Implementing Reliable, Efficient and Compact Control Solutions for Automotive Motors

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The role of electric motors in vehicles is increasing - more and more functions are moving from mechanical technology to electronic, bringing greater efficiency and reliability as well as more advanced automation. Many of today's vehicles now use small motors extensively to automate simple functions such as locks or mirror alignment and parking.

Designers of these systems face the same challenges as anyone designing for automotive applications – reliability, safety, size, efficiency, and Bill-Of-Material (BOM). These are all key – and sometimes competing – requirements.

Introduction

According to a recent report by research firm IHS, around 3 billion electric motors will be shipped into automotive applications this year. The vast majority will be DC brushed motors (~70%) while DC brushless and stepper motors account for the remaining 30% in equal proportions. IHS forecasts that brushless motors will grow faster than any other motor type in the automotive sector.

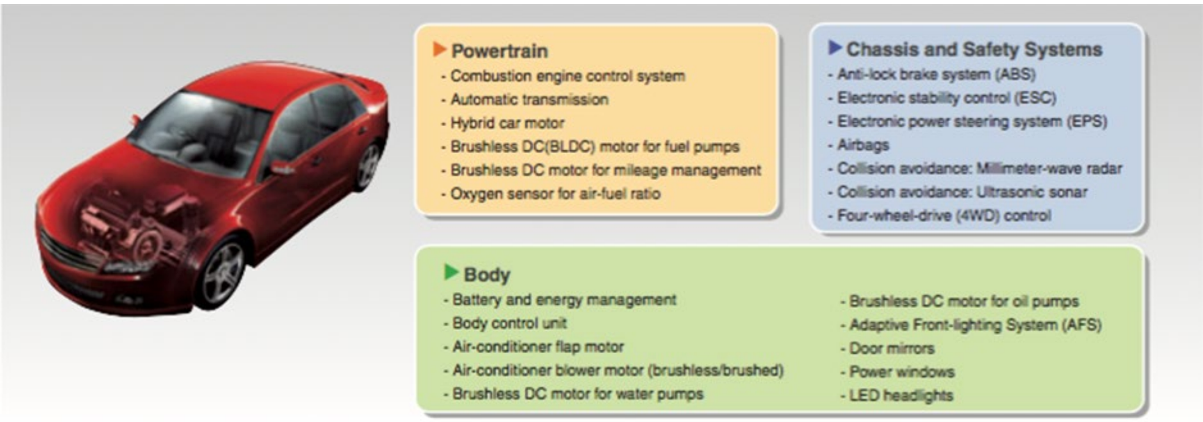

Figure 1: Electronics, including motors, are used in an ever-increasing number of automotive applications

With these high volumes of shipments, it is not surprising to see that motors are being used in a wide variety of applications. The largest motors are the main drive for Hybrid Electric Vehicles (HEV) while under the hood in conventional vehicles electric motors drive the main cooling fan and smaller motors provide electronic throttle control (ETC) and exhaust gas recirculation (EGR). BLDC motors are widely used in fuel pumps, whereas increasingly mechanical pumps for oil and water are being replaced with electric pumps. Or replaced completely in the case of Electric Power Steering (EPS) systems.

Inside the cabin, the use of motors is proliferating rapidly and in modern vehicles electric motors are used to drive and control the heat ventilation air conditioning (HVAC) system, operate door-locking mechanisms, move seats and mirrors into place and operate windows and the sunroof.

In general, under the hood motors are being deployed to bring greater reliability, efficiency and control whereas inside the cabin the focus is on greater automation and driver convenience. In all cases, the electric motors bring greater flexibility and convenience than the mechanical technologies that they replace.

With and Without Brushes

Although, in many ways, brushed and brushless motors are close cousins, there are a number of notable differences that determine the best application area for each type of motor. A brushed motor has its winding on the rotor and a permanent magnet on the stator and does not always require a motor controller. The windings and magnets are reversed in a brushless motor and an electronic control is required. Brushless motors have higher speed, torque, efficiency and life expectancy – mainly due to the lack of mechanical limitations imposed by the brushes and commutator.

