GaN based RF Power Amplifier (Design and Simulation)

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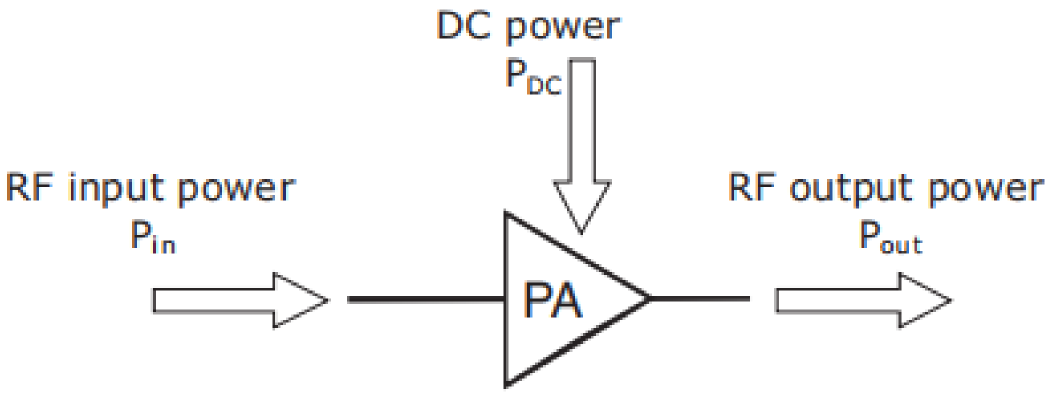
Outline

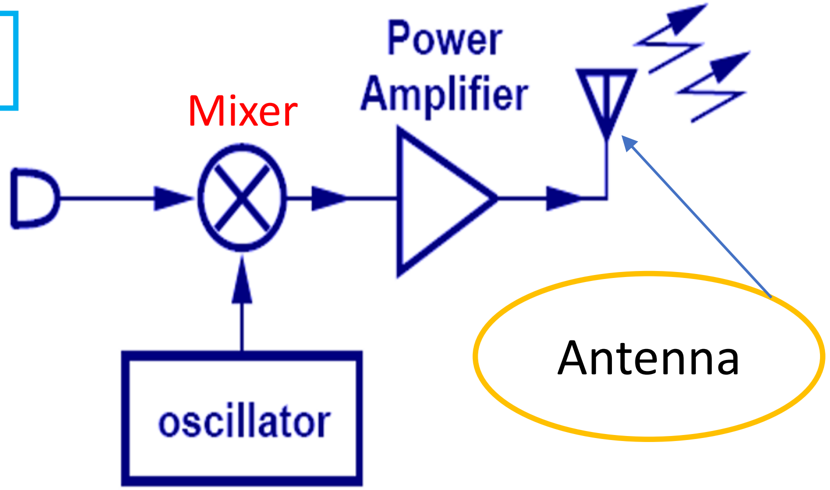
- RFPA and their key performance metrics
- Why GaN
- Classes of operation
- PA design steps
- Simulation Results

What is an RFPA?

Boosts input power (gives a power gain)

Gives high power at RF (things get heated)





Wireless communication Systems (Transmitter side)

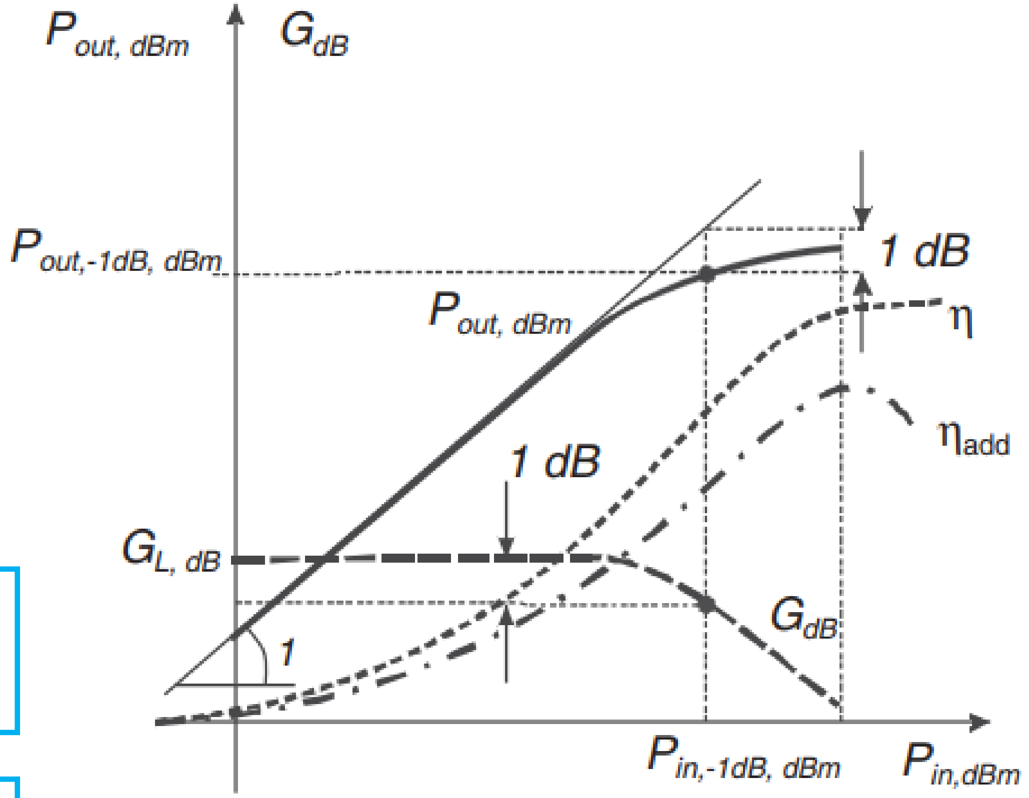
A Power Amplifier (PA) is needed to boost the power before transmission

Some key specifications

Gain $G(f) = \frac{P_{out}(f)}{P_{in}(f)}$

Efficiency $\eta = \frac{P_{out}}{P_{DC}}$

Power-aided Efficiency (PAE) $\eta_{add} \triangleq \frac{P_{add}}{P_{DC}} = \frac{P_{out} - P_{in}}{P_{DC}}$



PAE is a more meaningful figure as it subtracts the added RF input power as well.

It is advantageous to operate the PA near saturation to achieve high efficiency.

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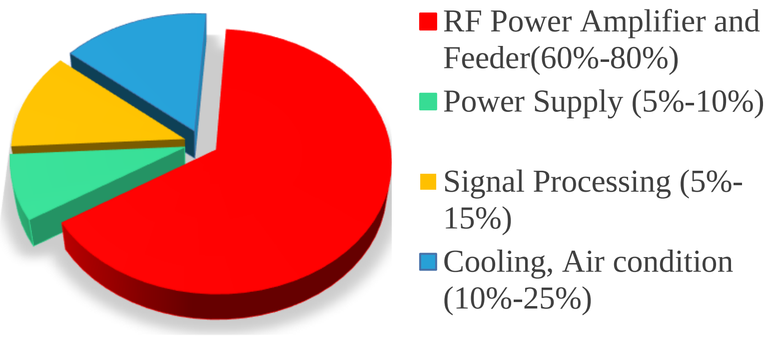
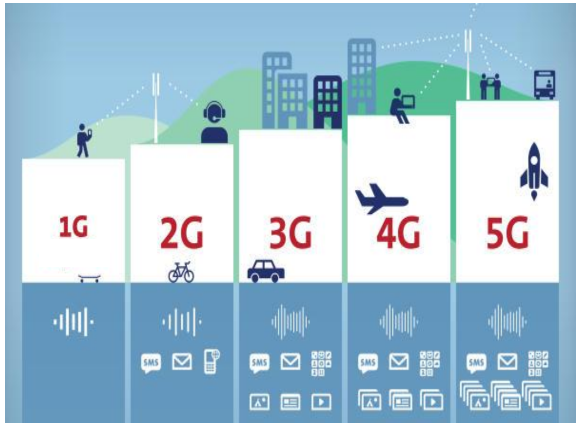
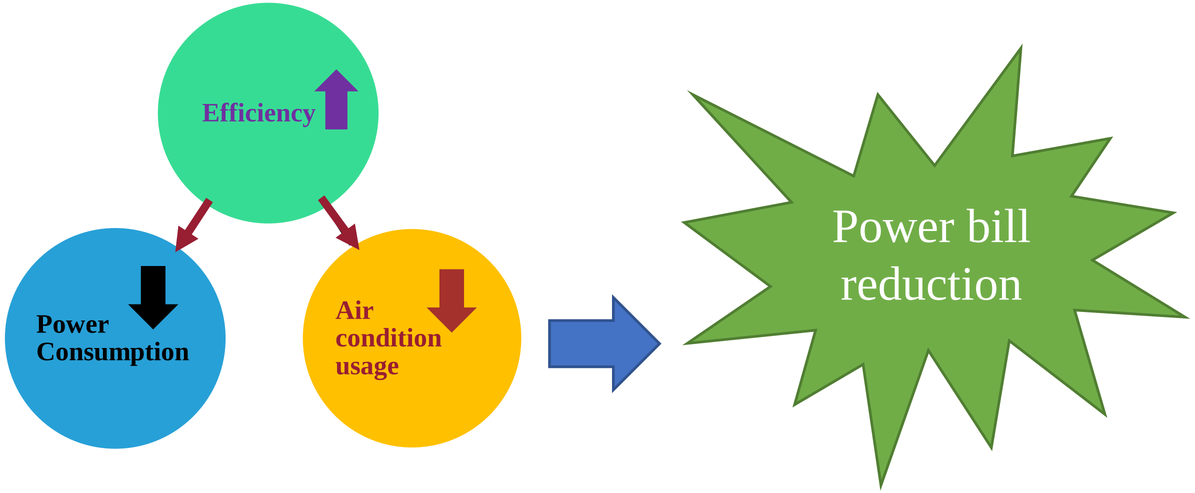
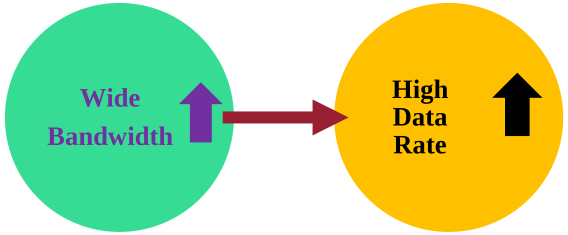
Some key specifications

