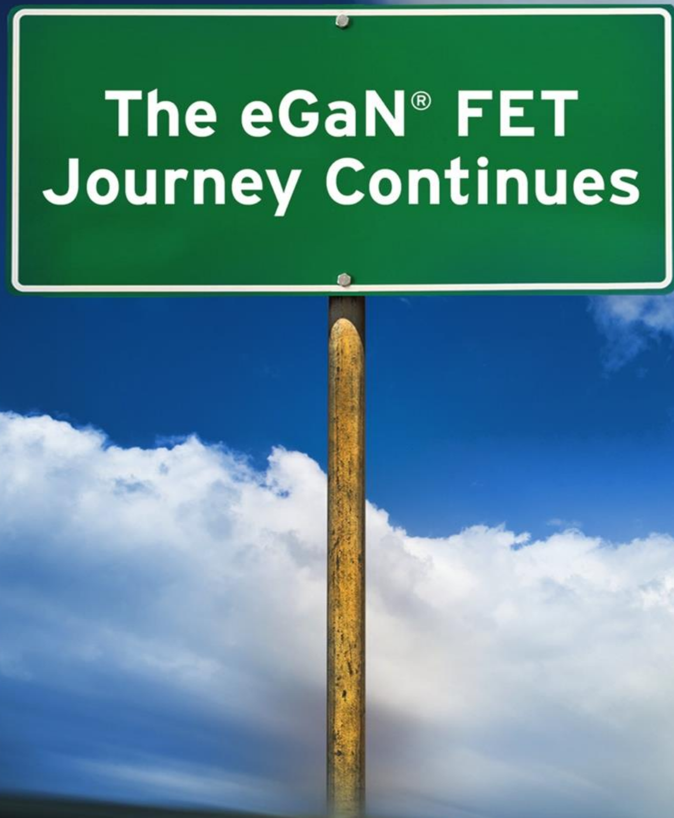


Michael de Rooij & Yuanzhe Zhang

Comparison of 6.78 MHz Amplifier Topologies for 33W, Highly Resonant Wireless Power Transfer

Efficient Power Conversion Corporation

Agenda

- Wireless power trends
- AirFuel™ Class 4
- High power capable amplifiers
- Experimental results
- Summary

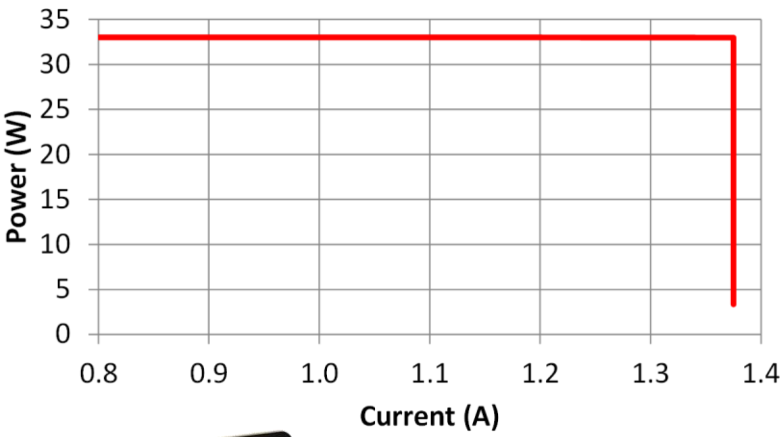
Wireless Power Trends

Higher power

- More devices needing wireless power
  - Smartphones (~6 W)
  - Tablets (~13 W)
  - Small laptops (~25 W)
- Fast charging
- Move toward wireless power, not just charging

