same structure. However, they were provided the different bias voltage. In order to achieve bandwidth 800 MHz, we suppose the design of the center frequency in the first stage at 3.7 GHz and in the second stage at 3.9 GHz.

A single-stage amplifier with matching networks at the input and output terminals of the transistor spf-3043 are shown in Fig.2. To deliver the maximum power from source to load, the input and output impedances of the transistor have to match to the source and load impedances Z_S and Z_L. In this case, Z_S and Z_L are equal Z_0 (50 Ω) [2].

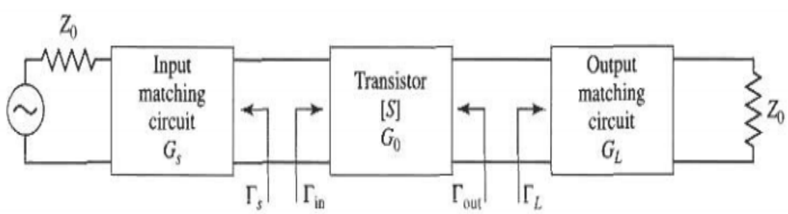

Fig. 2. The typical diagram of a single stage amplifier stage.

From the S parameters and noise parameters at 3.7 GHz is provided by Stanford Microdevices we can find the parameters of noise figure as follows: Minimum noise figure F_{min} = 0.54 dB, Γ_{opt} = 0.62 $e^{33\,j}$, the noise resistance $R_N = 50*r_n = 11\ \Omega$. The noise figure of the amplifier at this frequency is calculated to be as follows [4]:

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

In order to obtain the minimum noise figure, the reflection coefficient Γ_S look into the source is matched to Γ_{opt} and is found to be: $\Gamma_S = 0.62\ e^{33\,j}$.

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

$$\Gamma_L^* = \frac{S_{22} - \Delta\Gamma_S}{1 - S_{11}\Gamma_S\Delta} = -0.05553 + 0.2183 * j \qquad (2)$$

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 [4].

In order to transfer the maximum power from the input matching networks to the transistor will occur when $\Gamma_S = \Gamma^*_{in} = S^*_{11} = 0.571\ e^{102.549\,j}$ and the maximum power transfer from the transistor to the output matching network will occur when $\Gamma_L = \Gamma^*_{out} = S^*_{22} = 0.372\ e^{51.54\,j}$.

2.2. Design and simulation of the LNA

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, at high frequency, the design of the LNA using quarter-wave transformer and general transformer is the best choice.

The completed LNA with two stages was shown in Fig.3. The power supply for spf-3043 is 5V/40 mA and the voltage of biasing point is obtained at -0.5V [6].

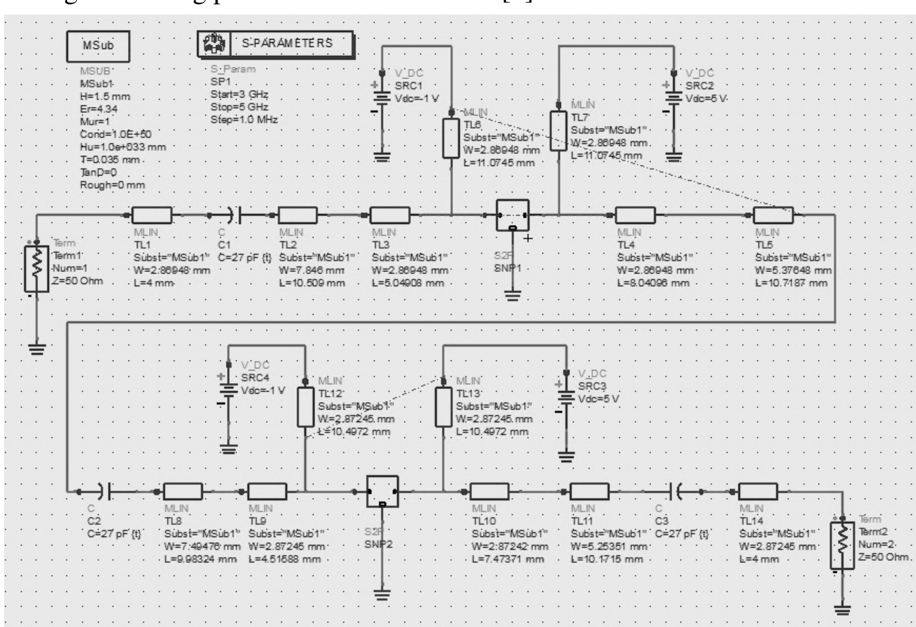

Fig. 3. Schematic of the two-stage cascade LNA.

