Technical Article

Quad Output Power Reference Design with Input Fault Protection for Automotive Applications

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Abstract

A quad output, triple monolithic buck converter and boost controller reference design is presented that applies to automotive electronics such as a telematics box. The reference design features a fault protection scheme to support against input transients such as load dump, cold crank, or reverse battery.

Introduction

Voltage transients from the energy generated by the car alternator and ignition system, or fault events due to external factors such as a car crash, can affect the electronic circuitry in an automotive system. Reliability of the electronic circuitry may be greatly affected; therefore, protection against these unpredictable events must be considered. A telematics box, for example, is an electronic system inside the car that requires high reliability and protection.

The power system design in this article is a reference design solution to provide protection and reliability to a car electronic module that requires four voltage inputs. It features input fault protection against load dump, cold crank, and reverse battery. A PowerPath™ controller allows smooth switch-over between the main and backup batteries when input fault protection is active. A quad output regulator provides four voltage outputs with a triple monolithic buck converter and a boost controller. One of the buck outputs can be made to handle high output peak current requirements, such as those on a communication module. There is a provision for charging the backup battery through a linear battery charger when the main battery is active. Figures 1 and 2 show the basic block diagram and the evaluation board of the reference design solution.

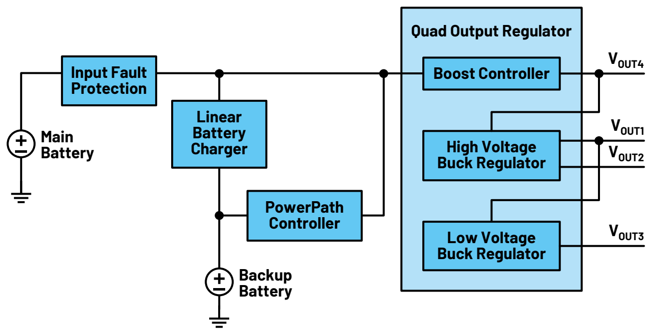

Figure 1. Basic block diagram of the reference design.

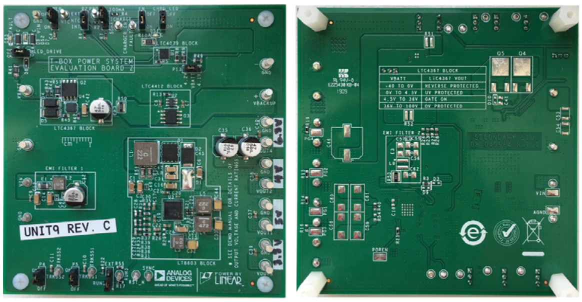

Figure 2. Evaluation board hardware.

Fault Events and Scenarios

Load Dump

Load dump occurs when the alternator system is charging a battery and the connection to the battery is lost. A battery may be disconnected because of cable degradation, improper connection, or purposeful separation while the engine is running, resulting in a load dump. Alternator systems without centralized load dump suppression allow the alternator to produce extremely high voltages in the event of a sudden battery disconnection. The voltage dumped onto the load can go up to 100 V for a 12 V system due to the stator's high inductance and the vehicle's voltage regulator's inability to reduce the field current rapidly enough.

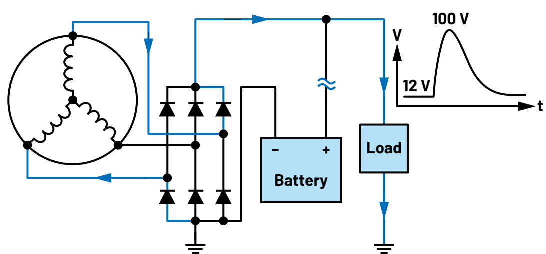

Figure 3. A load dump scenario.

Cold Crank

During startup or cranking, the engine requires more power, causing the battery voltage to dip. In general, starting an engine in a cold environment is harder than starting an engine in a warm environment. This requires the engine to draw more power, which results in a larger voltage drop compared to normal cranking. This condition is known as cold crank. The waveform in Figure 4 shows the waveform during cold crank where the main battery falls below its specified level.

