

High Efficiency, High Density, Switched Capacitor Converter Suitable for High Power Applications

Design Note 1043

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Introduction

The power density of a DC/DC converter is generally limited by bulky magnetic components, especially in applications where the input and output voltages are relatively high. One way to reduce inductor/transformer size is to increase the switching frequency, but this reduces converter efficiency because of switching-related losses.

Another way to increase power density is to use an inductorless switched capacitor converter (charge pump) topology. Charge pumps can increase power density as much as 10X over a conventional converter without sacrificing efficiency. Instead of an inductor, a “flying capacitor” is used to store and transfer the energy from input to output. Despite the advantages of a charge pump design, switched capacitor converters have been limited to low power applications, due

to the challenges presented in start-up, protection, gate drive and regulation.

The LTC7820 is a fixed ratio, high voltage, high power switched capacitor controller that yields small and cost effective solutions for high power, nonisolated intermediate bus applications with fault protection. The LTC7820's features include:

- Low profile, high power density, capable of 500W+
- V_{IN} max for voltage divider (2:1): 72V
- V_{IN} max for voltage doubler (1:2)/inverter (1:1): 36V
- Wide bias V_{CC} range: 6V to 72V
- Soft switching: 99% peak efficiency and low EMI

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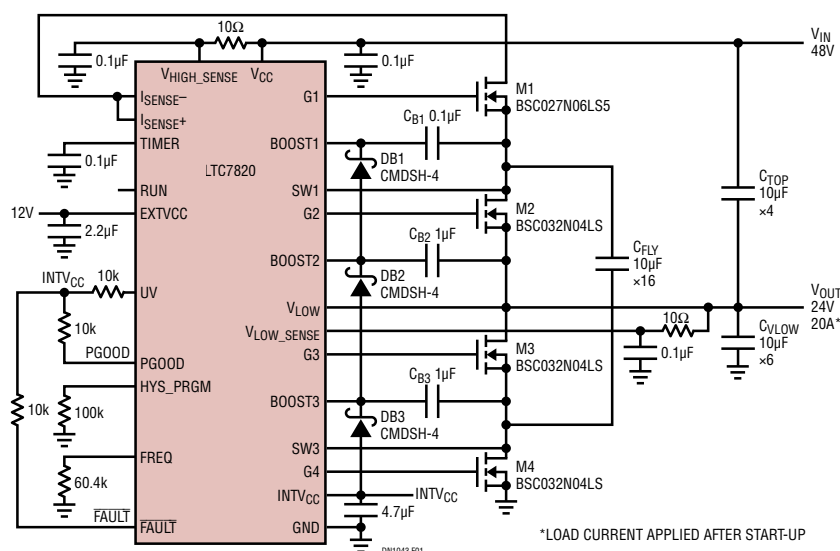


Figure 1. A 48V to 24V/20A Voltage Divider with a Power Density of 4000W/in³

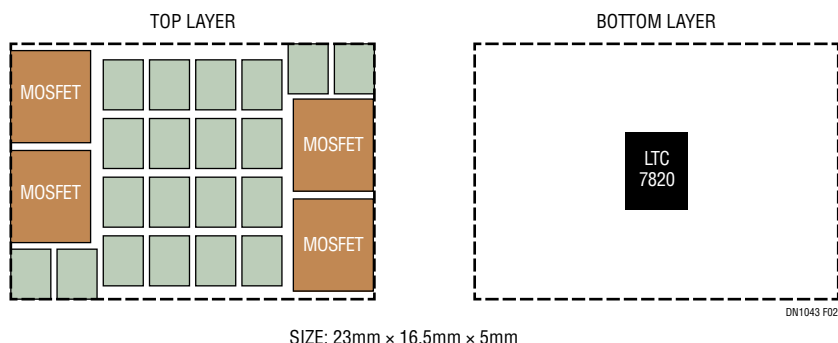


Figure 2. Estimated Solution Size Features 5mm Maximum Height

- Soft start-up into steady state operation
- Input current sensing and overcurrent protection
- Integrated gate drivers
- Output short-circuit/OV/UV protection with programmable timer and retry
- Thermally enhanced 28-pin 4mm × 5mm QFN package

A 48V to 24V/20A Voltage Divider with Power Density of 4000W/in³

Figure 1 shows a 480W output voltage divider circuit featuring the LTC7820. The input voltage is 48V and the output is 24V at up to 20A load. Sixteen 10µF ceramic capacitors (1210 size) act as a flying capacitor to deliver the power. The approximate solution size is 23mm × 16.5mm × 5mm as shown in Figure 2, and the power density is as high as 4000W/in³.

High Efficiency

Since there is no inductor used in the circuit, all four MOSFETs are soft switched, greatly reducing switching-related losses. The converter can achieve high efficiency as shown in Figure 3, where the peak efficiency is 99.3% and the full load efficiency is 98.4%. The thermograph in Figure 4 shows a balanced thermal design with a hot spot temperature about 82.3°C in an ambient environment of 23°C and no forced airflow.

