Design of a Low Noise Amplifier (LNA) Microwave Circuit Using Microstrip Line Technology

Mula Vishnu Veeranjan Sunkari
5389166
City University of Applied Sciences
Bremen, Germany
msunkari@stud.hs-bremen.de

Aditya Rao
5388820
City University of Applied Sciences
Bremen, Germany
arao@stud.hs-bremen.de

Anagha Varghese
5392470
City University of Applied Sciences
Bremen, Germany
anvarghese@stud.hs-bremen.de

***Abstract*—This report presents the design, simulation, and analysis of a low-noise amplifier (LNA) operating near 4.5 GHz using microstrip line technology on a Rogers RO4003C substrate. The objective was to achieve a high transducer gain, proper input and output matching, and unconditional stability using the Infineon BFP640 bipolar transistor biased at $I_c = 12mA$ and $V_{CE} = 4V$. The design procedure included theoretical calculations, Smith Chart analysis, conversion of lumped matching networks to distributed microstrip structures, and full-wave simulation using AWR Microwave Office. The final design achieved a peak gain of 15.6 dB at 4499 MHz with a bandwidth exceeding 100 MHz and return losses below –15 dB at both ports. The amplifier was verified to be unconditionally stable and ready for physical fabrication and testing. This work demonstrates a complete workflow from theory to layout for a practical microwave amplifier design, suitable for RF front-end applications.**

***Index Terms*—LNA, Amplifier, AWR, bfp640, S-Parameters, Microstrip lines, Matching network, Maximum transducer gain, Noise figure.**

I. INTRODUCTION

An LNA is a specialized amplifier designed to amplify weak signals while introducing minimal noise. These amplifiers are essential in communication and signal processing systems, where preserving signal integrity is critical.

A. Amplifier Design Approach

Using the S-parameters of the transistor, the source and load reflection coefficients Γ_S and Γ_L can be determined. This allows the design of matching networks that ensure maximum power transfer and minimum reflection, thus optimizing amplifier performance.

B. Calculating Values of Γ_S and Γ_L

S-parameter data at 4.5 GHz:
A two-port network like a transistor is characterized by four S-parameters: S_{11}, S_{21}, S_{12} and S_{22}

Parameter	Magnitude ∠ Phase	Rectangular form
S_{11}	$0.4107 \angle 135.1°$	-0.2912 + 0.2880j
S_{21}	$4.980 \angle 44.5°$	3.5522 + 3.4480j
S_{12}	$0.0959 \angle 29.1°$	0.0839 + 0.0467j
S_{22}	$0.1099 \angle -74.5°$	0.0291 - 0.1050j

TABLE I: Dimensions of transmission lines and stubs

Source (Γ_S) and load (Γ_L) reflection coefficients:

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

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

where,

$$\Delta = S_{11} * S_{22} - S_{12} * S_{21} = -0.1134 - 0.1415j$$

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 = 0.9669$$

$$B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 = 0.6552$$

$$C_1 = S_{11} - \Delta S_{22}^* = -0.3319 + 0.3121j$$

$$C_2 = S_{22} - \Delta S_{11}^* = 0.1169 - 0.2598j$$

Substituting these values in equations 1, 2

$$\Gamma_S = 0.6701\angle - 130.43°$$

$$\Gamma_L = 0.4327\angle 70.57°$$

The overall transducer gain G_T of the amplifier is given by:

$$G_T = G_S \cdot G_0 \cdot G_L$$

Where:

$$G_0 = |S_{21}|^2$$

$$G_S = \frac{1 - |\Gamma_S|^2}{|1 - S_{11}\Gamma_S|^2}, \quad G_L = \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2}$$

Using the above formulae, we get:

$$G_0 = 24.784$$

$$G_S = 1.995$$

$$G_L = 0.7523$$

Final transducer gain:

$$G_T = 24.784 \cdot 1.995 \cdot 0.7523 \approx 37.194$$

$$G_{T(dB)} = 10\log_{10}(37.194) \approx 15.7054\,\text{dB}$$

C. *Calculating λ_S and λ_l*

Source end

By calculating values with the help of smith charts we get the values:

$$\lambda_1{=}0.4952$$
$$\lambda_2{=}0.169$$

Load end

By calculating values with the of smith charts we get the values:

$$\lambda_1{=}0.264$$
$$\lambda_2{=}0.125$$

Conversion to Microstrip (Using RO4003C substrate)
$\varepsilon_r = 3.55,\ h = 0.8128\,\text{mm},\ t = 17\,\mu\text{m}$

By calculating values through TXLINE we get these corresponding Width and Height in mm.

