Designing-Out High-Power Automotive Relays

The Last Frontier for Advanced Vehicle Electrification

The electromechanical relay – at one time the power switch of choice for all automotive electrical systems – is progressively becoming replaced throughout the vehicle by lighter, smaller, more reliable and longer lasting semiconductor switches. Advanced fabrication processes such as BCDMOS, allowing power and logic circuitry to coexist on the same chip, enable manufacturers to deliver controllers comprising one or more MOSFET switches with an integrated driver as a single chip. These have already proved successful in a variety of low-power applications.

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With increasing electrification of major vehicle functions such as electric power steering (EPS), integrated starter/alternator (ISA) and other high-power loads both in internal combustion engine and hybrid-electric vehicles, demand is growing for efficient and durable semiconductor power switches for loads above 10A. The electromagnetic relay retains some advantages when used with higher loads, due to its inherently low resistance when turned on. This helps avoid unwanted conduction losses that otherwise would waste energy and cause internal heating which compromises reliability.

In order to replace electromechanical relays in high-current applications, a combination of discrete low on-resistance MOSFETs and separate driver IC can provide a better, lower-power solution a fully integrated controller.

Relay Replacement for High-Current loads
Ideally, a MOSFET with on-resistance (RDS(ON)) of only a few milliohms, at logic-level gate drive, is required. An even lower overall resistance can be achieved by connecting two MOSFETs in parallel using a control IC capable of driving a pair of MOSFET gates. The AUIRLS3034 and AUIRLS3034-7P are 40V MOSFETs are designed for high efficiency when controlling heavy loads. They are packaged as D2Pak or 7-pin D2Pak-7P surface-mount power devices. The D2Pak-7P package enables lower $R_{DS(ON)}$ by providing five pins for connection to the source, complementing the large exposed tab for connecting the drain. A single pin is provided for the gate connection. The standard D2Pak has one pin for connection to the source. Both devices use IR's latest trench HEXFET® semiconductor technology. The package-limited maximum drain current is 195A for D2Pak or 240A for the AUIRLS3034-7P in D2Pak-7P.

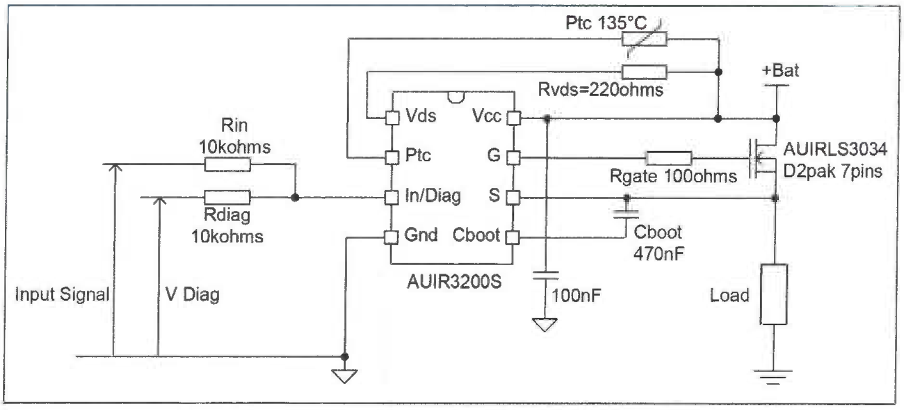

Figure 1: Driver and discrete MOSFET for high-power automotive load switching.

Effective use of either of these devices for relay replacement, or in battery switch applications, is dependent on a suitable controller/driver providing the necessary protection and diagnostic capabilities. The AUIR3200S automotive-qualified MOSFET driver IC can drive two power MOSFETs such as the AUIRLS3034-7P, thereby enabling a protected high-side switch to achieve $R_{DS(ON)}$ as low as 0.75mΩ.

Figure 1 shows the schematic of a high-side switch configured with a single MOSFET. Most of the circuitry needed for protection and diagnostics is integrated in the controller, which reduces external components to a small number of bias resistors, a gate-drive resistor, two capacitors, and a PTC (Positive Temperature Coefficient) temperature sensor, as shown.

Building a Protected High-Side Switch
Figure 2 shows the major functional blocks of the control IC, highlighting the current-source reference used for short-circuit protection.

