Design of Low Noise Amplifier (LNA)

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Abstract— Abstract— **The goal of this project is to create a low-noise amplifier with maximal transducer gain. Rogers RO4003c with thickness 32 mil and copper thickness. The amplifier is built around a transistor bfp620f and has the following specifications: Bias point: Vce = 2.00V, Ic = 15.00mA, Operating Frequency: f=4.50 GHz, Gmax after Stability = 13.337 db. National instruments' AWR software environment is used to build and simulate the proposed low noise amplifier. The maximum transducer gain was attained by including a matching circuit on the circuit's input and output. The amplifier is unconditionally stable. After that, the developed circuit was implemented and tested in the laboratory.**

Index Terms **— LNA, Amplifier, AWR, bfp620f, S-Parameters, Stability, DC Biasing Network, Microstrip lines. lumped element networks.**

I. Introduction

A low-noise amplifier (LNA) is an electrical amplifier used to amplify signals of extremely low amplitude, typically from an antenna, where the signals are hardly visible and must be improved without introducing any noise, or important data may be lost. LNAs are critical circuit components found in radio and other signal receivers. [1]

II. LOW NOISE AMPLIFIER SPECIFICATIONS

There are certain common requirements to evaluate the functioning of an amplifier.

A. Gain

An LNA's gain is its ability to amplify or enhance the input signal level to a level that the receiver can process. There are three types of gains related to low-noise amplifiers: power gain, available gain, and transducer power gain. The mathematical expressions of these improvements are explained further below.[2]

B. Stability

LNA should be stable. It must be steady throughout a very large frequency range. There are various approaches for determining stability. Some of them are utilized in the present research.

C. Matching circuit

Matching circuits should be applied to both input and output sides of the amplifier to achieve maximum gain.

III.METHODOLOGY

A. S-Parameters

The scattering matrix is referred to by the S-parameters. It describes the connection between the inputs and outputs of electrical circuits. Because a two-port system is noticed in this project S parameters are best characterized as follows:

- S_{12} indicates the amount of power transmitted from port 1 to port 2,
- S_{21} indicates the amount of power transmitted from port 1 to port 2,
- S_{11} is the input reflected power.
- S_{22} is the output reflected power.

B. Reflection Coefficients

When S-parameters are known it is possible to determine reflection coefficients for source (Γ_S) and for load (Γ_L). Γ_S and Γ_L can be calculated by (1) and (2) respectively.

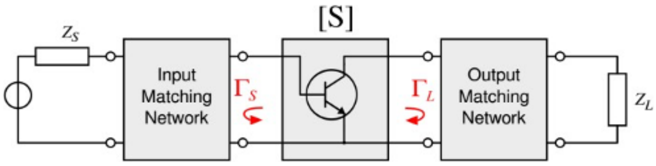

Fig 1: Definition of reflection coefficients [1]

Now the calculated values are used to calculate reflection coefficients.

$$\Gamma_S = \frac{B_1 \pm \sqrt{B_1^2 - 4|C_1|^2}}{2C_1} \qquad (1)$$

$$\Gamma_L = \frac{B_2 \pm \sqrt{B_2^2 - 4|C_2|^2}}{2C_2} \qquad (2)$$

Where B1, B2, C1, C2 can be found as following:

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \qquad (3)$$

$$B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \qquad (4)$$

$$C_1 = S_{11} - \Delta S_{22}^{*} \qquad (5)$$

$$C_2 = S_{22} - \Delta S_{11}^{*} \qquad (6)$$

Using the parameters we can determined the Scattering matrix,

$$\Delta = S_{11} \cdot S_{22} - S_{12} \cdot S_{21} \qquad (7)$$

For maximum transducer gain, a complex conjugate of the reflection coefficients is needed:

$$\Gamma_{in} = \Gamma_S^{*} \text{ and } \Gamma_{out} = \Gamma_L^{*}$$

The Overall Transducer gain will be the summation of three effective gains G_S, G_0, G_L.

