

High-Efficiency Multiphase DC/DC Converters

The electricity consumption of data centers worldwide has become an important issue in recent years as demands for Internet services grow significantly. The need to reduce the power dissipation will be a major focus for the next several years. Designers of POL DC/DC converters for almost any kind of system face many challenges due to the multiple constraints of limited space and cooling within a given enclosure, as well as the need for high efficiency throughout the entire load range. Despite having to navigate through this myriad of constraints, many of the recently introduced multiphase regulators provide a simple, compact and efficient solution. By moving toward the diverse multiphase topologies, designers can effectively save space, simplify layout, lower capacitor ripple current, improve reliability and reduce the amount of power wasted as heat. **Bruce Haug, Senior Product Marketing Engineer, Power Products, Linear Technology Corp., USA**

Data centers fill rooms, floors or even entire buildings that house computer, storage and networking equipment. The aggregate electricity used for data centers doubled worldwide from 70 billion kWh/yr in 2000 to 140 billion kWh/yr in 2005, and continues to grow at an average of 16.7 % per year, with the Asia Pacific region (without Japan) being the only major world region with growth significantly exceeding that average [1].

The computers used in data centers, commonly called servers, are similar to PC architectures, with a CPU, ASICs, FPGAs and memory. However, unlike PCs, servers in data centers are packed together as densely as possible and use substantial amounts of electricity, producing heat, which must then be dissipated. Power is delivered to these servers via uninterruptible power systems (UPS), typically followed by a distributed power system and then step-down DC/DC converters for point-of-load (POL) powering. These power delivery methods are not 100 % efficient and produce copious amounts of heat as well. This heat must be carefully and continuously managed to keep the systems running within their specified operating temperature ranges. Regardless of the type and efficiency of the cooling system, heat must be removed from the data center in some way. To do so requires additional energy to operate the cooling infrastructure.

Efficient power conversion required

The data centers' incremental overhead power consumption, due to inefficiencies and cooling systems is estimated to be

equal to the amount of power that is consumed by servers, storage and networking. The user of a single PC, workstation, or laptop doesn't see system heat generation as a concern, but for data centers, managing this thermal overhead is as important as the servers themselves. If system power is reduced, then the available overhead can handle a greater IT load and perform more useful work in the same power envelope.

As the data center power demand continues to increase, higher efficiency power conversion is required to reduce the amount of power wasted as heat. Smart multiphase controller technology is an excellent solution for high current POL applications. This architecture allows a high current regulator to achieve well over 90 percent efficiency at full load. However, most designs do not address the need for higher efficiency at light to medium loads. Wasted power at a light to medium load is just as important to save as wasted power at heavy loads.

Most embedded systems are powered via a 48 V backplane. This voltage is normally stepped down to a lower intermediate bus voltage of 24 V, 12 V or 5 V to power the racks of boards within the system. However, most of the sub-circuits or ICs on these boards are required to operate at voltages ranging from sub-1 V to 3.3 V at currents ranging from tens of milliamps to hundreds of amps. As a result, point-of-load DC/DC converters are necessary to step down from either of the 24 V, 12 V or 5 V voltage rails to the desired voltage and current level required by the sub-circuits or ICs.

It is clear that the growing demand for

increased current at ever decreasing voltages is driving power-supply development. Much of the progress in this area can be traced to gains made in power conversion technology, particularly improvements in power ICs and power semiconductors. In general, these components contribute to enhancing power supply performance by permitting increased switching frequencies with minimal impact on power-conversion efficiency. This is made possible by reducing switching and on-state losses thereby increasing efficiency while allowing for the efficient removal of heat. However, the migration to lower output voltages places more pressure on these factors, which in turn, creates significant design challenges.

Multiphase topology

Multiphase operation is a general term for conversion topologies where a single input is processed by two or more converters, where the converters are run synchronously with each other but in different, locked phases. This approach reduces the input ripple current, the output ripple voltage and the overall RFI (radio frequency interference) signature, while allowing high current single outputs, or multiple lower current outputs with fully regulated output voltages. It also allows smaller external components to be used, producing a higher efficiency converter and also providing the added benefit of improved thermal management with less cooling.