Line	l in λ	l in Deg.	w (mm)	h (mm)
Source Stub	0.169	60.84	1.798	6.722
Source	0.4952	178.272	1.798	19.699
Load	0.264	95.04	1.798	10.502
Load Stub	0.125	45	1.798	4.972

TABLE II: Dimensions of transmission lines and stubs

II. AWR SIMULATION

A. *Matching Impedance in Transmission Lines*

In the schematic shown below, the conventional lumped elements at both the input and output stages are replaced with transmission line components. Both ports are terminated with a 50 Ω characteristic impedance, which ensures impedance matching and minimizes signal reflections across the network.

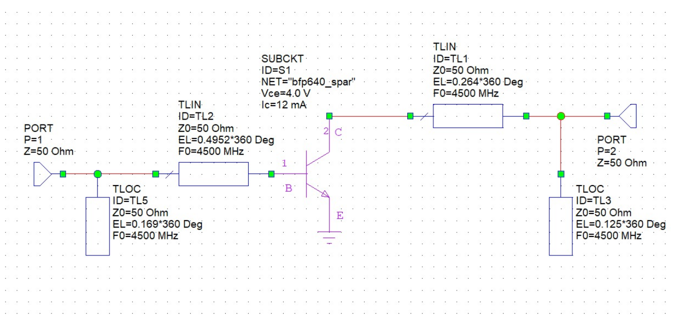

Fig. 1: TLIN Design with Graph Showing Response

The circuit comprises a series of transmission lines (TLIN) and open-circuited stub lines (TLOC), forming a distributed matching or filtering network. The TLIN components act as signal propagation paths, each defined by specific electrical lengths and impedances to control phase relationships and impedance transformations along the signal path. The TLOC elements are shunt stubs, strategically placed to introduce controlled reactance typically for tuning or resonance enhancement.

The following graph provides a thorough perspective of the amplifier's frequency response, making it possible to analyze the gain, input/output match designated frequency range.

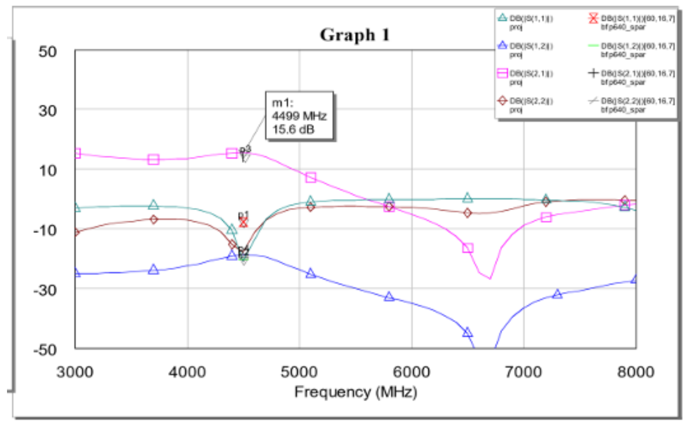

Fig. 2: Amplifier response of Transistor

The pink trace in the figure corresponds to S_{21}, which indicates the forward transmission gain. The peak gain occurs at 4499 MHz with a value of 15.6 dB, which satisfies the project's requirement to achieve maximum transducer gain near the design center frequency. The relatively flat gain around the peak suggests the amplifier maintains strong performance across the target bandwidth.

The blue and brown curves represent S_{11} and S_{22}, corresponding to the input and output reflection coefficients. Both exhibit sharp dips below –15 dB near the center frequency, indicating excellent input and output matching.

B. *Matching Impedance in Microstrip Lines*

MLIN is used for the microstrip lines in series, while MLEF is used for the shunt. To optimize gain at this point, the line lengths might need to be slightly adjusted using the software's tuning tool. The substrate utilized is Rogers R04003c, with material $\varepsilon_r = 3.55$, $h = 0.8128\,\text{mm}$, $t = 17\,\mu\text{m}$.

