Microwave Amplifier Design and Analysis Report

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1 Introduction

This report presents the design and analysis of a narrowband and broadband microwave amplifier centered at 4 GHz. The design involves:

- Stability analysis of the transistor using k and b parameters,
- Maximizing gain using conjugate matching,
- Implementing matching networks with ideal and microstrip lines,
- Optimizing the amplifier for narrowband and broadband performance.

These amplifiers are widely used in wireless communication systems for signal amplification.

2 Theory

2.1 Stability Analysis

Stability is ensured using the Rollett Stability Factor (k) and stability measure (b):

$$k > 1 \quad \text{and} \quad b > 0$$

When the device is unstable, matching networks are designed to avoid instability regions.

2.2 Maximum Gain

The transducer gain (G_T) is maximized when the source and load impedances are conjugately matched to the transistor input and output impedances:

$$G_T = \frac{4R_S R_L}{|Z_S + Z_{\text{in}}|^2 |Z_L + Z_{\text{out}}|^2}.$$

2.3 Matching Networks

Matching networks are implemented using:

- **Ideal transmission lines** for theoretical analysis,
- **Microstrip lines** for practical implementation.

Smith Chart analysis is used to transform impedances to $50\,\Omega$ for maximum power transfer.

3 Procedure

3.1 Ideal Matching Network Design

The transistor's S-parameters were loaded into ADS, and the matching impedances were obtained:

$$\text{SmZ1} = 32.264 - j57.575\,\Omega \quad \text{and} \quad \text{SmZ2} = 14.160 - j4.850\,\Omega.$$

The values for transmission line matching networks are provided in Table 1.

Table 1: Ideal Matching Network Design Values

Parameter	L_1(deg)	L_2(deg)	$Z_1(\Omega)$
Input (SmZ1)	33.989	99.209	25
	126.079	82.5	31.889
Output (SmZ2)	33.671	146.088	26.5
	174.339	28	55.758

3.2 Microstrip Line Matching Network

The ideal network was implemented using microstrip lines on a substrate with:

$$\epsilon_r = 2.2,\ h = 0.508\,\text{mm},\ t = 0.1\,\text{mm}.$$

The microstrip schematic and results are shown in Figures 1 and 2.

3.3 Tuning the Amplifier

The microstrip network was tuned to optimize the gain. The final schematic and gain performance are shown in Figures 3 and 4.

4 Broadband Amplifier Design

A broadband amplifier was designed to maintain flat gain across $3.5 - 4.5\,\text{GHz}$. The schematic and gain performance are shown in Figures 5 and 6.

The gain across the range is summarized as:

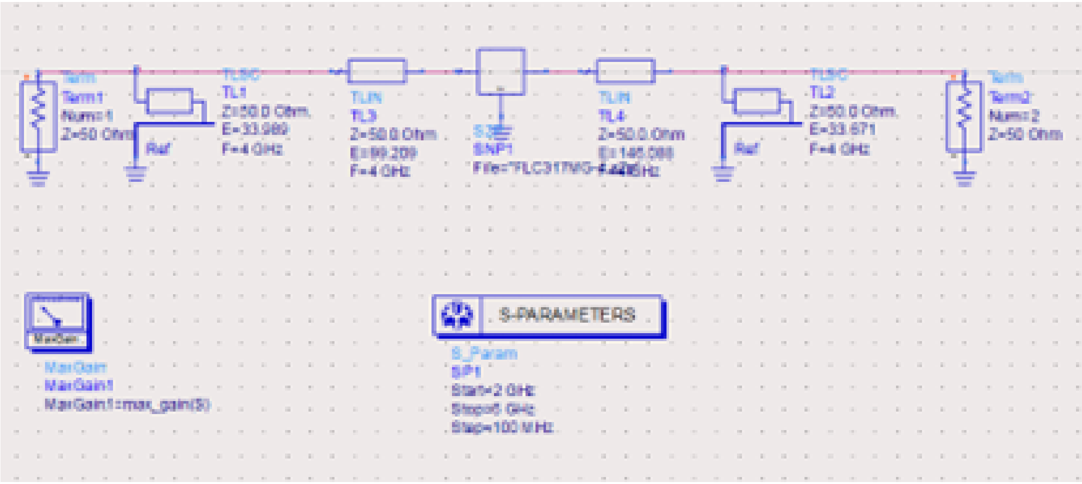

Figure 1: Schematic of narrowband microstrip line matching network amplifier.

