Low Noise Amplifier Design for Microwave Applications

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***Abstract* — Low Noise Amplifiers (LNA) are amplifiers which deal with small signals amplification and they play a vital role in microwave systems. Designs of an amplifier circuits is critical since it must be made to meet high gain, low noise, and stability requirements. This project presents the design, simulation and practical implementation of a LNA made of microstrip lines and a BJT-transistor for maximum gain of 9.18 dB. Stabilization and biasing are all designed for unconditionally stable circuit. During practical measurements gain of 7.473 dB was obtained and the difference was attributed to the influence additional biasing network and T-junction.**

***Keywords* — *S-parameters*, Low noise amplifier, transducer gain, Conjugate matching, Smith chart impedance matching.**

I. Introduction

Low Noise Amplifier is an electronic circuit designed to amplify a very low power signal without significantly degrading its signal to noise ratio. This is as opposed to a normal power amplifier which increases the power of both of signal and the noise present at its input. LNAs are designed to minimize additional noise. Designers minimize noise by considering trade-offs that include impedance matching, choosing the amplifier technology and selecting low noise biasing conditions.

These amplifiers are a significant part of a receiver circuit whereby the received signal is processed and converted into information. LNAs are designed to be close to the receiving device so that there is minimum loss due to interface. As the name suggests, they add a minimum amount of noise in the received signal because any more would highly corrupt the already weak signal.

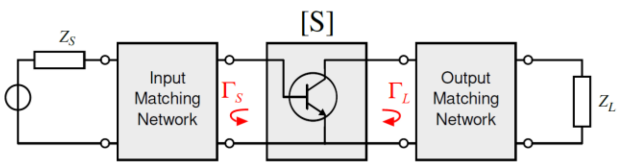

Figure 1: General transistor amplifier circuit [1]

II. Design

A. Using S-parameters

Using The S-parameters (scattering parameters) at high signal frequencies is easier than open-circuit and short-circuit terminations, and this is the main reason for preference S-parameters to other types of network representation parameters. In this project a two-port network is used, therefore the parameters can be described as: S_{11} is the input voltage reflection coefficient, S_{22} is the output voltage reflection coefficient, S_{12} represents the power that is transferred from port 1 to port 2, S_{21} the power that is transferred from port 2 to port 1.

The defined specifications for the BJT transistor used, bfp450 are:

V_{CE} = 2.00 V, I_{CE} = 20 mA, f = 3.50 GHz

The S-parameters of the transistor for the specified frequency are:

$$[S] = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \begin{bmatrix} 0.2262\angle 131.9° & 0.1091\angle 26.7° \\ 1.687\angle 28.8° & 0.5286\angle 139.9° \end{bmatrix}$$
(1)

The reflection coefficients were calculated as follows:

$$\Gamma_s = 0.88\angle -138.85$$
$$\Gamma_L = 0.44\angle 178.18$$

And the total expected gain was arrived at as;
$G_T = G_S + G_0 + G_L =$ **9.18 dB**

B. Distributed input and output Matching Circuit Design

For maximum power transfer from input (50 Ohm) port to output (50 Ohm) port, the impedance matching of the amplifying device (transistor bfp450) ports must be achieved as a necessary condition [2]. This can be achieved using transmission lines and using the following conditions:

$$\Gamma_{IN} = \Gamma_S^*$$
$$\Gamma_{OUT} = \Gamma_L^*$$

Smith Chart was used to find the resultant matching network with the combination of ideal transmission lines and stub lines and lengths were calculated accordingly. Figure 2 shows the simulated distributed elements network amplifier circuit using the obtained lengths of the transmission and stub lines. On the other hand, Figure 3 reflects the S-parameters of the simulated circuit showing the maximum obtained gain.

