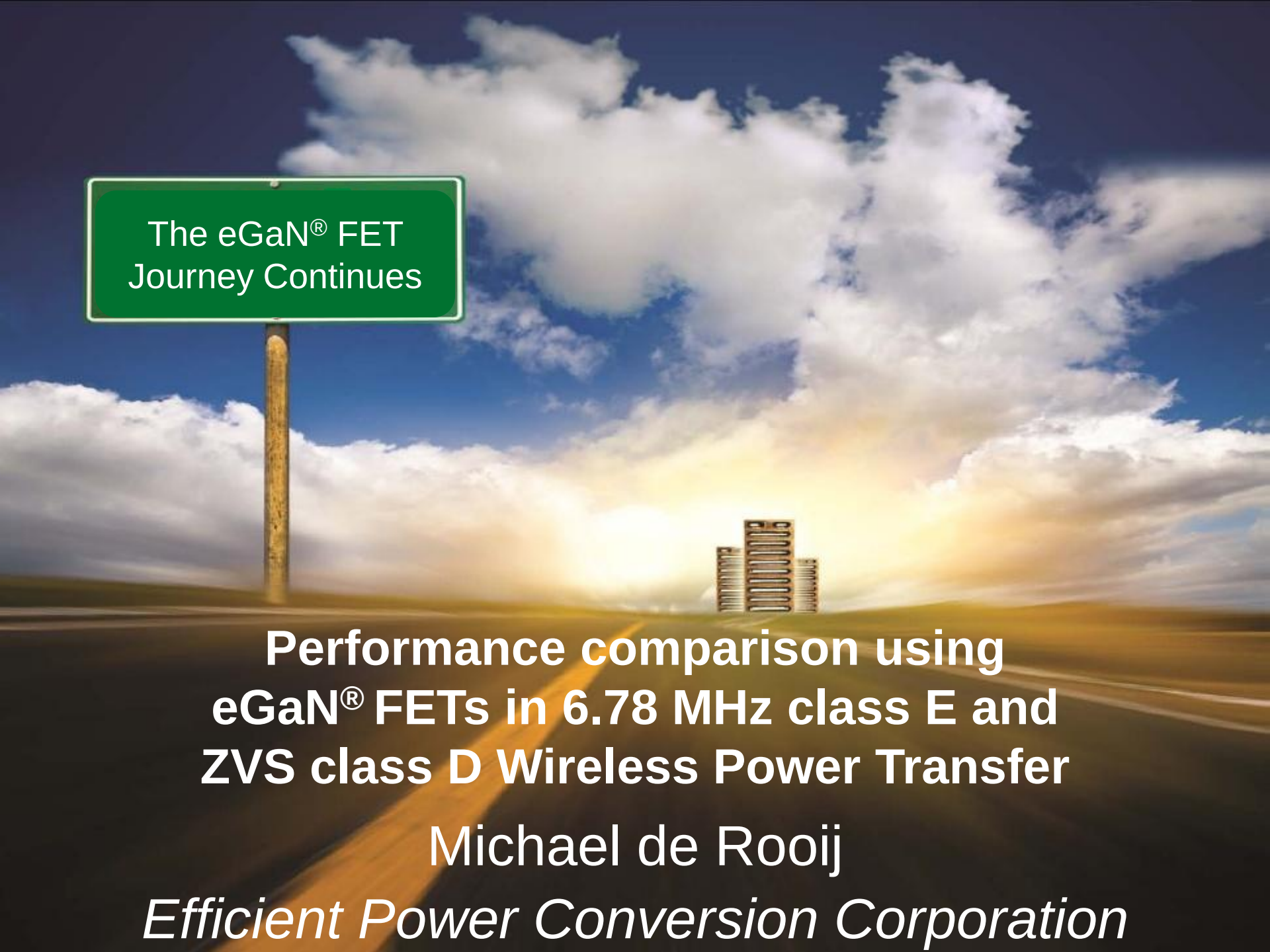


Performance comparison using eGaN® FETs in 6.78 MHz class E and ZVS class D Wireless Power Transfer

