भारतीय प्रौद्योगिकी संस्थान तिरुपति

TIRUPATI

Design of a 0.5-2.5 GHz Power Amplifier

Submitted by

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2nd Semester

In partial fulfilment of the course named
"**RF CAD Lab Based Project**"

Department of Electrical Engineering
Indian Institute of Technology Tirupati

Project Title

Design a 0.5-2.5 GHz Power Amplifier

Acknowledgement

I, **Rudraprasad Debnath**, a student of **Indian Institute of Technology Tirupati**, MTech 1st year, have completed this project titled **Design of a 0.5-2.5 GHz Power Amplifier** under the supervision of **Professor M. V. Kartikeyan**. I would like to convey my heartfelt gratitude to Kartikeyan Sir for his tremendous support and assistance in the completion of my project. I am thankful to him for his immense efforts to teach us new things and growing strong concepts on the subject. It was a great learning experience as well. The project work would not have been completed without his cooperation and inputs.

Regards,
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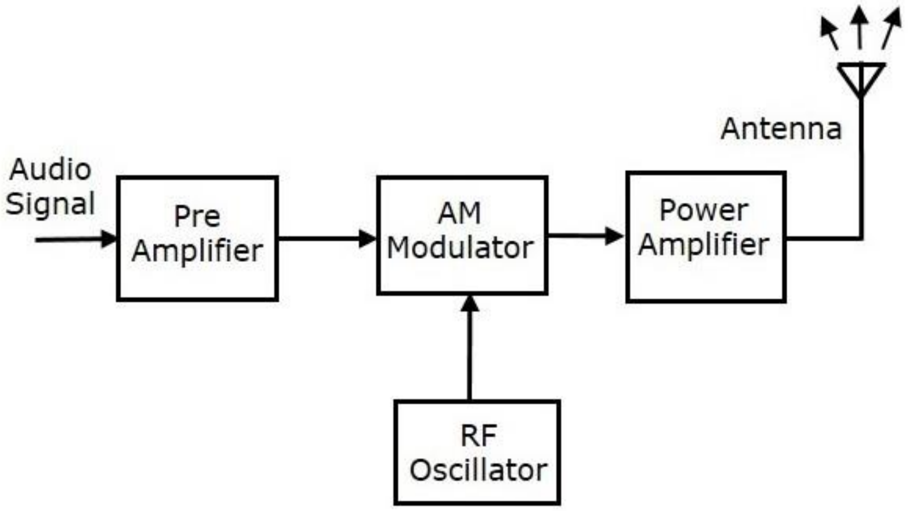
Introduction

An amplifier is an electronic gadget that enhances the force of an input sign to a level reasonable for driving a load like an antenna or a receiving wire. Amplifiers are utilized in many great applications, including sound speakers for instruments and sound frameworks, radio recurrence (RF) amplifiers for remote correspondence, and power speakers for modern and logical applications.

The output of a power amplifier is regularly a lot higher than the input power, and the intensification is accomplished utilizing different methods, for example, Class A, Class B, Class AB, Class D, and Class E amplification. Each of these amplifier classes has its own advantages and disadvantages in terms of efficiency, linearity, distortion, and cost.

Amplifiers can be found in different structures like coordinated circuits, discrete parts, or modules, contingent upon the application prerequisites. They can likewise be intended to work over many frequencies, from sound frequencies up to microwave frequencies, and with different result power levels, going from milliwatts to kilowatts.



The above diagram shows the use of a power amplifier in the circuit. It is seen that the PA is placed at the position just before the transmitting antenna. It is used to enhance the power of the signal that is intended to be sent. There are several factors that define the quality and usability of a power amplifier. They will be discussed later in the report. There are three types of PA –

- Audio Power Amplifier
- RF Power amplifier
- DC Power Amplifier

We will talk about RF Power amplifiers in this report.

Basic Building Blocks and Device Specifications

In this project, a **Cree Device Model** is used to implement the desired device. **Keysight ADS Software** is used to build and simulate the circuit. Now let us take a look at what are the PA design requirements –

- Efficiency of the PA must be good as it is the primary consumer of power in a Tx circuit.
- Efficiency translates into lower operation cost and longer battery life.
- Trade-off between **linearity** an **efficiency**.