Here, $G_S = \frac{1}{1-|\Gamma_S|^2}$ (8)

$$G_0 = |S_{21}|^2 \quad (9)$$

$$G_L = \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \quad (10)$$

So, the overall gain,

$$G_{T_{max}} = G_S + G_0 + G_L \quad (11)$$

IV. DESIGN FLOW OF LOW NOISE AMPLIFIER

A. Identifying Scattering parameters.

The proposed design of the amplifier is based on. Transistor bfp620f and has the following specifications: Bias point: Vce = 2.00V, Ic = 15.00mA, Operating Frequency: f=4.50 GHz, Gmax after Stability = 13.337 dB. The identified S parameters are tabulated as follows:

TABLE I
SCATTERING PARAMETERS

Parameters	Polar form	Rectangular form
S_{11}	0.244∠163.6	0.234+0.069j
S_{12}	0.1432∠46.6	0.098+0.104j
S_{21}	4.374∠59.4	2.22+3.76j
S_{22}	0.1232∠-111.3	-0.044-0.114j

B. Calculated the value of reflection coefficients and overall transducer gain

The reflection coefficients, and overall transducer gain is calculated from (1), (2) and (11). The calculated values are tabulated as follows:

TABLE II
REFLECTION COEFFIECENTS AND GAIN

Reflection coefficient at source side (Γ_S)	.579∠-175. 88
Reflection coefficient at load side (Γ_L)	0.523∠ 80.46
Overall Transducer gain (G T)	13.77dB

C. Matching circuit using lumped elements

TABLE III

VALUES OF LUMPED ELEMENTS

1. Source side

Capacitor in parallel	1.76 pF
Capacitor in series	1.6pF

2. Load side

Inductor in parallel	0.85 nF
Inductor in series	0.83nF

D. Replacement with ideal transmission lines and stub lines

The Smith chart is used to determine the lengths of transmission lines and stub lines.

ΓS= 0.579<-175.88

ΓL = 0.523<80.46

TABLE IV

IDEAL LINE LENGTHS

1.Source Side

Transmission line	0.07λ
Stub line	0.152λ

2) Load side

Transmission line	0.22λ
Stub line	0.141λ

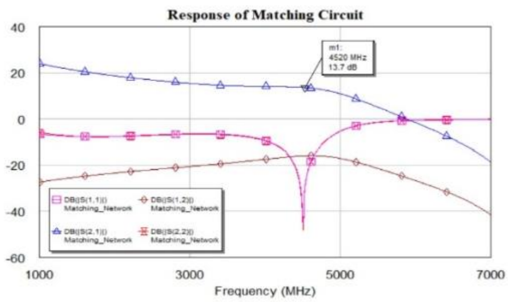

Fig 2. Response of Matching Bilateral Network

E. Design of circuit using microstrip lines

The amplifier must be stabilized prior to using the microstrip design.

1) Stability check of the amplifier

The stability of the amplifier is a crucial issue to consider when developing it. It can be found using the S parameters, matching networks, and terminations. The output port has a low resistance. Alternatively, the If all the following conditions are met, the amplifier will be unconditionally stable. Requirements are met [1]:

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{12}.S_{21}|} > 1$$

$$|\Delta| = S_{11}.S_{22} - S_{12}.S_{21} < 1$$

$$\mu = \frac{1-|S_{11}|^2}{|S_{22}-\Delta S_{11}^*|+|S_{12}S_{21}|} > 1$$

The calculated value of was determined to be 1.035. As a result, it is unconditionally stable. These conditions were found to be satisfied after calculations. Thus, the amplifier is unconditionally stable at 4.5 GHz.

2) Replacing ideal transmission lines with micro-strip lines

The ideal transmission lines TLIN are replaced by MLIN, and the stub line TLOC is replaced by MLEF in the next phase. The length and width of the microstrip lines are calculated using AWR's TX Line tool.

TABLE V

PARAMETERS OF LENGTH AND WIDTH OF TRANSMISSION LINE

Section	Electrical Length (mm)	Load Impedance	Width(mm)
Stub source	6.04	50 Ω	1.8
Stub load	5.6	50 Ω	1.8
Line source	2.78	50 Ω	1.8
Line load	8.75	50 Ω	1.8

4) Final circuit response

The introduction of microstrips and VIA increases network losses. As a result, line lengths were fine-tuned to get the desired outcomes.

