Scalable Server Voltage Regulator Design

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IBM  2004 Platform Symposium
Server Motherboard Power Challenge

- Power demands of next-gen microprocessors and other digital ICs for server applications require currents approaching 200A

- 10 or more motherboard power rails are needed for CPUs, chipsets, memory, disk drives, fans, and other loads

- Power rails must typically be generated from ~12V output of a AC-DC or DC-DC converter which may be located elsewhere in the server’s chassis or mounted on the motherboard itself

- Increasing power levels conflict with physical space and cooling solutions which are expected to remain constant or even decrease

- Meeting this challenge requires improvements in VR (voltage regulator) power density and efficiency
Server VR Thermal Design Constraints

- **Ambient Conditions**
  - Ambient Temperature ~ 45°C
  - Airflow 200-600 LFM (400LFM typical)
  - PCB temperature < 105°C to maintain reliability

- **PCB temperature limitation usually defines VR performance**
  - VRM (voltage regulator module) PCB area relatively small, thermal impedance relatively high
  - Motherboard PCB is thermally saturated limiting VRD (voltage regulator down) power loss
  - VR components can generally withstand higher temperatures than PCB

- **Thermal performance can be solved by:**
  - Reducing VR power loss
  - Reducing PCB thermal impedance
  - Do both simultaneously!
Methods to reduce VR Power Loss

1. Parallel MOSFETs and inductors to reduce conduction losses
   - Increased layout complexity
   - Increased PCB parasitic L & R
   - Increased ringing, voltage stress, and EMI
   - Increased switching losses
     - Increased Rise/Fall Times (high side)
     - Cdv/dt losses (low side)
     - Cross conduction (high & low side)

2. Use components with lower $R_{D\text{SON}}/\text{DCR}$
   - Increased Cost and/or Size

3. Reduce the switching frequency
   - Requires larger inductors to avoid saturation
   - Requires more input/output capacitors

4. Increase the number of phases
   - Decreased current-per-phase reduces switching and conduction losses
   - Smaller/lower cost components can be used
   - Ripple current in input filter reduced
   - Transient response improved
   - Output capacitors can be removed
Multiphase Architecture Limitations

- **Common multiphase Control ICs & drivers support a maximum of 4 phases**
  - Output currents exceeding 100A usually requires paralleling of power components
  - Power loss can not be reduced/controlled

- **A multiphase architecture that will allow 5, 6 or even more phases to be implemented can minimize power loss and layout complexity when output currents exceed 100A**
XPhase Scalable Multiphase Architecture

- **Supports 1 to X phases using a Control IC and a scalable array of phase converters, each containing a single Phase IC**
- **Control IC contains all required one-per converter circuitry**
  - VID (voltage identification) reference voltage
  - Oscillator to program switching frequency
  - Error Amplifier
  - Bias voltage
  - System Fault Protection (UVL, OCP, Enable, Soft Start)
- **Phase IC contains all required one-per phase circuitry**
  - Dual Gate Drivers
  - PWM Comparator and Latch
  - Current Sensing and Sharing
  - Phase Fault Detection
- **Control IC communicates with phase ICs through 5-wire bus**
  1. Bias Voltage
  2. Oscillator Ramp
  3. Bi-Directional Average Current Info
  4. PWM Control Voltage
  5. VID Voltage
- **The 5-wire bus eliminates point-to-point wiring to the phases reducing layout complexity**
XPhase Scalable Multiphase Architecture
DirectFET provides lowest power loss and best heat transfer

- Eliminates Leadframe
- Eliminates wire bonds and bumped die
- Source and gate connections are soldered directly on the pcb

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4 versus 5 phase 130A VR Performance

To illustrate the benefit of increased phase count, performance was compared with the following high performance components:

- **Pulse PAO515 225uH inductors**
  - Low DCR (0.63 mohm)
  - Large saturation current of 55A
  - 11 x 11 x 9 mm size

- **1 pair of DirectFETs per phase**

- **IRF6617 Control (high side) FET**
  - Low gate charge (11nC typ) for fast switching

- **IRF6691 synchronous (low side) FET**
  - Extremely low RDSon (1.2 mohm typ)

- **Heat sink for double-sided cooling**

- **400kHz switching frequency**
4 versus 5 phase 130A VR Performance

- The 4 phase design has slightly less losses at no load due to a reduction in switching losses (4 instead of 5 phases are switching)
- The 5 phase design has significantly lower losses at 130A (27W versus 34W) due to lower conduction losses from the extra phase
4 versus 5 phase VR @ $T_A = 45^\circ$C, 400LFM

