60V, 4-Switch Synchronous Buck-Boost Controller Regulates Voltage from Wide Ranging Inputs and Charges Batteries at 98.5% Efficiency at 100W+

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The LT®3791-1 is a 4-switch synchronous buck-boost DC/DC converter that regulates both constant voltage and constant current at up to 98.5% efficiency using only a single inductor. It can deliver well over a hundred watts and features a 60V input and output rating, making it an ideal DC/DC voltage regulator and battery charger when both step-up and step-down conversion is needed. In addition to the high voltage, power and efficiency, it features short-circuit protection, a SYNC pin for synchronization to an external clock, a CLKOUT pin for driving an external SYNC pin or for parallel operation, OVLO (overvoltage lockout), $\overline{\text{SHORT}}$ output flag, $\overline{\text{C/10}}$ detection and output flag for battery chargers, and a CCM pin for discontinuous or continuous conduction mode. The inclusion of DCM (discontinuous conduction mode) increases light load efficiency and prevents reverse current when it is undesirable.

120W, 24V 5A OUTPUT BUCK-BOOST VOLTAGE REGULATOR

The buck-boost converter shown in Figure 1 regulates 24V with 0A–5A load at up to 98.5% efficiency (Figure 2). It operates from an input voltage range of 12V to 58V. Adjustable undervoltage and overvoltage lockout protect the circuit. It has short-circuit protection and the $\overline{\text{SHORT}}$ output flag indicates when there is a short circuit on the output. It features DCM operation at light load for lowest power consumption and reverse current protection. R_{OUT} limits the output current during both

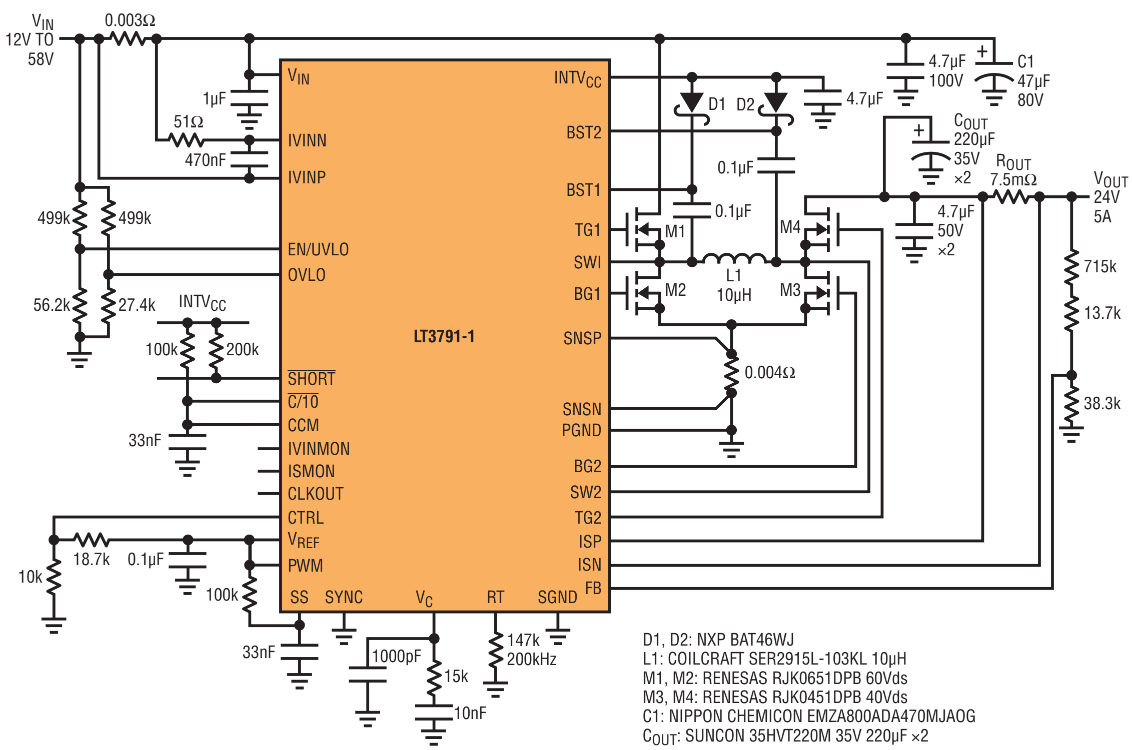

Figure 1. 120W 24V 5A output buck-boost voltage regulator accepts a 12V–58V input