The initial simulations to test the LNA performance were done with the s-parameter file of the transistor. The Fig. 4 displays the S_{21} parameter which have been achieved: overall gain is greater than 34 dB from 3.4 GHz to 4.2 GHz and the maximum gain obtains 41.668dB at 3.563GHz, the value of reverse isolation (S_{12}) is very good in working band, and less than -42.dB.

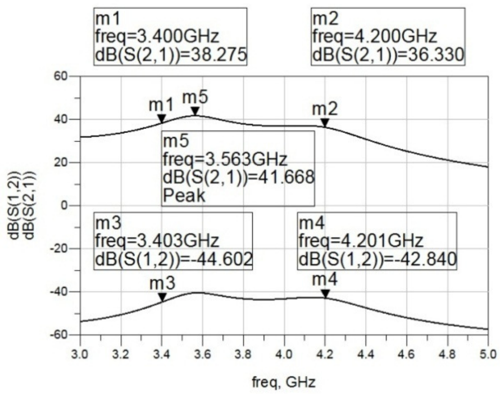

Fig. 4. The S_{21} and S_{12} of the LNA.

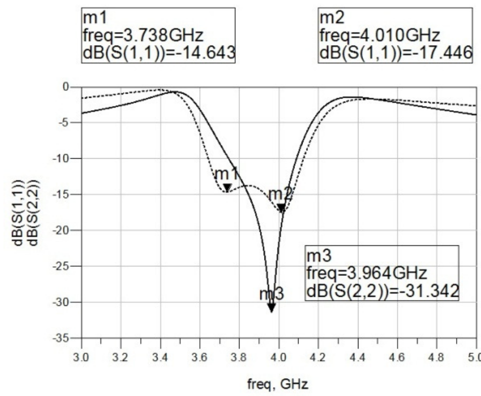

Fig. 5. The S_{11} and S_{22} of the LNA.

The result in Fig. 5 shows the value of the input impedance matching is quite good at from 3.7 GHz to 4.0 GHz. Although, the output impedance matching is very good at 3.96 GHz, but impedance matching range is very narrow.

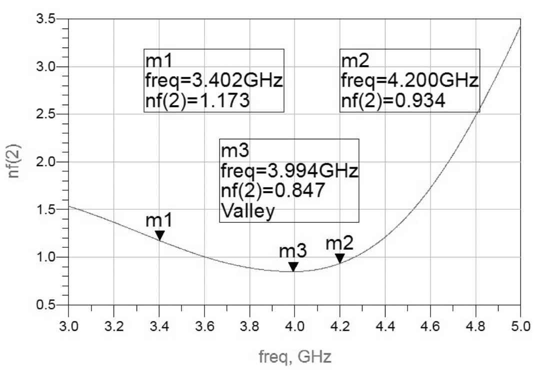

Fig. 6. The noise figure of the amplifier.

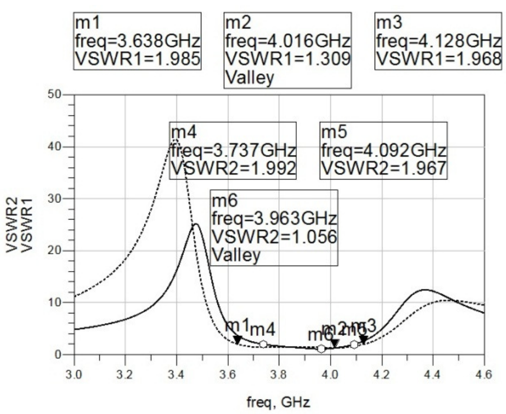

Fig.7. The voltage standing wave ratio of input and output terminal.

