Texas Instruments

Application Report
SNVA681A–March 2015

Load Dump and Cranking Protection for Automotive Backlight LED Power Supply

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ABSTRACT

Automotive electronic systems can be subjected to wide input voltage variations resulting from cold cranking and load dump conditions. The need for over voltage protection is particularly common in automotive 12 V and 24 V systems where peak load dump transients can be as high as 60 V. Cranking condition sags the battery voltage to a low value when the battery is supplying current to an electric starter motor. This application report presents a power supply design using LM5088-Q1 (wide input range non synchronous buck controller) with protection for load dump, reverse polarity and cold cranking conditions conducive to the automotive environment.

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1 Cold Cranking

Variation of the battery voltage is common in automotive applications. Normally, the output of a 12 V vehicle battery varies from 9 V to 16 V. Therefore, all circuits powered by the battery should be designed to account for the input-voltage variation. Furthermore, if a cold-cranking condition is to be considered, the battery voltage can drop down to 3 V ± 0.2 V, that is, 2.8 V in the worst case, for a short duration of around 15 ms. Then, the battery voltage goes up to 6 V, where it remains for a few seconds, before returning to the nominal voltage range within a rise time of a few seconds. Under a cold-cranking condition, the battery voltage profile is similar for different automotive manufacturers. But with respect to the voltage level and timing, there will be variations among the different manufacturers. Figure 1 illustrates typical battery voltage profile under a Cold Cranking Condition at low temperatures. Although the duration of the condition is not long, important automotive equipment like LCD panels and safety electronics are still required to maintain normal operation during this period.

