The eGaN® FET Journey Continues

Wireless Energy Transfer – Technology Drivers
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Agenda

• Overview of Wireless Energy Transfer
• Wireless Energy Transfer Enabling Technologies
• Wireless Energy Topology Overview
• Wireless Energy Experimental Results
Magnetic field Wireless Transfer

Ideal Transformer

\[ L_{rp}, L_{mp}, L_{rs}, L_{ms} \]
Highly Resonant Wireless Transfer

- Coils tuned to resonate at 6.78 MHz
- Series and Shunt tuned can be used
- Coupling and load variation can shift resonance
Why Wireless Energy

- Mobile device charging
  - Convenience
  - Extended battery life
- Medical Implants
  - Quality of life improvement
  - Life extender
- Hazardous environment systems
  - Explosive atmosphere
  - Corrosive locations
  - High Voltage
Challenges to Wireless Energy

• High Efficiency – limited dissipation budget

• Low Profile – mobile market

• Robustness to dynamic operating conditions (convenience factor)

• Foreign object response

• Regulatory compliance
Compliance Requirements

• Industrial Scientific Medical (ISM) Band
  • 6.78 MHz ± 15kHz (subject to local restrictions)
  • 13.56 MHz ± 7kHz
• No Power limit specified, but!
• FCC / EN Standards
  • Intentional radiator
  • Must comply with FCC part 15 / EN55011
Wireless Energy Standards

- Alliance for Wireless Power (A4WP / Rezence)
  - Highly resonant (ISM band)
  - Loosely coupled coils
- Wireless Power Consortium (WPC - Qi)
  - Low frequency (~100 - 200 kHz)
  - Tightly coupled (Inductive)
- Power Matters Alliance (PMA)
  - Joined with A4WP standard
Wireless Energy Transfer
Enabling Technologies

- Antenna
  - Design for high Efficiency
- eGaN FETs
  - Enable high frequency Amplifiers
  - Easy to use
  - Support structure – gate drivers
- Topologies
  - New topologies enabled by new FETs
Class E Overview

• Switch voltage rating \( \geq 3.56 \times \text{Supply} \, (V_{DD}) \).
• \( C_{OSS} \) “absorbed” into matching network.
• Susceptible to load variation - high FET losses
• Coil Voltage \( \approx 0.707 \times V_{DD} \, [V_{RMS}] \)

\[
\begin{align*}
V_{DD} & \quad L_{RFck} \quad L_e \quad C_s \\
Q_1 & \quad C_{sh} \quad Z_{load} \\
& \\
V/I & \quad 3.56 \times V_{DD} \\
V_{DS} & \quad 50\% \quad I_D \quad \text{time}
\end{align*}
\]
Current Mode Class D

- Switch voltage rating = 3.14 \cdot \text{Supply} (V_{DD})
- \(C_{\text{OSS}}\) “absorbed” into matching network.
- High current in resonant inductor
- Coil Voltage = 2.22 \cdot V_{DD} [V_{\text{RMS}}]
ZVS Voltage Mode Class D

- 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 = $\frac{1}{2} \cdot V_{DD}$ [$V_{RMS}$]

Ideal Waveforms

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 = $\frac{1}{2} \cdot V_{DD}$ [$V_{RMS}$]
Device Comparison

**FoM_{WPT} [nC·mΩ]**

### VM-CD
- **EPC2014**
- **MOSFET 0**

### SE-CE
- **EPC2012**
- **MOSFET 1\( V_{GS} = 10\,\text{V} \)**

### CM-CD
- **EPC2016**
- **MOSFET 4**

### ZVS-CD
- **EPC8009**
- **EPC2007**
- **MOSFET 2**
- **MOSFET 3\( V_{GS} = 10\,\text{V} \)**

\[
\text{FOM}_{WPT} = R_{DS(on)} \cdot (Q_G - Q_{GD})
\]
Peak Performance Comparison

23.6 Ω DC Load

Efficiency [%] vs. Output Power [W]

- η EPC8009 ZVS-CD
- η MOSFET 2 ZVS-CD
- η MOSFET 3 ZVS-CD
- η EPC2012 SE-CE
- η MOSFET 1 SE-CE
- η EPC2016 CM-CD
- η EPC2014 VM-CD
- η MOSFET 0 VM-CD

$T_{\text{gate\_driver}} > 95^\circ C$
Load Variation Performance

$T_{\text{gate\_driver}} > 95^\circ C$

- $\eta$ EPC2012 SE-CE
- $\eta$ MOSFET 1 SE-CE
- $\eta$ EPC2016 CM-CD
- $\eta$ EPC8009 ZVS-CD
- $\eta$ MOSFET 2 ZVS-CD
- $\eta$ MOSFET 3 ZVS-CD

Efficiency [%] vs. DC Load Resistance [Ω]
Summary

Wireless Energy Transfer Solutions Require:

• New enabling devices e.g. eGaN® FETs
• Operation at 6.78 MHz and 13.56 MHz
• Low profile and high efficiency solutions
• Easy to implement
• Drive new topologies e.g. ZVS Class D
• Growing support e.g. Gate drivers and products use them
• Robustness to operating conditions
The end of the road for silicon..... is the beginning of the eGaN FET journey!
Coil Simplification

Simplified representation of coil-set for easy comparison between topologies