The Fig. 6 indicates that the noise figure of the LNA reaches the minimum level 0.847 dB at 3.994 GHz and is less than 1.2 dB over all the designed frequency bands, this value is quite good for two-stages amplifier. The gragh in Fig. 7 exhibits the value of the input and output standing wave ratio of the LNA. We can see that the VSWR is less than 2 from 3.638 GHz to 4.128 GHz for input terminal and from 3.737 GHz to 4.092 GHz for output terminal.

3. Experimental results

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.8.

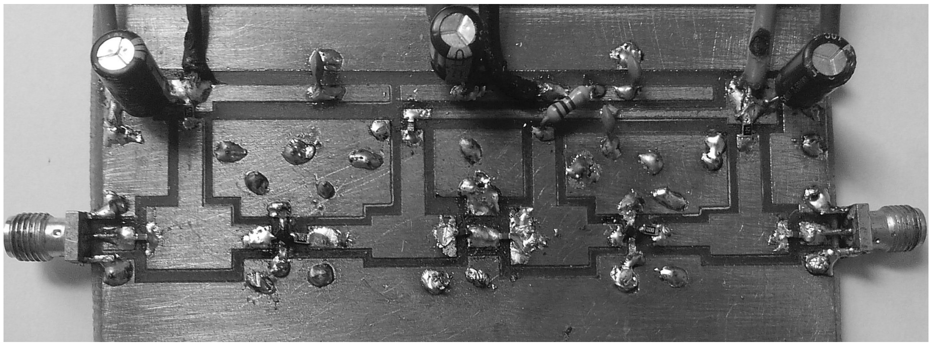

Fig. 8. The fabricated LNA.

The circuit was supplied with a 5V DC through the DC pins at the top of the board. The drain current was measured to be around 200 mA, which proved to be consistent with the simulated performance. SMA connectors were attached at both RF input and output. The testing results visually are measured on the vector network analyzer 37369D - Anritsu technology up to 40 GHz and the Signal Analyzer FSQ.

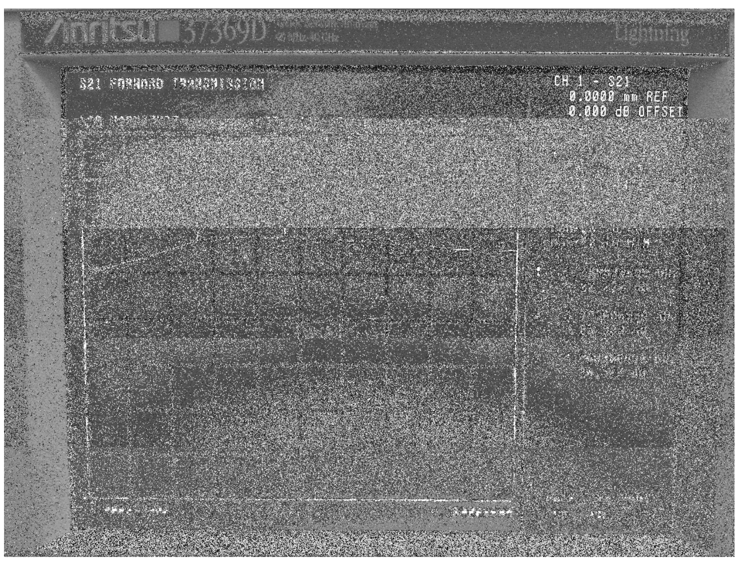

Fig. 9. The gain of the LNA.

The result in Fig.9 determines the maximum gain of 23.9 dB at 3.7 GHz and circuit amplifies wide band from 3.4 to 4.2 GHz with gain is greater than 20.328 dB.

