Driving Improvements in Motor Control Design

Electrically actuated automotive systems offer greater convenience for users, as well as enabling car makers to reduce the size, weight and cost of the equipment fitted to modern vehicles. Cars today use numerous electric motors in areas such as HVAC, seat and mirror adjusters, headlamp positioning mechanisms, various washer pumps, and larger systems such as electric power steering. New driver and power stage technologies for automotive BLDC motors can enhance performance, shorten time to market, and reduce costs for vehicle comfort and convenience features. **Dr Georges Tchouangue and Wolf Jetschin, Power Semiconductors Division, Toshiba Electronics Europe**

Electrically actuated automotive systems offer greater convenience for users, as well as enabling car makers to reduce the size, weight and cost of the equipment fitted to modern vehicles. Cars today use numerous electric motors in areas such as HVAC (heating, ventilation and air conditioning), seat and mirror adjusters, headlamp positioning mechanisms, various washer pumps, and larger systems such as electric power steering.

In most instances, a brushless DC (BLDC) motor is preferred for its high reliability, low friction, small size and relatively low cost. However, drives and controls for BLDCs are more complex than for conventional brushed motors. As a result, they have always challenged system designers to achieve attributes such as accurate speed or position control, high efficiency with low heat generation, and low audible noise. Moreover, in many cases such challenges must be delivered within a short development timeframe and at a highly competitive price.

Figure 1: Driver IC and Power MOSFET solution for automotive applications

Motor control challenges

Key challenges when building BLDC applications lie in designing the control electronics, as well as minimising losses in the power bridge delivering current to the motor windings.

Designing and programming a sensorless BLDC controller requires specialist expertise and can be time-consuming and expensive in terms of both circuit implementation and software development. Because of this, using an application-optimised controller IC that integrates much of the key functionality in hardware is often preferable, and is a solution that is increasingly employed in many industrial and home appliance applications. However, devices that deliver the requisite functionality in the automotive arena and that are also qualified to the required automotive standards have, conventionally, been much more difficult to identify.

It is for this reason that Toshiba is investing in the development of controller/pre-driver ICs and power MOSFETs (Figure 1) that are optimised to driving the power stage of an automotive motor application, while also meeting the stringent requirements of the AEC-Q100 and TS16949 standards. Such devices will make the implementation of BLDC motors much more commercially viable in the cost-sensitive automotive arena.

Automotive qualified driver ICs

A family of these dedicated automotive ICs is due to be launched in the second quarter of 2010. Among the devices planned, the TB9061FNG will be suitable for applications such as driving fans and pumps, where fast load regulation or minutely controlled rotor angles are not required.

Figure 2 shows a block diagram of the planned device, which will be supplied in a 24pin SSOP package and capable of operating with temperatures from -40 to 125ºC.

Billed as a three-phase sensorless/ brushless motor pre-driver, this IC will accept both PWM and DC control inputs and will incorporate six pre-driver (P channel/N Channel MOS) outputs for three-phase motor control.