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The LT3791-1 can regulate both constant voltage and constant current. Large capacitive loads such as supercapacitors and batteries require constant current charging until they are charged up to a termination voltage, at which point they require constant voltage regulation. The LT3791-1 easily satisfies this requirement.

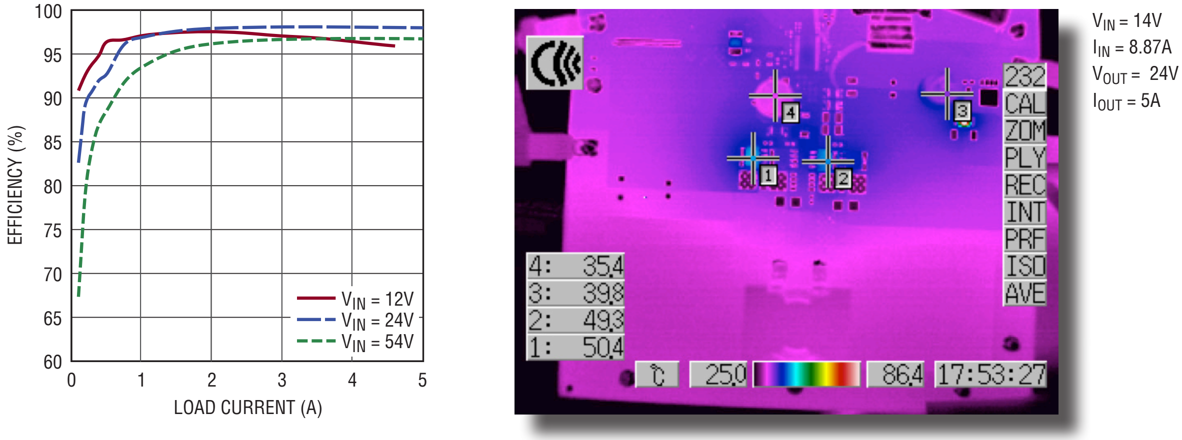


Figure 2. Efficiency and worst case thermal results for the 24V converter in Figure 1

a short circuit and an overload situation, making this a robust application.

The 14V, 10A voltage regulator in Figure 3 takes a slightly different approach. It runs in CCM throughout its entire load current range 0A–10A to provide the lowest EMI at light load. It is still very efficient. The circuit retains short-circuit protection even though R_{OUT} is replaced with a short. The main switch sense resistor RSW limits the short-circuit current at a higher level than R_{OUT}, but hiccup mode during short-circuit limits the power consumption of the IC, maintaining a low temperature rise on the components during a short. When DCM is not needed, R_{OUT} may not be necessary and removing R_{OUT} slightly increases circuit efficiency. OVLO is tied to the output to limit the output voltage transient during a 10A to 0A transition. This protects both the output capacitors and M3 and M4 switches from overvoltage.

