GaN Systems

AirFuel™

POWER AMPLIFIER AND COIL DESIGN OPTIMIZATION FOR LARGE AIR GAP APPLICATIONS

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AIRFUEL ALLIANCE DEVELOPERS FORUM
MARCH 12-13, 2019 SHENZHEN CHINA

OUTLINE

- WPT and WPT Applications
  - WPT Trends and Technology Drivers
  - Wireless Power System
- High efficiency PA for WPT with Gan Systems devices
  - PA topologies
  - Constant Current Power Amplifier
  - 50W/100W/300W/1000W Class EF2 PA design
- 50W WPT system with 200mm Gap
  - Coil design for large gap
    - Topology/Requirement/Performance
  - Coil coupling distance
  - 50W 200mm system test

Everything.
Applications for Cutting the Cord

- Laptops
- Phones
- Power Tools
- eBikes
- Scooters
- Drones
- Robots (AGV)
- IP Camera
- Home appliances

WPT TRENDS & TECHNOLOGY DRIVERS

30W

65W

180W

1000 to 2500W

6000 to 22000W

Trends

- Fast charge, spatial freedom, variable Tx/Rx spacing, increasing power

Technology Drivers

- High switching frequency, high current, high voltage

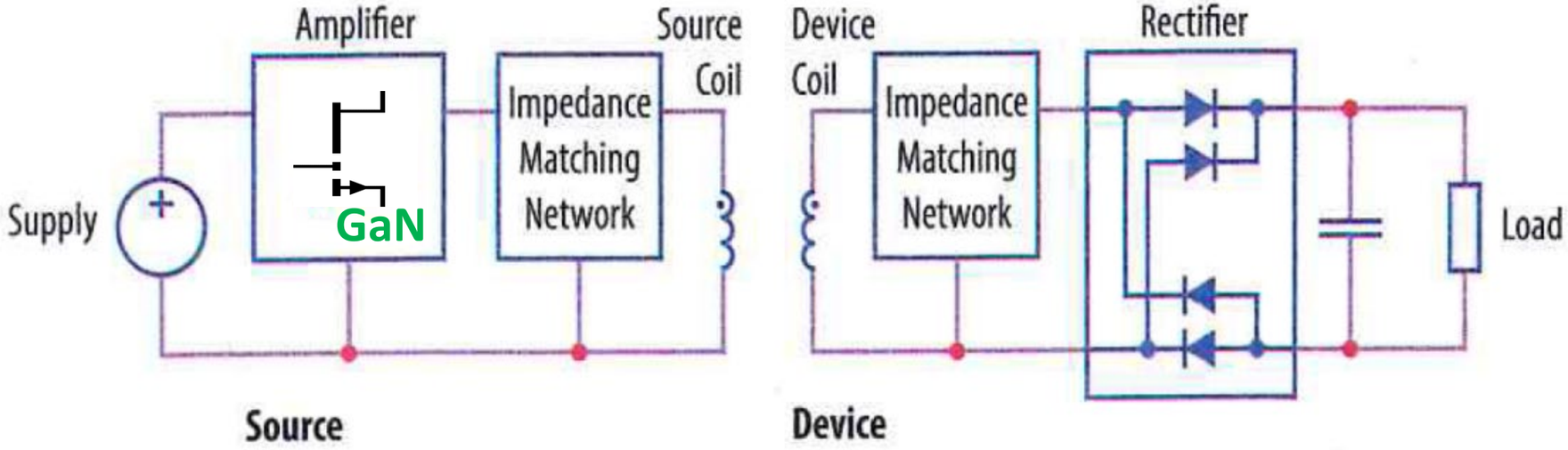
WIRELESS POWER SYSTEM

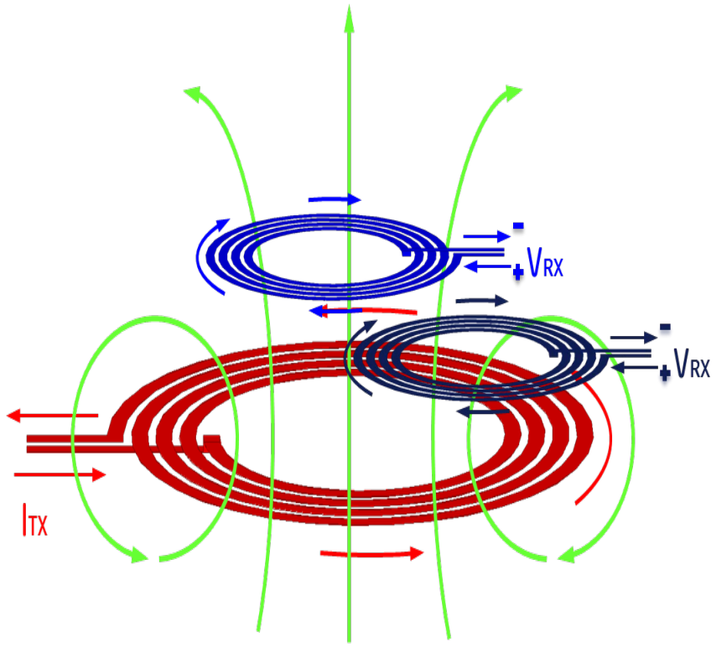
Source - Transmitter (Tx)

1. Amplifier
2. Impedance Matching Network
3. Tx Coil

Device - Receiver (Rx)

1. Rx Coil
2. Impedance Matching Network
3. Rectifier





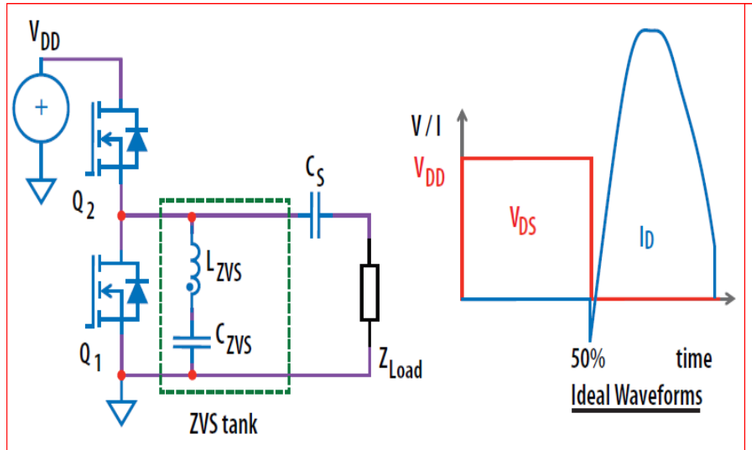
GaN FETs are used in the Transmitter Amplifier

Class D/E/EF2 topologies

Class D with ZVS

$$P = \frac{8}{\pi^2}\frac{V_R^2}{R_L} = \frac{8}{\pi^2}\frac{R_L}{(R_L + r_{sat})^2}V_{cc}^2.$$