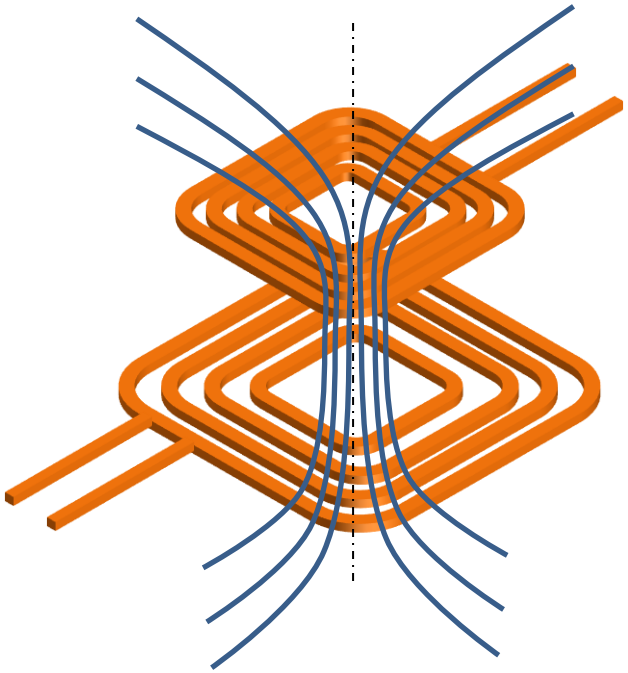
Michael de Rooij

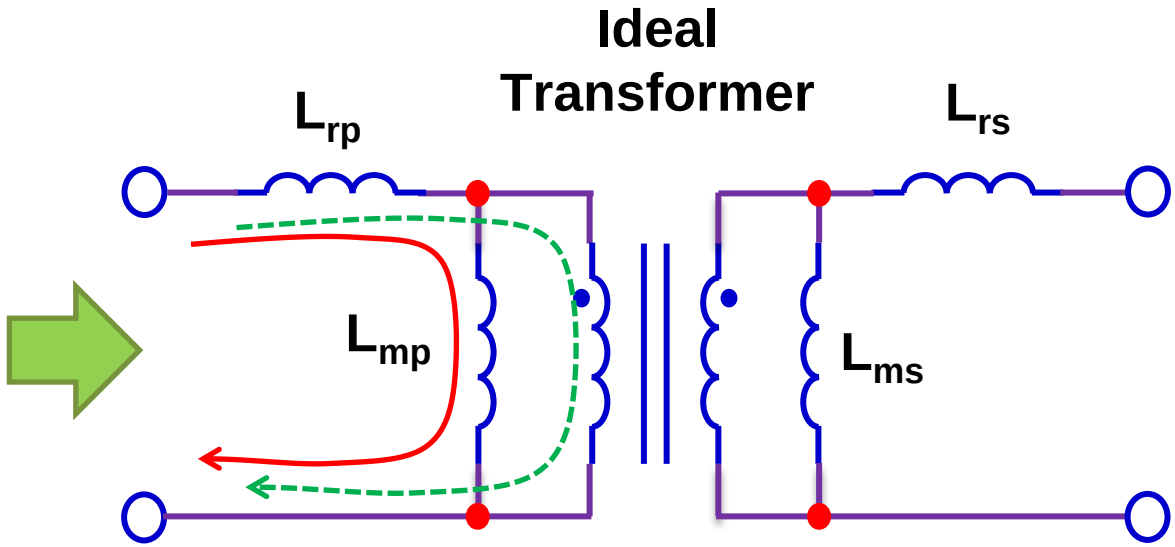
Efficient Power Conversion Corporation

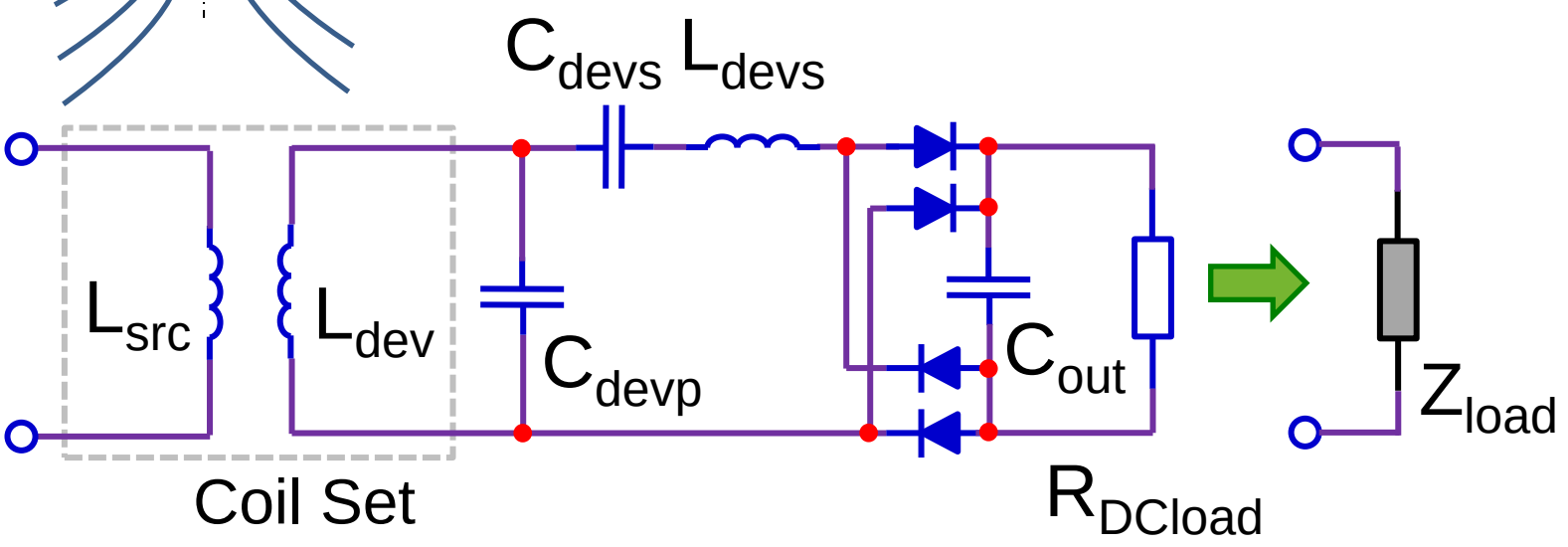
Agenda

- Why Wireless Energy
- Wireless Coil Overview
- Class E for Wireless Power Overview
- ZVS Class D for Wireless Power Overview
- Why eGaN® FETs for Wireless Energy Transfer
- Device comparison
- Experimental performance
- Summary

Wireless Coil-Set Overview

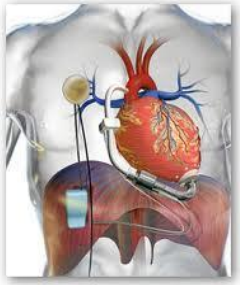






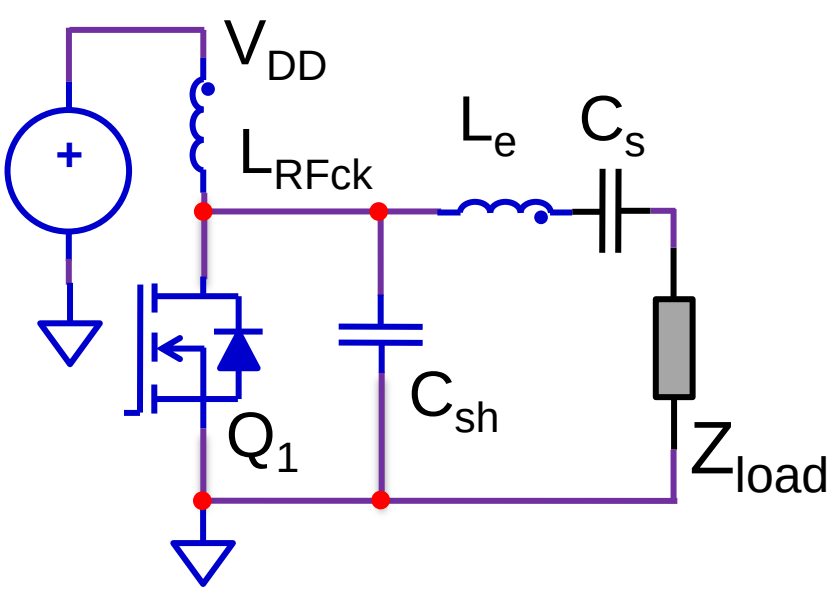
Why Wireless Energy

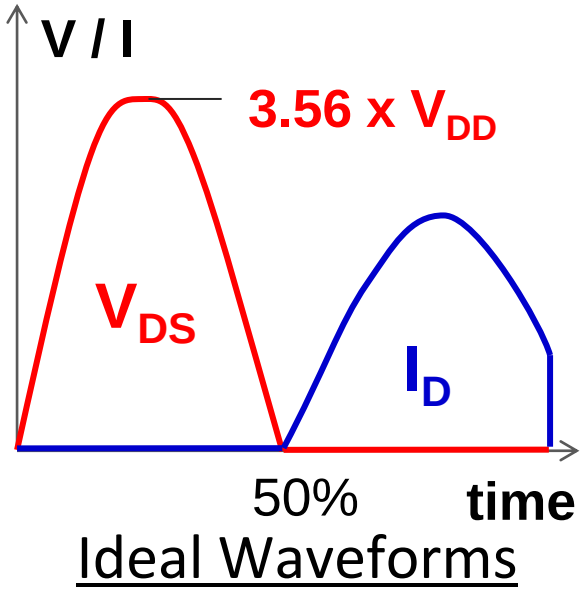
- Mobile device charging
  - Convenience
  - Extended battery life
- Medical Implants
  - Quality of life improvement
  - Life extender
- Hazardous environment systems
  - Explosive atmosphere
  - Corrosive locations
  - High Voltage



Class E Overview

- Switch voltage rating ≥ 3.56·Supply (V_{DD}).
- C_{OSS} "absorbed" into matching network.
- Susceptible to load variation - high FET losses
- Coil Voltage ≈ 0.707·V_{DD} [V_{RMS}]