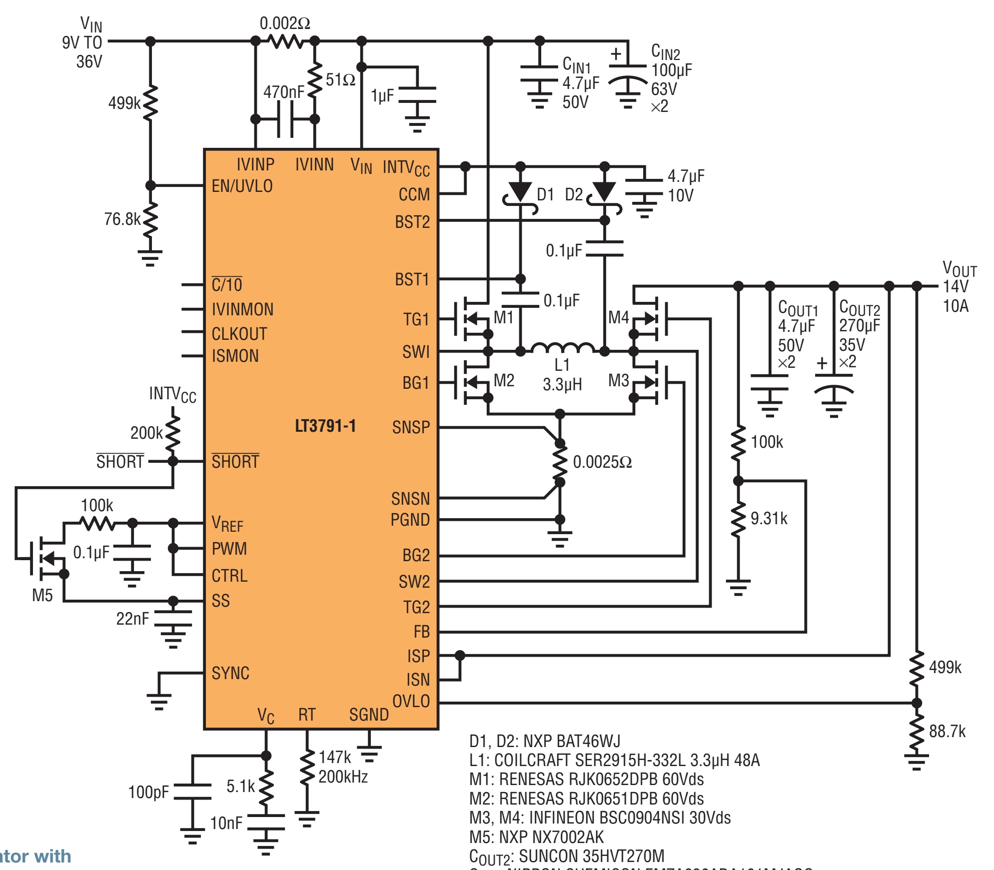


Figure 3. 140W (14V, 10A) CCM buck-boost voltage regulator with 9V–56V input has output OVLO for transient protection.

