TEXAS INSTRUMENTS

Linear Products

Automotive Solenoid and Lamp Control Using the TPIC2603

Today's automotive powertrains feature many types of loads which draw from a few hundred milliamperes of current up to 100 A. Most of these loads require fault diagnostics to meet regulations and to reduce repair time in the shop. The TPIC2603 is designed to switch up to six medium-current low-side loads and provide fault protection and diagnostics for each of its six channels. Among its fault protection attributes are a low duty cycle PWM mode to protect the output transistors during an over-current/short-to-battery fault, inductive voltage transient snubbing for over-voltage faults, open-load/short-to-ground protection, and global over-temperature sensing. The device also provides a serial interface to minimize interconnects to the system controller for reduced costs.

A typical automotive engine control unit (ECU) is shown in Figure 1. The ECU has inputs such as a coolant temperature sensor and a manifold absolute pressure (MAP) sensor. The coolant temperature sensor provides warning against overheating of the automobile. The MAP sensor monitors the air and fuel mixture in the engine to meet emission requirements. The ECU outputs control various loads which include solenoids, valves, lamps, relays, and ignition.

As shown in Figure 1, the TPIC2603 can be used to switch the ECU control outputs. In addition, it is well-suited to switch other loads such as door chimes, interior lighting, fuel pump pressure for the fuel injectors, and other emissions-related loads.

SYSTEM BENEFITS

- ▼ On-board diagnostics to identify load problems for improved fault isolation
- ▼ Serial interface to minimize interconnects to system controller for reduced costs
- ▼ Integrated solution in surface mount packaging for decreased printed board space and increased system reliability over discrete implementations

The TPIC2603 performs three basic functions: receiving and transferring serial input control data, identifying and reporting data errors, and

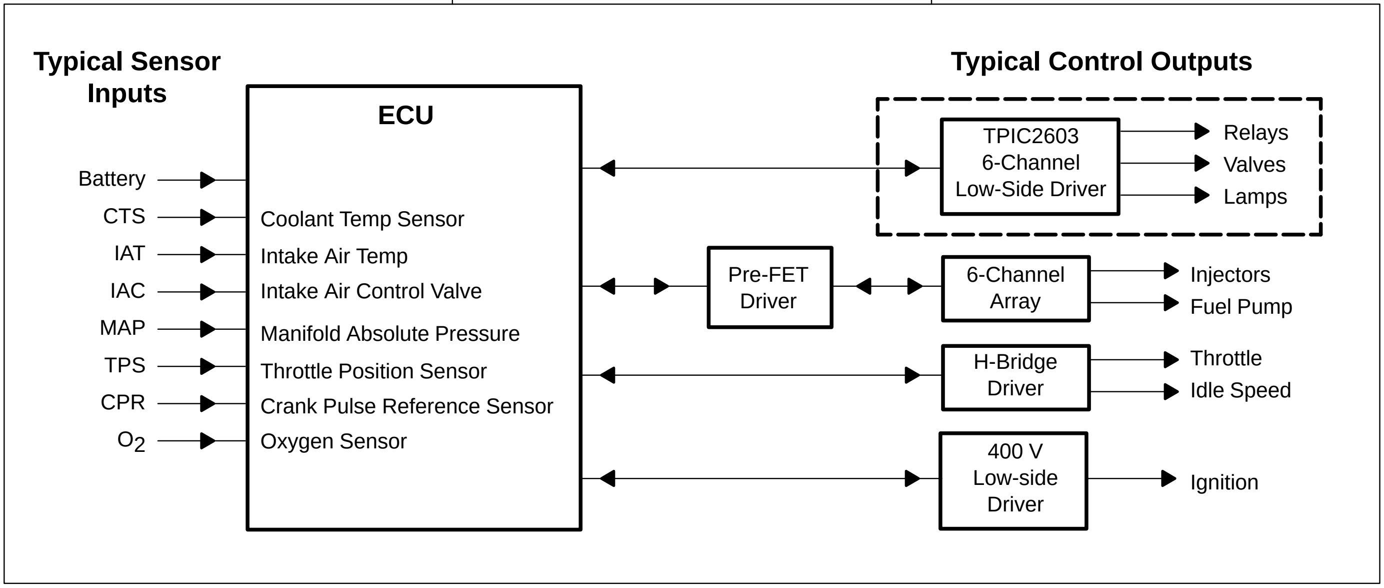


Figure 1. ECU Block Diagram

Application Brief

switching up to six loads. An example of how the device can be configured in a typical ECU system is shown in Figure 2.