Figure 4 depicts the completed circuit design, with the upper black box containing the biasing network (see figure 5) and the centre black box containing the transistor with parasitic components.

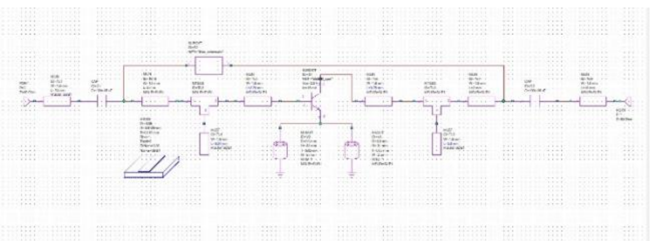

Fig 4. Final circuit design of the low noise amplifier

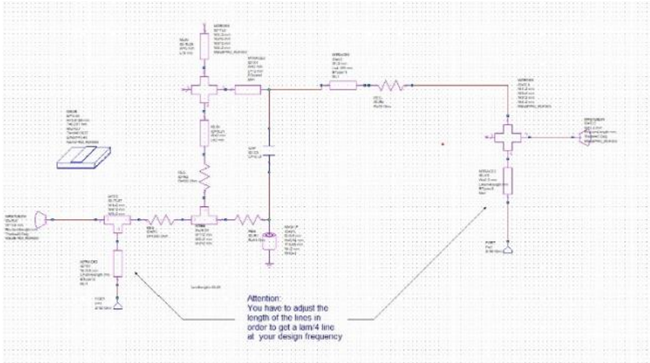

Fig 5. DC Biasing network for the LNA

The final response of the simulated circuit is shown in below.

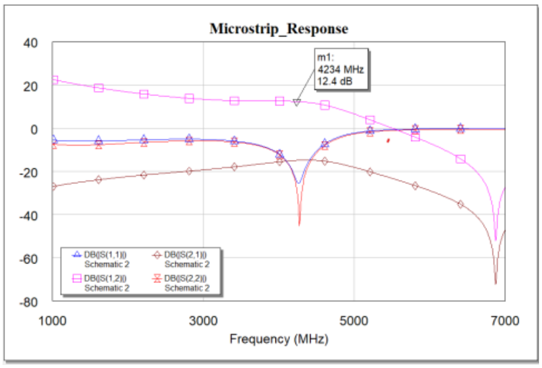

Fig 6. Circuit response using microstrip line.

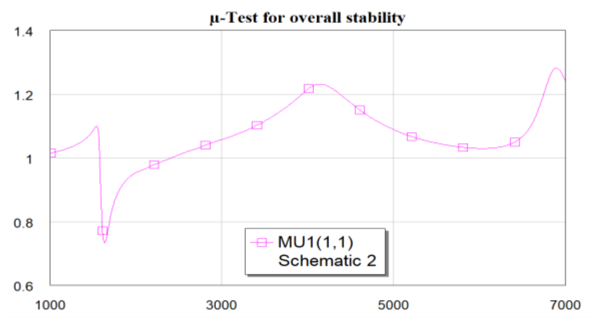

Fig 7. μ-Test for overall stability in AWR

5. DC Biasing Network

To create a low noise amplifier, the transistor must be DC biased at a suitable working point. It is determined by the application (low noise, high gain, high power) and the kind. Transistor (FET, HEMT, and so on) [2]. For transistors bfp620f, VCE (collector-emitter voltage) = 2V, IC (collector current) = 15 mA, hFE = 180.

The DC biasing network is made up of resistors and npn transistors. Resistor values are as follows: R1 = 150 Ω, R2 =300 Ω, R3 = 16 KΩ, R4 = 200 Ω.

6) Layout design of the LNA

Layout of the LNA is shown in figure 6. The Rogers RO4003c with copper thickness 17µm was used as the substrate. The 0805 housing is used for resistors and capacitors.

