A New Dual Channel Resonant Gate Drive Circuit for Synchronous Rectifier

Presented By:
Wilson Eberle

Authors:
Zhihua Yang, Sheng Ye and Dr. Yan-Fei Liu
1. **Introduction**
   1. *Why you should use resonant gate drive*
   2. *Drawbacks of existing techniques*

2. **Proposed Resonant Gate Driver and Operation**

3. **Loss Analysis**

4. **Simulation and Experimental Results**

5. **Conclusions**
1. Introduction

- **Application:** low voltage high current DC-DC power supplies

- **Trend to increase switching frequency** for improvements in:
  - power density
  - dynamic performance

- **Drawbacks of increased switching frequency:**
  - gate loss
  - switching loss
  - body diode conduction

Important for SRs in MHz range
Conventional MOSFET Driver

MOSFET Driver

Power MOSFET parasitics in blue

Gate Loss

\[ P_{\text{gate}} = Q_g V_{GS} f_S \]

Switching Loss

\[ P_{\text{switch}} = \frac{1}{2} (t_{\text{rise}} + t_{\text{fall}}) V_{DS} I_{DS} f_S \]

MOSFET, or BJT switches

Hard Switching Waveforms

\[ P_{\text{out}} = \frac{1}{2} C_{DS} V_{DS}^2 f_S \]
Techniques for Improvement

Gate Loss Savings

Resonant Gate Drive Techniques

Many good (~15) circuits proposed since early 1990s, but generally unused

- Existing methods emphasize gate energy savings, but ignore potential increase in switching speed

CURRENT SOURCE DRIVERS CAN REDUCE SWITCHING LOSS OR BODY DIODE CONDUCTION!
Conventional vs. Resonant Drive
Switching Loss and Body Diode Savings

Gate Current

Gate Voltage

Voltage source
RC-type charging
limits speed

Constant current source
type charging
improves speed!
Actual driver loss can be much higher than CV^2 loss... e.g. varies by driver, but typically 15-50%
Existing techniques suffer from several problems:

1. Slow dynamic response (large $C_o$)
2. Single MOSFET drive
3. Bulky transformer, or coupled inductor
4. Slow turn-on and/or turn-off
5. Gate not actively clamped high and/or low, so false triggering \((Cdv/dt)\) can result
Presentation Overview

1. Introduction

2. Proposed Resonant Gate Driver and Operation
   1. Circuit and Waveforms

3. Loss Analysis

4. Simulation and Experimental Results

5. Conclusions
Proposed Resonant Driver

**Applications:**
1. Synchronous rectifiers in isolated DC-DC
2. Push-pull primary switches
3. Interleaved low-side converters (e.g. Boost)
Principles of Operation

Mode 1 (t < t₀ and t₇ < t < t₈)

S1-S4 achieve ZVS at turn-on & turn-off

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Principles of Operation

Mode 2 ($t_0 < t < t_1$)

S1-S4 achieve ZVS at turn-on & turn-off
Principles of Operation

Mode 3 (t1 < t < t2)

S1-S4 achieve ZVS at turn-on & turn-off
Principles of Operation

Mode 4 \((t_2 < t < t_3)\)

S1-S4 achieve ZVS at turn-on & turn-off
Principles of Operation

Mode 5 (t3 < t < t4)

S1-S4 achieve ZVS at turn-on & turn-off
Principles of Operation

Mode 6 ($t_4 < t < t_5$)

S1-S4 achieve ZVS at turn-on & turn-off
Principles of Operation

Mode 7 (t₅ < t < t₆)

S1-S4 achieve ZVS at turn-on & turn-off
Principles of Operation

Mode 8 (t6 < t < t7)

S1-S4 achieve ZVS at turn-on & turn-off
Principles of Operation

• Overlap rectifier timing shown
• Gating can be adjusted for complementary operation
Presentation Overview

1. Introduction
2. Proposed Resonant Gate Driver and Operation
3. Loss Analysis
   1. Loss Components
   2. Equations
   3. Analysis Results
4. Simulation and Experimental Results
5. Conclusions
Loss Components

1. Inductor

\[ P_{\text{ind}} = P_{\text{copper}} + P_{\text{core}} \]

2. MOSFET’s gate resistance

\[ P_{\text{RG}} = 4R_G I_{\text{peak}}^2 t_{\text{sw}} f_s \]

3. Other resistive

\[ P_{\text{cond}} = P_{\text{top}} + P_{\text{bott}} = 2R_{\text{DS(on)}} I_{\text{peak}}^2 \frac{4D-1}{3} \]

4. Control switch gate

\[ P_{\text{Gate}} = 4Q_{g_s} V_{gs_s} f_s \]

Total

\[ P_{\text{DRV}} = P_{\text{cond}} + P_{\text{RG}} + P_{\text{Gate}} + P_{\text{ind}} \]
Loss Breakdown

![Bar chart showing Loss Breakdown]

- $P_{\text{con}}$
- $P_{\text{RG}}$
- $P_{\text{gate}}$
- $P_{\text{ind}}$

Legend:
- $D=0.25$
- $D=0.5$
- $D=0.75$
Total Gate Drive Loss

- **Logic circuit loss:** 40mW
- **No cross conduction loss**

E.g. Two IRF6618, $V_{gs} = 12V$, $f_s = 1$MHz, $D = 0.5$

<table>
<thead>
<tr>
<th>Calculated Loss</th>
<th>Logic Loss</th>
<th>Total Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.752W</td>
<td>0.04W</td>
<td>0.792W</td>
</tr>
</tbody>
</table>
## Gate Energy Savings

