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)

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.
Some key specifications

Base Station Power Consumption

- RF Power Amplifier and Feeder (60%-80%)
- Power Supply (5%-10%)
- Signal Processing (5%-15%)
- Cooling, Air condition (10%-25%)

Power bill reduction

Bandwidth is also important
Solid-State PA (SSPA)

**Microwave tube-based amplifiers**

**RF transistor-based amplifiers (SSPA)**

A cell phone uses a transistor PA

A TWT Amplifier (200W, CW, 18-26.5 GHz)
Solid-State PA (SSPA)

- Microwave tubes limitations
  - Maintenance
  - Size
  - High voltage

- Still a choice for very high power applications

SSPA are replacing the tubes.

SSPA advantages

- Low Maintenance
- Compact
- Greater reliability
High voltage and current swings translate into high output power \((P= V \times I)\).

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

Advantages and disadvantages of GaN device

**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

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

- 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 load pull simulation.
RFPA Design Steps

Choose an optimum load impedance

See the Load Pull Design Guide for improved and enhanced load pull simulation displays.
RFPA Design Steps

Design the matching networks
RFPA Design Steps

Perform EM simulation/optimize
RFPA Design Steps

Final optimized design
RFPA Design Steps

Simulated results of Final PA: Power sweep

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