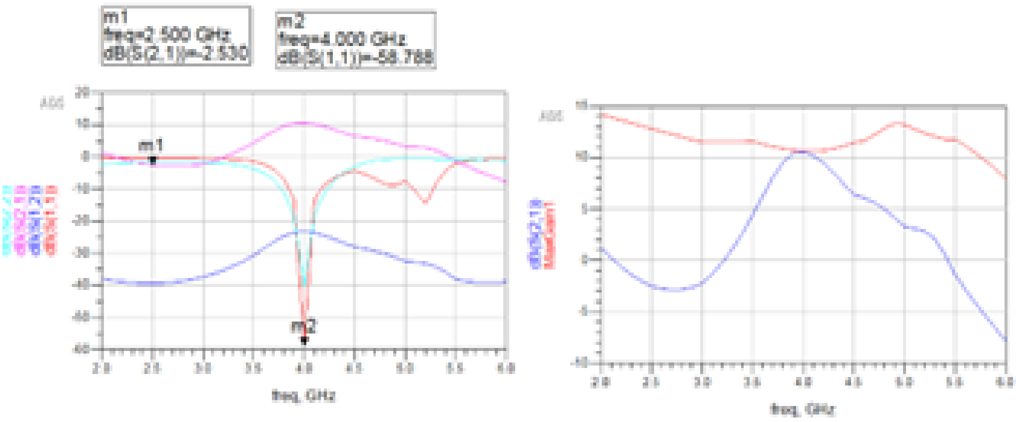

Figure 2: S-parameters and gain plot for narrowband microstrip amplifier.

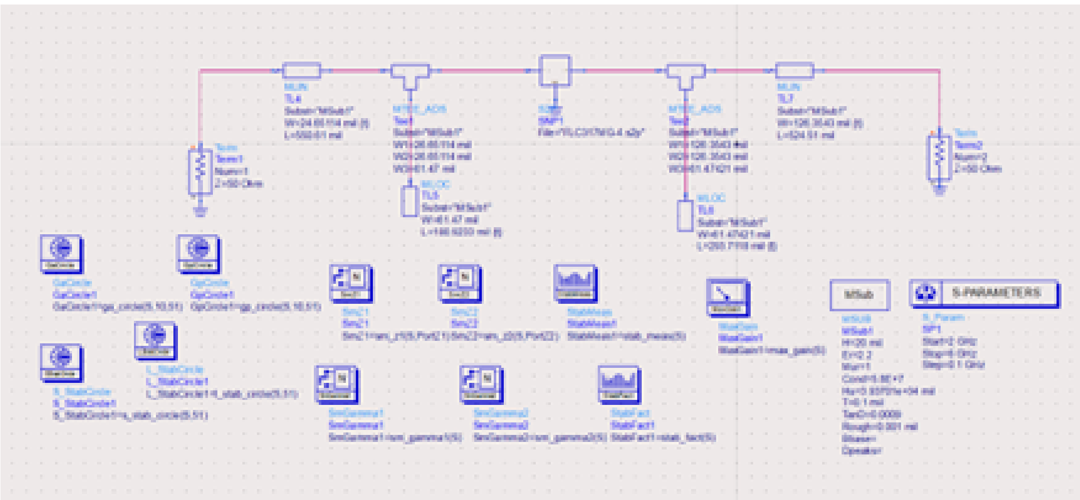

Figure 3: Schematic of narrowband microstrip amplifier after tuning.

- At 3.5 GHz, $S_{21} = 9.954\,\text{dB}$,

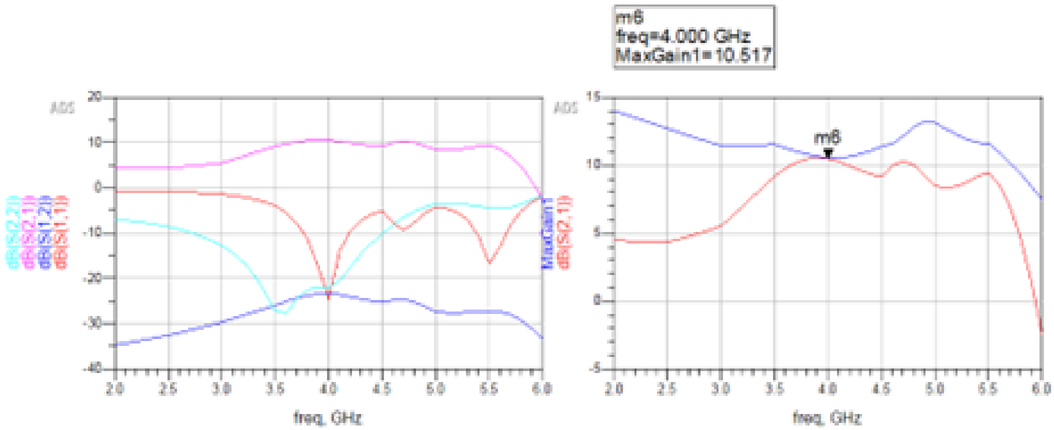

Figure 4: S-parameters and gain of the narrowband amplifier after tuning.

