BROADBAND RF POWER AMPLIFIER FOR RADAR APPLICATIONS

EC301 - Radio Frequency Circuits and Components Course Project Report

Submitted by

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Abstract

This report details the design and development of a broadband S-band RF power amplifier for radar applications, using the superior performance of Gallium Nitride (GaN) semiconductor technology. The amplifier has been designed using Advanced Design System (ADS) software to meet the stringent requirements of radar systems, including high power-added efficiency (PAE), linearity, and gain across the S-band frequency range. The design methodology includes biasing circuit optimization, load-pull analysis, and the implementation of input and output matching networks. The simulations demonstrated efficient operation with high output power and minimal signal distortion, showcasing the potential of GaN technology for high-power radar applications.

Contents

Introduction

Base paper referenced is : K. K. Joshua, P. Shanthi, and C. S. Varshney, ”Design of Class AB Power Amplifier for RADAR Applications,” International Journal of Research and Scientific Innovation (IJRSI), vol. 4, no. IA, pp. 1-5, Jan. 2017.

In radar systems, RF power amplifiers (PA) play a crucial role in amplifying transmitted signals to the required power levels, ensuring reliable detection and communication. The S-band frequency range (2–4 GHz) is widely used in radar applications due to its balanced resolution and long-range capabilities, making it an ideal choice for both military and civilian radar systems.

Gallium Nitride (GaN) semiconductors are increasingly favored in RF power amplifier designs due to their exceptional material properties, which include a wide bandgap, high breakdown voltage, and superior thermal conductivity. These attributes enable GaN devices to operate efficiently at higher frequencies and power levels than traditional materials like silicon or gallium arsenide, making them suitable for demanding radar applications.

This project focuses on the design and development of a broadband RF power amplifier operating in the S-band using GaN HEMT (High Electron Mobility Transistor) technology. The design process, carried out using Advanced Design System (ADS) software, includes key steps such as selecting optimal biasing points, performing load-pull analysis, and designing matching networks to achieve maximum efficiency and output power. The aim is to create an amplifier with high power-added efficiency (PAE) and linearity to meet the specific requirements of radar systems.

Methodology

A systematic approach to the PA design has been followed according to the paper:

- **DC Biasing Networks**: Critical for maintaining device stability and achieving desired operational characteristics.
- **Stability Analysis**: Ensures unconditional stability over operating frequencies.
- **Load-Pull Analysis**: Determines optimal source and load impedances for maximizing power-added efficiency (PAE) and gain.
- **Impedance Matching**: Smith chart utilities are used for input and output matching networks to minimize losses and enhance bandwidth.

Design

GaN HEMT CG2H40010

Gallium Nitride (GaN) is a wide-bandgap semiconductor that has become increasingly popular for high-power, high-frequency applications, particularly in radar and communication systems. The superior electrical, thermal, and mechanical properties of the material make it a prime candidate for use in power amplifiers, especially for demanding applications such as radar. The amplifier design centers around the CG2H40010 GaN HEMT, chosen for its unmatched broadband capabilities. Key specifications of the device include:

- Frequency Range: DC to 8 GHz.
- Output Power (PSAT): 17 W (typical).
- Small Signal Gain:
  - 18 dB at 2 GHz.
  - 16 dB at 4 GHz.
- Efficiency: Up to 70% at PSAT.
- Drain Voltage: 28 V.

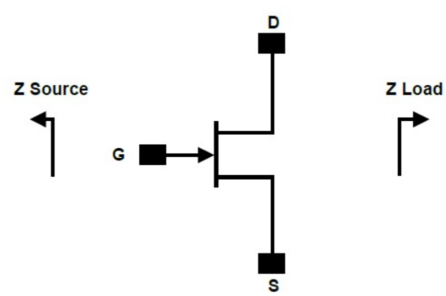

Figure 1: GaN

DC Analysis

The DC analysis determines the operating point of the amplifier, ensuring Class AB operation of the GaN HEMT transistor and helps us find the biasing voltage. The operating point choosen is Drain Voltage of 28V and Gate Voltage of -2.7V with Drain Saturation Current of 200mA. This region of operation ensures the amplifier works in Class AB mode of operation. The biasing circuit was simulated in Advanced Design System (ADS), and the I-V characteristics of the transistor confirmed stable operation within the desired region.