Pre-Balance Prevents Inrush Currents

In addition to impressive efficiency and thermal performance, the LTC7820 includes a proprietary pre-balance method to minimize inrush current in voltage divider applications. The LTC7820 controller detects the $V_{\text{LOW_SENSE}}$ pin voltage before switching

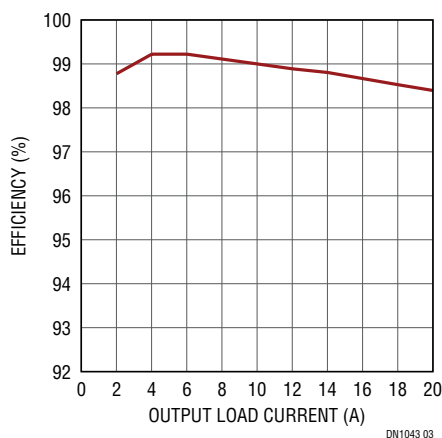


Figure 3. Efficiency at 48V Input, 24V Output and a 200kHz Switching Frequency

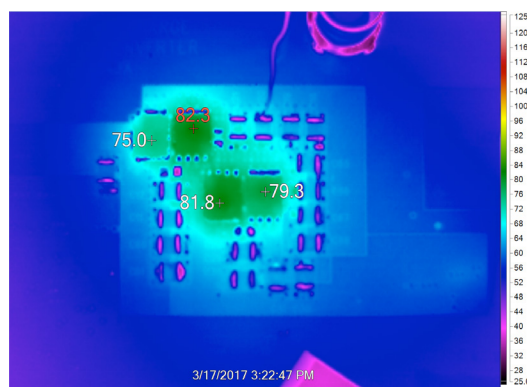


Figure 4. Thermal Test at 48V Input, 24V Output at 20A and 200kHz Switching Frequency

and compares it with the $V_{\text{HIGH_SENSE}}/2$ internally. If the voltage at the $V_{\text{LOW_SENSE}}$ pin is much lower than $V_{\text{HIGH_SENSE}}/2$, a current source injects 93mA of current at the V_{LOW} pin to pull V_{LOW} up. If the voltage

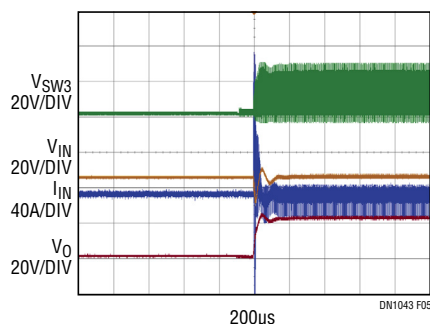


Figure 5. Start-Up Waveform without Pre-Balance Shows Large Inrush Current

at V_{LOW_SENSE} is much higher than $V_{HIGH_SENSE}/2$, another current source sinks 50mA from V_{LOW} to pull it down. If the voltage at V_{LOW_SENSE} is near $V_{HIGH_SENSE}/2$, that is, within the preprogrammed window, both current sources are disabled and the LTC7820 starts switching.

Figure 5 shows the enormous input inrush current that occurs at start-up without pre-charging—more than enough to damage the MOSFETs and capacitors. In contrast, no excessive inrush current is observed after the pre-balance method is applied, as shown in Figure 6.

Tight Load Regulation

Even though the LTC7820-based voltage divider is an open-loop controlled converter, load regulation is tight due to its high efficiency. As shown in Figure 7, the output voltage drops only 1.7% at full load.

Protection Features

The LTC7820 includes protection features to ensure high converter reliability. Overcurrent protection is enabled through a sensing resistor on the high voltage side. A precision rail-to-rail comparator monitors the differential voltage between the I_{SENSE+} pin and the I_{SENSE-} pin, which are Kelvin connected to a sensing resistor. When the voltage at I_{SENSE+} is 50mV higher than the I_{SENSE-} , an overcurrent fault is triggered, the FAULT pin is pulled down to ground, and the LTC7820 stops switching and starts retry mode based on the timer pin setup.

Further protection is available through the OV/UV window comparator. In normal operation, the voltage

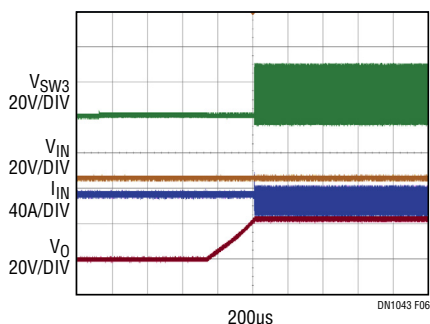


Figure 6. Start-Up Waveform with LTC7820 Pre-Balance Shows Elimination of Inrush Current

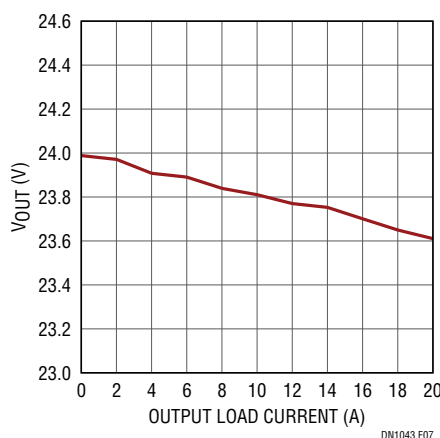


Figure 7. Load Regulation [$V_{IN} = 48V$, $V_O = 24V$, $I_O = 0A \sim 20A$]

at V_{LOW_SENSE} should approach half of V_{HIGH_SENSE} . A window comparator monitors V_{LOW_SENSE} and compares it to $V_{HIGH_SENSE}/2$. The hysteresis window voltage can be programmed and is equal to the voltage at the HYS_PRGM pin. With a 100k resistor on the HYS_PRGM pin, the $V_{HIGH_SENSE}/2$ voltage must be within a ($V_{LOW_SENSE} \pm 1V$) window during start-up and normal operation. Otherwise a fault is triggered and the LTC7820 stops switching.

Conclusion

The LTC7820 is a fixed ratio high voltage, high power switched capacitor controller that meets the power density demands of bus converters, high power distributed power systems, communications systems and industrial applications. No inductors are needed.

Data Sheet Download

www.linear.com/LTC7820

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