High-Side Cutoff Switches for High-Power Automotive Applications

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In high power automotive applications relays are commonly used as cutoff switches, such as battery load balancing and power distribution. Relays are used because they can control a high voltage system from a low power signal. However, they present many design constraints due to their mechanical nature, cost and size causing long term reliability issues, slow switching speeds and board space. Semiconductors, like MOSFETs and gate drivers, have been widely used to solve these issues increasing lifetime reliability and providing fast switching speeds. This tech note will describe methods to use gate drivers and MOSFETs as a solid state cutoff switch to replace mechanical relays in order to extend lifetime and reliability.

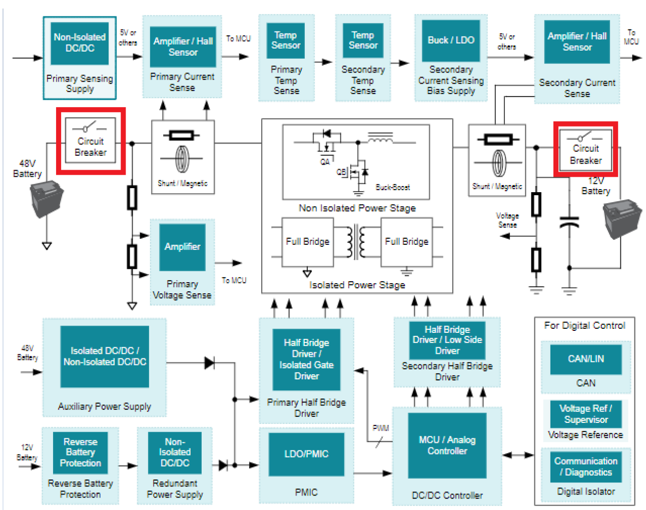

Figure 1. Block Diagram of a Bidirectional 48V to 12V System in Electric Vehicles

Figure 1 shows a block diagram of a DC-DC converter seen in Hybrid, Electric and Power Train Systems. This system helps transfer energy between the 48V battery and the rest of the low power system (12V battery). The high voltage system drives large loads such as traction motor and air conditioning whereas the low power system supplies low power components such as safety systems and infotainment. Relays are often used in these topologies to disconnect the 48V from the rest of the system in the event of a fault signal(overcurrent/overvoltage) to protect the rest of the circuit from the high voltage/current from the battery.

Mechanical Relays Design Constraints

A relay is an electromechanical switch which uses the magnetic field of an energized coil to make or break electrical contact in a circuit. This coil is typically controlled by a signal from a low powered circuit such as a microcontroller, and provides a way to isolate the two. In automotive applications, the most common type of relay used is the single-pole double-throw (SPDT). When the coil is not energized, points Y and Z are shorted therefore connecting the system to the battery. When there is a fault condition, the MCU sends a signal allowing current to pass through the coil and disconnecting the battery from the rest of the system as shown in Figure 2.

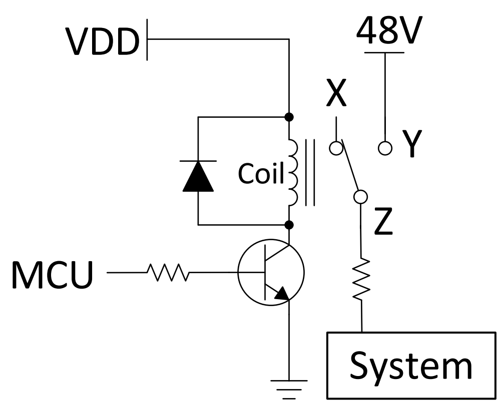

Figure 2. SPDT Configuration as Cutoff Switch During Fault Condition

Mechanical contacts wear out due to friction and oxidation. Over time this can lead to slow switching speeds. Cycling the contact at high voltage or current can form arcs, liquefying or vaporizing contact metal and forming pits which reduce the current capability and contact reliability.

Gate Driver and MOSFETs as Solid State Cutoff Switch

Designers can avoid these issues by using a gate driver with a MOSFET device to form a solid state relay. There are many integrated solutions on the market for this kind of application, however for higher power applications, where the MOSFET gate charge (Q_g) is higher, and faster switching rates are desired, a higher current drive is needed. MOSFETs have higher switching cycles over lifetime because there are no physical moving parts therefore no metal fatigue and wear. In automotive applications, for example, solid state drive solutions exhibits infinite effective lifetime as opposed to mechanical parts. Figure 3 shows the switching cycle performance of MOSFETs over mechanical relays. This illustrates a 10x higher lifetime switching cycle for the semiconductor over the mechanical counterpart.

