Hybrid Converter Simplifies 48 V/54 V Step-Down Conversion in Data Centers and Telecom Systems

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There has been a shift in data center and telecom power system design. Key applications manufacturers are replacing complex, expensive isolated 48 V/54 V step-down converters with more efficient, nonisolated, high density step-down regulators (Figure 1). Isolation is not necessary in the regulators' bus converter since the upstream 48 V or 54 V input is already isolated from hazardous ac mains.

For a high input/output voltage application (48 V to 12 V), a conventional buck converter is not an ideal solution because component size tends to be larger. That is, a buck converter must run at a low switching frequency (for example, 100 kHz to 200 kHz) to achieve high efficiency at high input/output voltage. The power density of a buck converter is limited by the size of passive components, especially the bulky inductor. The inductor size can be reduced by increasing the switching frequency, but this reduces converter efficiency because of switching-related losses and leads to unacceptable thermal stress.

Switched capacitor converters (charge pumps) significantly improve efficiency and reduce solution size over conventional inductor-based buck converters. In a charge pump, instead of an inductor, a flying capacitor is used to store and transfer the energy from input to output. The energy density of capacitors is much higher than inductors—improving power density by a factor of 10 over a buck regulator. However, charge pumps are fractional converters—they do not regulate the output voltage—and are not scalable for high current applications.

An LTC7821-based hybrid converter has the benefits of both conventional buck converters and charge pumps: output voltage regulation, scalability, high efficiency, and high density. A hybrid converter regulates its output voltage with closed-loop control just like a buck converter. With peak current-mode control, it is easy to scale the hybrid converter up for higher current levels (for example, a single-phase design for 48 V to 12 V/25 A to a 4-phase design for 48 V to 12 V/100 A).

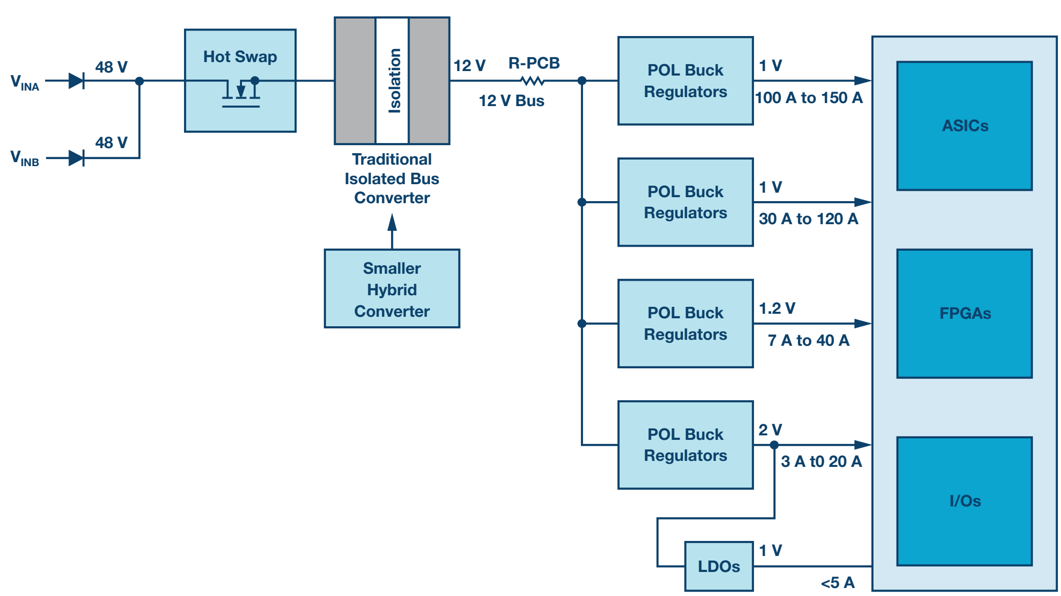


Figure 1. A traditional telecom board power system architecture with an isolated bus converter. The isolated bus converter is not necessary in systems where 48 V is already isolated from the ac mains. Replacing the isolated converter with a nonisolated hybrid converter significantly reduces complexity, cost, and board space requirements.