As commutation occurs mechanically within the motors themselves, brushed DC motors can be driven in one direction by a simple MOSFET switch with pulse-width modulation (PWM) using either a high side or low side driver. Using a classic H-bridge configuration it is possible to control a brushed motor bidirectionally as well as to provide forced braking of the motor, if desired.

With brushless DC motors commutation needs to be created externally through a BLDC motor driver IC and a power stage consisting of three half bridges which, when correctly controlled, create a rotating magnetic field within the motor. By varying the current flow through the coils in the motor, normally via PWM, both torque and speed can be controlled.

Brushed motors are used across the whole gamut of automotive applications. The smaller, lighter and more efficient brushless motors tend to find their main applications in pumps and cooling fans – the 'always on' applications where the greater reliability and efficiency brings more benefit. As well as in applications where precise speed and torque control is required, as is necessary for EPS systems.

Design Considerations for Automotive applications

Electric motors are used in automotive applications for one of two primary reasons. Either to replace a mechanically driven solution for greater reliability, reduced size/weight, and improved efficiency – this is particularly applicable to oil, water and fuel pumps – or for convenience to automate previously manual tasks, such as operating door mirrors or windows.

Although the considerations above apply to the motors themselves, by definition they also apply to the associated drive circuitry as to all intents and purposes they act as one. In order to achieve these objectives, increasingly fully integrated and sophisticated driver devices are being used which allow greater functionality to be included in the driver circuit.

Typically today's modern brushed motor drivers will include the fundamental H-bridge or high / low side driver circuitry required to drive the MOSFET stages – some even include a power stage to allow direct drive of small motors without the need for external MOSFETs. By including the power stage inside the driver itself it is much easier to mount the driver and motor as one unit in space-critical applications. Brushed motor drivers will also include a number of safety functions including over temperature, high / low voltage or short circuit detection.

Drivers for brushless DC motors offer the sophistication needed to drive these modern motors, whether with inbuilt sensors or the more popular sensorless types. The most basic types will rely on an external microcontroller to provide the PWM drive with the correct phasing, whereas more sophisticated types receive either a DC voltage or single-phase PWM signal to indicate desired motor speed and generate the low-level phasing required to control the motor. These drivers will also include safety functions such as over current, over voltage and over temperature protection.

As vehicles become more reliant on electronics, it is important not only that devices are qualified to automotive requirements but that the whole design philosophy is concerned with design for safety from the very start – especially those for use in safety critical applications such as power steering.

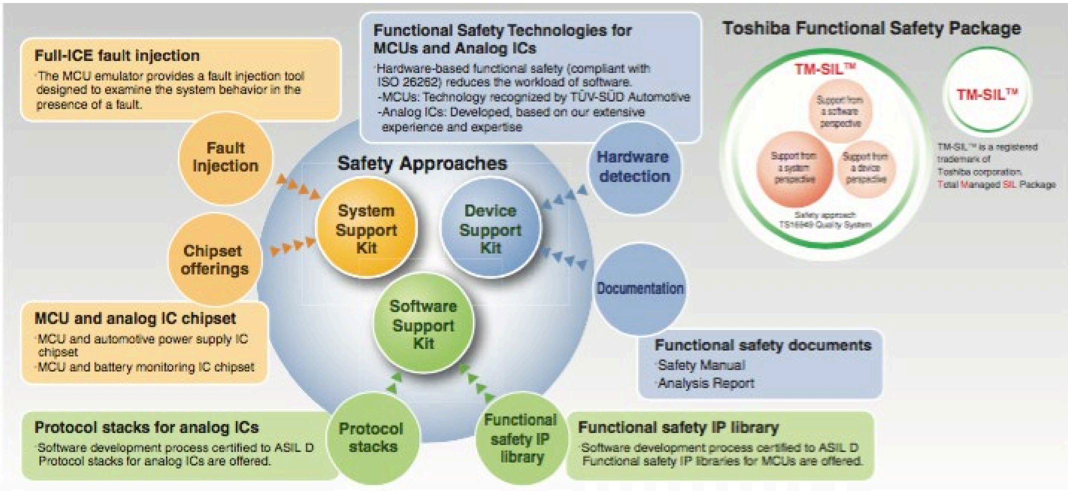

Figure 2: Key suppliers such as Toshiba have ASIL-D programs at the heart of their design philosophy.