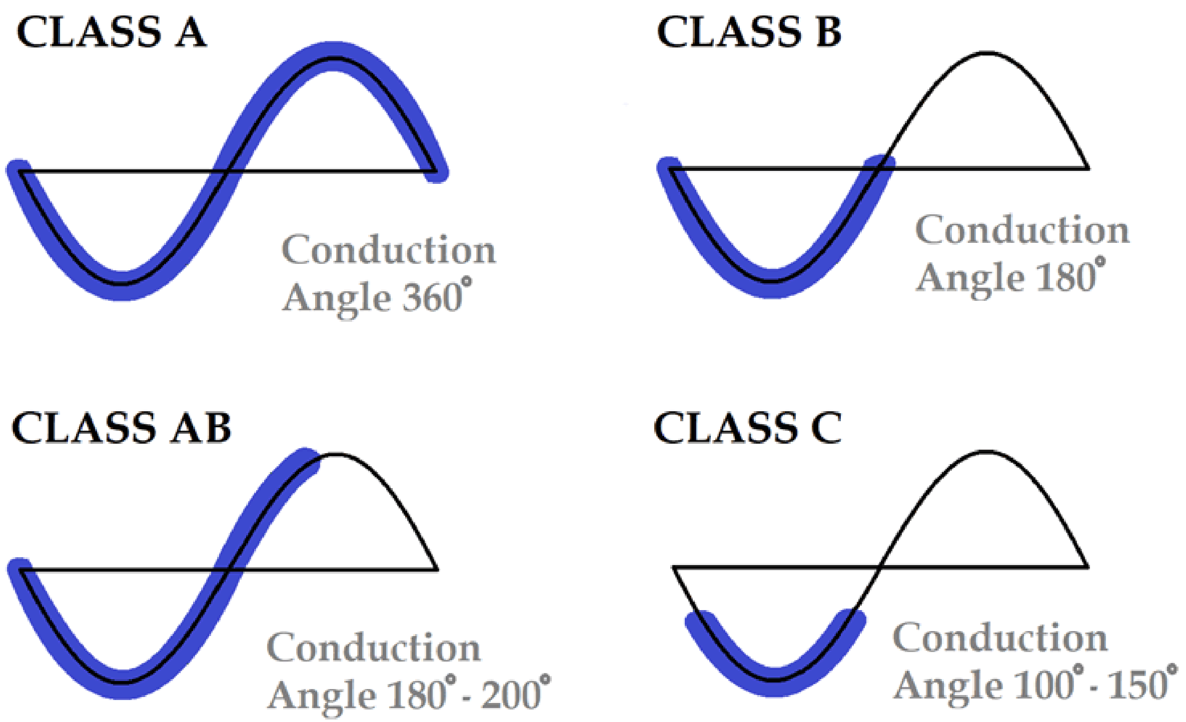
Power Amplifier Classes

Depending on the position of the Q-point or operating point on the load line, the Power amplifiers are classified into the following four categories:

1. Class-A amplifiers
2. Class-B amplifiers
3. Class-C amplifiers
4. Class-AB amplifiers

Sr. NO	Type of amplifier	Position of Q-point
1.	Class-A	At the center of the load line
2.	Class-B	In the cut-off region
3.	Class-AB	Just above the cut-off
4.	Class-C	Below the cut-off

Classes of PA



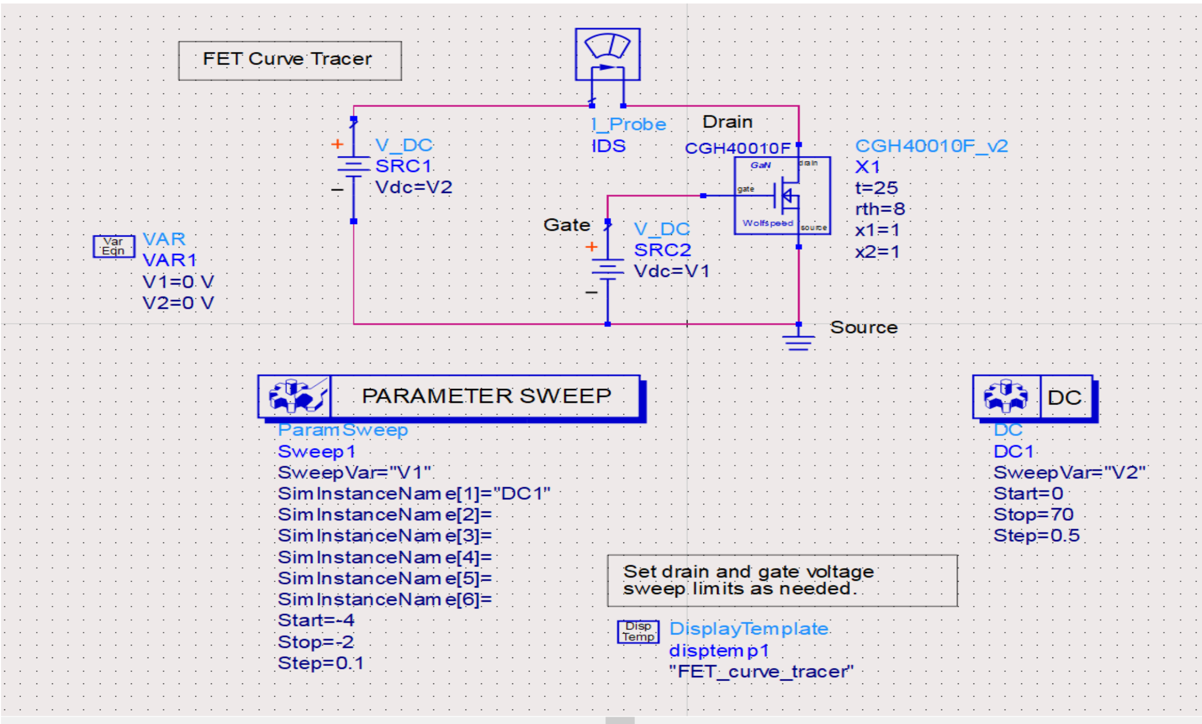
A good PA design requires a good non-linear model.