Buck Converter
- 1.1 in × 0.78 in × ≥0.6 in inductor
- 0.514 in^3 volume, body only
- 2× 80 V top FETs
- 2× 80 V bottom FETs
- f_{SW}: 125 kHz to ~200 kHz
- Same C_{IN} as hybrid converter

Hybrid Converter (Smaller, Faster)
- 0.76 in × 0.37 in × 0.42 in inductor
- 0.118 in^3 volume, body only (77% savings)
- 1× 80 V FET (Q1)
- 3× 40 V FETs (Q2, Q3, Q4)
- f_{SW}: 500 kHz to ~1 MHz
- Same C_{IN} as buck converter

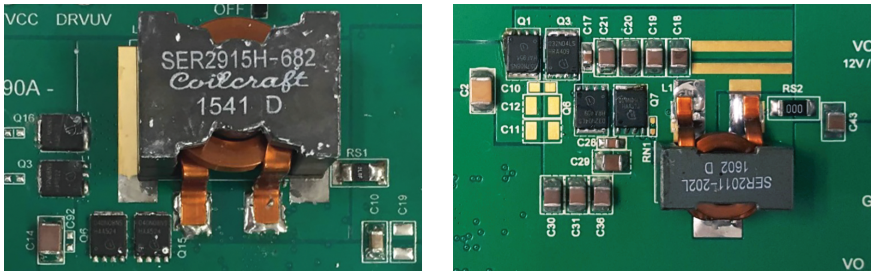


Figure 2. Size comparison of a nonisolated buck converter and equivalent 48 V to 12 V/20 A hybrid converter.