Base Station Power Consumption









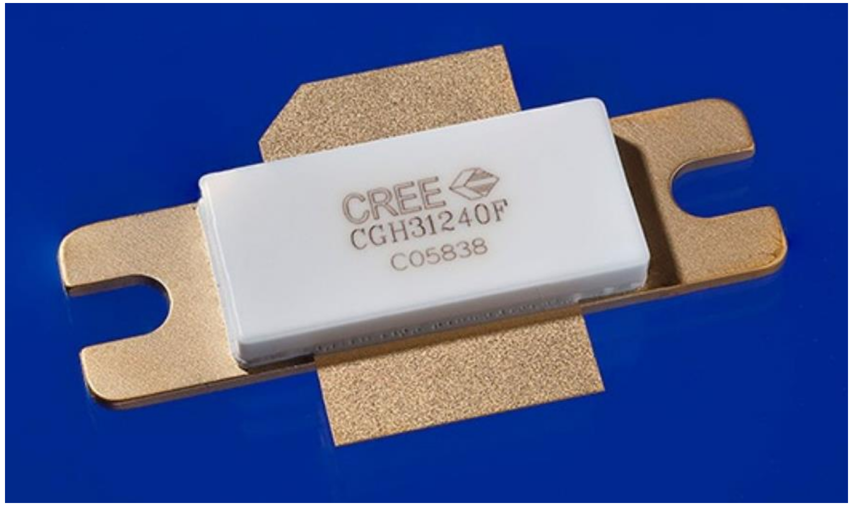
Bandwidth is also important

Solid-State PA (SSPA)

Microwave tube-based amplifiers

A TWT Amplifier (200W, CW, 18-26.5 GHz)

RF transistor-based amplifiers (SSPA)



A cell phone uses a transistor PA

Solid-State PA (SSPA)

Still a choice for very high power applications

Microwave tubes limitations

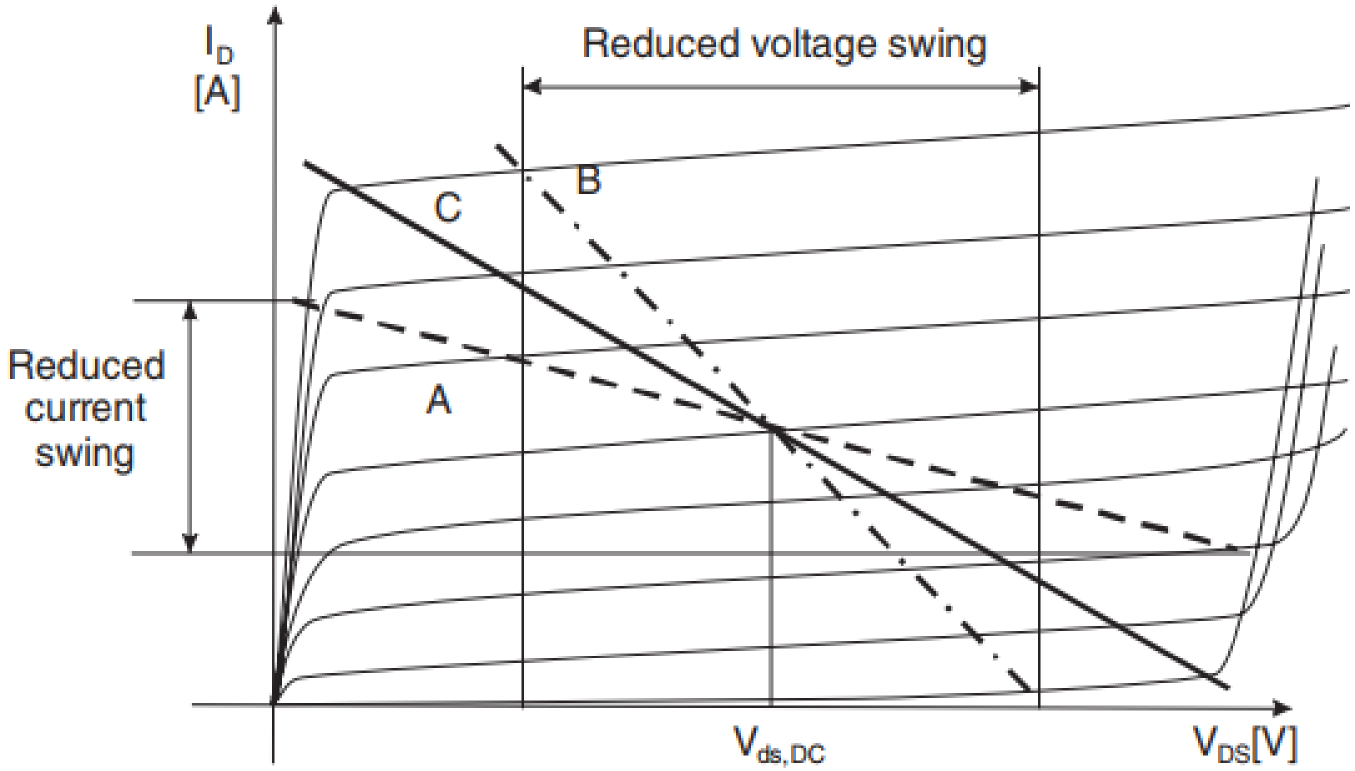
- Maintenance
- Size
- High voltage

SSPA are replacing the tubes.

SSPA advantages

- Low Maintenance
- Compact
- Greater reliability

PA power requirement



High voltage and current swings translate into high output power (P= V X I).

In RFPA, complex conjugate matching are not employed at output.

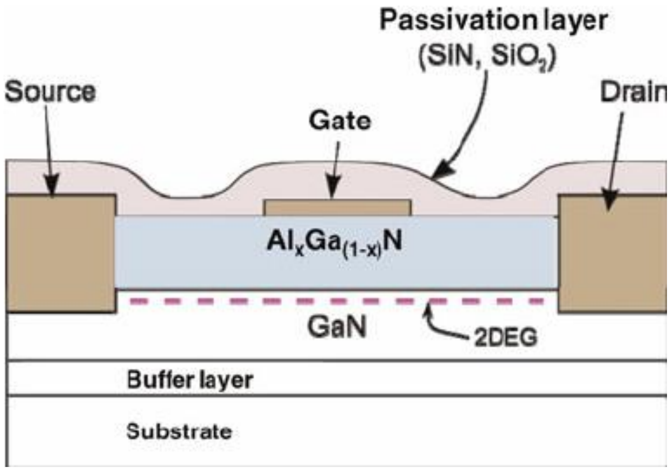
Why GaN

Advantages and disadvantages of GaN device

TABLE 1. Comparison of device material properties.

Material	Band Gap Energy eV	Breakdown E Field MV/cm	Mobility $cm^2/V/s$	Saturated Velocity cm/s	Thermal Conductance W/cm/°K
Gallium nitride	3.4	3.0	1,500	2.7×10^7	1.5
Silicon	1.1	0.3	1,300	1.0×10^7	1.5
Gallium arsenide	1.4	0.4	6,000	1.3×10^7	0.5

Low mobility partially offset by high saturation velocity



SiC substrate (GaN-on-SiC) provides excellent thermal conductivity

Advantages:

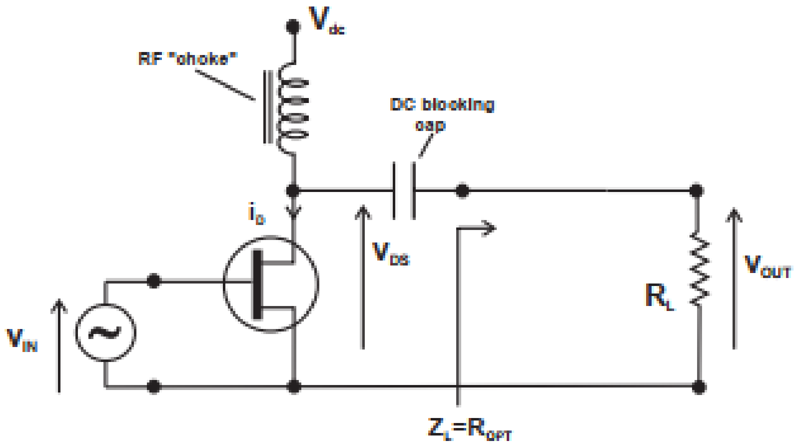
- High breakdown field enables to be used for high voltage
- High current density: high output power with smaller size
- Outstanding thermal properties with SiC substrate produces less heat
- Higher impedance level: more bandwidth and less loss
- High Efficiency: less source (battery) power required