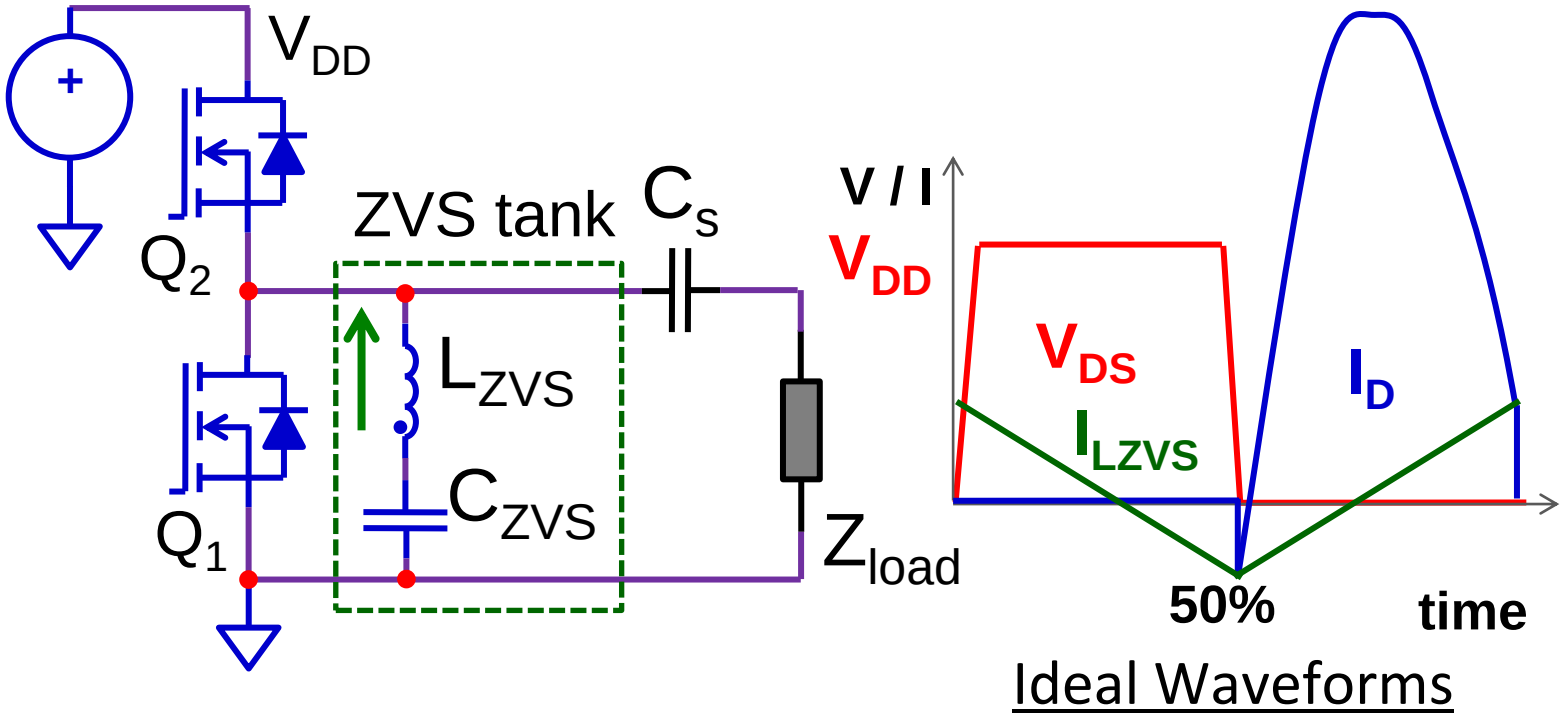




Ideal Waveforms

ZVS Voltage Mode Class D

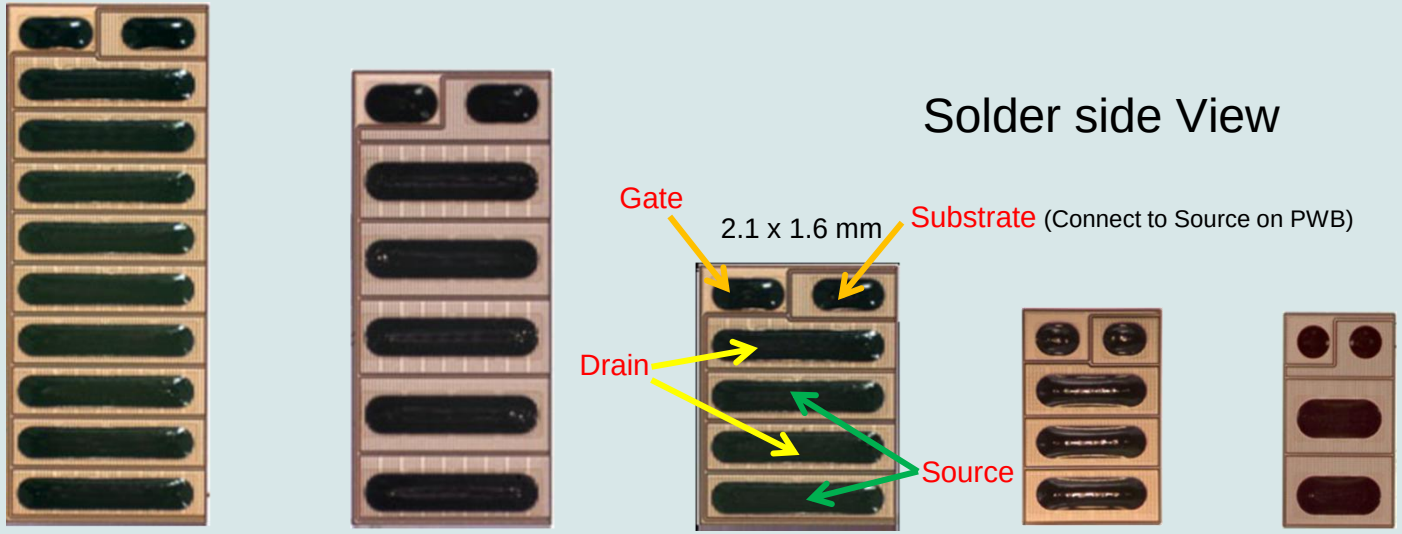
- Switch voltage rating = Supply (V_{DD}).
- C_{OSS} Voltage is transitioned by the ZVS tank
- ZVS tank circuit does not carry load current
- Coil Voltage = ½·V_{DD} [V_{RMS}]



Why eGaN FETs for Wireless

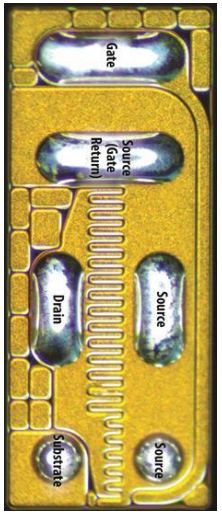
- Low C_{ISS} and C_{OSS}
- Zero Q_{RR}
- Low $R_{DS(on)}$ for equal voltage rating
- Low profile
- Gate Drivers available:
  - LM5113
  - LM5114
  - UCC27611
- dv/dt immunity

eGaN FET Low Voltage Family



Part Number	Package (mm)	V_{DS} (V)	V_{GS} (V)	$R_{DS(on)}$ @5V (mΩ)	Q_G @5 V Typ. (nC)	Q_{GS} Typ. (nC)	Q_{GD} Typ. (nC)	R_G Typ. (Ω)	V_{th} Typ. (V)	Q_{RR} (nC)	I_D (A)	T_J Max. (°C)
EPC2015	LGA 4.1x1.6	40	6	4	10.5	3	2.2	0.6	1.4	0	33	150
EPC2014	LGA 1.7x1.1	40	6	16	2.5	0.67	0.48	0.6	1.4	0	10	150
EPC2001	LGA 4.1x1.6	100	6	7	8	2.3	2.2	0.6	1.4	0	25	125
EPC2016	LGA 2.1x1.6	100	6	16	4.1	0.93	0.75	0.6	1.4	0	11	125
EPC2007	LGA 1.7x1.1	100	6	30	2.1	0.5	0.6	0.6	1.4	0	6	125
EPC2010	LGA 3.6x1.6	200	6	25	5	1.3	1.7	0.6	1.4	0	12	125
EPC2012	LGA 1.7x0.9	200	6	100	1.5	0.33	0.57	0.6	1.4	0	3	125