Multiphase topologies can be configured as step-down (buck), step-up (boost) and even as a forward converter, although

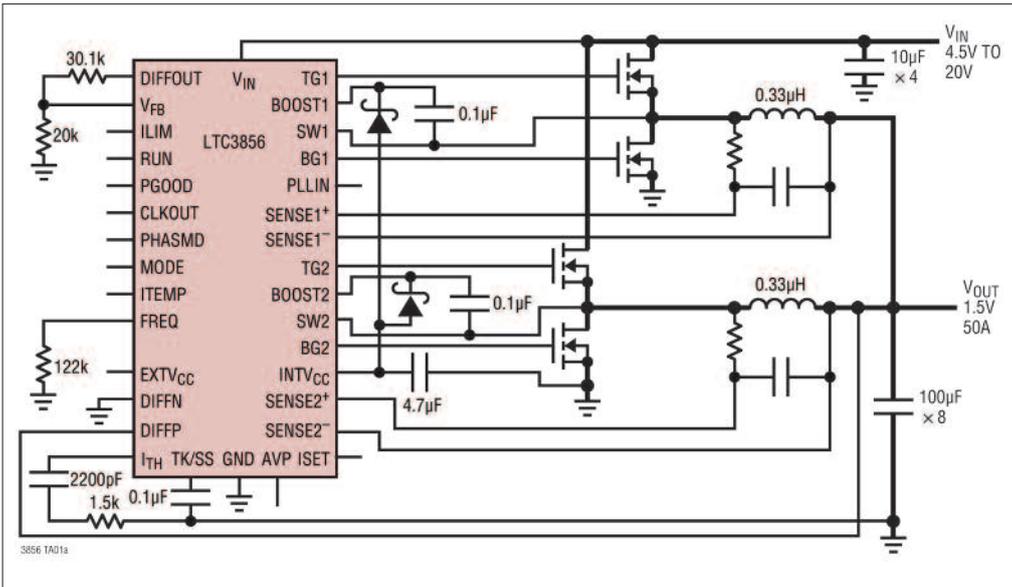


Figure 1: High output current 1.5 V/50 A application schematic

generally the buck regulator is the more prevalent application. Conversion efficiencies of up to 95 % from 12 V in to 1.xV out are commonplace today.

At higher power levels, scalable multiphase controllers reduce the size and cost of capacitors and inductors using input and output ripple current cancellation caused by interleaving the clock signals of several paralleled power stages. Multiphase converters help minimize the external component count and simplify the complete power supply design by integrating PWM (pulse width modulation) current mode controllers, true remote sensing, selectable phasing control, inherent current sharing capability, high current MOSFET drivers plus over-voltage and over-current protection features. The resulting manufacturing simplicity not only helps improve power supply reliability, but

it is also scalable. Such systems can be expanded up to 12 phases for high current outputs as high as 300 A.

Linear Technology has several multiphase DC/DC controllers, including the LTC3856 and LTC3829 single output synchronous step-down controllers for high current POL conversion. Not only can these parts increase full load efficiency, but they also have an optional Stage Shedding(tm) feature that decreases light to medium load power loss as well. The circuit in Figure 1 shows a typical LTC3856 application schematic for developing a 1.5 V/50 A output from a 4.5 V to 14 V input voltage using two phases.

The circuit in Figure 2 shows a typical LTC3829 application schematic for developing a 1.2 V/75 A output from a 6 V to 28 V input voltage with three phases.

The LTC3856 has two channels and up

to 12 phases possible with multiple ICs. The LTC3829 has three channels and can operate at up to 6 phases when used with two ICs. The onboard differential amplifier provides true remote output voltage sensing of both the positive and negative terminals, enabling high accuracy regulation independent of IR losses in trace runs, vias and interconnects.