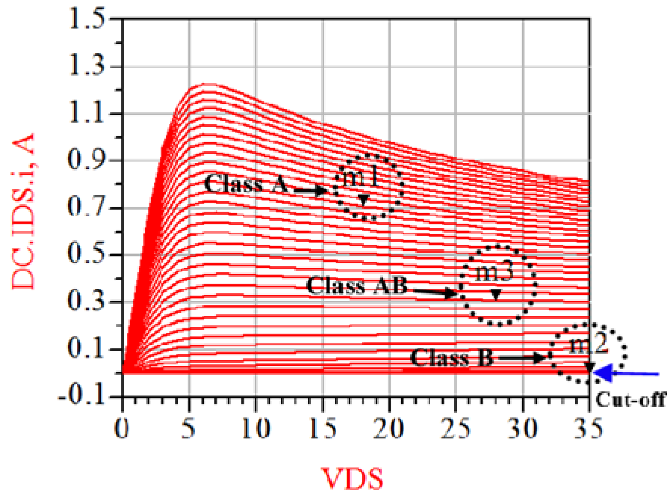
Disadvantages

- High cost
- Not good linearity compared to GaAs and Si LDMOS
- Not suitable for low power (but maybe possible in future)
- Requires harmonic control for high efficiency PA

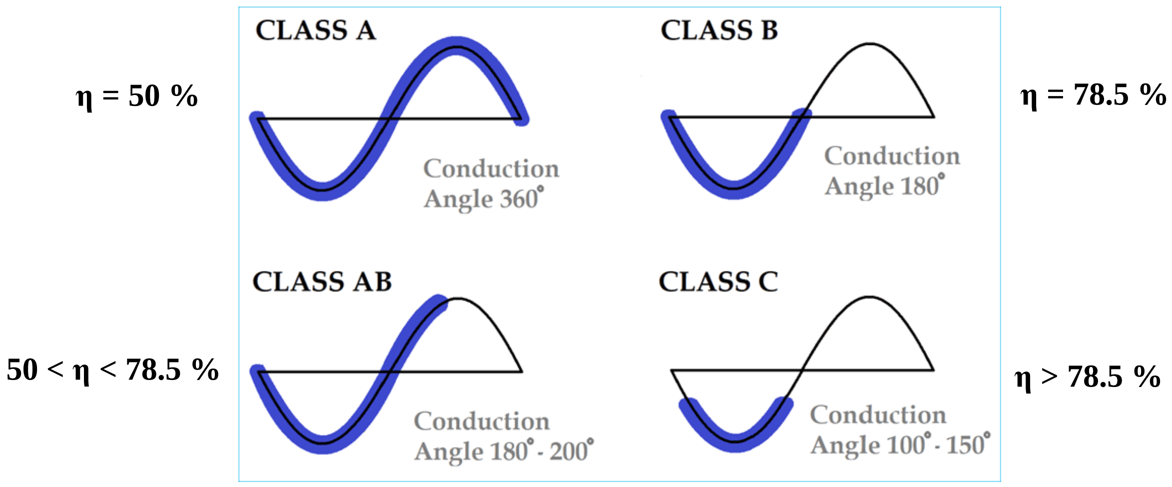
Ref: A. Katz and M. Franco, "GaN Comes of Age," in *IEEE Microwave Magazine*, vol. 11, no. 7, pp. S24-S34, Dec. 2010.

PA classifications

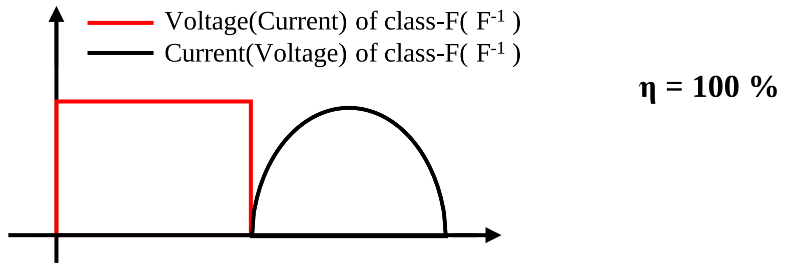




General classes



High efficiency modes, class- F and F^{-1}



Class AB is a good compromise between Class A and B with decent linearity and efficiency. Also, employed in Doherty PA.

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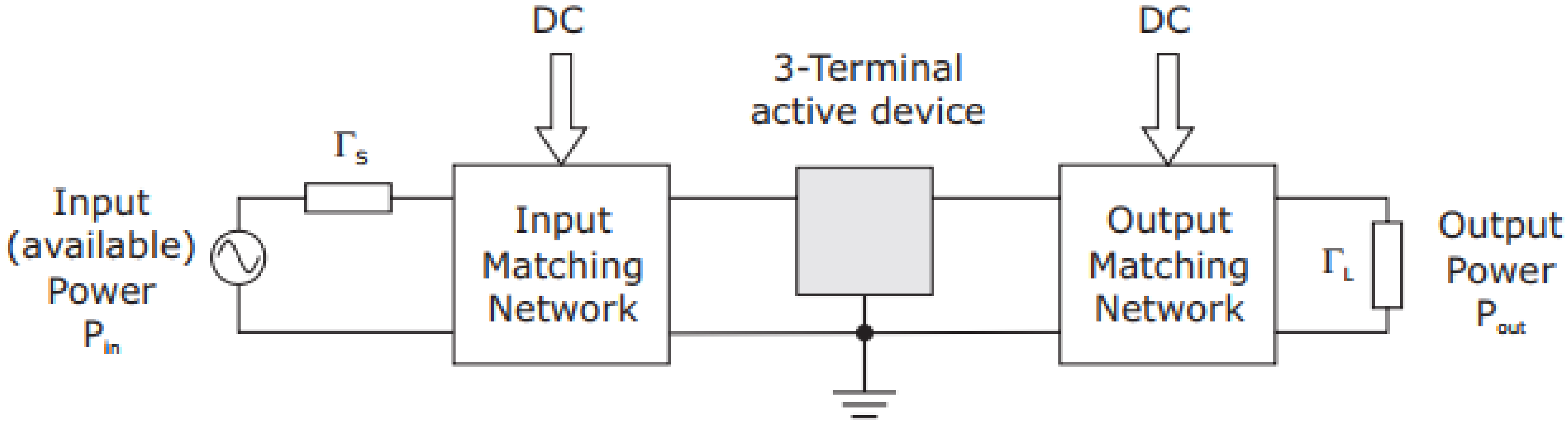
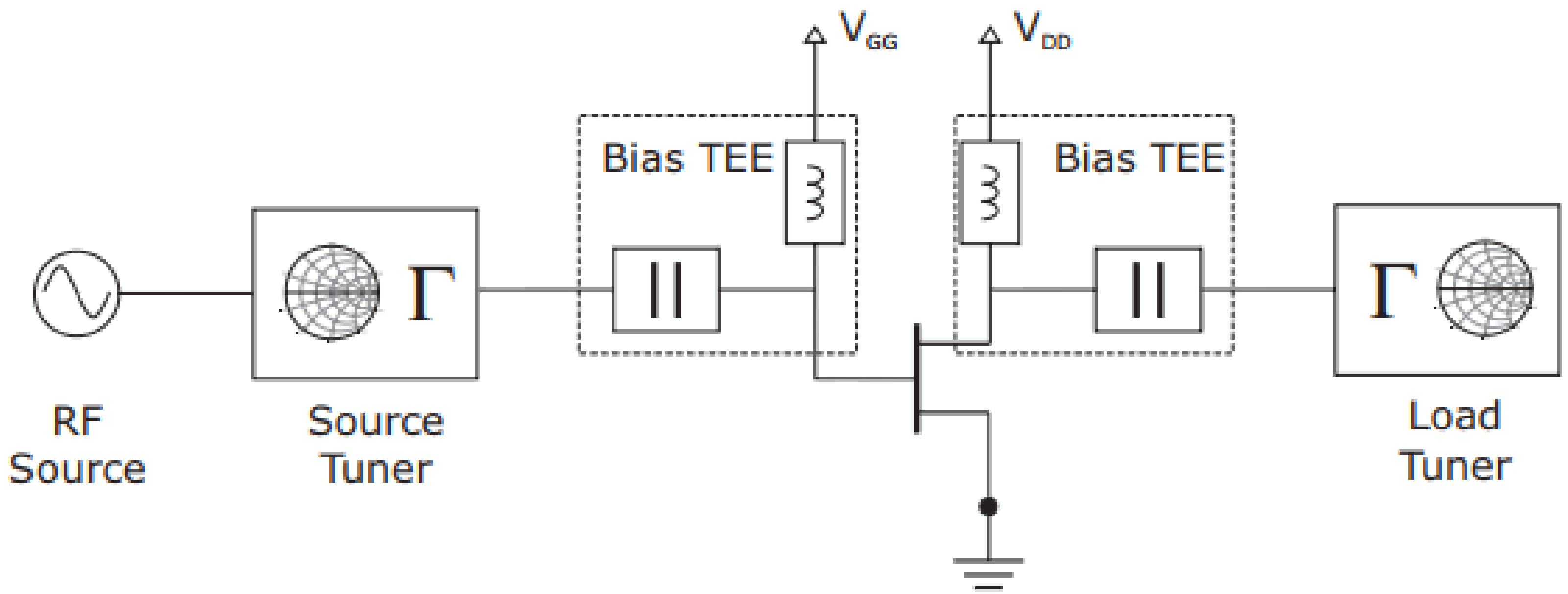
RFPA structure and design method