Ultra High Frequency eGaN FETs



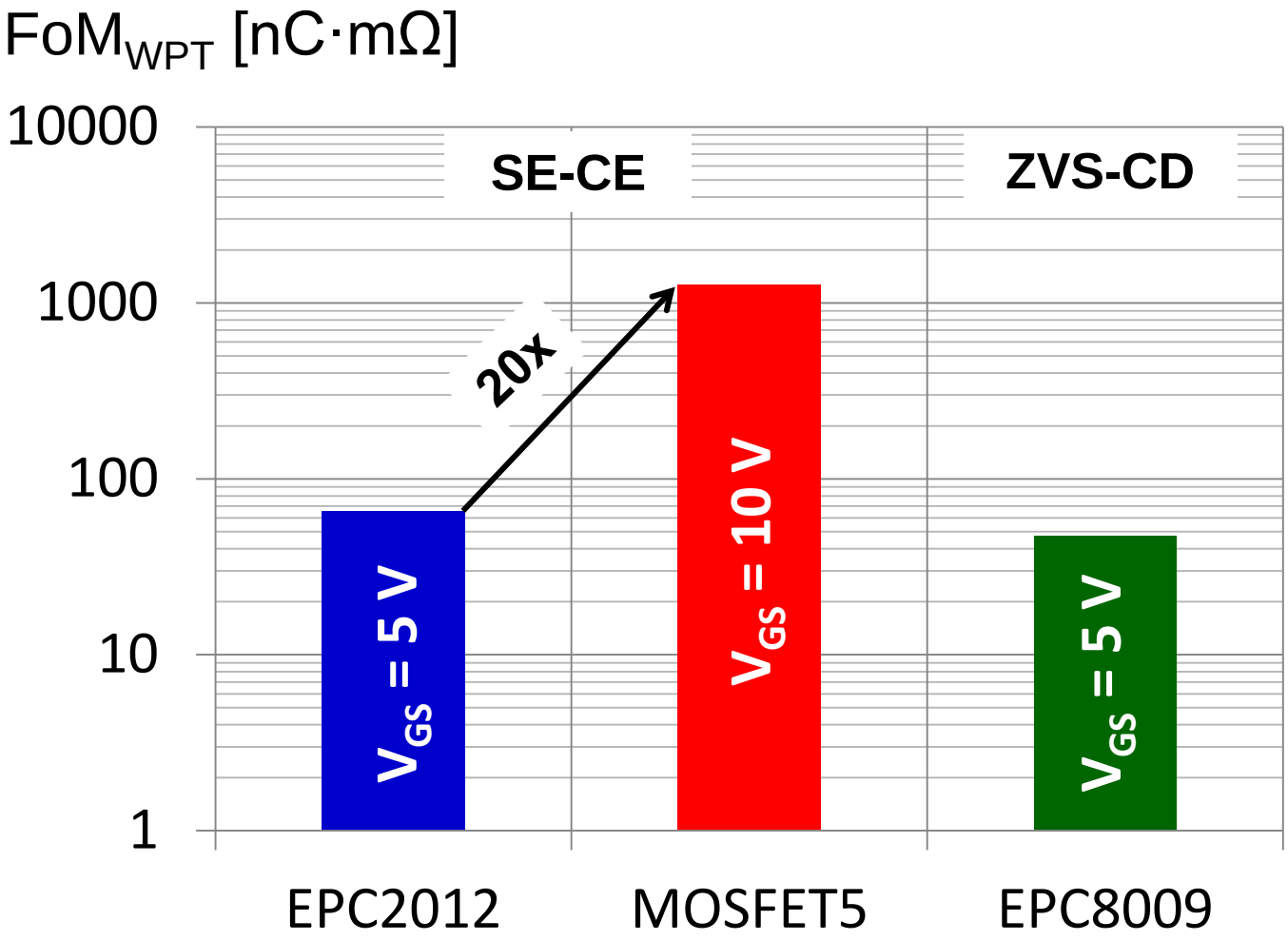
EPC Part No.	BV (V)	Max. $R_{DS(ON)}$ (mΩ) (V_{GS} = 5V, I_D = 0.5 A)	Min. Peak Id (A) (Pulsed, 25 °C, T_{pulse} = 300 µs)	Typical Charge (pC)					Typical Capacitance (pF) (V_{DS} = 20 V; V_{GS} = 0 V)		
				Q_G	Q_{GD}	Q_{GS}	Q_{OSS}	Q_{RR}	C_{ISS}	C_{OSS}	C_{RSS}
EPC8004	40	125	7.5	358	31	110	493	0	45	17	0.4
EPC8007	40	160	6	302	25	97	406	0	39	14	0.3
EPC8008	40	325	2.9	177	12	67	211	0	25	8	0.2
EPC8009	65	138	7.5	380	36	116	769	0	47	17	0.4
EPC8005	65	275	3.8	218	18	77	414	0	29	9.7	0.2
EPC8002	65	530	2	141	9.4	59	244	0	21	5.9	0.1
EPC8003	100	300	5	315	34	110	1100	0	38	18	0.2
EPC8010	100	160	7.5	354	32	109	1509	0	47	18	0.2

Wireless Power Figure of Merit

- All topologies are ZVS: $Q_G - Q_{GD}$ only
- C_{OSS} is "absorbed" in matching – excluded
- Q_{RR} ignored – poorly defined & eGaN FETs are zero and assuming optimal operation
- C_{OSS} still important:
  - Drives off resonance losses
  - Determines design-ability

$$FOM_{WPT} = R_{DS(on)} \cdot (Q_G - Q_{GD})$$

Figure of Merit Device Comparison



$$FOM_{WPT} = R_{DS(on)} \cdot (Q_G - Q_{GD})$$

Experimental Background

- Operating setup:
  - On resonance tuned source coil
  - Device tuning is fixed
- Performance testing:
  - Fixed load, variable supply (Peak Performance)
  - Fixed load voltage (15 V), variable DC load (20:1 ratio – 10 Ω through 200 Ω) (Load Regulation)
  - Category 3 power limited Constant Coil Current, emulates charging smart phone

Experimental Setup Overview

Amplifiers:

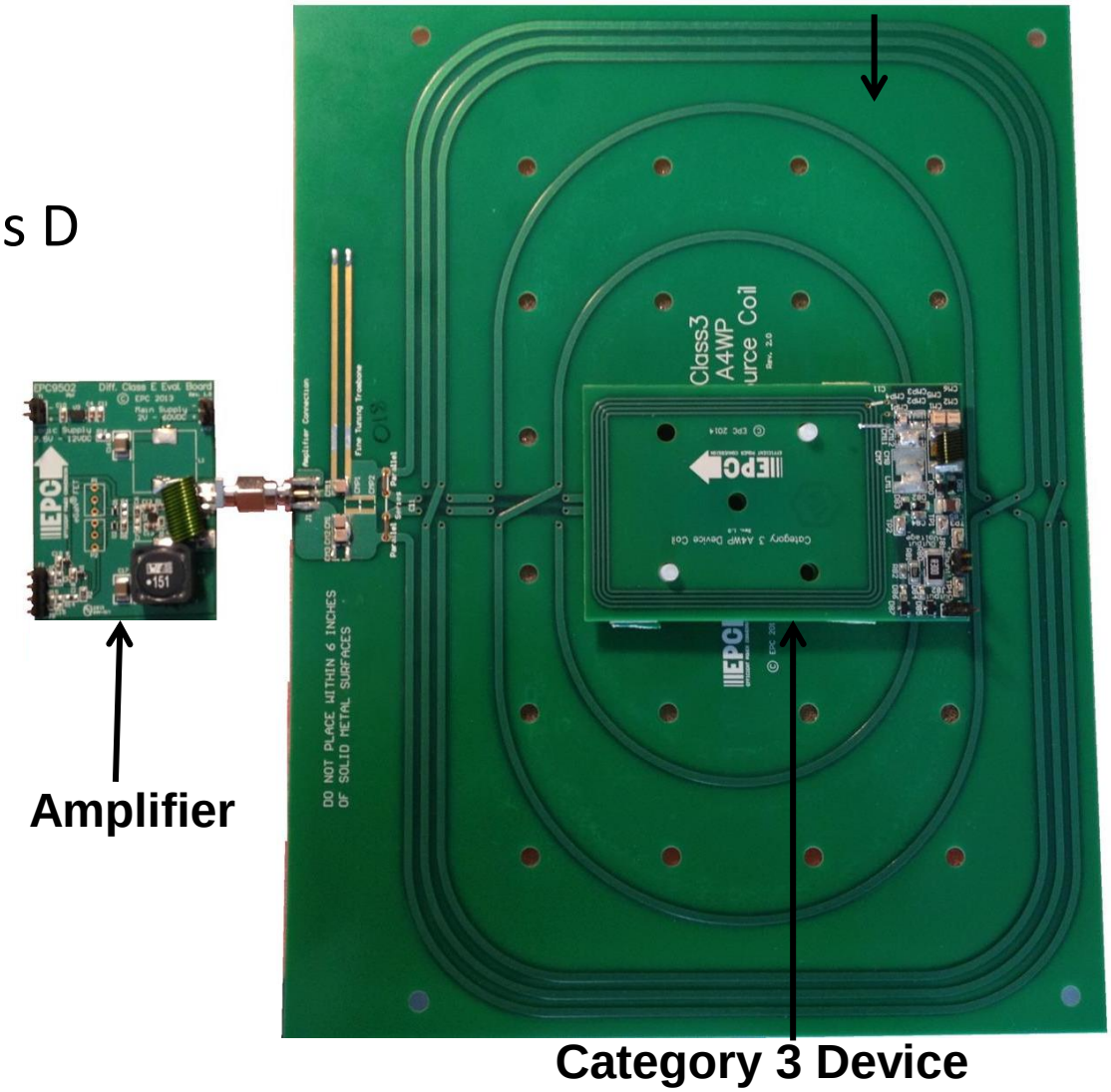
- EPC9502 (EPC2012) Class E
- EPC9503 (MOSFET5) Class E
- EPC9029 (EPC8009) ZVS Class D