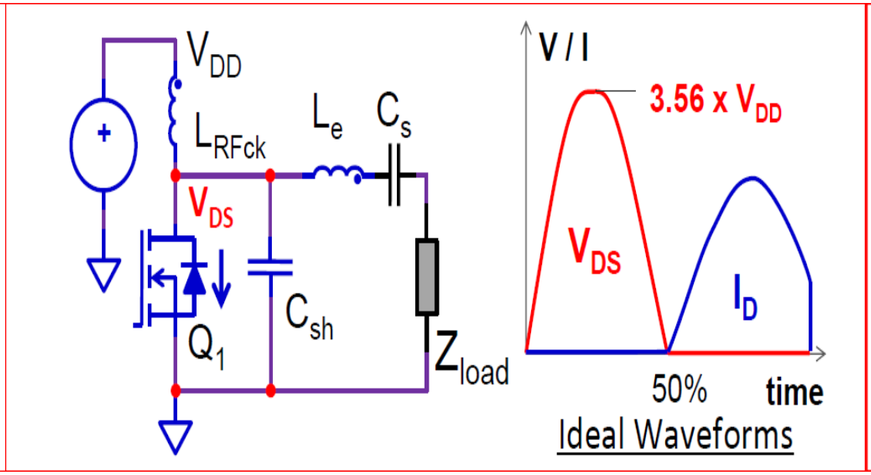
$$\eta = \frac{P}{P_0} = \frac{8}{\pi^2} \cong 81\%.$$



Class E with shunt C

$$R = \frac{8}{\pi^2 + 4}\frac{V_{cc}^2}{P_{out}} = 0.5768\frac{V_{cc}^2}{P_{out}}.$$

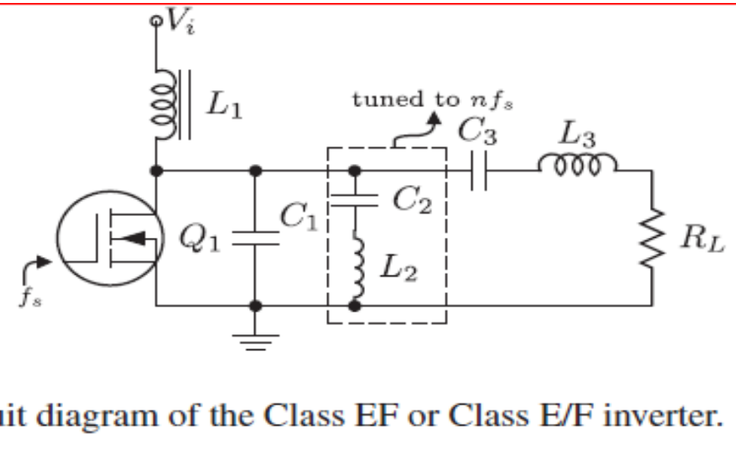
$$\eta = \frac{P_{out}}{P_0} = \frac{P_0 - P_{sat}}{P_0} = 1 - \frac{P_{sat}}{P_0}.$$



Class EF2

$$P_o = 0.6105\frac{V_{IN}^2}{R_L}.$$

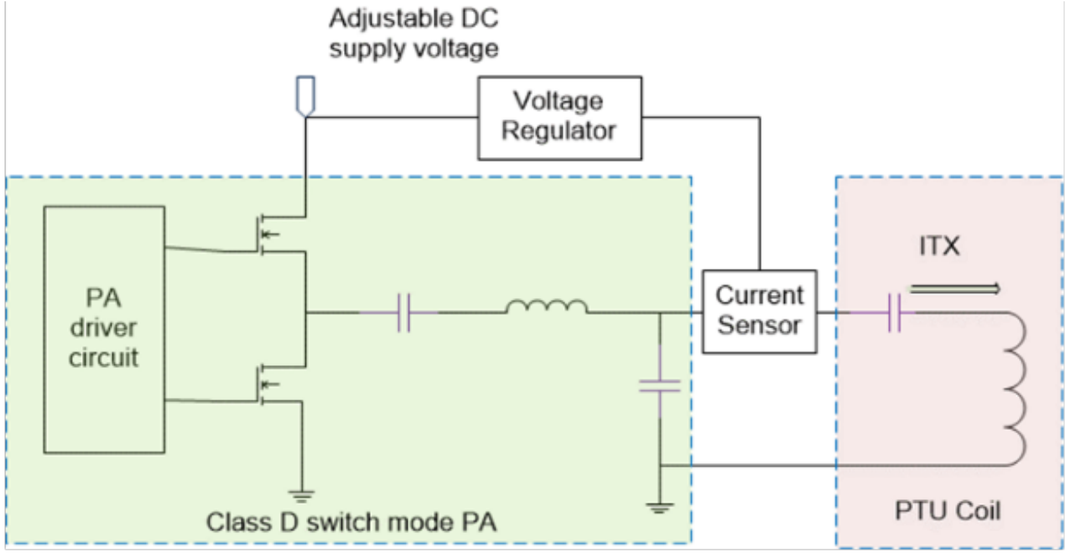
$$\eta = \frac{1}{1 + P_{L_1} + P_{DS} + P_{C_1} + P_{L_2C_2} + P_{L_3C_3} + P_{t_f}}.$$



Circuit diagram of the Class EF or Class E/F inverter.

CONSTANT CURRENT POWER AMPLIFIER

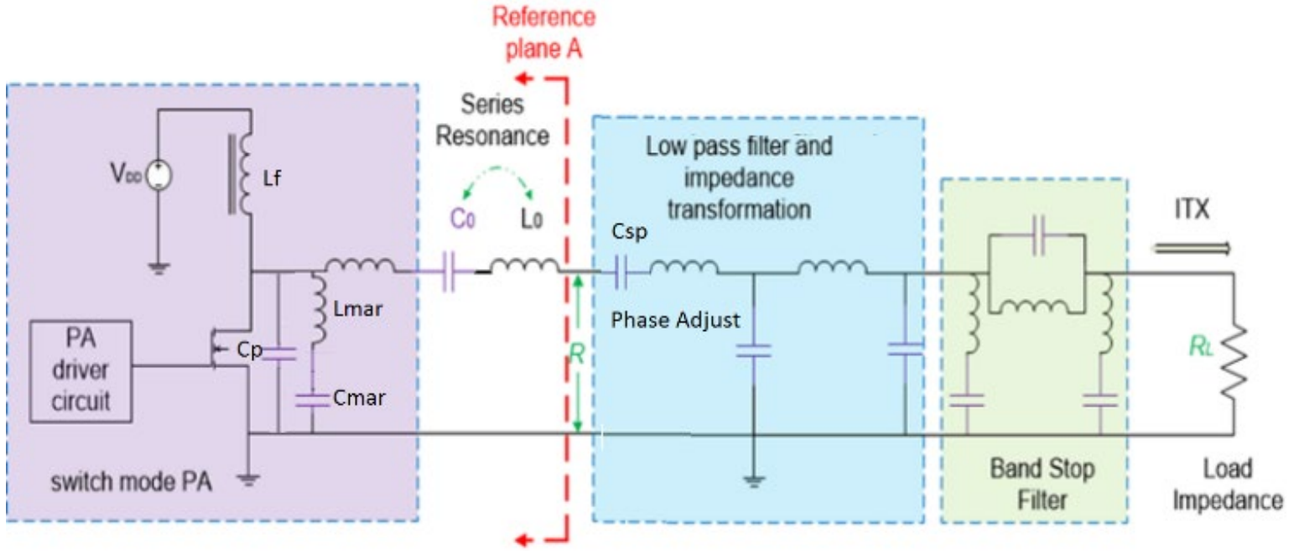
“SW engineer’s solution”



Constant Current through Feed back Control

Slow response time, poor transient handling

“RF engineer’s solution”

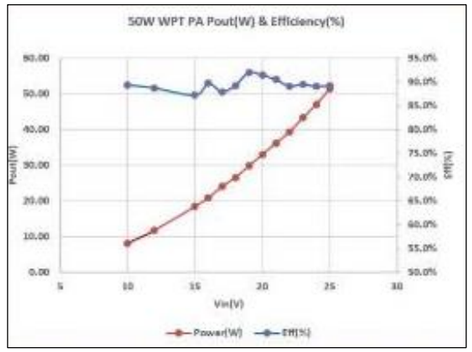


Unique output filter network designed to <u>naturally</u> provide constant current w/o SW feedback

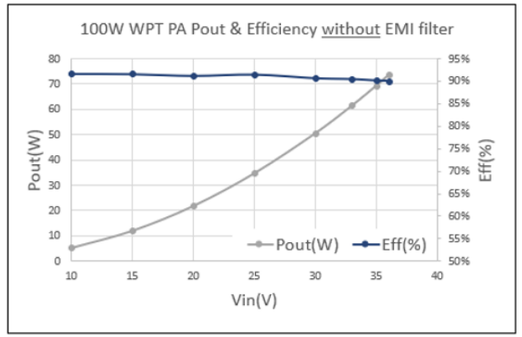
“Constant Current” design methodology developed to simultaneously achieve power, efficiency, EMI and constant current behavior.