Specifications of the GaN device used in the design

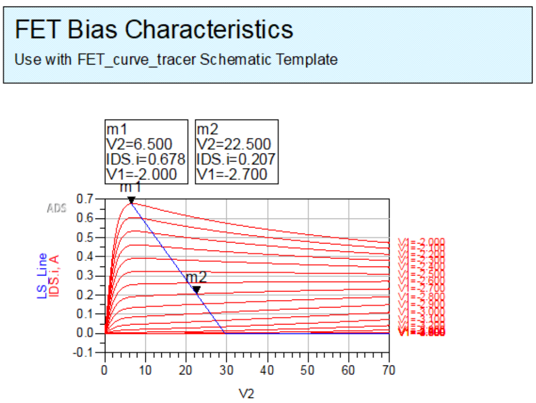
Parameter	Specifications
Centre Frequency	2.4 GHz
Bandwidth	+/- 100 MHz
Output Power	10 Watts
Gain	>10 dB
PAE	>30%
Device	Wolfspeed CGH40010

Step 1: DC-IV Simulation

DC-IV Simulation is required to test the DC-IV characteristics of a device. In ADS software, the model for the Cree device is included and simulated with DC simulation. For that purpose, the “FET Curve Tracer” in-built in ADS is used.



The curves obtained are presented as follows –

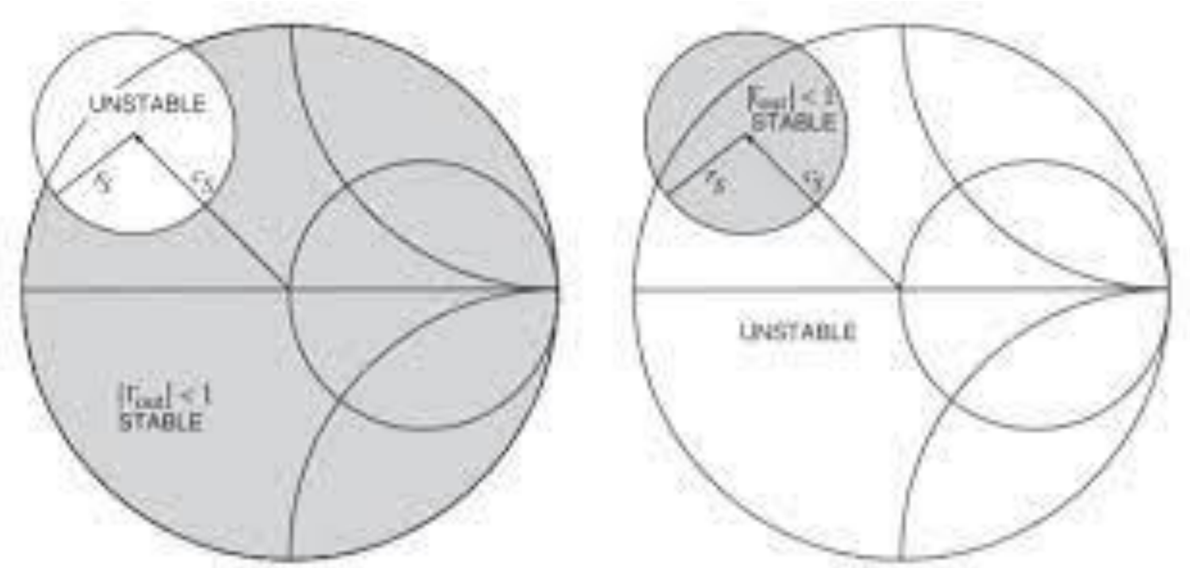


Values at bias point indicated by marker m1.
Move marker to update.