These controllers operate with all N-channel MOSFETs from input voltages ranging from 4.5 V to 38 V, and can produce ± 0.75 % accurate output voltages from 0.6 V to 5 V. The output current is sensed, monitoring the voltage drop across the output inductor (DCR) for highest efficiency or by using a sense resistor. Programmable DCR temperature compensation maintains an accurate over-current limit set point over a broad temperature range. The onboard gate drivers minimize MOSFET switching losses and allow the use of multiple MOSFETs connected in parallel. A fixed operating frequency can be programmed from 250 kHz to 770 kHz or synchronized to an external clock with its internal PLL. A minimum on time of 90 ns makes the LTC3729 and LTC3856 suited for high step-down ratio/high frequency applications.

Stage shedding operation

At light loads, switching-related power losses normally dominate the total loss of a switching regulator. Eliminating the gate charge and switching losses of one or more of the output stages during a light load will significantly increase efficiency.

Stage Shedding allows one or more phases to be shut down to reduce switching related losses during a light load condition and is typically used when the load current is reduced to less than 15 A. The overall efficiency can be increased by

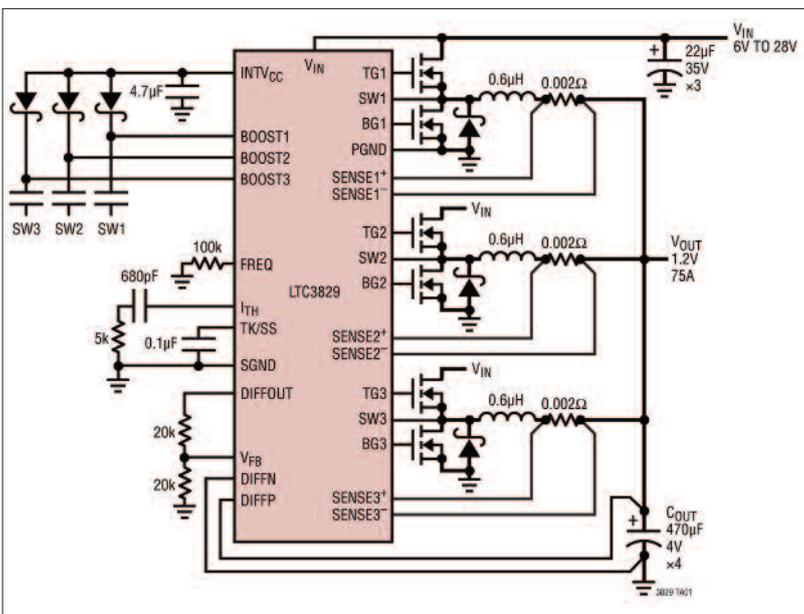


Figure 2: High output current 1.2 V/75 A application schematic

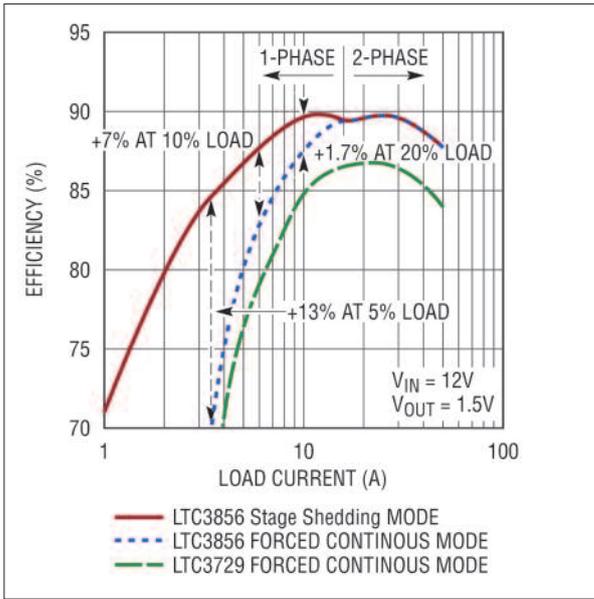


Figure 3: LTC3856 efficiency curve with Stage Shedding phase vs. an older controller

selectable. At heavy loads of greater than 15 A, these devices operate in constant frequency PWM mode. At very light loads, Burst Mode operation can be selected and produces the highest efficiency at load currents of less than 0.5 A. Burst Mode operation switches in pulse trains of one to several cycles, with the output capacitors supplying energy during internal sleep periods.