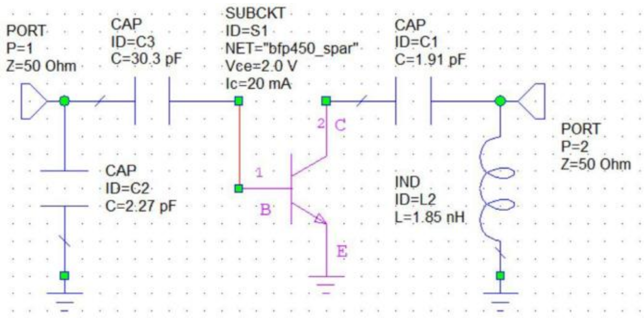

Figure 2: Amplifier Circuit Of Distributed Elements Network

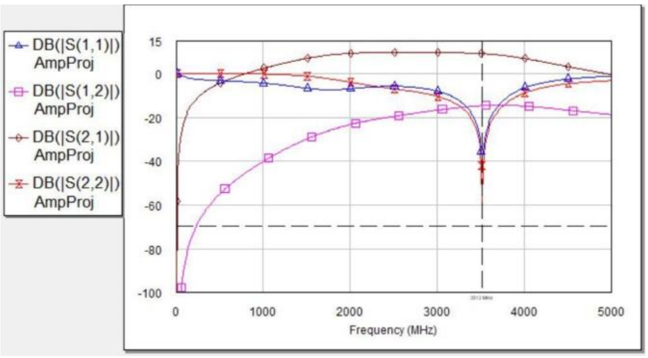

Figure 3: S-parameters Performance of Distributed Element Network

C. Circuit Stability Considerations

The stability of the transistor was checked by calculating K, Δ and μ-tests at 3.5 GHz s-parameters which are shown in Table 1.

Table (1) K, Δ and μ-tests

Factor	Formula	Calculated Value
Δ	$S_{11}\,S_{22} - S_{12}\,S_{21}$	-0.104 - j 0.27
K	$\frac{1+1\lvert\Delta\rvert^2 - \lvert S_{11}\rvert^2 - \lvert S_{22}\rvert^2}{2\lvert S_{12}\,S_{21}\rvert}$	0.022
μ	$\frac{1-\lvert S^2{}_{11}\rvert}{\lvert S_{22} - \Delta S^*{}_{11}\rvert + \lvert S_{12}S_{21}\rvert}$	0.059

The μ-test result in figure 4 shows that the transistor is unconditionally stable at 3.5 GHz. The condition of stability is when the following values must be |Δ| < 1, K < 1 and μ < 1.

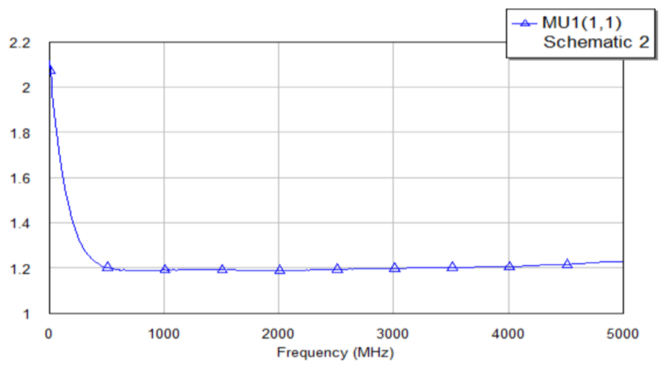

Figure 4: Matching Network μ-test

III. Microstrip design

A. Conversion to microstrip lines

The replacement of the ideal transmission lines by microstrip lines is needed to implemented the designed amplifier. The physical lengths and electric permittivity depend on the substrate used for the microstrip lines. The designed network with microstrip lines shown in figure 5.

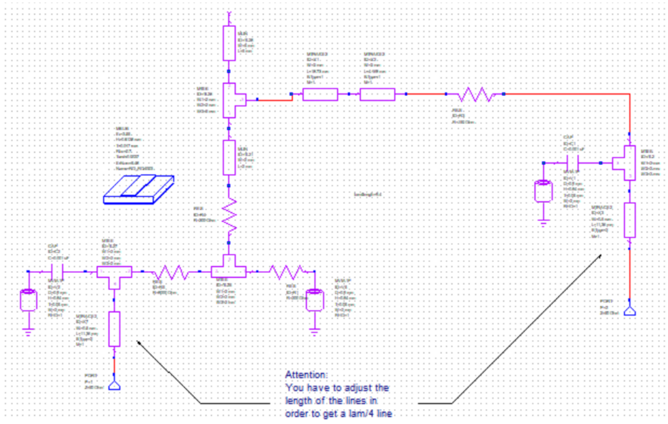

Figure 5: Network Design with Micro-strip Lines and Stabilized Transistor

The recommended substrate (Ro4003) has a height of 0.8128 mm and a thickness of 0.017 mm. The stub lines TLOC were replaced by MLEF and the ideal transmission lines TLIN were replaced by MLIN. The TX line tool in the AWR Microsoft office software is used to calculate the lengths and widths of the micro-strip lines.