V2	Idc	V2	Pout_max	SS_Gain	LS_Gain	Cond_angle	Duty_cycle	I_ideal
6.500	0.162	<invalid>	34.331	13.855	10.932 / -0.000	132.188	36.719	0.207 0.192 0.177 0.162

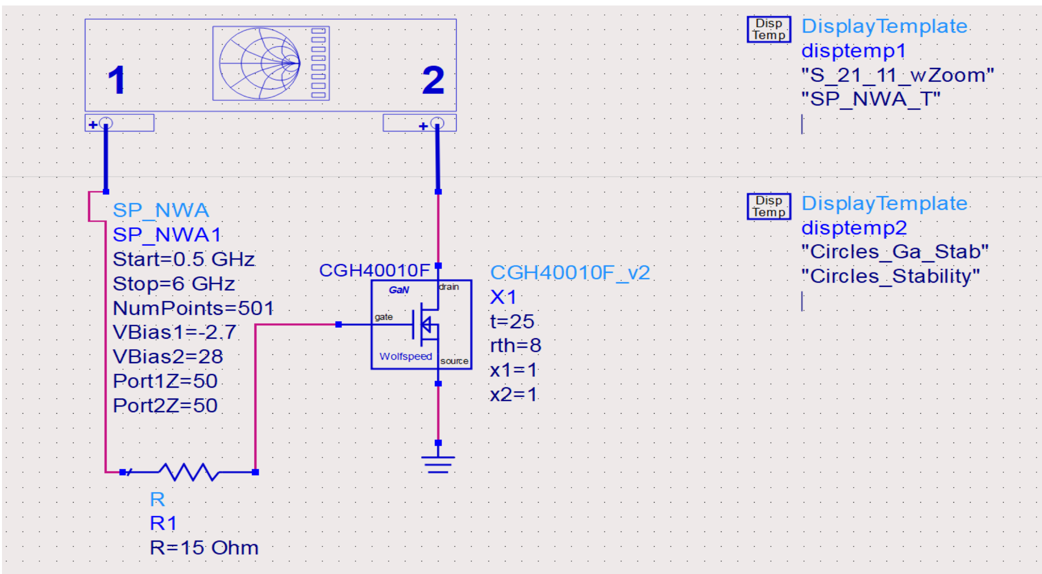
Step 2:Stability Analysis

When we say that an amplifier can be "unstable", we're referring to how the amplifier transitions away from its initial state when the input signal changes. We say an amplifier unconditionally stable if both of its input and output stability circles completely lie outside the Smith Chart. But a device is conditionally stable (potentially unstable) if the input/output stability circle intersects the Smith Chart. Our goal will be to bias the device in such a way so that it remains stable in the specified frequency range.