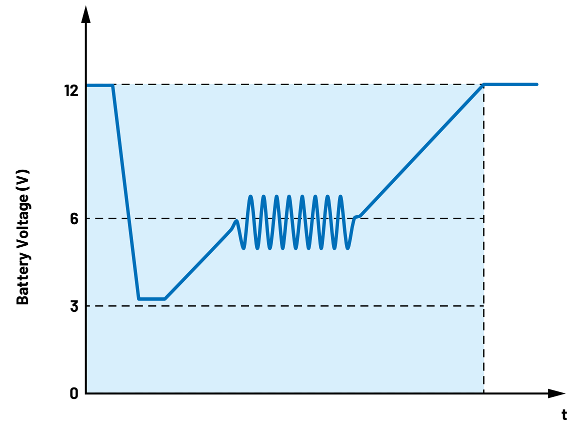

Figure 4. A sample cold crank scenario.

Reverse Voltage

A reverse voltage or, simply, reverse battery condition covers the human error scenario where someone connects a battery with the polarity reversed. This can result in destruction unless adequate protection is provided.

Circuit Function

Fault Protection

The LTC4367 serves as a fault protection for the circuit as it disconnects the V_{BATT} voltage to V_{IN} when the V_{BATT} voltage is too low, too high, or negative. It has accurate overvoltage and undervoltage comparators to ensure that power is applied to the system only if the input supply is within the allowable voltage window. The LTC4367 automatically isolates the load from negative input voltages. It can operate an overvoltage protection that can go as high as 100 V and undervoltage protection that can go as low as –40 V.

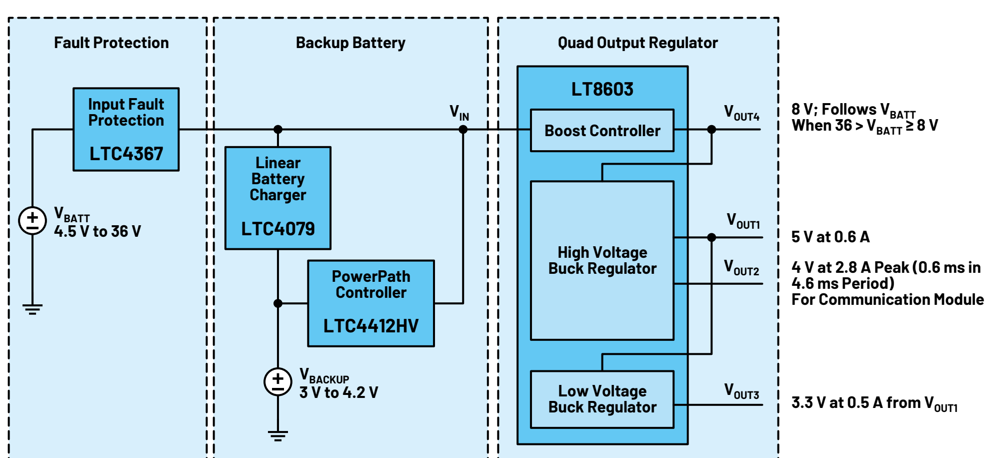

Figure 5. Block diagram of a typical circuit and its function.

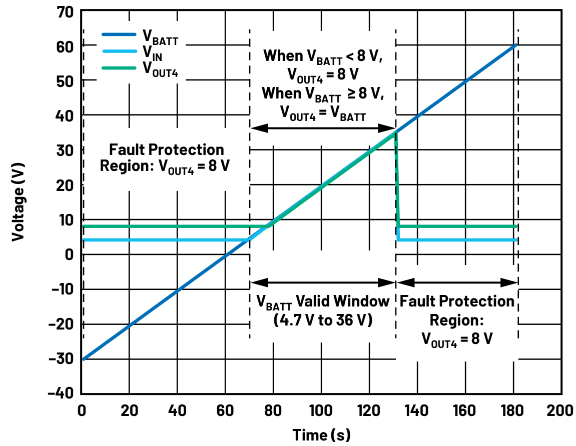

Figure 6. V_{BATT} valid and fault protection window.