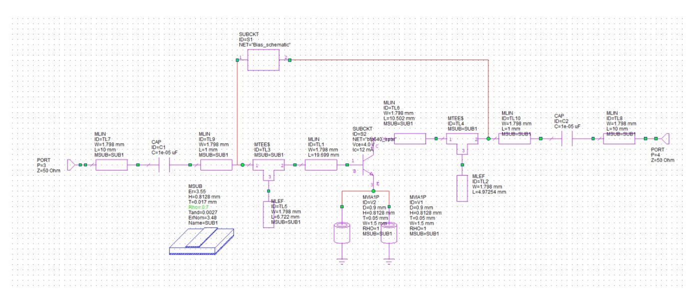

Fig. 3: Coordinating with T-junctions

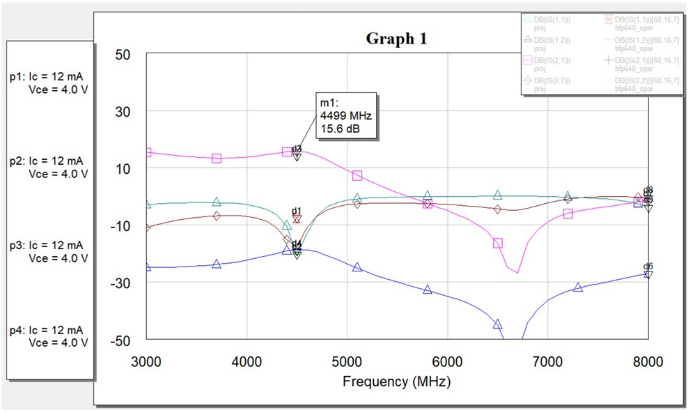

Fig. 4: Gain of the Microstrip Line

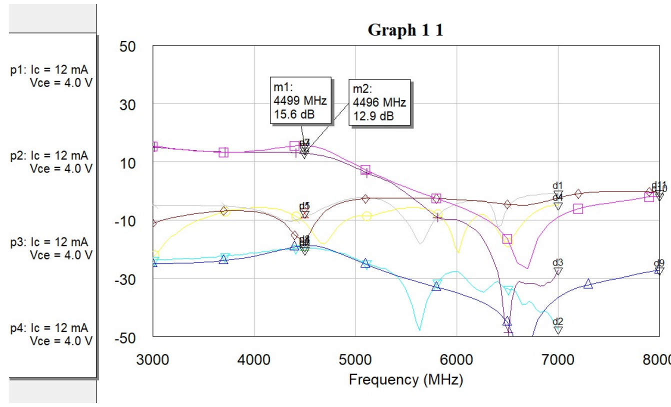

Fig. 7: Final Response

C. Biasing Network

The biasing network supplies the DC power required to guarantee the transistor operates correctly. When designing a biasing network, it is important to remember that the RF signal that is generated should not go to the DC supply (using RF blocking inductance or /4 line) and that the AC signal that is generated from the DC supply (primarily due to switching operations within a DC supply) should not go to the RF transmission line (using low impedance (at 3.0 GHz) bypass capacitors.

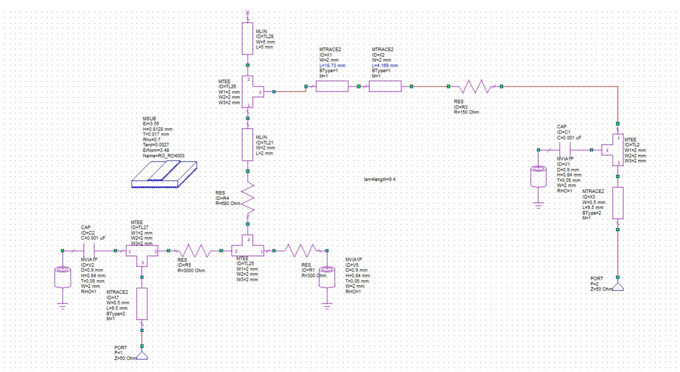

Fig. 5: Bias Schematic Network

D. Final Layout of Noise Amplifier

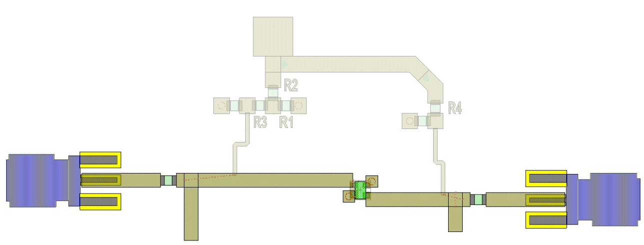

Fig. 6: Final Layout of circuit in MWO

The pink curve shows the response of S_{21}(gain). At m_1= 4499 MHz (approximately 4.5GHz) the amplifier achieves a gain of 15.6 dB, confirming the design's success in meeting the maximum transducer gain objective. Additionally, marker m_2= 4496 MHz shows the gain is still 12.9 dB, indicating a flat gain response over a 100 MHz bandwidth around the center frequency, satisfying the required bandwidth criterion. Input Matching (S_{11}) and Output Matching (S_{22}):The blue and cyan curves represent S_{11} and S_{22}, respectively. Both show distinct minima below –15 dB near the center frequency, which indicates good impedance matching at both input and output ports. This is essential for minimizing signal reflection and maximizing power transfer. Return Loss Across Bandwidth:The matching remains acceptable over a wide frequency range, which implies the amplifier is not only optimized at the design frequency (4.5 GHz) but also offers broadband input/output matching characteristics—an advantage in practical applications.

