Highly Efficient High Power PA Design for Resonant WPT

March 2018

Outline

- Brief company overview
- WPT applications
- MHz vs kHz
- Tx topologies for WPT
- High power PA design for WPT with Gan Systems devices
  - 300W Class EF2 PA with GS66508B
  - 100W Class FE2 PA with GS61008P
- GaN Systems offering for WPT application

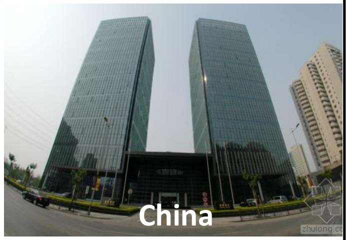
GaN Systems company overview

Market leader for gallium nitride (GaN) power transistors

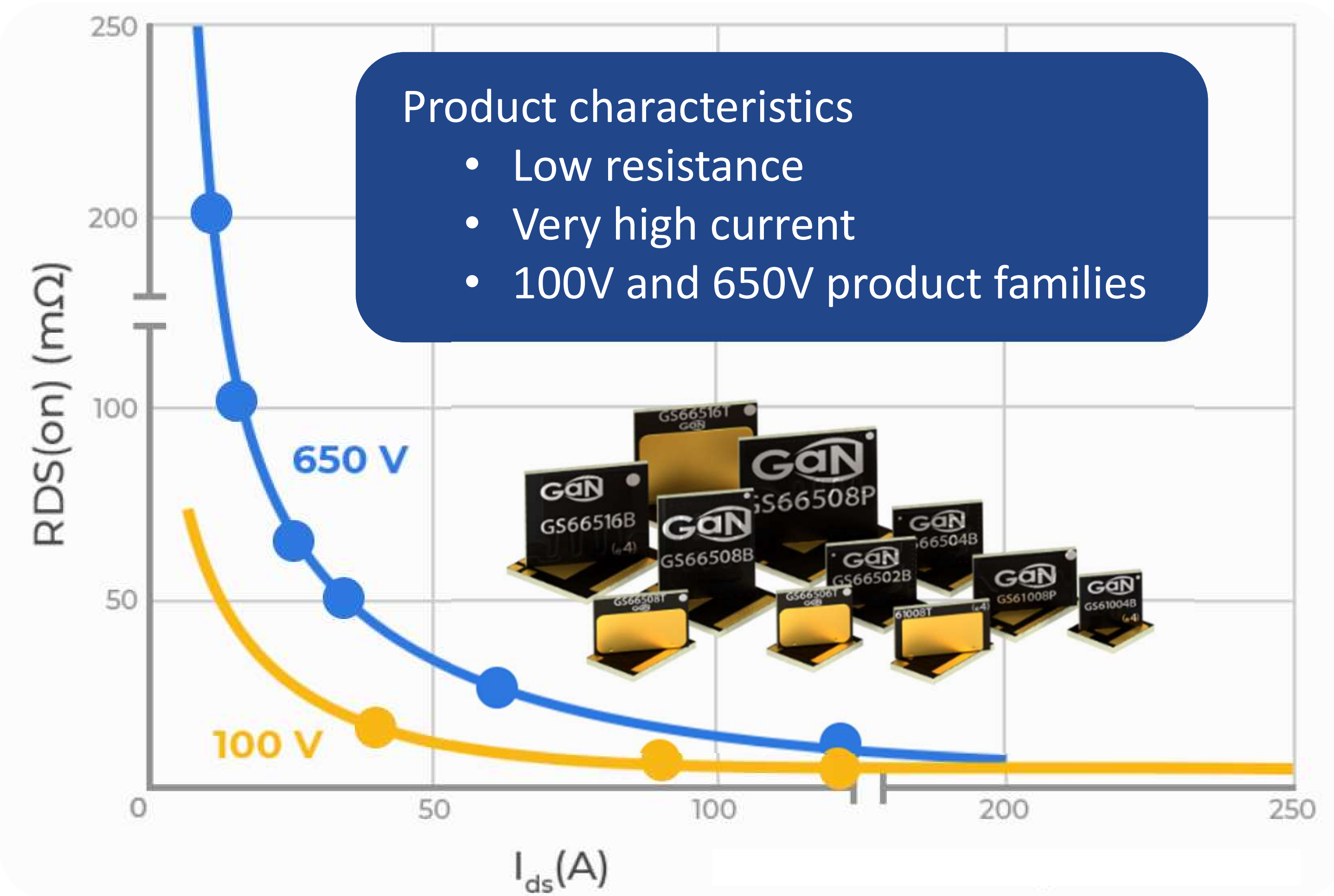
- GaN-on-Silicon power transistors for the power conversion market
- Industry’s most extensive & highest-performance product line
    - Enhancement mode devices
    - 100V & 650V devices; industry-best performance

Global company with decades of experience in GaN

- HQ and R&D in Ottawa, Canada
- Sales & App. Eng. in Germany, Japan, China, Taiwan, Korea, USA
- World-class fabless manufacturing and advanced packaging
- Parts shipping overnight from Mouser since 2014

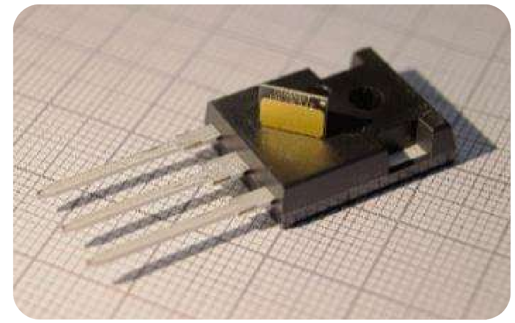


A complete GaN product portfolio



Product characteristics

- Low resistance
- Very high current
- 100V and 650V product families



GaN Systems device on a traditional T0-247 package

Wireless Power Transfer

Everything.
Applications for Cutting the Cord

- Laptops
- Phones
- Power Tools
- Home appliances
- eBikes
- Drones
- Robots
- ....

WPT Trends and Technology Drivers

30W

65W

180W

1000 to 2500W

6000 to 22000W

Trends

- Fast charge, variable Tx/Rx spacing, increasing power levels

Technology Drivers

- High switching frequency, high current, high voltage

Power Transfer Standards

Standard organization	Wireless Power Consortium (Qi)	AirFuel Alliance (Rezence)
Method	Inductive	Resonant
Frequency range	80 to 300 kHz	6.78 MHz
Max. Xfr range	5 mm	50 mm
No. charging devices	One	Multiple ok.
Communications system	Load modulation	Bluetooth

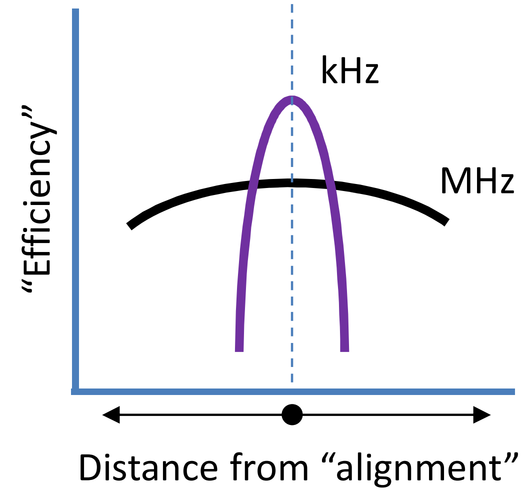
- **WPC**
  - Formerly Qi
  - Primarily inductive
- **AirFuel**
  - Formerly PMA, AW4P, Rezence
  - Primarily resonant

