

# Powering Complex FPGA-Based Systems Using Highly Integrated DC/DC $\mu$ Module Regulator Systems

Part 1 of 2 Circuit and Electrical Performance

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In a recent discussion with a system designer, the requirement for his power supply was to regulate 1.5V and deliver up to 40A of current to a load that consisted of four FPGAs. This is up to 60W of power that must be delivered in a small area with the lowest profile (height) possible to allow a steady flow of air for cooling. The power supply had to be surface mountable and operate at high enough efficiency to minimize heat dissipation. He also demanded the simplest possible solution so his time could be dedicated to the more complex tasks. Aside from precise electrical performance, this solution had to remove the heat generated during DC to DC conversion quickly so that the circuit and the ICs in the vicinity do not overheat. Such a solution requires an innovative design to meet these criteria:

1. Very low profile to allow efficient air flow and to prevent thermal shadow on surrounding ICs
2. High efficiency to minimize heat dissipation
3. Current sharing capability to spread the heat evenly to eliminate hot spots and minimize or eliminate the need for heat sinks
4. Complete DC/DC circuit in a surface mount package that includes the DC/DC controller, MOSFETs, inductor, capacitors and compensation circuitry for a quick and easy solution

## Innovation in DC/DC Design

The innovation is a modular but surface mount approach that uses efficient DC/DC conversion, precise current sharing and low thermal impedance packaging to deliver the output power while requiring minimal cooling. Because of the low profile and power sharing among four devices, a system using this solution depends on fewer fans or a slower fan speed as well as few or no heat sinks. (These

contribute to lower system cost, consuming less power to remove heat). Figure 1 shows a test board for such a circuit. The design regulates 1.5V output while delivering 40A (up to 48A) of load current. Each “black square” is a complete DC/DC circuit and is housed in a 15mm  $\times$  15mm  $\times$  2.8mm surface mount package. With a few input and output capacitors and resistors, the design using these DC/DC  $\mu$ Module™ systems is as simple as it’s shown in the photo.



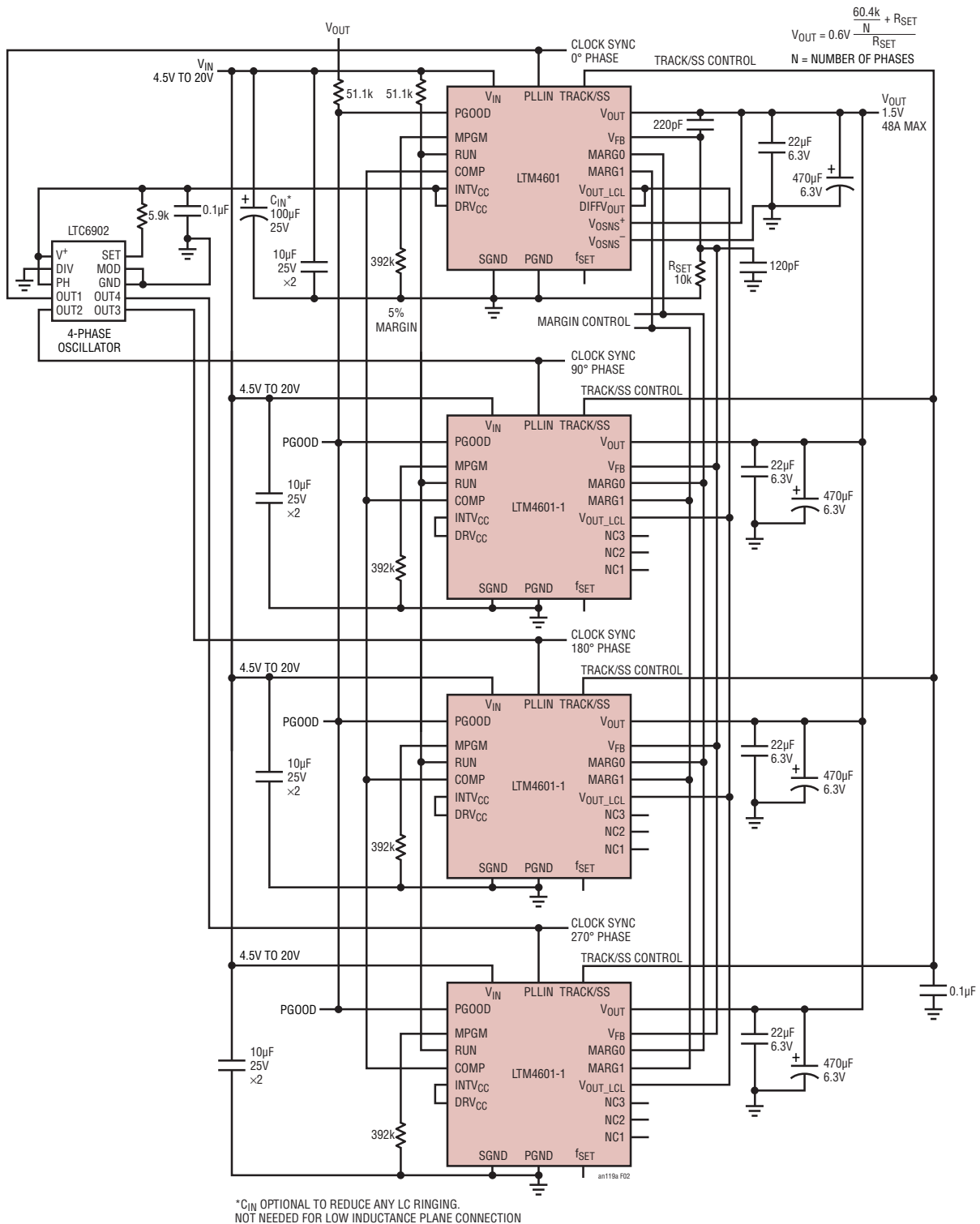
**Figure 1. Four DC/DC  $\mu$ Module Regulator Systems Current Share to Regulate 1.5V at 48A with Only 2.8mm Profile and 15mm  $\times$  15mm of Board Area. Each  $\mu$ Module Regulator Weighs Only 1.7g and Has an IC Form-Factor That Can Easily Be Used with Any Pick-and-Place Machine During Board Assembly**