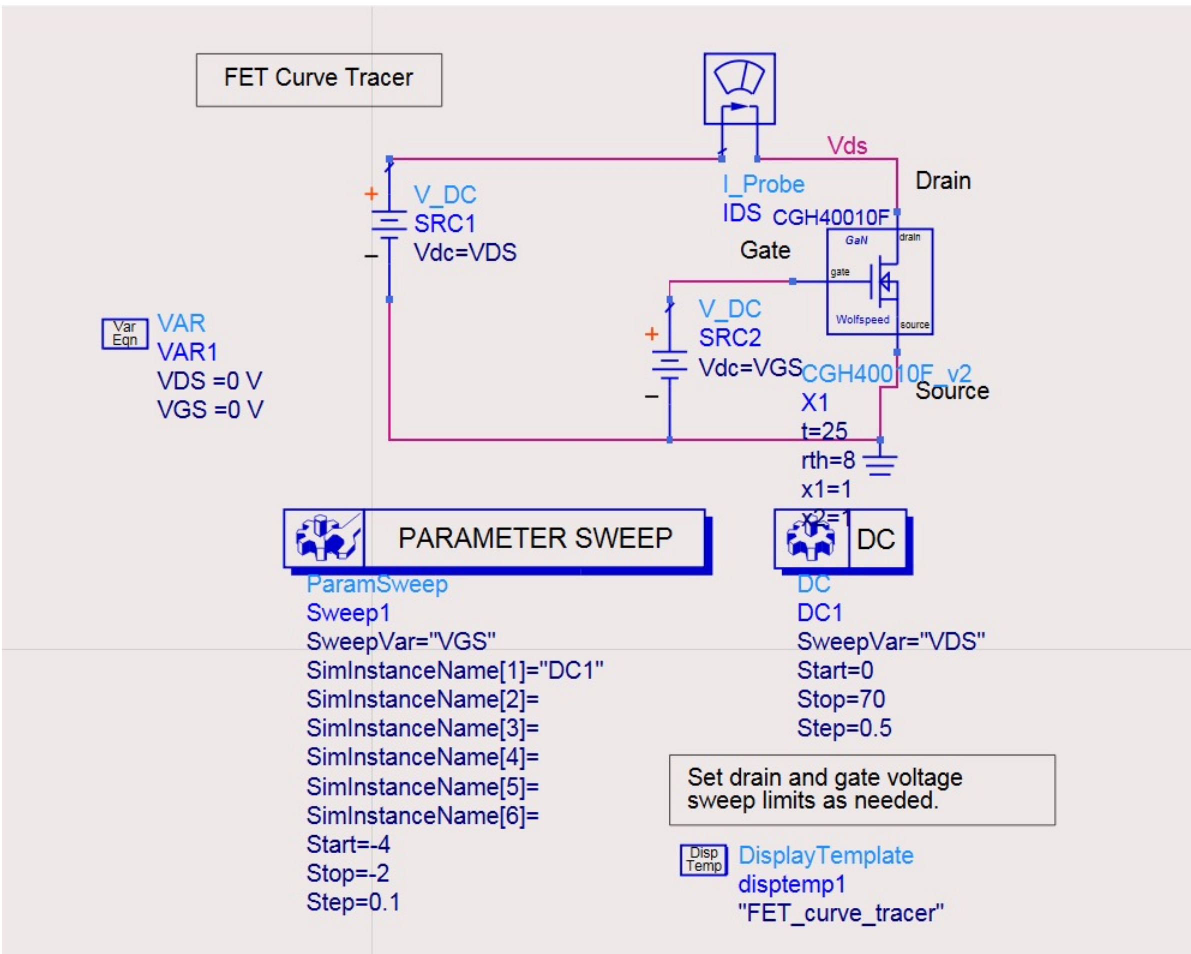

Figure 2: DC-IV Biasing Circuit (built on ADS)

