High-Side Switch for Motors and Lamps

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On-chip protection enables startup of a motor under heavy load conditions or a cold filament lamp while preventing damage to control circuitry under locked-rotor and short-circuit conditions.

Low-power dc motor control is one of the most common applications for power electronics, and one for which low-cost solutions are in demand. Design engineers are always on the lookout for solutions that cater to the need for low costs and short design cycles. Even so, such applications have their subtle aspects and warrant a careful design.

The principal requirement for the electronics used in motor control applications is the ability to start the motor under heavy load conditions while preventing damage to control circuitry under locked-rotor and short-circuit conditions. Although these requirements are easy to understand, the electronics required to implement them are often intricate and elaborate.

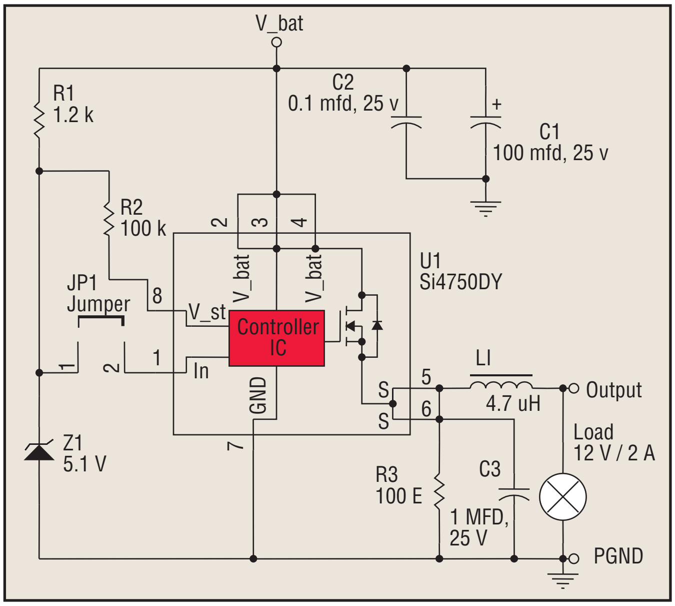

Fig. 1. *A fully protected, high-side MOSFET switch, the Si4750DY, implements a 12-V, 2-A unidirectional motor control circuit.*

Most motor-control designs consist of control intelligence, implemented with discrete components or an IC controller, and a MOSFET, which serves as the power-handling device. The challenge is to protect the MOSFET under fault conditions. This can be done using several discrete components or with an integrated solution, such as a protected high-side smart MOSFET switch.

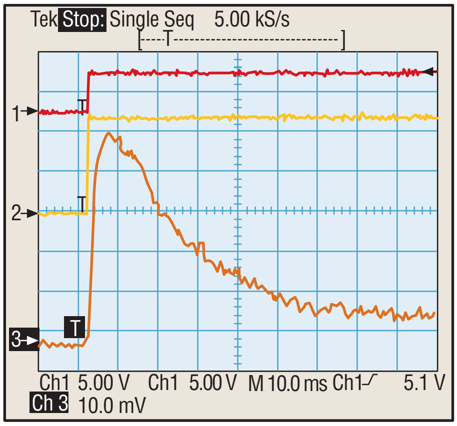

Fig. 2. *Measurements taken on the motor control circuit in Fig. 1 include V_{IN}, a 5-V logic level control signal (Ch1); V_{OUT}, a 12-V output signal measured at the motor terminal (Ch2); and I_L, the motor current (Ch3, 0.5 A/div). At startup, the motor draws a peak pulse of 5.25 A, which falls to a nominal current of 0.5 A.*

Fig. 1 shows a 12-V, 2-A unidirectional motor control using a fully protected, high-side MOSFET switch, the Si4750DY from Vishay Siliconix. Packaged in the SMT SO-8 package, this smart MOSFET combines a 50-mΩ power MOSFET with a controller IC. This device takes the logic-level signal and provides a high-side gate drive for the MOSFET, and also protects the MOSFET by removing the gate drive under fault conditions.

The Si4750DY is powered by a 12-Vdc-regulated supply (pins 2, 3 and 4 to +12 Vdc and pin 7 to ground). On-board capacitor filters (C1 and C2) ensure stable operation. For C1, a 100-µF aluminum electrolytic capacitor provides on-board charge to absorb minor fluctuations in

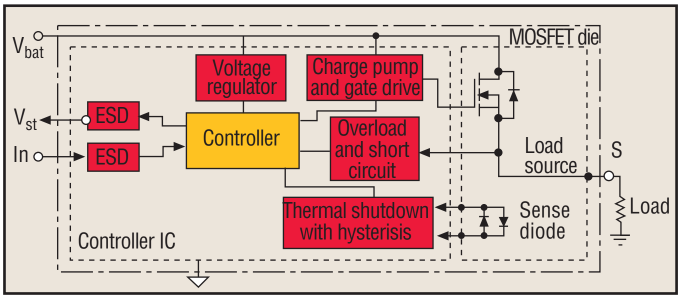

Fig. 3. *A functional block diagram of Si4750DY reveals MOSFET-protection features.*

the battery supply. For C2, a 0.1-µF ceramic capacitor filters any high-frequency noise present on the line.