III. EXPERIMENTAL SETUP AND PROCEDURE

The experimental setup involved evaluating a pre-designed RF amplifier circuit using a vector network analyzer (VNA) and a DC voltage supply. The primary active device used in the circuit was a BFP640 transistor. Supporting passive components included resistors ($R_1 = 300\,\Omega$, $R_2 = 682.8\,\Omega$, $R_3 = 5541.7\,\Omega$, $R_4 = 83.3\,\Omega$) and capacitors (10 pF and 100 pF). The network analyzer was connected to the circuit through two ports to facilitate S-parameter measurements, specifically focusing on the gain (S_{21}). The circuit was powered using a 5 V DC source to provide the necessary biasing conditions.

The procedure commenced in the laboratory, where the circuit layout had already been transferred to a printed circuit board (PCB) coated with photoresist. Vias were drilled and filled with metal, followed by the removal of the photoresist using SENO 4010V01. The required components were then soldered onto the PCB according to the design schematic. Once assembled, the circuit was connected to the VNA via Port 1 and Port 2, and the DC supply was applied. The gain

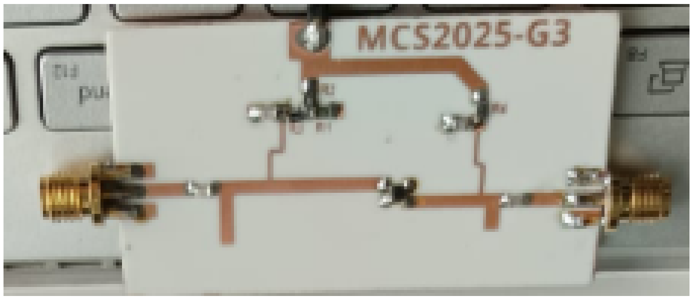

Fig. 8: Implemented LNA circuit design on a PCB

response was observed and recorded using the analyzer, and the measured data was subsequently saved and compared with theoretical values to validate the circuit's performance.

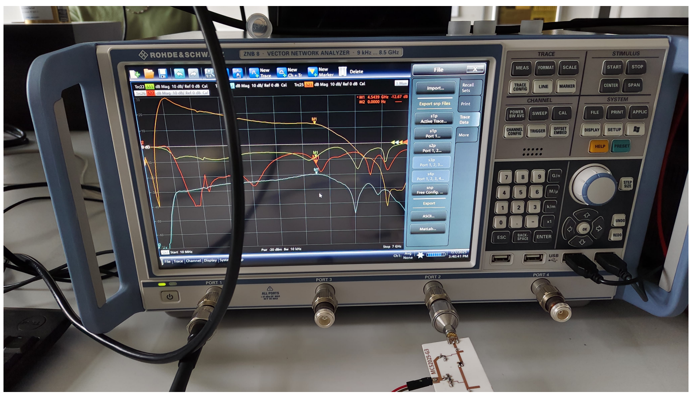

Fig. 9: Experimental Result Gain

Conclusion

A complete design methodology for a microstrip-based low-noise amplifier was successfully implemented, fulfilling the key performance specifications defined. The amplifier was designed around the BFP640 transistor, with a bias point of $I_C = 12mA$ and $V_{CE} = 4V$, and targeted a center frequency of approximately 4.5 GHz.

The design process began with idealized lumped component analysis for matching network synthesis and was followed by systematic conversion to distributed microstrip networks. Analytical results were validated through frequency sweep simulations and S-parameter analysis in AWR Microwave Office. The final design achieved a maximum gain of 15.6 dB at 4499 MHz, with a –3 dB bandwidth exceeding 100 MHz. The input and output return losses remained below –15 dB.

The simulation results confirmed the correctness of the theoretical design and microstrip implementation, indicating that the circuit is ready for physical fabrication and measurement. This report demonstrates a rigorous approach to microwave amplifier design, integrating theory, simulation, and layout, and highlights the practical aspects of RF design for real-world applications.

References

[1] S.Peik, *Microwave Circuits and Systems*, Lecture Notes, Hochschule Bremen.