AirFuel Class 4 Operation

- 1.375 A_{RMS} into the coil or de-rated at 33 W
- 6.78 MHz



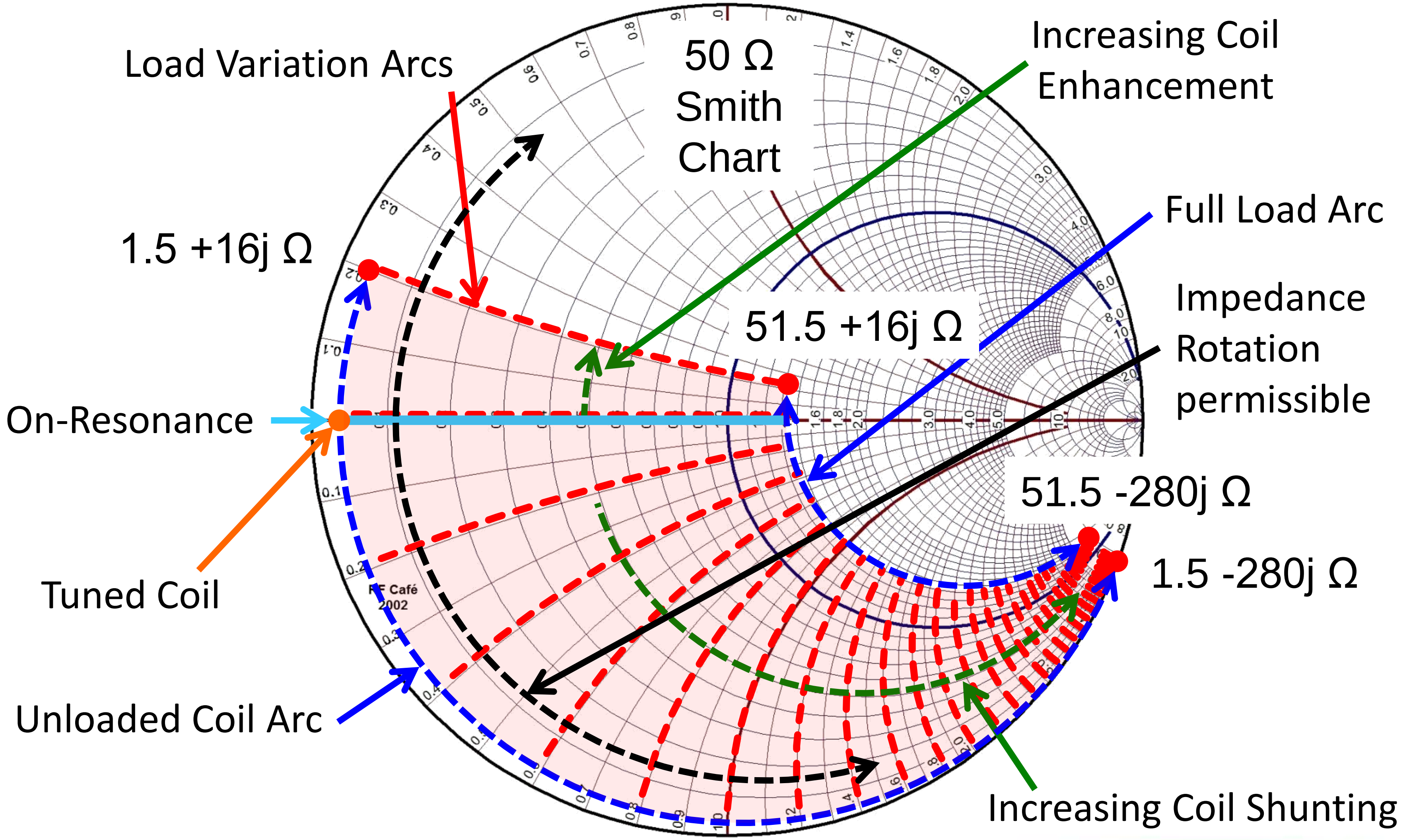
AirFuel™ Alliance

- Devices
  - 1x Category 5 (20 W)

  up to

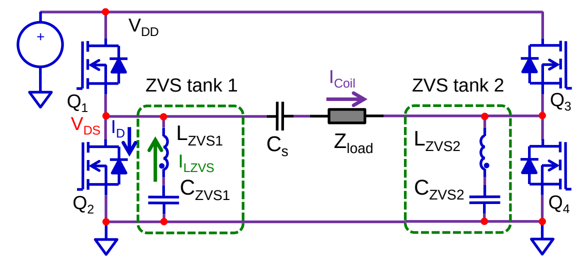
  - 3x Category 3 (6.5 W)

AirFuel Class 4 Impedance

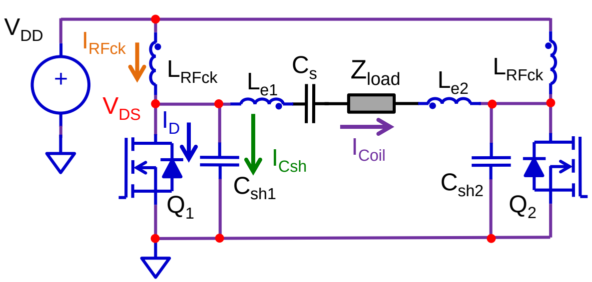


Wireless Power Amplifiers

- Differential mode ZVS class D
  – Robust to load variations
  – Requires level shifting gate driver

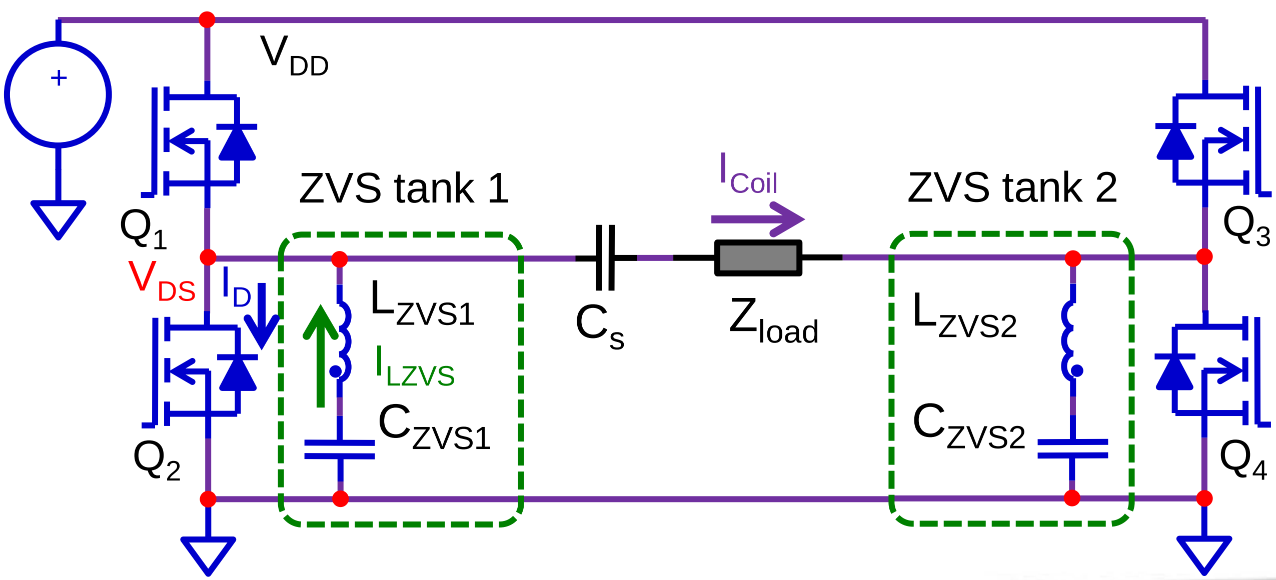


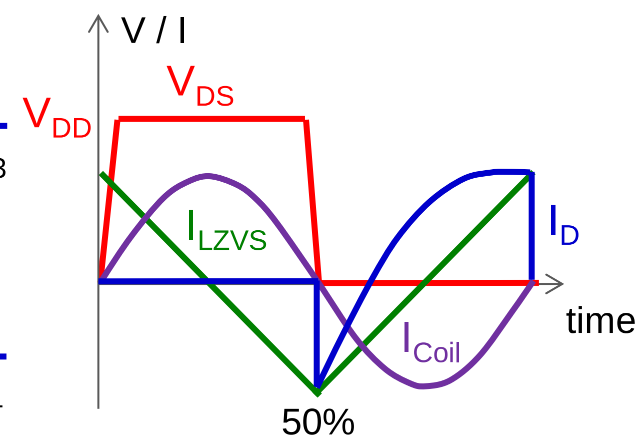
- Differential mode class E
  – Simple and low cost
  – Susceptible to load variations