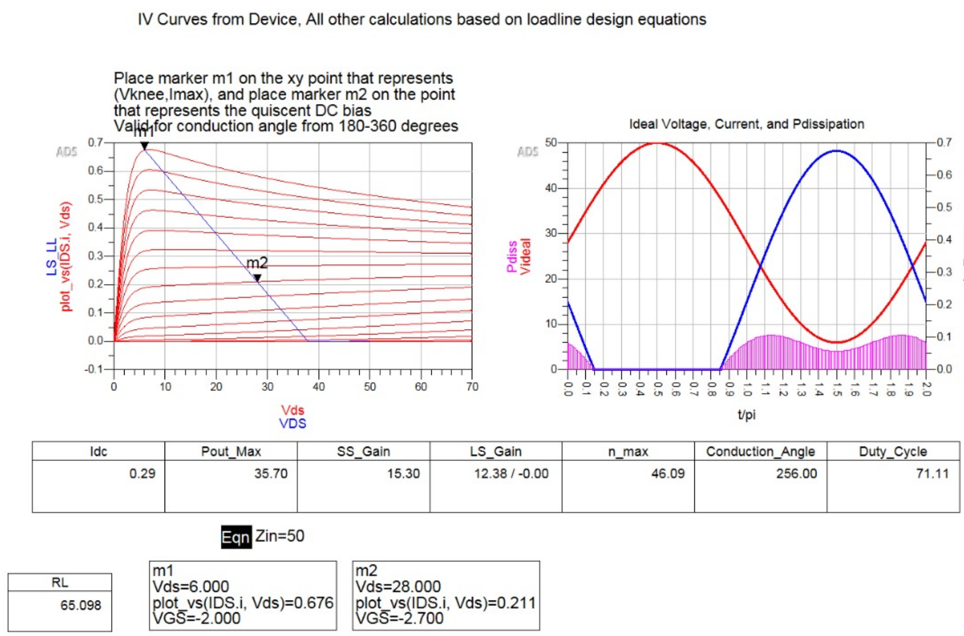

Figure 3: DC-IV Biasing Simulation (built on ADS)

Stability Analysis

The designed broadband power amplifier was analyzed for stability using small-signal S-parameters in Advanced Design System (ADS). The stability factor (K) was used as the main metric, with a target of achieving K > 1 across the operating range of 0.5 GHz to 6 GHz, indicating unconditional stability. The following configurations were applied:

- Load and Source Impedance: $50\,\Omega$
- Series Stabilization Resistor: $5\,\Omega$ added at the gate.

The $5\,\Omega$ resistor was introduced at the gate to suppress low-frequency oscillations without significantly degrading amplifier performance.
The implemented stabilization network effectively mitigated low-frequency instability.
These results ensure that the amplifier is stable across the S-band frequency range, suitable for radar applications.