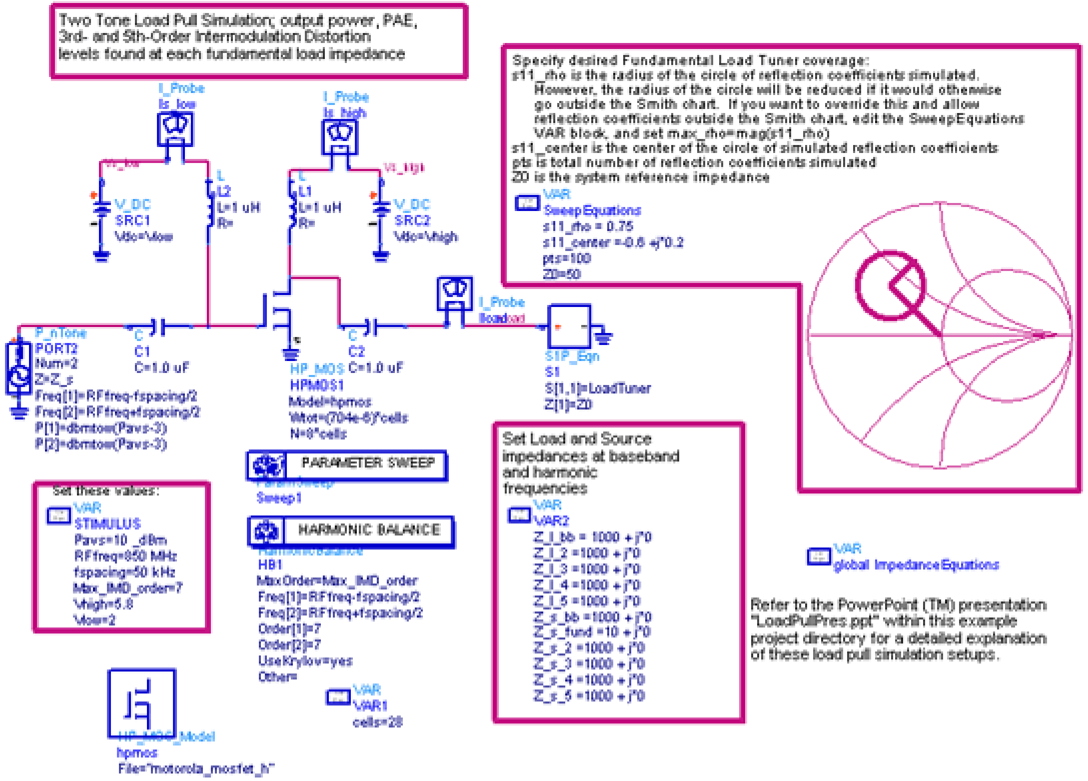
Impedance matching network design is the main task

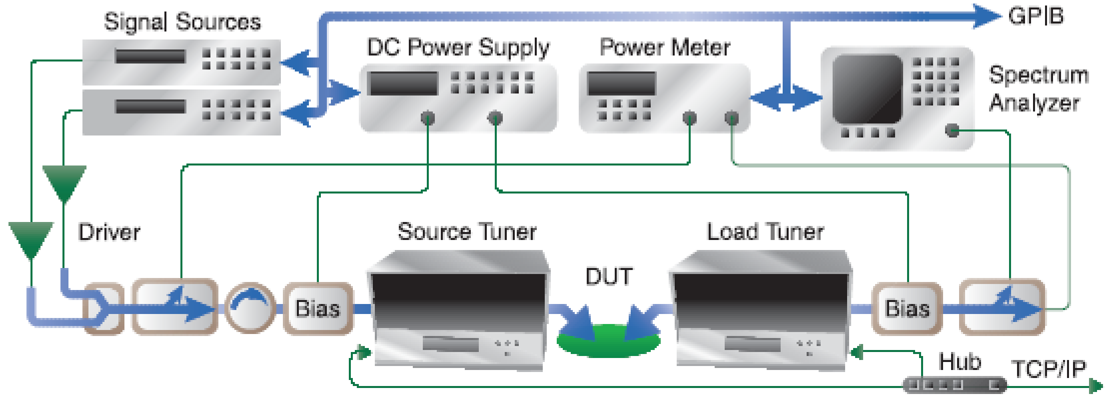
How to find the optimum load



Loadpull: Tune output load to see at what load the Pout and PAE are maximized

How to find the optimum load

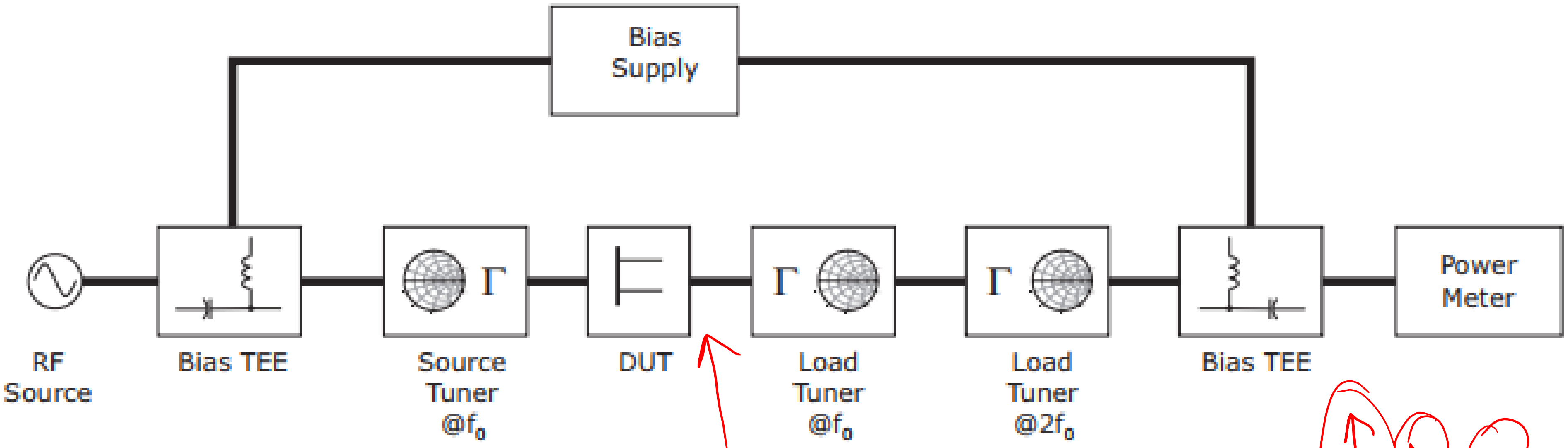


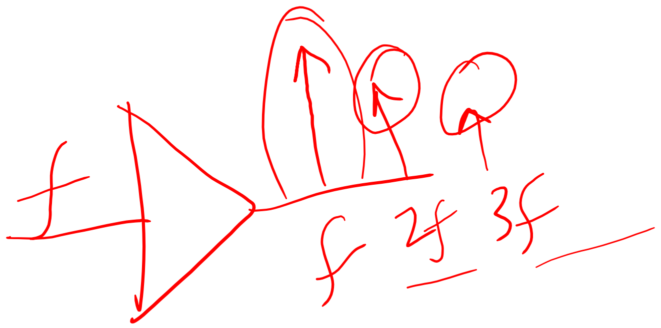


Load Pull Measurement setup

Loadpull either using a model in NI AWR/Keysight ADS
Or buy dedicated hardware (mechanical setup)