GaN compatible with all standards

MHz vs kHz frequencies – Inverter

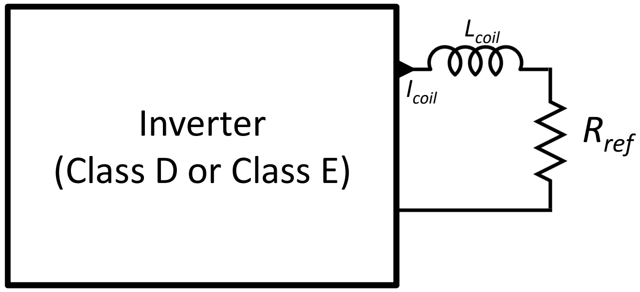
kHz WPT systems

- Good efficiency **only** for very low distances, a few millimeters, and **only** when the coils are precisely aligned
- Efficiency drops rapidly as the coils move apart and the induced voltage at the receiver becomes very low and therefore is inefficient to rectify.
- Uses a lot of ferrite to guide the magnetic flux, this limits the position of the receiver to a fixed a position



MHz WPT systems

- High power transfer efficiency across a much greater distance
- Allows for better tolerances to coil misalignment
- The inverter 'sees' more of the receiver, i.e. the reflected resistance (*Rref*) of the load increases
- Therefore power can be transferred at lower coil currents
- Lower coil currents mean less conduction losses in the inverter, resulting in higher inverter efficiency and higher system efficiency

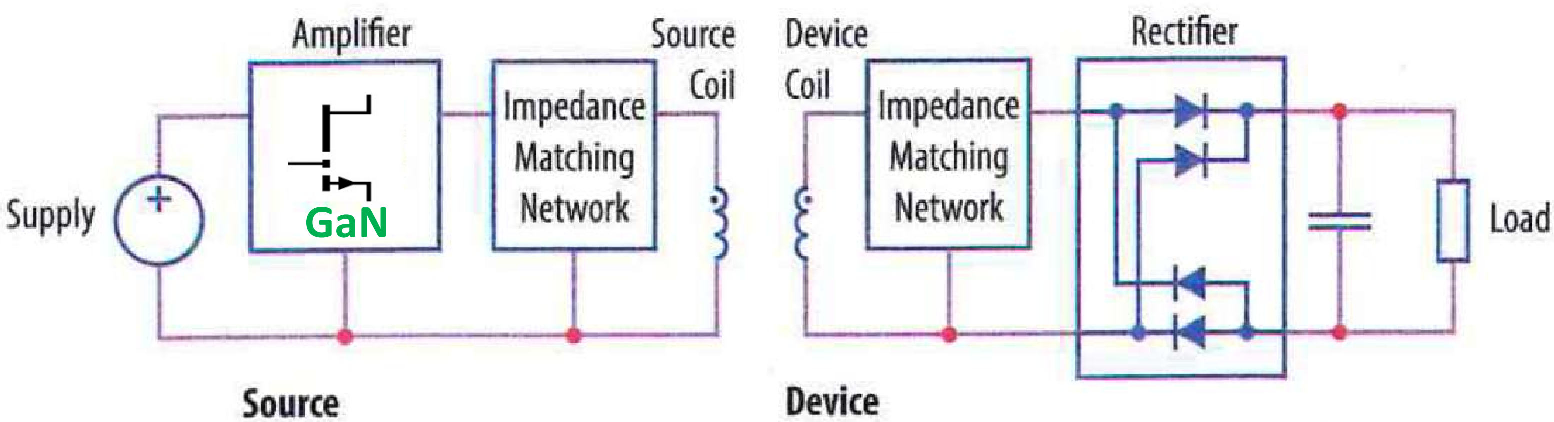


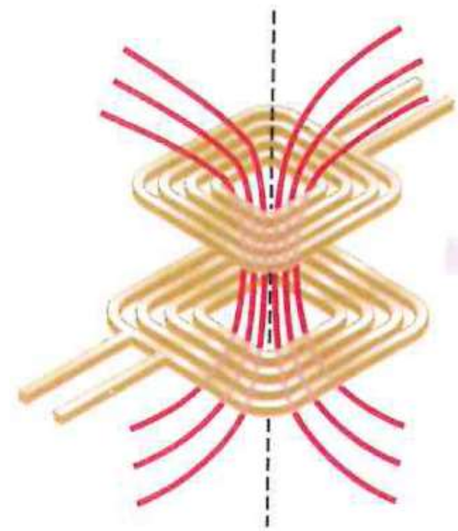
$$R_{ref} = \frac{\omega^2 M^2}{R_{Load}}$$

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**
4) **Load**





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

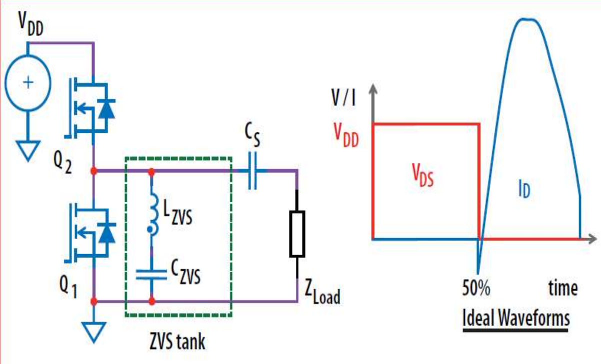
$$R = \frac{8}{\pi^2+4}\frac{V_{cc}^2}{P_{out}} = 0.5768\frac{V_{cc}^2}{P_{out}}.$$

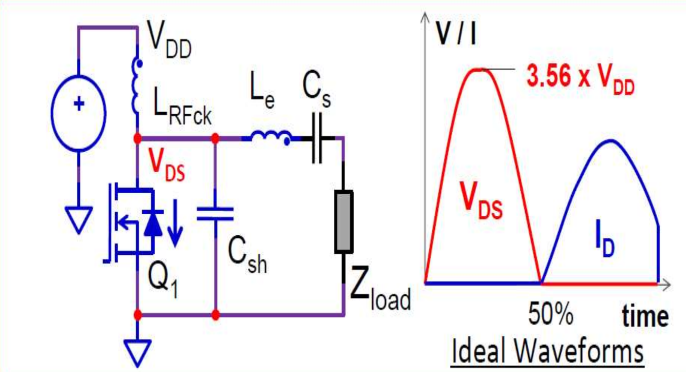
$$\eta = \frac{P_{out}}{P_0} = \frac{P_0 - P_{sat}}{P_0} = 1 - \frac{P_{sat}}{P_0}.$$

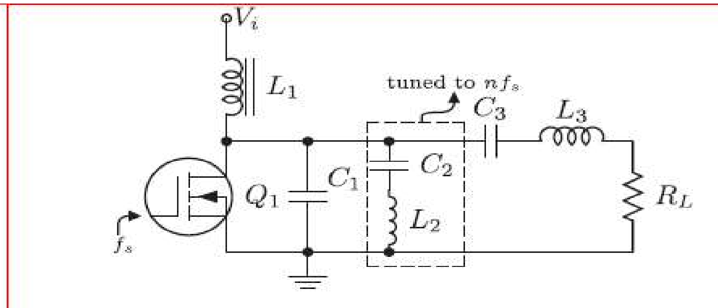
Class EF2

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

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





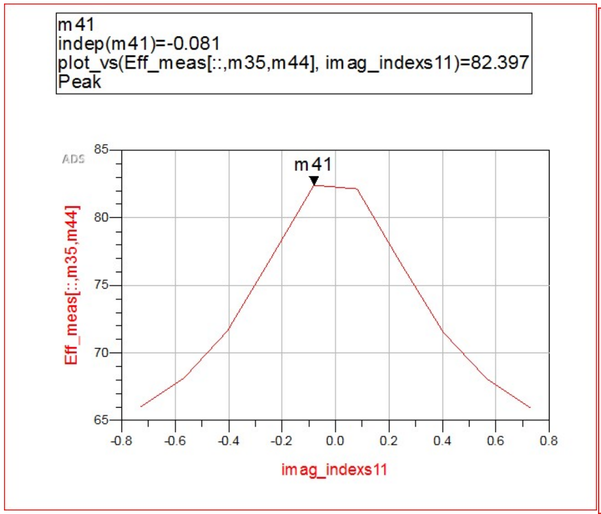


Circuit diagram of the Class EF or Class E/F inverter.