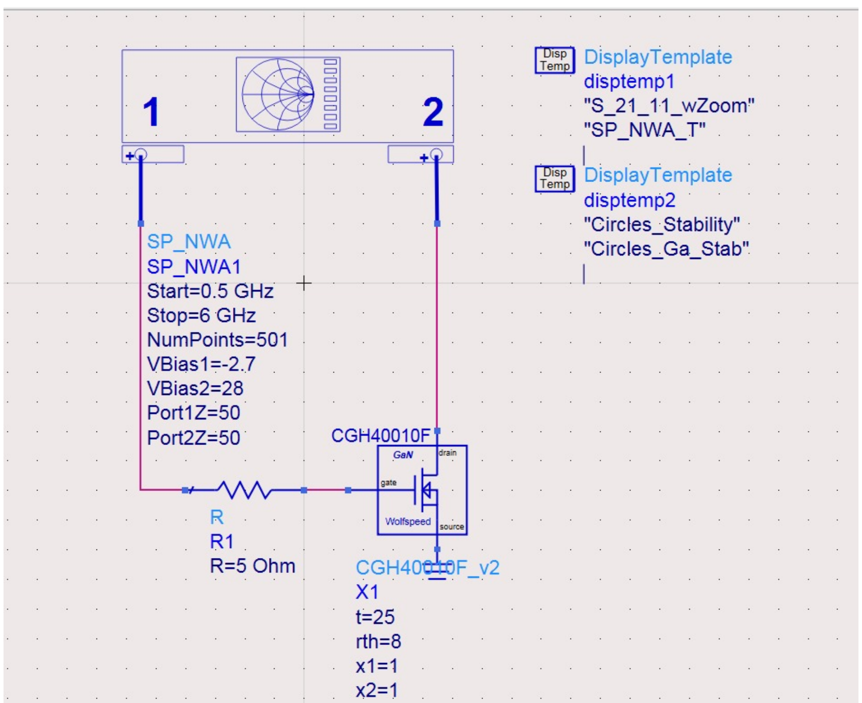

Figure 4: Stability Analysis

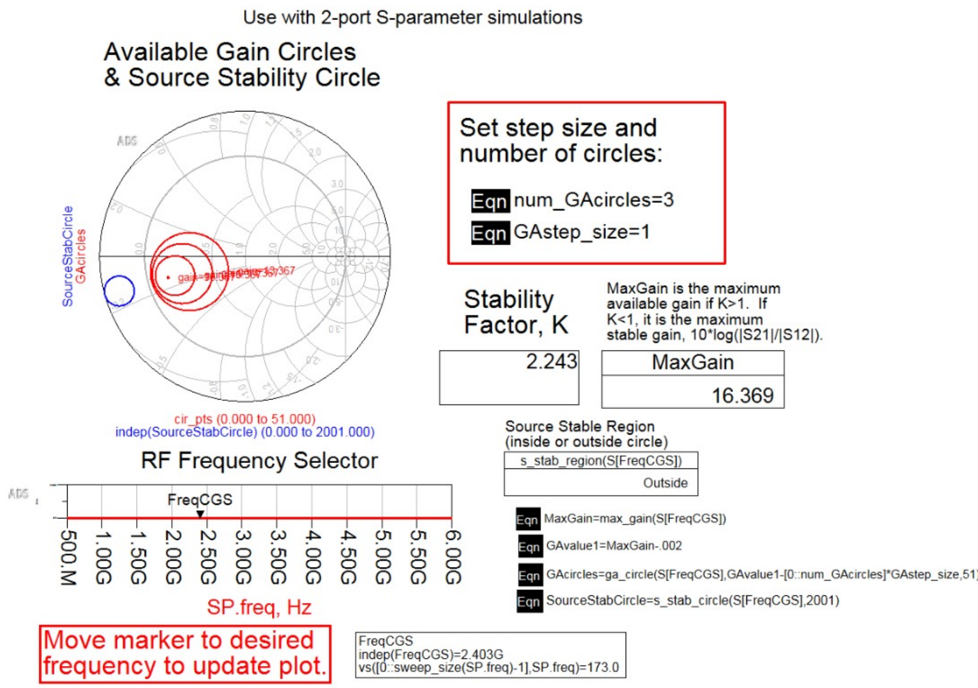

Figure 5: Stability Analysis

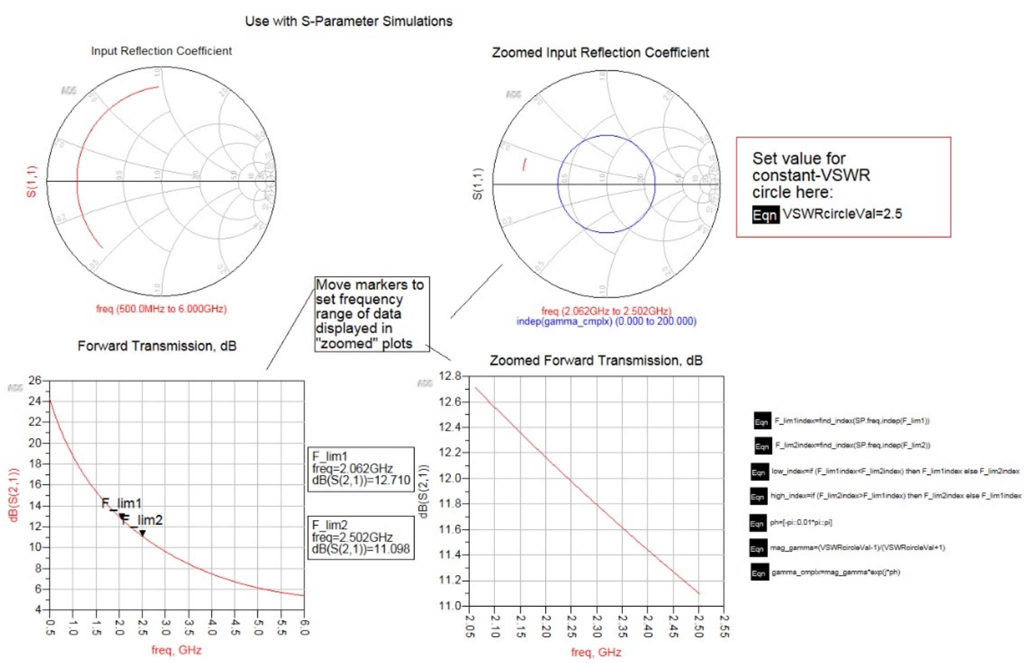

Figure 6: S-parameter plot

Load Pull Simulation

The load pull simulation allows for the determination of the output power and Power Added Efficiency (PAE) at various fundamental and harmonic load impedances. This process helps identify the optimal load impedance that maximizes both power and efficiency over the desired frequency range.
The parameters used are:

- Frequency: 2.4 GHz (S-band).
- Input Power: 29 dBm.
- Load Impedance: The load impedance was varied across a range of real and imaginary components, specified as:
  - Real Component: From -0.55 to -0.85.
  - Imaginary Component: From 0.1 to 0.6.
  - Load Radius: 0.7.
  - Baseband: 0° phase.

The simulation focused on determining the output power and PAE at different load conditions across the specified frequency band. This was achieved by modifying the load impedance and calculating the corresponding power output and efficiency.