Serial Data Transfer

The serial interface consists of a serial clock (SCLK), chip select ($\overline{\mathrm{CS}}$), serial data input (SDI), and a serial data output (SDO). Data transfer is initiated when $\overline{\mathrm{CS}}$ transitions from high to low. The device can shift either an 8 or 16-bit string of data. The first two bits of input data are unused and should be set to zero. The last six bits provide control information for the outputs. In a 16-bit configuration, the first 10 bits of data should be set to zero as input data is being transferred into the device. As each of the consecutive eight rising edges of the SCLK occurs, the state of the SDI pin will be clocked into the device. Simultaneously at each rising clock, the SDI and the corresponding bit of the fault register are exclusive OR'ed and output on the SDO pin.

During normal operation, the status of the SDO is the same as the SDI after the rising edge of each SCLK. After the eighth SCLK and before the next rising edge, the $\overline{\mathrm{CS}}$ must be taken high. The rising edge of $\overline{\mathrm{CS}}$ transfers the six least significant bits (LSB) of input data to the output drivers, terminates serial communication, and loads the new fault data. Each output driver is then turned ON with a logic high and OFF with a logic low, respectively.

An example of normal serial data transfer is illustrated in Figure 3. When $\overline{\mathrm{CS}}$ (trace 1) is low, it determines which eight clocks of SCLK (trace 3) will transfer the SDI (trace 2) to the SDO (trace 4). The serial interface will typically operate at 4 MHz. However, for this example, the SCLK has been reduced to 1 kHz.

Fault Conditions

As mentioned previously, the TPIC2603 provides on-board diagnostics to identify load problems for improved fault isolation. The four types of fault that can be detected are over-current/short-to-battery, open-load/short-to-ground, over voltage, and global over temperature.

Over-Current/Short-to-Battery Sensing and Protection

If the load is shorted to the battery when an output transistor has been turned on, an over-current condition will occur. When the current limit is reached, the current will be limited at the rated value until the end of the short-circuit sense time. If the short circuit has not been corrected by the time the short-circuit sense time period has passed, the output will transition into a low duty cycle PWM mode. Once the short has been removed, normal operation will resume.

