Performance Comparison for A4WP Class-3 Wireless Power Compliance between eGaN® FET and MOSFET in a ZVS Class D Amplifier
Agenda

• Introduction to the A4WP Class-3 Specifications
• ZVS Class D Amplifier
• eGaN® FET versus MOSFET Comparison
• Synchronous Bootstrap FET Gate Driver
• Experimental Results
• Summary

eGaN® is a registered trademark of Efficient Power Conversion Corporation
Introduction

• Wireless power transfer solutions must address convenience-of-use such as: device orientation and distance, multiple device capability, user simplicity, and power.

• Only the Alliance for Wireless Power (A4WP / Rezence) standard does:
  • Highly resonant (6.78 MHz ISM band)
  • Loosely coupled coils
  • Operation off-resonance

• ZVS Class D amplifier will be tested to the Class-3 requirements
A4WP Class-3 Impedance Requirements

- Load Variation Arcs
- 1 +10j Ω
- On Resonance
- Matched Coil
- Unloaded Coil Arc
- 50 Ω Smith Chart
- Increasing Coil Inductance
- Full Load Arc
- Impedance Rotation permissible
- 55 +10j Ω
- 55 -150j Ω
- 1 -150j Ω
- Decreasing Coil Inductance
ZVS Class D Amplifier

- 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 $= \frac{\sqrt{2}}{\pi} \cdot V_{DD} \ [V_{RMS}]$

Ideal Waveforms
Ultra High Frequency eGaN FETs

- Proven in various wireless power transfer amplifiers
- Low $C_{ISS}$
- Low $C_{OSS}$
- Zero $Q_{RR}$
- Full dv/dt immunity

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Package (mm)</th>
<th>$V_{DS}$ (V)</th>
<th>$V_{GS}$ (V)</th>
<th>$R_{DS(on)}$ @5 V (mΩ)</th>
<th>$Q_G$ @5 V Typ. (pC)</th>
<th>$Q_{GS}$ Typ. (pC)</th>
<th>$Q_{GD}$ Typ. (pC)</th>
<th>$R_G$ Typ. (Ω)</th>
<th>$V_{th}$ Typ. (V)</th>
<th>$Q_{RR}$ (nC)</th>
<th>$I_D$ (A)</th>
<th>$T_J$ Max. (°C)</th>
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<td>LGA 2.05x0.85</td>
<td>40</td>
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<td>125</td>
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<td>1.4</td>
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<td>2.7</td>
<td>150</td>
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- 2.05 x 0.85 mm
- Gate Return
- Source
- Substrate (Connect to Source on PWB)

- Proven in various wireless power transfer amplifiers
- Low CISS
- Low COSS
- Zero $Q_{RR}$
- Full dv/dt immunity

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Wireless Power Transfer
Figure of Merit

Best-In-Class MOSFET comparison

- All topologies are ZVS: $Q_G - Q_{GD}$
- $C_{OSS}$ is “absorbed” in matching but is important as it:
  - Drives off resonance losses
  - Determines design-ability
- $Q_{RR}$ ignored – poorly defined, amplifier is soft switching, BUT, transition time $< t_{RR}$:
  - eGaN FET $Q_{RR} = 0$ nC
  - MOSFET 2 $Q_{RR} = 18.1$ nC!
  
\[
FOM_{WPT} = R_{DS(on)} \cdot \left( Q_G - Q_{GD} + Q_{OSS} \right)
\]

(EPC8010 MOSFET 2

FoM$_{WPT}$ [nC·mΩ]
Gate Driver Induced Losses

- Gate drivers with internal bootstrap diodes always have $Q_{RR}$ (schottky diode is very difficult to implement in IC form)
- Bootstrap diode $Q_{RR}$ induces losses in the high side device
  - $Q_{RR}$ losses proportional to frequency
- Present even with ZVS as $t_{ZVS}$ (Switch-node voltage transition time) is shorter than $t_{RR}$
Synchronous FET Bootstrap

- $Q_{BTST}$ – Bootstrap FET for main switch ($Q_1$) zero $Q_{RR}$
- $Q_{BTST}$ – Switches synchronously with $Q_2$
- No additional active gate driver circuitry needed
- $C_{ENH}$ – Used for level shifting
- $D_{ENH}$ – Bootstrap diode for $C_{ENH}$ (Low voltage < 20V zero $Q_{RR}$)
Load Variation (jΩ) Results

Effect of $Q_{BTST} C_{OSS}$

- 38 % lower
- 24 % lower
- 42% lower

Total Amplifier Losses

Power [W]

Imaginary Impedance [jΩ]

- EPC8010 10 Ω 7 W
- MOSFET 10 Ω 7 W
- EPC8010 36 Ω 16 W
- MOSFET 36 Ω 16 W
- EPC8010 55 Ω 16 W
- MOSFET 55 Ω 16 W
Load Variation (Ω) Results

Total Amplifier Losses

- 15% - 48% lower
- 13% higher
- ~40% lower

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<tr>
<td>0</td>
<td>MOSFET 0j Ω</td>
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Waveform Improvements

$V_{DD} = 45 \text{ V, No load}$

Original Internal Bootstrap Diode

- $Q_{RR}$ effect
- Lower $dv/dt$
- $\Delta t = 4.2 \text{ ns}$
- $\Delta t = 6.6 \text{ ns}$

HF Output

Oscillator reference

eGaN FET Synchronous Bootstrap FET

- No $Q_{RR}$ effect
- Equal $dv/dt$
- $\Delta t = 4.2 \text{ ns}$
- $\Delta t = 4.2 \text{ ns}$

Summary

eGaN FETs in a ZVS Class D amplifier were tested to the A4WP Class-3 specifications:

• eGaN FETs always yield higher efficiency than best-in-class MOSFETs
• Gate driver and eGaN FET temperature remain below 100°C
• eGaN FET’s lower $C_{OSS}$ reduces the ZVS current needed, resulting in lower power dissipation for both FET and $L_{ZVS}$
• eGaN FETs reduce board space by 40%
• eGaN FETs enable a wider impedance drive range than MOSFETs
Handbook on wireless power that covers this work and much more – available at Digi-Key (917-1098-ND)
Where is GaN going...