How to find the optimum load

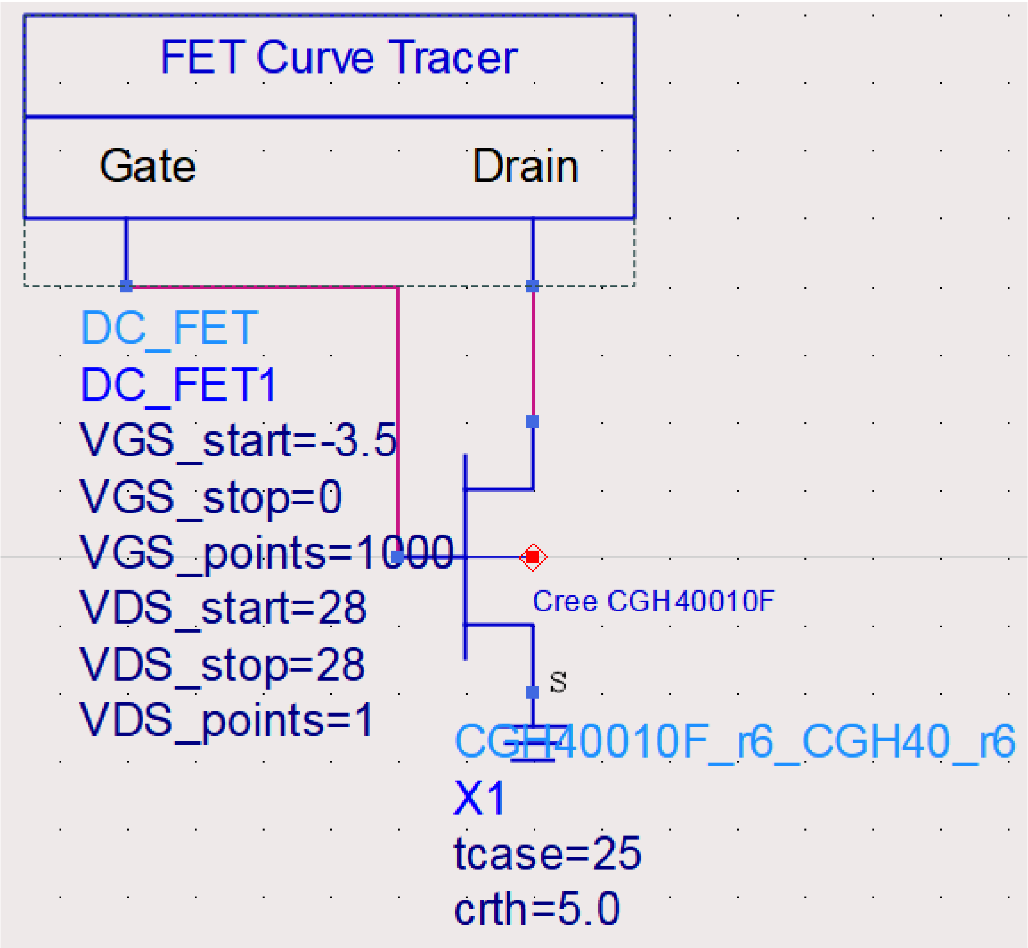


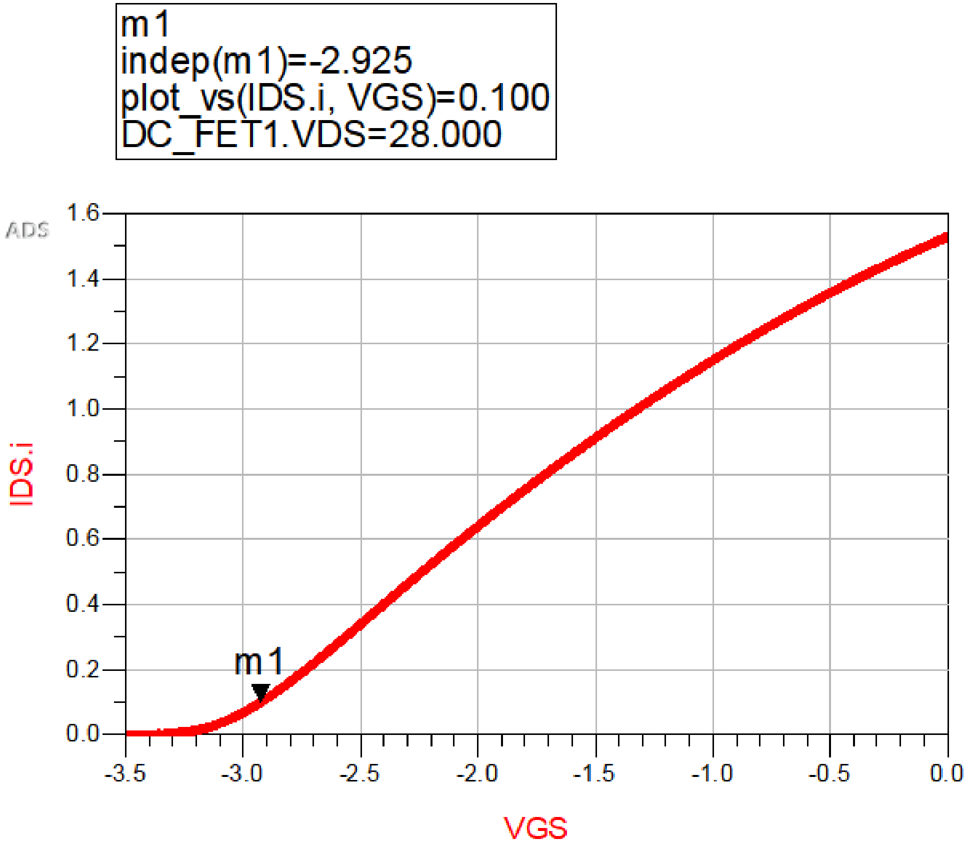


You have to do harmonic loadpull as well

RFPA Design Steps

Choose a device and perform a DC simulation to plot ID-VGS

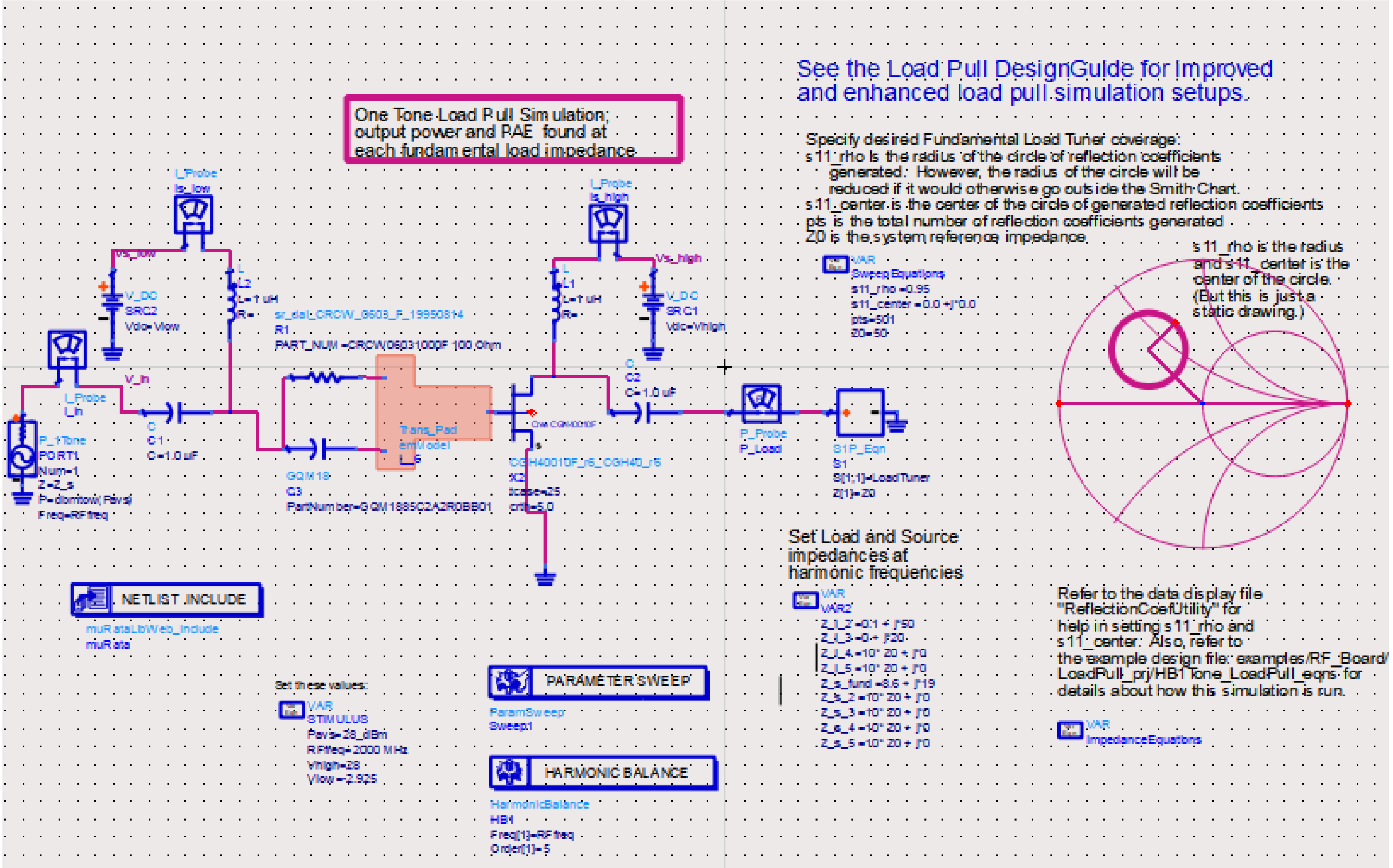




Subsequently, we stabilize the device.