ZVS Class D Design

- Analytical design: -50j Ω through +50j Ω & 1 Ω through 52 Ω
- Optimal L_{ZVS} and dead-time:
  - EPC2007C (30 mΩ) = 390 nH, 8ns
  - EPC8010 (160 mΩ) = 500 nH, 3.5 ns
- Requires synchronous bootstrap

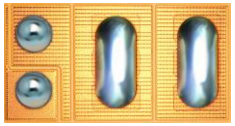


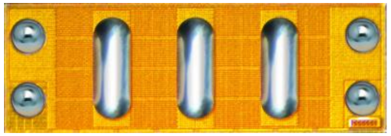


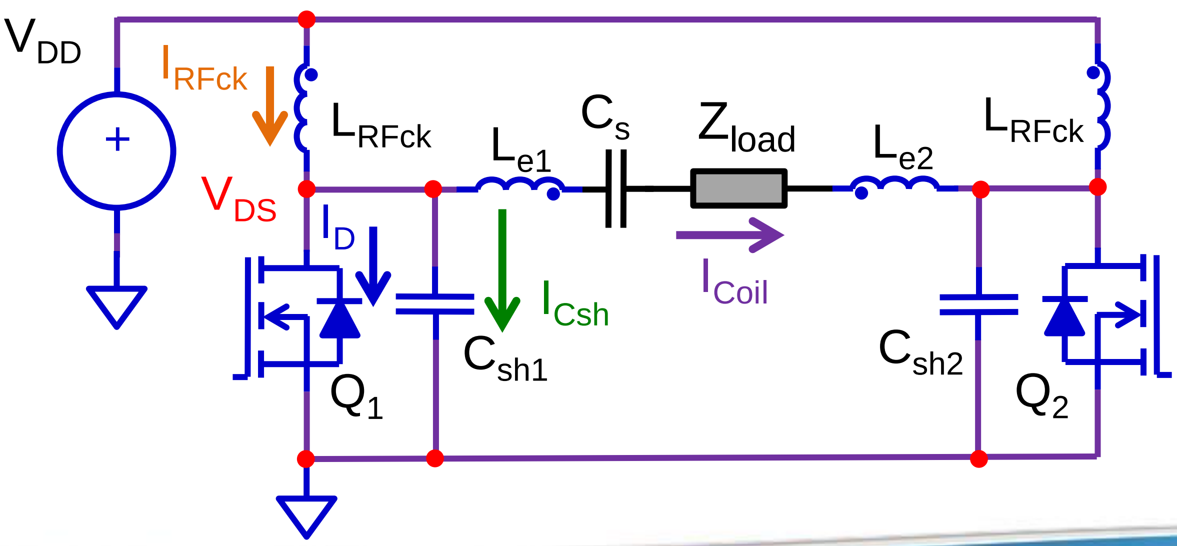
Ideal Waveforms

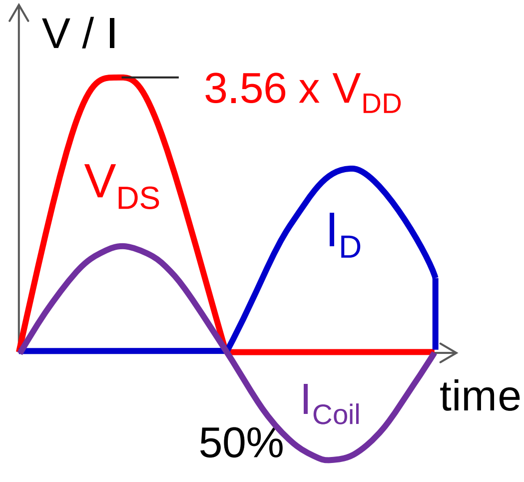
Class E Design

- Optimal load point analysis by simulation
- Realizable design FET selection:
  - EPC2012C (100 mΩ), C_{sh} = 68 pF
  - EPC2019 (50 mΩ) , C_{sh} = 0 pF
- Le = 600 nH, L_{RFck} = 39 µH