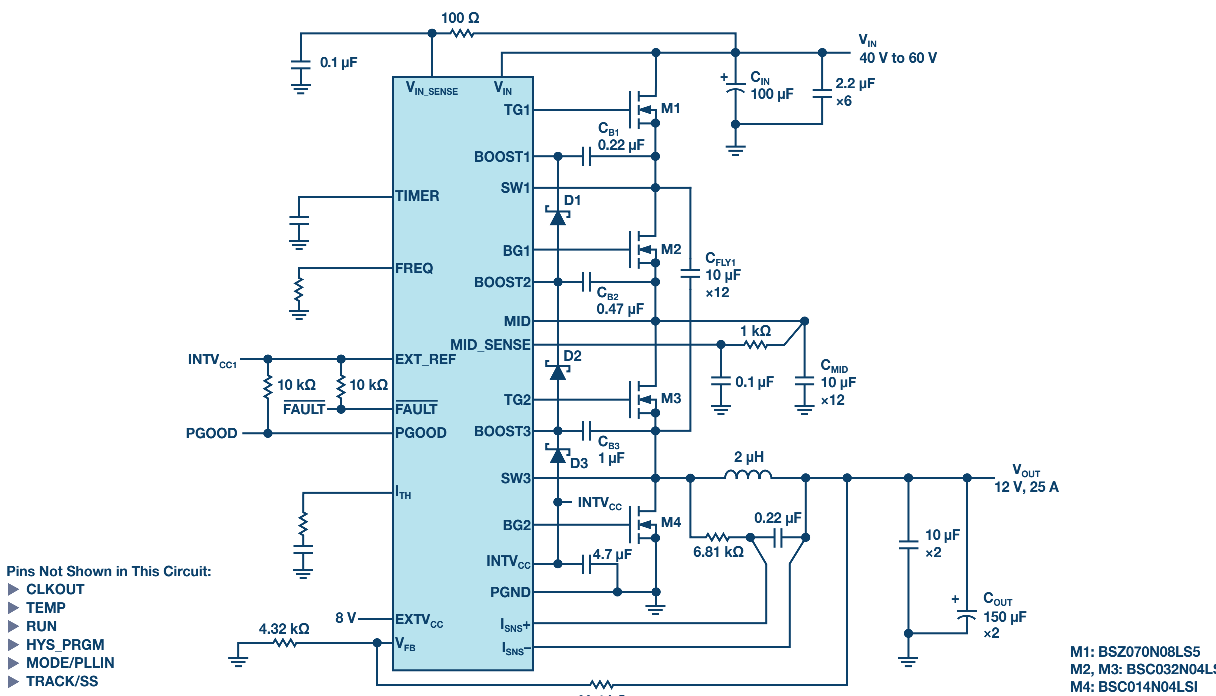


Figure 3. A 48 V to 12 V/25 A hybrid converter using the LTC7821.

All switches in a hybrid converter see half of the input voltage in steady state operation, enabling the use of low voltage rating MOSFETs to achieve good efficiency. The switching-related losses in a hybrid converter are lower than a conventional buck converter, enabling high frequency switching.

In a typical 48 V to 12 V/25 A application, efficiency above 97% at full load is attainable with the LTC7821 switching at 500 kHz. To achieve similar efficiency using a traditional buck controller, the LTC7821 would have to operate at a third of the frequency, which results in a much larger solution size. Higher switching frequencies allow the use of smaller inductances, which yield faster transient response and smaller solution size (Figure 2).

The LTC7821 is a peak current-mode hybrid converter controller with the features required for a complete solution of a nonisolated, high efficiency, high density step-down converter for an intermediate bus converter in data centers and telecom systems. The LTC7821's key features include:

- Wide V_{IN} range: 10 V to 72 V (80 V abs max)
- Phase-lockable fixed frequency: 200 kHz to 1.5 MHz
- Integrated quad ~5 V N-channel MOSFET drivers
- R_{SENSE} or DCR current sensing
- Programmable CCM, DCM, or Burst Mode® operation
- CLKOUT pin for multiphase operation
- Short-circuit protection
- $EXTV_{CC}$ input for improved efficiency
- Monotonic output voltage start-up
- 32-lead (5 mm × 5 mm) QFN package

48 V to 12 V at 25 A Hybrid Converter Featuring 640 W/IN^3 Power Density

Figure 3 shows a 300 W hybrid converter using the LTC7821, switching at 400 kHz. The input voltage range is 40 V to 60 V and the output is 12 V at loads up to 25 A. Twelve 10 µF (1210 size) ceramic capacitors are used for each flying capacitor, C_{FLY} and C_{MID}. The relatively small size 2 µH inductor (SER2011-202ML, 0.75 in × 0.73 in) can be used because of the high switching frequency and the fact that the inductor only sees half of V_{IN} at the switching node (small volt-second). The approximate solution size is 1.45 in × 0.77 in, as shown in Figure 4, resulting in a power density of about 640 W/in^3.

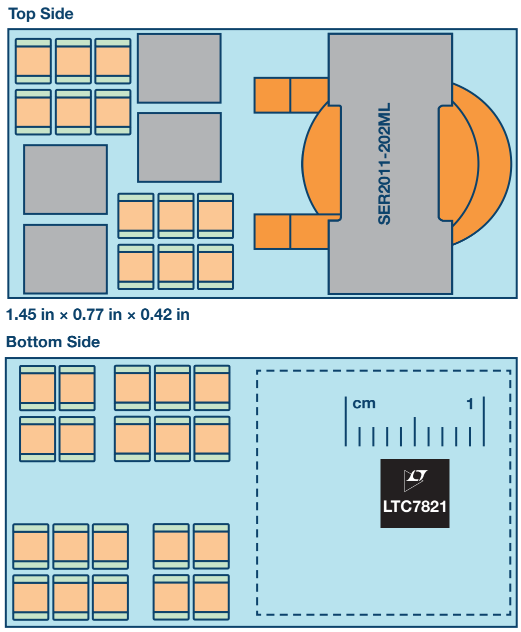


Figure 4. Possible layout for a complete bus converter uses the top and bottom sides of the board, requiring only 2.7 cm² of the topside of the board.

