

Cut power, improve performance with brushless DC motors

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The European sales market forecast for integral horsepower (750W and above) motors is dominated by AC motors. Sales of these motors represent 96 per cent (or over 9 million) of all units sold, of which 87 per cent consists of 3-phase AC induction motors.

The market for efficient motors in the EU has seen a significant transformation and demand, following the introduction of the CEMEP/EU agreement, where the lowest efficient motor of the three classifications have since been virtually withdrawn from the market.

As a result, brushless DC (BLDC) and permanent magnet synchronous motors (PMSM) are

technologies that have seen an increase in demand, because of high efficiency and increasingly cheaper production cost. These types of motors are expected to gain market importance in the low power range 750W to 5kW particularly.

There is pressure therefore on designers to cut the cost of motor installation, including the control systems, and this is where more efficient low-cost microcontrollers can help. Understanding the requirements, however, can help illustrate what features control circuit designers need to focus on to get the best performance for the smallest investment in silicon.

Furthermore, modular software blocks and hardware reference designs offer fast motor control solutions. The core motor control software routines

are proven and remain the same, independent of the motor size, so applications including white goods through to major industrial installations can be driven by the same core device.

Understanding motors

A motor has two primary parts: The non-moving part is called the stator and the moving part, typically inside the stator, is called the rotor. Depending on the motor type, the stator and rotor can consist of coil windings or permanent magnets.

To enable a motor to rotate, two magnetic fluxes are required, one from the stator and the other from the rotor. By controlling the current applied, a rotating magnetic field can be generated. The motor rotates because of the interaction of the rotating magnetic fields, as the

magnetic field from the rotor attempts to align with that of the stator.

Brushed DC motors depend on a mechanical system to transfer current. The brushed motors have a wound rotor attached to the centre with a permanent magnet stator bonded to a steel ring surrounding the rotor. A commutator provides a means for connecting a stationary power source to the rotating coils, typically via conductive brushes that ride on smooth conductive plates. As the brushes come into contact with the commutator, current passes through to the rotor coil. The uneven torque that results from a single coil rotor can be smoothed by adding additional coils and commutator segments.