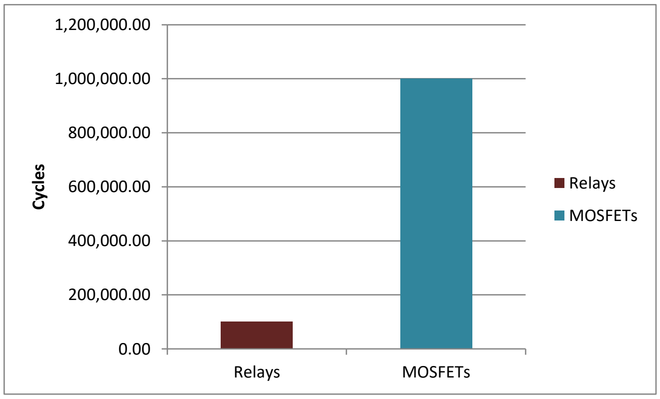

Figure 3. Switching Cycles Comparison

To construct the solid state relay using 2 MOSFETs, either the drains or the sources are tied together. This is to prevent current flow through the body diode of the MOSFETs when there is no conduction. Though the P-channel FETs drive circuit is easier to implement, high-power and cost-sensitive systems use N-channel FETs for its lower $R_{ds,on}$ and lower cost. The diagram in Figure 4 shows the cutoff switch consisting of three blocks: the level-shifter, the bias supply, and the driver/power switch.

The external level-shifting portion of the circuit is required in this example because the low power signal coming from the MCU needs to be shifted in order to drive the FET at 48V. This portion would be integrated into a half-bridge gate driver such as UCC27712-Q1 by using the high-side input and grounding the low-side input. A non-inverting BJT buffer circuit may be added between the level shifter and the driver's input to implement faster turn-off at the cost of board space and component count.

The second portion of this circuit is the external bias supply where the primary winding of the transformer is referenced to the controller ground and the secondary winding referenced to the switch source of the MOSFET. This bias supply provides the driver with sufficient drive voltage and eliminates any duty cycle limitations associated with bootstrap circuits.

The third portion of the circuit is the low-side driver configured as a high-side driver where the output of the level-shifted signal from the MCU drives UCC27524A-Q1 (dual low-side driver with enable function capability). Tying the driver's outputs together allows this topology to meet the fast turn-on/off requirements of such applications by doubling the drive current. This topology allows the low-side driver, referenced to the drain of the lower MOSFET, to disconnect the battery from the rest of the circuit during any fault conditions effectively protecting the system from damage. This discrete solution provides high power handling capability (>500W) often required in automotive applications.

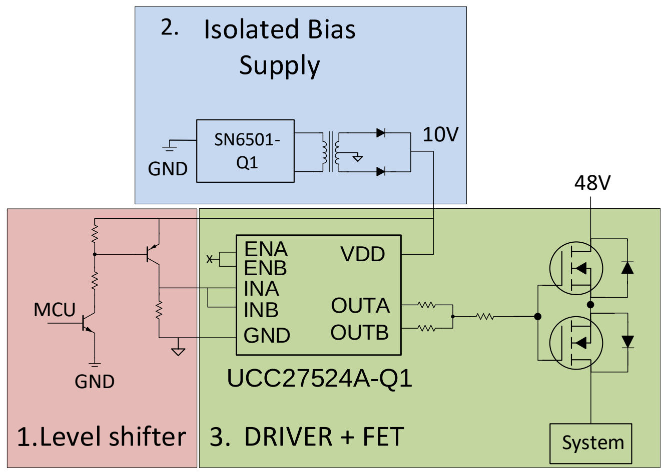

Figure 4. Low-side driver as high-side switch

In summary, this tech note demonstrates a way to replace relays with MOSFETs and low-side gate drivers to solve design constraints associated with mechanical relays. This solution is more viable for its robustness, reliability and performance over time in high power automotive applications.

Related Documentation

- UCC27524A1-Q1 product folder
- UCC27524A1-Q1 datasheet
- UCC27528-Q1 product folder
- UCC27532-Q1 product folder
- SN6501-Q1 product folder

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (November 2018) to A Revision	**Page**
• Changed "Figure 1"	1
• Changed "Section 3 isolated bias supply to section 2 Isolated bias"	2

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