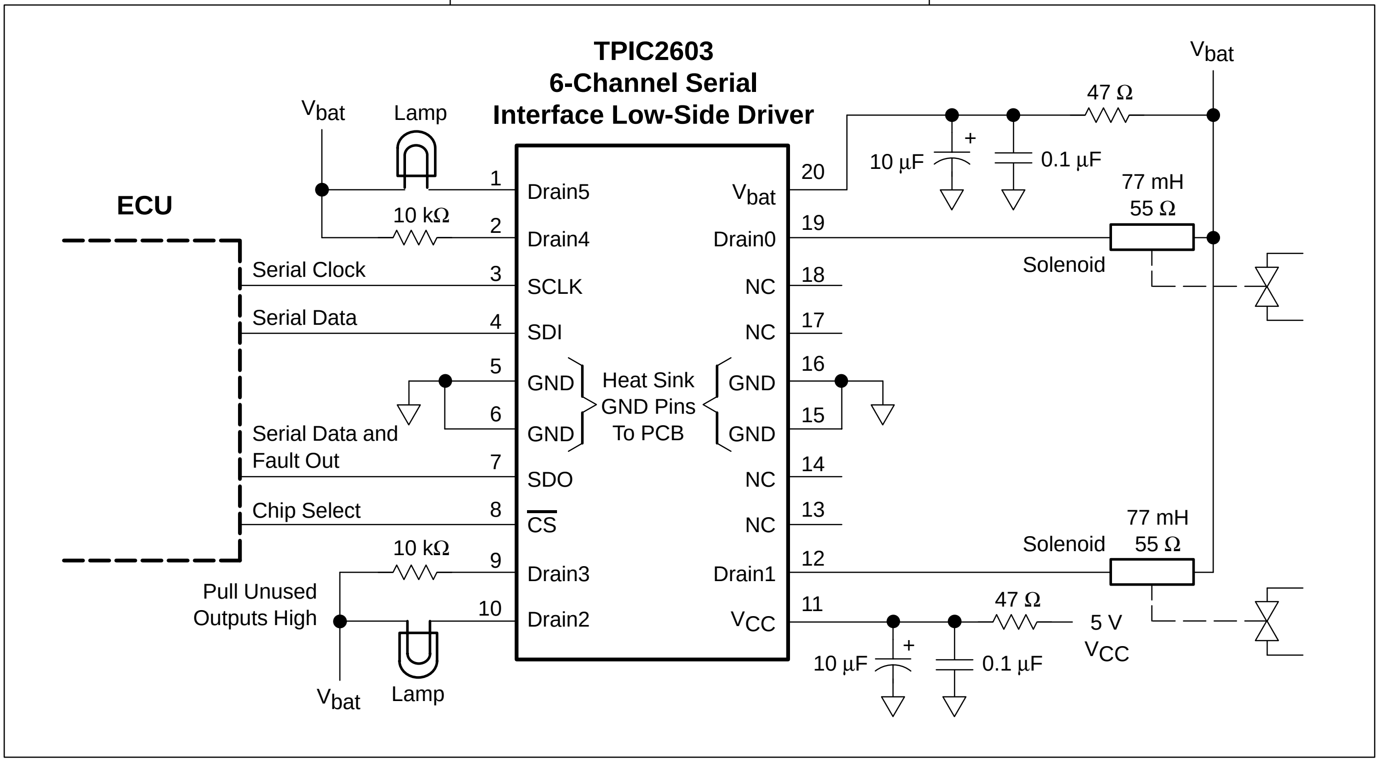


Figure 2. Circuit Schematic of the TPIC2603 Integrated Driver

Figure 4 displays serial data transfer with a short-to-battery fault. In this example, the output of drain 5 (D5) was intentionally shorted to show that the SDO has been inverted in the D5 position. It must be noted that the fault data is locked into the fault register at the beginning of serial transfer. Therefore, the fault information represents the condition prior to the data being loaded. In this example, a fault was indicated because D5 was shorted in the previous data transfer.

Open-Load/Short-to-Ground Sensing

The open-load test is performed when the output transistor is turned off. A 40 µA current source is applied to the drain to pull the output low. If the output is open, the current source will be sufficient to pull the output below the threshold of the open-load reference voltage. An internal deglitch time is provided to allow the output to stabilize before fault reporting is enabled. As shown in Figure 2, unused drain outputs have pull-up resistance to prevent false open-load faults from being reported.

Over-Voltage Sensing and Protection

When the battery voltage exceeds the over-voltage shutdown threshold, all output channels will be disabled. The serial interface will continue to transfer data, but new control data will not become effective until the battery voltage has returned to the normal operating range. The outputs will then be re-enabled and the fault bit reset. The advantage of over voltage shutdown is to protect the output and the load from damage resulting from excess current and thermal stress.

Global Over-Temperature Sensing

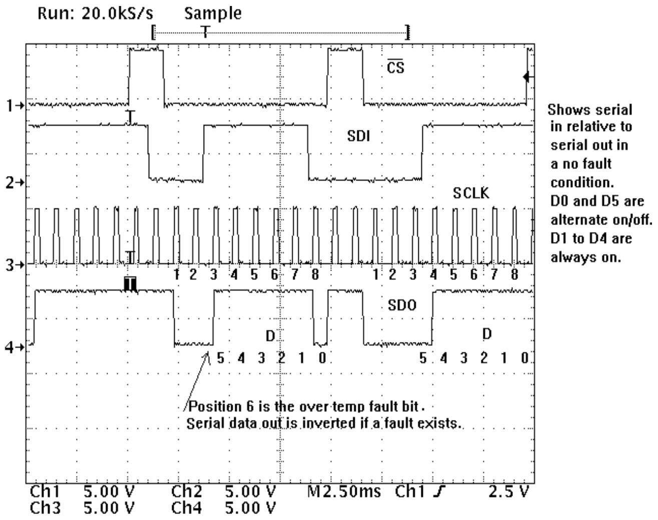
When the temperature of any output exceeds the over-temperature threshold, a global temperature fault will be reported in the serial fault data. This fault is for information purposes and does not affect the state of the output transistors. The over-temperature fault bit will reset after the temperature returns to normal.