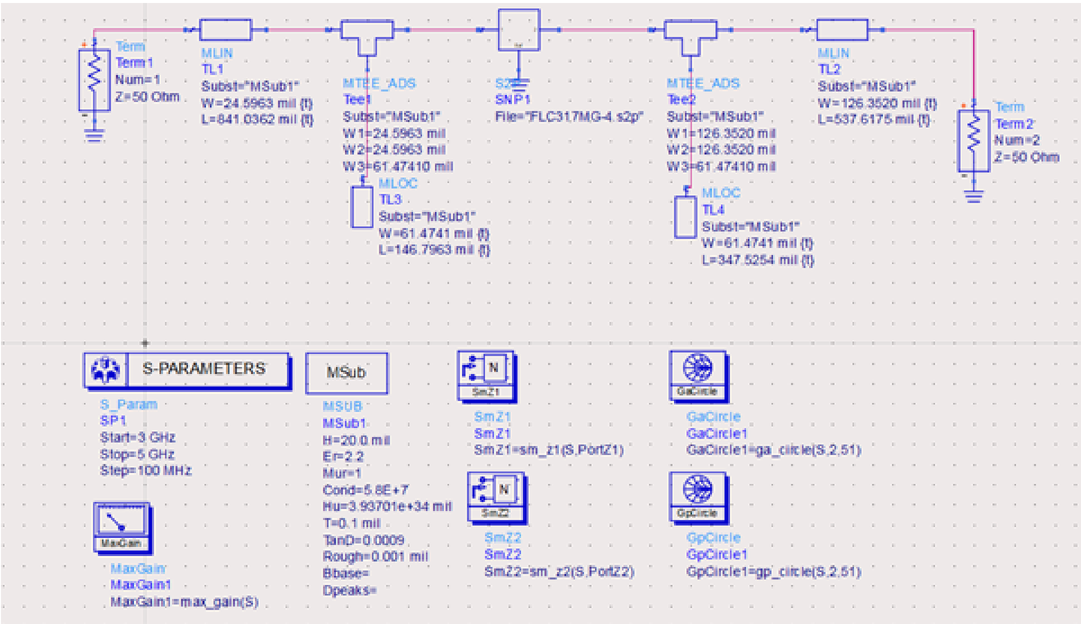

Figure 5: Schematic for broadband microstrip line matching network amplifier.

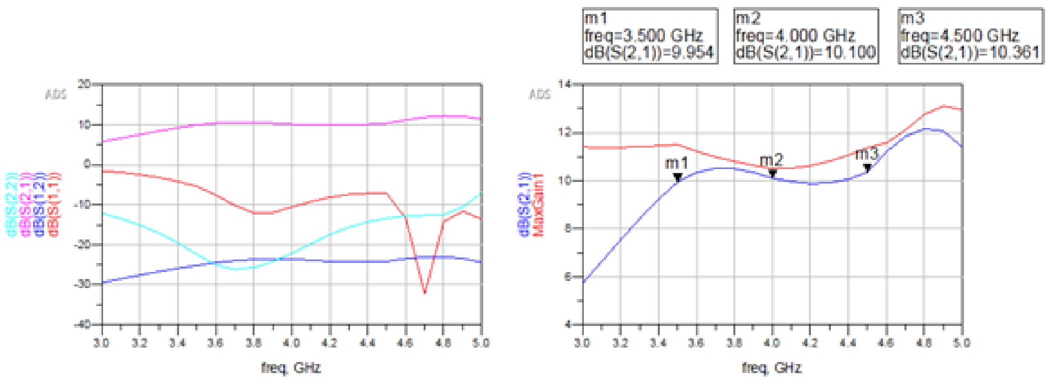

Figure 6: S-parameter results and broadband gain response of the power amplifier.

Table 2: Simultaneous Match Impedances at 4 GHz

Parameter	**Value**
Simultaneous Input Impedance ($SmZ1$)	$32.264 - j57.575\,\Omega$
Simultaneous Output Impedance ($SmZ2$)	$14.160 - j4.850\,\Omega$

- At 4.0 GHz, $S_{21} = 10.100$ dB,
- At 4.5 GHz, $S_{21} = 10.361$ dB.

