Topology and Analysis of a New Resonant Gate Driver

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Outline

• Introduction
• Proposed Resonant Gate Driver and Operation
• Loss Analysis and Optimization Design
• Experimental Results
• Conclusion
• Introduction
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Conventional MOSFET Driver

MOSFET Driver

Power MOSFET

Hard Switching Waveforms

Gate Loss

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

Switching Loss

\[ P_{\text{switching}} \approx \frac{V_{DS} \cdot I_D}{2} \left( t_{\text{rise}} + t_{\text{fall}} \right) \cdot f_s \]
Switching Loss: Common Source Inductance

Buck converter with parasitic inductors

Equivalent circuit of MOSFET switching transition (turn-on)
Switching Loss: Common Source Inductance

$L_s = 0$

$L_s = 2nH$

$V_D = 12V, I_L = 20A, f_s = 1MHz, MOSFET: IRF7821$

Switching loss increases significantly due to common source inductance!
Resonant Gate Drive Techniques

Limitations of voltage source driver:
- No gate charge energy recovered
- Low switching speed and high switching loss due to common source inductance

Resonant gate driver techniques:
- Many good circuits proposed since 1990s, but generally unused
- Existing methods emphasize gate energy savings, but ignore potential switching loss savings
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Proposed Dual Channel High-Side and Low-Side Gate Driver

Key waveforms

Resonant Gate Driver

$V_{in}$

$C_{g1}$

$Q_1$

$L_f$

$C_f$

$R_{ld}$

$+V_o$

$-$

$Q_2$

$S_1$

$S_2$

$S_3$

$S_4$

$V_c$

$S_1$

$S_2$

$S_3$

$S_4$

$D_1$

$L_r$

$C_b$

$i_{Lr}$

$I_{Lr,pk}$

$t_0 t_1 t_2$

$t_3 t_4 t_5$

$t_6 t_7 t_8$

$t_9 t_{10} t_{11}$
Before $t_0$
Turn-off $Q_2: [t_0, t_1]$
Turn-on $Q_1: [t_1, t_2]$

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Driver Loss Analysis

• The conduction loss of $S_1$-$S_4$

$$P_{\text{cond \_s1-s4}} = 2I_{s1 \_ \text{RMS}}^2 \cdot R_{ds(\text{on})} + 2I_{s2 \_ \text{RMS}}^2 \cdot R_{ds(\text{on})}$$

$R_{ds(\text{on})}$ is the on-resistance of $S_1$-$S_4$

• The resonant inductor loss

$$P_{\text{ind}} = P_{\text{copper}} + P_{\text{core}}$$

• The loss of MOSFET mesh resistance $R_G$

$$P_{R_G} = 2R_{G1}I_{Lr \_ pk}^2 \cdot t_{sw1} \cdot f_s + 2R_{G2}I_{Lr \_ pk}^2 \cdot t_{sw2} \cdot f_s$$

t_{sw1} and $t_{sw2}$ are the switching time, $I_{Lr \_ pk}$ is the peak current of resonant inductor

• The loss of gate charges of switches $S1$-$S4$

$$P_{\text{Gate}} = 4 \cdot Q_{g \_ s} \cdot V_{gs \_ s} \cdot f_s$$
**V_{cc}** Selection of Resonant Gate Driver

\[ V_{in} = 12V; \ I_o = 20A; \ f_s = 1MHz; \]

\[ Q_1: \text{IRF7821(30V, } R_{DS(on)} = 9m\Omega@V_{GS} = 6V); \ Q_2: \text{FNS7088(30V, } R_{DS(on)} = 3.5m\Omega@V_{GS} = 6V); \]

\[ S_1-S_4: \text{FDN335N(20V N-channel, } R_{DS(on)} = 0.07\Omega@V_{GS} = 4.5V); \ L_r = 2.2uH. \]
1. Switching loss $P_{\text{switching}}(I_G)$ as function of driven current $I_G$ is calculated.

2. Total loss $P_{\text{circuit}}(I_G)$ of the resonant gate drive circuit as function of driven current $I_G$ is calculated.

3. The Objective function is established by adding switching loss and the resonant gate driver loss together.

$$F(I_G) = P_{\text{circuit}}(I_G) + P_{\text{switching}}(I_G)$$
Conventional Driver vs. Resonant Driver

- Loss (W)

<table>
<thead>
<tr>
<th>Mode</th>
<th>+5V Conventional Driver</th>
<th>Resonant gate driver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduction</td>
<td>1.85</td>
<td>1.62</td>
</tr>
<tr>
<td>Turn-on</td>
<td>1.32</td>
<td>0.3</td>
</tr>
<tr>
<td>Turn-off</td>
<td>2.65</td>
<td>0.35</td>
</tr>
<tr>
<td>Gate/ RGD circuit</td>
<td>0.36</td>
<td>0.38</td>
</tr>
<tr>
<td>Body diode</td>
<td>1.92</td>
<td>0.7</td>
</tr>
</tbody>
</table>

$V_{in}$ = 12V; $V_o$ = 1.5V; $I_o$ = 20A; $f_s$ = 1MHz;
Control FET: IRF7821 (30V, $R_{DS(on)}$ = 9mΩ @ $V_{GS}$ = 6V)
Syn FET: FNS7088 (30V, $R_{DS(on)}$ = 3.5mΩ @ $V_{GS}$ = 6V)
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Experimental Results: Fast Switching Speed

Fast speed
No miller plateau

Gate drive signal and drain-source voltage (control FET)

Resonant inductor current and drain-source voltage (Synchronous FET)

\[ V_{in} = 12V; \quad I_o = 20A; \quad f_s = 1MHz; \quad \text{Control FET: IRF7821; Syn FET: FNS7088} \]
Experimental Results: Reduced Dead Time

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{in}$</td>
<td>12V</td>
</tr>
<tr>
<td>$V_o$</td>
<td>1.5V</td>
</tr>
<tr>
<td>$I_o$</td>
<td>20A</td>
</tr>
<tr>
<td>$f_s$</td>
<td>1MHz</td>
</tr>
<tr>
<td>Control FET</td>
<td>IRF7821</td>
</tr>
<tr>
<td>Syn FET</td>
<td>FNS7088</td>
</tr>
</tbody>
</table>

Resonant gate driver (TPS2832 TI) vs. Conventional gate driver (TPS2832 TI)
Experimental Results: Loss Savings

\[ \Delta P_{\text{loss}} = P_{\text{loss, conventional}} - P_{\text{loss, resonant gate driver}} \]

\( f_s = 1 \text{MHz} \)

- Io=5A
- Io=10A
- Io=15A
- Io=20A

**4.5W Loss Reduction**

@Vo=1.5V/20A (15% of the output power)
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Conclusion

• A New Resonant Driver Proposed
  ✓ Switching Loss Reduction
  ✓ Immunity to Common Source Inductance
  ✓ Gate Energy Recovery
  ✓ ZVS for Driver Switches
  ✓ High $C_{dv/dt}$ Immunity (Low Impedance)
  ✓ Reduced Body Diode Conduction Time

• Loss Analysis and Design Procedure Presented

• 4.5W Loss Reduction @Vo=1.5V/20A/1MHz (15% of output power)
Thank You For Your Time

Other Resonant Gate Drive Material at:
www.QueensPowerGroup.com