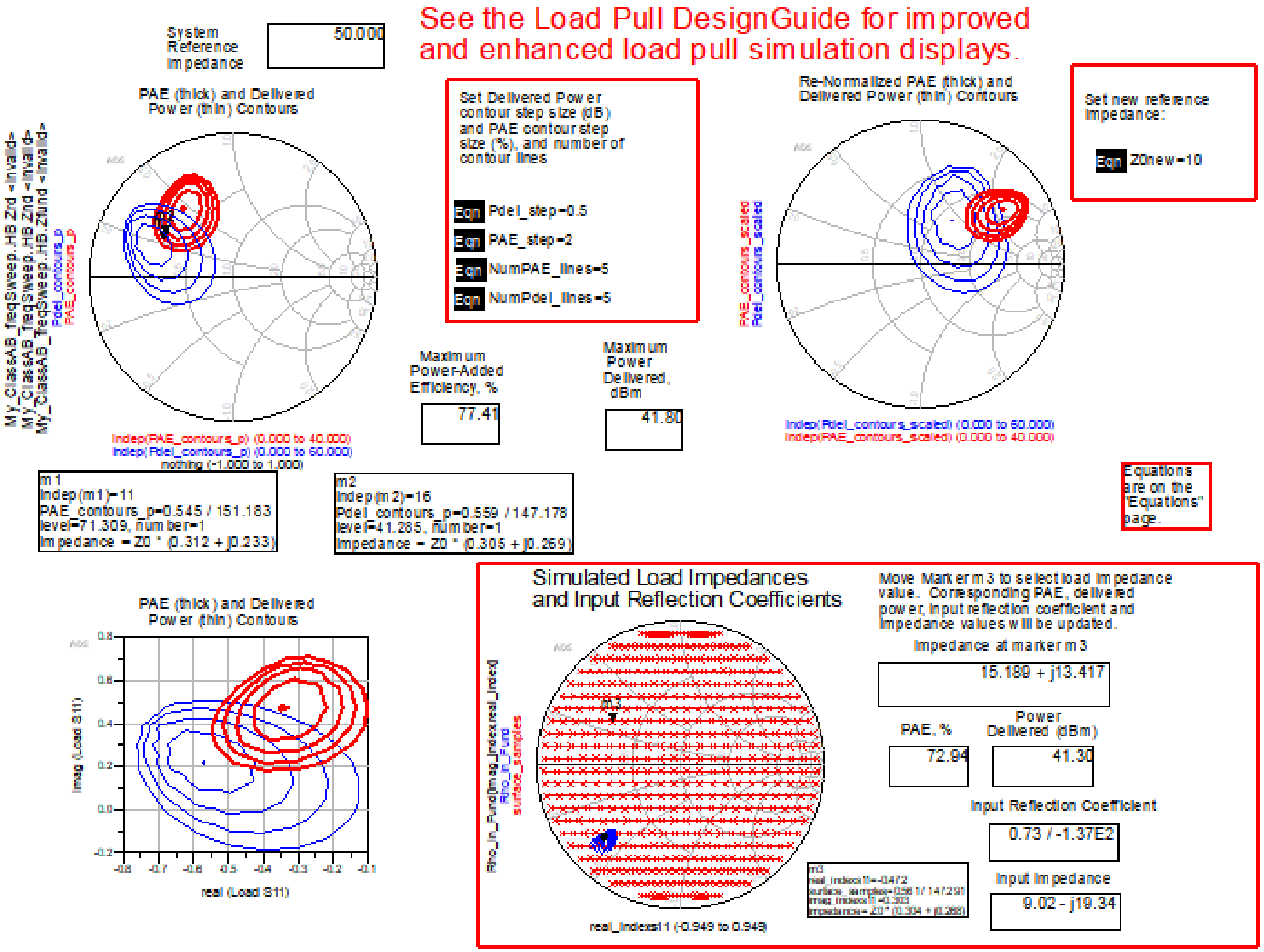
RFPA Design Steps

Perform a fundamental loadpul simulation



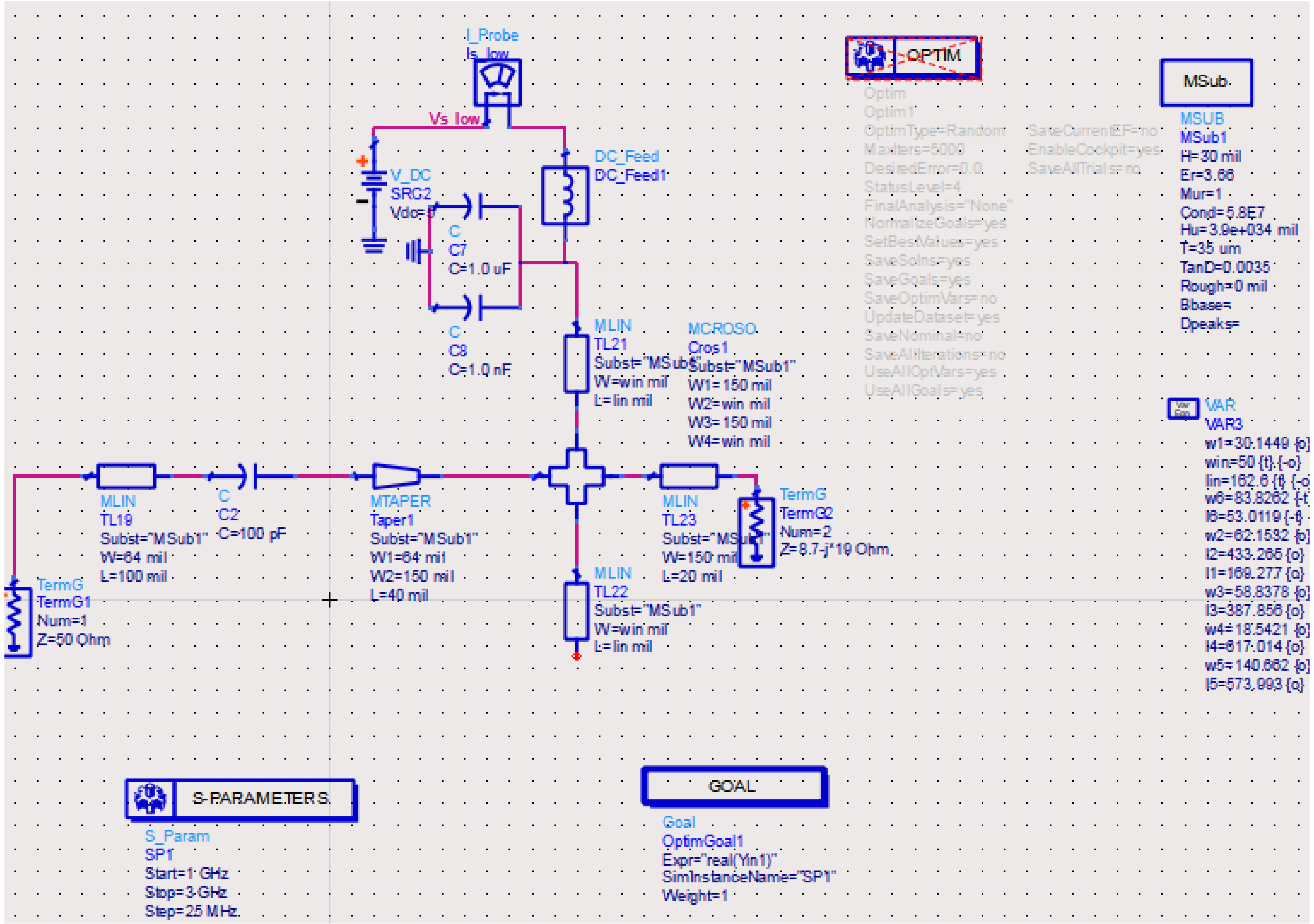
RFPA Design Steps

Choose an optimum load impedance



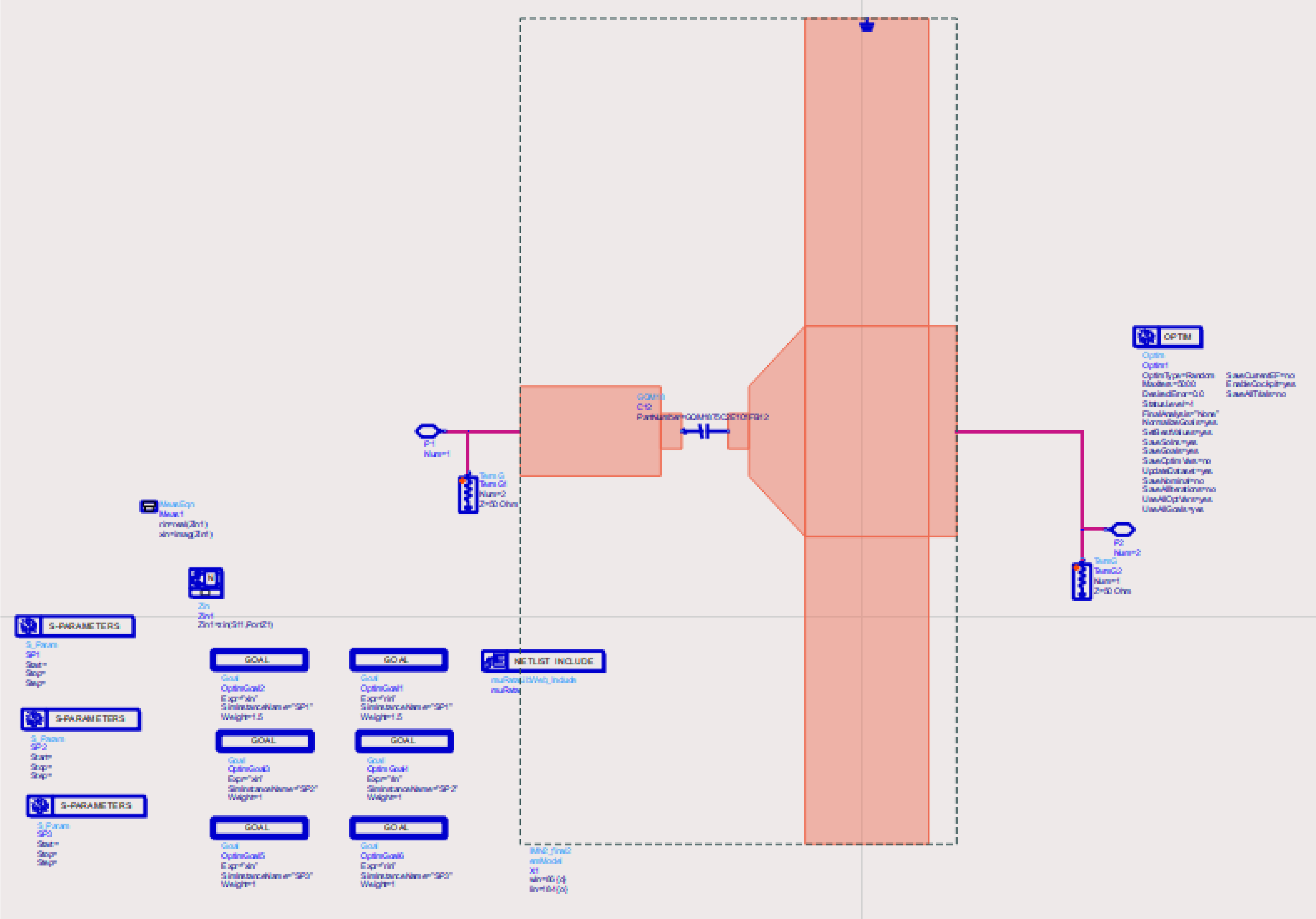
RFPA Design Steps

Design the matching networks



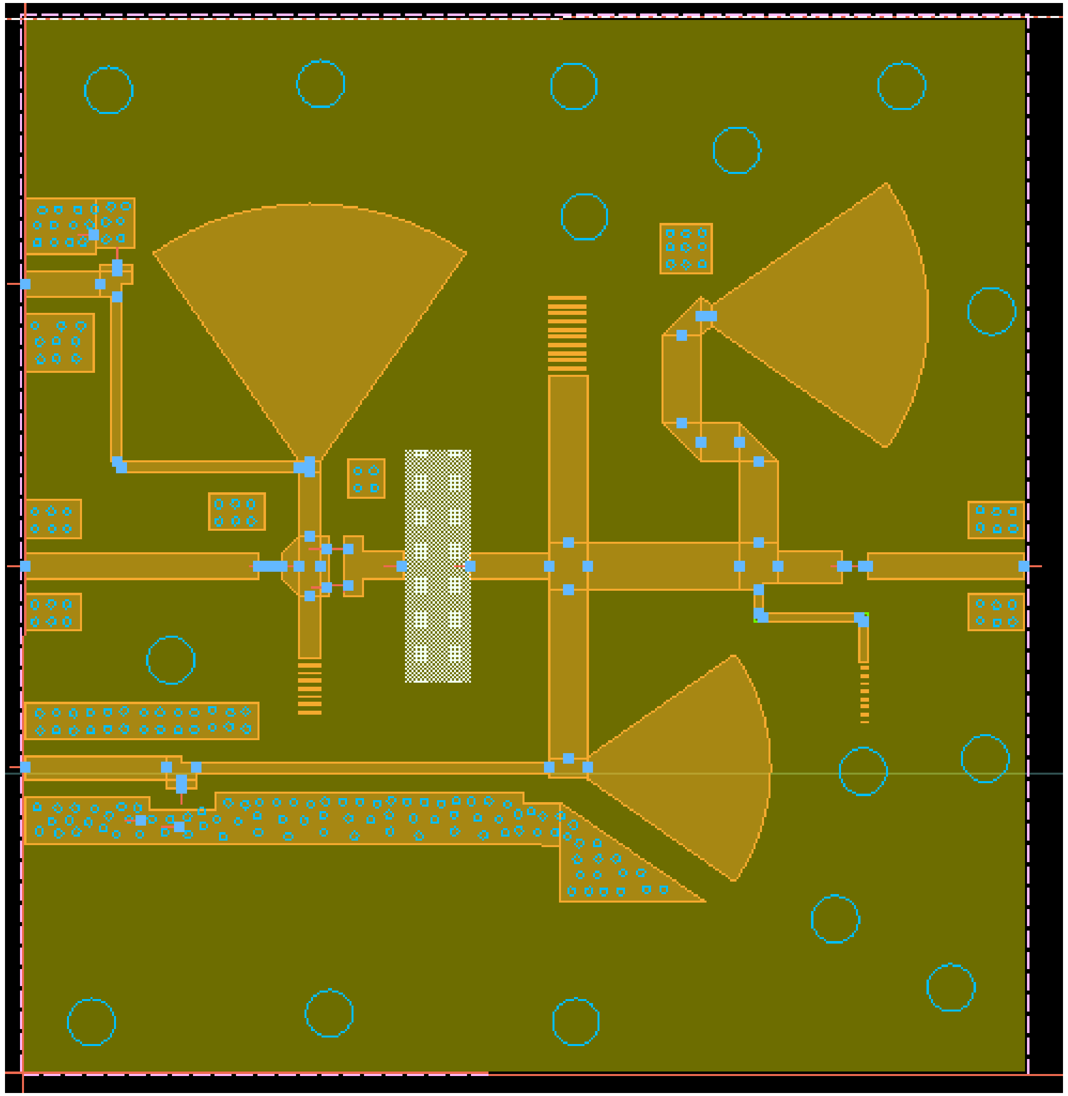