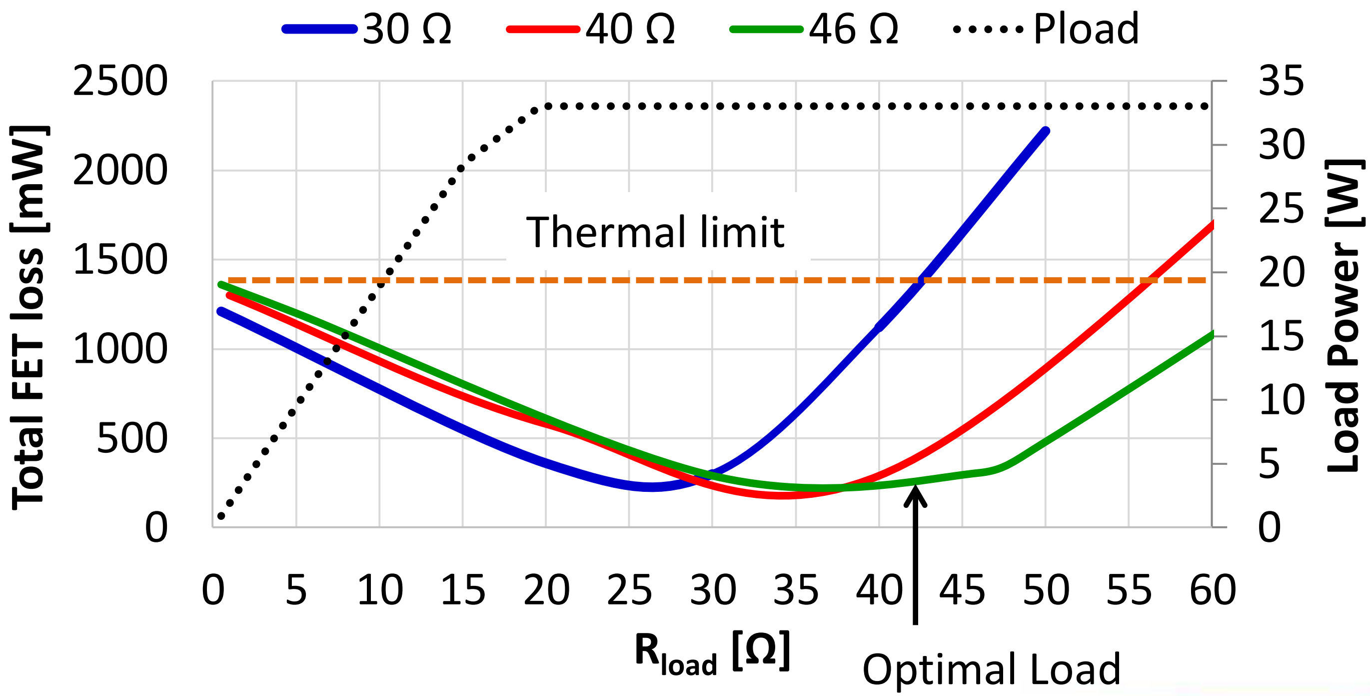




Ideal Waveforms

Class E Optimization

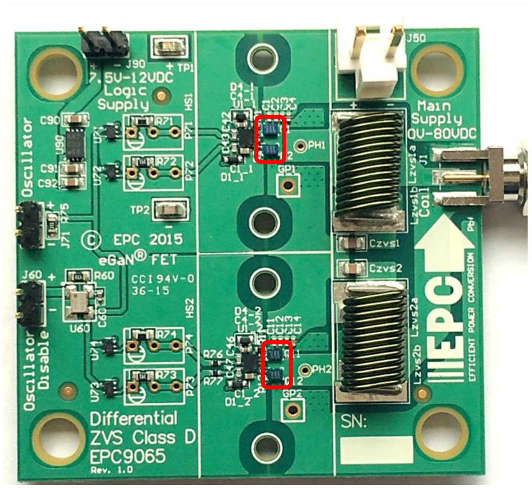
- LTSpice simulation: Total FET power loss
- Optimal load resistance – lowest cumulative FET loss over entire Load resistance range