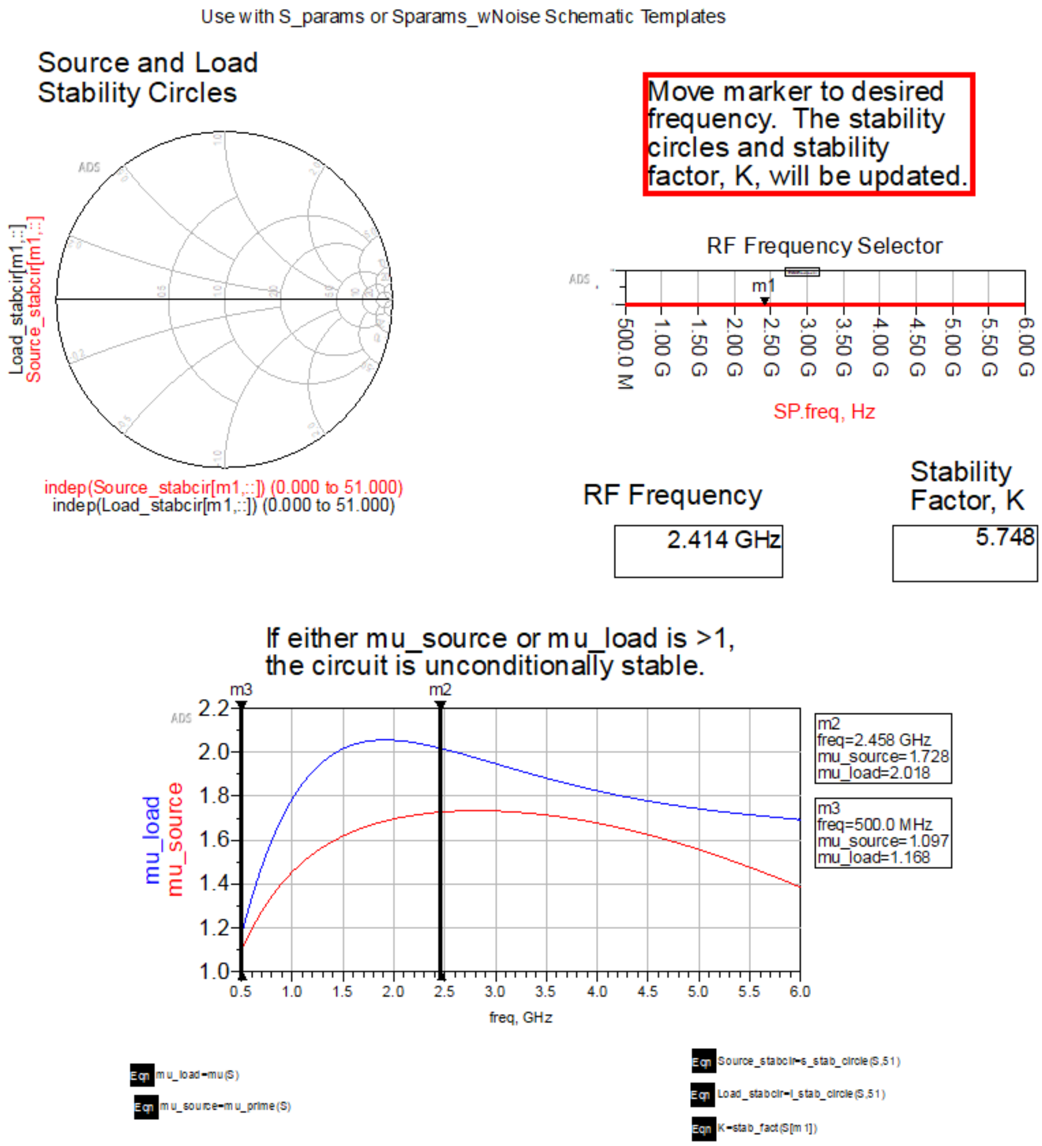


(a) $|S_{22}| < 1$ (b) $|S_{22}| > 1$

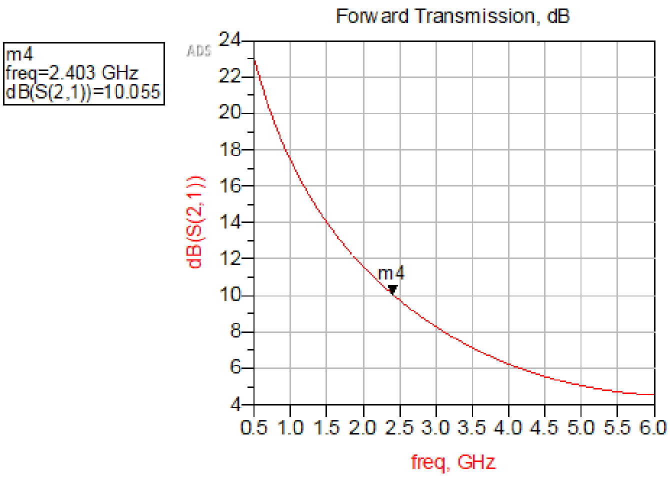
The following setup of SP Network analyzer is used for the stability analysis of the device—



Stability circles –



From the outputs it is clear that the device is stable for the range of 0.5-2.5 GHz. For sake of stability, a 15 ohm resistor is connected to the gate terminal of the device.



Step 3:Loadpull Analysis

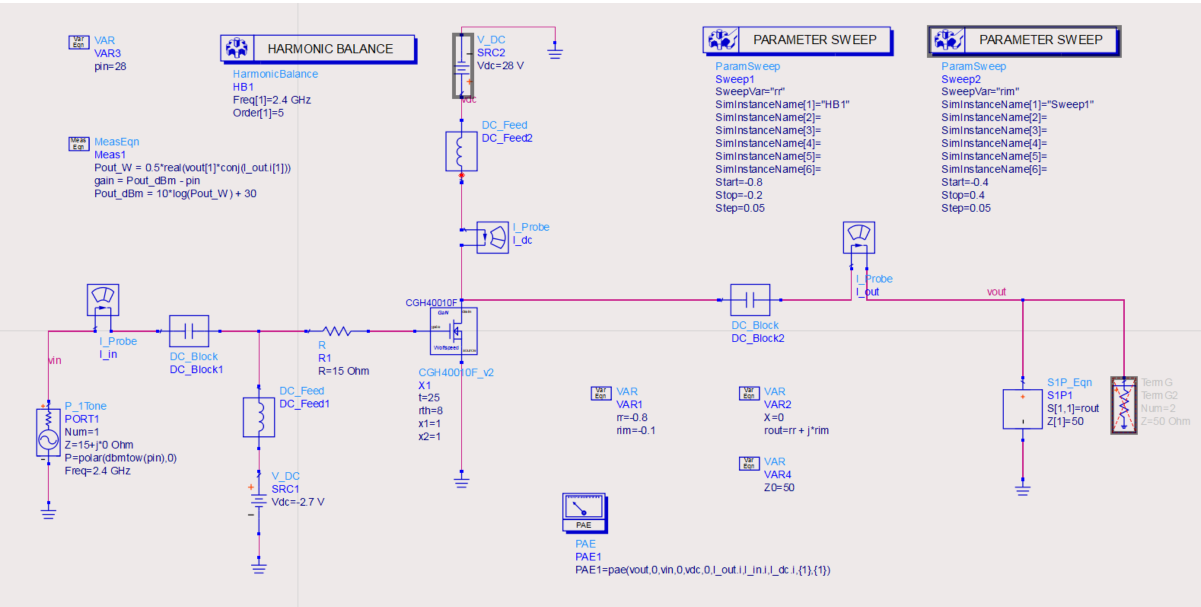
What is Loadpull?