Backup Battery

Backup battery charging is possible through the LTC4079, which features a multi-chemistry battery charger that allows a flexible battery voltage to be used. With the reference design circuit, a charging voltage of around 4.2 V is used. To avoid overcharging the battery, the LTC4079 also features a charge termination capability through a C/10 detector or a set charge timer of around 2 hours and 30 minutes.

Automatic switch-over between V_{BATT} and V_{BACKUP} is possible through the LTC4412 PowerPath controller. This feature allows the LT8603 to maintain an output voltage on V_{OUT4} by having a V_{IN} drawing from either V_{BATT} or V_{BACKUP}. In the event of V_{BATT} disconnection or fault detected, the controller allows the current to flow from the V_{BACKUP} to the V_{IN} of the LT8603. When no fault is detected, the LTC4412 will block the path connecting the V_{BACKUP} to the V_{IN} of the LT8603. Figure 7 shows the waveform of the power switch-over event.

In the event of a cold crank, V_{BATT} goes down from 12 V to 2 V. The V_{BATT} path is disconnected, and V_{BACKUP} now serves as the V_{IN} of the boost converter in order to maintain an 8 V output on V_{OUT4}. When V_{BATT} increases to ~5 V, it will again serve as the V_{IN} for the boost converter. V_{OUT4} will still be maintained at 8 V until V_{BATT} reaches 8 V. As V_{BATT} recovers to its original voltage of 12 V, V_{OUT4} will then follow the voltage of V_{BATT}. A small voltage drop on V_{OUT4} is due to the diode forward voltage. The power switch-over allows V_{OUT1}, V_{OUT2}, and V_{OUT3} to maintain its regulation.

Quad Output Regulator

The LT8603 features a boost regulator, V_{OUT4}, with two high voltage buck regulators, V_{OUT1} and V_{OUT2}, and a low voltage buck regulator, V_{OUT3}. The boost regulator is capable of providing power to the buck regulators. The LT8603 provides good input and output load regulation at different input voltage levels. Figure 8 shows the output regulation of the LT8603.

The high output peak current capability of one of the buck regulator outputs, V_{OUT2}, of the LT8603 is used for applications that involve a communication module. A typical 3.6 V to 4 V output voltage and an output peak current on-time of 0.6 ms over a 4.6 ms period is required for a communication module. On the tested conditions shown in Figure 9, the system's transient behavior is monitored. V_{OUT2} features a good transient response with minimal voltage undershoot and overshoot.

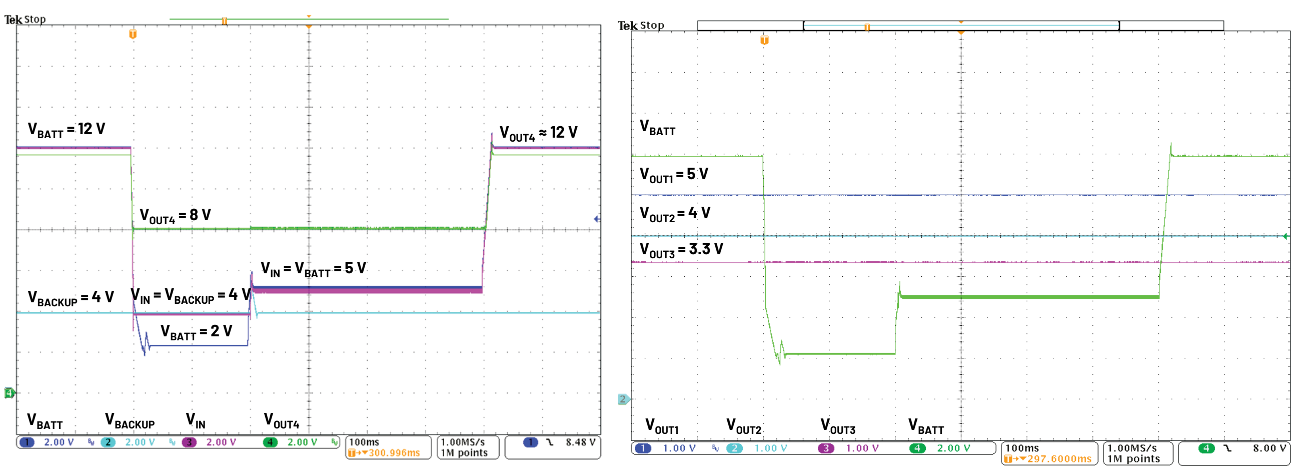

Figure 7. Power switch-over event at cold crank.

