Experiment 2: Open Loop Boost

Driving a Power MOSFET Switch

- MOSFET is off when $v_{gs} < V_{th} \approx 3 \text{ V}$
- MOSFET fully on when $v_{gs}$ is sufficiently large (10-15 V)
- Warning: MOSFET gate oxide breaks down and the device fails when $v_{gs} > 20 \text{ V}$.
- Fast turn on or turn off (10's of ns) requires a large spike (1-2 A) of gate current to charge or discharge the gate capacitance
- MOSFET gate driver is a logic buffer that has high output current capability
Driving a Power MOSFET Switch

- MOSFET gate driver is used as a logic buffer with high output current (~1.8 A) capability
- The amplitude of the gate voltage equals the supply voltage VCC
- Decoupling capacitors are necessary at all supply pins of LM5104 (and all ICs)
- Gate resistance used to slow dv/dt at switch node

Power Converter Layout: Buck Example

Use loop analysis

switched input current $i_s(t)$ contains large high frequency harmonics
- hence inductance of input loop is critical
  - inductance causes ringing, voltage spikes, switching loss, generation of B- and E-fields, radiated EMI
the second loop contains a filter inductor, and hence its current $i_f(t)$ is nearly dc
- hence additional inductance is not a significant problem in the second loop
Parasitic inductances of input loop explicitly shown:

Addition of bypass capacitor confines the pulsating current to a smaller loop:

high frequency currents are shunted through capacitor instead of input source

Even better: minimize area of the high frequency loop, thereby minimizing its inductance

B fields nearly cancel
Gate Driver Example

Solution: bypass capacitor and close coupling of gate and return leads

High frequency components of gate drive current are confined to a small loop

A dc component of current is still drawn output of 15V supply, and flows past the control chips. Hence, return conductor size must be sufficiently large
Half Bridge Gate Drive Waveforms

- Gate driver chip must implement $v_{gs}$ waveforms
- Sources will have pulsating currents and need decoupling

MOSFET Gate Charge

- Charge is supplied to both $C_{gs}$ and $C_{gd}$ in order to move gate voltage and switch MOSFET
- Would like to supply the charge in minimum time to quickly switch FET
- Results in high peak currents
Gate Drive Implementation

- Gate driver is cascades back half-bridges of decreasing size to obtain quick rise times
- Reminder: keep loops which handle pulsating current small by decoupling and making close connections
Capacitor Sizing Notes

- Area of current pulse is total charge supplied to gate of capacitor
- All charge must be supplied from gate drive decoupling capacitor

\[ \frac{q_{\text{gate}}}{\Delta V_{DD}} = C \]

Gate Drive Losses

- Gate charge is supplied through driver resistance during switch turn-on
- Gate charge is dissipated in gate driver on switch turn-off

\[ E_{\text{loss}} = q_{\text{gate}} V_{DD} \]
\[ P_{\text{sw},g} = E_{\text{loss}} f_s \]
High Side Signal Ground

- Gate driver chip must implement $v_{gs}$ waveforms
- Issue: source of $Q_2$ is not grounded

Generating Floating Supply

- Isolated supplies sometimes used; Isolated DC-DC, batteries
- Bootstrap concept: capacitor can be charged when $V_s$ is low, then switched
IRS21094 Gate Driver

Typical Connection

(Refer to Lead Assignments for correct configuration. These diagrams show electrical connections only. Please refer to our Application Notes and Design Tips for proper circuit board layout.)

IRS21094 Internal Block Diagram

IRS21094

IN
DT
SD
VSS
VB
HO
VS
VCC
LO
COM
PC board
DRAIN
SINK
SOURCE
Bootstrap Diode Loss

- Conduction losses due to pulsating currents are relatively small
- Switching losses are significant
- Diode capacitance and reverse recovery play a role

Figure 5. Diode Power Dissipation $V_{in} = 80V$

<table>
<thead>
<tr>
<th>Direct Drive</th>
<th>Easiest high-side application the MOSFET and can be driven directly by the PWM controller or by a ground referenced driver, but it must meet two conditions, as follows: $V_{CC} &lt; V_{GS, MAX}$ and $V_{DC} &lt; V_{CC} - V_{GS, SAT}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floating Supply Gate Drive</td>
<td>Cost impact of isolated supply is significant. Optocoupler tends to be relatively expensive, limited in bandwidth, and noise sensitive.</td>
</tr>
<tr>
<td>Transformer Coupled Drive</td>
<td>Gives full gate control for an indefinite period of time, but is somewhat limited in switching performance. This can be improved with added complexity.</td>
</tr>
<tr>
<td>Charge Pump Drive</td>
<td>The turn-on times tend to be long for switching applications. Inefficiencies in the voltage multiplication circuit may require more than low stages of pumping.</td>
</tr>
<tr>
<td>Bootstrap Drive</td>
<td>Simple and inexpensive with limitations; such as, the duty cycle and on-time are both constrained by the need to refresh the bootstrap capacitor. Requires level shift, with the associated difficulties.</td>
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