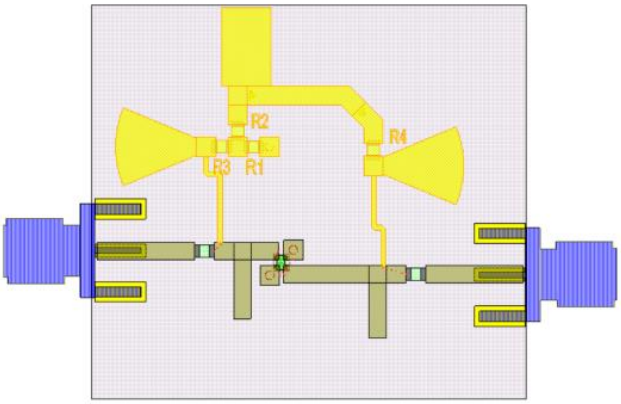

Fig.8. Low Noise Amplifier Layout

V. LABORATORY TEST

Finally, the designed layout was implemented and tested as a printed circuit board (PCB). Data collected during laboratory tests was imported into AWR and depicted in figure 10 as a diagram. The diagram shows that a reasonable gain of amplifier was achieved, which is even lower than the simulated results.

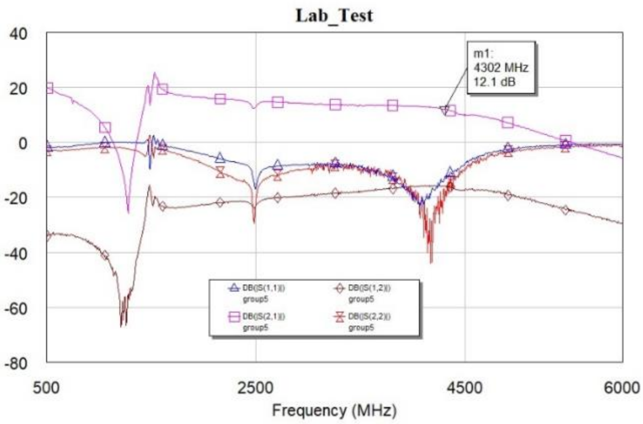

Fig. 9. Laboratory test results imported to AWR.

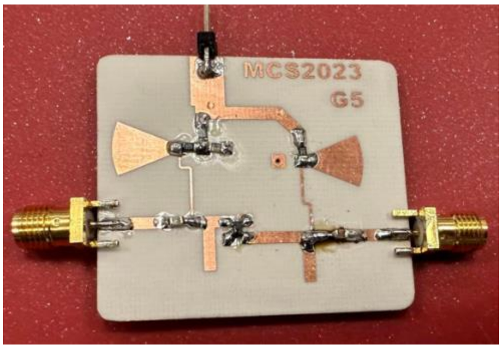

Fig. 10. The designed LNA implemented on PCB.

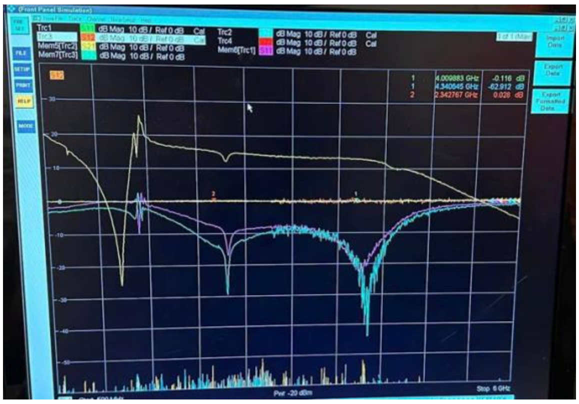

Fig. 11. Laboratory test results

V. CONCLUSION

The specified low noise amplifier was developed for optimum transducer gain. Lumped components, perfect transmission lines, and micro-strip lines were used to create the necessary input and output matching networks. At 4.5GHz, the device is unconditionally stable and has a gain of 13.337dB.

The designed amplifier was implemented on a PCB and tested in the lab. The test findings demonstrated that the equipment was properly developed.

ACKNOWLEDGMENT

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