不需要電感的高功率、切換式電源設計

JACKY CHEN
48V 直接降壓轉換, Charge Pump 架構簡介
Charge Pump 高功率設計要點
LTC7820 規格重點簡介
LTC7820 線路性能表現
Charge 和 Buck 架構整合
Traditional Motherboard Power Architecture

48V (54V)

Bus Converter

10-12V_{BUS}

ASICS

FPGAs

I/Os

400W 48V-to-12V active clamp forward (96.5%)

Off-the-shelf 600W-800W 48V-to-12V Brick (97.4%)

48v direct conversion
Is ¼ current than 12v conversion!
16x less loss!

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How to Improve the Power Density?

- Power density is limited by the bulky magnetics (especially for high voltage applications)
- Increase $F_{sw}$ → increased Power loss
- Trade off between efficiency and density

48V to 12V/20A, 125kHz, Buck converter design
Inductor-less Switched Capacitor Converters

No Magnetics & High Power density

Pre-charge technique can make high power design

Unity Gain Converter

Voltage Inverter

Voltage Doubler

Voltage Divider

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LTC7820-based Voltage Divider

- **High Efficiency**
- **High Density**
- **Low Profile**

- **Start up**
- **Gate driver**
- **OV/UV/OC Protection**
- **...**

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Voltage Divider and Its Operation Modes

**Mode I:**
- $V_o \approx \frac{1}{2} V_{in}$
- $Q_1$ & $Q_3$
- $Q_2$ & $Q_4$

**Mode II:**
- $V_{gs}$
- $50\%$ Duty Cycle

- $t_1 \sim t_2$
- $t_2 \sim t_3$
Power Loss Overview

1. Switching-related loss:
   - Capacitive turn-on loss
     \[ = \frac{1}{2} V_{in} \cdot Q_{oss} \cdot F_{sw} \cdot 4 = V_{in}^2 \cdot C_{oss} \cdot F_{sw} \]
   - Gate drive loss \((Q_g)\)
     \[ = V_g \cdot Q_g \cdot F_{sw} \cdot 4 \]

2. Conduction loss:
   - MOSFET \(R_{ds\_on}\) loss
     \[ = \frac{1}{2} I_{fly\_rms}^2 \cdot (R_{ds\_on1} + R_{ds\_on2} + R_{ds\_on3} + R_{ds\_on4}) \]
   - Flying capacitor ESR loss
     \[ = I_{fly\_rms}^2 \cdot ESR \]
   - Input Capacitor ESR loss
1. Voltage rating:
   - $V_{DS\_Q1} > V_{in} \, @ \, \text{Startup}$
   - $V_{DS\_Q2} > \frac{1}{2} V_{in}$
   - $V_{DS\_Q3} > \frac{1}{2} V_{in}$
   - $V_{DS\_Q4} > \frac{1}{2} V_{in}$

   Low voltage-rating device can be used

2. Figure of Merit (FOM) (-new definition)
   - $FOM = Q_{oss} \times R_{ds(on)}$
   - $(Q_{oss} = Q_{gd} + Q_{ds})$
1. Voltage rating:
   - $C_{fly}$ and $C_o$’s voltage rating $> \frac{1}{2} V_{in}$

2. Capacitor type
   - Multilayer Ceramic Capacitors (MLCC) is preferred due to small ESR loss
   - Capacitance vs. DC bias
   - RMS current rating

$V_{C_{fly}} \approx V_o \approx \frac{1}{2} V_{in}$
Ceramic Capacitor Capacitance vs. DC Bias

10µF/50V/1210/X7R, Murata GRJ32ER71H106KE11

More than 40% drop in capacitance @ 24V DC bias
Ceramic Capacitor RMS Current Rating

10µF/50V/1210/X7R, Murata GRJ32ER71H106KE11

- Temperature Rise [°C]:
  - Trise = 20°C
  - Trise = 10°C

- Current [Ams]: 0 to 6

- Frequency [kHz]: 400kHz, 800kHz

- Cap Change Rate [%]:
  - -100 to 40

- Temperature [°C]: 0 to 125

Keep the temperature rise below 20°C (even 10°C)

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LTC7820 Overview

❖ High Voltage High Power Charge pump DC/DC Controller
❖ Wide Vcc range from 6V to 72V
❖ Wide operating frequency range from 100 KHz to 1 MHz
❖ Soft start up into steady state operation
❖ Input current limit and protection
❖ Input current sensing and over current protection
❖ Short circuit protection with programmable timer and re-try
❖ Quad Integrated Powerful N-Channel MOSFET Gate Drivers
❖ Available in a 28 lead QFN Package with skipped pins
❖ Applications including voltage divider / doubler / inverter

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Application Example #1: $V_{in} = 48V$, $V_o=24V/20A$