A 5-Vdc Zener regulated logic-level supply (resistor R1 and Zener diode Z1) provides the drive signal and biases the status pin through an external pull-up resistor (R2). Setting resistor R1 to 1.2 kΩ provides a Zener current of 5.8 mA $\{(V_{bat}-V_{Zener})/R1 = (12\text{ V} - 5.1\text{ V})/1.2\text{ k}\Omega = 5.83\text{ mA}\}$, which is a little more than 5% of the 500-mW Zener capacity but adequate to stabilize the Zener operation. A 100-kΩ pull-up resistor for R2 connects the status pin 8 to the 5-V supply with negligible power loss.

The output of the device drives a load, which in this case is a dc motor. A dummy load (resistor R3 and capacitor C3) avoids a floating output condition. The value of resistor R3 is chosen to provide approximately 6% of the rated 2-A load ($R3 = V_{OUT}/120$ mA = 12 V/120 mA = 100Ω). The value of capacitor C3 at 1 µF is a typical capacitive load. The inductor (L1) has a special purpose and function during short-circuit mode that we'll discuss later. A jumper (JP1) between 5 V and the input pin 1 [IN] controls the circuit operation.

Circuit operation can be divided into two states: normal operation with the rated load of 2 A at 12 V, and heavy load/short-circuit operation.

In the first state, normal operation up to the rated load, a high logic-level signal on pin 1 of Si4750DY turns on the output and powers the motor, while a low logic-level signal on pin 1 of Si4750DY turns off the output and de-energizes the motor. Fig. 2 shows a typical wave form for V_{IN}, a 5-V logic level input; V_{OUT}, a 12-V output on the motor terminal; and I_L, the motor current.

In the second state, heavy load/short-circuit operation, the self-limiting current is set to 20 A. This mode of operation uses one or more protection features of the device to protect the MOSFET. Fig. 3 shows all of these in functional block diagram for the Si4750DY device.

In the case where the load is a filament lamp, the initial condition is a cold filament condition, which is classified as a "fault condition." However, these conditions are inevitable, especially in the automotive industry. The resistance of a filament lamp at power-on is very low and the current draw is almost like a short-circuit condition. Typical overcurrent protection circuitry instantaneously shuts down the power to protect the power device. As a result, the circuit is unable to start the lamp load.

The Si4750DY has a novel built-in feature to circumvent the problem of cold filament start-up for automotive lamp loads (Fig. 4). Here, the overcurrent tripping feature (set at the $I_{L(SCp)}$ level in Fig. 4) is disabled for first 400 µs (shown as $t_{off(SC)}$ in Fig. 4), but supervised by thermal shutdown. $I_{L(SCp)}$ represents the initial peak short circuit current, while $I_{L(SCr)}$ represents the repetitive short-circuit current limit. This limit is lower than initial peak due to increased operating junction temperature of the MOSFET. The latter leads to higher $R_{ds(on)}$ and in turn lowers the short-circuit current limit.

This MOSFET is turned off only when the junction temperature exceeds the 150°C rating. At power-on into the cold filament lamp, the current shoots up instantaneously, heating up the lamp filament. By the time thermal shutdown occurs, the filament is heated up enough and offers higher resistance at next cycle to ease the current draw and permit the full turn on of the lamp. This feature also helps the motor to start up under heavy load conditions.

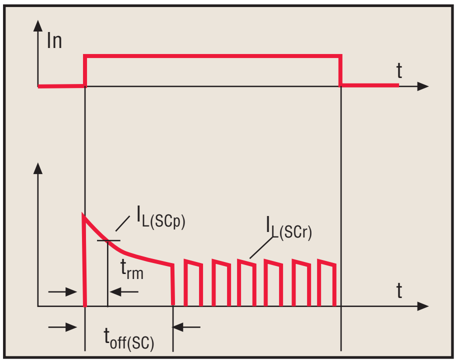

Fig. 4. *The Si4750DY controls turn-on into a cold filament lamp load, producing the load current waveform shown.*