Loadpull is a term colloquially used to represent the process of symmetrically varying the impedance presented to a device under test (DUT), most often a transistor, to assess its performance and the associated conditions to deliver the performance to a network.

- In Loadpull, the impedance at the load port is varied gradually to optimize the performance.

In maximum loadpull simulations, a specific region of the smith chart is selected and vary the impedances of the region one by one and plot the Power and PAE contours. After that we decide which impedance is suitable for the performance of the device.

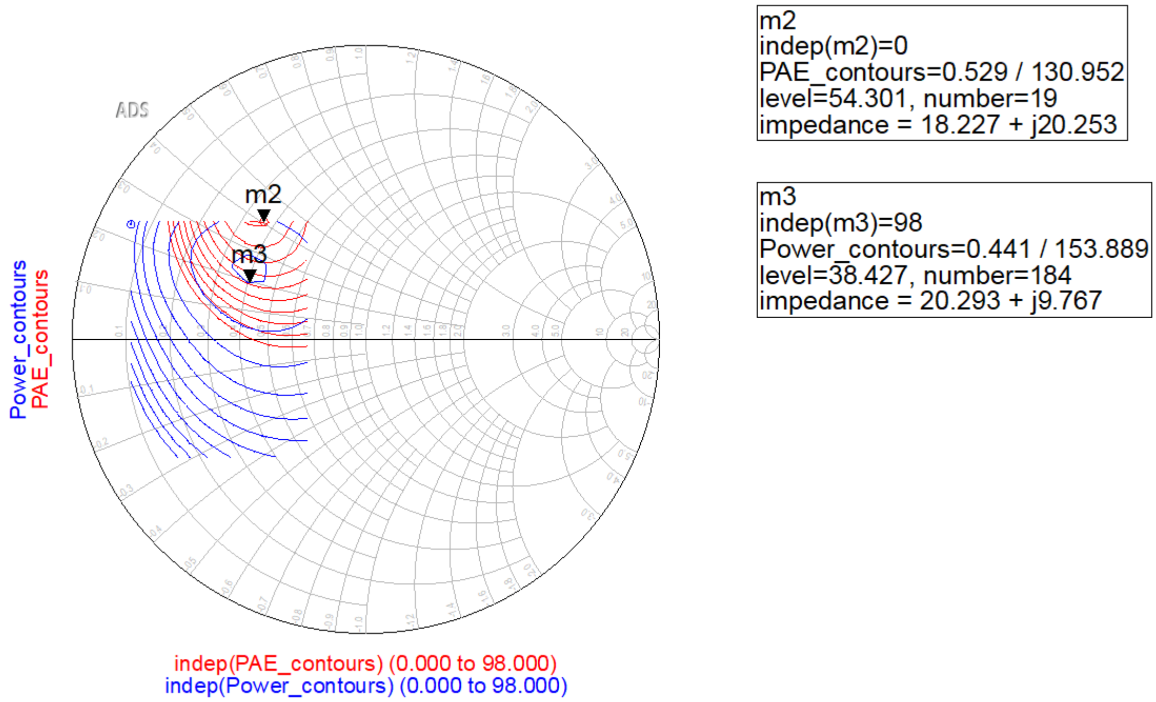
For loadpull analysis in ADS, the following arrangement is made –



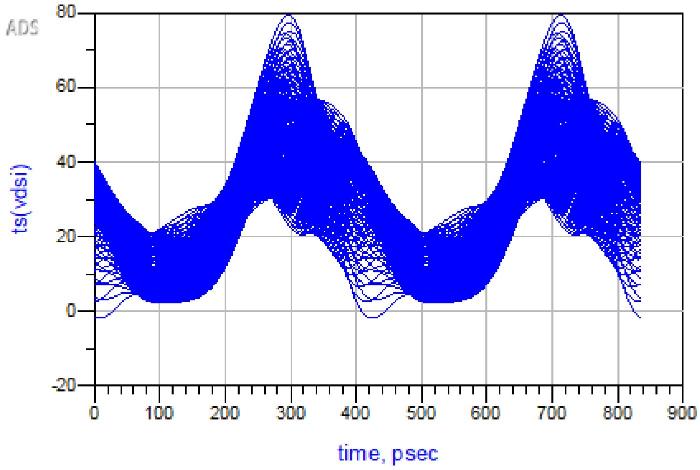
A harmonic balance simulation is done along with two nested parameter sweeps. A S1P equation block is used to terminate the device.