RFPA Design Steps

Perform EM simulation/optimize



RFPA Design Steps

Final optimized design



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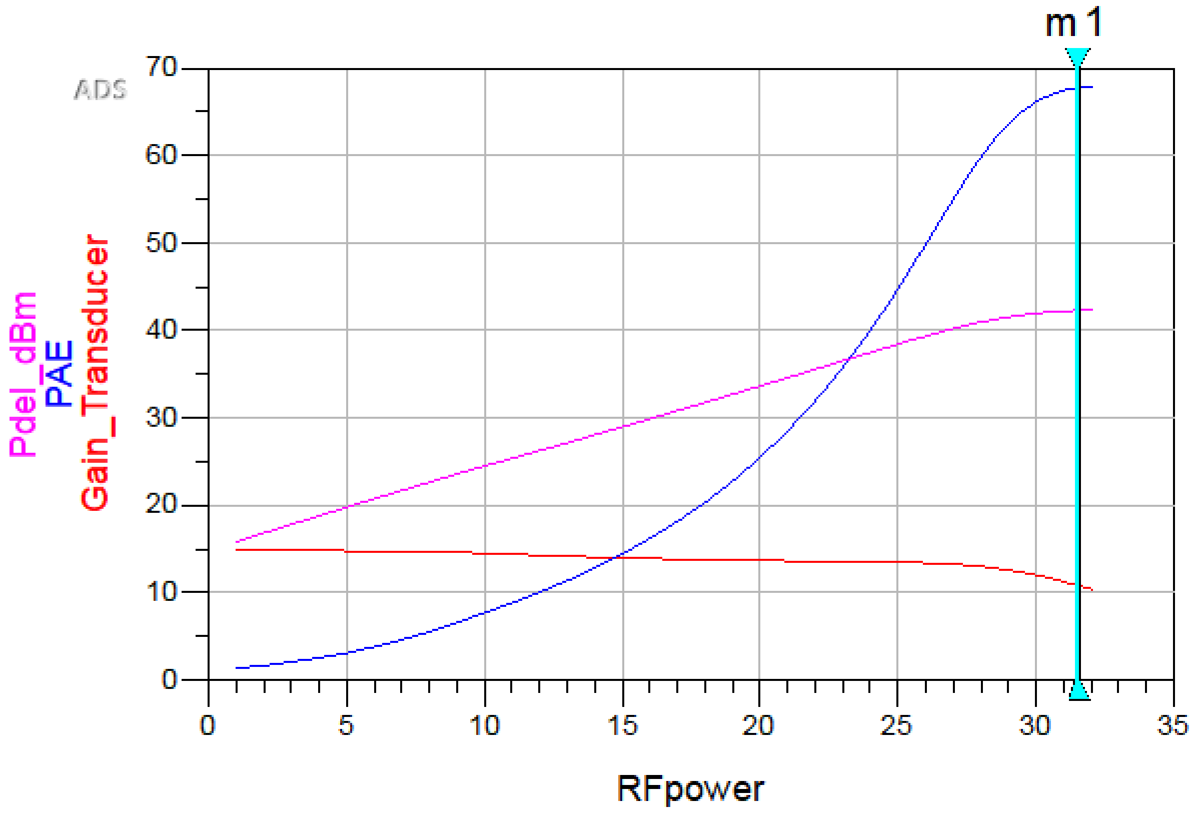
RFPA Design Steps

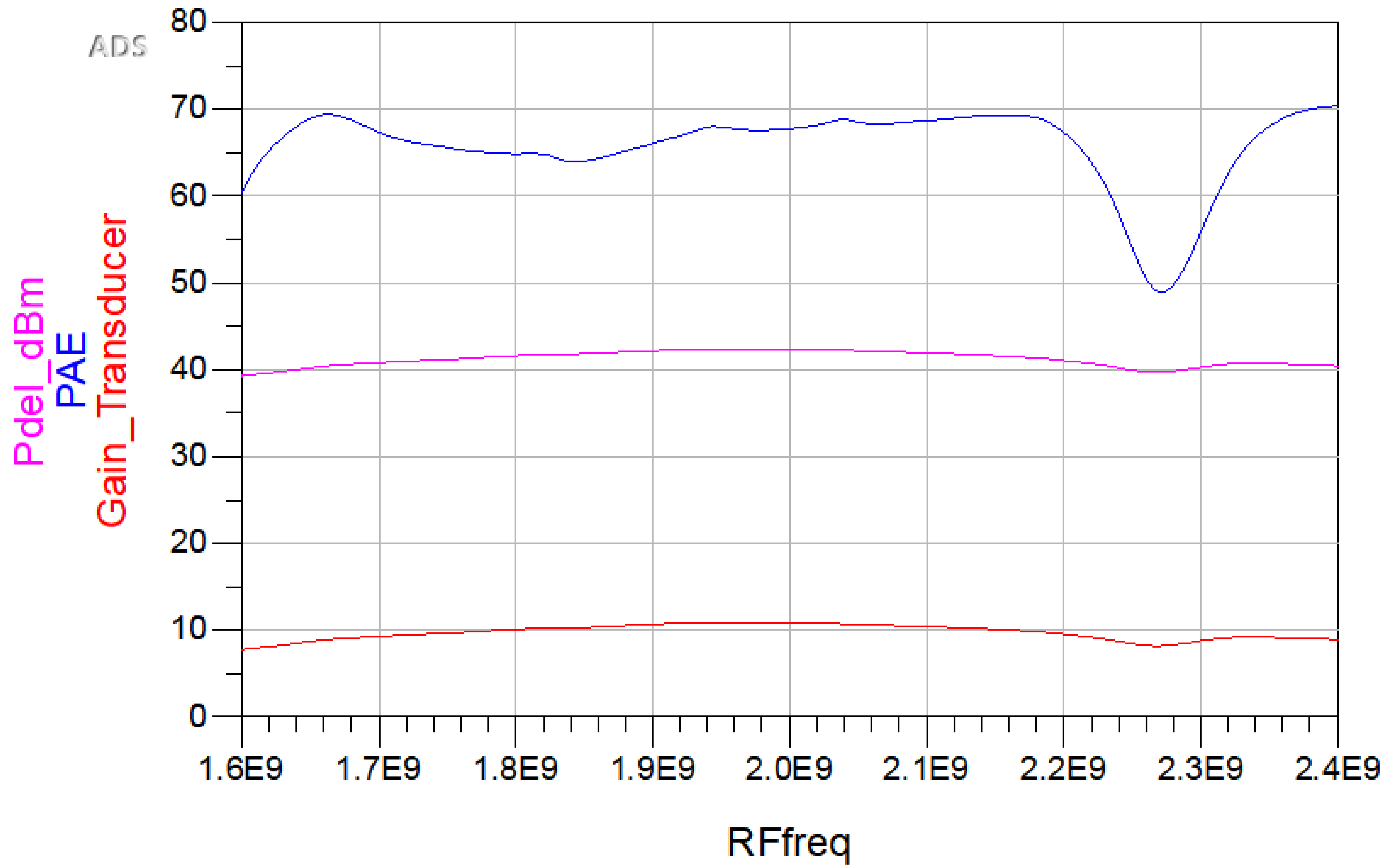
Simulated results of Final PA: Power sweep

