Constant On-Time Controlled Four-Phase Buck Converter via Two Ways of Saw-Tooth-Wave Circuit and PLL Circuit

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Research Objective

**Objective**

Development of power supply with
- Large current
- Fast response

**Approach**

- Constant on-time for ripple control converter
- Make the power supply multi-phase
Contents

• Research background
• Constant on-time control
• Four-phase converter solution of PLL way
• Simulation result of PLL way
• Four-phase converter solution of Saw-tooth-wave circuit way
• Simulation result of Saw-tooth-wave way
• Conclusion
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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>

- Ripple control
- High speed response
- Multi-phase

Large current

Four-phase Ripple Control Converter
Contents

• Research background
• **Constant on-time control**
  • four-phase converter solution of PLL way
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Merit of Constant on-time control

Ripple Control

Hysteresis window control

Extremely fast response

No phase compensation

Constant on-time control

Frequency swings usually

Frequency keeps stable

Ripple Control
Operation of Constant on-time control

Proposed COT Converter

Constant Ton

Stable frequency

No clock

Difficult to get multiphase

Tracking PWM with PWM1 is demanded without clock
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Proposed Four-Phase Converter Solution

Main Power Stage

Use PLL

Four-phase Generator Design

Without PLL

Other Three Sub Power Stages
Generation of Four-Phase PWM within PLL

Use PLL circuit

Main PWM ➔ PLL ➔ Logic Gate ➔ Digital Multiphase PWM Generator

PWM1 ➔ PD ➔ CP ➔ LPF ➔ VCO ➔ 1/4 Divider

Differentiation

Latch up pulse2

Latch up pulse3

Latch up pulse4

PWM2 ➔ PWM3 ➔ PWM4

Counter A

Latch

LUT2

A Comp B

PWM2

A

B

A=B

PUL2

Counter B

Latch

LUT3

A Comp B

PWM3

A

B

A=B

PUL3

Counter

Latch

LUT4

A Comp B

PWM4

A

B

A=B

PUL4

COT Circuit2

COT Circuit3

COT Circuit4
Generation of Tracking PWM

Operation waveform

PLL

Tracking PWM (D1) is generated

Logic circuit

Three-phase pulse tracking with D1
Generation of Four-phase PWM

Digital multiphase PWM generator

PLL

Counter A

Counter B

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Current Balance (Within PLL)

Current balance

- Current balance is NOT good

Large load transient response

- Slow response to large load transient

- Low pass filter inside PLL makes response slow

- REJECT
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Four-phase converter solution without PLL

Without PLL

Main PWM → Saw-tooth-wave Generator → Tracking Saw-tooth-wave → Peak Hold

Voltage Divider & Comparator

PMW4 → PMW3 → PMW2
Generation of Four-Phase PWM

**Peak Hold**

- Current Source
- Sampling Pulse
- Voltage Follower
- Differentiator
- Buffer
- Main PWM

**Voltage Divider & Comparator**

- Peak Hold Voltage
- Saw-tooth Voltage
- \( \frac{3}{4} V_p \)
- \( \frac{2}{4} V_p \)
- \( \frac{1}{4} V_p \)

Four-phase PWM is generated.
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Current Balance (without PLL)

\[ I_{L1} = I_{L2} = I_{L3} = I_{L4} \]

\[ \Delta I_{L1} = I_{L1} - I_0/4 \]

\[ = |1.26 - 5.06/4| = 0.005 \text{A} \]

\[ \delta = \frac{0.005}{(5.06/4)} \times 100\% = 0.39\% \]

Good current balance during transient response

Large load current achieved

Good current balance
Comparison (without PLL)

Vout = 3V

Static state characteristic

<table>
<thead>
<tr>
<th>Vout</th>
<th>Ripple peak to peak</th>
<th>Ripple range</th>
</tr>
</thead>
<tbody>
<tr>
<td>57%off</td>
<td>under 1%</td>
<td></td>
</tr>
</tbody>
</table>

Dynamic load regulation

<table>
<thead>
<tr>
<th>Transient response</th>
<th>Overload</th>
<th>Underload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak to Peak voltage</td>
<td>70%off</td>
<td>59%off</td>
</tr>
<tr>
<td>Recovery time</td>
<td>75%off</td>
<td>80%off</td>
</tr>
</tbody>
</table>
Conclusion

- Proposal of four-phase DC-DC converter with constant-on-time control
- Four-phase PWM generators designed with digital and analog circuits
- Good current balance
- Large load current
- Low output voltage
- Fast response
Thank you for listening
谢谢
思而不学则殆
学而不思则罔
Q: How many times did you do the simulation until the result coming out.
A: Actually, the current balance error changes by the on-time of PWM. So I did many the simulation for many times to find out the appropriate on-time in order to get the best current balance.

Q: What is the difference between convectional and two-phase converter.
A: Just like the result in the previous paper. Both voltage shoot and recovery time has become much better during the transient response.