2-Step Power Conversion: Portable Power for the Future

As microprocessor operating voltages continue to decrease, power conversion for CPU core power is becoming a daunting challenge. A core power supply must have fast transient response, good efficiency, and low heat generation in the vicinity of the processor. These factors will soon force a move away from 1-step power conversion from battery or wall adapter to processor, to 2-step conversion where the CPU core power is obtained from the 5V supply. While new to the portable arena, distributed power systems using 5V as a bus voltage have been used in large systems for many years. And although it may not be absolutely necessary to adopt this architecture in portables today, the clock is ticking for the old brute-force approach.

Let's start with the biggest argument against 2-step conversion: the perceived drop in efficiency and attendant heat generation in the 5V supply. Quick calculations may give a false impression that efficiency significantly decreases. It does not! Later in this paper we will show accurate calculations of efficiency for 2-step power conversion based on actual demo board measurements that show overall efficiency numbers equal to 1-step high efficiency converters.

On the other hand, many benefits result from 2-step conversion: more symmetrical transient response, lower heat generation in the vicinity of the processor, and easy modification for lower processor voltages in the future. Peak currents taken from the battery are also reduced, which leads to better battery efficiency that can often improve upon the efficiency measured using laboratory power supplies. Consequently, battery life in a real notebook computer may actually *exceed* that of 1-step architectures.