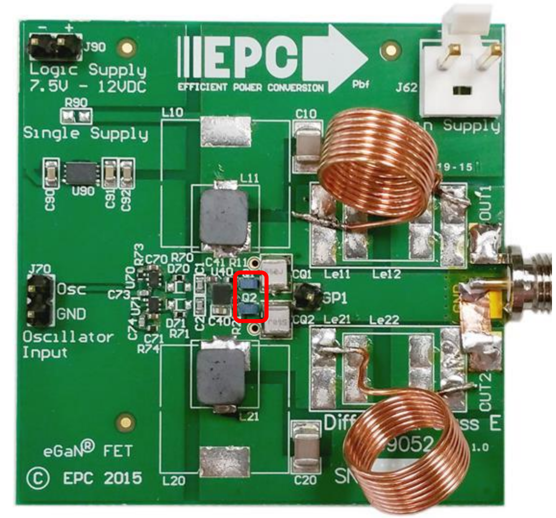
Experimental Units

ZVS class D | Class E

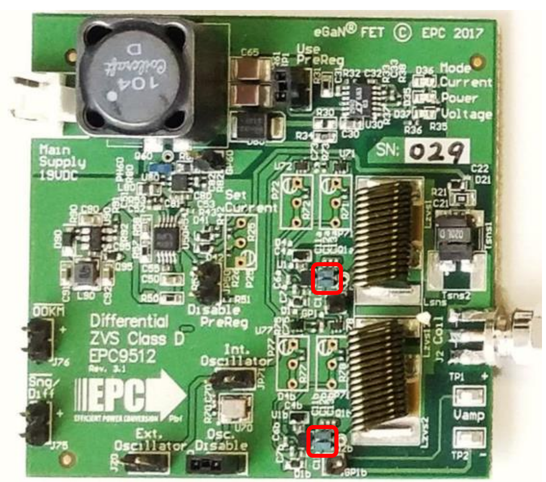
EPC2007C



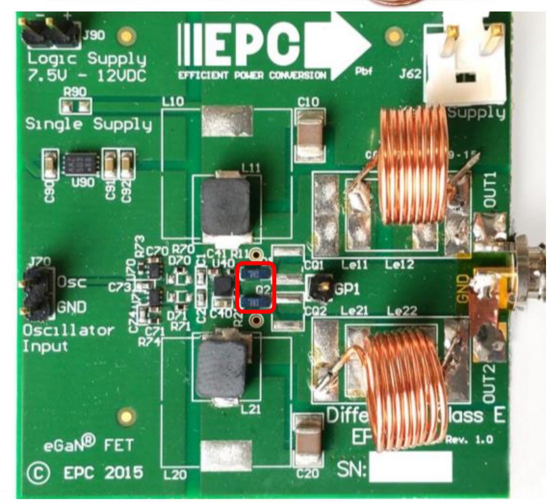
EPC2012C



EPC8010

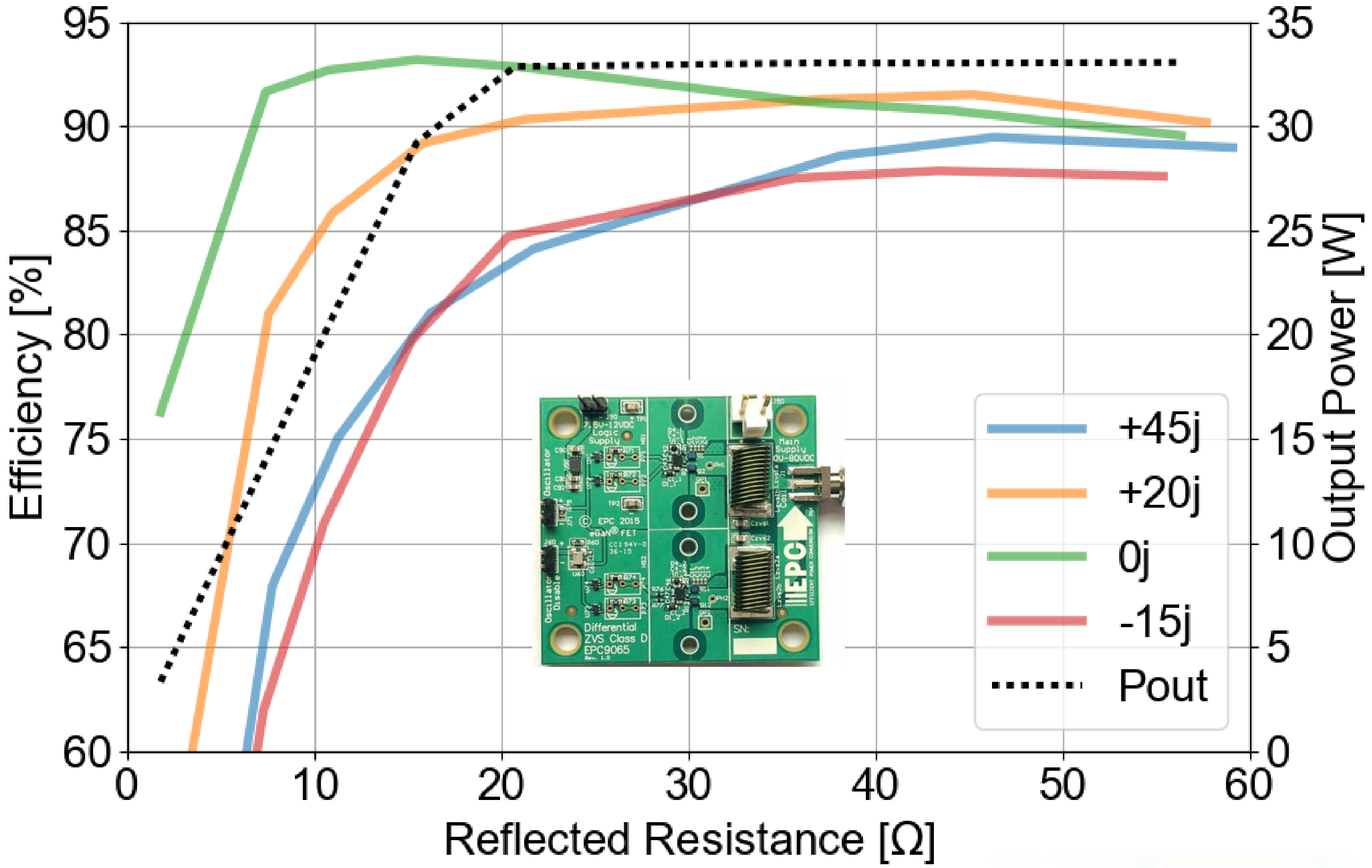


EPC2019



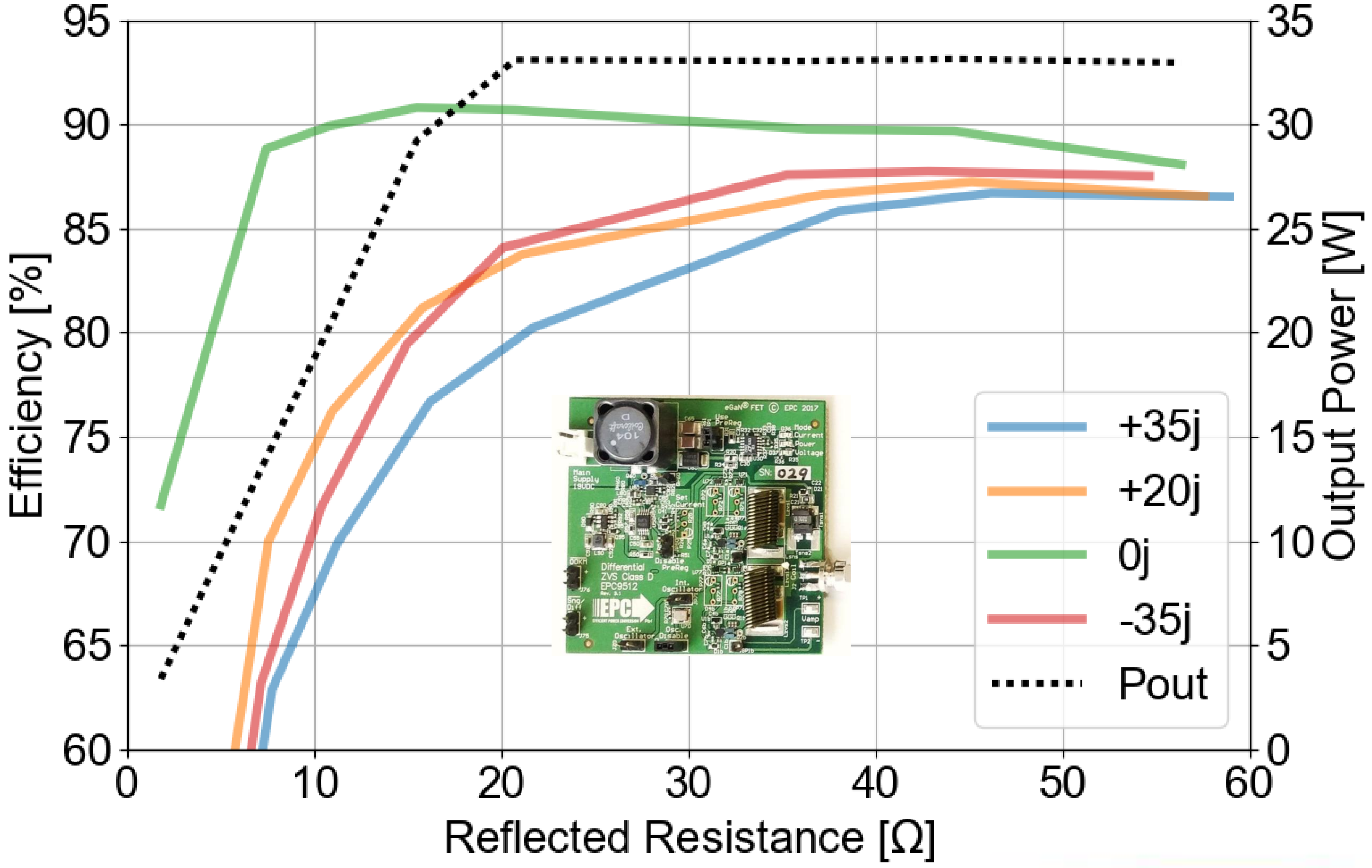
Class D – EPC2007C

- Thermally limited at extreme load impedances