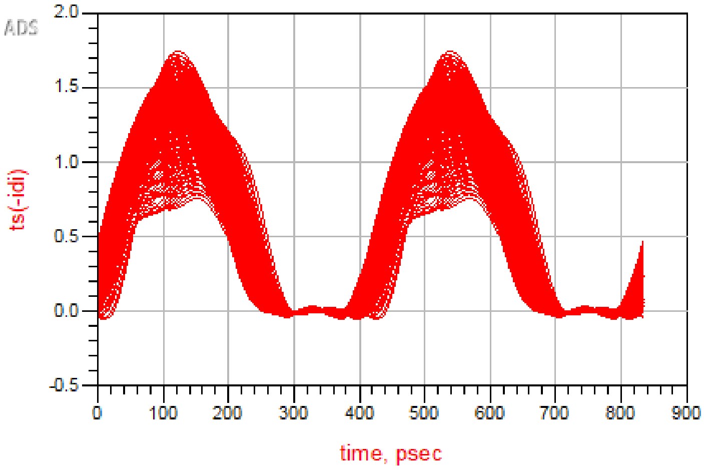
Some equations required for the favourable operation of the device is written in the Var eqn sections and the MeasEqn section. Harmonic Balance simulation is set at f = 2.4 GHz.

The following result is obtained at the loadpull simulation—



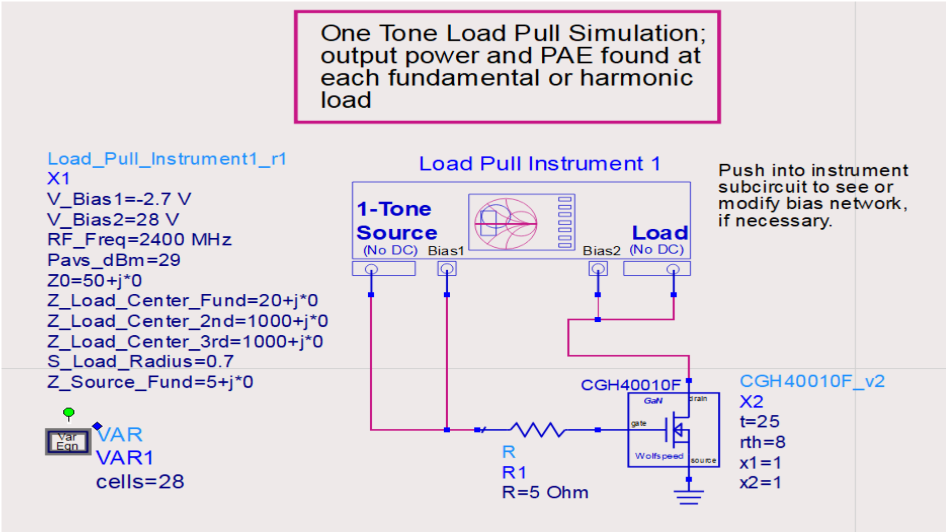
The drain voltage and currents are also plotted –





It shows the class AB operation of the device.

For our device, instead of the ADS inbuilt loadpull simulation, we will use the **One-tone constant output load pull simulation model**.



There are some parameters defined at the Loadpull instrument. The V_Bias1 V_Bias2 and values are those obtained from the DC analysis. The Z_Load_Center_Fund value we take from the Datasheet.

The loadpull analysis giver the following outcomes—

At load that gives maximum power (and gain):

BiasCurrent_at_MaxPower	Zload_at_MaxPower	MaxPowerRho
0.564	17.047 + j6.412	0.498 / 163.527

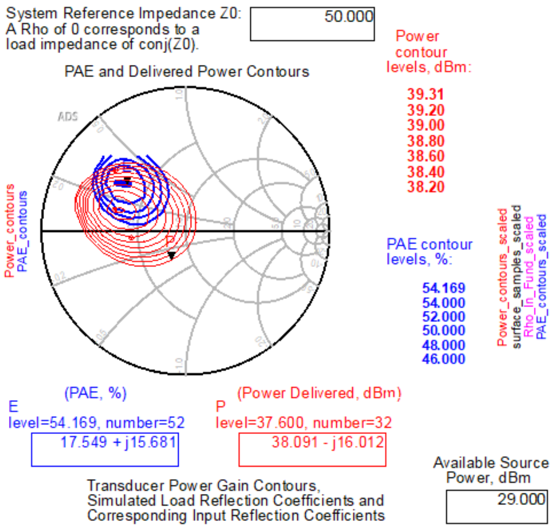
PAE_at_MaxPower	Z_In_at_MaxPower	Gain_at_MaxPower	Pdel_dBm_Max
49.596	15.859 + j5.216	10.351	39.351

At load that gives maximum PAE:

BiasCurrent_at_MaxPAE	Zload_at_MaxPAE	MaxPAE_Rho
0.446	14.772 + j14.533	0.574 / 144.936

PAEmax	Z_In_at_MaxPAE	Gain_at_MaxPAE	Pdel_dBm_at_MaxPAE
54.223	15.719 + j5.915	9.771	38.771

The Z_in value is also displayed by the simulation so we don't need to perform Source-Pull.



