Multi-Phase Clock-less Switching Converter with EMI Noise Reduction

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Research Objective

Objective

Development of power supply with
- EMI noise Reduction
- Fast response
- Low output voltage ripple control

Approach

- Constant on-time control
- Multi-phase
Contents

• Research background
• Constant on-time control
• Four-phase converter solution
  via saw-tooth wave circuit
• Simulation result
• EMI reduction via pulse phase modulation
• Conclusion
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What is Power Supply

Power supply demanded everywhere to provide appropriate voltage for electronic device.

- **100~240V AC**
  - AC-DC Converter
- **4.2V DC**
  - DC-DC Converter

Power Supply
Classifications of DC-DC Converter

- **Buck**
  - $V_{in} > V_o$

- **Boost**
  - $V_{in} < V_o$

- **Buck-Boost**
  - $V_{in} \leq V_o$

Basic configuration of DC-DC converter.
Operation of Buck Converter

**On State:** Q on, D off

\[ V_{\text{Lon}} = \text{Vin} - \text{Vo} = L \cdot \left( \frac{\Delta i_L^+}{\Delta t_{\text{on}}} \right) \]

**Off State:** Q off, D on

\[ V_{\text{loff}} = -\text{Vo} = L \cdot \left( \frac{\Delta i_L^-}{\Delta t_{\text{off}}} \right) \]

\[ \Delta i_L^+ = \Delta i_L^- \]

\[ \text{Vo} = \text{Vin} \frac{T_{\text{on}}}{T_s} \]
Demand for Power Supply of Process

<table>
<thead>
<tr>
<th>DC input</th>
<th>DC output</th>
<th>Max. output current</th>
<th>Max. output current step</th>
<th>Max. output current slew rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>12V</td>
<td>1.5V</td>
<td>120A</td>
<td>100A/us</td>
<td>930A/us</td>
</tr>
</tbody>
</table>

- Four-phase Ripple Control Converter
- Ripple control
- High speed response
- Large current
- Multi-phase

Intel Xeon
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Merit of Constant on-time control

Ripple Control

Hysteresis window control

Extreme fast response

Constant on-time control

\[ V_{out} = V_{in} \frac{T_{on}}{T_s} \]

\[ f_s = \frac{1}{T_s} \]

\[ f_s = \frac{V_{out}}{V_{in} \cdot T_{on}} \]

Frequency swings usually

Frequency keeps stable
Operation of Constant on-time control

Proposed COT Converter

Operation waveform

State $t_0 \sim t_1$
1. $V_r$ reaches to $V_{ref}$, $V_{comp}$ comes out
2. RS flip-flop is started by $V_{comp}$
3. PWM goes to HIGH, Ton timer starts
4. Ton timer is over
5. RS flip-flop is reset
6. PWM goes to LOW.

State $t_1 \sim t_2$
7. PWM keeps LOW until next cycle
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Demerit of Single-Phase Converter

Io flows only through inductor Lo

Lo large

Large load on inductor Lo

$i_{Lo} = i_o$

$V_o$
Merit of Multi-Phase Converter

Multi-phase Converter

Tracking PWM2 with PWM1 without clock is demanded

Inductor L1 and L2 will go shares with Io

L1 and L2 small

180° phase difference

Load of each phase’s inductor halved

Simulative frequency multiplication

Low ripple by shifted two-phase peak current
Proposed Four-Phase Converter Solution

Main Power Stage

PWM1

SAW Generator

Tracking SAW

Voltage Divider & Comparator

Peak Hold

Peak Voltage

Four-phase PWM Generator

Sub Power Stages

Vin 10V

PWM1

10kΩ

1nF

Rf

Cf

Vo 3V

10uH

IL1

C

RL

3.9kΩ

1mF

R1

200uF

IL2

PWM2

Cot Controller

IL3

PWM3

Sub-Converter 2

IL4

PWM4

Sub-Converter 3

Sub-Converter 1

Four-phase Generator

R2

470kΩ

Sub-Converters

Vo 10V

3V

10uH

1mF

1nF

10kΩ

200uF
Generation of Four-Phase PWM

SAW Generator & Peak Hold

Voltage Divider & Comparator

Operation waveform
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Current Balance

Current balance offset $\Delta I_L$

$\Delta I_L = \frac{|I_L - I_o|}{n}$

$I_o = 3.04A$

$I_{L1}, I_{L2}, I_{L3}, I_{L4} = 0.67A \sim 0.84A$

$\Delta I_L = I_L - I_o/4 = 0.09A$

$\delta = \frac{0.09}{(3.04/4)} \times 100% = 11.8%$

Large load current achieved

Good current balance during transient response
Single and multi-phase Comparison

**Static state characteristic**

<table>
<thead>
<tr>
<th>Vout: 3V</th>
<th>Ripple peak to peak</th>
<th>Ripple range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vout</td>
<td>86%off</td>
<td>under1%</td>
</tr>
<tr>
<td></td>
<td>83mV ⇒ 5mV</td>
<td></td>
</tr>
</tbody>
</table>

**Dynamic load regulation**

<table>
<thead>
<tr>
<th>I&lt;sub&gt;load&lt;/sub&gt;: 5A → 10A → 5A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transient response</td>
</tr>
<tr>
<td>Peak to Peak voltage</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Recovery time</td>
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Pulse Phase Modulation

Single-phase Converter

Phase Modulated Pulse

Comparison between SAW & Triangle wave

EMI Reduction Circuit

Synchronized SAW signal to $V_{\text{comp}}$

Synchronized pulse signal to PWM
Spectrum of Conductive Noise

Conductive noise at input side

Without EMI reduction

With EMI reduction

Single phase

Four phase

Spectrum level at clock frequency (Fpwm=390kHz)

Single phase

300 mV

100 mV 9.5 dB reduction

Four phase

50 mV

10 mV 14 dB reduction
Conductive Noise and Vref

Theoretically less level at Vref=0.9848 V

Minimum level of conductive noise

input current noise

90 degrees

no spectrum

Vref turn-on time of the switch change

input current noise

The Spectrum dB

[Vref/V]
Conclusion

• Design of good relationship between conductive noise and reference voltage for COT pulse is proposed.
• Four-phase ripple controlled converter with EMI reduction is proposed
• Peak level of spectrum at 4Fpwm is reduced
• Low output voltage ripple, Fast response
• Current balance is very good even at large output current
Thank you for your attention