<table>
<thead>
<tr>
<th></th>
<th>Gate Loss</th>
<th>Additional Chip Loss</th>
<th>Total Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conventional Driver</strong></td>
<td>2.232W</td>
<td>0.3W</td>
<td>2.532W</td>
</tr>
<tr>
<td><strong>Resonant Driver</strong></td>
<td>0.752W</td>
<td>0.04W</td>
<td>0.792W</td>
</tr>
<tr>
<td><strong>Loss Savings</strong></td>
<td>1.48W</td>
<td>0.26W</td>
<td>1.74W</td>
</tr>
</tbody>
</table>

No cross-conduction loss in proposed driver
Turn-off Switching Loss Reduction

\[ V_{gs} = 12V \quad R_{DRV} = 6\Omega \]
\[ V_{gs(th)} = 2V \quad V_p = 3V \]

**Drive Current Comparison**

<table>
<thead>
<tr>
<th></th>
<th>Conventional Drive</th>
<th>Resonant Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peak Current</strong></td>
<td>2 A</td>
<td>1.5 A</td>
</tr>
<tr>
<td><strong>Average Charge Current</strong></td>
<td>1.54 A</td>
<td>1.5 A</td>
</tr>
<tr>
<td><strong>Average Discharge Current ((I_{dis}))</strong></td>
<td>0.46 A</td>
<td>1.5 A</td>
</tr>
</tbody>
</table>

**Gate Charge Characteristic (IRF7821 datasheet)**
Design Considerations

Peak drive current

\[ I_{L_{\text{peak}}} = \frac{Q_g}{t_{sw}} \]

Duty cycle \( D > 0.5 \)

\[ L = \frac{V_{gs}(1-D)T_s}{2I_{L_{\text{peak}}}} \]

Duty cycle \( D < 0.5 \)

\[ L = \frac{V_{gs}DT_s}{2I_{L_{\text{peak}}}} \]

Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Device Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1, Q2</td>
<td>IRF6618</td>
</tr>
<tr>
<td>S1-S4</td>
<td>FDN335N</td>
</tr>
<tr>
<td>L1</td>
<td>2.2uH</td>
</tr>
<tr>
<td>( V_{gs} )</td>
<td>12V</td>
</tr>
</tbody>
</table>
1. Introduction
2. Proposed Resonant Gate Driver and Operation
3. Loss Analysis
4. Simulation and Experimental Results
   1. Waveforms
   2. Driver Loss Savings
   3. Switching Loss Savings
5. Conclusions
Simulation Results

- Constant charge/discharge current
- Charge/discharge current at peak $I_L$
Boost Experimental Results:
2-Phases, 1MHz, IRF6618, 10TQ040, Vin=5.7V, Vo=11.35V, Vgs=12V

Resonant Driver: S1-S4: FDN335N, Inductor: DS3316P-2.2u

Gate Loss Comparison

<table>
<thead>
<tr>
<th></th>
<th>Calculated Drive Loss</th>
<th>Measured Drive Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Drive</td>
<td>2.532 W</td>
<td>2.61 W</td>
</tr>
<tr>
<td>Resonant Drive</td>
<td>0.792 W</td>
<td>0.864 W</td>
</tr>
<tr>
<td>Loss Savings</td>
<td>1.74 W</td>
<td>1.747 W</td>
</tr>
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Boost Experimental Results:
1MHz, IRF6618, 10TQ040, Vin=5.7V, Vo=11.35V, Vgs=12V

Resonant Driver: S1-S4: FDN335N, Inductor: DS3316P-2.2u

<table>
<thead>
<tr>
<th>Case</th>
<th>$R_{ext}$</th>
<th>I load</th>
<th>Loss: UCC27323</th>
<th>Loss: Resonant</th>
<th>Loss Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>2.5 Ω</td>
<td>0.4 A</td>
<td>2.07 W</td>
<td>1.92 W</td>
<td>0.15 W</td>
</tr>
<tr>
<td>Case 2</td>
<td>2.5 Ω</td>
<td>0.8 A</td>
<td>2.78 W</td>
<td>2.32 W</td>
<td>0.46 W</td>
</tr>
<tr>
<td>Case 3</td>
<td>1 Ω</td>
<td>0.4 A</td>
<td>1.98 W</td>
<td>1.92 W</td>
<td>0.06 W</td>
</tr>
<tr>
<td>Case 4</td>
<td>1 Ω</td>
<td>0.8 A</td>
<td>2.50 W</td>
<td>2.32 W</td>
<td>0.18 W</td>
</tr>
</tbody>
</table>

- Switching loss reduced with faster speed
- Greater savings with heavier load
Measured Typical Waveforms

Gate charge/discharge current is nearly constant
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Conclusions

New Resonant Driver Proposed:

- Gate Energy Recovery
- Switching Loss Reduction
- Body Diode Loss Reduction
- Specific Advantages:
  - Quick turn on & off due to relatively constant inductor current at charge/discharge intervals
  - No Cdv/dt false triggering (low impedance)
  - No cross conduction
  - Simple inductor

- 0.46W savings in Boost test circuit
- Wide range of applications
Thank You For Your Time

Other Resonant Gate Drive Material at:

www.queenspowergroup.com

and

2.6 (Tuesday) and 9.3 (Yesterday)