m1
RFpower=31.500
Gain_Transducer=10.792
PAE=67.742
Pdel_dBm=42.292



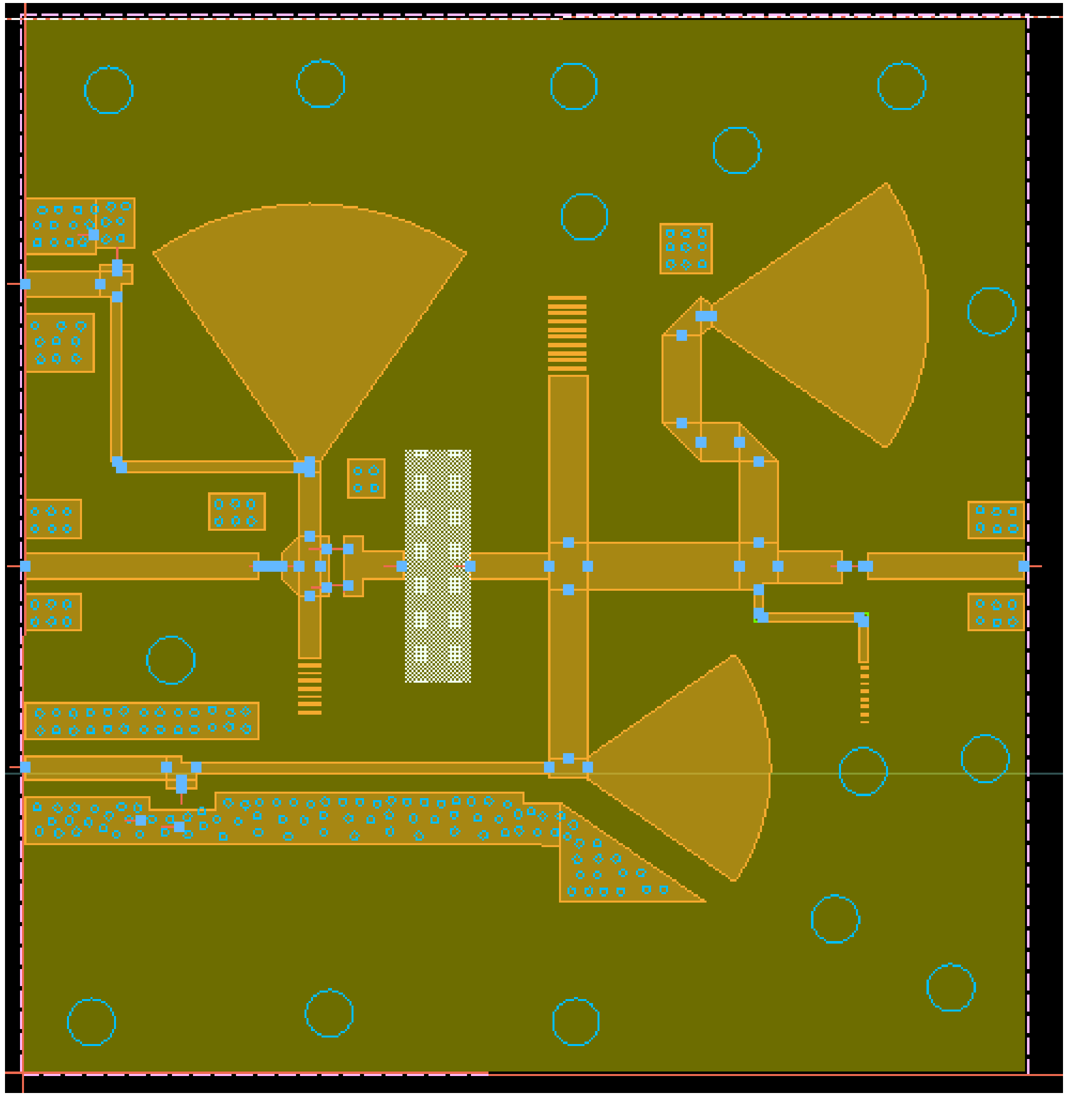
RFPA Design Steps

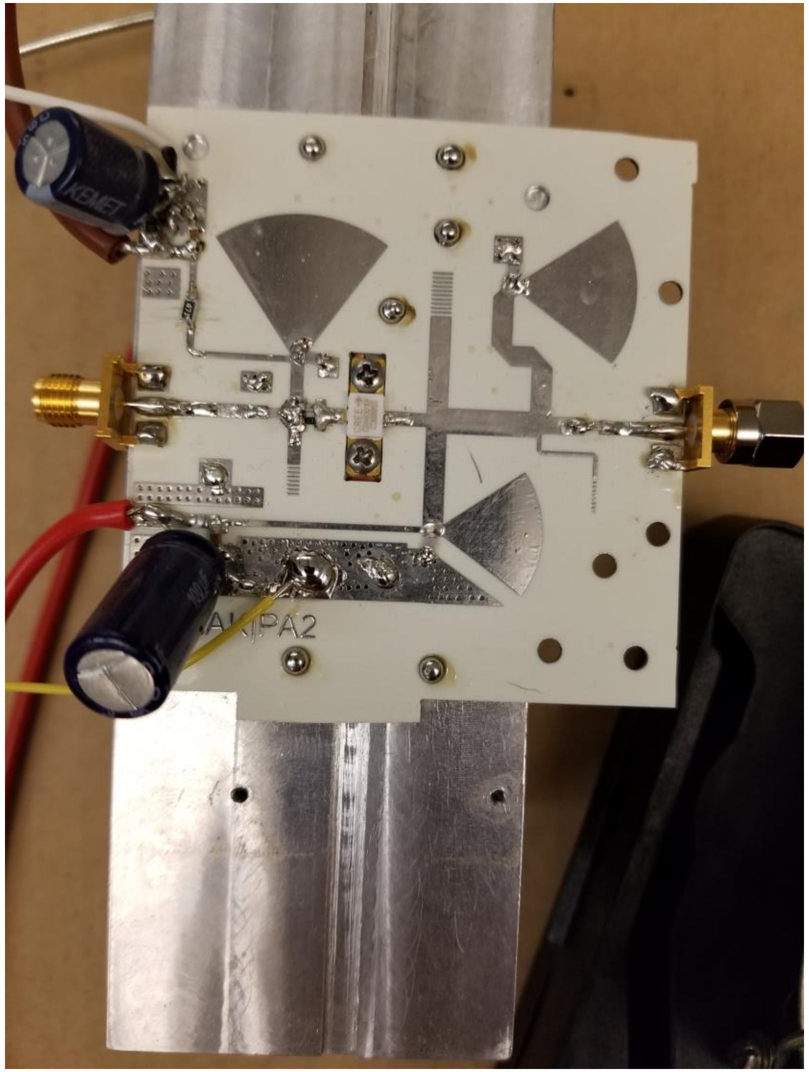
Simulated results of Final PA: Frequency Sweep



RFPA Design Steps

Final optimized design





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Conclusion

RFPA design employing a GaN device is a very current topic

RFPA design involves a great deal of time on simulation, a good device model and an EDA tool are quite helpful.

One needs to perform a number of simulations and optimization at different level.

Our RFPA design using a Wolfspeed 10W GaN device shows an excellent performance in simulation.

The measurement results of prototype will be shared once the measurements are complete.

If you have any questions or would like to collaborate with me, please feel free to drop me an email at mohammad.maktoomi@scranton.edu.

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References

(1) S. C. Cripps, RF Power Amplifiers for Wireless Communications. Norwood, MA, USA: Artech House, 2006

(2) P. Colantonio, F. Giannini and E. Limiti, High Efficiency RF and Microwave Solid State Power Amplifiers, New York:Wiley, 2009

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