CLASS EF2 PA PERFORMANCE

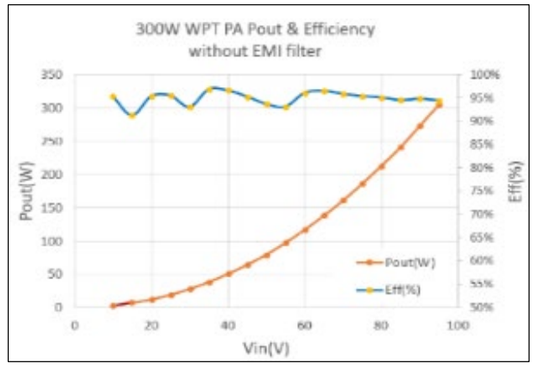
50 Watt



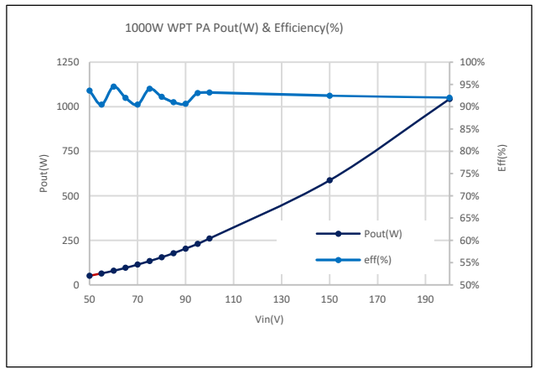
100 Watt



300 Watt



1000 Watt

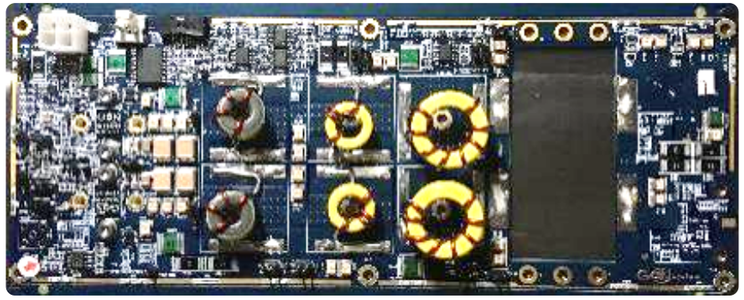


50W PA w/GS61004B

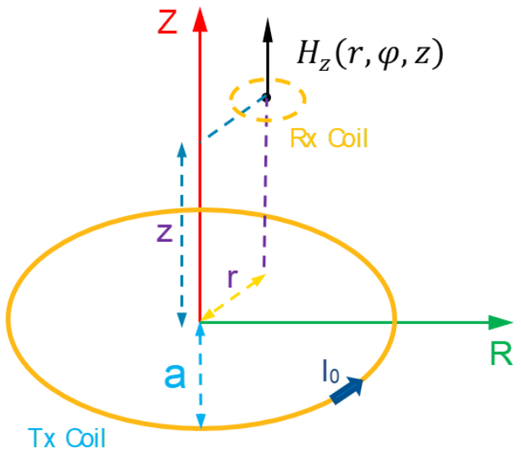
100W PA w/GS61008B

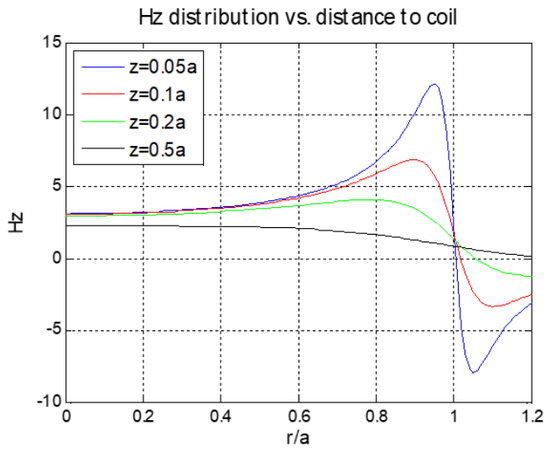
300W PA w/GS66508B

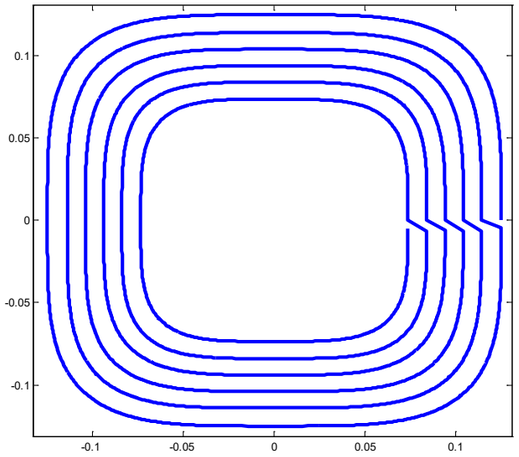