Active voltage positioning

The LTC3856 and LTC3829 also have Active Voltage Positioning (AVP), which reduces the maximum voltage deviation during a step load and reduces the power dissipation at heavier loads further increasing its efficiency. Figure 5 shows the difference in behavior between the circuit in Figure 1 with and without AVP. Without AVP, the maximum voltage deviation for a 25 A step load is 108 mV. With AVP, the maximum voltage deviation is 54 mV for the same 25 A step load. In addition, the output voltage drops by 54 mV with AVP when the output current goes from 25 A to 50 A, resulting in a lower 2.7 W dissipation by the load.

up to 13 %, as shown in Figure 3. This figure also shows the efficiency of an older comparable LTC3729 2-phase controller. Due to the stronger gate drive and shorter dead time, the LTC3856 can achieve 3-4 % greater efficiency than the LTC3729 over the whole load range.

Stage Shedding operation is triggered when the onboard feedback error amplifier output voltage reaches a user-programmable voltage. At this programmed voltage, the controller shuts down one or more of its

phases and stops the power MOSFETs from switching on and off. This ability to program when Stage Shedding takes place provides the flexibility to determine when to enter this mode of operation. The diagrams in Figure 4 show the SW waveform and how the LTC3829 goes into and out of Stage Shedding operation.

The LTC3856 and LTC3829 can operate in any of three modes: Burst Mode(r) operation, forced continuous or Stage Shedding mode, all of which are user

Literature

[1] "Worldwide electricity used in data centers," by Jonathan Koomey, Lawrence Berkeley National Laboratory, 2008

Figure 4: LTC3829 Stage Shedding phase waveforms - going into Stage Shedding (left) and coming out of Stage Shedding (right)

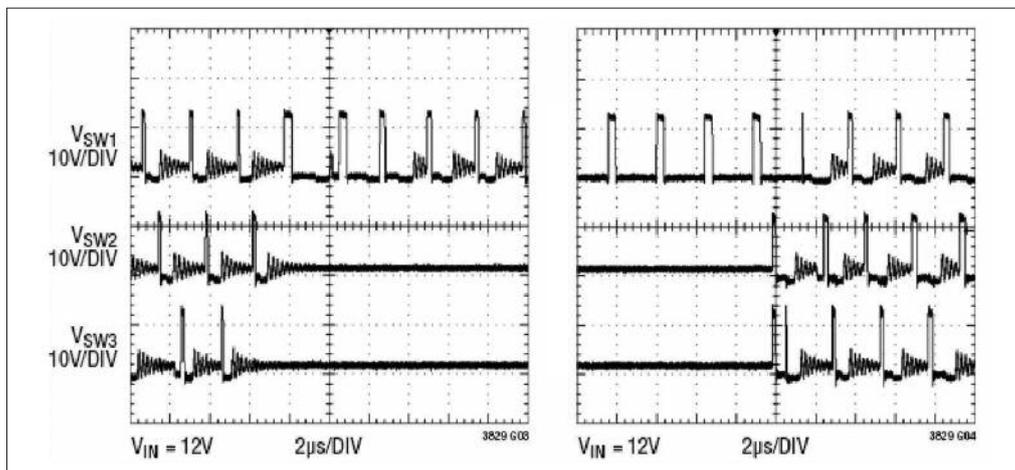


Figure 5: Load step characteristics without Active Voltage Positioning (left) and with Active Voltage Positioning (right)