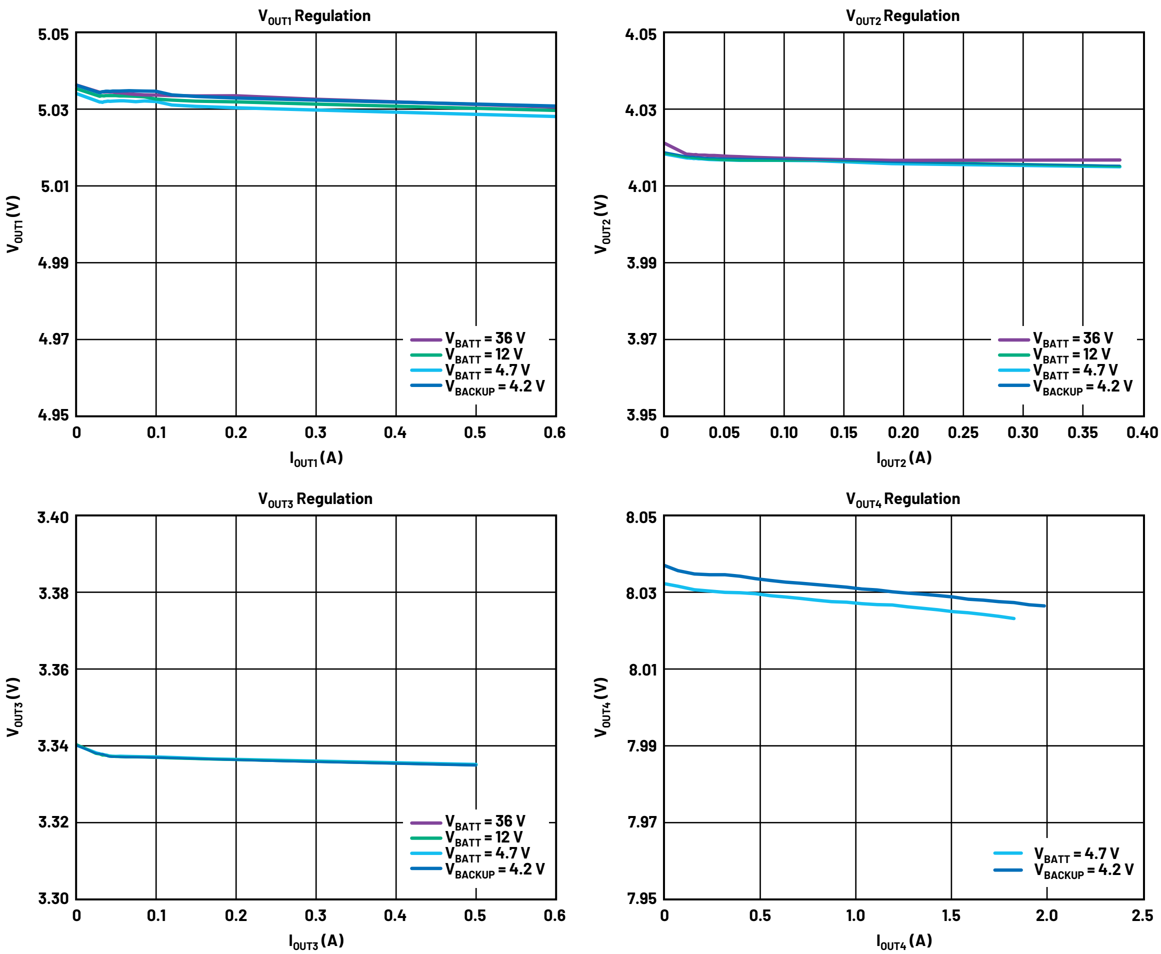

Figure 8. Output regulation of the LT8603.