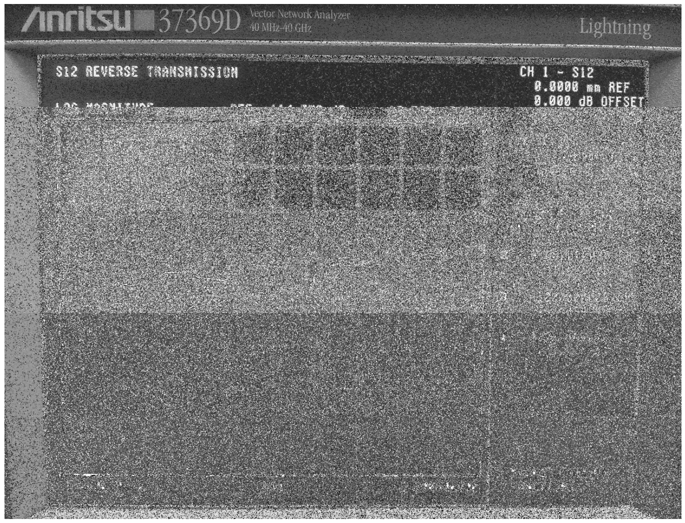

Fig. 10. The S_{12} parameter.

The result in the Fig. 10 shows that the reverse isolation is good agreement between the simulated and measured results can be observed.

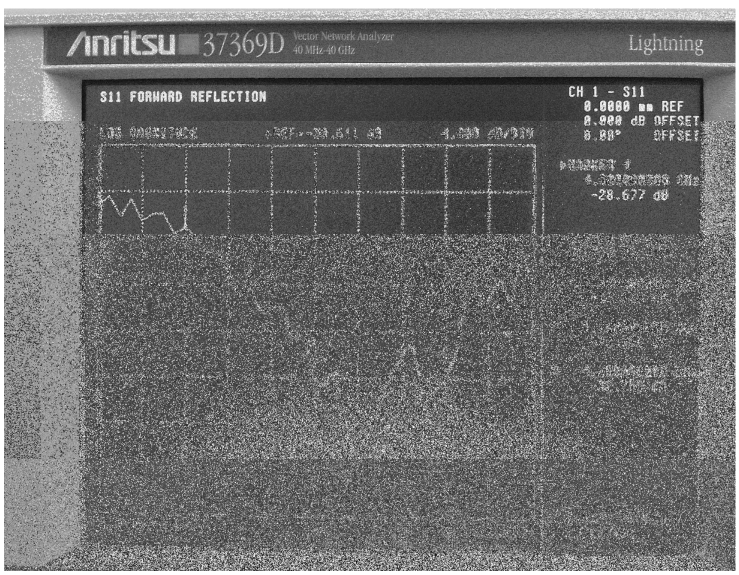

Fig. 11. The input reflection coefficient S_{11}.

Looking into the results, both simulated and measured results show similar response. Whereas the measured S_{11} resonates at 4.1 GHz, compared to 3.7 GHz and 4 GHz of the simulation. However, the measured results have been observed to be greater than simulation.

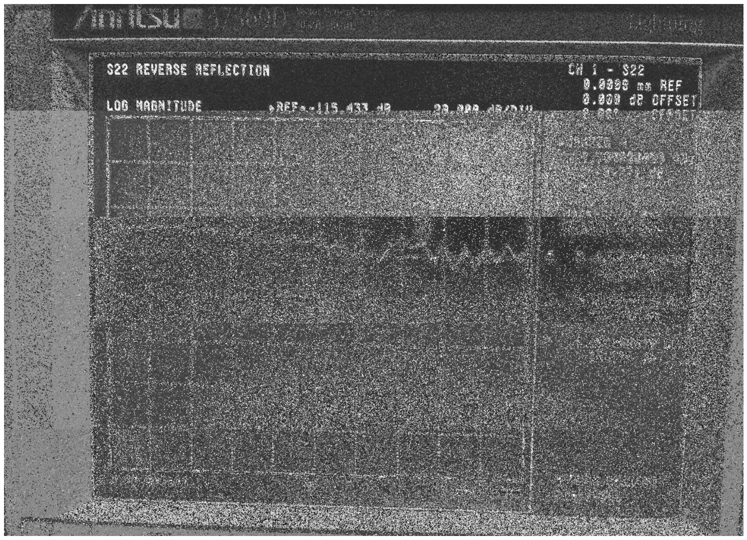

Fig. 12. The output reflection coefficient S_{22}.

