Achieving higher power density, efficiency, and voltage accuracy in point-of-load DC/DC converters

Point-of-Load Power for Processors
5 design challenges for point-of-load power

- Voltage regulation accuracy
- Fast transient response
- Eliminating beat-noise in sensitive applications
- High power density and efficiency
- Finding a suitable POL DC/DC converter to use
Challenge #1: voltage regulation accuracy

As process technology advances, processor voltage requirements are lower and require high accuracy.

3% tolerance requirement includes:
- Reference voltage accuracy
- Resistor divider tolerance
- Routing and PCB I*R losses
- Input voltage variations
- Temperature variations
- Load transients

Recommended Operating Conditions

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPGA Logic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{CCINT}$</td>
<td>0.87</td>
<td>0.90</td>
<td>0.93</td>
<td>V</td>
</tr>
<tr>
<td>$V_{CCBRAM}$</td>
<td>0.87</td>
<td>0.90</td>
<td>1.03</td>
<td>V</td>
</tr>
</tbody>
</table>

Source: Texas Instruments
Solution: voltage regulation accuracy

1. A DC/DC converter with tighter voltage reference accuracy will allow headroom to meet the 3% processor voltage requirement. An example:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Reference</td>
<td>0 A ≤ IOUT ≤ 10 A, –40°C ≤ TA ≤ 150°C</td>
<td>0.594</td>
<td>0.6</td>
<td>0.606</td>
<td>V</td>
</tr>
</tbody>
</table>

TPS54020 ELECTRICAL CHARACTERISTICS:
TJ = –40°C to 150°C, VIN = 4.5V to 17V, PVIN = 4.5V to 17V (unless otherwise noted)

2. Choose tighter tolerance resistor dividers
   • 0.1% or 0.5% resistors cost more than 1% resistors
   • High accuracy for lower voltages is not difficult, since low divider ratios are inherently accurate
   • Search “Kollman Power Tip #18” to learn more about voltage dividers and accuracy

3. A remote sense feature in the POL DC/DC converter will compensate for I*R drops and maintain accuracy
Challenge #2: transient response

The point-of-load power supply must respond to a processor’s quickly changing load demand to meet 3% tolerance with minimal bulk capacitance.

- Transient response affects the regulation accuracy of the power supply system.
- Do not exceed the processor maximum voltage during a transient.
- To provide better regulation accuracy during a transient:
  - Reduce the inductor value to allow faster response.
  - Increase the value of capacitance that store/provide energy during a load transient charge.
  - Use low ESR capacitors.

**Diagram: 1.0V (Nom)
1% DC Tolerance = 10mV
2% AC Transient = 20mV**

**Texas Instruments**
System sources of current to meet load transients

- The power supply is not the only current source in the system.
- In most cases is not the supplier of the bulk of the transient current required.
- A processor’s local bypass capacitors are good for “instantaneous” sources of current, but bulk capacitance will provide the most.
- Higher switching frequency > 1MHz will allow a smaller L and C and improve transient response time.
Solution: fast transient response

- TI’s **non-linear** control modes provide faster transient response than traditional linear fixed frequency **current mode** or **voltage mode** control
  - Constant On-Time
  - D-CAP™ versions

### Simplified COT diagram

**Capabilities**
- No loop compensation
- Excellent transient response
- Lack of oscillator prohibits fixed-frequency operation
- DCAP™ versions minimize frequency shift

[Diagram showing waveforms and control modes]
Fast transient example: TPS54A20

TPS54A20
Constant on-time

$V_{IN} = 12V$

$V_{OUT} = 1.2V$

$I_{OUT} = 10A$

$C_{OUT} = 2 \times 47uF$

120 mm$^2$ total solution

4MHz switching frequency

Low Profile <2mm

Load step: 1A to 6A at 5A/us

Vout deviation: +/- 25mV (1.175V to 1.225V)

For more information on TI control modes, visit (or search):
Challenge #3: reduce noise – alternative control mode