A Modern H-bridge Controller – and the Future

One example of a modern single channel H-bridge controller for brushed motors is Toshiba's TB9051FTG driver. The device is based upon Toshiba's advanced BiCD 0.13um mixed signal process that allows logic and high-voltage circuitry to be fabricated on a single IC. The extremely high gate density (~200,000 gates/mm2) supports significantly greater logic capability on-board and means that control functionality can be offloaded from the host microcontroller, resulting in simpler software and circuit design – and a single chip solution to motor control.

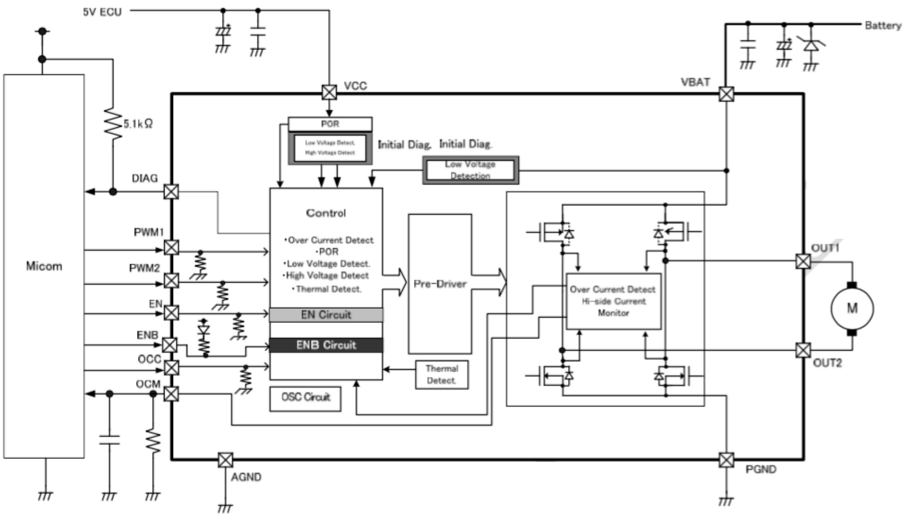

Figure 3: Block diagram overview of the highly integrated TB9051FTG brushed motor driver.

Housed in a small (6mm x 6mm) P-QFN28 package and able to operate in ambient temperatures as high as 125°C, the device includes an H-bridge output stage capable of driving up to 5A and offers high efficiency with a low on-resistance (Ron) of 450mΩ. The fully integrated driver includes protection for over temperature and high / low voltage as well as various other self-diagnostic mechanisms. The on-board PWM operates from 1kHz to 20kHz to provide wide-ranging speed and torque control of motors. The device operates from a simple, ECU-derived, 5V supply for all major functions and the power stage can accept DC voltages up to 28V directly.

Controlling a motor using the TB9051FTG is simplicity itself. There are a pair of enable pins (EN & ENB) that need to be held respectively high and low. Directional control and braking is facilitated by the PWM pins – if they are opposite polarity then the motor is being driven and when they are both high or both low, then braking is applied.

	PWM1	PWM2	EN	ENB	DIAG pin	OUT1	OUT2
Forward	H	L	H	L	H	H	L
Brake	L	L	H	L	H	L	L
Reverse	L	H	H	L	H	L	H
Brake	H	H	H	L	H	L	L

Figure 4: The TB9051FTG requires very simple control inputs for sophisticated motor control.