- **60j Ω** range class 4 capable



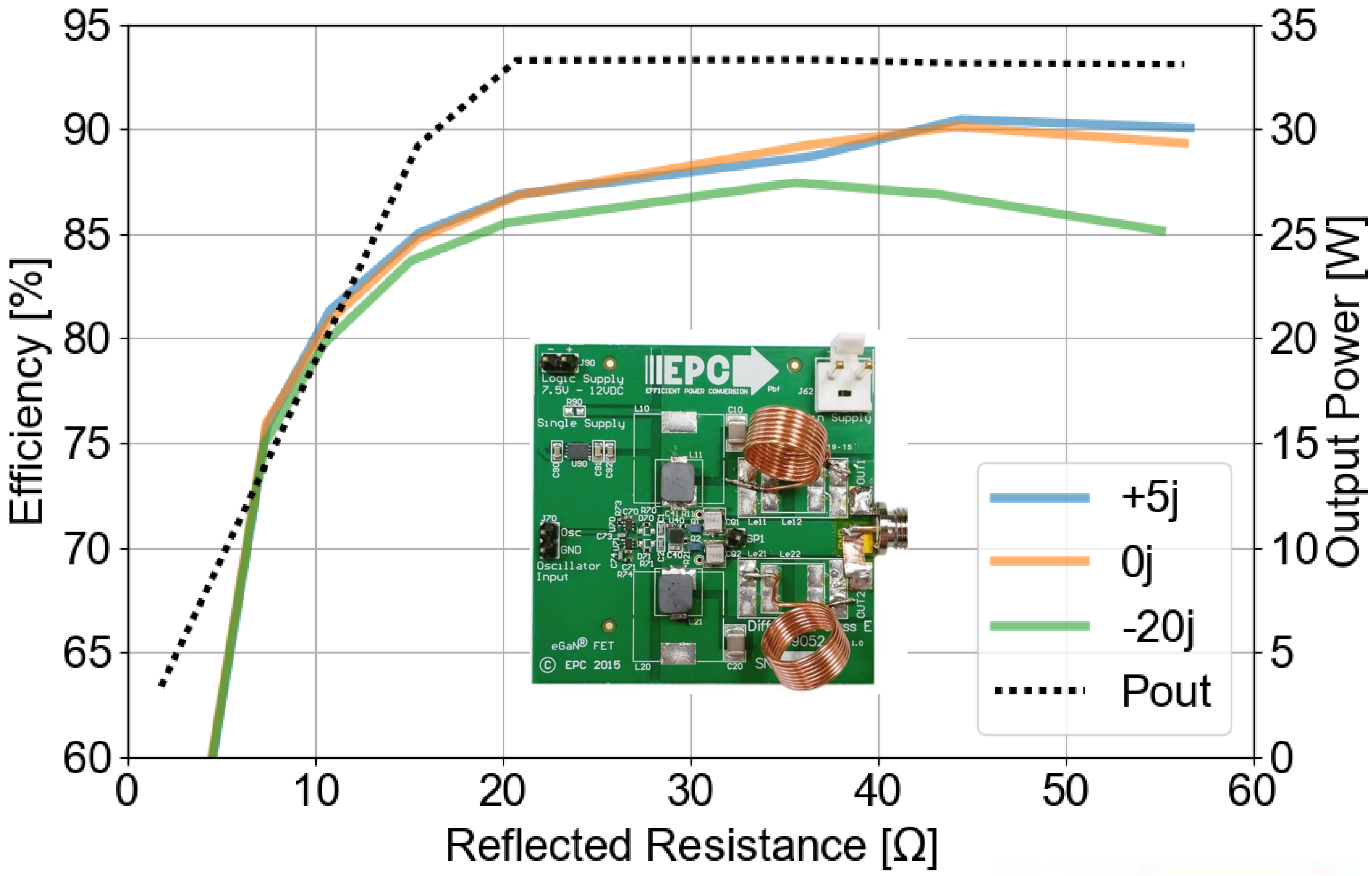
Class D – EPC8010

- Thermally limited at extreme load impedances
- **70j Ω** range class 4 capable



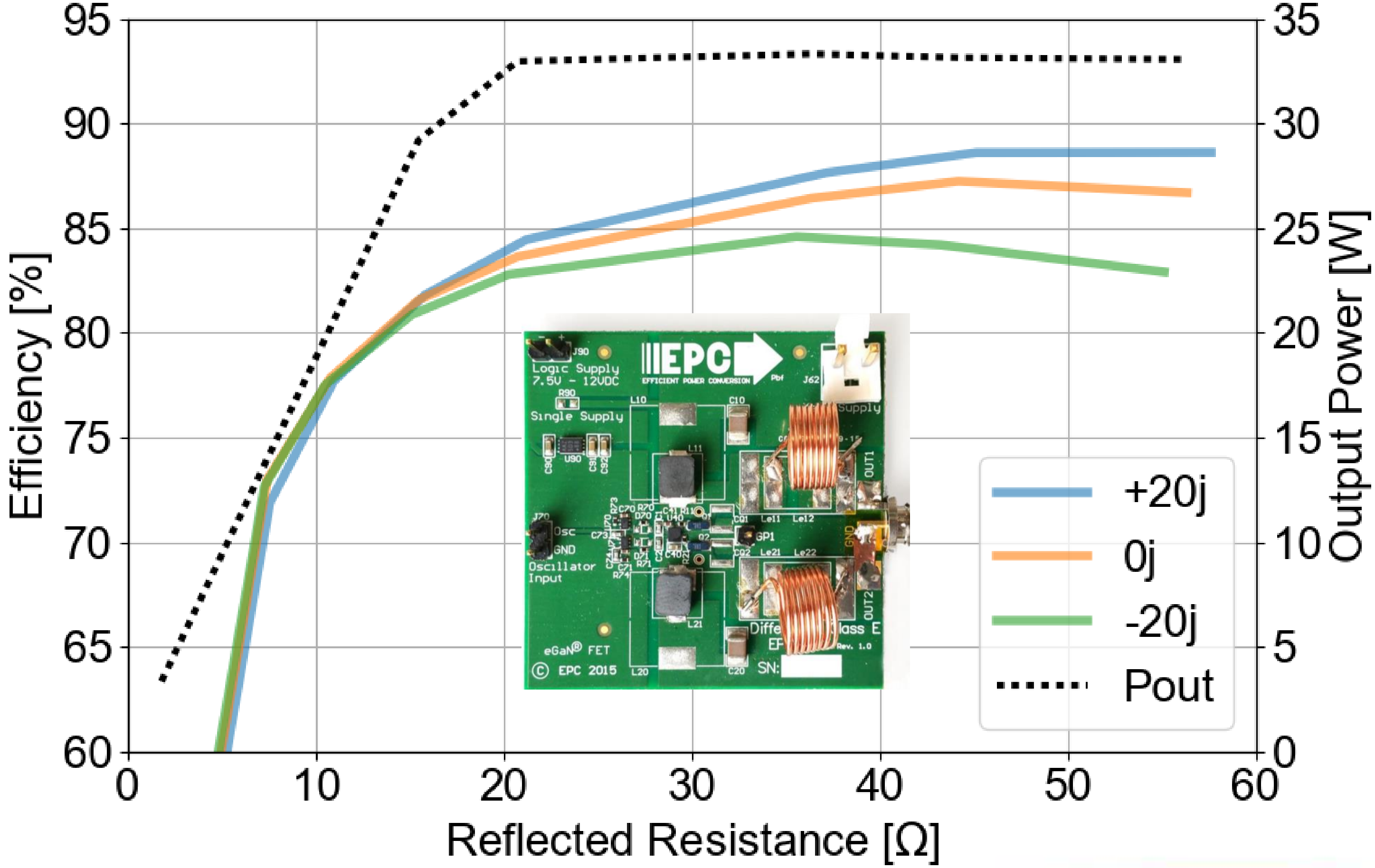
Class E – EPC2012C

- Thermally and voltage limited
- **25j Ω** range class 4 capable



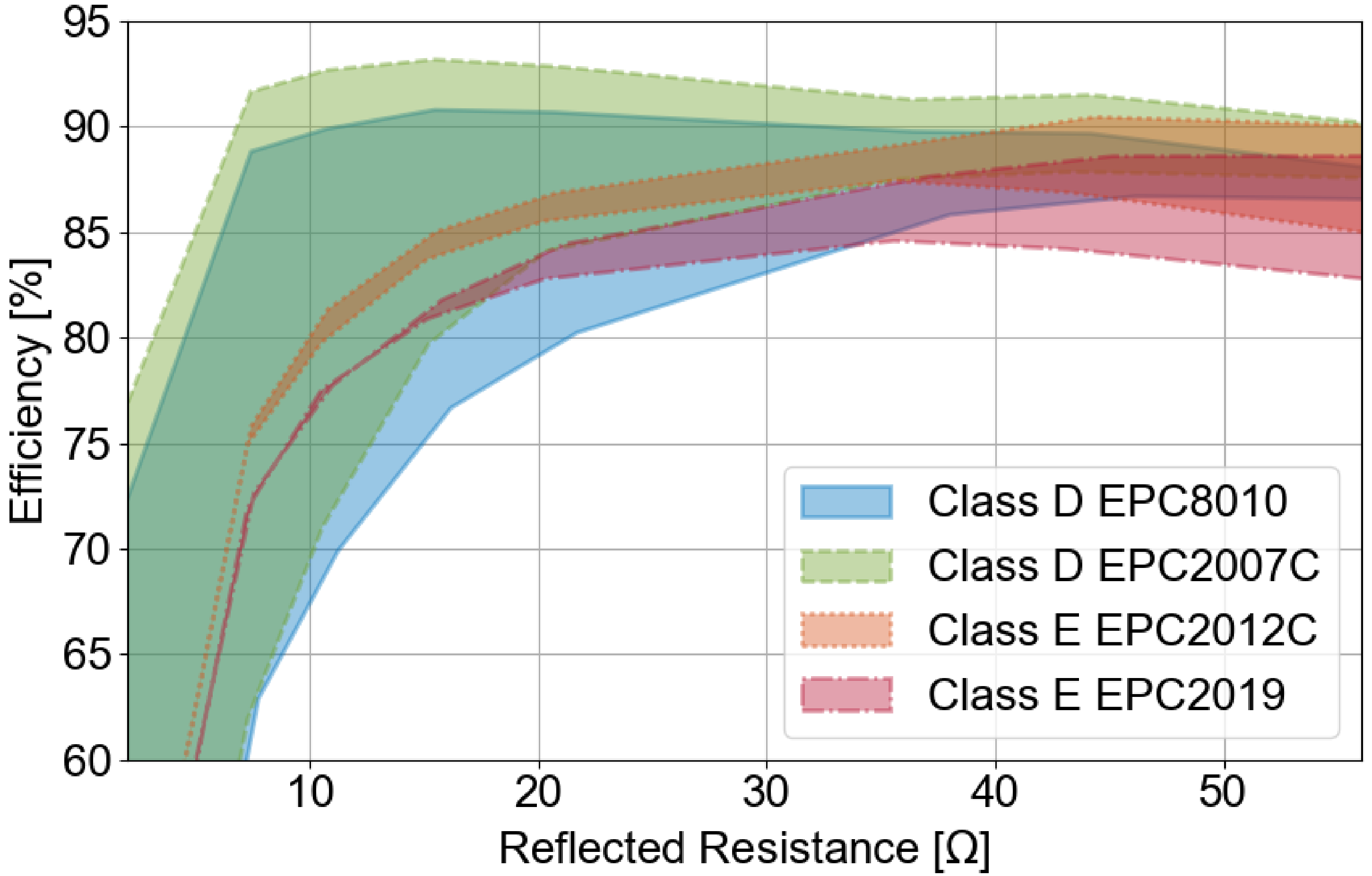
Class E – EPC2019

- Thermally and voltage limited
- **40j Ω** range class 4 capable



Efficiency ranges – all designs

Class D - wide variation due to wider impedance range



Amplifier Performance Summary

- Class E performance nearly identical when compared over same impedance range
- Class D yields greater improvement from lower R_{DSon}