Consider current mode control

Capabilities

- Fast response to output current changes
- Requires loop compensation
- Inherent feed forward
- Predictable switching behavior
- Can synchronize to external clock to eliminate beat noise
Solution: frequency synchronization

- Synchronizing switching frequencies eliminates low beat frequency noise in the system.
- Devices synchronize together or from a master clock. Check for `sync` or `clock` pin.
- Ideal for RF or data acquisition applications like medical imaging, test and measurement, or network communications.
Challenge #4: high power density and efficiency

Increasing the switching frequency reduces the size of the output inductor and capacitance to save space, but increases switching losses.

Frequency a key component of efficiency
- FET driving loss ($Q_g \times V \times F$)
- FET switching loss – $f(V_{in}, I_{out}, T_{on/off}, F)$
- FET resistance ($I^2 \times R_{ds(on)}$)
- Inductor loss ($I^2 \times DCR + \text{Core losses}$)
- Capacitor loss ($I_{RMS}^2 \times ESR$)
- IC loss ($I_q$)

Minimum on-time constraint
- DC/DC converters won’t always work well at a low duty cycle and fast frequency
- Check the minimum controllable on time in the datasheet
- $\text{Min. Duty Cycle} = \text{Min. on time} \times F_{sw}$
Solution: size and efficiency trade-off

The better solution depends on system goals!

TPS53515
Fsw – 500kHz
V\textsubscript{IN} – 12V
V\textsubscript{OUT} – 1.2V
I\textsubscript{OUT} – 10A
C\textsubscript{OUT} - 6x47uF 4x22uF
0.309 sq. inches
Profile ~4mm

Advantage in efficiency and loss
- Lower switching loses in the MOSFETs
- Lower inductor DCR
- Lower RDS(on) MOSFETs

TPS54A20
Fsw – 4MHz
V\textsubscript{IN} – 12V
V\textsubscript{OUT} – 1.2V
I\textsubscript{OUT} – 10A
C\textsubscript{OUT} - 2 x 47uF
0.186 sq. inches
Low Profile <2mm

Advantage in size
- Uses smaller chip inductors and capacitors to meet the same transient requirement
- Lower profile for backside mounting

Both supplies designed for the same transient requirements
Solution: high density packaging

Advanced QFN packaging allows higher current in smaller packages

**Traditional QFN**
- Flexible manufacturing
- Easy assembly
- Good thermal performance
- Higher resistance

**HotRod™ QFN**
- Solder lands on all sides for high-current capability
- Similar to QFN thermals
- Testability of QFN
- Reduced parasitics
- Lower resistance

**Stacked-Clip QFN**
- 3D for highest power density & lowest Rds(on)
- Highest current capability
- Reduced parasitics
- Large single GND pad versus competition
Example: high efficiency in small QFN packaging

**Vin = 12 V**

12Vin to 1.0Vout at 600kHz

Inductor $\rightarrow$ WE 744311100
(1.0 $\mu$H, 4.6 m$\Omega$, 7040 size)

HotRod™ QFN – 3.5x3.5mm

Traditional QFN – 3.5x3.5mm

HotRod QFN allows lower Rds(on) in same package size
PMBus™ saves space & provides flexibility

The Power Management Bus is a wire **communications protocol** based on I²C with a fully defined command language that facilitates communication with power converters and other devices in a power system.