## DC/DC $\mu$ Module Regulators: Complete Systems in an LGA Package

The LTM4601  $\mu$ Module DC/DC regulator is a high performance power module shrunk down to an IC form factor. It is a completely integrated solution—including the PWM controller, inductor, input and output capacitors, ultralow  $R_{DS(ON)}$  FETs, Schottky diodes and compensation circuitry. Only external bulk input and output capacitors and one resistor are needed to set the output from 0.6V to 5V. The

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**Figure 2. Simply Parallel Multiple DC/DC µModule Regulator Systems to Achieve Higher Output Current. Board Layout Is as Easy as Copying and Pasting Each µModule Regulator's Layout With Very Few External Components Required**

supply can produce 12A (more, if paralleled) from a wide input range of 4.5V to 20V, making it extremely versatile. The pin-compatible LTM4601HV extends the input range to 28V.

Another significant advantage of the LTM4601 over power-module- or IC-based systems is its ability to easily scale up as loads increase. If load requirements are greater than one  $\mu$ Module regulator can produce, simply add more modules in parallel. The design of a parallel system involves little more than copying and pasting the layout of each 15mm  $\times$  15mm  $\mu$ Module regulator. Electrical layout issues are taken care of within the  $\mu$ Module package—there are no external inductors, switches or other components to worry about.

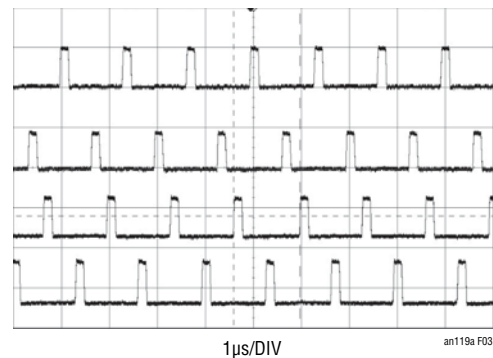
Output features include output voltage tracking and margining. The high switching frequency, typically 850kHz at full load, constant on-time, zero latency controller delivers fast transient response to line and load changes while maintaining stability. Should frequency harmonics be a concern, an external clock can control synchronization via an on-chip phase-locked loop.

## 48A from Four Parallel DC/DC $\mu$ Module Regulators

Figure 2 shows a regulator comprising four parallel LTM4601s, which can produce a 48A ( $4 \times 12A$ ) output. The regulators are synchronized but operate 90° out-of-phase with respect to each other, thereby reducing the amplitude of input and output ripple currents through cancellation (Figure 3).

Synchronization and phase shifting is implemented via the LTC6902 oscillator, which provides four clock outputs, each 90° phase shifted (for 2- or 3-phase relationships, the LTC6902 can be adjusted via a resistor). By operating the  $\mu$ Module regulators out-of-phase, peak input and output current is reduced by approximately 20% depending on the duty cycle (see the LTM4601 data sheet). The attenuated ripple, in turn, decreases the external capacitor RMS current rating and size requirements, further reducing solution cost and board space.

The clock signals serve as input to the PLLIN (phase-locked loop in) pins of the four LTM4601s. The phase-locked loop of the LTM4601 is comprised of a phase detector and a voltage controlled oscillator, which combine to lock onto the rising edge of an external clock with a frequency range of 850kHz. The phase-locked loop is turned on when a pulse of at least 400ns and 2V amplitude at the PLLIN pin is detected, though it is disabled during start-up. Figure 3 shows the switching waveforms of four LTM4601  $\mu$ Module regulators in parallel.