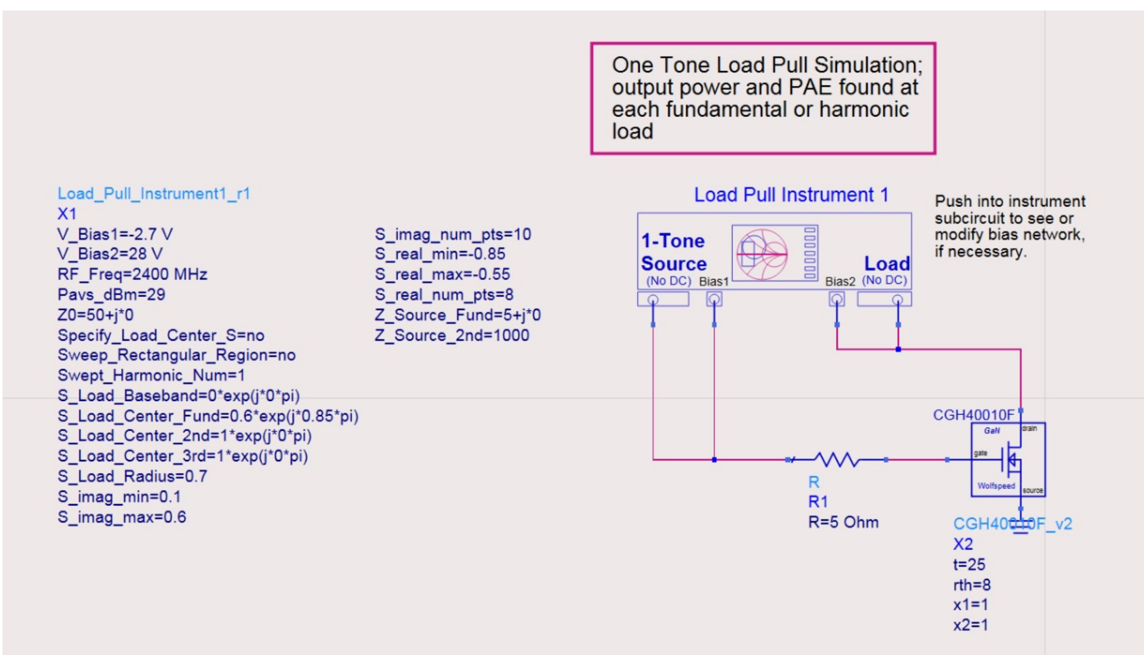

Figure 7: Load Pull Circuit

By varying the load impedance across a specified range of real and imaginary components, the simulation identified the optimal load conditions that maximize both output power and Power Added Efficiency (PAE) at the operating frequency of 2.4 GHz.

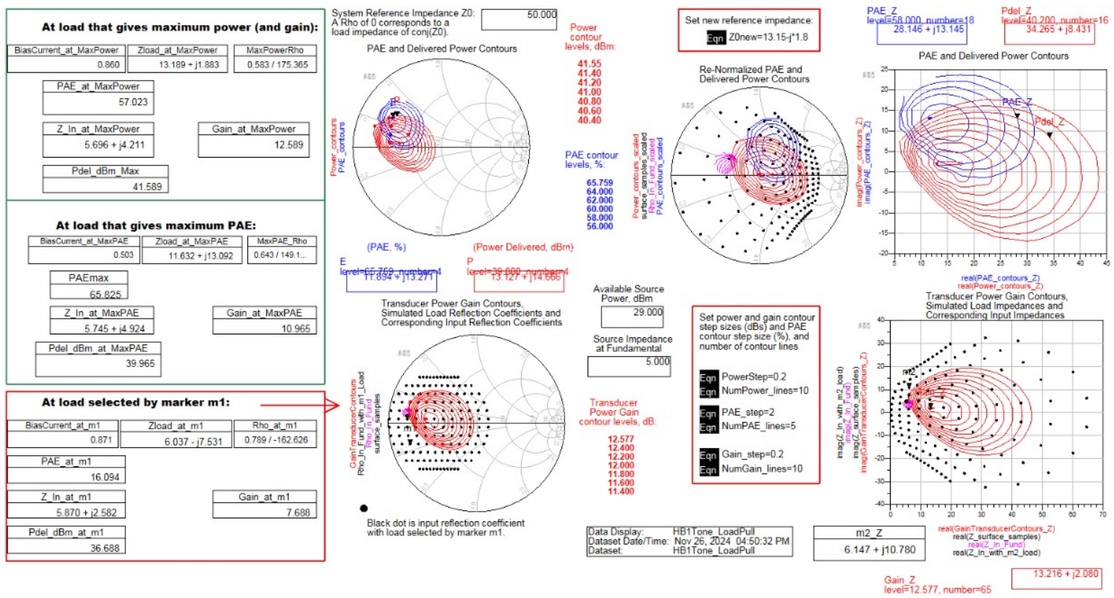

Figure 8: Load Pull Analysis

Impedance Matching

The primary goal of impedance matching networks in PA design is to convert the device's optimal output impedance to maximize output power, PAE, and gain.
Here, we have focused on output impedance matching as it directly impacts power transfer and efficiency, ensuring maximum signal delivery to the load. Input matching is not as relevant, as the source can typically handle minor mismatches without significant performance loss.
The load impedance (ZL) is set to 28 - j0.5 Ω while the source impedance (ZS) is 6.5 - j3.7 Ω