B. T-junctions and Ground

To connect the series and parallel micro-strip lines T-Junctions (MTEE$) are used. Additional micro-strip lines are utilized between resistor, transistor Connections and T-Junction. A line is also placed in the ground location to the substrate background.

C. Bias Network Design:

DC biasing of the transistor is designed with 5 Volts DC supply. The values of the resistors are to be calculated for the considered transistor DC parameters V_{CE}=2 V, I_{CE}=20 mA and V_{BE}=1.5 V. According to the data sheet of the bfp450 transistor, the h_{fe} (β) is 100. The resulting resistors are also shown in Figure 6.

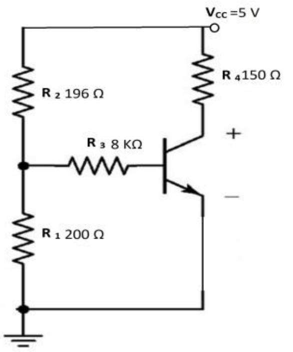

Figure 6: DC biasing circuit of Transistor.

Now illustrates the response of the network final performance. At a frequency of 3.5 GHz, the maximum transducer gain is 7.4 dB shown in figure 7. The gain reduced by 1.78 dB (from 9.18 dB to 7.4 dB) due to the losses of the added bias and the additional lines.

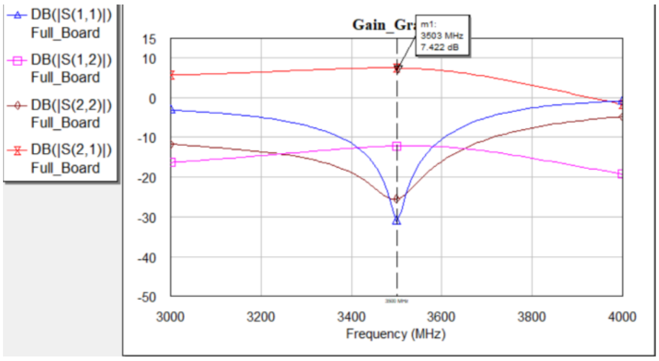

Figure 7: S-parameters performance versus frequency

The input and the output stability of the stabilized and matched network were also checked by the stability circles on the smith chart shown in Figure 8.

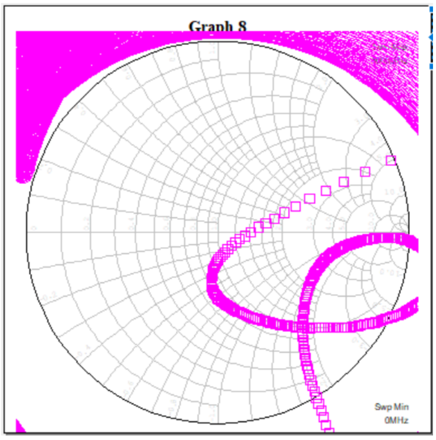

Figure 8: Stability Circles for the Stabilized and Matched Network

The center and radius values of the input and output stability circles for 3.50 GHz have been calculated and are shown in Table (2.

Table (2) Center and radius values for stability circles

Parameter	Formula	Value
C_S	$\frac{(S_{11}-\Delta\cdot S_{22}^*)^*}{\vert S_{11}\vert^2-\vert\Delta\vert^2}$	1 .95 – j 29.29
C_L	$\frac{(S_{22}-\Delta\cdot S_{11}^*)^*}{\vert S_{22}\vert^2-\vert\Delta\vert^2}$	1.61 + j 1.48
R_S	$\left\vert\frac{S_{12}\cdot S_{21}}{\vert S_{11}\vert^2-\vert\Delta\vert^2}\right\vert$	.6852
R_L	$\left\vert\frac{S_{12}\cdot S_{21}}{\vert S_{22}\vert^2-\vert\Delta\vert^2}\right\vert$	0.685

IV. RESULTS

A. Layout of Matched Network with Bias Network

For the capacitors and resistors, the housing size 0805 is used. The RO4003 material is used. The copper strip thickness is 0.017 mm.