1-Step Approach for CPU Power **2-Step Approach for CPU Power**

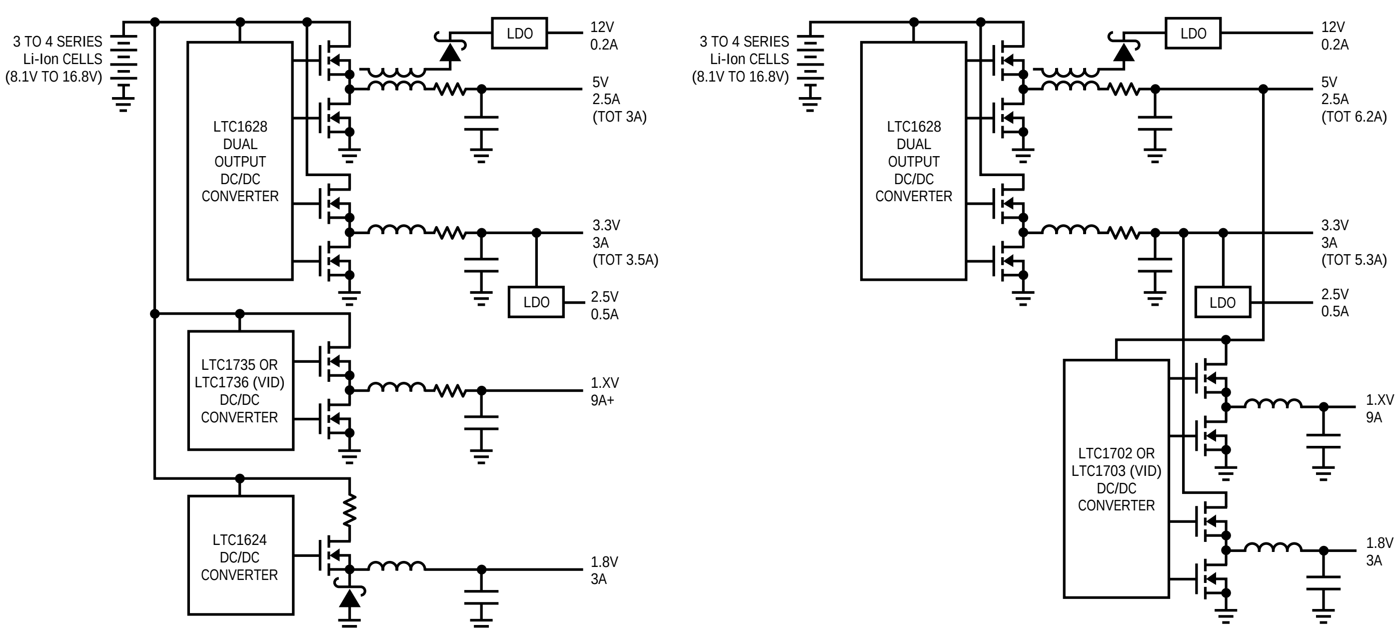

Figure 1. As CPU Core Voltages Continue to Drop, the Traditional 1-Step Approach Will Become Obsolete Due to Infinitesimal Duty Cycles and Severely Skewed Transient Behavior. The 2-Step Approach Eliminates These Issues by Splitting the Conversion Into Two Stages, Thus Yielding Faster Transient Response and Lower Heat Generation Near the CPU.

The culprit lies in the duty cycle for a step-down switching regulator, given by the ratio of V_{OUT} to V_{IN}. In 1-step power conversion, the switch on-time must be very short because the step-down ratio is large. This gives a very fast inductor current ramp-up and a much slower current ramp-down. The inductance value must be large enough to keep the current under control during the ramp-up. This requires a larger inductance than for operation with a low input voltage. Fast current rise and slow current decay means that the transient response of the regulator is good for load increases but poor for load decreases. The lower, constant input voltage for a 2-step conversion process not only yields a more symmetrical transient response, but it completely eliminates the headaches associated with optimizing loop dynamics over widely varying battery and wall adapter voltages.

Because the duty cycles are closer to 50% with 2-step conversion, and there is less switching loss due to the lower voltage swings, the switching frequency may also be increased. This allows smaller, lower cost external components to be used and further aids the transient response.

To minimize the high current PCB trace lengths, the core supply must be located near the processor. With a 1-step converter, the power lost is significantly higher than for the second step of a 2-step conversion. Switching regulators for converting high input to low output voltages rarely approach 90% efficiency. A properly designed 5V to core voltage converter can add up to five points of efficiency, thereby minimizing heat generation near the processor.

A common mistake when computing the efficiency of a 2-step power conversion system is to simply multiply the efficiency of the first conversion by the efficiency of the second conversion. While expedient, this method does not reveal the overall system efficiency nor the distribution of losses on the board. The correct approach to evaluate 2-step power conversion efficiency is to return to the definition of efficiency:

$$\text{Efficiency} = \frac{\text{Total Power Out}}{(\text{Total Power Out} + \text{Total Power Lost})} \bullet 100\%$$

The “Total Power Out” term must include not only the power ultimately supplied to the CPU core, but also the additional power supplied at each conversion from which the CPU core voltage is derived. The “Total Power Lost” term is the sum of the powers lost at every conversion and is calculated from the respective operating efficiencies.

Table 1 compares the power lost at each stage for 1-step and 2-step CPU power conversions from a 12V input voltage. Note that when all of the Figure 1 outputs are considered, the overall efficiency is identical for 1-step and 2-step conversion.

Table 1. 1-Step vs 2-Step Operating Efficiency, V_{IN} = 12V

1-Step for CPU Power

OUTPUT / I_{LOAD} †	DC/DC OUTPUT POWER	EFFICIENCY*	POWER LOST
3.3V/1.5A	5.61W	93%	0.42W
5V/1A	5W	95%	0.26W
1.6V/5.5A	8.8W	86%	1.43W
1.8V/1.5A	2.7W	80%	0.68W
2.5V/0.2A	0.5W	76%	0.16W
CCFL	8W	90%	0.89W
TOTAL POWER TO LOADS	30W	**88.6%**	3.84W

2-Step for CPU Power

OUTPUT/ I_{LOAD} †	DC/DC OUTPUT POWER	EFFICIENCY*	POWER LOST
3.3V/1.5A	8.54W††	93%	0.64W
5V/1A	14.78W††	94%	0.94W
1.6V/5.5A	8.8W	90%	0.98W
1.8V/1.5A	2.7W	92%	0.23W
2.5V/0.2A	0.5W	76%	0.16W
CCFL	8W	90%	0.89W
TOTAL POWER TO LOADS	30W	**88.6%**	3.84W

$$\text{*Efficiency} = \frac{\text{Total Output Power}}{\text{Total Output Power} + \text{Total Power Lost}} \times 100\%$$

†Average output current; the 12V output is normally off.