1000W PA w/GS66508B

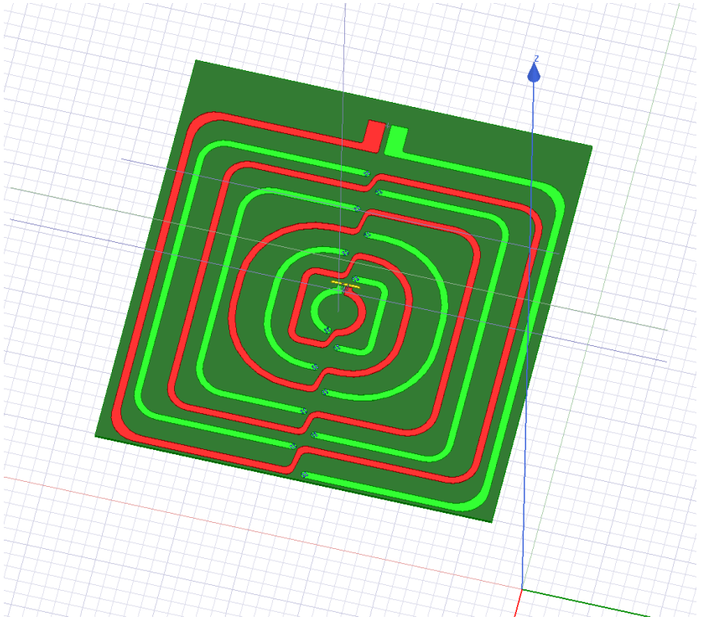


COIL DESIGN FOR LARGE GAP - TOPOLOGY



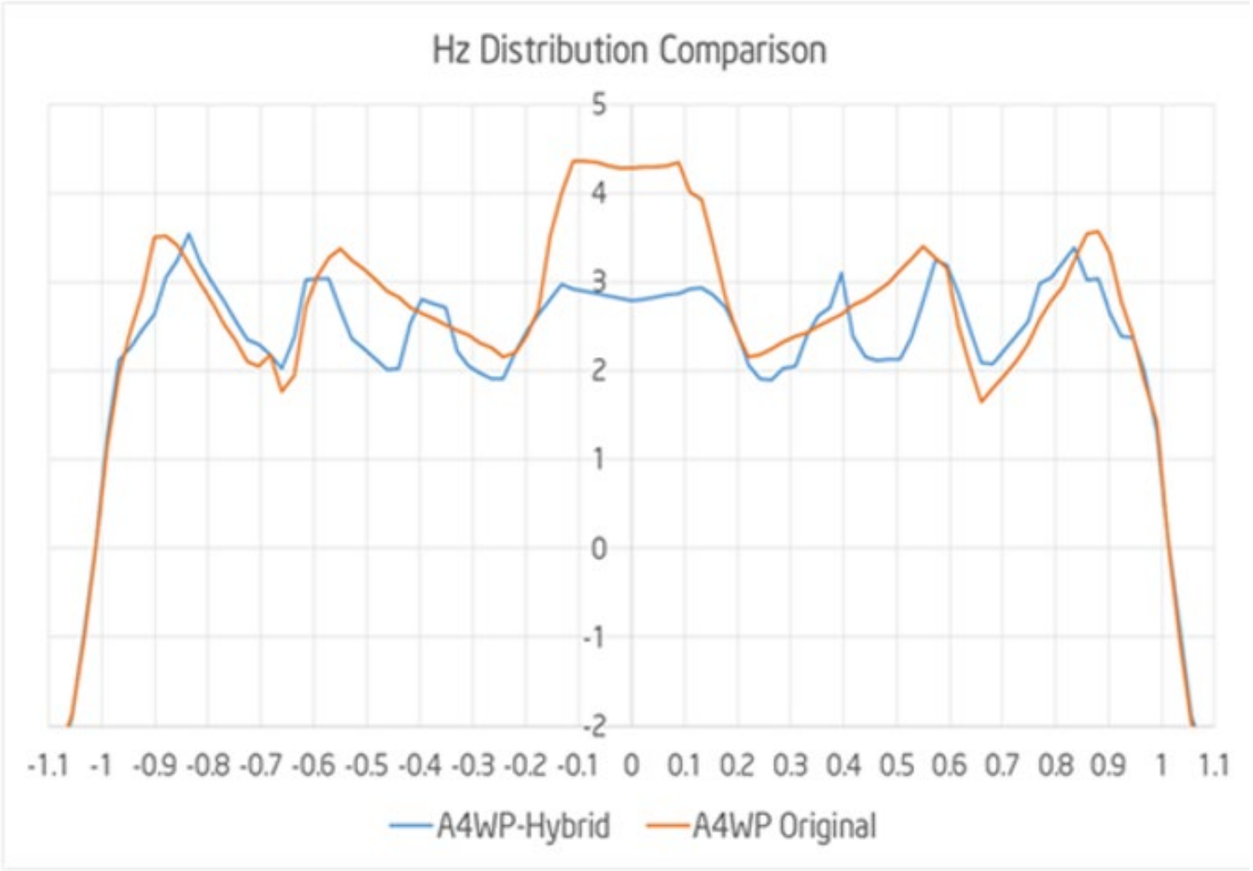




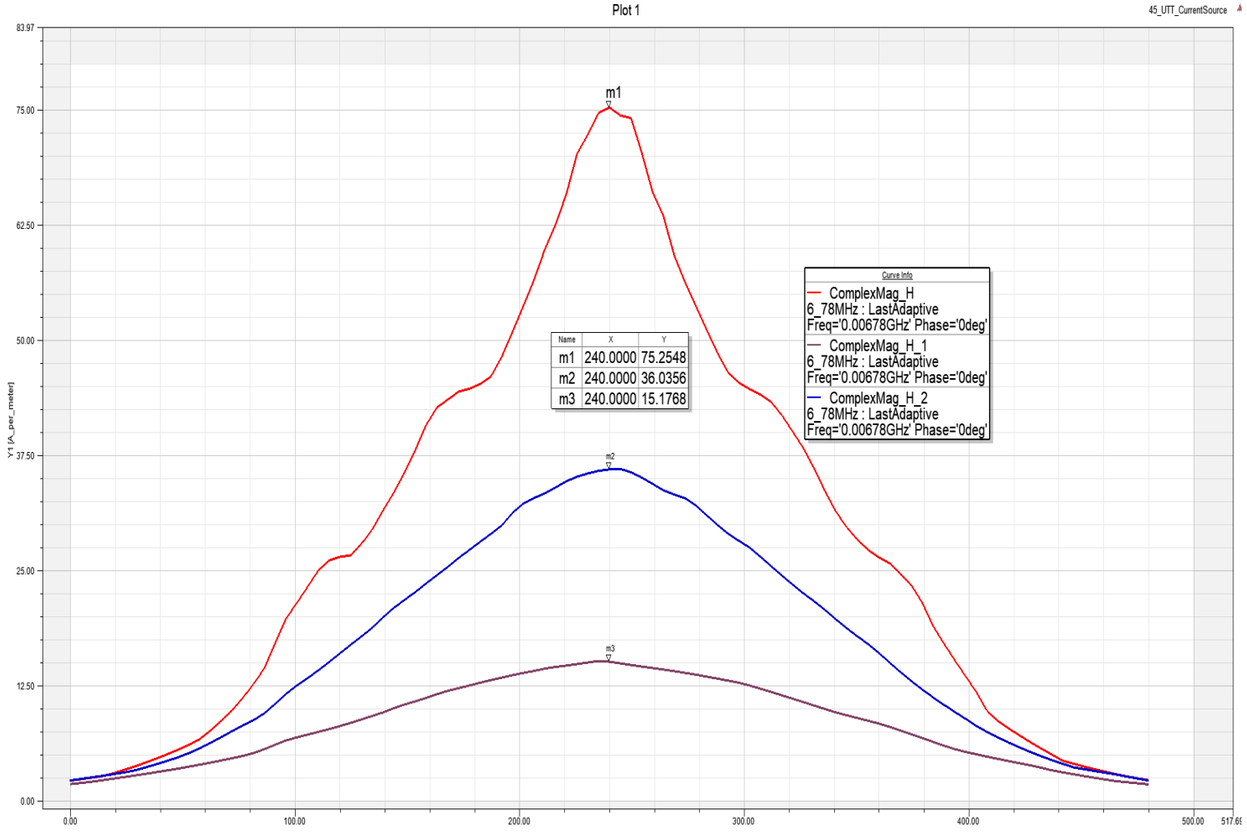


- Optimized uniform magnetic field distribution in the target area for small gap design
- Optimized high mutual coupling magnetic filed distribution in the target area for large gap design