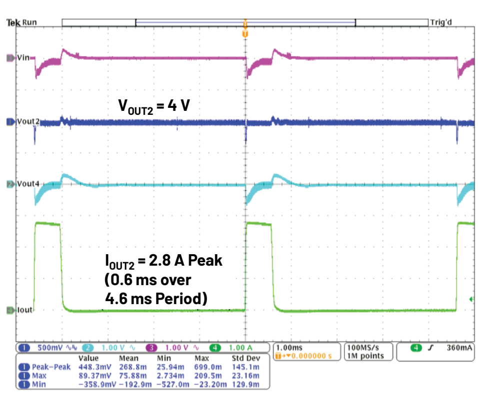

Figure 9. High output peak current performance of V_{OUT2}.

Load Dump Response

The input fault protection and power switch-over feature of the reference design board allows the LT8603 to operate despite being in a load dump event. Figure 10 shows a simulated waveform of a load dump condition where V_{BATT} goes as high as 100 V and the response of the boost, V_{OUT4}, and one of the buck regulators, V_{OUT3}. During the overshoot due to load dumping, the 36 V V_{BATT} limit is reached and the LTC4367 disconnects the path connecting V_{BATT} to V_{IN}. V_{OUT4} now sources its V_{IN} from V_{BACKUP} to maintain the regulated 8 V level. As V_{BATT} restores to its original level, V_{OUT4} will then follow V_{BATT}.

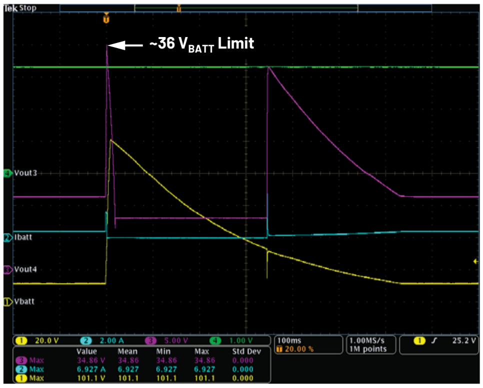

Figure 10. Load dump response.

Circuit Variations and Implementations

The flexibility of the schematic design allows variations on how the circuitry can be implemented. The reference design board has "Do Not Install" components and path connectors that allow the user to configure the board with either Topology 1 or Topology 2. This also allows the configuration of either a boost or SEPIC converter on V_{OUT4} depending on the application. An additional circuit option for added input fault protection can be implemented on the LTC4367 for 150 V transient conditions. More details on the configuration are shown on the schematic of the reference design board.

The circuit configuration presented in Figure 5 is Topology 1, which has a minimum V_{BACKUP} voltage of 2.5 V, one EMI filter after V_{IN}, and is capable of power switch-over through the LTC4412HV. The V_{IN} of the boost controller sources its power from V_{BATT} or V_{BACKUP}. During the V_{BATT} valid window, V_{OUT4} maintains a regulated voltage level through the boost converter or follows V_{BATT} as shown in Figure 6. Outside the V_{BATT} valid window, V_{OUT4} sources from V_{BACKUP} in order to maintain a regulated set level.

Topology 2 addresses the need for a lower V_{BACKUP} voltage application such as a 1.5 V level. When there is no input fault, V_{BATT} is directly connected to V_{OUT4} while V_{BACKUP} is the V_{IN} to the boost controller. Additional filters are required on the input of the buck regulators for better noise filtering and EMI performance. Power switch-over is achieved seamlessly when V_{BATT} falls below or goes above its valid window. The minimum V_{BATT} voltage level of the valid window is set to the regulated level of V_{OUT4}. During the V_{BATT} valid window, V_{OUT4} follows V_{BATT}. Outside of the V_{BATT} valid window, V_{BACKUP} is used to maintain a regulated set level.