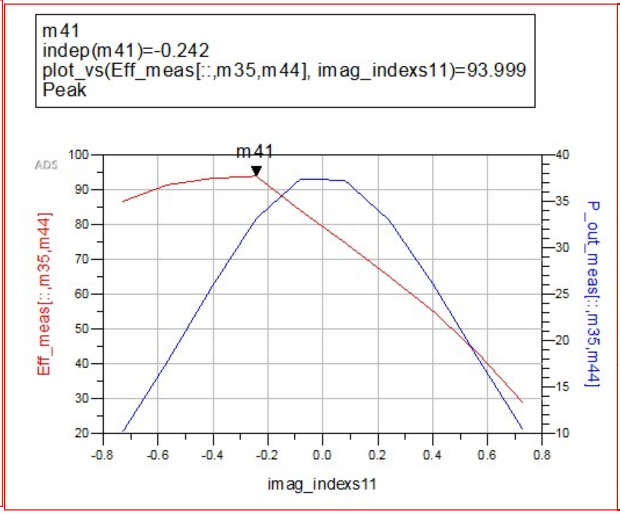
Efficiency comparison typologies Class D/E/EF2

- Simulations of MOSFET at 6.78MHz, 25V DC
  - Class D : Max efficiency 82.4%
  - Class E : Max efficiency 93.9%
  - Class EF2 : Max efficiency 93.4%

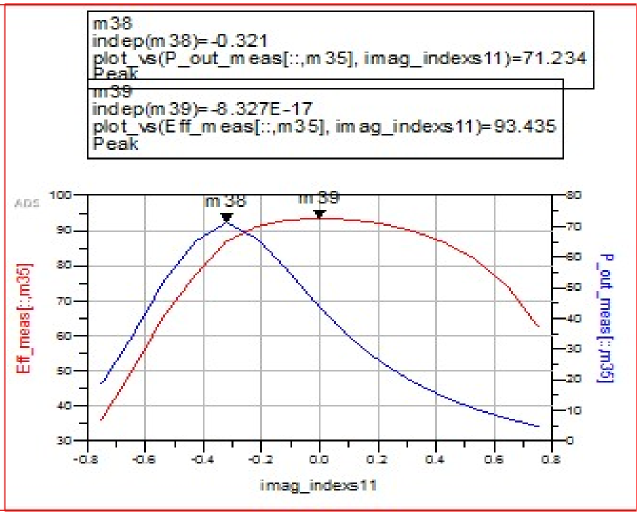
Class D with ZVS



Class E with Cshunt



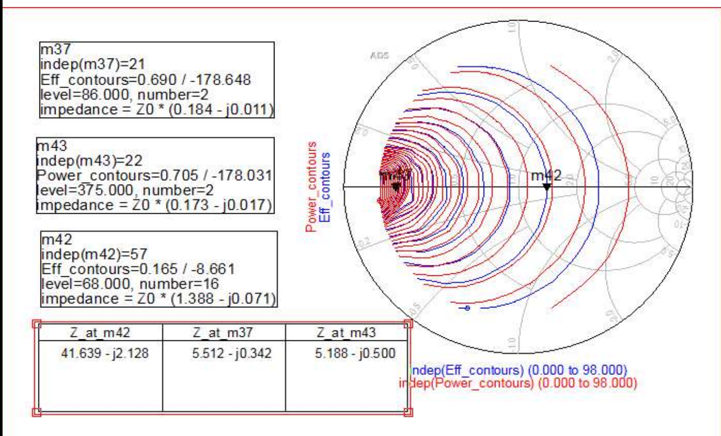
Class EF2



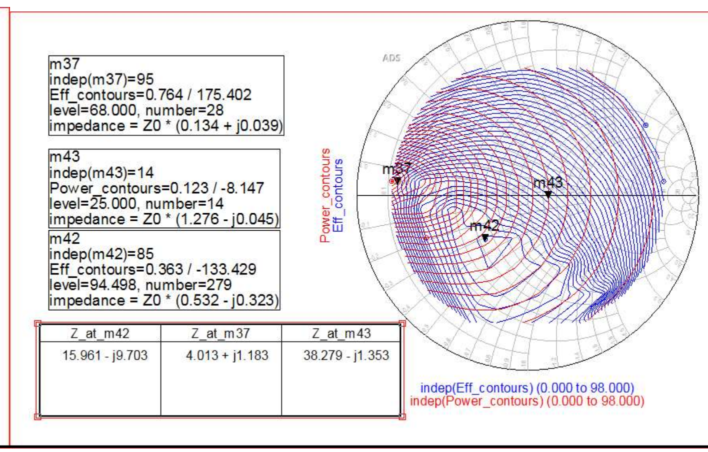
Impedance window comparison typologies Class D/E/EF2

- Single ended configuration at 6.78MHz, 25V DC, red = power, blue = efficiency
  - ➢ Class D : low impedance point is point of maximum power and efficiency, power is limited by dissipation power, so PA cannot operate at maximum power and efficiency
  - ➢ Class E : low impedance point is the maximum power point, not near its optimum power and efficiency point
  - ➢ Class EF2 : both efficiency and power are maximized