COIL DESIGN FOR LARGE GAP – PERFORMANCE



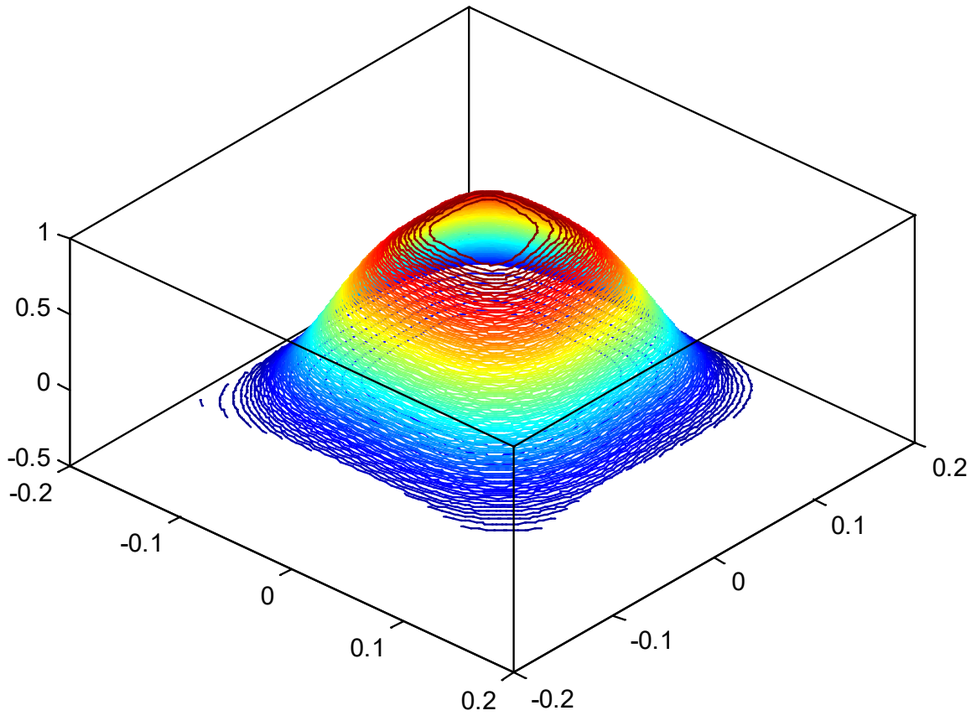
Uniform magnetic field distribution simulation in the target area for small, 25mm gap, design



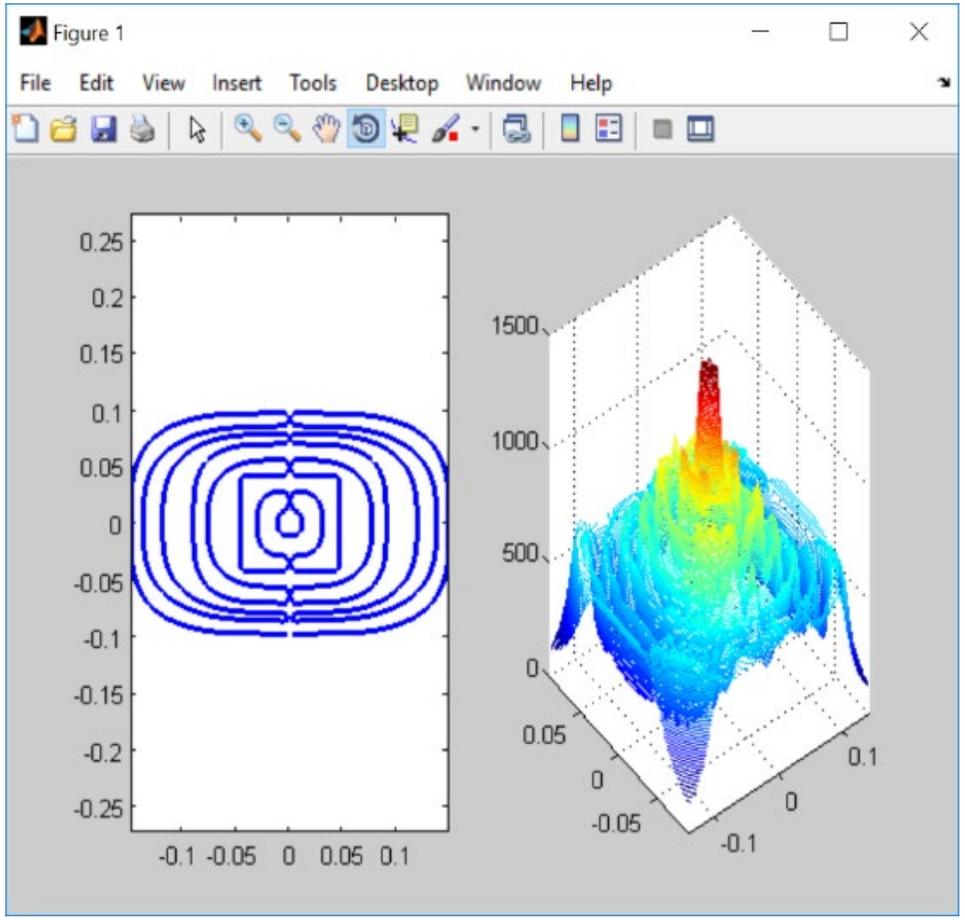
High mutual coupling magnetic filed distribution simulation in the target area for large gap design at 50, 100, 150mm height position

COIL DESIGN FOR LARGE GAP – PERFORMANCE

Synthesize coil design with software for arbitrary size/shape for large gap coils