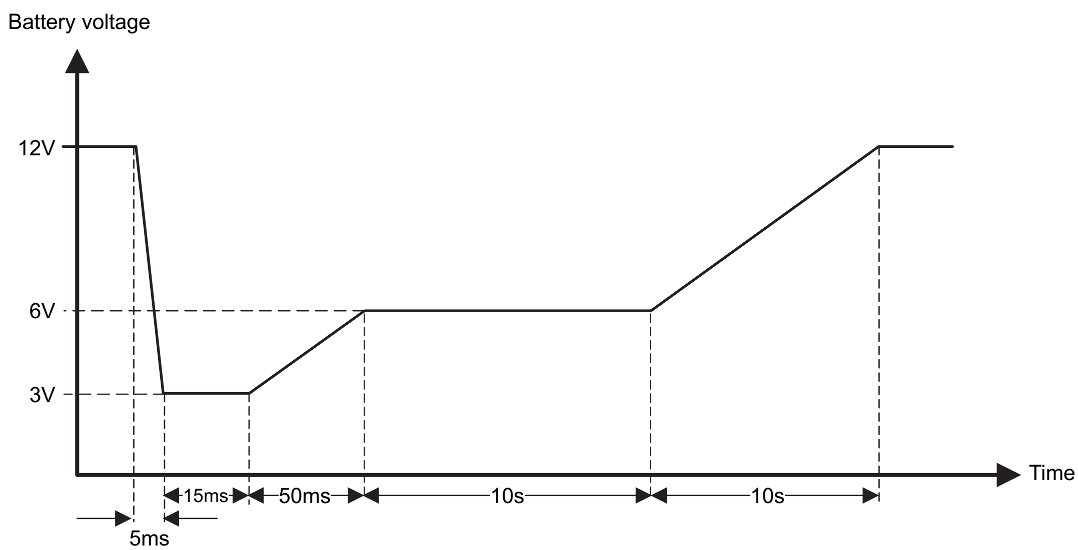

Figure 1. Typical Battery Voltage Profile Under a Cold-Cranking Condition

It is becoming increasingly important for automotive subsystems to operate during engine cold-cranking conditions. To increase fuel economy, some new automobiles are being equipped with automated start-stop systems that shut down the combustion engine when the automobile is stopped at a traffic light or in a traffic jam. As the brake pedal or the clutch is released, the electric starter motor cold cranks the battery to get the combustion engine operating. For safety and convenience, the power management system must sustain the input operating voltage levels in such start-stop systems to insure continuous operation of electronic components found in navigation systems, dashboard electronics, LED brake lights, or headlights. This requires power management solutions capable of operation at very low minimum input operating voltages. LM5088-Q1 Automotive Grade 1 qualified controller can be configured to operate over an ultra-wide input voltage range of 4.5 V to 75 V. For systems where the voltage level is 4.5 V or above, the LM5088-Q1 provides a good solution. The system operation, when the input goes below the output of the controller (LM5088-Q1), can be taken care by having a bridge rectifier followed by a Super Cap or high value aluminum electrolytic capacitors at the input, thus, providing continuous operation in cold-cranking condition for the duration specified in Figure 1.

The LM5088 is available in two versions: the LM5088-1 provides a ±5% frequency dithering function to reduce the conducted and radiated EMI, while the LM5088-2 provides a versatile restart timer for overload protection. Additional features include a low dropout bias regulator, tri-level enable input to control shutdown and standby modes, soft-start and oscillator synchronization capability. The device is available in a thermally enhanced TSSOP-16EP pin package. Figure 2 shows the simplified application schematic of the controller.

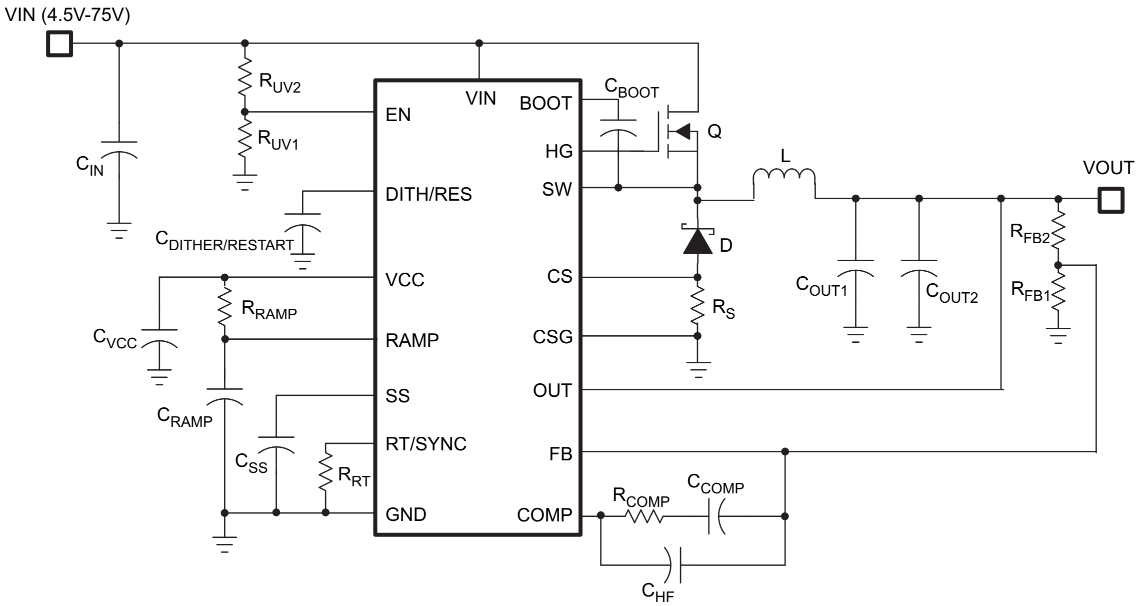

Figure 2. Simplified Application Schematic LM5088

2 Load Dump

A load dump occurs when the load to which a generator is delivering current is abruptly disconnected. In automotive electronics, this applies to disconnecting a battery while it is being charged by the alternator. It can be "as high as 120 V and may take up to 400 ms to decay". Figure 3 shows typical load dump condition, when the alternator gets disconnected from the battery.