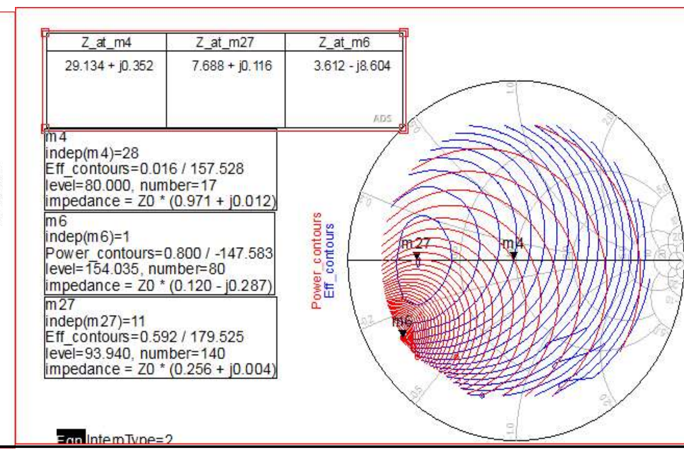
Class D with ZVS



Class E with Cshunt

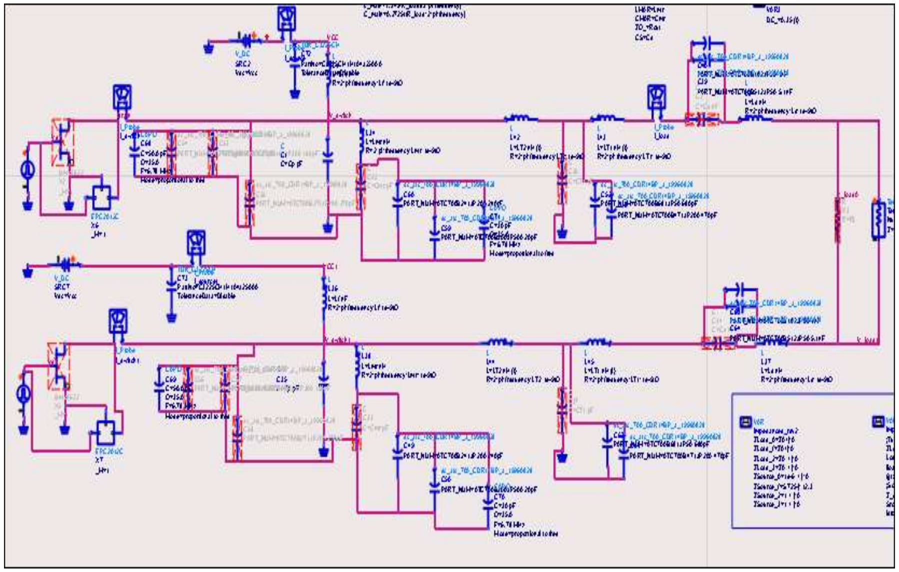


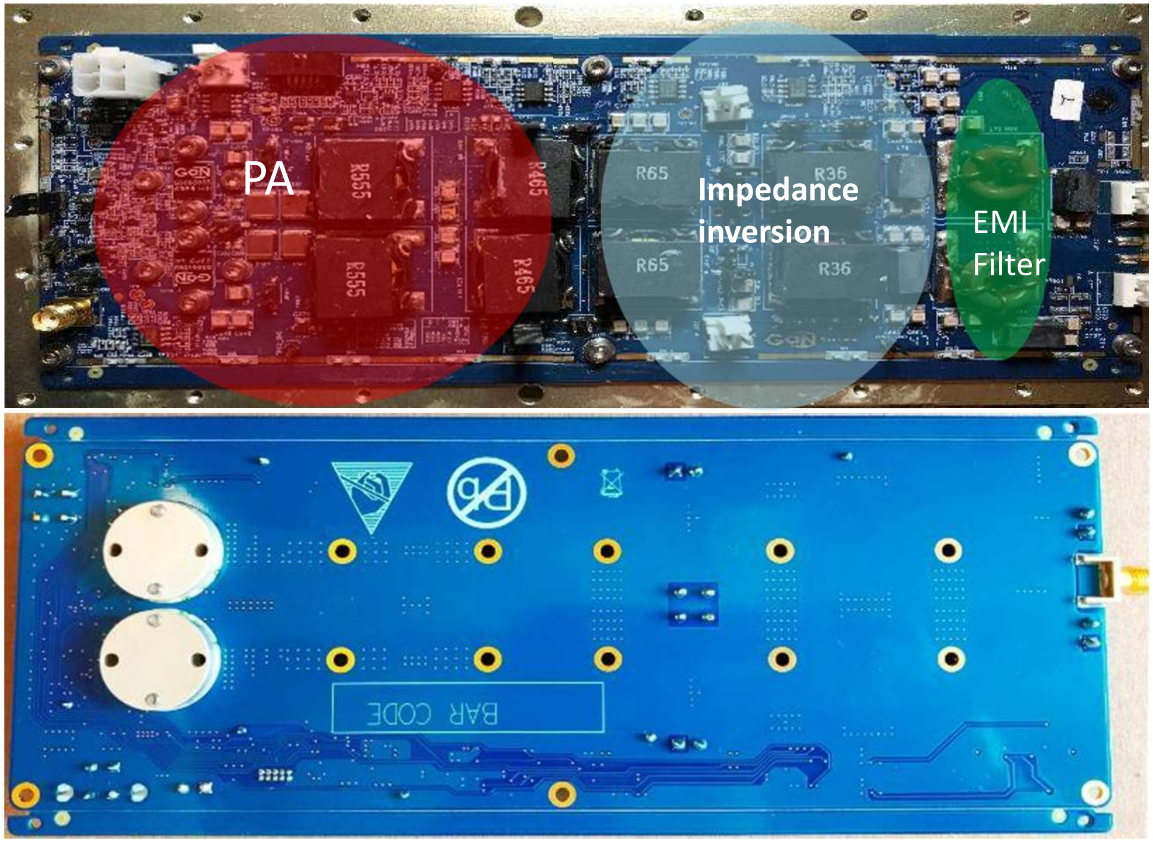
Class EF2



Turn key solution of Class EF2 150W/300W PA for WPT

GaN Systems WPT Class EF2 turn key PA solution



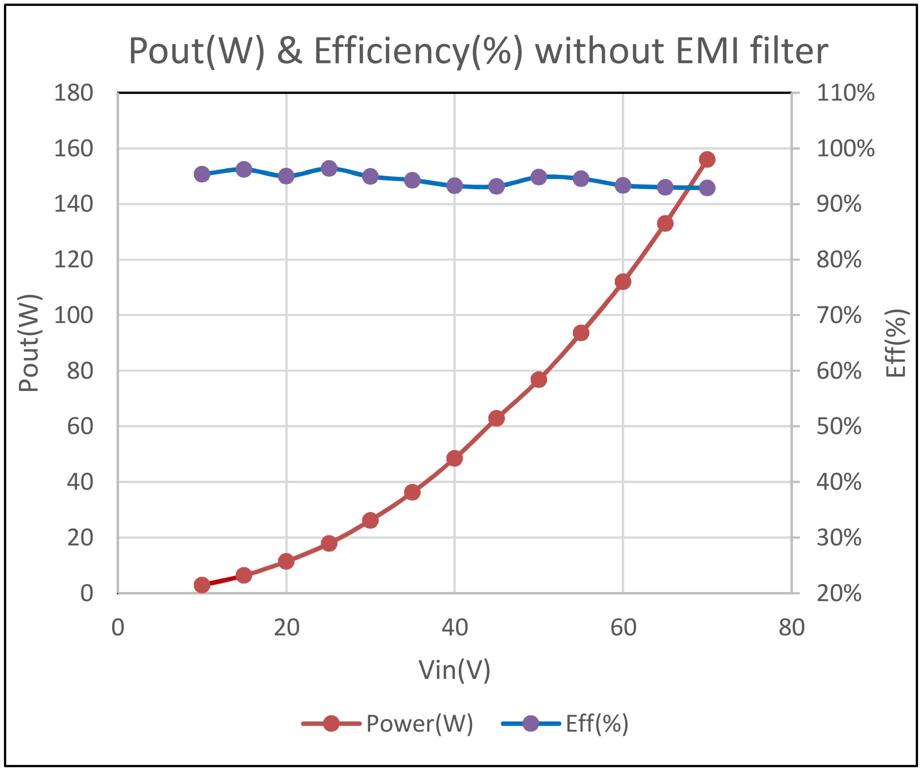


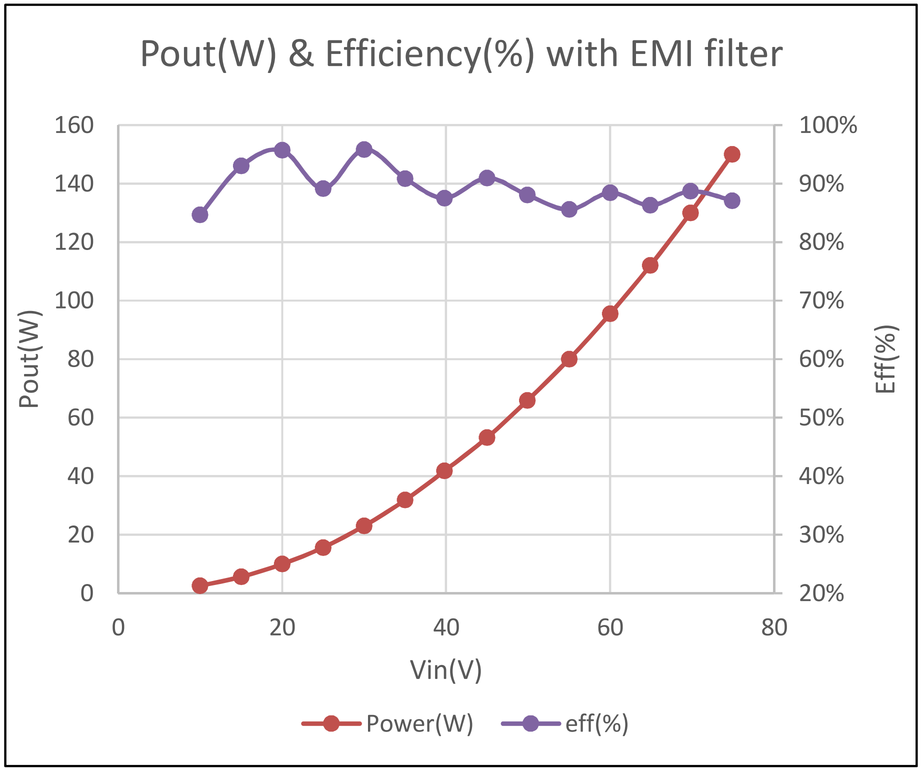
- Device 650V, GS66508B, Push Pull
- Thermal solution: copper coins solder down
- Design built in EMI filter
- Unique output filter network design naturally provide constant current

