Edward Herbert Designs

Multiphase Buck Converter vs. Switched Current Power Converter

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Solutions for Advanced Performance Power Supplies

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Specifications: The hypothetical specifications are based upon Intel® VR 10.2, with variation to highlight design differences.

### Multiphase buck converter

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>12 V dc, isolated</td>
</tr>
<tr>
<td>Output voltage (per VID)</td>
<td></td>
</tr>
<tr>
<td>Output current</td>
<td>120 A</td>
</tr>
<tr>
<td>Phases</td>
<td>four</td>
</tr>
<tr>
<td>Spec</td>
<td>VR 10.2</td>
</tr>
<tr>
<td>Output impedance</td>
<td>1.2 mΩ*</td>
</tr>
</tbody>
</table>

*Note: The high output impedance specified in VR 10.2 has no benefit for the processor. It stands to reason that a higher voltage at a lower current serves no useful purpose and only wastes power. The high impedance is only to accommodate the poor response characteristics of present power supplies.*

### Switched current power converter

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>12 A, unisolated</td>
</tr>
<tr>
<td>Output voltage (per VID)</td>
<td></td>
</tr>
<tr>
<td>Output current</td>
<td>120 A</td>
</tr>
<tr>
<td>Channels</td>
<td>ten</td>
</tr>
<tr>
<td>Spec</td>
<td>VR 10.2*</td>
</tr>
<tr>
<td>Output impedance</td>
<td>0.5 mΩ*</td>
</tr>
</tbody>
</table>
Multiphase Buck Converter—vs.—Switched Current Power Converter

Overview:

**Multiphase buck converter**

The multiphase buck converter uses parallel buck converters to control the output current.

![Diagram of multiphase buck converter]

- Bandwidth: $\approx 30 \text{ kHz}$
- $\frac{\text{di}}{\text{dt}} \approx 30 \text{ A/us}$
- $\frac{\text{dv}}{\text{dt}} \approx 6 \text{ mV/us}$
- $Z_{out} \approx 1.25 \text{ m\Omega}$
- $C_1 \approx 10,000 \text{ uF}$
- $C_2 \approx 500 \text{ uF}$

**Switched current power converter**

The SCPC uses a number of parallel current sources that are switched to the output capacitor and the load or to the return.

![Diagram of switched current power converter]

- Bandwidth: $\approx 5 \text{ MHz or higher.}$
- $\frac{\text{di}}{\text{dt}}$ — no limit except parasitic impedances.
- $\frac{\text{dv}}{\text{dt}} \approx 40 \text{ mV/us} (1,600 \text{ mV/us with switched charge circuits})$
- $Z_{out} \approx 0.5 \text{ m\Omega}$
- $C_1$ — **not used**
- $C_2 \approx 500 \text{ uF}$
Multiphase Buck Converter—vs.—Switched Current Power Converter

Physical differences, Magnetics:

Multiphase buck converter

The multiphase buck converter uses an inductor for each phase as an energy storage device.

Switched current power converter

The preferred SCPC uses a coaxial transformer.

A typical size is $7 \times 6 \times 5 \text{ mm}$.

Proposed SCPC module.

The primary windings are two "U" shaped wires.
**Multiphase Buck Converter—vs.—Switched Current Power Converter**

**Physical differences, Capacitors:**

**Multiphase buck converter**

The multiphase buck converter uses 7,500 to 9,000 uF of bulk capacitors:

**Switched current power converter**

The SCPC does not use bulk capacitors.
## Physical differences,

### Power Semiconductors:
The Power Semiconductors are represented by hypothetical die size based upon the current switched, the duty cycle and the voltage.