**Features**
- Integrated Adaptive Voltage Scaling (AVS) for processor voltage adjustment
- Internal V, I, T telemetry to reduce components
- Power sequencing to eliminate sequencers
- Configure frequency, soft-start time, etc.
- Fault adjust & reporting
- Voltage margining
- Data logging
- Built in NVM for ‘set and forget’
- Default settings – communication is not required
- Others…features are device specific
Challenge #5: finding a suitable converter to use

- Searching for a performance DC/DC converter
- Simulation design tools
- Reference designs, samples & evaluation modules
- Support
Solution: SWIFT™ DC/DC Converters

Switchers with Integrated FETs
- High Efficiency & High Power Density
- Ideal for Powering Processors from 3.3/5/12V Rails
- Supported by WEBENCH® Tool

Visit www.ti.com/swift

Same color groups are pin compatible
SWIFT™ devices with PMBus marked with *

symbols

• High Efficiency & High Power Density
• Ideal for Powering Processors from 3.3/5/12V Rails
• Supported by WEBENCH® Tool

visit www.ti.com/swift
SWIFT DC/DC converters for processor power

- **High voltage regulation accuracy**
  - Reference accuracy as tight as +/- 0.5% over temperature

- **Fast transient response help meet +/- 3% voltage tolerance**
  - COT and D-CAP versions for minimal output capacitance
  - Current and voltage mode versions allow predictable fixed-frequency operation and flexibility in inductor / capacitor selection

- **High power density**
  - Support 1MHz or higher frequency to reduce inductor and capacitor size
  - Advanced packaging allows high-current capability in smaller QFN packages
  - PMBus reduces DC/DC converter component count and eliminates additional circuitry

- **High efficiency**
  - Integration of low Rds(on) power FETs supporting low output voltages

- **WEBENCH® designer and tool support**
Solution: Webench Power Architect

visit www.ti.com/webench - Webench Designer
Solution: FPGA Power Reference Designs

<table>
<thead>
<tr>
<th>Tool Number</th>
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<tbody>
<tr>
<td>PMP8251</td>
<td>Power Solution for Xilinx FPGA Zynq 7</td>
</tr>
<tr>
<td>PMP10520</td>
<td>Xilinx Virtex UltraScale FPGA Multi-Gigabit Transceiver (MGT) Power Solution</td>
</tr>
<tr>
<td>PMP10555</td>
<td>Xilinx Ultrascale 16nm Power Solution with PMBus</td>
</tr>
<tr>
<td>PMP6776</td>
<td>Xilinx Kintex FPGA Power Solution</td>
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<tr>
<td>PMP9407</td>
<td>Xilinx Virtex Ultrascale FPGA Multi-Gigabit Transceiver (MGT) Power Reference Design with PMBus</td>
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<tr>
<td>TIDA-00432</td>
<td>Synchronization of JESD204B Giga-Sample ADCs w/Xilinx for Phased Array Radar Systems</td>
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<tr>
<td>PMP11328</td>
<td>30A PMBus Reference Design for Xilinx Zynq Ultrascale+ ZU9EG MPSoC Core Rail</td>
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<tr>
<td>PMP9357</td>
<td>Altera Arria V FPGA Power Supply Reference Design</td>
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<tr>
<td>PMP5006</td>
<td>20V Input Sync Buck Designs to Power Altera Arria GXII</td>
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<tr>
<td>PMP2543</td>
<td>Altera Cyclone III FPGA Power Management Reference Design</td>
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<tr>
<td>PMP8824</td>
<td>7 to 12Vin 1.2Vout 8A Step-down Conv for Powering Rails in Altera Arria V FPGA Reference Design</td>
</tr>
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</table>

- Test report, BOM, schematic, design files, and test report. Search Tool Number
- Visit [www.ti.com/tidesigns](http://www.ti.com/tidesigns) to see a complete searchable design list
Complete Design/Product Cycle Support

- Seminars, webcasts, collateral and design notes
- Selection guides, Web search tools, industry brochures, application notes, data sheets
- Rapid delivery samples, EVMs
- WEBENCH design tools, PowerLab reference designs, Cookbooks, design services
- TINA-TI™ SPICE-based simulation
- Distributor partners, manufacturing capacity
- Distributor FAEs and internal support teams
Conclusion

• Point of load power for processors is challenging and TI has the power solutions

• SWIFT™ DC/DC converters provide a high density, high performance power solution ideal for processors

• TI has tools and resources to simplify point-of-load design

Thank you!