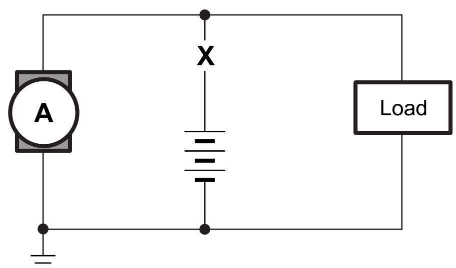

Figure 3. Typical Load Dump Condition

ISO7637-2:2004[1] pulse 5 (load dump pulse) is designed to simulate the voltage surge produced by spinning alternators when the battery or some other significant load is accidentally disconnected. The basic method of protecting an automotive electronic subsystem is to shunt the supply voltage at the ESA input with a semiconductor transient suppressor. In many cases, however, the device has to absorb more energy than it can safely handle, leading to the failure of the system. The unsuppressed ISO7637-2:2004[1] pulse 5 (load dump pulse) is shown in Figure 4.

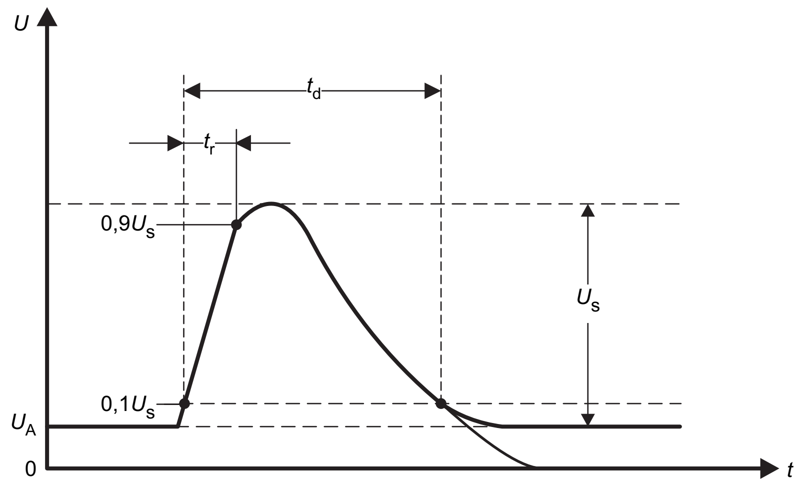

Figure 4. Load Dump Pulse

The typical values of the unsuppressed ISO7637-2:2004[1] pulse 5 (load dump pulse) for a 12 V and 24 V battery system is shown in Table 1:

Table 1. Typical Values of the Unsuppressed ISO7637-2:2004[1] Pulse 5 (load dump pulse)

Parameter	12 V System	24 V System
U_s	65 V to 87 V	123 V to 174 V
R_i	0.5 Ω to 4 Ω	1 Ω to 8 Ω
t_d	40 ms to 400 ms	100 ms to 350 ms
t_r	$\left(10\,{}^{0}_{-5}\right)$ ms	

An alternative approach to address the load dump transients is to disconnect the input supply to the controller or electronic subsystem for the specified duration of the pulse and then reconnect with a fixed delay when conditions return to normal. LM5088-Q1 has the input operating range up to 75 V that is acceptable for typical load dump transients, thus, allowing the controller operation but for transients above the controller upper operating range, input supply needs to be disconnected.

3 Reverse Polarity Connection

Automotive systems need to be prevented against reverse polarity connection. The electronic subsystem can be disconnected in case the system operation is not so critical. It can be done using a N-channel or P-channel Mosfet in series with the supply. Figure 5 presents the typical application circuit for the reverse polarity protection. N-channel Mosfet is typically preferred because of the lower RdsON when compared to a P-channel Mosfet.

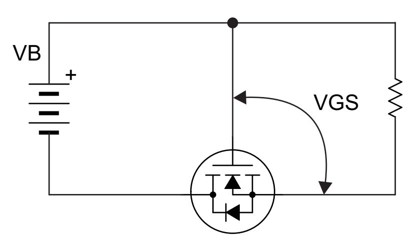

Figure 5. Reverse Polarity Protection With N-Channel Mosfet

But for the automotive systems where the reverse polarity connection errors are unavoidable, a bridge rectifier at the input supply is the cheapest but less efficient solution as the continuous power dissipation in the diodes reduces the system efficiency.