The 3D-view of the matched network layout is shown in figure 9. The 3D-view is created by using the Microwave office.

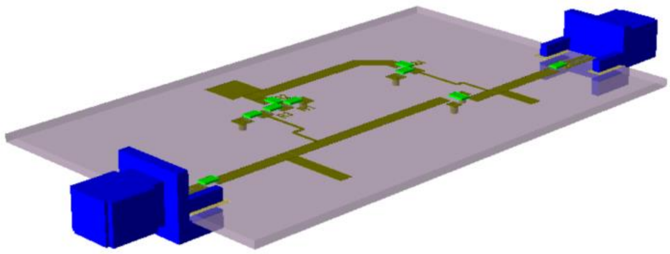

Figure 9: 3D-view of the matched network

B. Hardware Implementation

The simulated low noise amplifier is implemented in a circuit board in the Microwave Engineering Laboratory, Hochschule Bremen. All the calculated components were placed on the board.

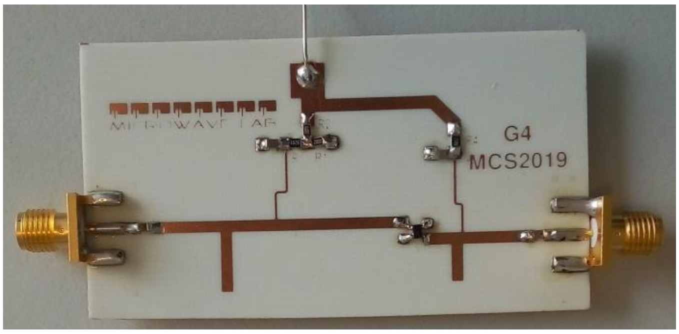

Figure 10. Implemented circuit board

The final amplifier circuit with all the lines, components and input and output shown in figure 10. The stabilization network stays unconnected due to the self-stabilizing behavior of the biasing network.

C. Measured S-parameters Response

The designed amplifier S parameter response was measured in order to compare it with the simulated values. Figure 11 shows the measured S-parameters performance versus frequency of the amplifier. The measured gain is little bit higher than simulated result (increased from 7.4 dB to 7.6 dB) at 3.5 GHz.

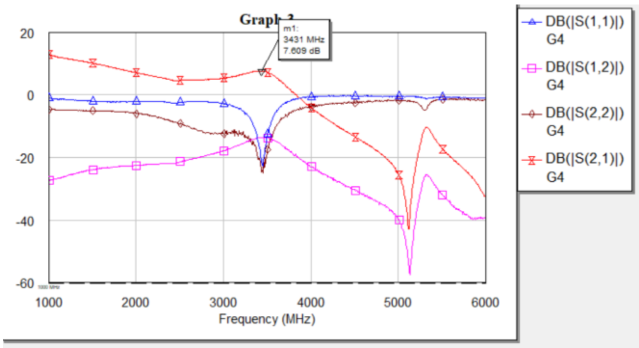

Figure 11: The Measured Amplifier Response

V. Conclusion

The design, simulation and practical implementation of a low noise amplifier has been carried out successfully. Initial stage was the design of the matching networks using distributed elements, which were later replaced by micro-strip lines with physical and feasible lengths in millimeters. Moreover, the network was subjected to matching and stabilization analysis using Microwave Office package, where the stabilization circles and stabilization conditions were verified. The maximum amplifier gain recorded practically with the value of 7.6 dB reaches above the simulated gain 7.4 dB but 1.5 dB less than theoretical designed value of 9.1 dB. At the time of implementing the components on the designed circuit, different physical lengths eventually effect the designed transmission lines lengths. These added lengths definitely affect the designed value of frequency where the maximum transduced gain should occur. So, the measured gain is satisfactory comparing with the theoretical gain.

Acknowledgment

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References

[1] Prof. Peik, Sören: Microwave Circuits and Systems, 11 March, 2019.

[2] Prof. Peik, Sören: Amplifier Design, May 9, 2016.