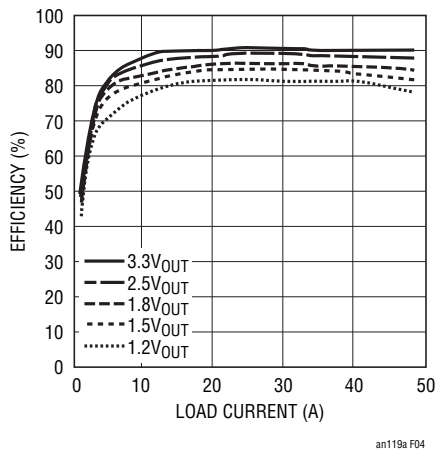


**Figure 3. By Operating Each DC/DC  $\mu$ Module 90° Out-of-Phase, the Input and Output Ripples Are Reduced, Which Also Reduces the Requirement for Input and Output Capacitors. Photo Shows Individual  $\mu$ Module Switching Waveforms for Figure 2**

Only one resistor is required to set the output voltage. In a parallel set-up, the value of the resistor depends on the number of LTM4601s used. This is because the effective value of the top (internal) feedback resistor changes as you parallel LTM4601s. The LTM4601's reference voltage is 0.6V and its internal top feedback resistor value is 60.4k $\Omega$ , so the relationship between  $V_{OUT}$ , the output voltage setting resistor ( $R_{FB}$ ), and the number of modules ( $n$ ) placed in parallel is:

$$V_{OUT} = 0.6V \frac{\frac{60.4k}{n} + R_{FB}}{R_{FB}}$$

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**Figure 4. Efficiency of the Four DC/DC μModules in Parallel Remains High Over a Wide Range of Output Voltages (12V Input)**

Figure 4 illustrates the system's high efficiency over the vast output current range up to 48A. The system performs impressively with no dipping in the efficiency curve for a broad range of output voltages.

## Start-Up, Soft-Start and Current Sharing

The soft-start feature of the LTM4601 prevents large inrush currents at start-up by slowly ramping the output voltage

to its nominal value. The relation of start-up time to  $V_{OUT}$  and the soft-start capacitor ( $C_{SS}$ ) is:

$$V_{OUT(MARGIN)} = \frac{\%V_{OUT}}{100} \cdot V_{OUT}$$

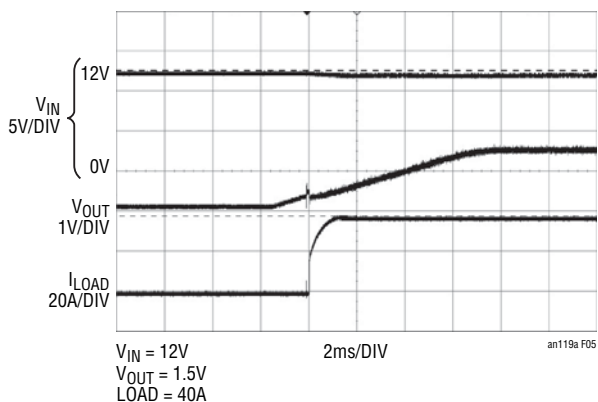
$$t_{SOFTSTART} = 0.8 \cdot (0.6V - V_{OUT(MARGIN)}) \cdot \frac{C_{SS}}{1.5\mu A}$$

For example, a 0.1μF soft-start capacitor yields a nominal 8ms ramp (see Figure 5) with no margining.

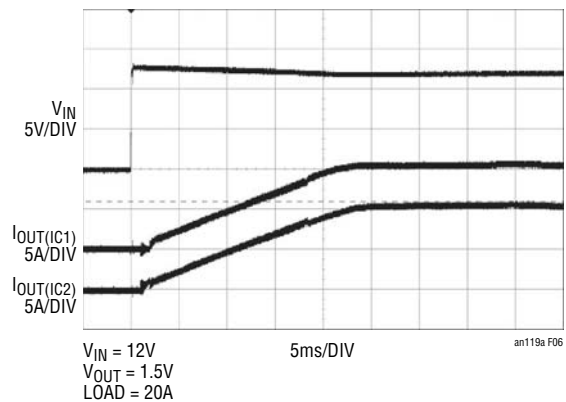
Current sharing among parallel regulators is well balanced through start-up to full load. Figure 6 shows an evenly distributed output current curve for a 2-parallel LTM4601 system, as each rises to a nominal 10A each, 20A total.

## Conclusion

The DC/DC μModule regulators are self-contained and complete systems in an IC form factor. The low profile, high efficiency and current sharing capability allow practical high power solutions for the new generation of digital systems. Thermal performance is impressive at 48A of output current with balanced current sharing and smooth uniform start-up. The ease and simplicity of this design minimizes development time while saving board space. In part two of this discussion, the focus will be on thermal performance and layout of this circuit.



**Figure 5. Controlled Soft-Start Is Important in Proper Start-Up of the FPGA or the System as a Whole; Soft-Start Current and Voltage Ramp for Four DC/DC μModule Regulators in Parallel**



**Figure 6. Each DC/DC μModule Regulator Starts and Ends By Sharing the Load Current Evenly and Balanced, a Crucial Feature to Prevent One Regulator from Overheating; Two Parallel LTM4601s, as Each Rises to a Nominal 10A Each, 20A Total**