- 4 Phase design reached 105$^\circ$C limit with no safety margin
- Reduced power loss results in PCB temperatures running about 10 degrees C cooler in the 5 phase versus the 4 phase design
High Efficiency, High Density 7 phase VRD

- In many high density server designs with 2 or more processors and their VRDs spaced close together even the 27W of power loss @ 130A may be unacceptable

- Height restrictions may prevent the use of a heat sink or it may block airflow to the processors

- To solve these problems a 7 phase VRD reference design providing extremely high density and efficiency was developed using the same XPhase chipset and IRF6617/6691 DirectFETs

- Pulse PAO511 220nH inductors for reduced power loss and size
  - 0.36 mohm DCR
  - 32.5A Saturation Current
  - 10 x 7 x 5 mm size
High Efficiency, High Density 7 phase VRD

- 2.5 x 0.95 inch Powertrain PCB area
- 1 x 0.75 inch Control PCB area
- 400 kHz switching frequency per phase achieves an equivalent ripple frequency of 2.8 MHz
High Efficiency, High Density 7 phase VRD

- 7 phases with small inductors improves load transient response eliminating the need for bulky electrolytic capacitors, greatly reducing required PCB area
- Meets 100A load step with minimal output capacitors
  - 8x 2R5TPE470M9 470µF POSCAP (9mOhm ESR)
  - 48 x 10µF 1206 MLCC
- Finned heat sink measuring 3.25 inches long, 0.5 inches wide and 0.5 high attached to PCB by 4 screws
- Adhesive thermal tape (Berquist A300) between the heat sink and DirectFETs provides thermal interface and electrical insulation
• Power loss of approximately 24W is 11% lower than the 5 phase and 29% lower than the 4 phase designs
• Power Loss not strongly effected by airflow/temperature
Thermal Performance with Heat Sink, $T_A = 45^\circ C$, 400 LFM

- 7 phase design runs considerably cooler than the 4 or 5 phase design, despite power loss being concentrated in a smaller area
- Highest temperature $\sim 83^\circ C$
- Reduced Power Loss allows;
  - Reduced airflow
  - Higher ambient temperature
Thermal Performance without Heat Sink, $T_A=45^\circ\text{C}$, 400LFM

- 400LFM airflow required to maintain a safe temperature
- VRD height is reduced to a maximum of just 5mm
Scalable Server POL Power Solution

• *XPhase* architecture allows selection of appropriate power components to optimize efficiency, cooling, and layout of a single phase

• Number of phases can be scaled to provide the required amount of output current
  – Common Design Approach
  – Common System Interface
  – Reduced development time and cost
  – Easily modify the design if (or when) the power requirements change
IBM Server Design Example

- **7 voltage rails generated on the motherboard**
  - 1.3V @ 180A (240W)
  - 1.5V @ 120A (180W)
  - 1.8V @ 60A (110W)
  - 2.5V @ 80A (200W)
  - 3.3V @ 60A (200W)
  - 5.0V @ 20A (100W)
  - 12V @ 15A (180W)

  1200W total output power

- **Input voltage provided by DC-DC bus converter with semi-regulated 12V primary output and 18V secondary output**

- **85% minimum efficiency required to avoid exceeding chassis AC V-A limitation**

- **1 inch Height Restriction**

- **Minimal motherboard PCB area available**

- **Software controlled fine adjustment of all output voltages to optimize system performance**
XPhase Scalable Solution

- Horizontal mount VRMs, no heat sinks
- VRMs soldered to the motherboard
  - Reduced cost
  - Reduced power loss
  - Improved reliability
  - Field replacement/upgrade not required
- 6 bit VID based upon Intel’s VR10 specification provides fine adjustment of output voltage
- Common Phase Powertrain components/design
  - 20A per phase selected to maximize efficiency
  - 300kHz per phase
  - IRF6617/6618 DirectFETs
10 Phase 1.3V @ 180A VRM

Phase IC & DirectFETs
10 Phase 1.3V @ 180A VRM
6 phase 1.5V @ 120A VRM
3 phase 3.3V @ 60A VRM
1 phase 12V @ 15A VRM
Conclusions

• The need to constrain PCB temperatures to safe levels generally determines VR output current capability
• Increasing the number of phases improves voltage regulator efficiency and allows a reduction in the size of the passive components and overall design
• High performance ICs, MOSFETs, inductors, and capacitors allow the designer to meet difficult server design goals
• Simultaneous reductions in power loss and PCB area provide a large increase in power density enabling the designer to meet future systems requirements
• Scalable server power solutions can be used to meet the complete POL needs of an entire motherboard