Designed to simultaneously achieve power, efficiency, EMI and constant current behavior.

150W PA Efficiency

GaN Systems



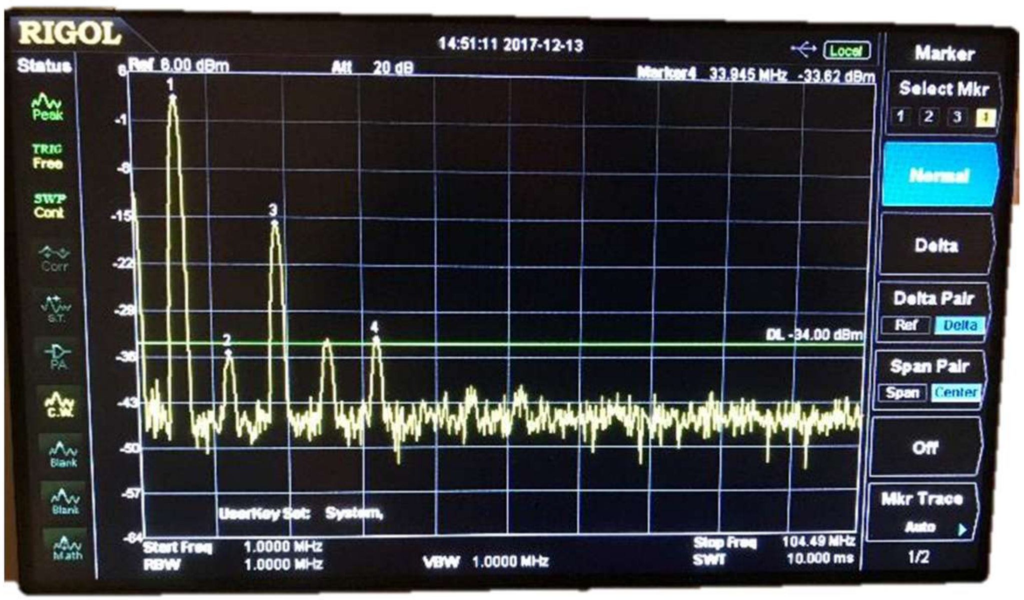


- 50ohm load
- 156W output
- 93% efficiency
- T rise 2 degree at device

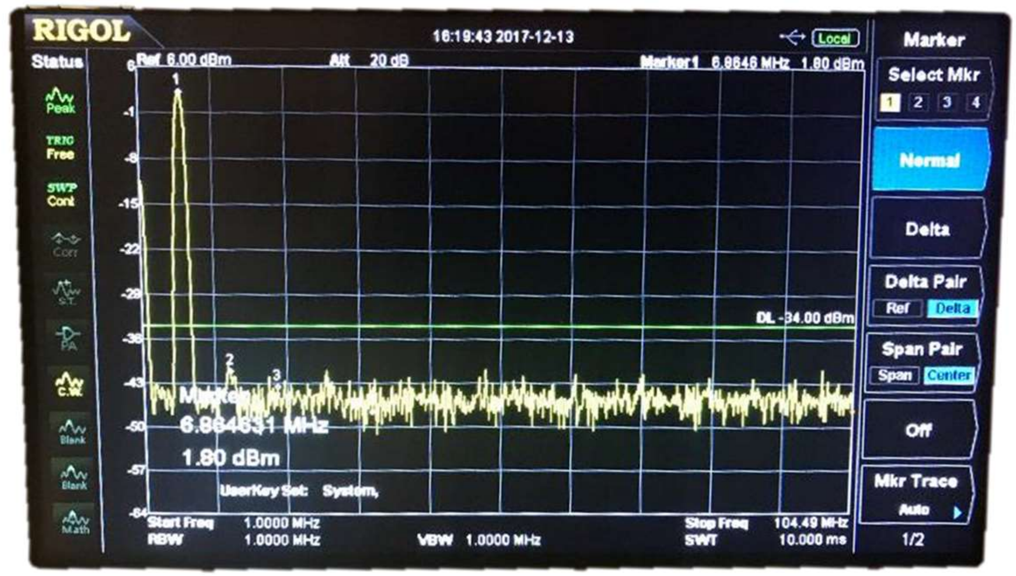
- 50ohm load
- 150W output
- 87% efficiency
- T rise 2 degrees at device