4 Application Circuit

The circuit in Figure 6 is the series disconnect circuit used to prevent LM5088-Q1 against load dump transients. The circuit is designed using TL431A precision programmable reference used for precision series disconnect.

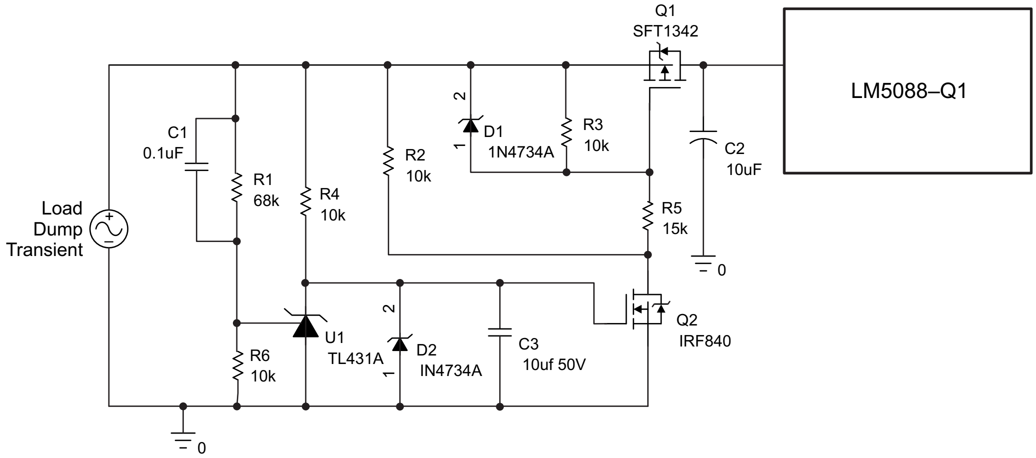

Figure 6. Load Dump Protection Application Circuit

The circuit above uses TL431A for precision series disconnect; for a 12 V battery system the trip point can be selected to be 20 V, whereas, for 24 V battery system 30 V can be set as the trip point. The TL431A is a three-terminal adjustable shunt regulator, with specified thermal stability over applicable automotive, commercial, and military temperature ranges. The output voltage can be set to any value between Vref (approximately 2.5 V) and 36 V, with two external resistors. These devices have a typical output impedance of 0.2 Ω. Active output circuitry provides a very sharp turn-on characteristic, making these devices excellent replacements for Zener diodes in many applications such as onboard regulation, adjustable power supplies and switching power supplies. Figure 7 shows the functional block diagram of TL431A . The internal reference voltage of the comparator Vref (inverting input) is 2.5 V. The non-inverting end of the comparator can be set accordingly to drive the output transistor that finally decides the trip point.

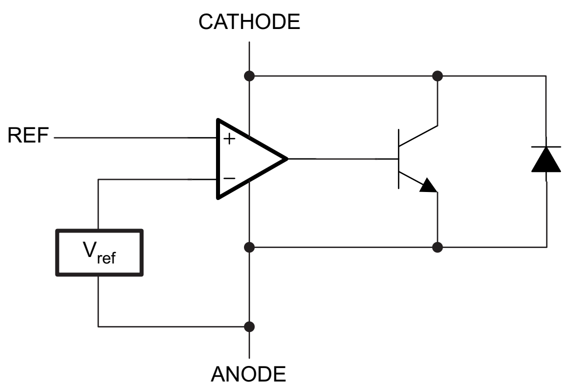

Figure 7. Functional Block Diagram TL431A

The ON state voltage of TL431A is 2 V, which turns OFF the N-channel Mosfet (Q2) having Vgs(min)=2.5V. P-channel Mosfet (Q1) also turns OFF, thereafter, disconnecting the input load dump transient. The trip point can be selected anywhere above 2.5 V as below it, the FET's Q1 and Q2 enter the OFF state because of insufficient input voltage to satisfy gate to source thresholds of the FET's. Zener diodes D1 and D2 are necessary to clamp the gate to source voltage of the FET's, which should not exceed beyond Vgs max (typically 20 V) of the FET's Q1 and Q2. The Vtrip point can be calculated as:

$$V_{trip} = 2.5 \times \left(\frac{R1 + R6}{R6} \right)$$

5 Response Time Measurement

The response of load dump protection circuitry with C2 = 10 µF (Figure 6) is shown in Figure 8. The trip point voltage decays slowly because of C2 (10 µF) at the output, the nature of the expected load dump transient with the available capacitance will determine the actual response time. Figure 9 shows the response time with C2 = 1 µF at the output.

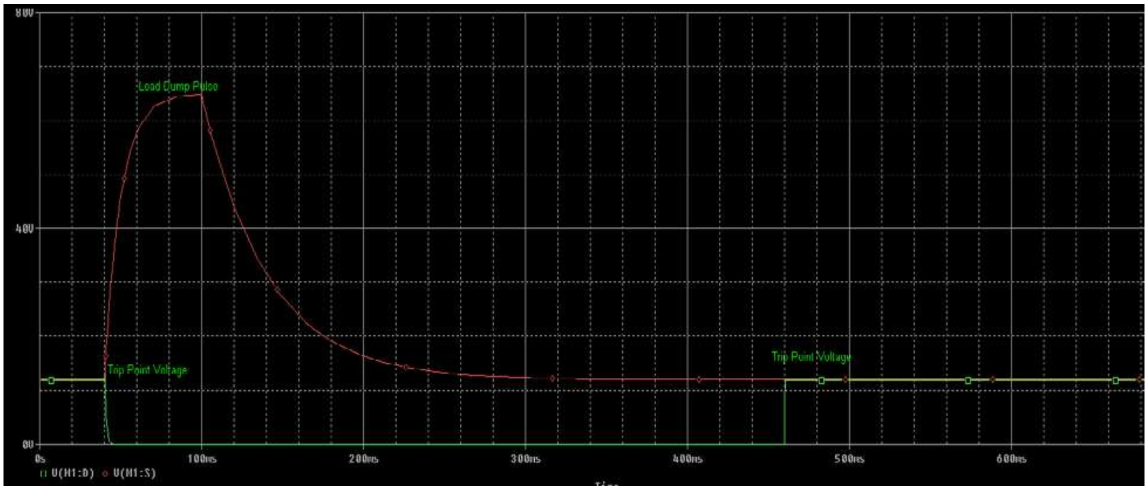

Figure 8. Response Time Measurement With C2 = 10 µF at the Output (Delayed Response)

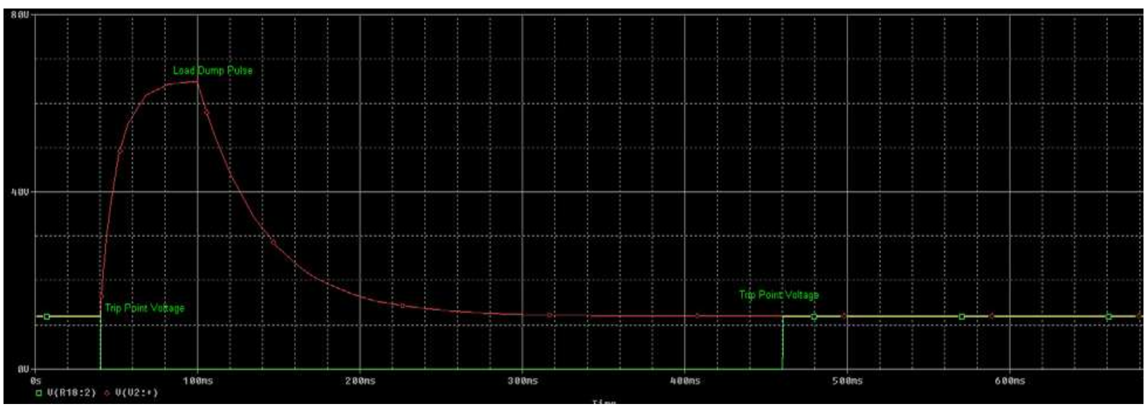

Figure 9. Response Time Measurement With C2 = 1 µF at the Output (Fast Response)