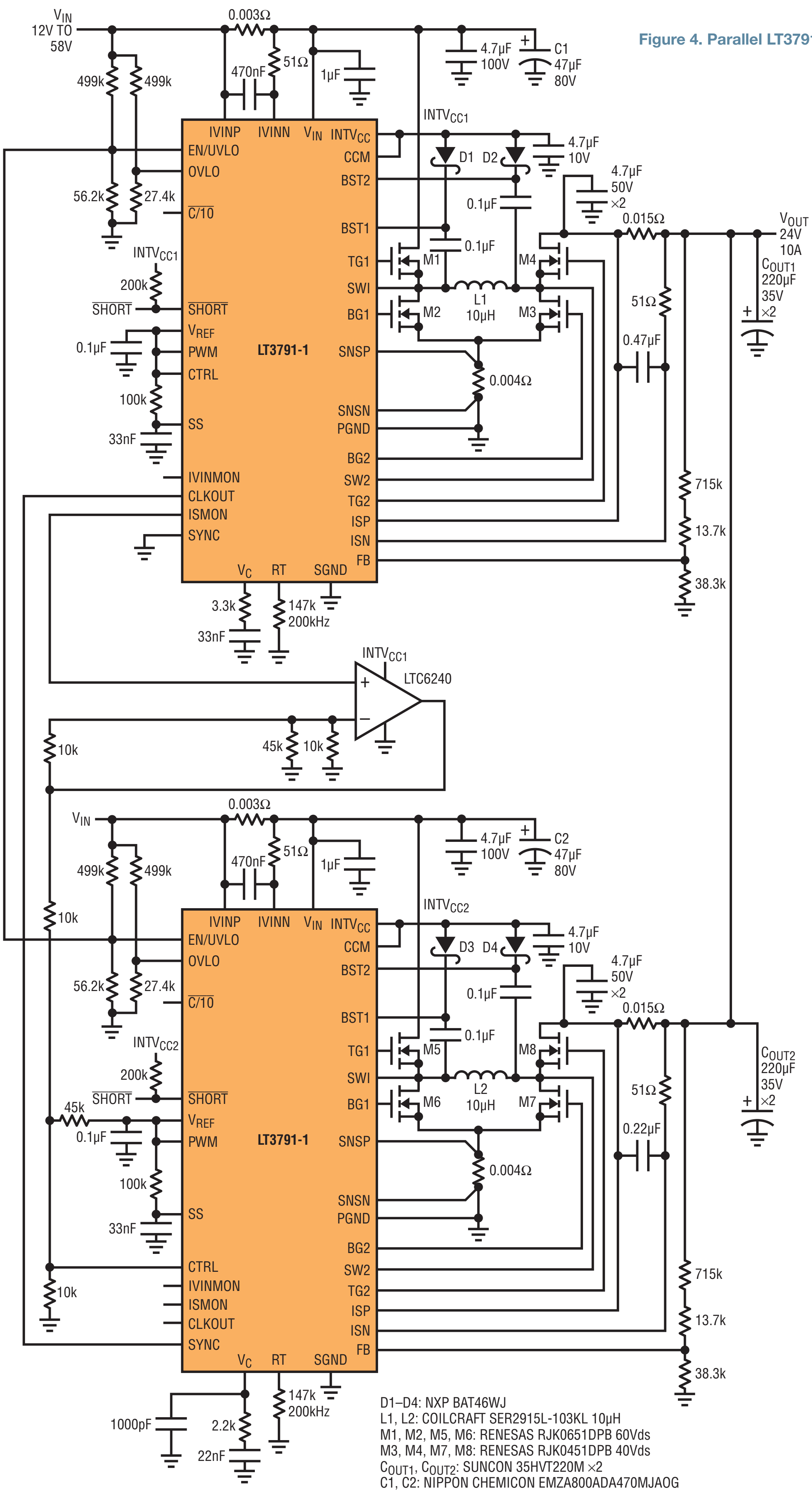


Figure 4. Parallel LT3791-1s in a 240W application

PARALLEL CONVERTERS FOR HIGH POWER USING CLKOUT AND SYNC

The LT3791-1 has a CLKOUT output that can be used to synchronize other converters to its own clock with a 180° phase shift. By tying the CLKOUT of one converter to the SYNC input of another, the maximum output power is doubled while the output ripple is reduced.

Figure 4 shows a 24V, 10A regulator formed by running two LT3791-1s in parallel. By using two parallel circuits, the maximum temperature rise seen on any one discrete component is only 28°C on the M3 and M7 MOSFETs at the lowest V_{IN}. The top converter (master) in Figure 4 commands the current level provided by the bottom (slave) converter. The ISMON output of the master indicates how much current the master is providing, and by connecting ISMON to the CTRL input of the slave, the slave is forced to follow the master. A single op amp is needed to provide the simple 200mV level shift needed to match the CTRL input to the ISMON output levels. The master converter runs in constant voltage regulation while the slave converter is running in constant current regulation. Note that the output voltage of the slave is set slightly higher (28V) so that the voltage feedback loop of the slave is not in regulation for it to be able to follow the master.

The LT3791-1 features both continuous conduction mode (CCM) and discontinuous conduction mode (DCM). CCM provides continuous switching at light load and inductor current can be either positive or negative. When the LT3791-1 enters DCM operation at light load, it prevents backward running current (negative inductor current) and light load power dissipation is minimized.