Driving an Inductive Load

A key design consideration when switching inductive loads is the ability to minimize the effect of transients that are often a source of damaging voltage spikes. Figure 2 shows the addition of decoupling circuitry at the power inputs to isolate the IC from voltage transients from the battery. Figure 2 also shows solenoid controlled valves connected to drains 0 and 1. The voltage and current responses for driving these inductive loads can be seen in Figure 5.

The $\overline{CS}$ waveform (trace 1) indicates the data transfer turning the solenoid on then off. Trace 2 shows the drain voltage going low when the transistor is on and then the inductive transient as the transistor turns off. The internal circuitry of the TPIC2603 senses the drain voltage and turns the output transistor back on when the drain voltage reaches a snubbing value of approximately 65 V. The output transistor will temporarily turn on to dissipate the energy stored in the inductor, preventing the transient from exceeding the maximum drain-to-source breakdown voltage.

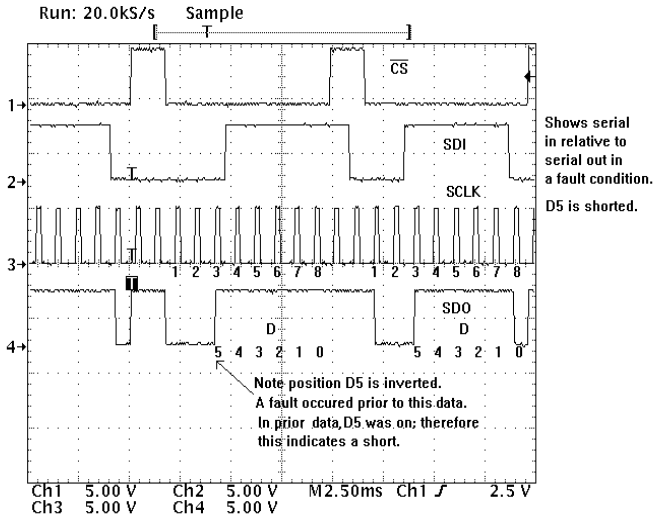
A significant benefit of this internal circuitry is that the transistor life is



Shows serial in relative to serial out in a no fault condition. D0 and D5 are alternate on/off. D1 to D4 are always on.

Position 6 is the over temp fault bit. Serial data out is inverted if a fault exists.

Figure 3. Serial Data Transfer



Shows serial in relative to serial out in a fault condition.

D5 is shorted.

Note position D5 is inverted. A fault occured prior to this data. In prior data, D5 was on; therefore this indicates a short.

Note that SDI shown in Figure 4 repeats every two cycles of $\overline{CS}$.