5 Results and Discussion

Below is the analysis based on the provided plots and simulation results.

5.1 Stability Analysis

The Rollett Stability Factor (k) and Stability Measure (b) were analyzed across the frequency range of 2 GHz to 6 GHz.

From the stability plots:

- At 4 GHz, the transistor is stable since $k > 1$ and $b > 0$.

5.2 S-parameters

From the S-parameter plots:

- S_{11} and S_{22} (Input and Output Return Loss) are below -10 dB at 4 GHz, indicating good impedance matching.
- S_{21} (Gain) peaks near 4 GHz, providing excellent amplification performance.

5.3 Impedance Matching (Simultaneous Match)

At 4 GHz, the simultaneous match input and output impedances ($SmZ1$ and $SmZ2$) are as follows:

These values are essential for designing matching networks that ensure conjugate matching for maximum transducer gain (G_T).

5.4 Maximum Gain

From the **MaxGain1** plot, the maximum transducer gain at 4 GHz is approximately 13 dB.

- The gain peaks at 4 GHz and gradually declines at higher and lower frequencies.

Table 3: Summary of Results at 4 GHz

Parameter	**Value at 4 GHz**
Stability Factor (k)	> 1 (Stable)
Simultaneous Input Impedance ($SmZ1$)	$32.264 - j57.575\,\Omega$
Simultaneous Output Impedance ($SmZ2$)	$14.160 - j4.850\,\Omega$
Gain (S_{21})	13 dB
Return Loss (S_{11}, S_{22})	< -10 dB

5.5 Matching Network Design Discussion

To achieve conjugate matching for optimum power transfer:

- **Input Matching:** Match $SmZ1 = 32.264 - j57.575\,\Omega$ to $50\,\Omega$ using transmission lines or lumped components (ideal or microstrip networks).
- **Output Matching:** Match $SmZ2 = 14.160 - j4.850\,\Omega$ to $50\,\Omega$ for optimum power transfer.

By designing proper matching networks, the input and output return losses (S_{11} and S_{22}) will improve, ensuring maximum power transfer and gain.

5.6 Summary Table

The key parameters at 4 GHz are summarized in Table 3.

5.7 Discussion

The transistor demonstrates stable performance at 4 GHz with excellent impedance matching and gain performance:

- The stability analysis confirms that the transistor is unconditionally stable at 4 GHz ($k > 1$, $b > 0$).
- The input and output impedances ($SmZ1$ and $SmZ2$) align well with the matching networks for conjugate matching.
- The S_{21} gain peaks at 13 dB, and return losses (S_{11}, S_{22}) remain below -10 dB, indicating minimal reflection.

The results validate the design approach, and matching networks effectively maximize the gain performance.

6 Conclusion

This report presented the design and analysis of narrowband and broadband microwave amplifiers operating at 4 GHz. The key findings and outcomes are summarized as follows:

- **Stability Analysis:** The transistor demonstrated unconditional stability at 4 GHz, with the Rollett Stability Factor $k > 1$ and Stability Measure $b > 0$. This confirms the device can operate without oscillations in the desired frequency range.

- **Impedance Matching:** Simultaneous input and output impedances at 4 GHz were extracted as:

$$SmZ1 = 32.264 - j57.575\,\Omega \quad \text{and} \quad SmZ2 = 14.160 - j4.850\,\Omega.$$

  Proper matching networks were designed to transform these impedances to $50\,\Omega$ for maximum transducer gain.

- **Maximum Gain:** The narrowband amplifier achieved a maximum transducer gain of approximately 13 dB at 4 GHz. Gain performance was optimized using conjugate matching techniques.

- **Narrowband Amplifier:** The microstrip line implementation validated the ideal matching network design. The optimized narrowband amplifier achieved excellent return losses ($S_{11}, S_{22} < -10\,\text{dB}$) and peak gain at 4 GHz.

- **Broadband Amplifier:** For broadband operation, a flat gain of $10 \pm 0.2\,\text{dB}$ was achieved across $3.5 - 4.5\,\text{GHz}$. This demonstrates the effectiveness of the matching network design for wider bandwidth applications.

In conclusion, the narrowband amplifier provides high gain at a single frequency, making it suitable for targeted applications. The broadband amplifier, on the other hand, delivers consistent gain performance over a wider frequency range, which is ideal for multi-frequency applications. The results validate the importance of stability analysis, impedance matching, and careful optimization in achieving desired amplifier performance.

References

1. RA Soares, *GaAs MESFET Circuit Design*, Artech House, 1988.
2. Keysight ADS Documentation.