One of the key features of the TB9051FTG is its comprehensive suite of protection features. The device is suitable for, and used in, a wide variety of applications including throttle valve control, pumps, cooling fans, seat positioning, door mirrors and many more. While the failure of a cooling fan would not have immediate consequences, unexpected movement of a throttle valve or driver's seat position could have immediate and catastrophic effects.

Key to the failure detection and signalling at the heart of the TB9051FTG is the DIAG pin. Essentially, this combines all of the in-built protection functions into a single, latching, output that signifies the ability of the motor to run. It is an open collector active-low function that requires a simple pull-up resistor to provide logic-level information to the rest of the system.

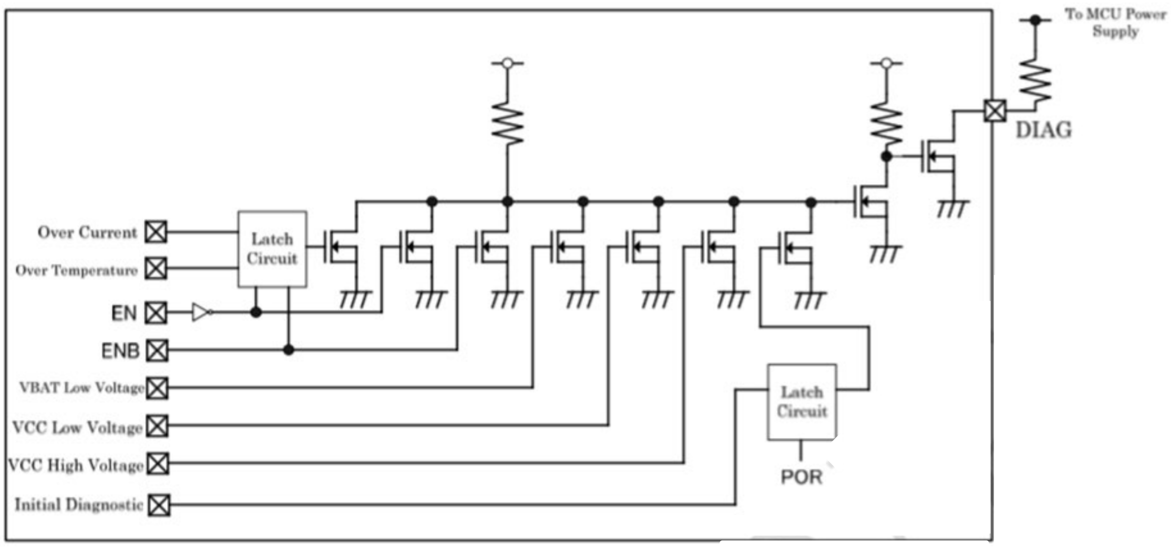

Figure 5: The DIAG pin provides a summary of all conditions that stop the motor from running.

Within the DIAG function over temperature and over current are latching and can be cleared by the ENABLE inputs. A problem with the motor supply voltage (VBAT) being too low or the IC supply voltage being out of specification would also cause DIAG to be activated. These functions are non-latching and as soon as the voltage returns to specification, the DIAG pin is released. Irrespective of the PWM control inputs or the ENABLE inputs, if there is a fault condition the TB9051FTG drives the motor control outputs to a high-impedance state thus disabling the motor drive.

	PWM1	PWM2	EN	ENB	DIAG pin	OUT1	OUT2
Over-temperature detection (Notes)	Even if however different an input signal will be, output is established in the off state.				L	Z	Z
Over-current detection (Notes)					L	Z	Z
VBAT Low voltage detection					L	Z	Z
VCC Low voltage detection					L	Z	Z
VCC high voltage detection					L	Z	Z

Figure 6: Irrespective of the control inputs, the TB9051FTG disables the motor drive during a fault condition.

If there is an issue with the initial diagnostic check, this would also cause the DIAG pin to latch. This could indicate a potentially serious issue and can only be reset by a power on reset.