Figure 4. Serial Data Transfer With Fault

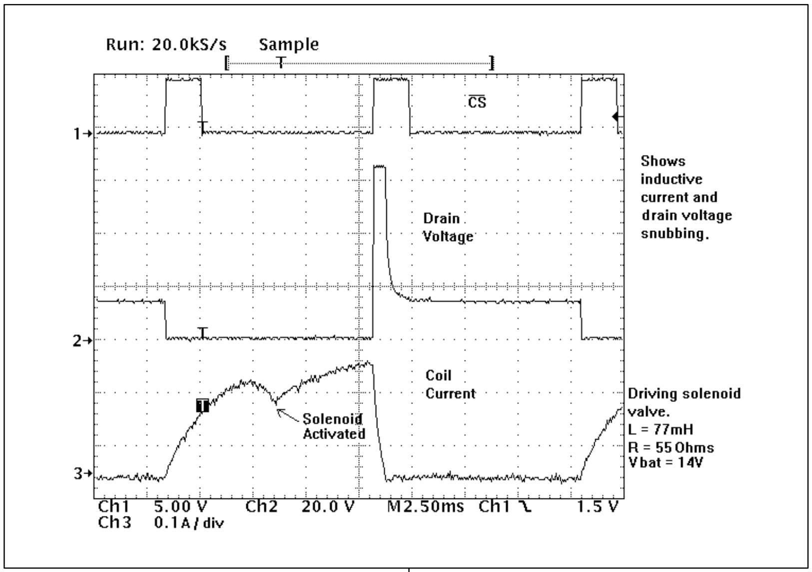


Figure 5. Inductive Load

extended and the number of external snubbing components is reduced, saving both board space and cost. Trace 3 shows the current rising at a rate determined by the L/R time-constant of the solenoid and the battery voltage rising to a value determined by the solenoid resistance.

Driving Lamps

Another key design consideration is the device's ability to handle unsafe current levels. A lamp load is unique in that when the filament is cold the resistance is very low and at the instant of turn on the initial inrush current can be eight or ten times the steady state value. TPIC2603 is well-suited for this application because of it's internal over-current sense circuitry and low duty cycle PWM mode.

Figure 2 shows lamps connected to drains 2 and 5. The voltage and current responses to drive this particular load can be seen in Figure 6. The $\overline{\text{CS}}$ waveform (trace 1) transitioning high transfers the serial data to the outputs, in this case, turning on a lamp. The drain voltage is trace 2 and the drain or lamp current is trace 3. Note that at the instant the lamp turns on, the current rises to 2 A, ten times the 200 mA the lamp will draw when the filament is hot (steady state on). The narrow pulses are the result of the TPIC2603's PWM mode allowing the filament to warm up while keeping the power dissipation of the output transistor within the operating range.

During the time the IC is in the PWM mode, the associated fault status bit will indicate a short. After the inrush, the output will return to a steady on state and the fault will no longer be indicated.

The over-current and PWM mode of the TPIC2603 provide soft-start for the lamps to protect the output transistors and to extend the life of the lamps. Also, since this protection is performed by the device's internal circuitry, the need for external components is reduced saving both board space and cost.

Thermal and Power Considerations

The TPIC2603 has demonstrated its effectiveness in serial data transfer and driving various types of loads. The thermal and power considerations are also of interest. The device is available in thermally enhanced dual-in-line and surface-mount packages to reduce thermal resistance when mounted to a copper-clad circuit board (see Figure 7). The surface-mount package offers decreased printed board space requirements. This package can have a thermal resistance ($R_{\theta JA}$) as low as 35°C/W when properly mounted (see Figure 8). The maximum power dissipation for the device in this example is determined as follows:

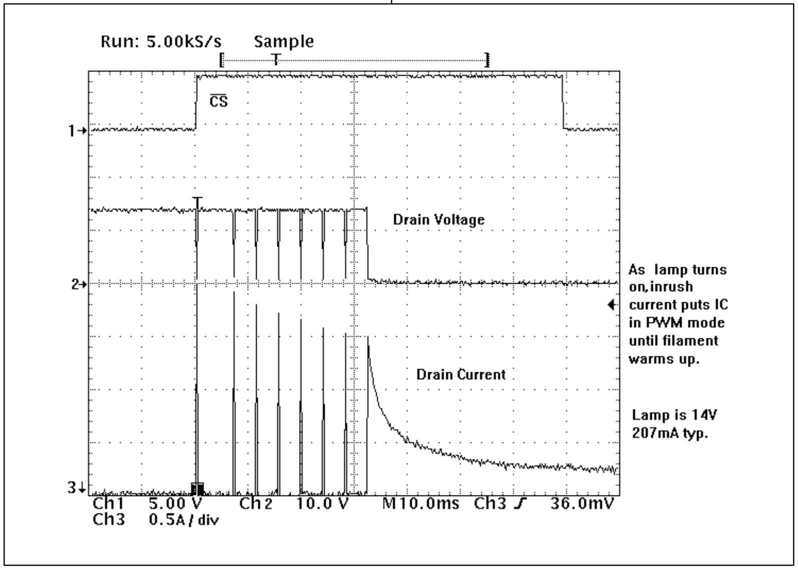


Figure 6. Lamp Load

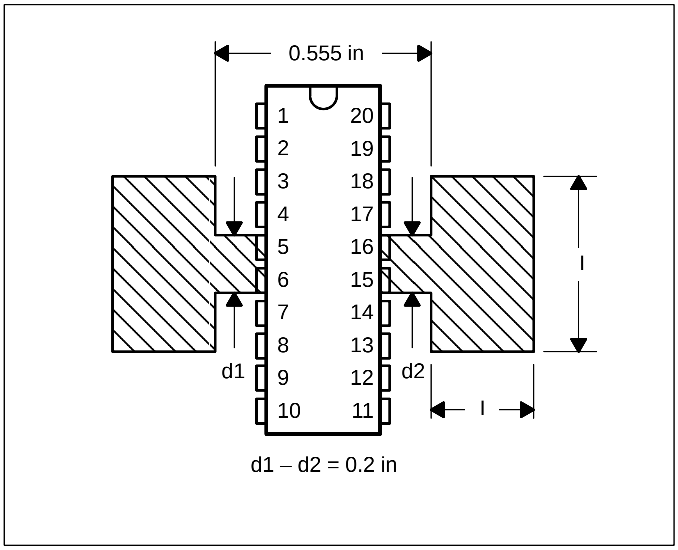


Figure 7. Copper PC Board Used as a Heat Sink

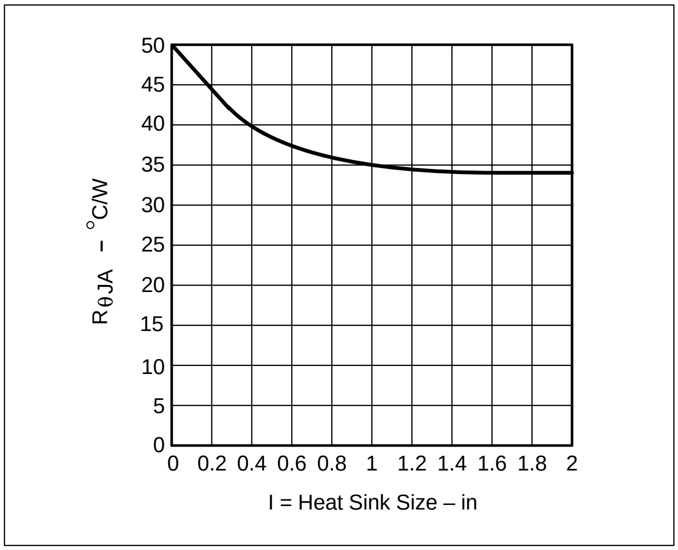


Figure 8. Junction-to-Ambient Thermal Resistance vs Heat Sink Size

Assume a maximum ambient operating temperature (T_A) of 125°C. Then with a maximum junction temperature (T_J) of 150°C;

Equation 1: $(T_J - T_A)/R_{\theta JA} = P_D$

Solution 1: $(150 - 125)/35 = 0.714$ W, for the device.

Then assuming all outputs are used with equal loads, the total power dissipation is divided by the number of outputs, six in this case, to determine the maximum power dissipation for each output.

Equation 2: $P_D/n = P_m$

Solution 2: 0.714 W/6 = 119 mW, per output.

Refer to Table 1 for other key specifications of the TPIC2603.

Conclusions

The TPIC2603 is an integrated low-side driver combining both power and logic into a single package. In addition, the device features on-board fault diagnostics to reduce down-time and increase system reliability. The thermally enhanced package increases the power capability of the device and provides more flexibility for design engineers to incorporate the TPIC2603 into their system solutions.

Table 1. TPIC2603 Key Specifications

PARAMETERS	MIN	TYP	MAX	UNITS
V_{bat}	5.5		25	V
V_{CC}	4.5		5.5	V
I_{CC}			5	mA
$r_{DS(on)}$		0.7	1	Ω
I_{drain}		0.35	2.25	A
Vbreakdown	52	58	68	V
Frequency	1.8	4		MHz
Over-Voltage Shutdown	30		38	V
Thermal Flag	150	170	185	°C

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