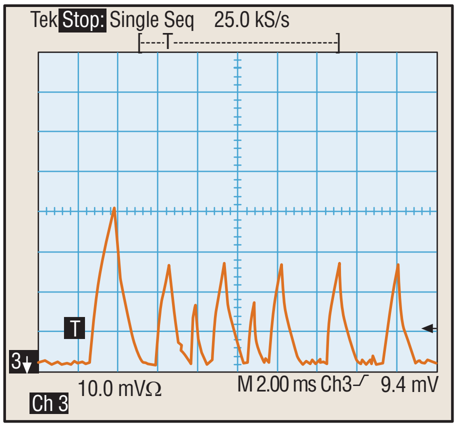

Fig. 5. *In overload, a 50-W motor is unable to start due to thermal shutdown even before current limit is reached. Load currents measured on Ch3 are shown on a 5-A/div scale.*

During motor startup under heavy load conditions, either over-current or thermal shutdown initiates the tripping. Which of these comes into play depends on the operating ambient and resulting junction temperature. Because the circuit operates in pulse-by-pulse tripping mode, it resets at a much faster rate at lower ambient temperatures.

In other words, the device on-period (torque buildup period) is longer than the device off-period (no torque period). In turn, this permits torque to build up and provides a higher starting torque. Hence, the motor has a better chance to overcome a heavy load condition and start run-

ning. Once it picks up speed, the current value drops to its nominal level and normal operation is established or restored.

At higher load levels, the MOSFET junction temperature may reach the trip value of 150°C (minimum), even before the current tripping, and cooling times are longer than at lower ambient temperatures. This can result in lower or inadequate starting torque and the motor may not start (Fig. 5).

Short-circuit conditions involve very fast rising currents, in which overcurrent trip occurs for the initial period. However, the fast repetition leads to a quick rise in junction temperature and thermal shutdown takes over. The latter results in reduced repetition due to a 12°C hysteresis temperature. The shutdown repetition rate thus varies, but the MOSFET and the rest of the device are protected from failure (Figs. 6 and 7).

Another crucial aspect of short-circuit protection is that a very high rate of rise of current di/dt can lead to thermal runaway in the MOSFET and result in the catastrophic failure of the device even before the controller initiates the turn-off. Invariably, this isn't evident in the actual assemblies, where the wiring harness impedance curtails the di/dt.

However, a screwdriver test (direct short circuiting) on the output of the actual device isn't a practical scenario. Therefore, a small 4.7-µH inductor (L1) is included to simulate the wiring impedance (Fig. 1). This keeps the di/dt rate at a reasonable value and enables the device control circuit to react in a timely manner.

A high-side fully protected MOSFET switch for low-power unidirectional dc motor control represents a low-cost solution with all the features required by the application, and one that accommodates a short design cycle. The system cost is optimized as all the control functions are integrated into the IC, which is an integral part of the MOSFET package. Another saving is derived from reduced component count and the corresponding reduction in board size.

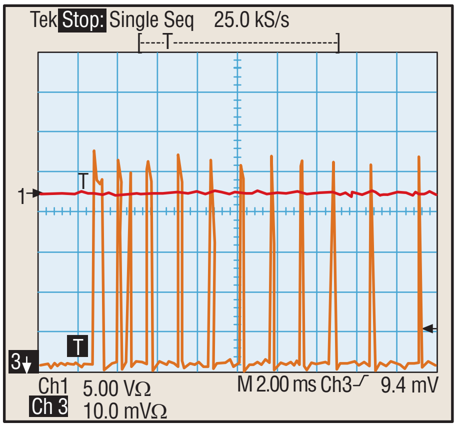

Fig. 6. *Pulse-by-pulse current limiting protects the Si4750's MOSFET under short-circuit conditions. Measurements of load current taken on Ch3 are shown at 5 A/div and reveal 20-A to 25-A peaks.*

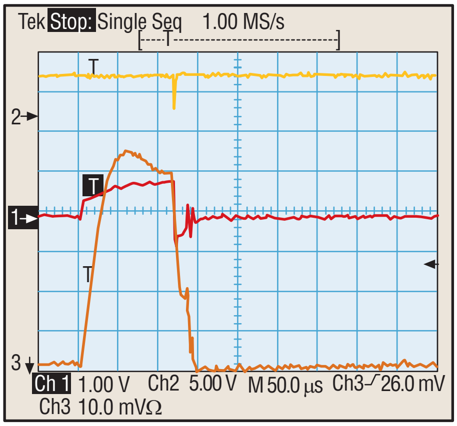

Fig. 7. *Expanded waveforms for the short-circuit condition show output voltage (Ch1) and load current (Ch3, 5 A/div) when the overcurrent protection trips.*

Elimination of almost all external components enhances reliability in the production and assembly processes. The control IC offers essential protection against adverse operating conditions such as overcurrent, short circuit, over/undervoltage and overtemperature. Design time is saved as well, because the controlled IC is predesigned, eliminating the need for this to be engineered and enabling a faster turnaround. **PETech**

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