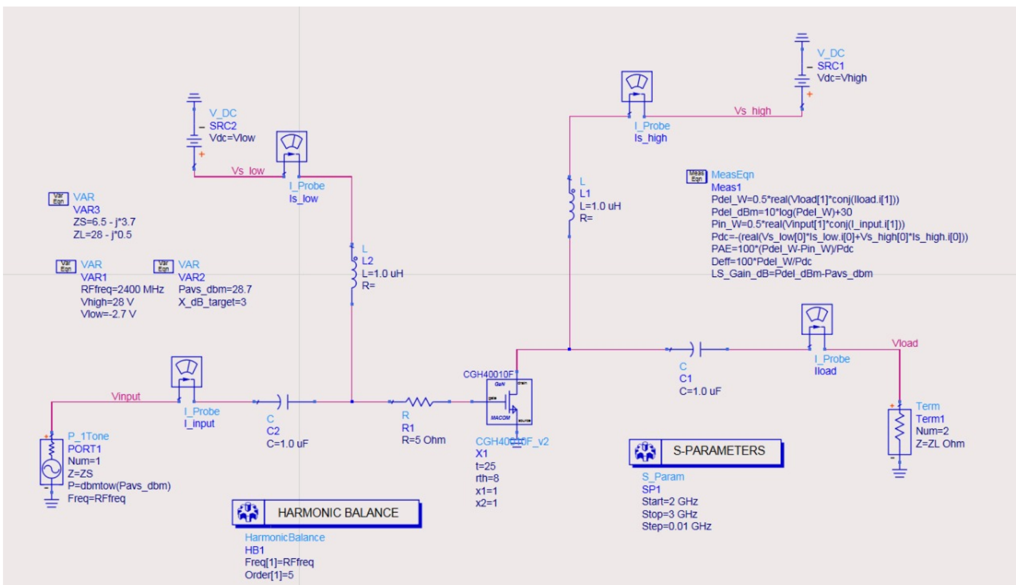

Figure 9: Impedance Matching Requirements

In the following output matching circuit, TL1, TL2, TL4, and TL5 provide impedance transformation between various points. TL7 is a shunt stub to ground, used for impedance matching and harmonic suppression. C1 is a coupling capacitor for blocking DC while passing RF signals, and C2/C3 are shunt capacitors in the matching network for impedance optimization. P1 is the input port. P2 is the output port. P3 represents a branch for testing or an additional load.

Delivered power is 41.624 dBm (14.534 W). PAE (Power-Added Efficiency) is 61.667% which indicates good efficiency. LS Gain is 12.924 dB, showing signal amplification.

