A Synchronous eGaN® FET Class E Rectifier for Highly Resonant Wireless Power Receivers

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Outline

• Resonant wireless power receivers and rectifiers
• Class E rectifier
• Synchronization
• Experimental results
• Conclusions
Resonant Wireless Power Overview
Full Bridge Rectifiers

Typical diode rectifier

- Simple
- Popular choice at low frequency
- High Losses at 6.78 MHz

Synchronous rectifier

- More efficient
- Complicated gate drive
- Requires controller
- Operating power offsets benefit
Class E Rectifiers

Typical diode location: in series with output


Proposed Synchronous Class E Rectifier

- Source grounded GaN FET
- Simple gate drive
- High efficiency – no $Q_{RR}$, low $C_{OSS}$, $C_{ISS}$, $R_{DSon}$

![Ideal Waveforms]

$V_{DS}$ $I_D$ $3.56 \times V_{Out}$

50% time

$V_{rect}$ $C_{out}$
Gating Synchronization

- RX coil zero current cross detect
- Output disabled at low current (<\(I_{th}\))
Gating Synchronization Detail

a) Current sensing with waveform clipping  
b) AC-coupled zero crossing detect  
c) Magnitude detect
Experimental Setup

- Transmit coil current: $1.375 \text{ A}_{\text{RMS}}$
- Receive coil at 25 mm distance

**Synchronization circuit**

- Clock outputs
- From Coil

**EPC2012C Class E rectifier**

- $C_{sh} = 77 \text{ pF}$
- $L_{ex} = 540 \text{ nH}$
- $L_{ck} = 22 \mu\text{H}$
Diode Rectifier for Comparison

- 60 V best in class Schottky diodes
- Full bridge Configuration
Synchronization Circuit Test

- $I_{th}$ set to 100 mA\(_{RMS}\)
- Compensated for proper phase shift
- Both gate signals are off in “diode” mode

\[ I_{coil,RX} = 99 \text{ mA rms, ‘diode’ mode} \quad \text{and} \quad I_{coil,RX} = 127 \text{ mA rms} \]

- $V_{DS}$
- $i_{coil}$

- $1 \text{ A/div}$
- $5 \text{ V/div}$

- $\approx -2 \text{ V}$
- $\approx 0 \text{ V}$
Measured Efficiency

Total system efficiency at fixed 40 Ω DC load

Impact of Operating power

Efficiency vs. Output Power [W]

- Diode
- Class E
- Class E w/Gate drive
• Fixed $I_{coil,TX} = 1.375\ A_{RMS}$
• Variable DC load (Resistance)

Measured Efficiency

Can be improved
Experimental Waveforms

Fixed $I_{\text{coil, TX}} = 1.375 \, A_{\text{RMS}}$

- **40 Ω load, 38.2 V$_{\text{DC}}$, 36 W output**
- **67 Ω load, 40 V$_{\text{DC}}$, 24 W output**

Hard switching

20 V/div 1 A/div

20 V/div 1 A/div
Conclusions

6.78 MHz eGaN FET synchronous class E rectifier

• More efficient than Schottky diode
• > 20% lower system power loss at > 35 W load
• Concept can be monolithically integrated
  – Gate driver
  – Signal detect
Thank You

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