The DIAG functionality also allows for system failures such as high impedance on the ENABLE pins that could indicate a broken control wire. In other systems, this could lead to uncontrolled motor operation but the TB9051FTG detects this state and enters an active-low condition.

In order to ensure safe operation, the TB9051FTG performs an initial diagnostic function that checks for correct levels on the VBAT and VCC supplies – as well as detecting faults, this also ensures that the power supply voltages have risen and are stable before the DIAG output is released, allowing the motor to run. During the short (80us) test, the motor drive outputs are in a high-impedance state – preventing motor operation.

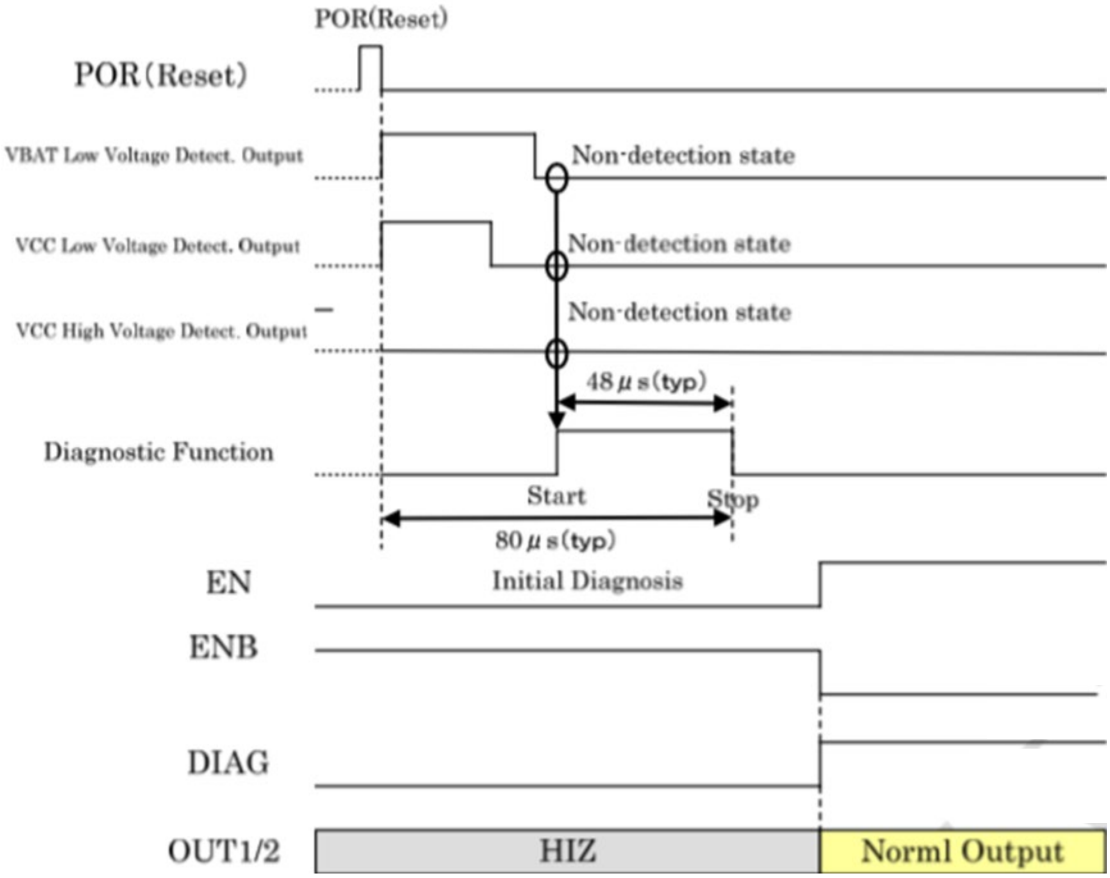

Figure 7: The power-on test holds the motor drive in a high impedance state while supply voltages are checked

The power-on test is initiated by a pulse on the power-on reset line. A similar test can be initiated during a restart at any time by pulsing either of the ENABLE pins into their non-active state.