After using a readymade setup from Keysight, the input and output load values are optimized as-

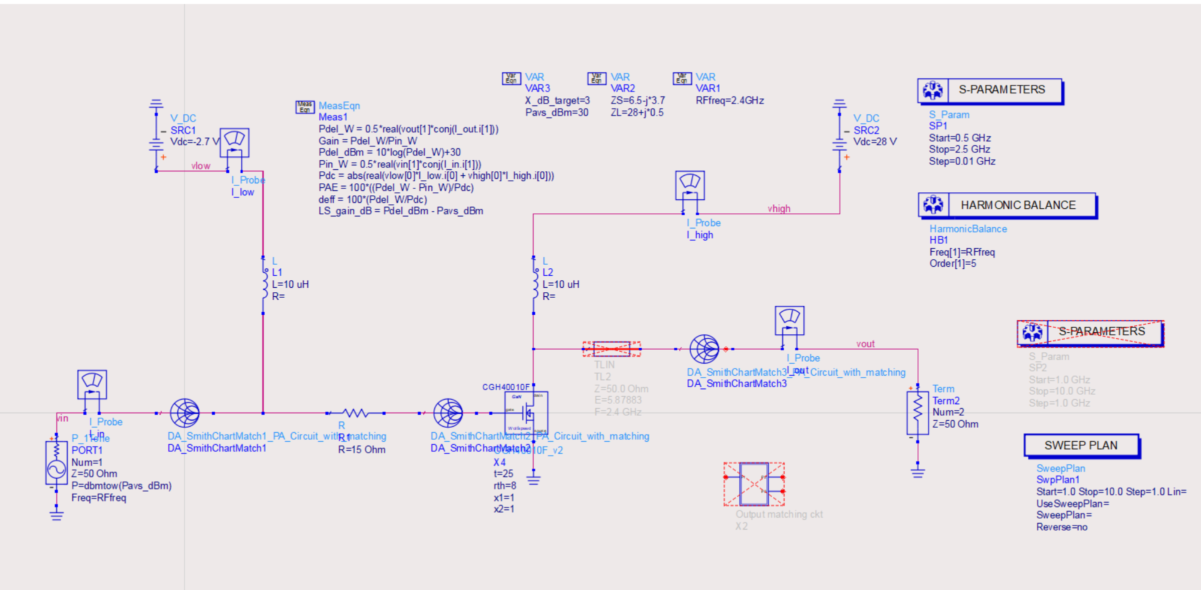
Zload_Fund_at_max_Power
28.115 + j0.497

Zin_Fund_at_max_Power
6.575 + j3.783

These values will be used to design the matching network.

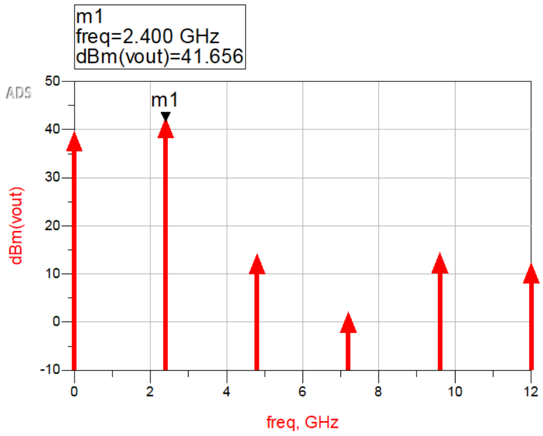
Step 4:Input and Output Matching Circuits

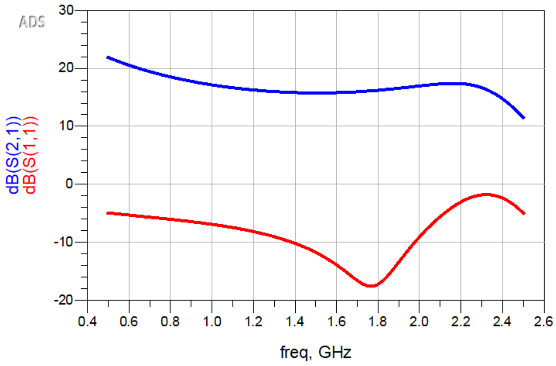
To design the input and output ciruits, the **Smith Chart Matching** technique is used and circuits are designed using the open-series stub matching networks.



The whole amplifier circuit is shown in the above figure. Three Matching circuits are used in the whole circuit.

LS_gain_dB	Pdel_dBm	PAE	Pdc	Pdel_W	Pin_W	Gain
11.656	41.656	36.226	39.456	14.644	0.350	41.803





The output shows that the device gives a favourable gain at 2.4 GHz and favourable S11 and S21 values over the specified frequency range.

Conclusion and References

In the above work, An attempt was made to design a power amplifier over a specified range. The final result was a device with a basic input output matching that provides a gain of 11 dB at 2.4 GHz.

References

[1] *Microwave Engineering*, D.M. Pozar, 4th Edition, John Wiley and Sons Inc.