Source Coil:

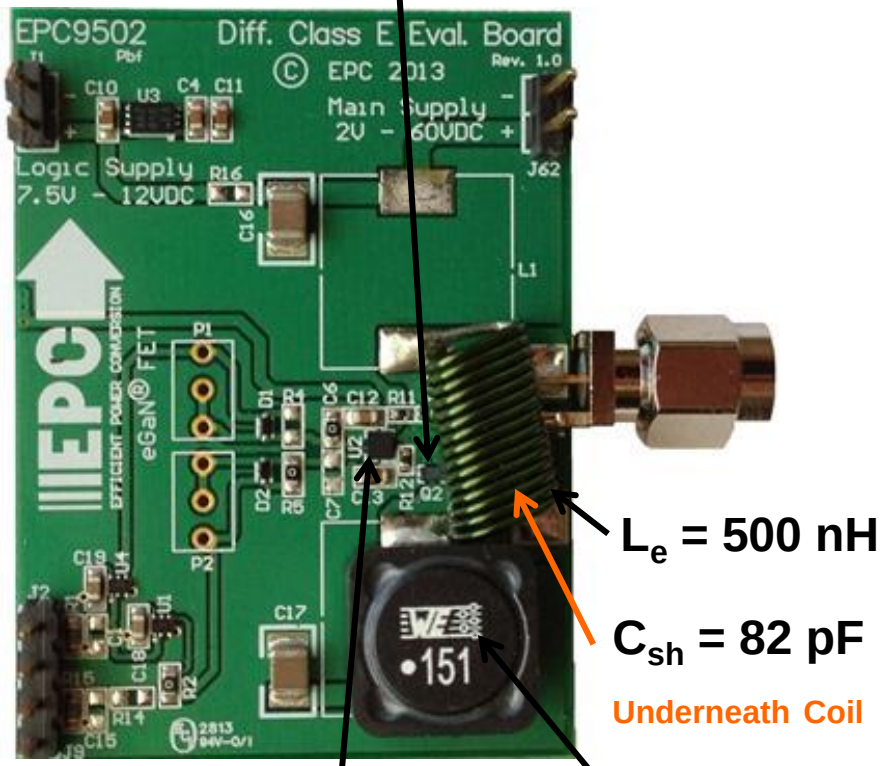
- A4WP Class 3 Compliant

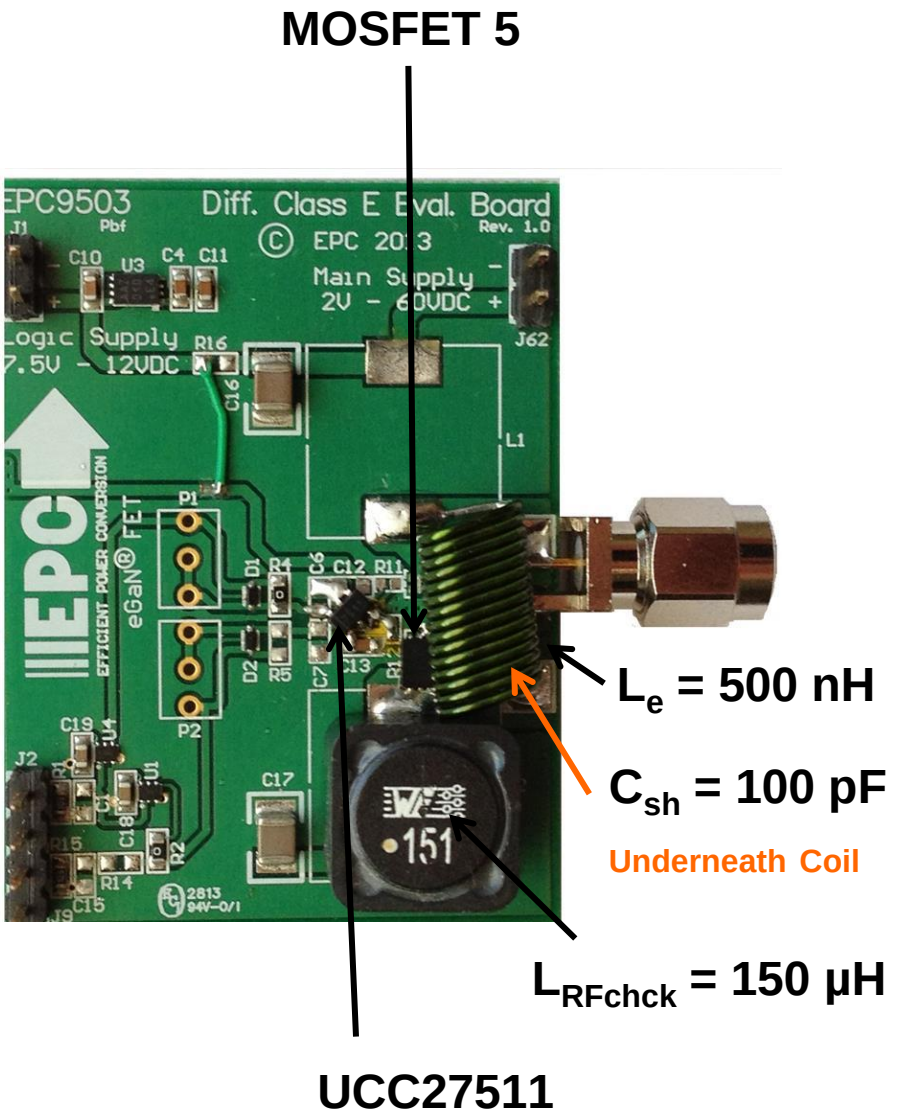
Device Coil:

- A4WP Category 3 Compliant

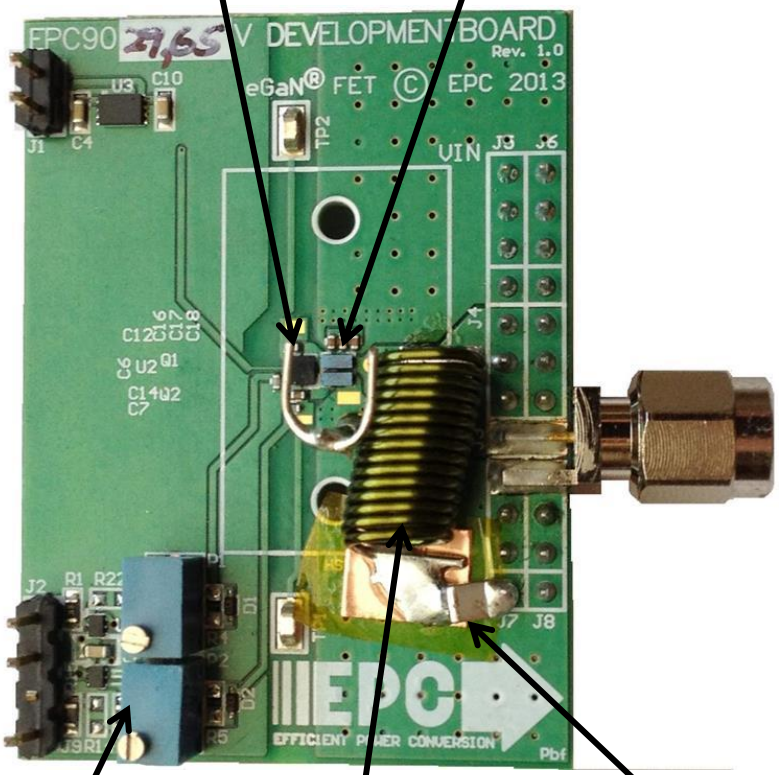


Class E Amplifiers





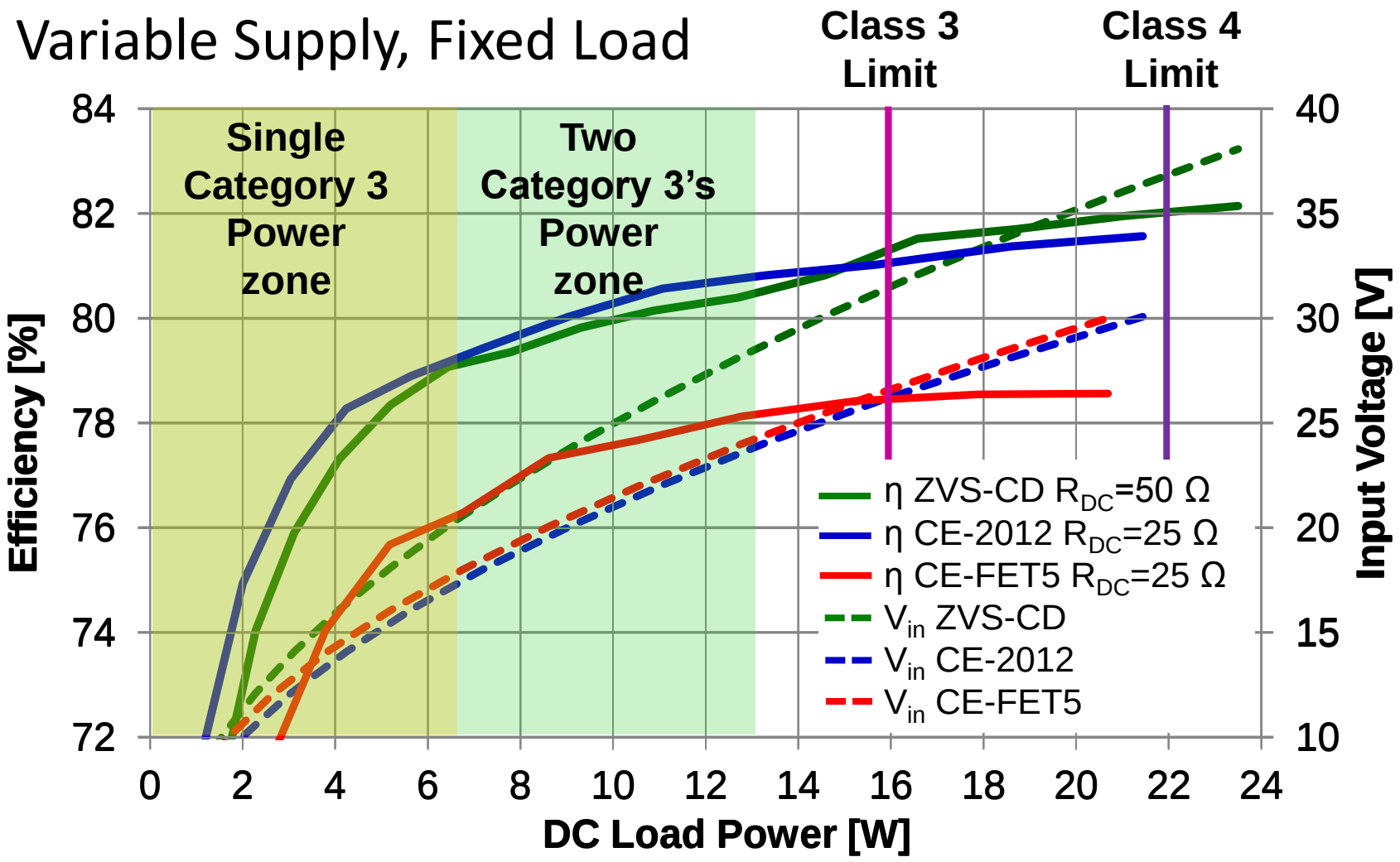
eGaN FET ZVS Class D Amplifier



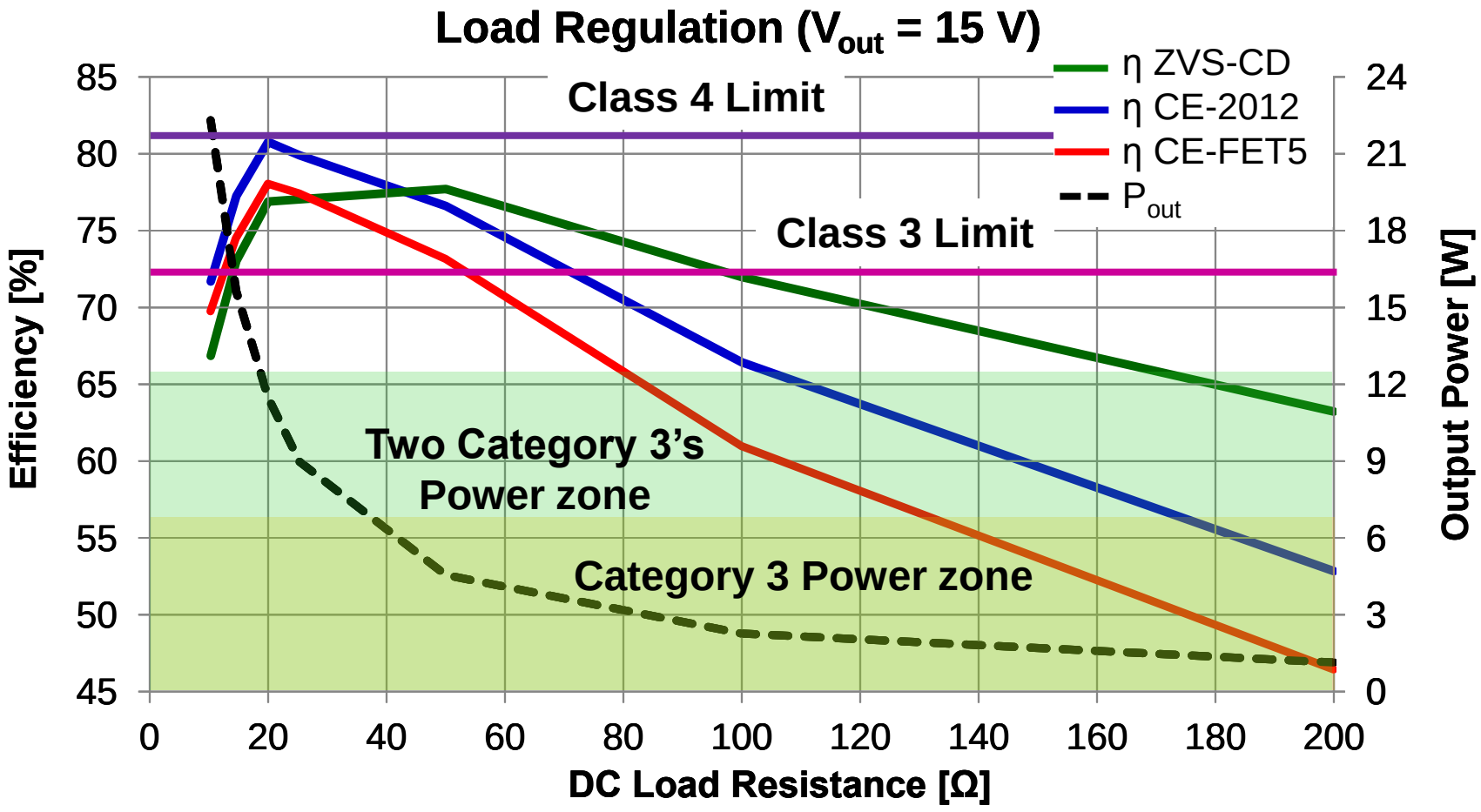
Peak Performance Results

Peak Efficiency, Single load capability

Variable Supply, Fixed Load

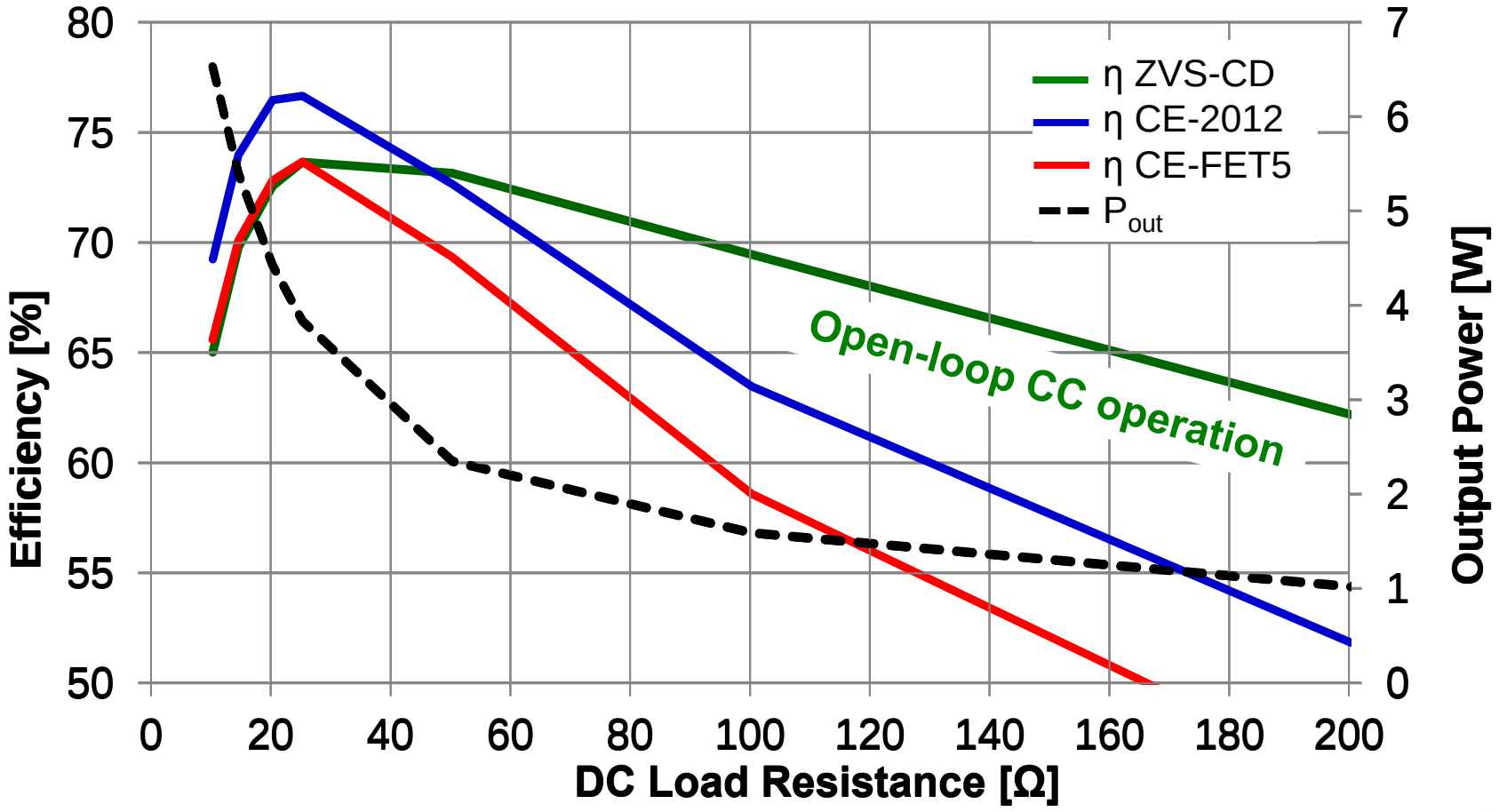


Load Regulation Results

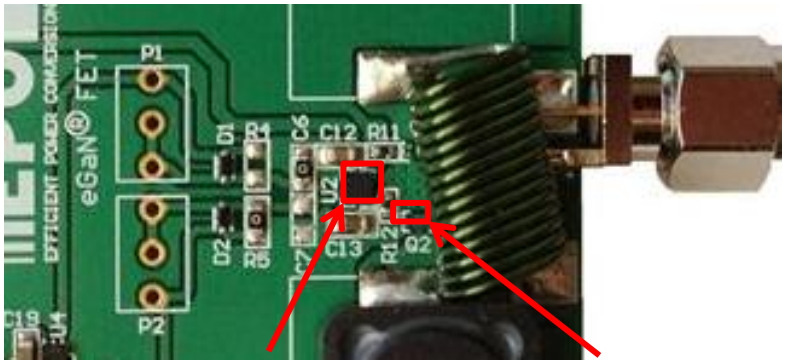


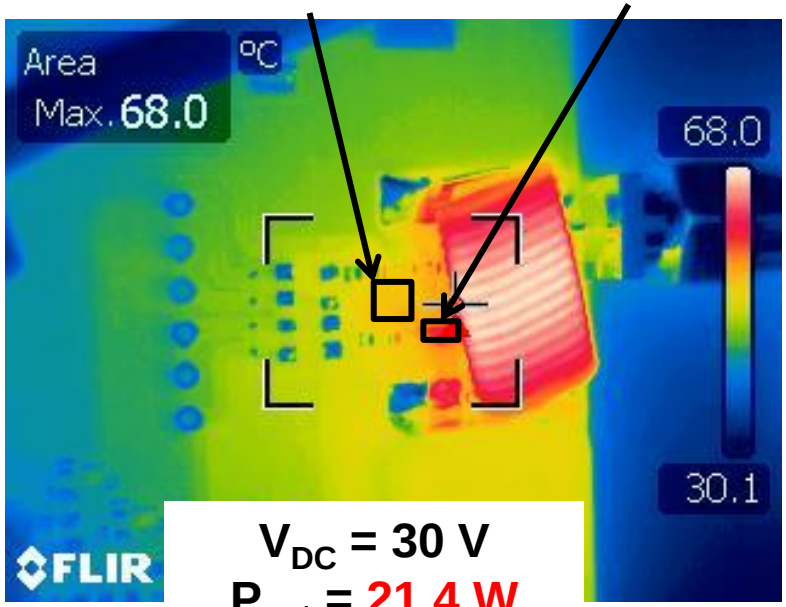
Load Variation Results

Evaluation Load profile emulating charging Smart Phone
A4WP Category 3 Device

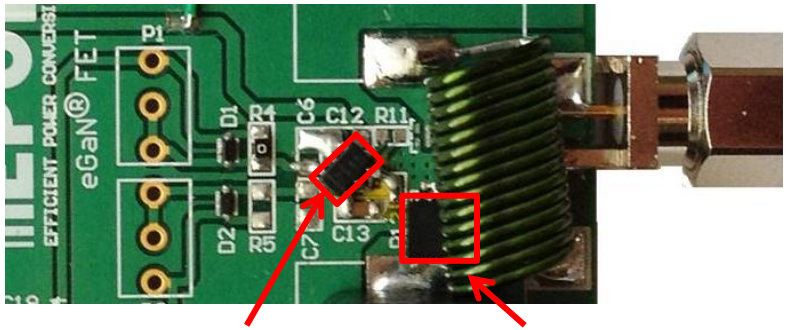