150W PA Harmonics

Harmonics performance before EMI filter



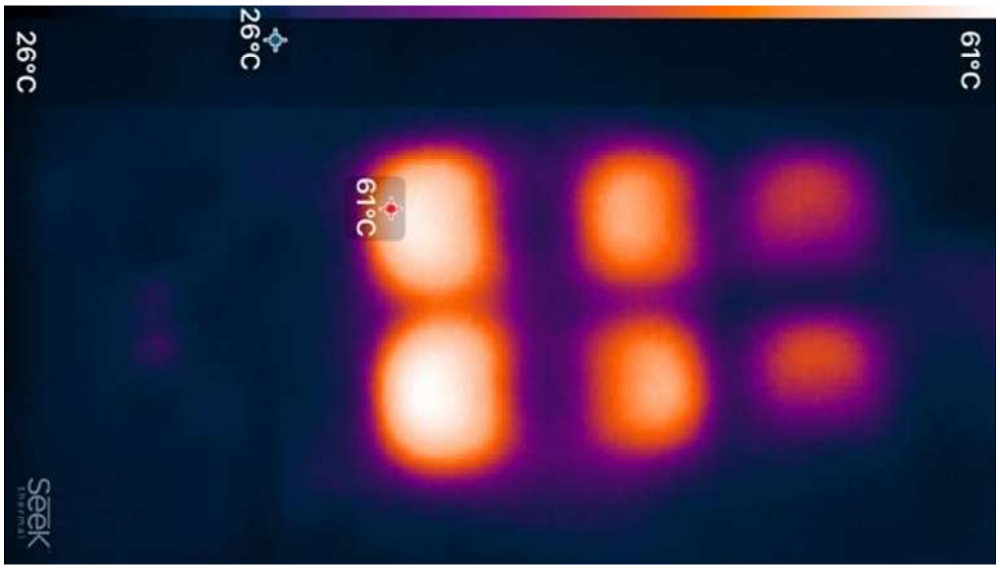
Harmonics performance with EMI filter



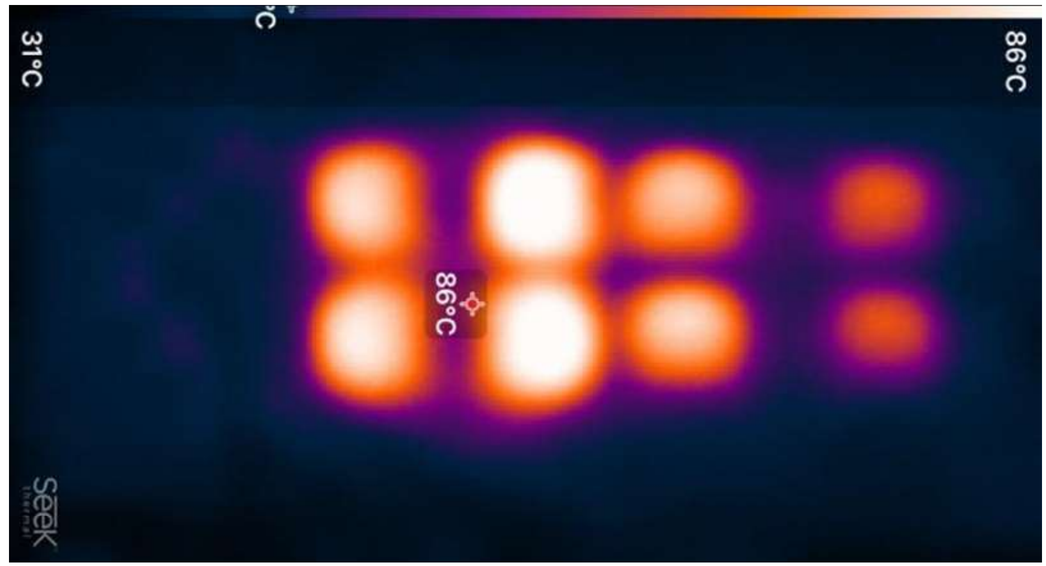
At 150W output power, 3rd harmonic rejection is -42dBc with EMI filter, more than -60dBc rejection on high order harmonics

150W PA Thermals

Thermal picture without EMI filter at 70V



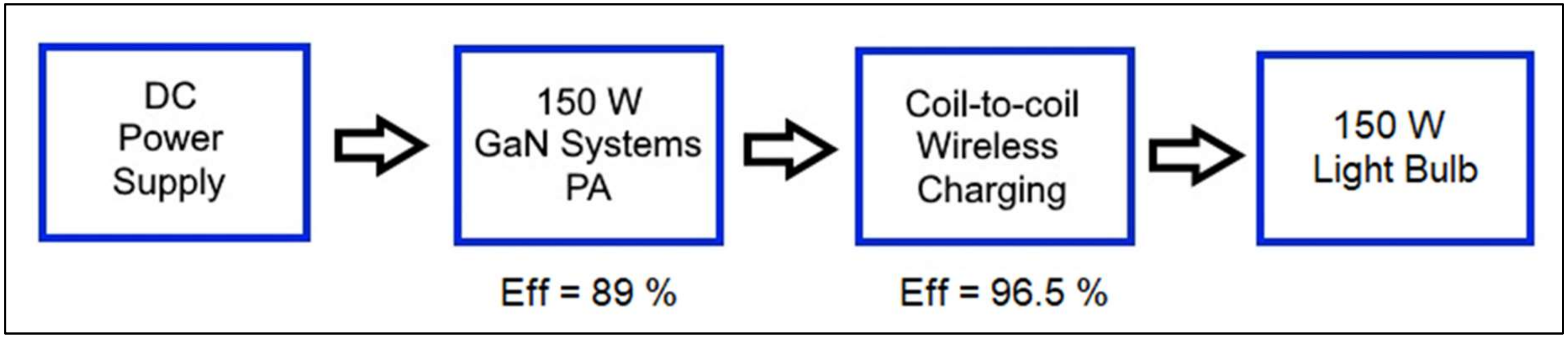
Thermal picture with EMI filter at 75V



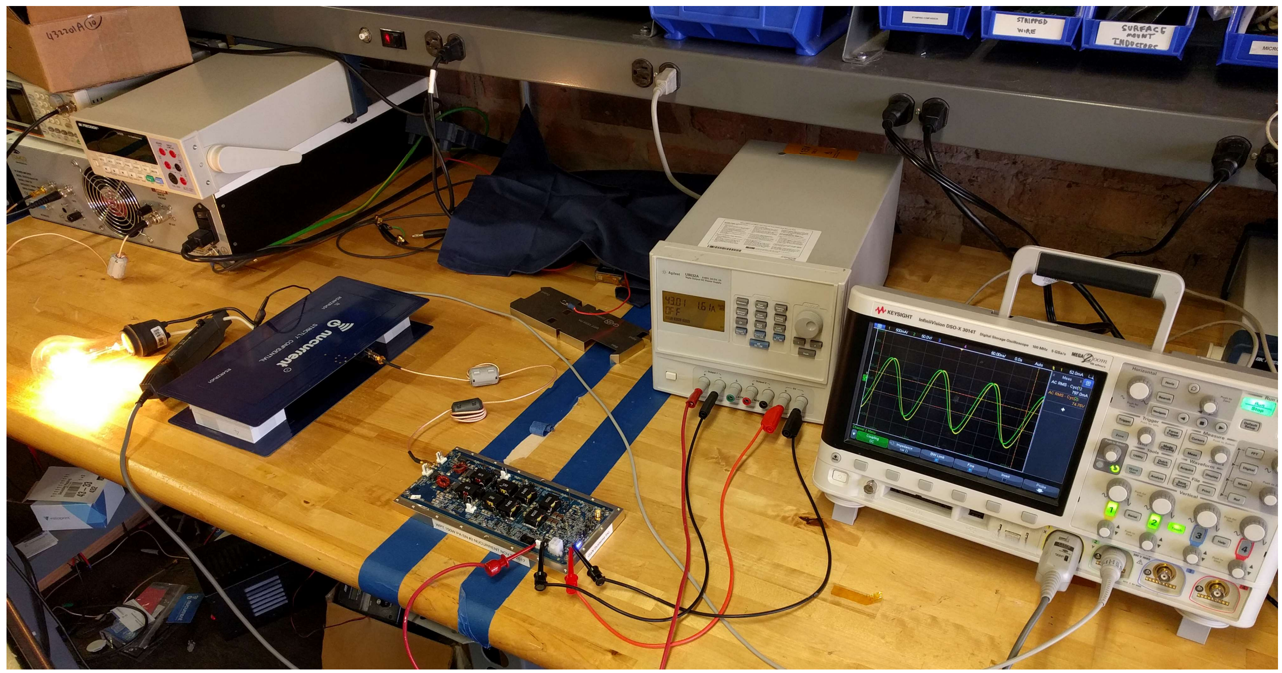
- At 150W output power without EMI filter, hottest point is located at RF choke inductor 61 degree C.
- Hottest point is located at 2nd harmonic shunt inductor, 86 degree C , temperature at device is in control, less than 31 degrees C.