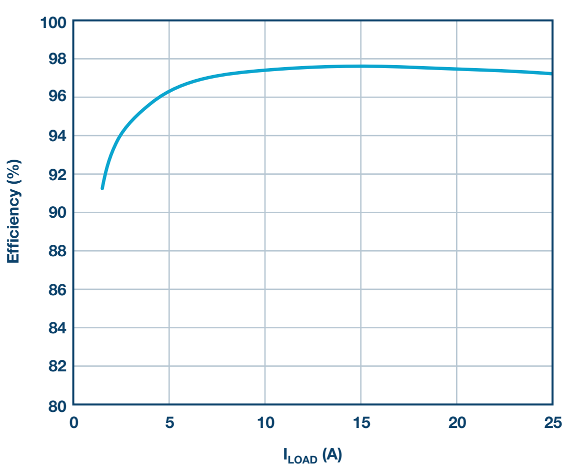


Figure 5. Efficiency at 48 V input, 12 V output, and 400 kHz f_{SW}.

As the bottom three switches always see half the input voltage, 40 V rated FETs are used. An 80 V rating FET is used for the very top switch because it sees the input voltage at the beginning of the precharge of C_{FLY} and C_{MID} during startup (no switching). During steady state operation, all four switches see half of the input voltage. Therefore, the switching losses in a hybrid converter are much smaller compared to a buck converter in which all switches see the full input voltage. Figure 5 shows the efficiency of the design. The peak efficiency is 97.6% and the full load efficiency is 97.2%. With high efficiency (low power loss), the thermal performance is very good, as shown in the Figure 6 thermograph. The hot spot is 92°C at an ambient temperature of 23°C with no forced airflow.

The LTC7821 implements a unique C_{FLY} and C_{MID} prebalancing technique, which prevents input inrush current during startup. During initial power-up, the voltage across the flying capacitor C_{FLY} and C_{MID} are measured. If either of these voltages are not at $V_{IN}/2$, the TIMER capacitor is allowed to charge up. When the TIMER capacitor voltage reaches 0.5 V, internal current sources are turned on to bring the C_{FLY} voltage to $V_{IN}/2$. After the C_{FLY} voltage has reached $V_{IN}/2$, C_{MID} is charged to $V_{IN}/2$. The TRACK/SS pin is pulled low during this duration and all external MOSFETs are shut off. If the voltages across C_{FLY} and C_{MID} reach $V_{IN}/2$ before the TIMER capacitor voltage reaches 1.2 V, TRACK/SS is released, and a normal soft start begins. Figure 7 shows this prebalancing period and Figure 8 shows the V_{OUT} soft start at 48 V input, 12 V output at 25 A.

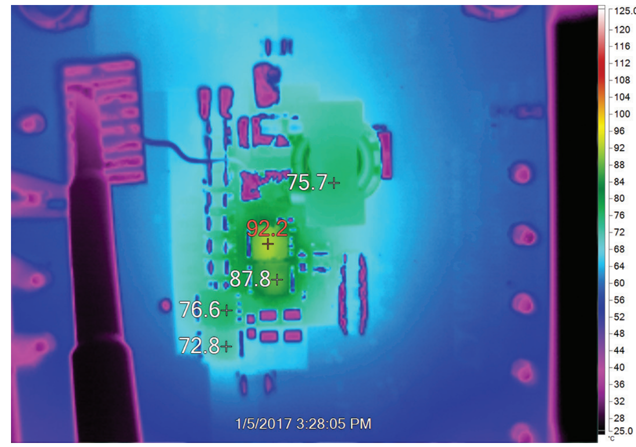


Figure 6. Thermograph of the hybrid converter solution in Figure 2.