Short-circuit Protection
Short-circuit protection is one of the most important functions in a protected high-side switch or battery switch. Usually this kind of

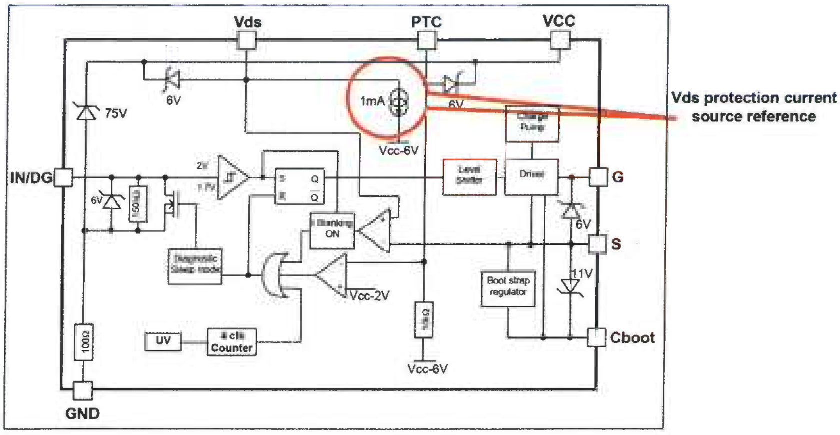

Figure 2: Major internal functions of driver for protected high-side switch applications.

protection requires sensing of the load current using a shunt resistor, which not only produces undesirable power dissipation but also requires an additional operational amplifier. Technically, a current-sensing MOSFET may be considered as an alternative, but this also would impose power losses and in any case no suitable devices are currently available in the market.

To overcome this, the AUIR3200S implements smart monitoring of the MOSFET drain-source voltage. Since smart Vds monitoring is integrated in the controller, designers have freedom to select the best MOSFET for their application. With smart Vds monitoring, the controller is able to switch off the MOSFET when Vds increases above a threshold determined by the resistor Rvds shown in figure 1. In order to maintain a consistent over-current shutdown level over the temperature range, the AUIR3200S features an internal current-source reference, highlighted in figure 2, which is designed to have a temperature coefficient similar to the $R_{DS(ON)}$ of a MOSFET. The programming resistor Rvds allows the Vds protection threshold to be adjusted according the application requirement.

The short-circuit protection based on Vds monitoring works only when the MOSFET is turned fully on such that $V_{DS} = R_{DS(ON)} \times$ IDS. During MOSFET turn on the Vds protection is blanked in order to avoid an unwanted shutdown. The AUIR3200S has an integrated bootstrap regulator, which maintains a fixed voltage of 6V on the bootstrap capacitor regardless of the battery voltage, to ensure the MOSFET turn on can be completed before the blanking time expires. As a rule the bootstrap capacitor, Cboot in figure 1, should be 10 times the MOSFET gate capacitance.

Over-Temperature Protection

In a typical application using a protected switch, over-temperature protection is also required. The AUIR3200S simplifies over-temperature protection by providing a dedicated pin as shown in figure 1 for connecting an external PTC sensor. The PTC sensor displays rapidly increasing resistance within a few degrees of its nominal temperature, allowing fast and accurate temperature protection.

Figure 3:
Sample board showing position of the PTC sensor for over-temperature protection.

Figure 3 shows how the PTC is implemented in a practical circuit. It is mounted as close as possible to the tab of the MOSFET to ensure accurate sensing of the junction temperature. Due to the low $R_{DS(ON)}$ of the MOSFET, the junction temperature will increase relatively slowly during an overload condition. Hence the PTC temperature is able to follow accurately with minimal lag. The over-temperature protection can be adjusted by selecting a PTC sensor having a different temperature characteristic.

Diagnostic Reporting

In a protected switch application, the host system must be informed whether the load condition is normal, short circuit, or over-temperature. The AUIR3200S provides a diagnostic indication by shorting the input pin to ground during a fault condition. This allows the system to detect abnormal load conditions by monitoring the input pin voltage. The fault condition is latched until the AUIR3200S is deactivated allowing the device to enter sleep mode.

Repetitive Short-Circuit Ruggedness

A high-side protected switch comprising the AUIR3200S controller and AUIRL3034S MOSFET has been tested under short-circuit conditions according to AEC Q100-12, which requires the MOSFET case temperature to be fixed at 125°C by adjusting the activation frequency. The switch was able to sustain 10 million cycles without failure.

Conclusion

Electrification of automotive systems such as power steering can be enhanced by replacing bulky and less reliable electromechanical relays with alternative semiconductor switches. Low $R_{DS(ON)}$ MOSFETs can be used to overcome the last remaining barrier to relay replacement by significantly reducing power dissipation when the switch is turned on.

To use such devices successfully, designers need an automotive-qualified driver that integrates the necessary protection features and diagnostic capability. The AUIR3200S is a highly integrated driver capable of controlling two MOSFETs such as the AUIRLS30304-7P connected in parallel, to create a protected high-side switch of extremely low resistance enabling efficient and reliable control of high-power loads.

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