Small gap coil distribution



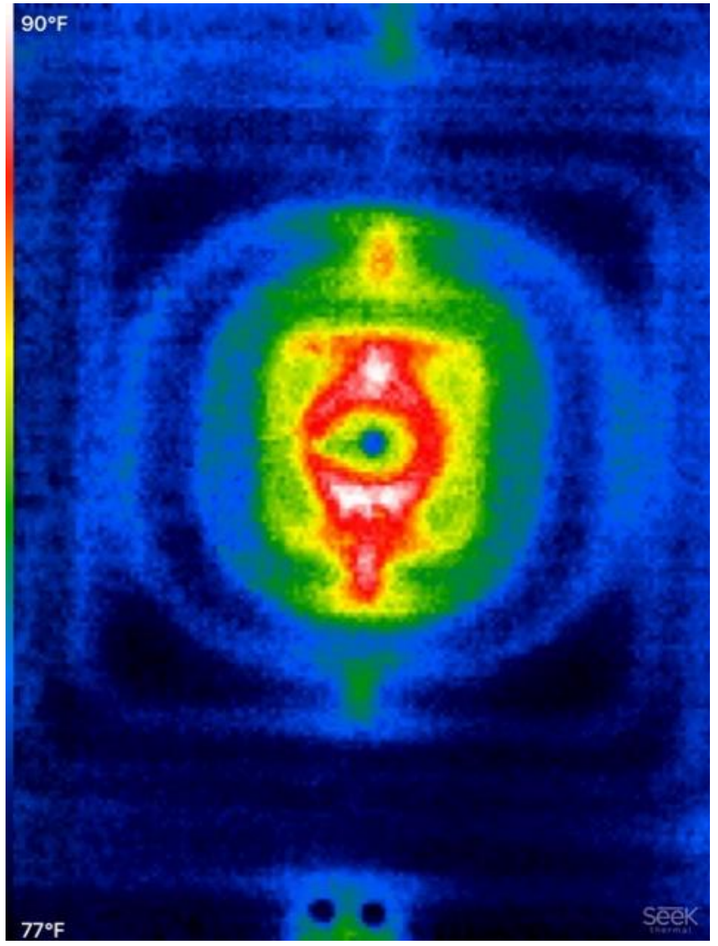
Large gap coil distribution

COIL OPERATING TEMPERATURE

Coil to Coil Gap - 200 mm

Through wall demo platform

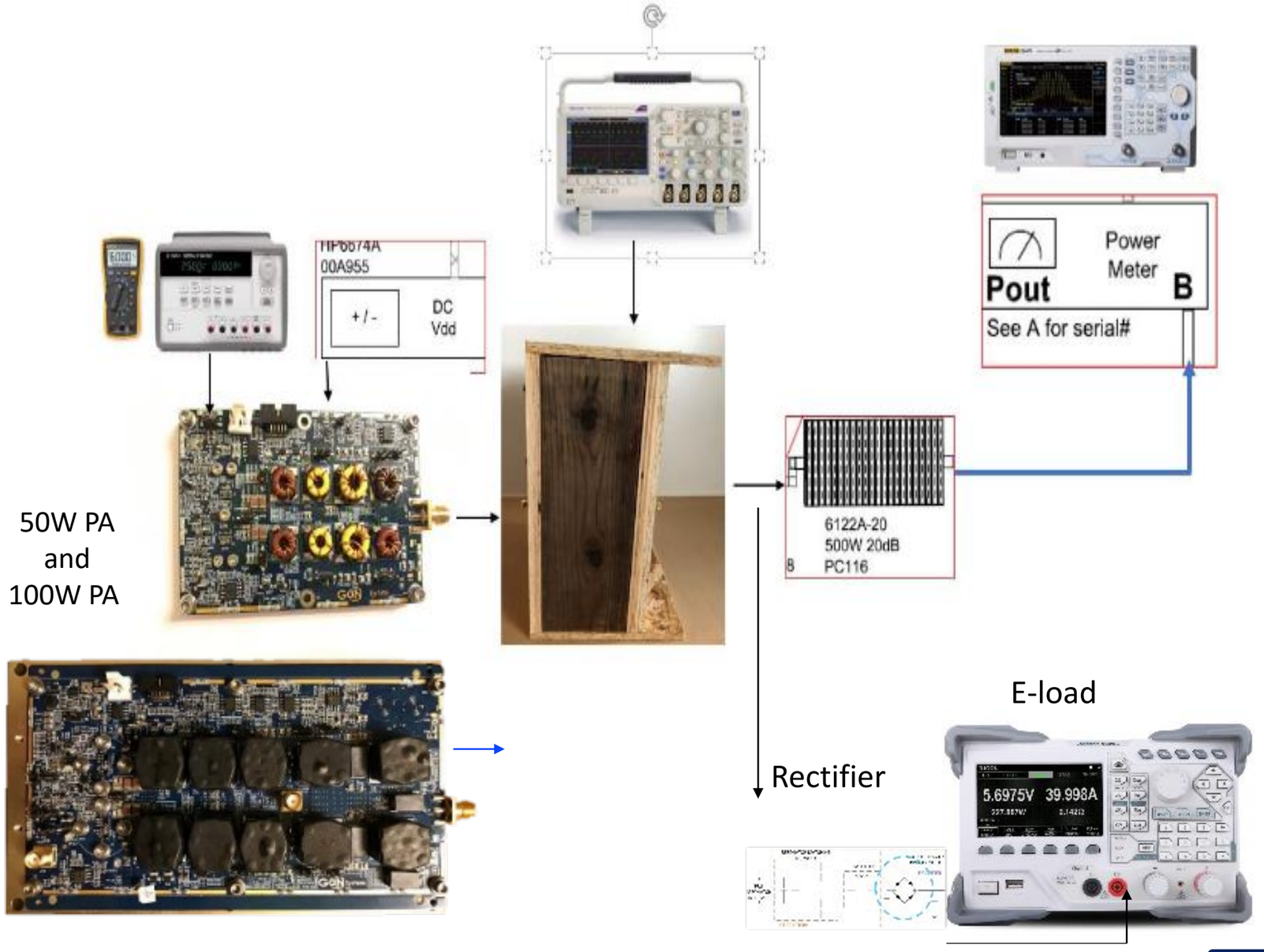
Tx coil temperature at 50W



Acceptable temperature rise

50W & 100W PA SYSTEM WITH 200mm GAP

- System test setup for performance tests
- End to End measurement with 50 ohm system
- End to End system tests performed with electronic load
- Two PAs tested for 25W and 50W Rx power



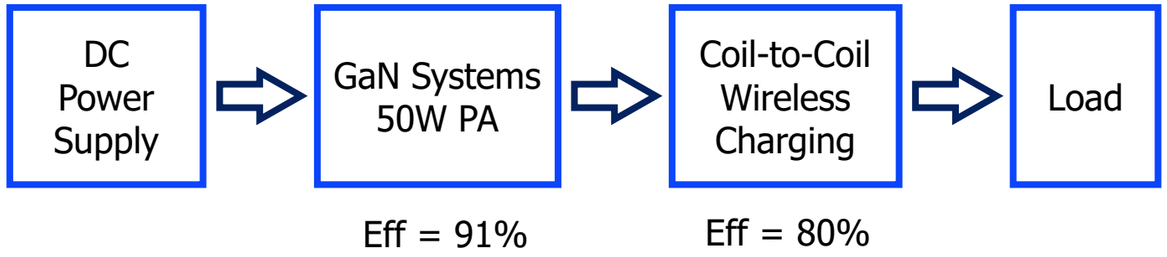
50W PA IN 200mm GAP SYSTEM E2E EFFICIENCY