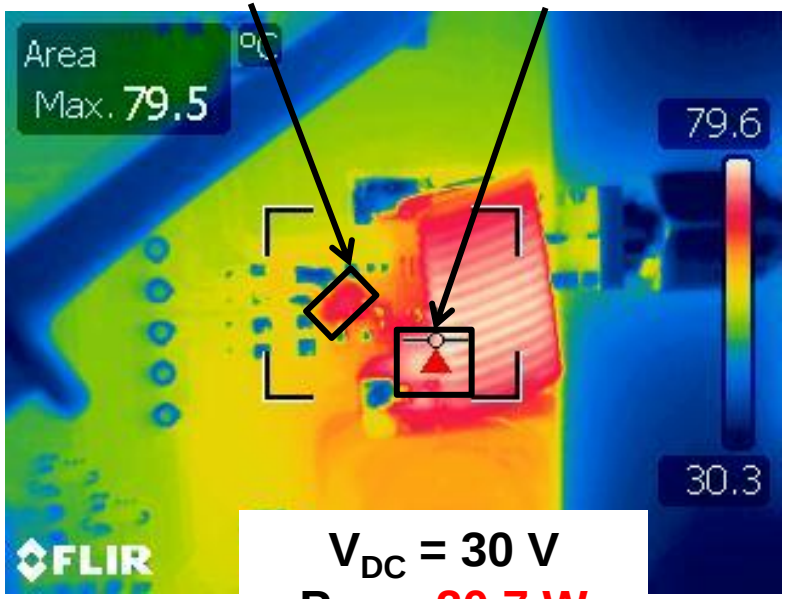
Class E Thermal Performance





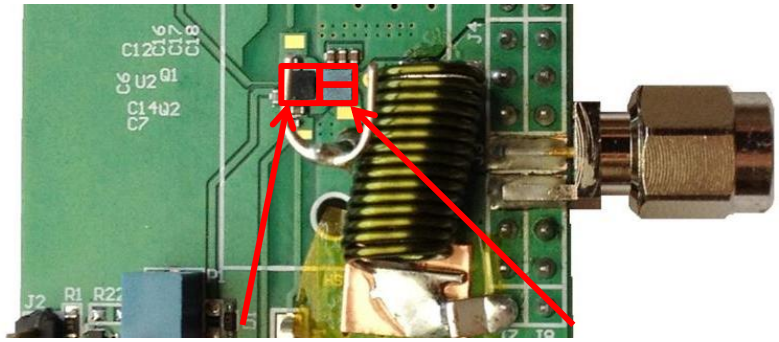
V_{DC} = 30 V
P_{out} = 21.4 W
R_{DCload} = 25.3 Ω



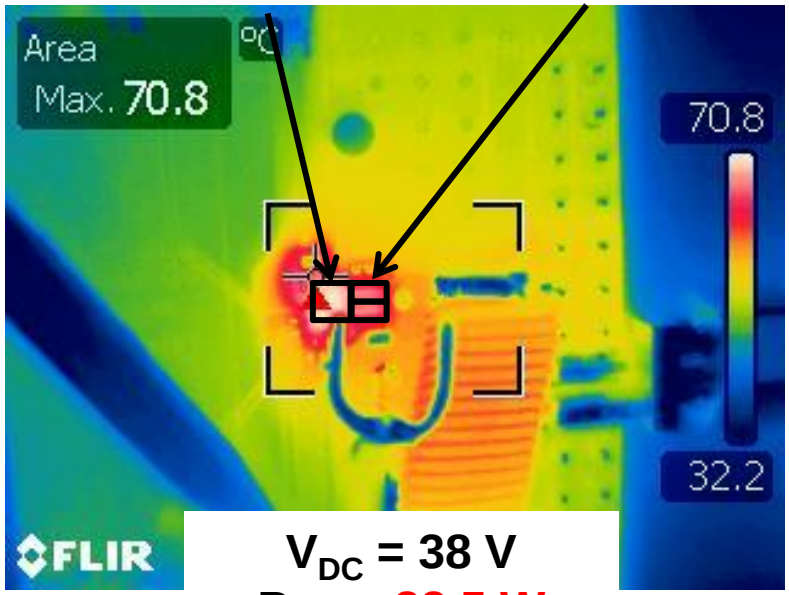


V_{DC} = 30 V
P_{out} = 20.7 W
R_{DCload} = 25.3 Ω

ZVS Class D Thermal Performance



LM5113 EPC8009



V_{DC} = 38 V
P_{out} = 23.5 W
R_{DCload} = 50.3 Ω

Summary

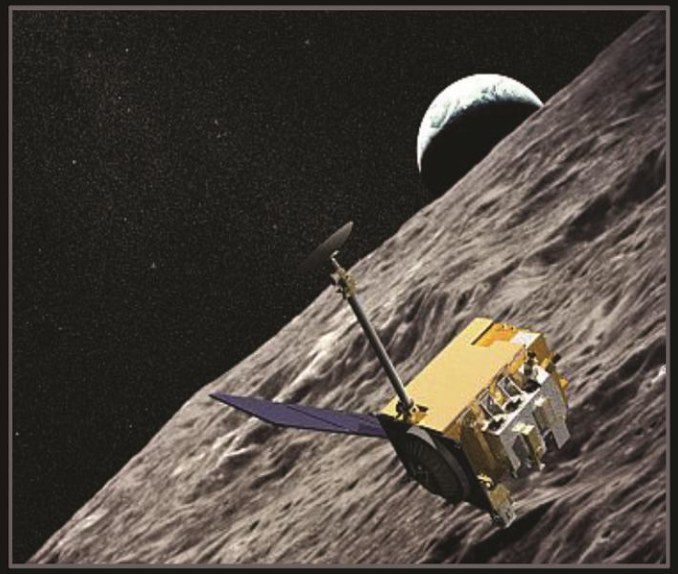
eGaN® FETs are disruptive in Wireless Energy:

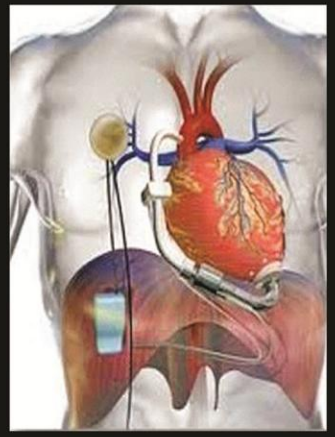
- Enable Wireless Power
- Yield Higher Efficiency than MOSFETs