150W PA System Test

GaN Systems



End to end efficiency = 86%



Power Ratings

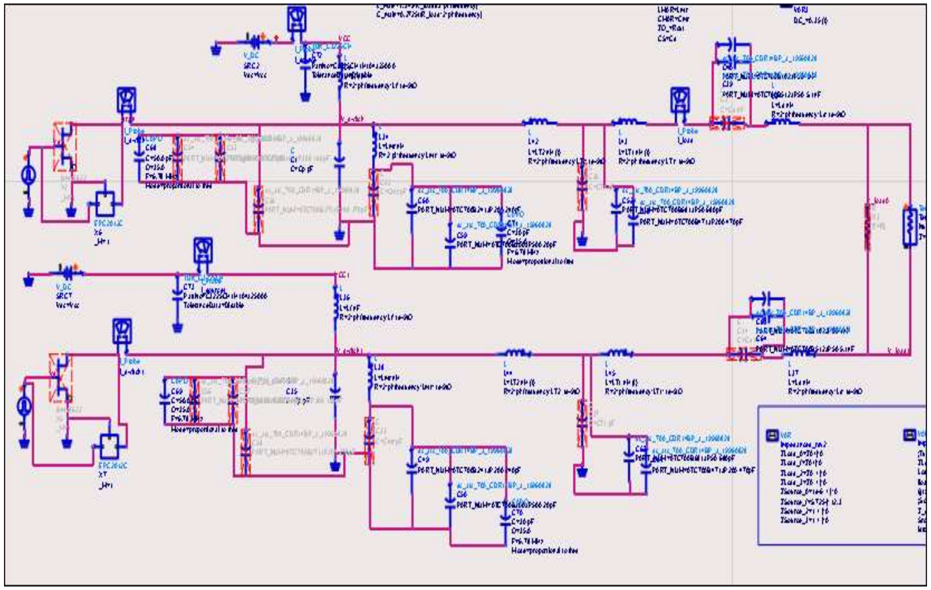
- Input Voltage = 43 V (DC)
- Input Current = 1.61 A (DC)

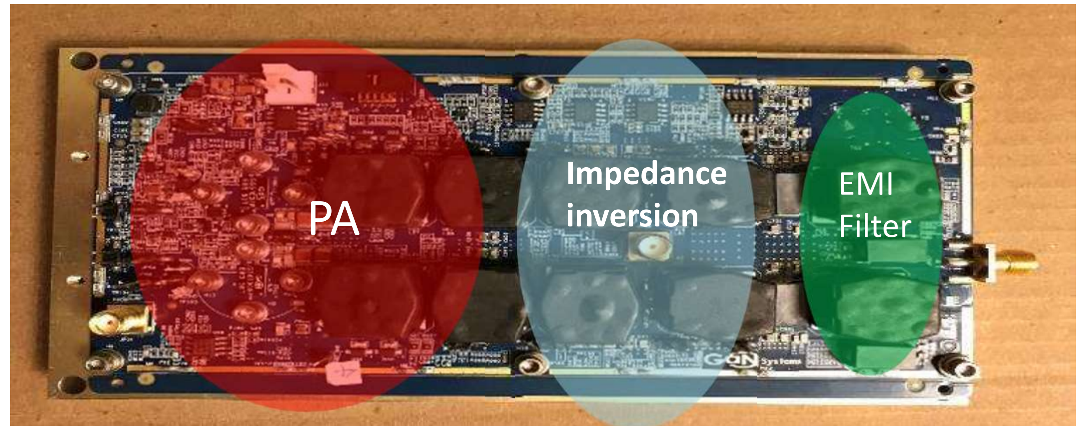
- Output Voltage = 74.8 V (rms)
- Output Current = 0.8 A (rms)

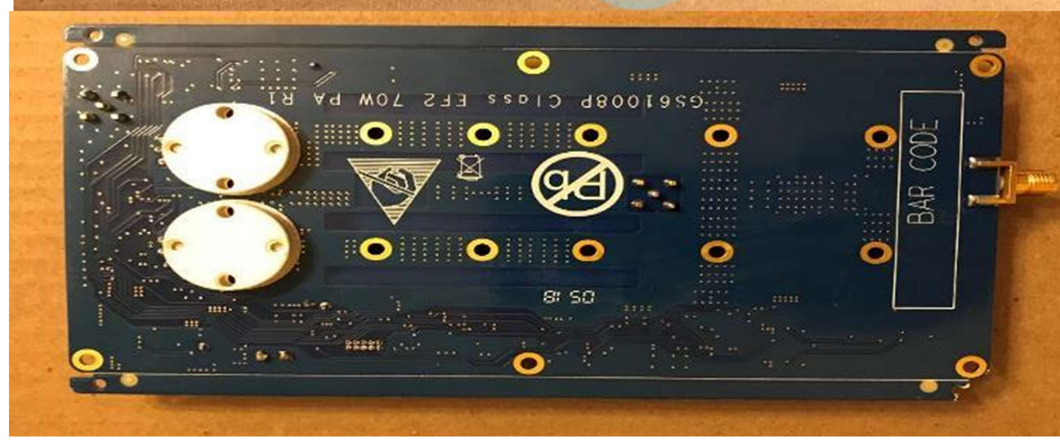
Turn key solution of Class EF2 70W/100W PA for WPT

GaN Systems

GaN Systems WPT Class EF2 turn key PA solution



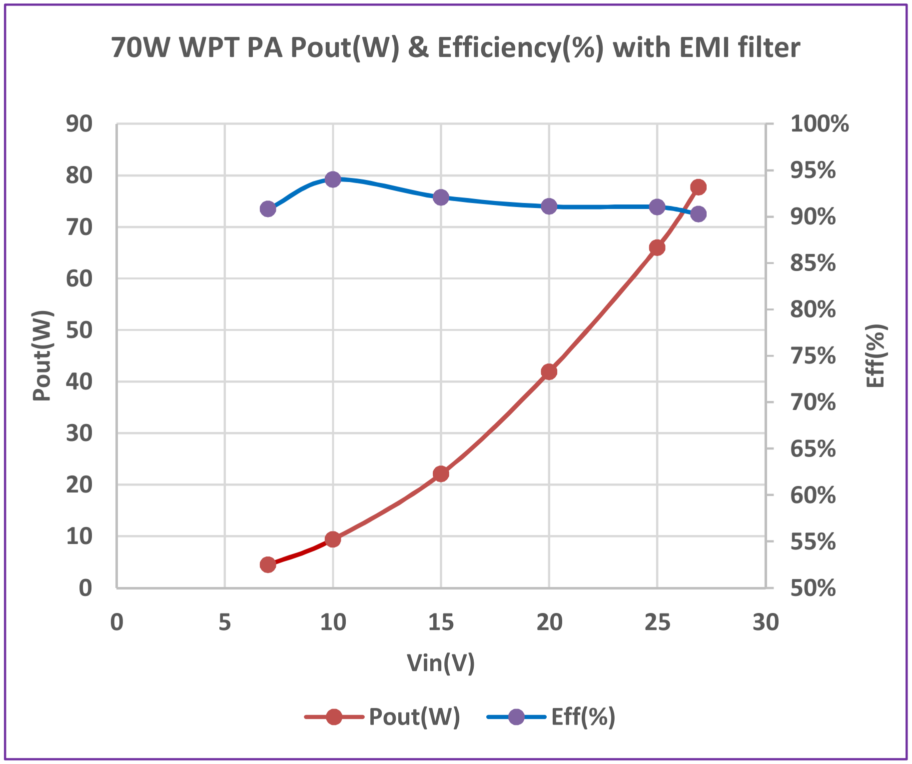




- Device 100V, GS61008P, Push Pull
- Thermal solution: copper coins solder down
- Design built in EMI filter
- Unique output filter network design naturally provide constant current

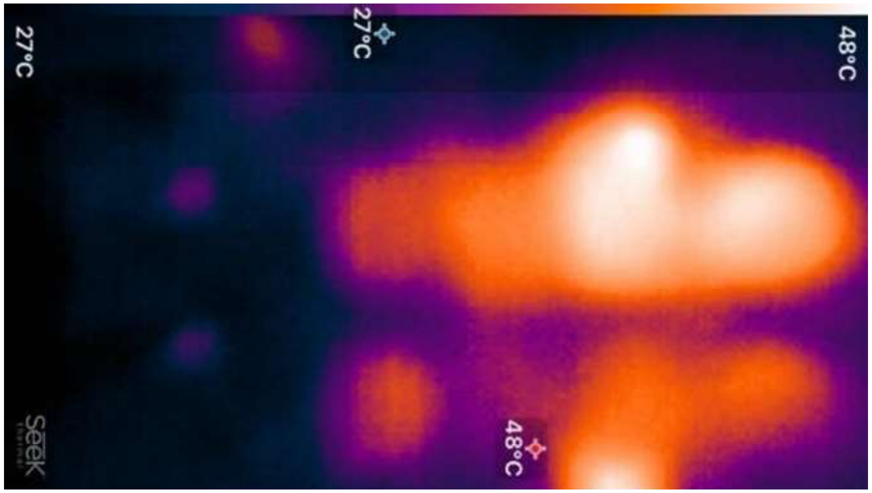
Designed to simultaneously achieve power, efficiency, EMI and constant current behavior.