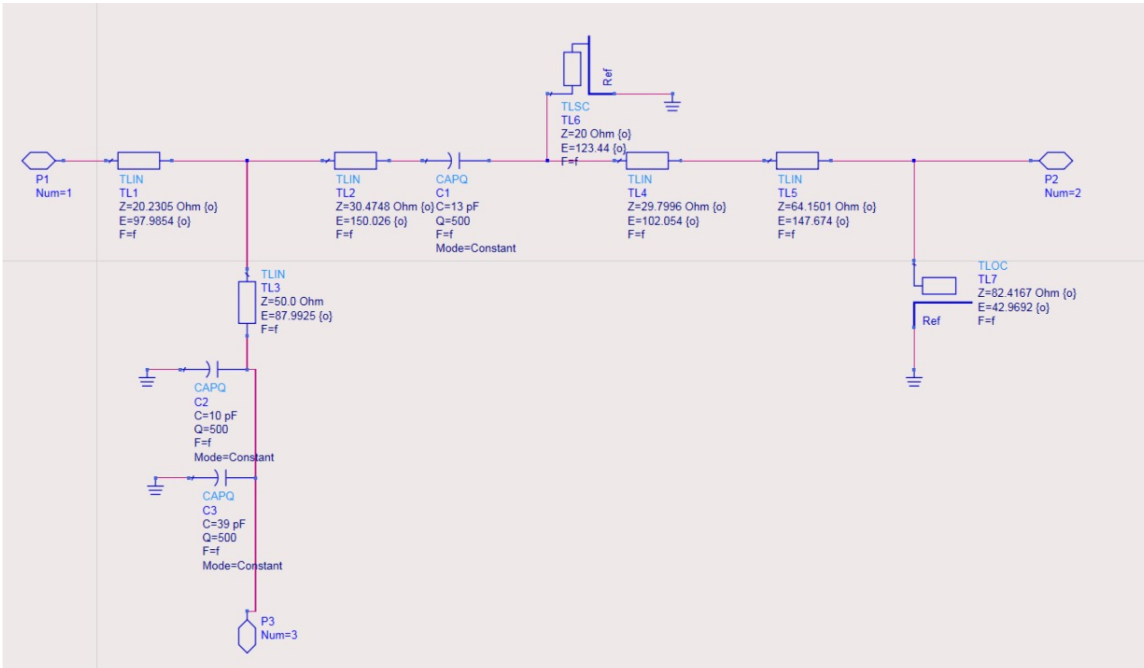

Figure 10: Output Matching Circuit

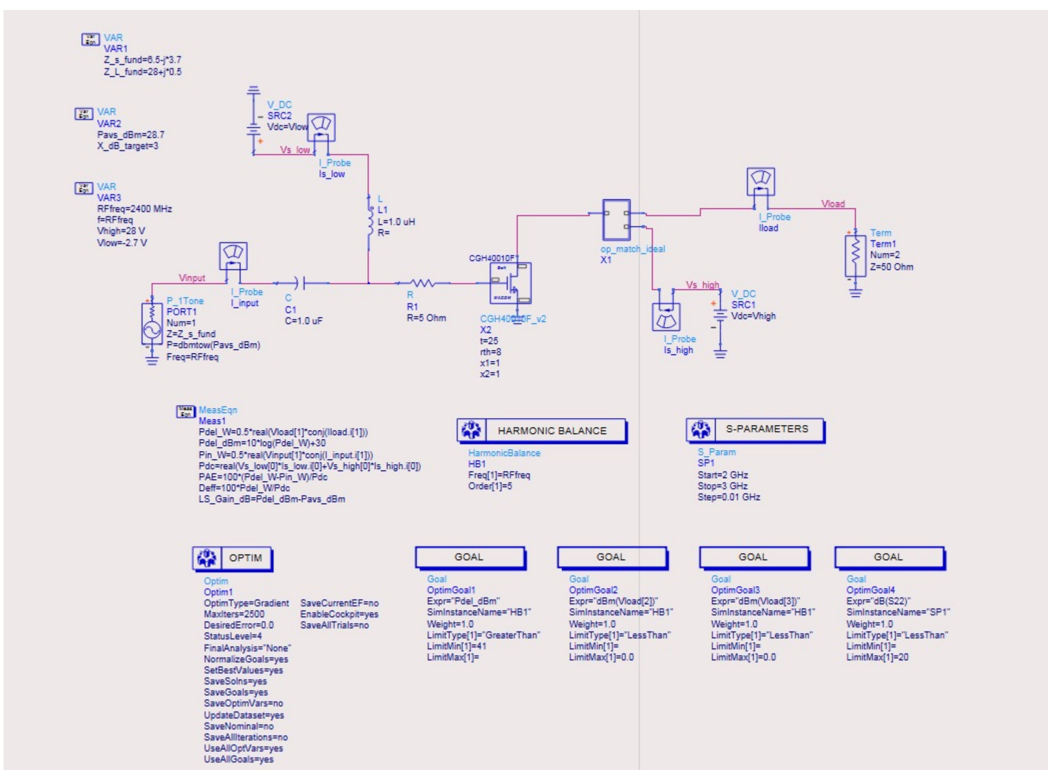

Figure 11: Power Amplifier with Output Matching Circuit

optIter	Pdel_dBm	Pdel_W	PAE	Deff	LS_Gain_dB
2	41.624	14.534	61.667	64.967	12.924

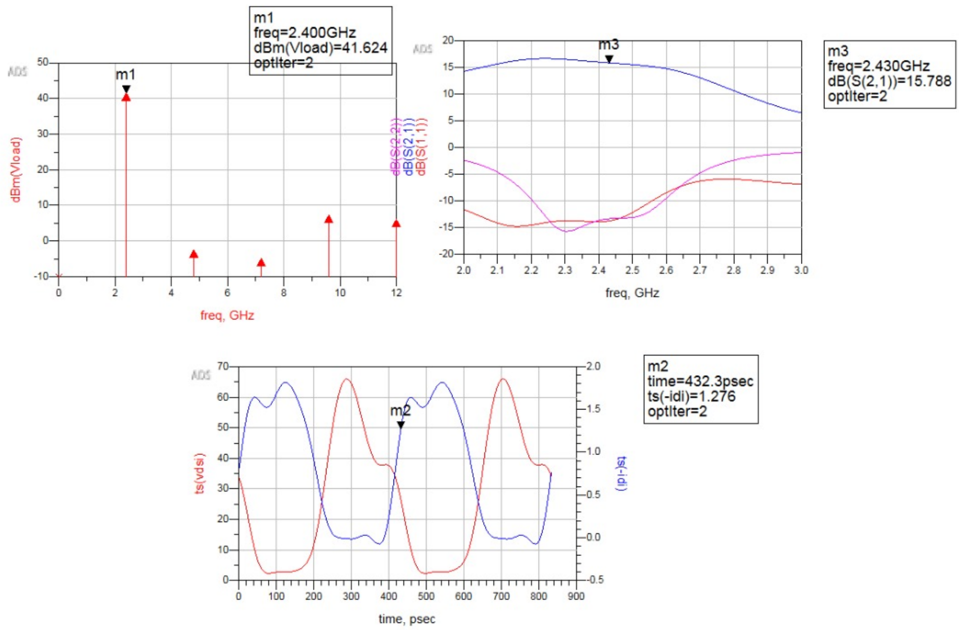

Figure 12: Power Amplifier with Output Matching

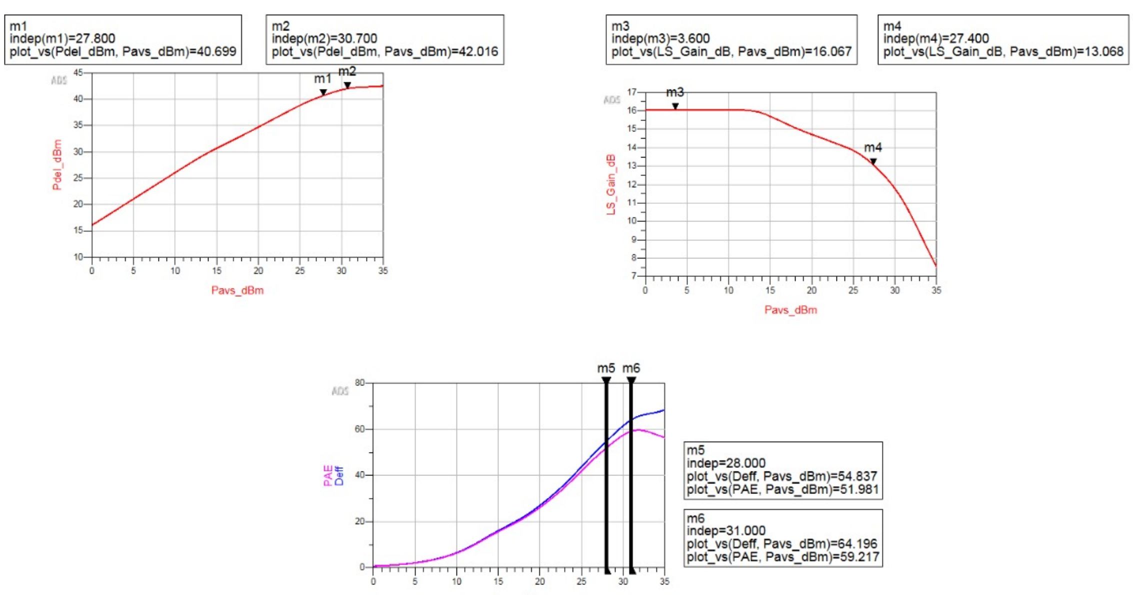

Figure 13: Powersweep

Improvements

Design	**Frequency**	**Pdel**	**Gain**	**PAE**
Paper	3.3 GHz	36.5 dBm	19 dB	54%
Our Simulation	2.4 GHz	41.624 dBm	12.924 dB	61.667%

Table 1: Comparison of Specifications between Base Paper and Our Simulations

The power delivered at the output (Pdel) and the power efficiency at the output (PAE) are significantly improved in our simulation in comparison to the base paper.

Conclusion

The broadband GaN power amplifier for Radar applications was successfully designed with a focus on stability, efficiency, and power output. The simulations confirmed that the amplifier operates stably across the S-band frequency range and delivers optimal performance with the correct load impedance. The design meets the stringent requirements for radar applications, ensuring high reliability and efficiency.

The power delivered at the output (Pdel) and the power efficiency at the output (PAE) have been significantly improved in our simulation in comparison to the base paper. By incorporating stability analysis, load-pull optimization, and DC biasing considerations, this design offers a robust solution for radar systems requiring high power and efficiency.

References

1. K. K. Joshua, P. Shanthi, and C. S. Varshney, ”Design of Class AB Power Amplifier for RADAR Applications,” International Journal of Research and Scientific Innovation (IJRSI), vol. 4, no. IA, pp. 1-5, Jan. 2017.

2. Ambudhi Shukla & K. P. Ray (2024) Design and Development of GaN Based Power Amplifier for Radar Applications, IETE Technical Review, 41:5, 557-577, DOI: 10.1080/02564602.2024.2341056

3. D. M. Pozar, Microwave Engineering, 4th ed. Hoboken, NJ, USA: Wiley, 2011.