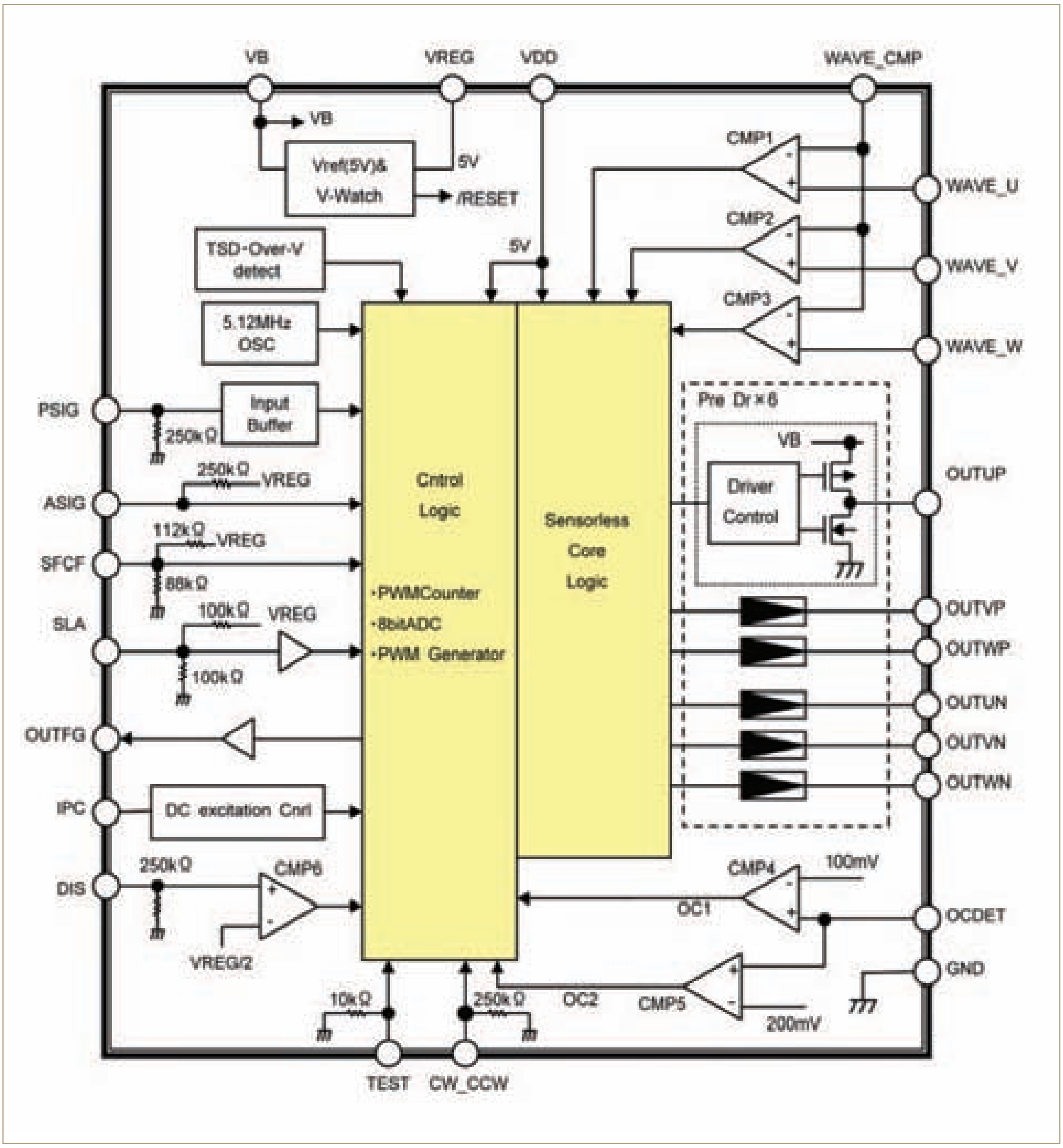

Figure 2: **BLDC Driver TB9061FNG block diagram**

The design significantly reduces the need for additional software programming by implementing sensorless core logic for motor control in hardware alongside control logic that includes a PWM counter, an 8bit ADC and a PWM generator. Input PWM frequencies ranging from 10Hz to 1kHz can be accommodated with valid duty cycles from approximately 5% to 95%. The input PWM signal is measured and calculated in the on-board logic circuit. The IC then generates a corresponding 20kHz PWM three-phase signal at the outputs.

Motor direction can be controlled clockwise and anti-clockwise using a single external pin, while built-in three-channel comparators minimise the need for additional components for the detection of the motor's induced voltage. Furthermore, built-in stall mode detection and automatic recovery control ensure robust and reliable operation, as do other safety mechanisms including over-current detection and over-voltage detection. The over-current detector can be triggered by two different current conditions (limited and over-current).

Power semiconductors

Of course, the driver is only one part of the total motor drive solution. It is also important to implement an optimised power stage, and it is here that the latest advances in power MOSFET technology can make things easier for the automotive designer.

MOSFETs used in automotive motor control designs are typically required to be small in size yet capable of handling high currents and many thousands of power cycles. At the same time, they must exhibit high reliability in the often harsh automotive environment and meet the AECQ101 and TS16949 standards requirements.