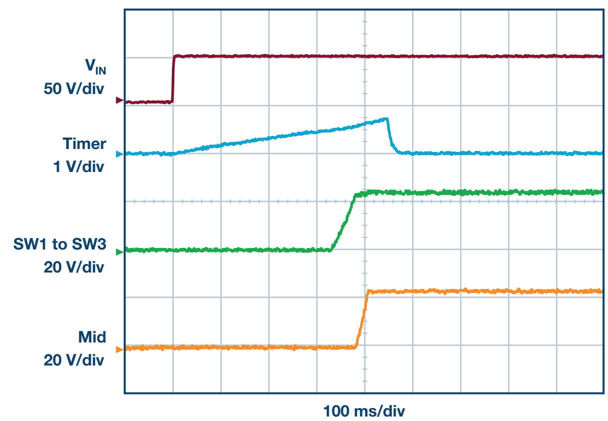


Figure 7. The prebalancing period in the LTC7821 startup avoids high inrush currents.

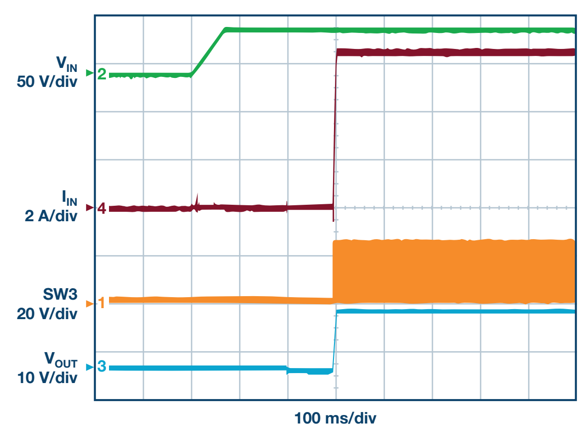


Figure 8. LTC7821 startup at 48 V input, 12 V output at 25 A (no high inrush current).