### Multiphase buck converter

The multiphase buck converter uses 20 V MOSFETs

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Current (A)</th>
<th>Duty Cycle (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>49</td>
<td>30</td>
<td>8.3</td>
</tr>
<tr>
<td>64</td>
<td>30</td>
<td>91.7</td>
</tr>
<tr>
<td>49</td>
<td>30</td>
<td>8.3</td>
</tr>
<tr>
<td>64</td>
<td>30</td>
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</tr>
<tr>
<td>64</td>
<td>30</td>
<td>91.7</td>
</tr>
</tbody>
</table>

452 total

### Switched current power converter

All of the secondary power MOSFETs for the SCPC can be integrated into a single simple power IC. Max voltage: 5V. To handle 120A, division into 5 identical power ICs is preferred. There is also a driver IC for the transformer primary.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Description</th>
<th>Current (A)</th>
<th>Duty Cycle (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Dual primary driver</td>
<td>12</td>
<td>50-50%</td>
</tr>
<tr>
<td>90</td>
<td>2 channel Simple IC</td>
<td>24</td>
<td>30-100%</td>
</tr>
<tr>
<td>90</td>
<td>2 channel Simple IC</td>
<td>24</td>
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<td>2 channel Simple IC</td>
<td>24</td>
<td>30-100%</td>
</tr>
</tbody>
</table>

470 total

See Appendix for more information on the Simple IC.
Multiphase buck converter—vs.—Switched current power converter

Performance differences:
Di/dt.

Multiphase buck converter

Intel ® P4 Spec:  Load Dump:

Switched current power converter

SCPC with Binary Switched Charge:
Simultaneous Load Dump and VID decrease to 0:

25 us
50 mV overshoot

0.5 us
No overshoot

SPICE simulation.
Multiphase buck converter—vs.—Switched current power converter

**Performance differences, DV/dt.**

**Multiphase buck converter**

From Intel® VR 10.2

- 450 mV in 180 us

**Switched current power converter**

Basic SCPC:

- 1,000 mV in 10 us

SCPC with Binary Switched Charge Circuits

- 800 mV in 0.5 us
### Performance differences,
#### Output impedance:

<table>
<thead>
<tr>
<th>Multiphase buck converter</th>
<th>Switched current power converter</th>
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</thead>
<tbody>
<tr>
<td>1.2 mΩ</td>
<td>0.5 mΩ</td>
</tr>
</tbody>
</table>
### Performance differences, Switching Frequency:

<table>
<thead>
<tr>
<th>Multiphase buck converter</th>
<th>Switched current power converter</th>
</tr>
</thead>
<tbody>
<tr>
<td>All phases have switching losses:</td>
<td><strong>Straight switching:</strong></td>
</tr>
<tr>
<td>1 MHz</td>
<td>1 channel switches</td>
</tr>
<tr>
<td>Current: Io/4</td>
<td>1 MHz</td>
</tr>
<tr>
<td>Duty cycle: Vo/Vi</td>
<td>Current: max Io/10</td>
</tr>
<tr>
<td></td>
<td>Distributed switching:</td>
</tr>
<tr>
<td></td>
<td>10 channels switch</td>
</tr>
<tr>
<td></td>
<td>100 kHz</td>
</tr>
<tr>
<td></td>
<td>Current: max Io/10</td>
</tr>
<tr>
<td></td>
<td>Duty Cycle: Io/max Io</td>
</tr>
</tbody>
</table>
**Multiphase buck converter—vs.—Switched current power converter**

**VRD Input Power:**

**Multiphase buck converter**

Isolated 12 V dc power source. Prime power source must include a transformer.

Filtering: The 12 V dc power source is probably a buck converter, requiring emi filtering on its input and a ripple filter capacitor on its output.

The multiphase buck converter also requires emi filtering on its input due to the current pulses on its input.

**Switched current power converter**

12 A current source input, which need not be isolated. A transformer is not needed.

Filtering: The current source is probably a buck converter, requiring an emi filter on its input. No ripple capacitor is used on its output.

The SCPC needs little or no filtering, as the input current is constant.

If only a 12 V dc power source is available in a system, a buck converter configured as a current source is needed at the SCPC input.
**Multiphase buck converter—vs.—Switched current power converter**

**Input Current:**
The waveform of the current into the VRM or VRD largely determines the emi filtering that is necessary.

**Multiphase buck converter**
The multiphase buck converter has a pulsing input current with pulse widths of the period times $V_o/V_i$.

The peak current is the output current divided by the number of phases, $I_0/n$.

**Switched current power converter**
The input current is a constant dc value equal to the maximum output current divided by the number of channels, $I_{o\text{max}}/n$.

(Reducing the current, or turning it off, are options for a reduced power mode.)
**Multiphase buck converter—vs.—Switched current power converter**

### Input Voltage:

**Multiphase buck converter**

The input voltage is a fixed dc voltage, typically 12 V dc.