Topology	eGaN FET (R_{DSon})	Efficiency Range at max. Power	Reactance Range	Relative Range
ZVS class-D	EPC8010	80.2% to 90.6%	**-35j to +35j Ω**	70j Ω
	EPC2007C	**87.5% to 92.8%**	-15j to +45j Ω	60j Ω
Class-E	EPC2012C	85.1% to 90.4%	**-20j to +5j Ω**	25j Ω
	EPC2019	82.8% to 88.6%	-20j to +20j Ω	40j Ω

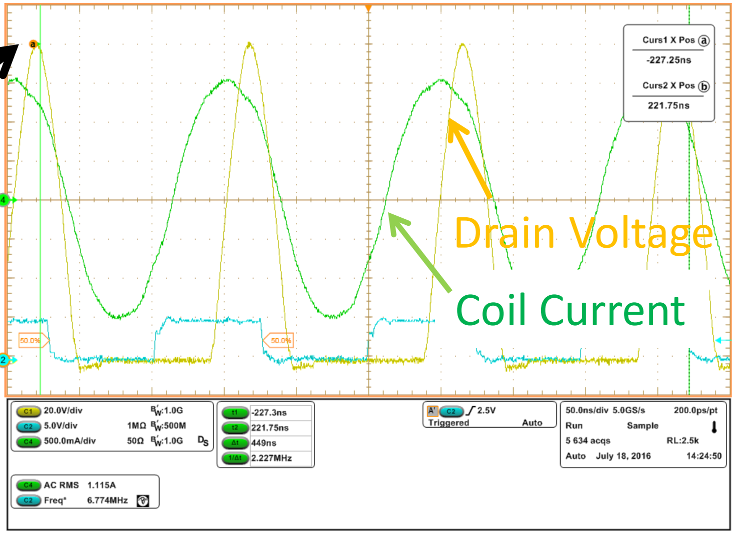
Class E – Limitations

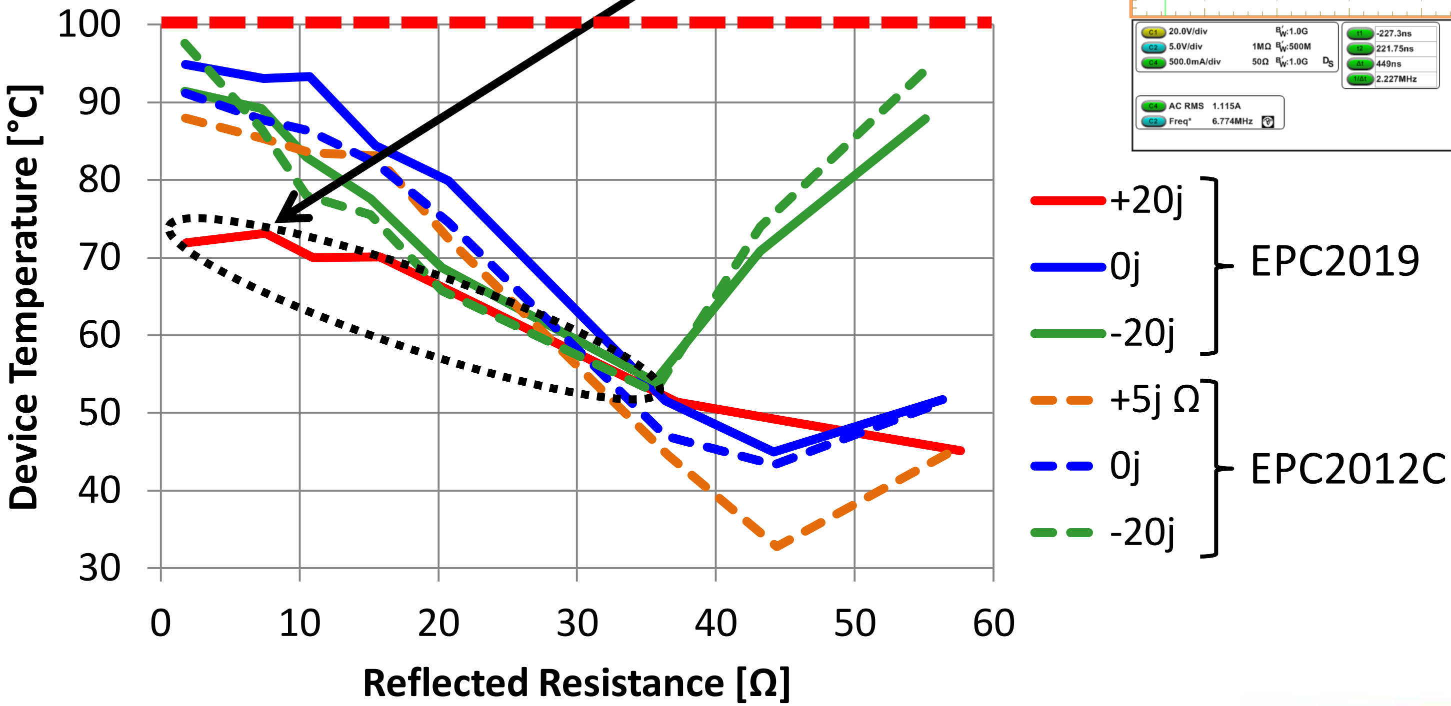
- 160 V limit – 80% of rated

or

- 100°C

Voltage limited





Summary

- 33 W wireless power amplifiers compared
  - Wider impedance range leads to lower cost systems
  - <u>ZVS Class D:</u> 75% wider impedance range than class E
  - <u>Class E:</u> Easier to drive and more popular
- eGaN FETs yield high efficiency at full power
  - Lower R_{DSon} improves performance

  but higher C_{OSS} leads to
  - Higher soft-switching energy for class D
  - Design with negative C_{sh} for Class E

EFFICIENT POWER CONVERSION

The end of the road for silicon…

but a clear road ahead for GaN FETs and ICs!