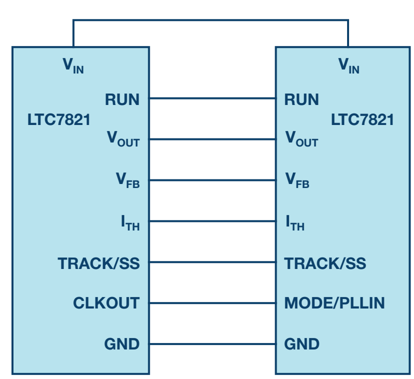
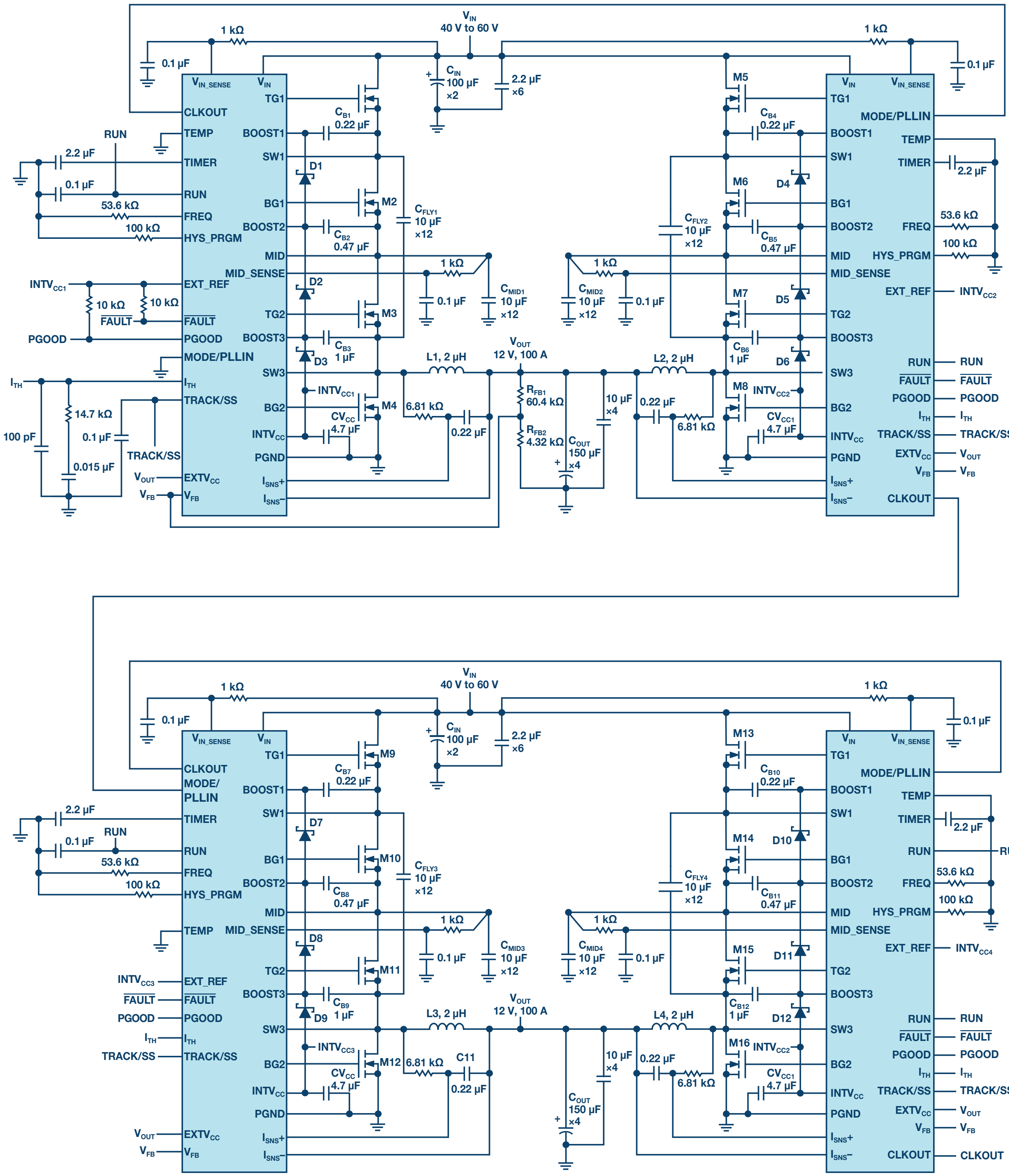


Figure 9. Connection of key signals of LTC7821 for a 2-phase design.



M1, M5, M9, M13: Infineon BSZ070N08LS5
M2, M3, M6, M7, M10, M11, M14, M15: Infineon BSC032N04LS
M4, M8, M12, M16: Infineon BSC014N04LSI
L1, L2, L3, L4: Coilcraft SER2011-202ML
D1–D12: Central Semiconductor CMDSH-4
C_{FLY}, C_{MID}: Murata GRM32ER71H106KA12

Figure 10. A 4-phase, 1.2 kW hybrid converter using four LTC7821s.

1.2 kW Multiphase Hybrid Converter

The easy scalability of the LTC7821 makes it a good fit for high current applications, such as those found in telecom and data centers. Figure 9 shows the key signal connections for a 2-phase hybrid converter using multiple LTC7821s. The PLLIN pin of one LTC7821 and the CLKOUT pin of another LTC7821 are tied together to synchronize the PWM signals.

For a design with more than two phases, the PLLIN pin and CLKOUT pin are connected in a daisy chain. Since the clock output on the CLKOUT pin is 180° out of phase with respect to the main clock of LTC7821, even numbered phases are in phase with each other, while those with odd numbers are antiphase to the evens.