A common issue with many drive circuits giving rise to the potential for destructive failure is the potential for both the high-side and low-side drivers to be 'on' at the same time. In this condition the MOSFETs provide a low-impedance path directly between the supply and ground allowing destructive 'through currents' to flow. Guarding against this condition normally requires designers to implement some sophisticated timing circuitry around the MOSFET drivers.

With the TB9051FTG, the IC itself addresses this situation by introducing a 4ms 'dead time' delay during transitions between when the motor is being driven and entering a braking mode.

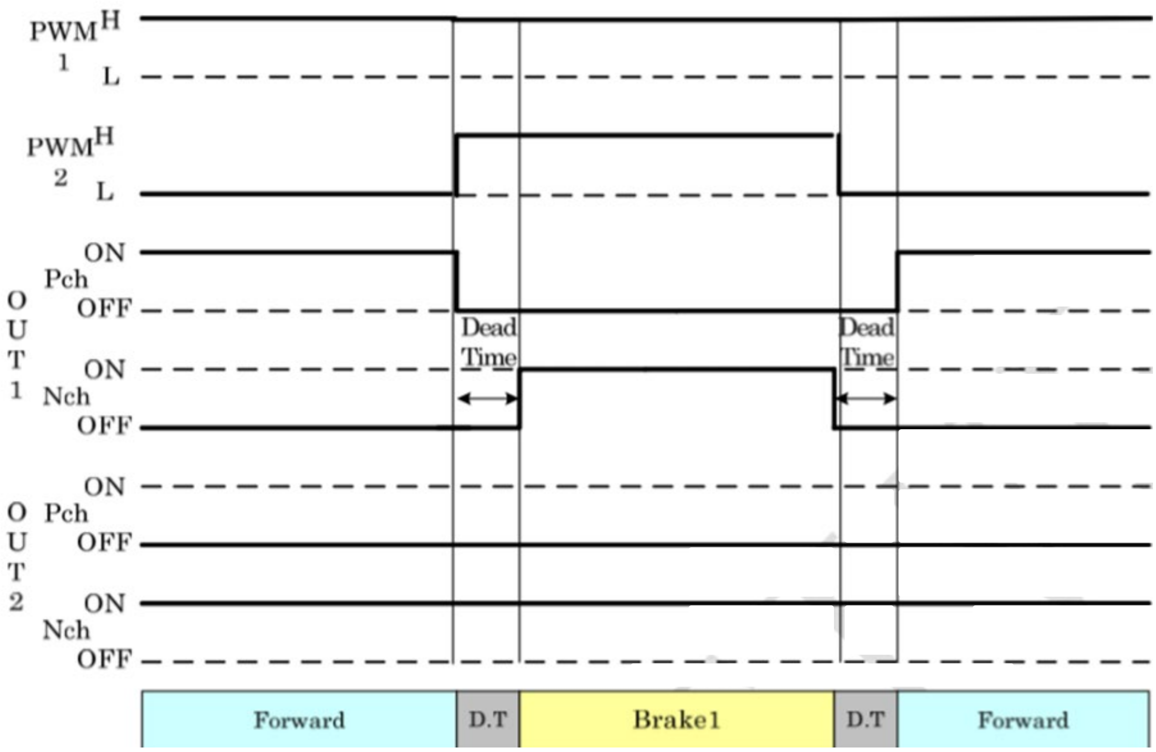

Figure 8: The TB9051FTG introduces a 4ms dead time during changes in motor operation

Summary

In common with all of Toshiba’s motor drivers, the TB9051FTG driver is available on an evaluation board that includes all necessary components and interfaces for quickly and reliably developing and debugging a sophisticated motor control design for an automotive application.

Toshiba continues to innovate its product line and, looking to the future, expects to see a number of developments including higher power on-board drivers supporting > 5A as well as multi-channel devices.

Contact us to discuss incorporating our products and solutions into your design:
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