The load dump protection circuit has no protection for reverse polarity connection as the body diode of the P-channel FET conducts in case of reverse connection. The reverse polarity protection for the application circuit is provided by means of the bridge rectifier so that the circuit remains functional even in case of reverse polarity connection. Figure 10 shows the complete application schematic for the automotive backlight LED power supply having load dump, reverse battery and cold cranking protection.

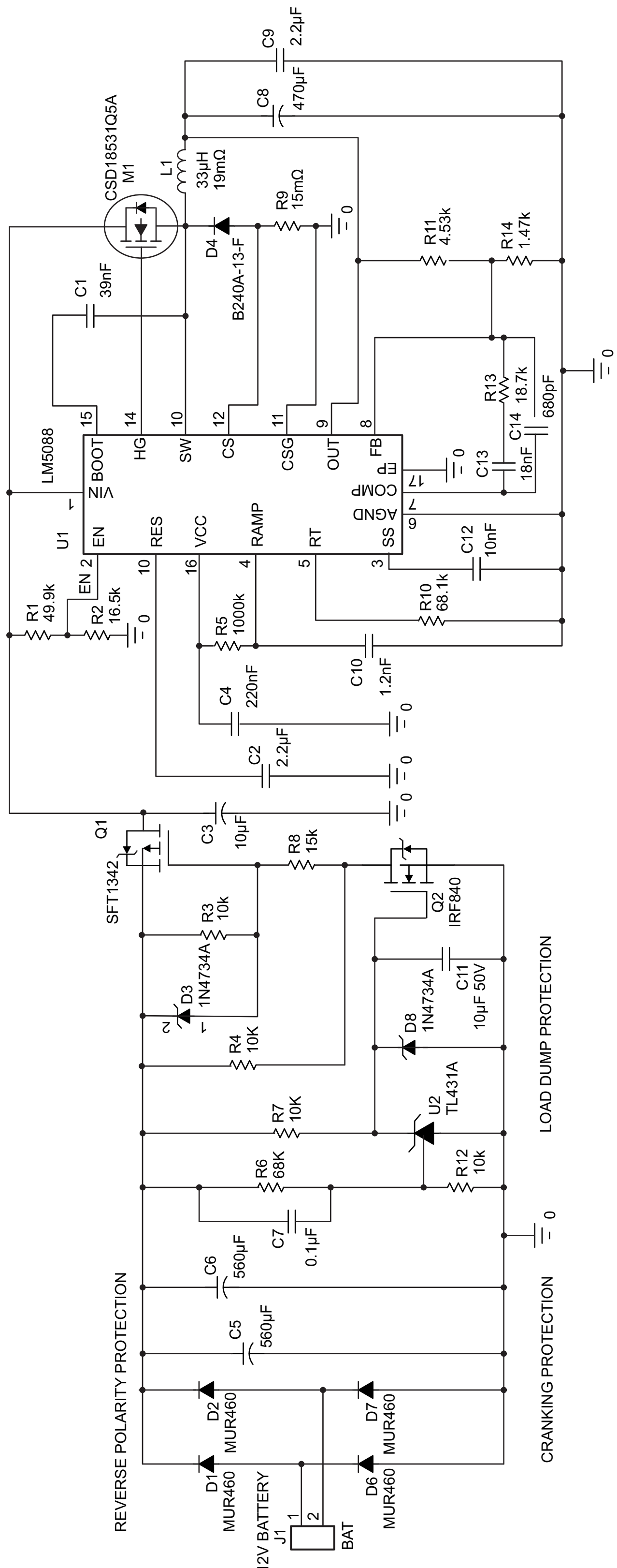

Figure 10. Application Schematic: Automotive Power Supply for Backlight LED Driver Using LM5088-Q1