A 4-phase, 1.2 kW hybrid converter is shown in Figure 10. The power stage of each phase is identical to the single-phase design in Figure 3. The input voltage range is 40 V to 60 V and the output is 12 V at load up to 100 A. The peak efficiency is 97.5% and the full load efficiency is 97.1% as shown in Figure 11. The thermal performance is shown in Figure 12. The hot spot is 81°C at an ambient temperature of 23°C with 200 LFM forced airflow. Inductor DCR sensing is used in this design. As shown in Figure 13, current sharing is well balanced among the four phases.

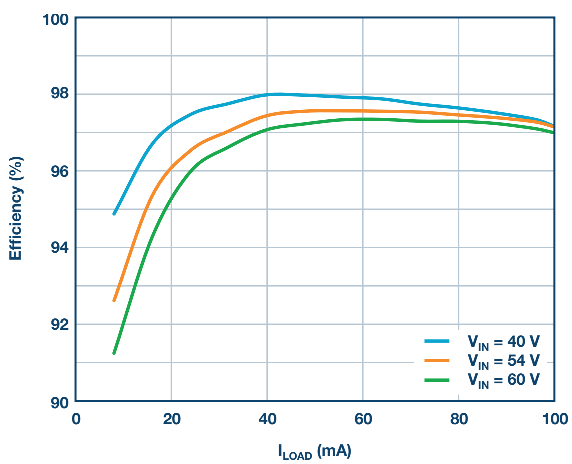


Figure 11. Efficiency for a 4-phase, 1.2 kW design.

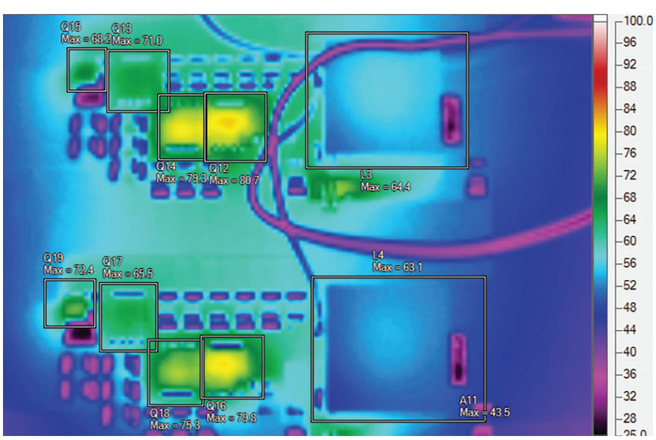


Figure 12. Thermograph of the multiphase converter shown in Figure 9.

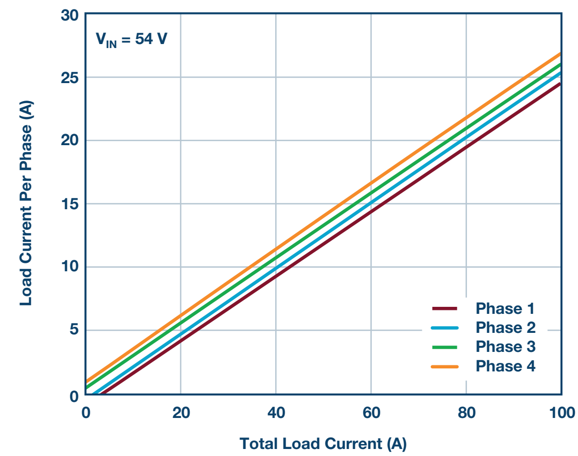


Figure 13. Current sharing for the multiphase converter shown in Figure 9.

Conclusion

The LTC7821 is a peak current-mode hybrid converter controller that enables an innovative, simplified approach to intermediate bus converter implementation in data centers and telecom systems. All switches in a hybrid converter see half of the input voltage, significantly reducing the switching related losses in high input/output voltage applications. Because of this, a hybrid converter can run at 2× to 3× higher switching frequency than a buck converter without compromising efficiency. A hybrid converter can be easily scaled for higher current applications. Lower overall cost and easy scalability differentiate hybrid converters from traditional isolated bus converters.

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