The magnitude of S_{22} in the Fig.12 clearly illustrate the quite good output impedance matching. Although the measured results have impedance matching to be larger than simulation, but they both display S_{22} value is acceptable and satisfies the requirement set.

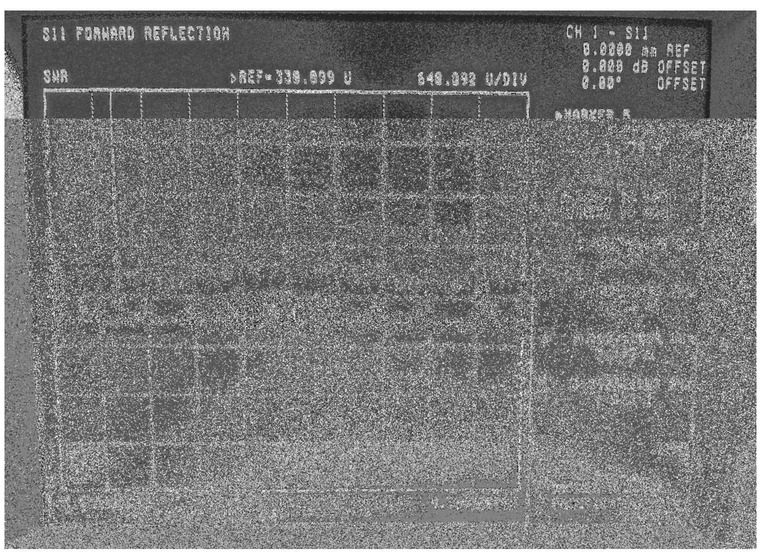

Fig. 13. The input standing wave ratio.

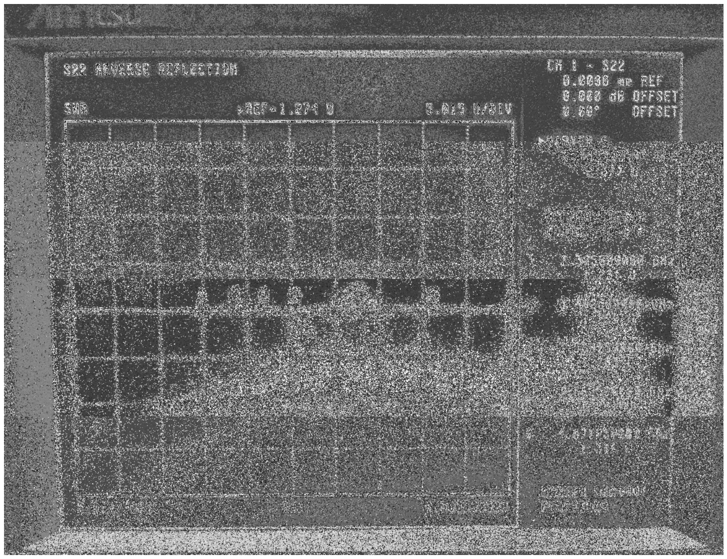

Fig. 14. The output standing wave ratio.

The results from the input and output standing wave ratio in Fig.13 and Fig. 14 show that the value of SWR is less than 1.9 in C band. This is quite good value.

4. Conclusion

A two-stage LNA with spf-3043 is 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 wideband low noise amplifier circuit has successfully designed and fabricated operating at C band with following parameters:

- Working frequency: 3.4 - 4.2 GHz
- Maximum gain: 23.9 dB
- Standing wave ratio: 1.9
- Noise figure: 1.2dB
- The reverse isolation: -41dB
- Power supply 5V and total current consumptions of 200 mA.

The benefits of this LNA design are the stability of its performances throughout the wideband frequency range, high gain with smaller PCB fabrication. Overall, this LNA could be used for the satellite receiver device working at C band.

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