100W+ 2.5A BUCK-BOOST 36V SLA BATTERY CHARGER

The LT3791-1 can regulate both constant voltage and constant current. Large capacitive loads such as supercapacitors and batteries require constant current charging until they are charged up to a termination voltage, at which point they require constant voltage regulation. The LT3791-1 easily satisfies this requirement. As an example, the buck-boost converter shown in Figure 5 charges a 36V 12Ah SLA battery at 44V with 2.5A DC from a 9V-to-58V input. DCM operation prevents reverse battery current when the output load is overcharged, protecting the circuit from large negative currents.

In some battery charger applications, once termination voltage is reached and charge current tails off, a standby or float voltage regulation level is needed that is different from the charge voltage. The $\overline{\text{C/10}}$ detection level of the LT3791-1 provides this capability. In the circuit in Figure 3 the $\overline{\text{C/10}}$ function drops the battery voltage from charging (44V) to float (41V) when the battery is near full charge. When the battery voltage is then pulled down from an increased load, the voltage feedback loop returns the charger to its charge state of 44V.

The LT3791-1 can be tailored to charge a range of battery chemistries and capacities from a variety of input sources regardless of the voltage relationship between them. Furthermore, a microcontroller can be used to create a maximum power point tracking (MPPT) charger from a solar panel. The output diagnostics ISMON and IVINMON and current control pin CTRL make it easy to create a high power solar panel battery charger.

DCM INCREASES EFFICIENCY AND PREVENTS REVERSE CURRENT

The LT3791-1 features both continuous conduction mode (CCM) and discontinuous conduction mode (DCM). Figure 6 shows the difference between CCM and DCM. The mode is selected by simply connecting the CCM pin to either the $INTV_{CC}$ or $\overline{\text{C/10}}$ pin. CCM provides continuous switching

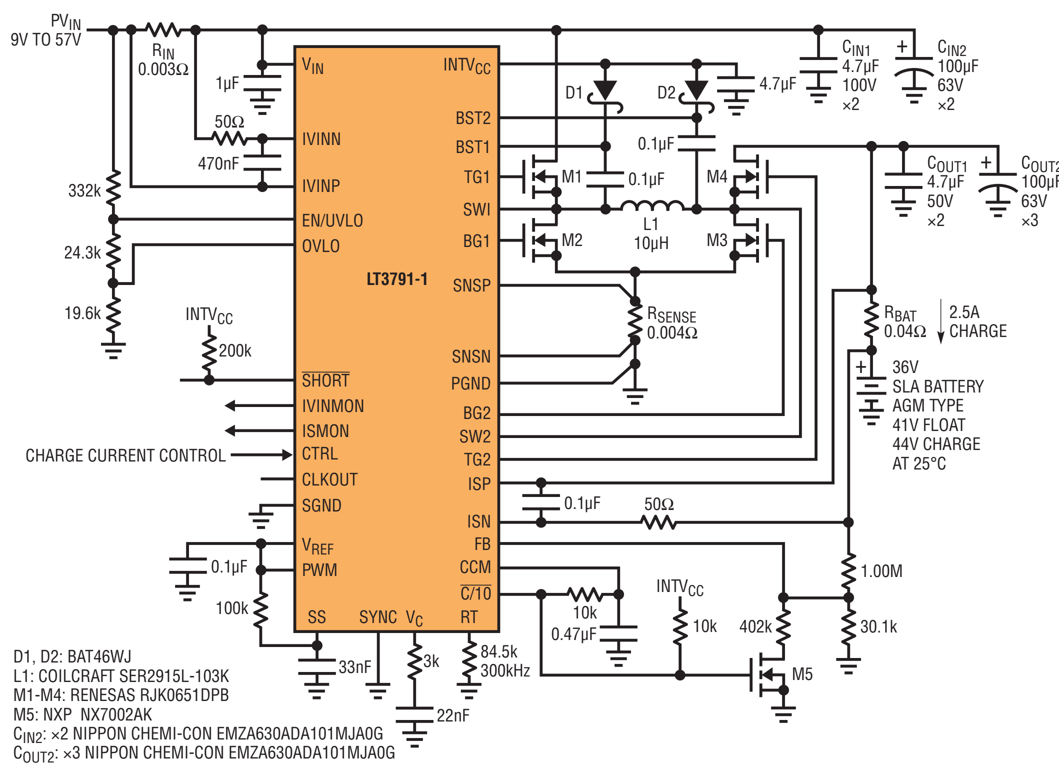
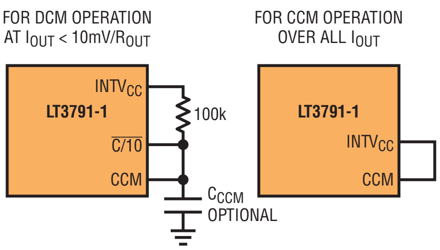
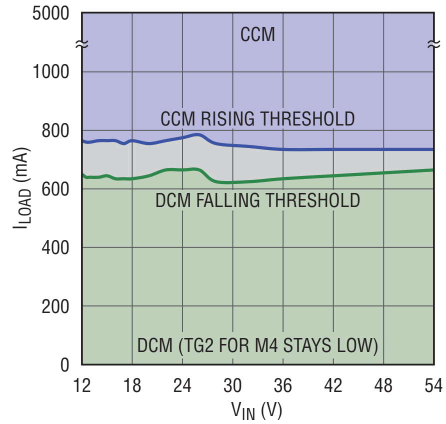


