The eGaN® FET Journey Continues

eGaN® FET Wireless Energy Transfer Solutions

Efficient Power Conversion Corporation
Agenda

• Wireless Power Topologies Overview
• Wireless Power Results for each Topology
• Summary
Output Power < 30 W

Loosely coupled, 6.78 MHz (ISM band) based on A4WP standard

Topologies Reviewed
- Class D (Current and Voltage Mode)
- Class E
- ZVS Voltage Mode Class D
Wireless Coil-set Overview

Simplified representation of coil-set for easy comparison between topologies

\[ L_{\text{src}} \quad L_{\text{dev}} \quad C_{\text{devp}} \quad C_{\text{devs}} \quad L_{\text{devs}} \quad C_{\text{out}} \quad R_{\text{DCload}} \quad Z_{\text{load}} \]
Experimental Setup

- Coil Feedback
- eGaN FETs RF connection
- Device
  - Device Coil
  - RF connection
- Source Board
- Source Coil
Traditional Voltage Mode Class D

- Switch voltage rating = Supply ($V_{DD}$).
- Level shifting gate driver required.
- $C_{OSS}$ plays an important role in losses.

Ideal Waveforms
Voltage Mode Class D Efficiency

6.639 MHz, 23.6 Ω load

Efficiency [%]

Output Power [W]

EPC8004
EPC2014
MOSFET
Voltage Mode Class D Load Effect

6.699MHz, Fixed 14V supply

EPC 2014
Current Mode Class D

- EPC2012 has lower FoM than MOSFET
- $C_{OSS}$ is absorbed into matching network.
Current Mode Class D Efficiency

6.78 MHz, 23.6 \( \Omega \) Load

Efficiency [%]

Output Power [W]

EPC 2012

- eGaN FET
- MOSFET
Current Mode Class D Load Effect

- Fixed 5.5 V supply

![Graph showing efficiency and power vs. DC load resistance](image)

- DC Load Resistance [Ω]
- Output Power [W]
- Efficiency [%]

EPC 2012

- Fixed 5.5 V supply
Class E Overview

- Switch voltage rating = > 3.56·Supply (V_{DD}).
- C_{OSS} “absorbed” into matching network.

![Class E Circuit Diagram]

Ideal Waveforms

- V_{DD}
- L_{RFck}
- L_e
- C_s
- Q_1
- C_{sh}
- Z_{load}

- V_{DS}
- I_D
- 3.56 x V_{DD}

Ideal Waveforms

- 50% time
Class E Efficiency as Function of Load

Efficiency [%] vs. Output Power [W]

6.78 MHz, 20.5 Ω Load

- EPC 2012
- eGaN FET
- MOSFET
Class E Load Effect

6.78 MHz, Fixed 20 V supply

![Graph showing Efficiency and Power vs. DC Load Resistance for Class E Load Effect.](image)

**Efficiency**

**Power**

EPC 2012
Class E Thermal Performance

- NO HEAT-SINK
- 30 W, 20.2 Ω Load
Class E – eGaN FET vs. MOSFET

**Total FET Power losses**

<table>
<thead>
<tr>
<th>Load Power [W]</th>
<th>FDMC86248</th>
<th>EPC2012</th>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
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</tr>
<tr>
<td>15</td>
<td>15</td>
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<tr>
<td>20</td>
<td>20</td>
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</tr>
<tr>
<td>35</td>
<td>35</td>
<td>70</td>
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</table>
ZVS Voltage Mode Class D

- $C_{OSS}$ Voltage is transitioned by the ZVS tank
- Lower eGaN FET $C_{OSS}$ leads to higher available duty cycle
- Highest system efficiency

Ideal Waveforms

- COSS Voltage is transitioned by the ZVS tank
- Lower eGaN FET $C_{OSS}$ leads to higher available duty cycle
- Highest system efficiency
ZVS Voltage Mode Class D Efficiency

Efficiency [%] vs Output Power [W]

- 35.4 Ω load
- 23.6 Ω load

EPC 2007
ZVS Voltage Mode Class D Load Effect

Fixed 26 V supply

EPC 2007

DC Load Resistance [Ω]

Efficiency [%]

Output Power [W]

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EPC - The Leader in eGaN® FETs

Electronica Asia 2014

www.epc-co.com
ZVS Class D Thermal Performance

- **NO HEAT-SINK**
- \( R_{D\text{CLoad}} = 35 \, \Omega \), \( V_{\text{in}} = 42 \, V \), \( P_{\text{out}} = 35 \, W \), \( f = 6.78 \, MHz \)

![Thermal Image](image.png)
ZVS Class D FoM Comparison

<table>
<thead>
<tr>
<th></th>
<th>EPC2007</th>
<th>FDMC8622</th>
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<tbody>
<tr>
<td>$B_{V_{DSS}}$</td>
<td>100 V</td>
<td>100 V</td>
</tr>
<tr>
<td>$Q_{OSS}$</td>
<td>8.9 nC at 40 V</td>
<td>7.3 nC at 40 V</td>
</tr>
<tr>
<td>$Q_{G}$</td>
<td>2.1 nC at 5 V</td>
<td>5.2 nC at 10 V</td>
</tr>
<tr>
<td>$R_{DS(on)}$</td>
<td>24 mΩ</td>
<td>43.7 mΩ</td>
</tr>
</tbody>
</table>

FOM [nC·mΩ]

- $Q_{OSS} \cdot R_{DS(on)}$
- $Q_{G} \cdot R_{DS(on)}$
ZVS Class D – eGaN FET vs. MOSFET

Total FET Power losses

- FDMC8622
- EPC2007

Load Power [W]

P_{FET} [mW]
Summary of Efficiency Results

Efficiency [%] vs. Output Power [W] for 6.78 MHz, 23.6 Ω Load, eGaN FETs

- EPC 2007
- EPC 2012
- EPC 2014

Key Points:
- ZVS-CD
- SE-CE
- CM-CD
- VM-CD
Simulated FET Losses – All Topologies

Per FET Power loss [mW] vs. DC Load Resistance [Ω]

- Exceeds thermal capability of FET
- Fixed Supply Voltage

- ZVS-CD
- SE-CE
- CM-CD
- VM-CD

15 W
Summary

• Wireless Power Transmission is one of the largest potential markets for power transistors.

• ZVS Class D shows great promise for a simple, low cost, and high efficiency topology for wireless power. eGaN FETs enable greater duty cycle and higher efficiency.

• eGaN FETs enable the highest efficiency in all topologies using 6.78 MHz and 13.56 MHz frequencies.

• eGaN® technology is disruptive.
The end of the road for silicon..... is the beginning of the eGaN FET journey!