Introducing eGaN® IC targeting Highly Resonant Wireless Power

Efficient Power Conversion Corporation

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The eGaN® FET Journey Continues
Agenda

• Introducing the Synchronous Bootstrap FET
• eGaN ICs targeting Wireless Power
• Experimental results in a ZVS class D amplifier
• Summary

eGaN® is a registered trademark of Efficient Power Conversion Corporation
Gate drivers with internal bootstrap diodes have $Q_{RR}$:
- Schottky diode cannot be integrated.

This $Q_{RR}$ induces losses in the high side device:
- Proportional to frequency
- Present even with ZVS

370 mW at 50 V, 6.78 MHz
~ 40% of total FET losses
Implementing a Synchronous FET Bootstrap Supply

$V_{\text{Drvr}}$ $Q_{\text{BTST}}$ $D_{\text{ENH}}$ $C_{\text{ENH}}$ $C_{\text{BTST}}$ Gate Driver + level shift $Q_2$ $Q_1$ $V_{\text{Main}}$
Synchronous Bootstrap FET Design Considerations

- **Timing:**
  - Turn on - Delay
  - Turn off – Immediate

- **Off state margin** – if lower FET reverse conducts

- **Drain inductance** – to prevent over-voltage
Synchronous FET Bootstrap Supply Implementation

Waveform Improvements at 13.56 MHz Operation

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

**Original Configuration**

- Q$_{RR}$ effect
- Δ$t = 4.2$ ns
- Lower $dv/dt$
- Δ$t = 6.6$ ns

**Sync-Bootstrap Configuration**

- No Q$_{RR}$ effect
- Δ$t = 4.2$ ns
- Equal $dv/dt$
- Δ$t = 4.2$ ns

5 V/Div. 20 ns/Div. 5 V/Div. 20 ns/Div.
Synchronous Bootstrap Power Dissipation Results

Total FET power, excludes gate driver

- Thermal Limit reached at 628 mW
- Increased operating range

- Original 13.56 MHz
- SyncBoot 13.56 MHz

FET Power losses [mW] vs Supply Voltage [V]
### eGaN ICs targeting Wireless Power Applications

#### Solder Side View

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**Table:**

<table>
<thead>
<tr>
<th>EPC Part Number</th>
<th>Package (mm)</th>
<th>$V_{DS}$ (V)</th>
<th>$V_{GS}$ (V)</th>
<th>$R_{DS(on)}$ @5V (mΩ)</th>
<th>$Q_G$ @5 V TYP. (pC)</th>
<th>$Q_{GS}$ TYP. (pC)</th>
<th>$Q_{GD}$ TYP. (pC)</th>
<th>$R_G$ (Ω)</th>
<th>$V_{th}$ (V)</th>
<th>$Q_{RR}$ (nC)</th>
<th>$I_D$ (A)</th>
<th>$T_J$ Max. (°C)</th>
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Device Comparison

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

Zero Voltage Switching Class D

FOM_{WPT} = R_{DS(on)} \cdot (Q_{OSS})

FOM_{WPT} = R_{DS(on)} \cdot (Q_G - Q_{GD})
ZVS Class D Experimental Power Schematic

Bypass Mode connection

Pre-Regulator Jumper

V_{\text{IN}}

Q_{1_a}

L_{ZVS1}

C_{ZVS1}

EPC9509 and EPC9510

JP1

Q_{2_a}

L_{ZVS12}

EPC9509 only

Coil Connection

EPC9510

only

L_{ZVS2}

C_{ZVS2}

Single Ended Operation Jumper

Q_{1_b}

Q_{2_b}
Experimental Single-Ended ZVS Class D Amplifier

Configured for 6.78 MHz Operation

- Gate Driver LM5113 (5 V)
- eGaN IC
- Oscilloscope Probe Post
- ZVS Inductor $L_{ZVS}$
- Coil Connection
- ZVS Capacitor $C_{ZVS}$ (Bottom Side)
- EPC2107 – 100 V, 220 mΩ, $V_{GS} = 5$ V
Experimental Differential-Mode ZVS Class D Amplifier

Configured for 6.78 MHz Operation

Gate Driver LM5113 (5 V)

Coil Connection

ZVS Inductor $L_{ZVS}$

Oscilloscope Probe Post

ZVS Capacitor $C_{ZVS}$ (Bottom Side)

EPC2108 – 60 V, 150 mΩ, $V_{GS} = 5$ V

EPC9509 eGaN IC

EPC - The Leader in eGaN® FETs
Load Calibration Results for Class 2

Measured at 6.78 MHz

High Q coil used as an inductor ONLY

Low Inductance Resistance Network

Tuning Capacitors

Current Probe

50 Ω Smith

-35j Ω
-30j Ω
-20j Ω
-10j Ω
0j Ω
+10j Ω
+20j Ω
+30j Ω
+35j Ω
Load Calibration Results for Class 3

Measured at 6.78 MHz

High Q coil used as an inductor ONLY

Tuning Capacitors

Current Probe

Low Inductance Resistance Network

50 Ω Smith

- +40j Ω
- +30j Ω
- +20j Ω
- +10j Ω
- 0j Ω
- -5j Ω
- -10j Ω
- -20j Ω
- -35j Ω
- -50j Ω
- -55j Ω
- -60j Ω
Single-Ended ZVS Class D Class 2 Experimental Results

Measured at 6.78 MHz

EPC9510 Total Amplifier Efficiency

Includes Gate Driver Power

Output Power [W]

Efficiency [%]

Reflected Resistance [Ω]

Includes Gate Driver Power

Pout

-35j Ω
-10j Ω
0j Ω
+20j Ω
+35j Ω

Includes Gate Driver Power
Differential-Mode ZVS Class D Class 3 Results

Measured at 6.78 MHz

EPC9509 Total Amplifier Efficiency

Includes Gate Driver Power

Output Power [W]

Efficiency [%]

Reflected Resistance [Ω]

Pout

Includes Gate Driver Power
Summary

Introduced the eGaN IC

- Lateral eGaN FET structure enables high voltage integration
- Three (3) FETs in one 1.35 mm x 1.35 mm chip-scale package
- Integration improves efficiency and power density
- Experimentally verified in a ZVS Class D amplifier
- eGaN ICs enable lower cost, higher performance wireless power
Wireless Power Handbook

• Visit EPC’s Booth #2244 to see several demonstrations in operation

• 2nd Edition Handbook on wireless power that covers this work and much more – available at Digikey (917-1136-ND) or Amazon
Where is GaN going...

Powering Innovation at the Speed of GaN