70W PA Efficiency and Thermals



- 50ohm load
- 27V, 78W output
- 90% efficiency
- T rise is 2 degrees at the device

Thermal image with EMI filter at 27V

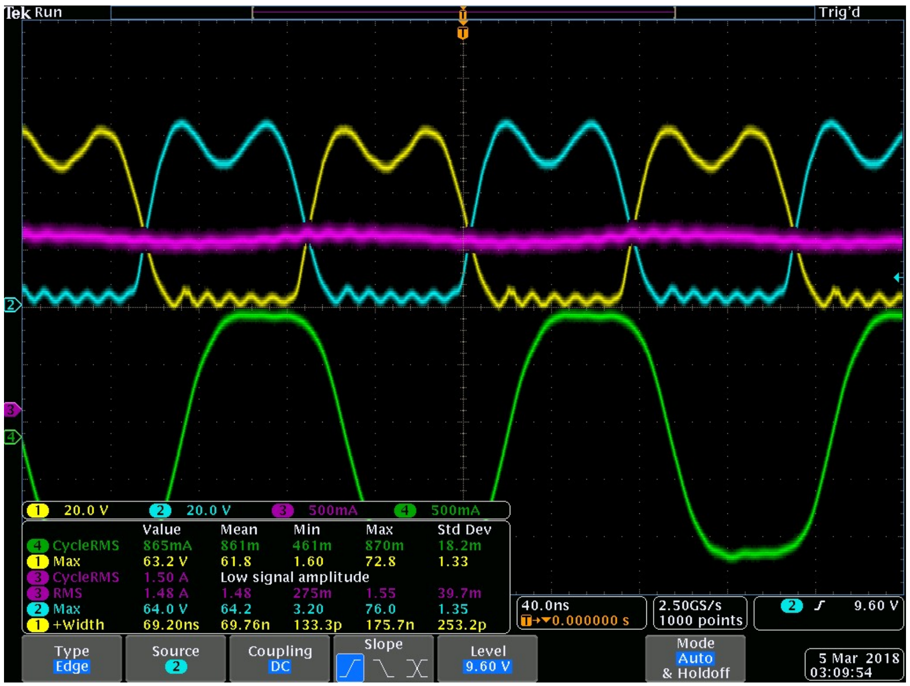


- 77W output power
- Warmest point is at RF choke, 48 deg. C
- Transistor temp is less than 31 deg. C

70W PA Class EF2 voltage waveforms

GaN Systems

70W PA Class EF2 without EMI filter



- Low stress voltage wave at both devices at 27V
- Vmax/Vcc = 2.3 at 50ohm
- Output current is not a perfect sine wave due to harmonics

70W PA Class EF2 with EMI filter

- Low stress voltage wave at both devices at 27V
- Vmax/Vcc = 2.6 at 50ohm
- Output current is almost a perfect sine wave

High Power GaN devices for Resonant WPT

GS61004B

- 300W CW at 50V
- 1 kHz – 150 MHz
- 40 dB gain at 10 MHz
- 91% efficiency at 10 MHz
- GaN*PX*® package
- Handles >10:1 VSWR
- Advanced integrated design provides gate-source voltage range (-10V to +7V) to enhance performance when operating in switching modes such as Class C, E, EFn.

GS61008B

- 600W CW at 50V
- 1 kHz – 120 MHz
- 40 dB gain at 10 MHz
- 90% efficiency at 10 MHz
- GaN*PX*® package
- Handles >10:1 VSWR
- Advanced integrated design provides gate-source voltage range (-10V to +7V) to enhance performance when operating in in switching modes such as Class C,E,EFn.

GS66508B

- 600W CW at 100V
- 1 kHz – 80 MHz
- 37 dB gain at 10 MHz
- 91% efficiency at 10MHz
- GaN*PX*® package
- Handles >10:1 VSWR
- Advanced integrated design provides gate-source voltage range (-10V to +7V) to enhance performance when operating in in switching modes such as Class C,E,EFn.

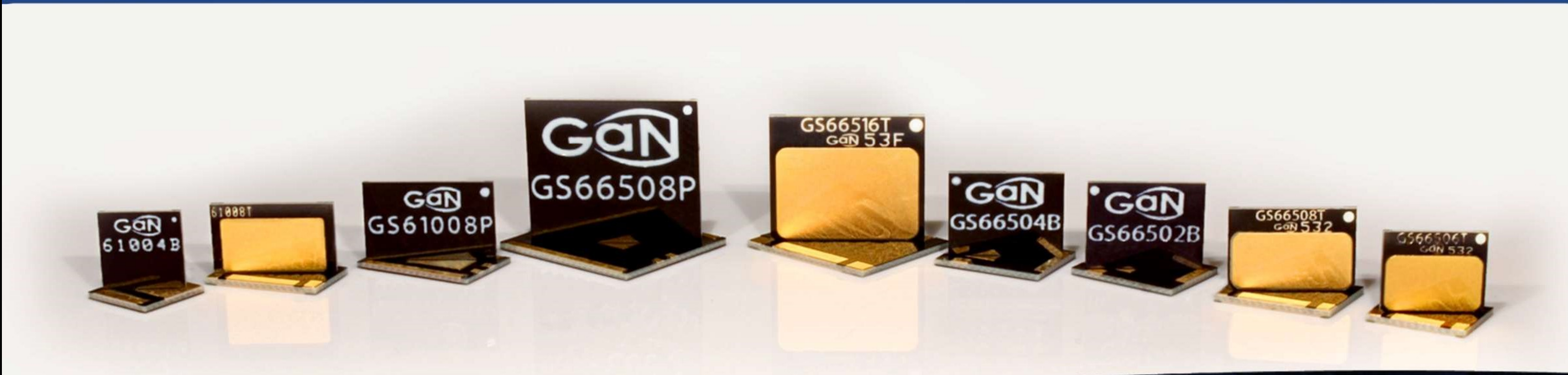
DS66516B

- 1000W CW at 100V
- 1KHz – 80 MHz
- 37 dB gain at 10 MHz
- 90% efficiency at 10MHz
- GaN*PX*® package
- Handles >10:1 VSWR
- Advanced design integrated provides gate-source voltage range (-10V to +7V) to enhance performance when operating in in switching modes such as Class C,E,EFn.

GaN Systems enables compact, low cost, high power wireless charging

Conclusions

- **WPT is growing in many markets and applications**
  - Need high power, spatial freedom and high efficiency
- **MHz systems are better than kHz**
  - Wireless power is about mobility, you want to be able to charge and power devices without being limited to a fixed position. MHz provides this capability.
- **GaN Systems provides high performance solutions**
  - 100W and 300W PA kits demonstrate high efficiency at high power output
  - The Tx architecture design offers exceptional EMI performance
  - Enable end-to-end efficiency approaching 90%



GaN Systems

www.gansystems.com • North America • Europe • Asia