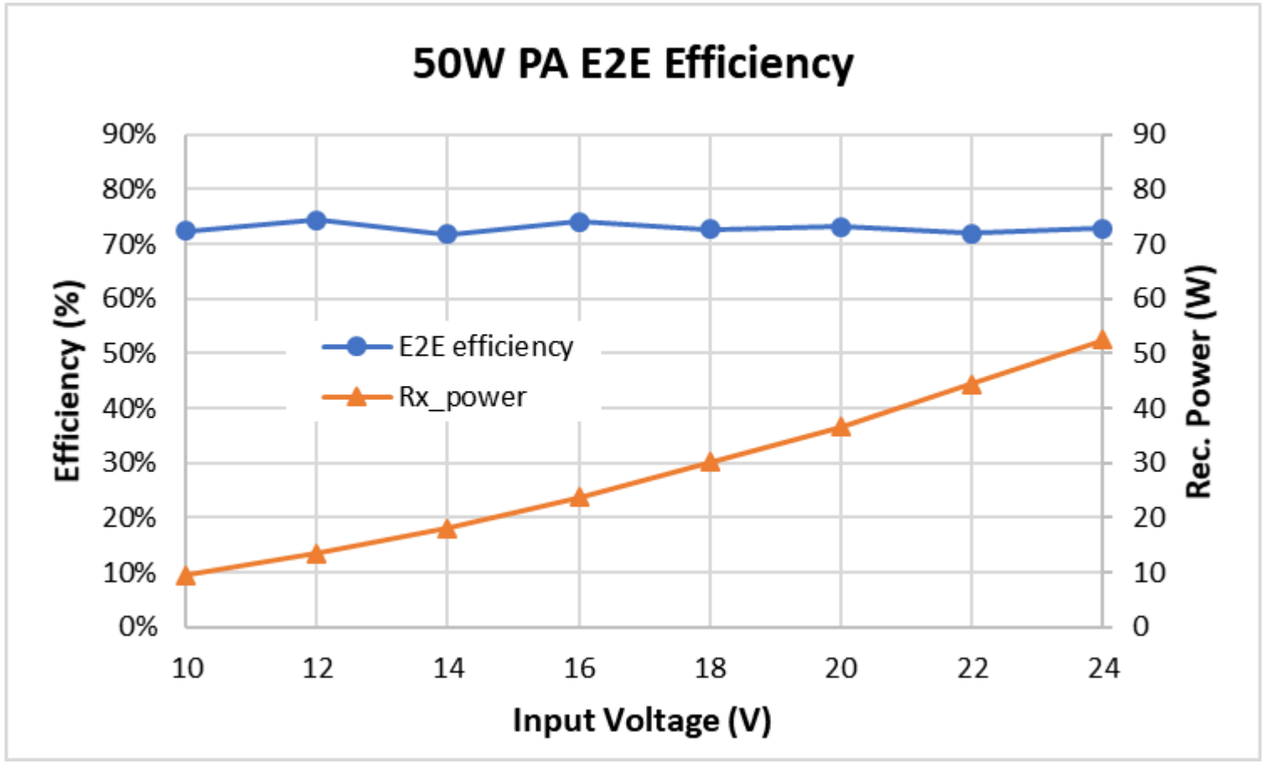
Conditions

- 50W PA
- 200mm air gap
- 50 ohm load, no rectifier

Results

- PA efficiency: 91%
- Coil to coil efficiency: 80%
- End to end efficiency: 72%

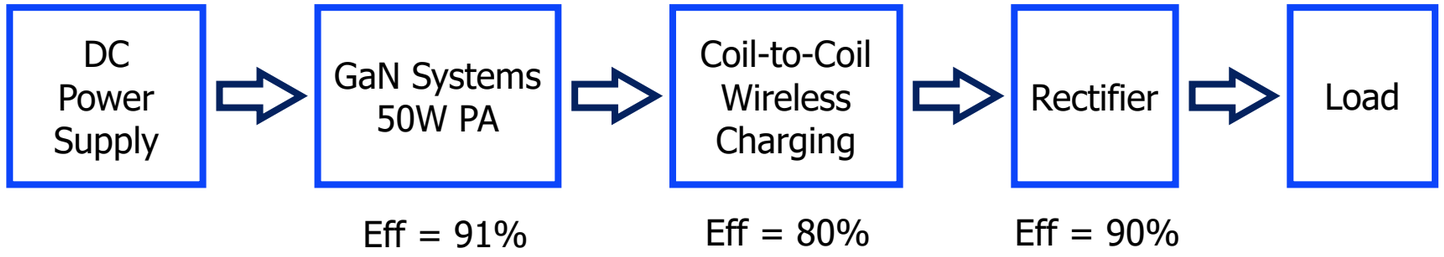




50W PA IN 200mm GAP SYSTEM E2E EFFICIENCY

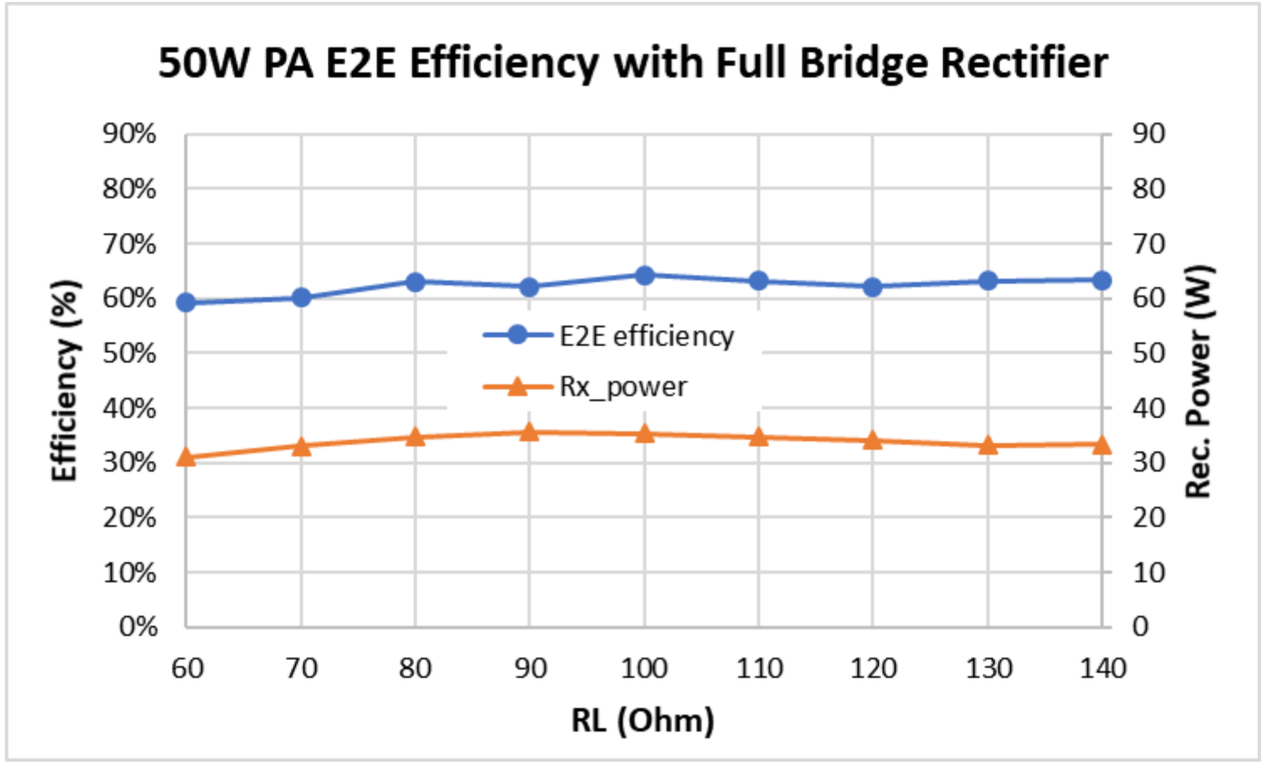
Conditions

- 50W PA
- 200mm air gap
- Rectifier in system
- Sweep 60-140 ohm @25V



Results

- PA efficiency: 91%
- Coil to coil efficiency: 80%
- Rectifier efficiency: 90%
- End to end efficiency: 63%



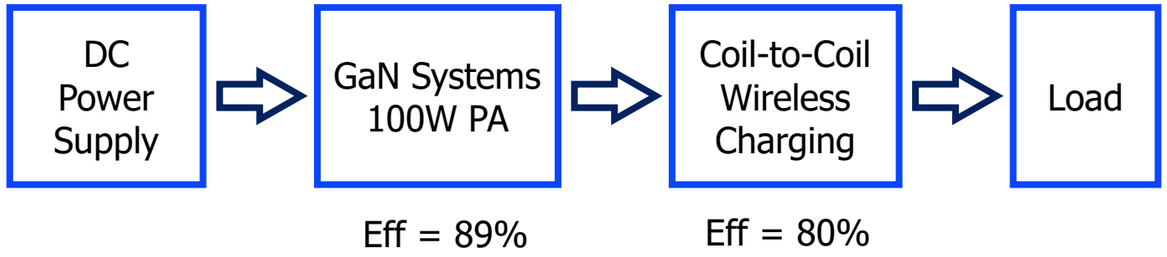
100W PA IN 200mm GAP SYSTEM E2E EFFICIENCY