††Including the additional power required for the 1.6V and 1.8V outputs.

And what about the increased burden on the 5V regulator? Table 1 reveals that while the power lost in the 5V supply does increase with 2-step conversion, it is still less than that lost in the 1-step CPU core supply. Furthermore, power lost in the core and I/O supplies is in the worst possible thermal environment for a notebook computer—next to the processor. In this example, 2-step conversion reduced the power dissipated in the vicinity of the CPU by 0.9W.

An additional concern sometimes voiced by power supply designers is that there might be pitfalls from loading the output of one switching regulator with the input of another. In fact, the input current of a switching regulator is directly proportional to its output voltage and current and inversely proportional to its input voltage. This represents a benign load for an upstream switching regulator, and cascaded switching regulators have been used in a host of different power distribution applications over the years. Today’s desktop computers, for example, use precisely the same architecture as proposed here for portables.

As time goes forward, microprocessor fabrication lithography will continue to shrink and force still lower CPU core operating voltages and higher operating currents. 1.1V supplies and 15A peak operating currents are already on the horizon for portable systems. These demands will render the traditional 1-step conversion approaches unworkable as a result of infinitesimal duty cycles and severely skewed transient behavior.

Linear Technology has developed a third generation of high efficiency DC/DC converters with unique features that are ideal for implementing 2-step conversion strategies. The LTC® 1628 2-phase dual system power supply controller is an ideal solution for providing 3.3V and 5V system power and the first conversion step in a 2-step solution. For the highest first step conversion efficiency, an LTC1625 No R_{SENSE}™ current mode controller can be used to provide 5V at up to 10A. For the second step, the LTC1702 and LTC1703 (VID option) 2-phase dual controllers convert 5V or 3.3V to CPU core and I/O supplies at efficiencies of up to 95%. The LTC1702/LTC1703 require no sense resistors and operate at 550kHz for fast transient response and low external component cost.

No R_{SENSE} is a trademark of Linear Technology Corporation.

LTC1703 Load Transient Response

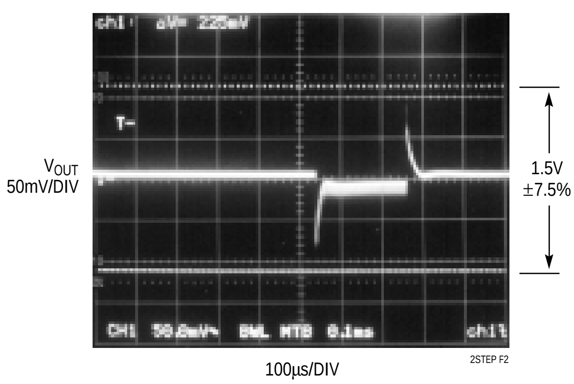

Figure 2. Operating at 550kHz from a 5V Supply Allows the Use of a Much Smaller Inductor, Resulting in Excellent Transient Response

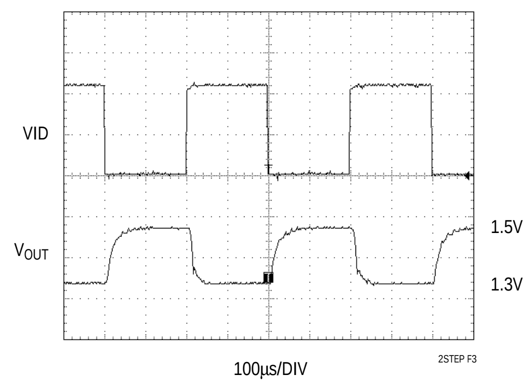

Figure 3. The LTC1703 Exhibits a Settling Time Less Than 100µs When V_{OUT} is Changed Using the VID Control Inputs

