Experiment 3: Open Loop Boost

Power Converter Layout: Buck Example

Use loop analysis
\[ V_{PZ} = I_P \cdot L_i(t) \]

switched input current \( I_i(t) \) 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 \( I_o(t) \) 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
Capacitor Packaging

- MOSFET conduction losses due to \((r_{ds})_{on}\) depend given as

\[
P_{cond,FET} = I_{d,rms}^2 (r_{ds})_{on}
\]
Driving a Power MOSFET Switch

- MOSFET is off when $v_{gs} < V_{th} \approx 3$ V
- MOSFET fully on when $v_{gs}$ is sufficiently large (10-15 V)
- Warning: MOSFET gate oxide breaks down and the device fails when $v_{gs} > 20$ 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
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.
Op-amp Pulsed Decoupling

**Figure 12.68**: Effects of Inadequate Decoupling on the Phase Response of the AD9631 Op Amp

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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

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

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

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

- **Gate driver chip must implement** \( v_{gs} \) **waveforms**
- **Issue:** source of \( Q_2 \) is not grounded

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### Generating Floating Supply

- **Isolated supplies** sometimes used; Isolated DC-DC, batteries
- **Bootstrap concept:** capacitor can be charged when \( V_s \) is low, then switched
<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>Direct Drive</td>
<td>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: $V_{cc} &lt; V_{th_{MAX}}$ and $V_{DC} &lt; V_{cc} - V_{th_{MIN}}$.</td>
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<tr>
<td>Floating Supply Gate Drive</td>
<td>Cost impact of isolated supply is significant. Opto-coupler tends to be relatively expensive, limited in bandwidth, and noise sensitive.</td>
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<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>
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<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>
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<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>
</tr>
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LM5104 Gate Driver

8.2 Typical Application

Figure 15. LM5104 Driving MOSFETs Connected in Synchronous Buck Configuration
• Conduction losses due to pulsating currents are relatively small
• Switching losses are significant
• Diode capacitance and reverse recovery play a role
Wiring Advice

- Take the time to wire board cleanly
- Very difficult to find a short in sloppy-wired circuit