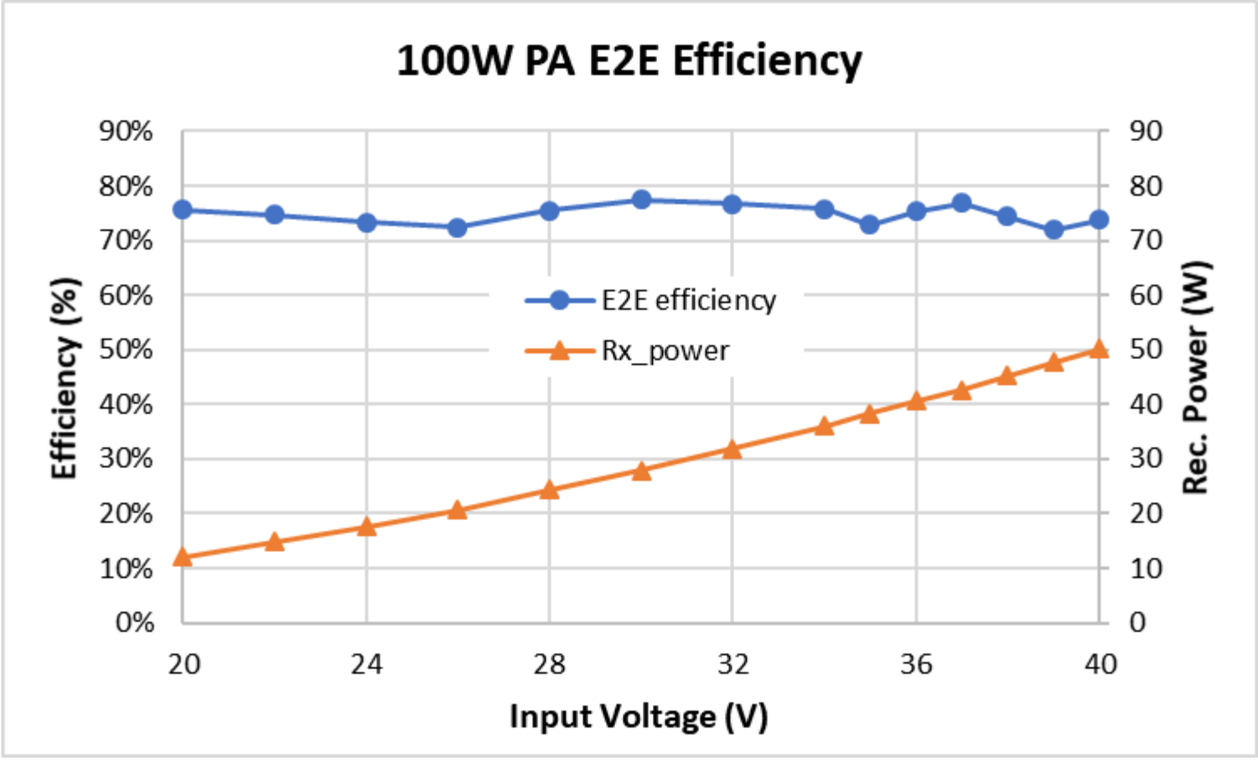
Conditions

- 100W PA
- 200mm air gap
- 50 ohm load, no rectifier

Results

- PA efficiency: 89%
- Coil to coil efficiency: 80%
- End to end efficiency: 75%

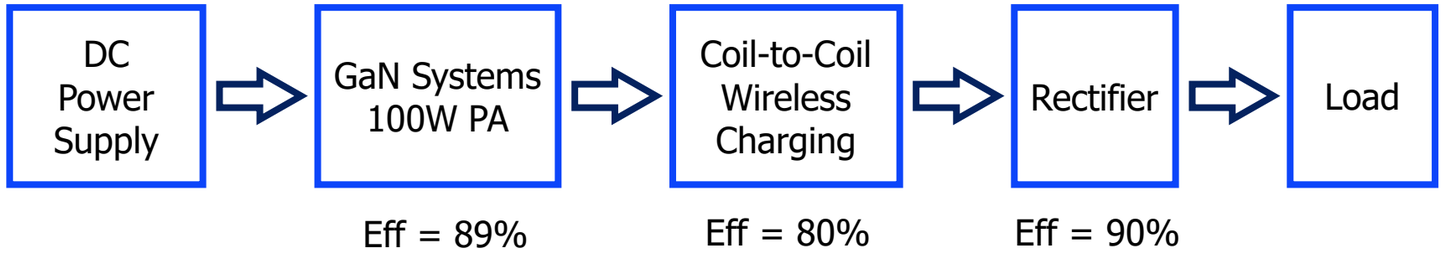




100W PA IN 200mm GAP SYSTEM E2E EFFICIENCY

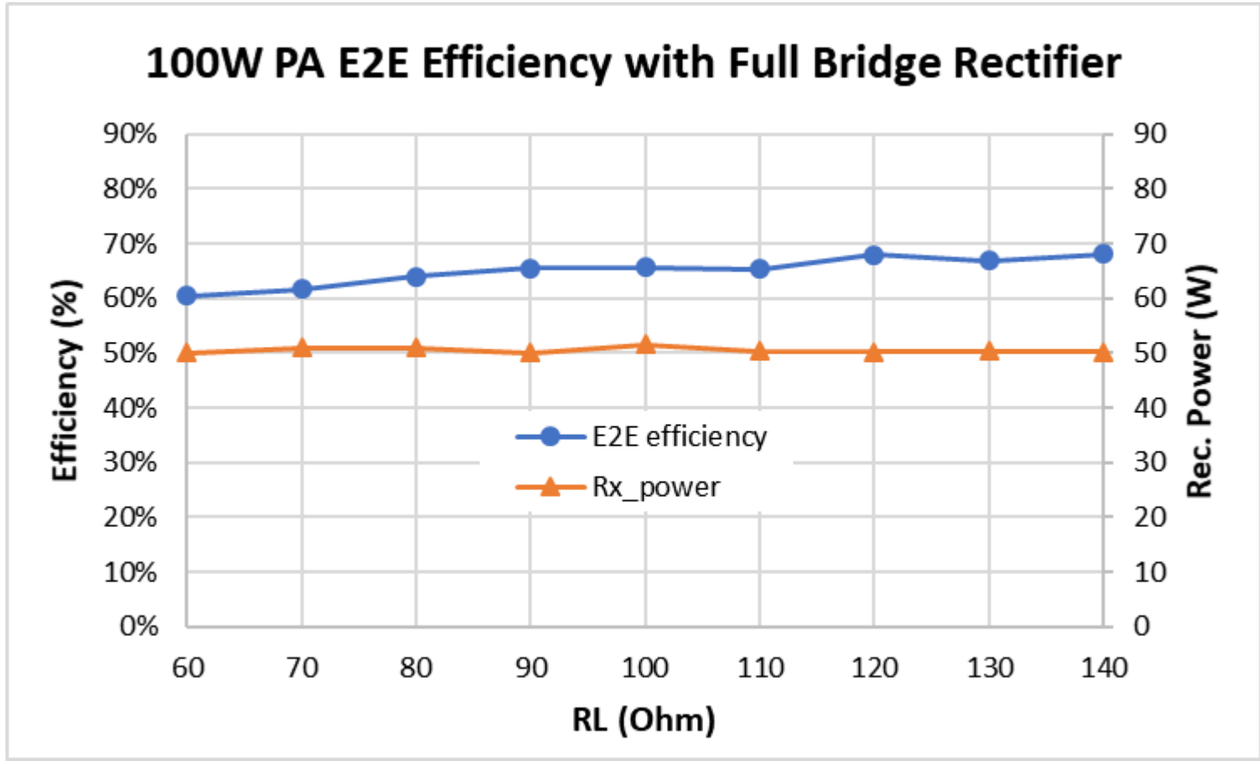
Conditions

- 100W PA
- 200mm air gap
- Rectifier in system
- Sweep 60-140 ohm @29V



Results

- PA efficiency: 89%
- Coil to coil efficiency: 80%
- Rectifier efficiency: 90%
- End to end efficiency: 68%



SUMMARY

- Seeing more and more applications
  - Industrial, Consumer, Medical
- Application requirements
  - High Tx power (50W to 1000W)
  - Spatial freedom
  - Large coil-to-coil gap
- Achieve excellent performance with GaN Systems devices
  - High efficiency
  - Good EMI
  - Low thermals