  - Including over a wide load range
- Can easily operate at 6.78 MHz
- Easy to use
- Drive new topologies e.g. ZVS Class D
- Growing support e.g. Gate drivers and products use them.

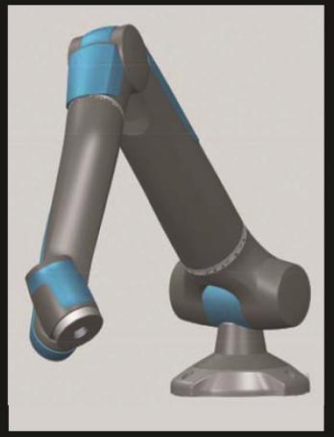
EPC

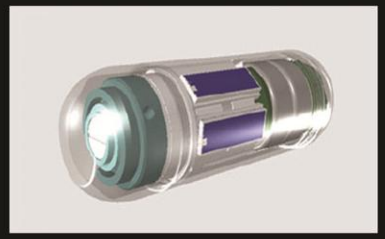
EFFICIENT POWER CONVERSION

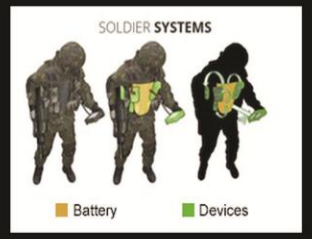
Where is GaN going…











Evaluation Load Profile

- Emulates Mobile phone charging
- Based on ZVS class D operating with 250 mA fixed supply current into tuned source coil
- Max. output power set at 10 Ω DC load Resistance (assumes typical post regulator current draw)