The key to developing MOSFETs that are small, reliable and able to handle high currents and many thousands of power cycles lies in low loss device design at both the silicon and the packaging level. Indeed, low-loss device design is

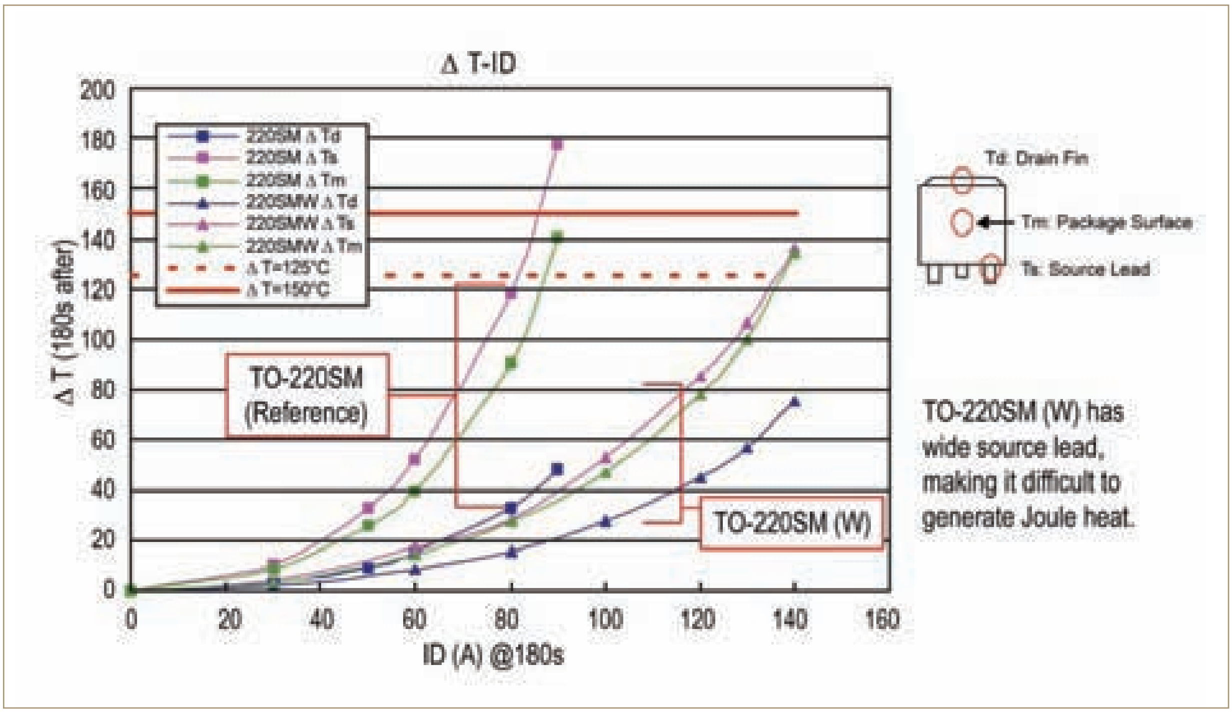

Figure 3: MOSFET temperature comparisons

imperative to maximising reliability by minimising the heating effects of continuous and pulse currents to which the device may be exposed. Because of this, reducing on resistance ($R_{DS(ON)}$) and other factors influencing the creation of I^2R losses is clearly important. However, at the same time, switching performance demands consideration of factors such as gate charge (Q_g) and input capacitance (C_{iss}).

As far as package design is concerned, optimising the characteristics of the device leads and internal ohmic connections can help to minimise I^2R heating by reducing electrical resistance. Low thermal resistance throughout the leads, connections and overmold is also necessary, to help the device dissipate internally generated heat as efficiently as possible.

At the silicon level, reducing the typical on-resistance also helps to minimise I^2R heating within the die. A low C_{iss} is highly desirable for automotive MOSFETs as this reduces turn-on energy and allows fast response to control signals. For use in an H-bridge, MOSFET turn-off behaviour is not an issue. For three-phase BLDC, the dead time has to be controlled, which means the turn-off time has to be fast enough to prevent short-circuit conditions damaging high- and low-side MOSFETs.

Toshiba's own solution to these challenges has been to develop a family of MOSFETs that combine package advances with advanced U-MOS IV trench technology. The trench architecture delivers

Opportunities in Automotive Market for Electric Motors

The automobile market has crashed, and whilst this has affected component suppliers, there still remain areas where the electrical motor market is growing, according to a new report from IMS Research.