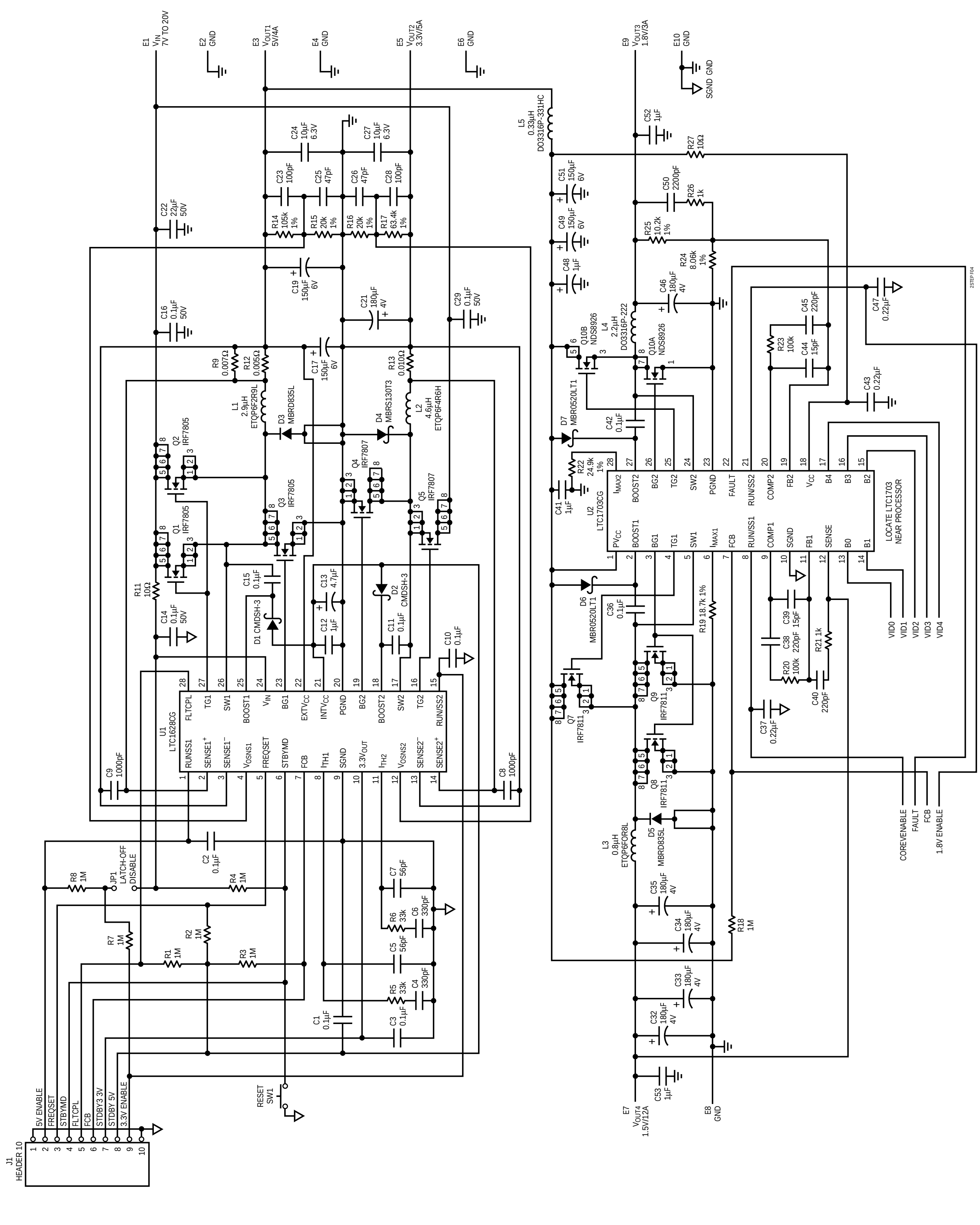

Figure 4. The LTC1628 and LTC1703 Are 2-Phase, Dual Output DC/DC Controllers That, When Combined, Form a High Efficiency 4-Output Notebook PC Power Supply that Requires a Minimum of PC Board Area

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