**Switched current power converter**

The input voltage is proportional to the output current. Its maximum value is the output voltage times the number of channels, \( n \cdot V_o \).

At steady state conditions, the input voltage will have a peak to peak ripple voltage equal to the output voltage, \( V_o \).
Control:
The control ICs of both the multiphase buck converter and the SCPC can be highly integrated, so any cost differential is small.

Multiphase buck converter

1. The response time is limited by the di/dt of the inductors.
2. The positive going and negative going di/dt differ by an order of magnitude. There is a significant overshoot and a long recovery time after a load dump.
3. The current of each phase must be measured and controlled.
4. The output voltage is measured and fed back as the control input.

Switched current power converter

1. The response time is limited by the propagation delay through comparators, digital logic, the MOSFETs and their drivers.
2. The positive going and negative going di/dt are the same. There is no overshoot and the recovery time is less than 2 us after a load dump.
3. No current measurement is used.
4. The total charge on the output capacitors is measured as the control input.
## Failure modes and effects:

<table>
<thead>
<tr>
<th>Multiphase buck converter</th>
<th>Switched current power converter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Several failure modes of a buck converter can result in the input voltage appearing on the output.</td>
<td>No single failure in the transformer coupled SCPC will apply the input voltage to the output.</td>
</tr>
</tbody>
</table>
Multiphase buck converter—vs.—Switched current power converter

Appendix: Proposed integrated circuit (IC): Schematic:

Following, there is a discussion of the MOSFET switches and a method of integrating them into a Simple Power IC. The circuit being discussed is the following, and in particular, the MOSFET switches.

See: Http://eherbert.com for more information on the Simple Power IC.
Multiphase buck converter—vs.—Switched current power converter

Appendix:
Integrating the synchronous rectifiers:

The synchronous rectifier MOSFETs can be integrated into one die with a common drain at the bottom of the substrate. A trench structure can be used, with half of the trenches connected to each source, to make back-to-back MOSFETs with a common drain.

If the two sources are highly interdigitated, such that the pitch P is small compared to the thickness of the substrate L, then the currents will diffuse sufficiently that the source from which it originated will be indistinguishable at the drain connection. The common drain will have twice the area and half the current density, for significantly reduced impedance compared to two individual MOSFETs of the same total area.

More important, the high frequency effects (skin depth) will not be present in the drain connection for 100 % duty-cycle operation.

This IC will have applications far beyond switched current power converters, as it will be a superior synchronous rectifier for many other applications, particularly when paired with a coaxial transformer.
Appendix:
Integrating the ac shorting switch:

In the schematic, the shorting switch is shown as back-to-back MOSFETs. In a practical IC, the MOSFETs can be integrated with a common drain and a common gate.

The shorting switches can be made using trench MOSFET construction all having a common gate. In any one trench, one side is connected to the first source, S1 and the other side is connected to the second source, S2. The metallization is striped, so that the facing sides of adjacent trenches have the same source. When on, the current will flow from source to source in either direction through the buried drain under the trenches. Because the current does not have to flow through the substrate and the external drain connection, the resistance will be very low.

If used as a low voltage ac switch alone, no isolation to the substrate is needed. However, it is contemplated to integrate this circuit with the synchronous rectifiers, in which case an isolation barrier is needed, either an insulating layer or a junction barrier.

This IC will have applications far beyond switched current power converters, as it will be a superior bi-directional switch for many other applications. If the bi-directional switch is used as a separate component, the barrier is not required.
Multiphase buck converter—vs.—Switched current power converter

Appendix:
Integrating the shorting switches into synchronous rectifiers:

Starting with the interdigitated synchronous rectifier design, the shorting switches can be integrated into the margins between the sources. A barrier is needed between the sources, and this region can be enlarged to accommodate the shorting switches from the previous page.

The gate connections are not shown. The die size will be increased somewhat to accommodate the shorting switches, but far less than the area that would be required by a separate die with separate source terminations. This will further increase the drain area, improving the synchronous rectifier because the current density is further reduced at the common drain.

This IC will have applications far beyond switched current power converters. When paired with a coaxial transformer, it can be used for a transformer with variable turns.