Figure 5. SLA battery charger

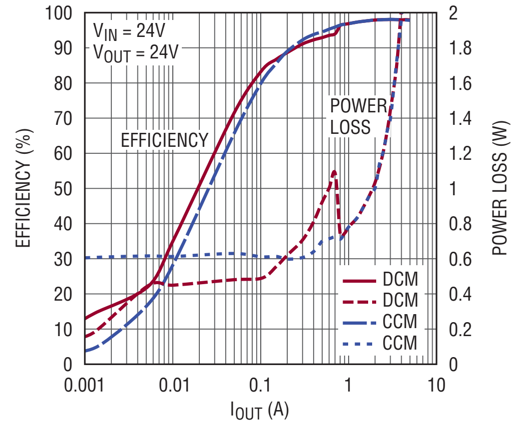
Figure 6. Overview of continuous conduction mode (CCM) for low noise and discontinuous conduction mode (DCM) for light load efficiency



a. DCM vs CCM setup



b. DCM/CCM transition thresholds remain stable as the LT3791-1 moves through boost, buck-boost and buck modes of operation.



c. DCM improves efficiency at light loads.

at light load and inductor current can be either positive or negative. Although zero-load inductor current in CCM is both positive and negative and more power is consumed than DCM, the switch node ringing associated with DCM is eliminated for those that do not want it.

When DCM is selected, the converter remains in CCM until the load drops below about 10% of the programmed maximum output current. When the LT3791-1 enters DCM operation at light load, the TG2 driver for M4 stays low and M4 no longer runs as a switch, but instead as a catch diode. This prevents backward running current (negative inductor current) and light load power dissipation is minimized.

CONCLUSION

The LT3791-1 synchronous buck-boost controller delivers over 100W at up to 98.5% efficiency to a variety of loads. Its wide, 4.7V to 60V input range and 0V to 60V output range make it powerful and versatile, and its built-in short-circuit capabilities make for robust solutions in potentially hazardous environments. CCM and DCM operation make it useful for highest efficiency or lowest noise operation at light load. Its multiple control loops make it ideal for regulating constant voltage, constant current or both. This feature-rich IC easily fulfills buck-boost requirements where other topologies fail. ■

Figure 7. 48V application