The eGaN® FET Journey Continues

The ZVS Class-D Amplifier, an eGaN® FET-enabled Topology for Highly Resonant Wireless Power Transfer

Efficient Power Conversion Corporation
Agenda

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

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Introduction

• Wireless power transfer solutions must address convenience-of-use such as: any device orientation, distance, multiple devices, simplicity, 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

Unloaded Coil Arc

On Resonance

Matched Coil

50 Ω Smith Chart

Increasing Inductance

Full Load Arc

Impedance Rotation permissible

Decreasing Capacitance

$1 + 10j \Omega$

$1 - 150j \Omega$

$55 + 10j \Omega$

$55 - 150j \Omega$

$50 \Omega$
Class-3 Coil Drive Requirements

Vector sum of real (R) and imaginary (X) impedance range

Power Limit 16 W

800 mA Region

Amplifier Limited
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 = $(\sqrt{2}/\pi) \cdot V_{DD} [V_{RMS}]$
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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<tr>
<td>EPC8004</td>
<td>LGA 2.05x0.85</td>
<td>40</td>
<td>6</td>
<td>125</td>
<td>358</td>
<td>110</td>
<td>31</td>
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<td>1.4</td>
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<td>2.7</td>
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<td>380</td>
<td>116</td>
<td>36</td>
<td>0.3</td>
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<td>0</td>
<td>2.7</td>
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<tr>
<td>EPC8010</td>
<td>LGA 2.05x0.85</td>
<td>100</td>
<td>6</td>
<td>160</td>
<td>354</td>
<td>109</td>
<td>32</td>
<td>0.3</td>
<td>1.4</td>
<td>0</td>
<td>2.7</td>
<td>150</td>
</tr>
</tbody>
</table>

- Gate
- Drain
- Substrate *(Connect to Source on PWB)*

Solder side View

- 2.05 x 0.85 mm

- Gate Return
- Source
- 2.05 x 0.85 mm

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

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

- **Gate Driver LM5113 (5 V)**
- **eGaN FET EPC8010 125 mΩ**
- **MOSFET 2 105 mΩ**
- **Oscilloscope Probe Holder**
- **Load Connection**
- **ZVS Inductor L_{ZVS}**
- **ZVS Capacitor C_{ZVS}**
- **Load Connection**
Load Variation (Ω) Results

Total Amplifier Efficiency

Efficiency [%] vs Real Reflected Resistance [Ω]

- EPC8010 -30j Ω
- EPC8010 0j Ω
- EPC8010 +20j Ω
- MOSFET -30j Ω
- MOSFET 0j Ω
- MOSFET +20j Ω

Output Power [W]
Load Variation (jΩ) Results

![Graph showing load variation results for different impedances and powers.](image)
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%
Wireless Power Handbook

• Visit EPC’s Booth #1405 to see several demonstrations in operation

• Handbook on wireless power that covers this work and much more – available at Digikey
Where is GaN going...

Thank You