Table 1. Comparison Between Topology 1 and 2

	Topology 1	Topology 2
ICs Used	LT8603, LTC4412HV, LTC4367, LTC4079	LT8603, LTC4367, LTC4079
Backup Battery Operation	V_{BACKUP} operates as low as 2.5 V	V_{BACKUP} operates as low as 1.5 V
EMI Input Filtering	Connected before boost regulator	Connected before boost and buck regulators input
Minimum V_{BATT} Valid Window	V_{BATT} can go as low as the V_{BACKUP} level	V_{BATT} must be equal to V_{OUT4} regulated set level

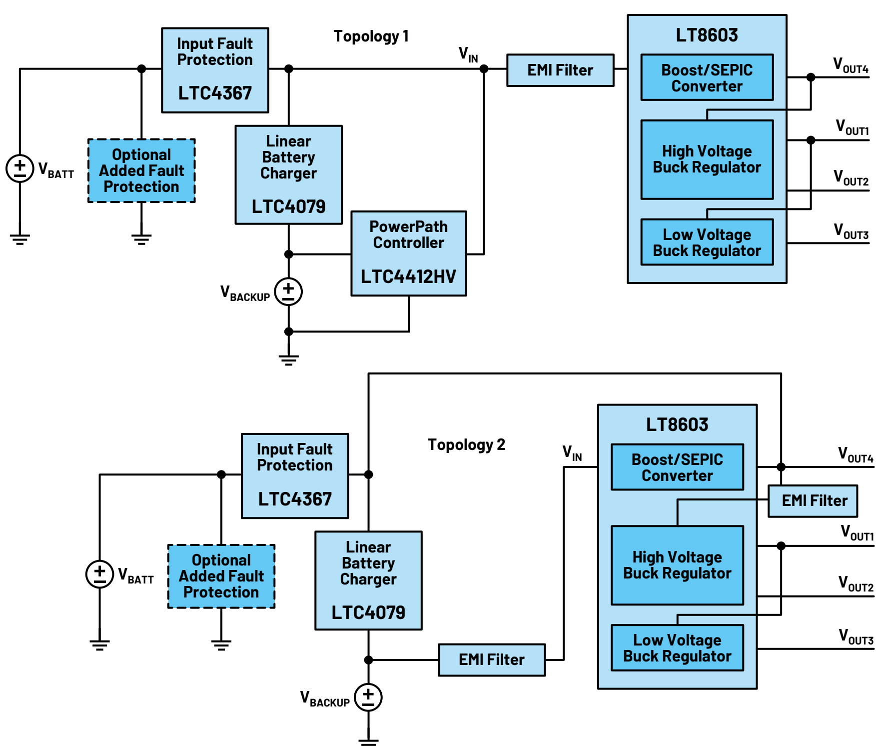

Figure 11. Circuit variations.

Conclusion

The ever-growing advancement of automotive applications requires more reliability and safety considerations. The standards defined by international organizations have played a significant role for designers focusing on what contributes to the voltage transients that may be harmful or can cause degradation of the electronic system. In conclusion, the quad output power reference design has proven its capability when exposed to the simulated test conditions of input overvoltage, undervoltage, and reverse voltage operations. Also, the different circuit variations allow flexibility with regards to the backup battery operation, minimum battery voltage level, EMI input filtering, and the number of components. For more information about the reference design board, contact the authors or your local ADI representative.

Reference Design ICs and Files

Attached here are the schematic, PCB Gerber files, and the bill of materials (Topology 1) of the quad output regulator. For evaluation board availability, contact the authors or your local ADI representative.

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About the Authors

Terry Lo received his B.Eng. (Hon.) degree from The University of Hong Kong in 1992 and his M.Sc. degree in electronic engineering from City University of Hong Kong in 1998. In 1999, Terry joined Linear Technology (now part of Analog Devices) as a field applications engineer, and he moved to the U.S. in 2016. He is now a power system engineering manager. Terry enjoys painting in his leisure. He can be reached at terry.lo@analog.com.

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