$V_{in} = 48V$, $V_o = 24V/20A$, $C_{fly} = 16x\ 10\mu F/50V/X7R/1210$

$F_{sw} = 200kHz$, $Q_1 = \text{BSC027N06LS5}$, $Q_2 = Q_3 = Q_4 = \text{BSC032N04LS}$

Vin = 48V, Vo=24V/20A, Fsw = 200kHz

Efficiency

Power Loss

98.4%

15mm x 13mm x 5mm

(0.59” x 0.51” x 0.2”)

Power density: 4000W/inch$^3$

(800W/inch$^2$)
Application Example #3: \(V_{\text{in}} = 12\text{V}, V_{\text{o}}=6\text{V}/10\text{A}\)

\[V_{\text{in}} = 12\text{V}, V_{\text{o}} = 6\text{V}/5\text{A}, C_{\text{fly}} = 8 \times 47\mu\text{F}/16\text{V/X7R/1210}
F_{\text{sw}} = 200\text{kHz}, Q_1 = Q_2 = Q_3 = Q_4 = \text{BSZ014NE2LS5IF}\]

Efficiency vs Load Current
\(V_{\text{in}}=12\text{V}, V_{\text{o}}=6\text{V}, F_{\text{sw}}=200\text{kHz}\)

- Efficiency: 98.2%
- Power Loss: 0.2

Power density: 1150W/inch\(^3\)
\((230\text{W/inch}^2)\)
Quick Summary

- LTC7820-based voltage divider offers ultra high density (up to 4000W/inch³) and low profile solution with over 98% efficiency.

- Design trade-off between efficiency and density:
  - Choose the lowest switching frequency to meet the density requirement, which can maximize the efficiency
  - For low current design, choose the FETs with smaller $Q_{oss}$
  - For high current design, choose the FETs with smaller $R_{ds\_on}$
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Comparison between Buck and Voltage divider

❖ **Buck Converter**

- $V_o = D \cdot V_{in}$, Regulated
- Hard switching
- High voltage stress
- High switching loss
- Bulky magnetics

❖ **Voltage Divider**

- Inductor-less
- Soft switching
- Low voltage stress
- $V_o = \frac{1}{2}V_{in}$, non-regulated
Hybrid Converter Concept

Hybrid Converter
The Benefits of Hybrid Converter

- Low FET voltage stress
- Low switching loss
- High switching frequency
- Small inductor
- $V_o = \frac{1}{2}V_{in}D$, Regulated
- Current Mode control
- Current Sharing
The Operation Modes of the Hybrid Converter - 1

**t₁ ~ t₂, Mode I:**

- Duty cycle D
- Q₁ & Q₃
- Q₂ & Q₄

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**Q₃**: reduced conduction loss, reduced switching loss

\[ i_{Ls} = i_{Cty} + i_{Cmid} \]
\[ i_{Q3} = i_{Cmid} \]
Efficiency Test

$V_{in} = 48V \sim 54V$, $V_o = 12V/25A$, $F_{sw} = 400kHz$

$Q_1 = \text{BSC039N06NS}$, $Q_2 = Q_3 = \text{BSC032N04LS}$, $Q_4 = \text{BSC014N04LSI}$

$L = 2\mu H \ (\text{SER2011-202ML})$, $C_{fly} = C_{mid} = 12x10\mu F$, $\text{EXTVcc} = 8V$

Efficiency vs Load Current

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Thermal Test @ 25A w/o Air Flow

\[ V_{in} = 48V \sim 54V, \quad V_o = 12V/25A, \quad F_{sw} = 400kHz \]
\[ Q_1 = \text{BSC039N06NS}, \quad Q_2 = Q_3 = \text{BSC032N04LS}, \quad Q_4 = \text{BSC014N04LSI} \]
\[ L = 2\mu H (\text{SER2011-202ML}), \quad C_{fly} = C_{mid} = 12\times10\mu F, \quad E X T V_{cc} = 8V \]

\[ V_{in} = 48V, \quad V_o = 12V/25A \]

\[ V_{in} = 54V, \quad V_o = 12V/25A \]

\[ T_{amb} = 23^\circ C \]
Solution Size Estimation

Size: 1.45” x 0.77” x 0.42”
## Comparison with Artesyn’s ¼ Brick AVQ300 Series

<table>
<thead>
<tr>
<th></th>
<th>Power Brick</th>
<th>LTC7821 Hybrid Converter</th>
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</thead>
<tbody>
<tr>
<td><strong>F (_{sw})</strong></td>
<td>145kHz</td>
<td>400kHz</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>95%</td>
<td>97.1%</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>2.3” x 1.45” x 0.5”</td>
<td>1.45” x 0.77” x 0.42”</td>
</tr>
<tr>
<td><strong>Footprint</strong></td>
<td>3.34 inch(^2)</td>
<td>1.12 inch(^2)</td>
</tr>
<tr>
<td><strong>Power Density</strong></td>
<td>180W / inch(^3)</td>
<td>640W / inch(^3)</td>
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Thanks your time!