With light vehicle sales having experienced the largest drop in living memory in most western economies, one would expect a reduction in the number of electrical motors used in automotive applications. However, 'The World Market for Electrical Motors in Automotive Applications' report shows that the continued growth in vehicle sales in regions such as China and South America, the continued penetration of actuated systems into a greater number of vehicles and the innovation of new technologies requiring motors, has helped soften the drop in demand to some degree.

Demand for some types of electrical motors is holding up better than for others. The brushless DC motor market, for example, is performing relatively well. To quantify this, worldwide sales of motors used in automotive applications are estimated to have dropped by almost 20%, from 2.3 billion units, over the period 2007 to 2009. In contrast, sales of brushless DC motors are estimated to decrease by only 6% over the same period. Nevertheless, the market for brushless DC motors in automotive is still small, accounting for only around 5% of motors used in automotive applications. Also, many high volume applications, such as seat adjustment or window actuation, only require intermittent operation. So while brushless DC motors may be used in some top-end vehicles, primarily to benefit from the reduced noise levels of the motor, this is not true for the 'mass market'.

"In spite of the higher cost of these products, the greater reliability and energy efficiency as well as longer lifetimes of brushless DC motors, make them popular in applications with high duty cycles. Already, many of the fuel pump applications have switched from brushed to brushless. This replacement trend is expected to continue in water pump applications, such as in cooling systems", comments IMS analyst Alex West. "Other applications also using this technology include dual clutch and automated manual transmission, as well as HVAC and power steering systems. Also, as the market for electric and hybrid vehicles increases, this is expected to spur demand for the more efficient brushless DC motors".

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the low $R_{DS(ON)}$, low input capacitance, low gate charge and high current-handling capability.

So far, automotive MOSFETs have used conventional package architectures and materials. This has effectively restricted performance, but Toshiba WARP packages now introduce a number of innovations aimed at simultaneously reducing internal heat generation, increasing heat dissipation, and improving overall durability.

Conventional aluminium bondwires are replaced with a copper clamp, for example, and the clamping mechanism is optimised to maintain a reliable mechanical bond, so as to withstand repeated power cycling as well as exposure to shock and vibration. The clamp has a larger cross-sectional area than a multi-bondwire interconnect, and this combines with the higher electrical conductivity of the copper material for a drastic reduction of I^2R heating due to package losses. Furthermore, because the copper clamp lowers package inductance, not only is heat generation further reduced but improved noise performance and faster switching times are possible. Finally, an enlarged source terminal creates a low-resistance pathway for current entering the device. Combining the direct copper clamping structure and wide source lead has been shown to improve package thermal resistance by around 20%.

These package technology advances and the U-MOS IV channel architecture have come together in the Toshiba WARP-FET automotive MOSFET family offering current-handling capability up to 150A and maximum voltage of $75V_{DSS}$. The trench technology contributes to typical $R_{DS(ON)}$ as low as 1.7mΩ and typical C_{iss} down to 4500pF.

The improvements in performance throughout the package and the die have enabled a valuable reduction in electrical losses combined with improved heat dissipation. As a result, the average MOSFET operating temperature is appreciably lower than for a comparable device using conventional packaging and trench architecture. Figure 3 confirms this by comparing the temperature at the drain, package surface and source lead of automotive trench MOSFETs in the standard TO-220SM package (also known as D^2PAK) and the TO-220SM(W) WARP package.

The combined effects of the enhancements to silicon performance and low-loss packaging allow these MOSFETs to achieve many thousands of power cycles. This will serve to boost reliability in automotive BLDC motor-control applications.

System solution

Figure 3 shows the planned driver IC and the latest automotive MOSFET technology. Because the TB9061FNG IC is optimised for use with these power devices they can, together, simplify and speed the implementation of a full automotive motor drive system. To accelerate development, further an evaluation board will soon be launched that combines a TB9061FNG driver IC with six WARP-FETs and a sample automotive pump. The pump motor can be controlled using a pulse generator connected to the board's PWM input, or by applying a DC control signal.

By enabling a true system solution for automotive brushless motor control, this driver IC/automotive MOSFET combination will significantly reduce the time engineers need to spend identifying and selecting components and designing circuitry, at the same time as providing an assurance of quality and reliability in the end product.