AC induction motors, on the other hand, do not depend

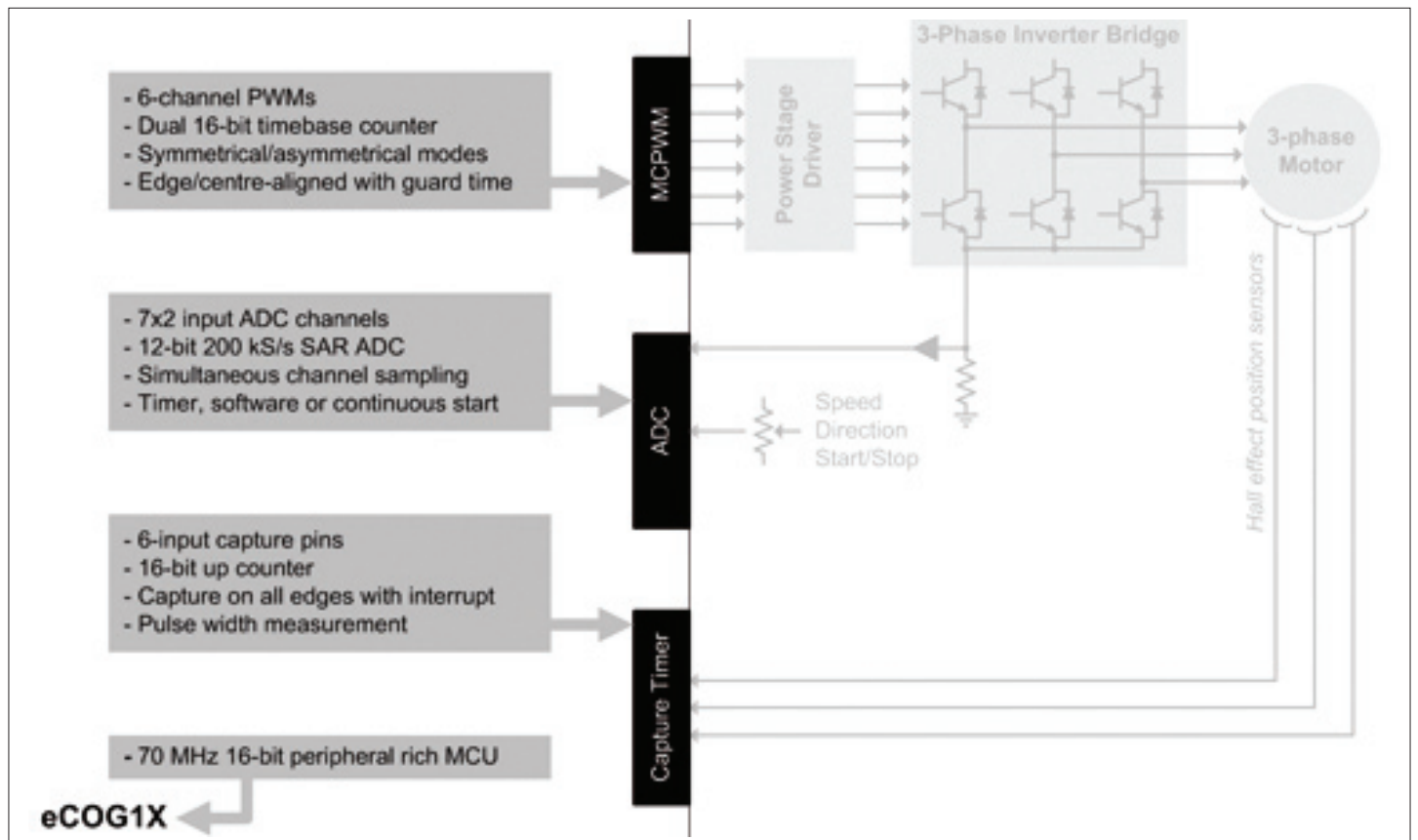


Figure 1: Here are Cyan eCOG1X motor control specific peripherals.

upon the mechanical system to control current, but instead pass current through the stator which is connected to an electrical supply directly or via a solid-state circuit.

The motor stator has a number of coil windings, that when driven by an alternating current, operates as a set of electromagnets to generate the required flux. It typically has a squirrel-cage rotor, consisting of a ring at either end of the rotor, with bars connecting the rings running the length of the rotor. In a 3-phase motor, the stator coils energise and de-energise sequentially, creating a rotating magnetic field. This induces current to flow in the bars of the squirrel-cage rotor, which in turn creates another magnetic field.

The term BLDC is a marketing-driven label to promote the idea that a BLDC motor with the appropriate drive is a suitable drop-in replacement for a brushed DC motor and its drive. Technically, a BLDC motor is still an AC motor; that is, alternating current inputs are required for the motor to move.

A BLDC motor is a rotating electric machine where the stator is a classic 3-phase wound stator, like that of an induction motor. Rather than inducing the rotor, the BLDC rotor has surface-mounted permanent magnets which provide the steady-state magnetic field.

When the wound stator is energised by a 3-phase alternating current, it creates a rotating magnetic field that causes the rotor to rotate synchronously with it. The BLDC motor, with trapezoidally distributed windings, is driven by trapezoidal currents coupled with the given rotor position.

Similar to the BLDC motor, the rotor of a PMSM consists of permanent magnets. The stator of a PMSM has its 3-phase windings distributed sinusoidally, as opposed to the trapezoidal distribution found in a BLDC motor. It operates in the same way as a BLDC motor, when the

wound stator is energised by a 3-phase alternating current, it creates a rotating magnetic field that causes the rotor to rotate synchronously with it.

The PMSM, with sinusoidally distributed windings, is driven by sinusoidal currents coupled with the given rotor position. A motor will draw only as much power and consume only as much energy as it takes to satisfy the load. Thus to save energy, the options are to reduce the load, reduce the operating time or increase efficiency.

The efficiency of a motor is a measure of how well it converts electrical energy into useful work. The difference between the output mechanical power and the input electrical power is due to five different kinds of losses occurring in the motor:

Electrical losses—expressed as I^2R are consequently most significant and increase rapidly with the motor load. These appear as heat generated by electric resistance to current flowing in the stator windings and in the rotor conductors;

- Magnetic losses—occur in the steel laminations of the stator and rotor due to hysteresis and eddy currents;
- Mechanical losses—from friction in the bearings, ventilation and windage;
- Stray load losses—due to leakage flux associated with air gap imperfection;
- Brush contact losses—result from the voltage drop between the brushes and the commutator, in the case of a brushed DC motor.

Higher efficiency BLDC, PMSM

Using permanent magnets in the rotor helps keep BLDC motor and PMSM rotors small and inertias low. More significantly, the motors have less electrical losses than induction motors because they do not have the secondary windings in their rotors, and the rotor magnetic losses are also much lower.

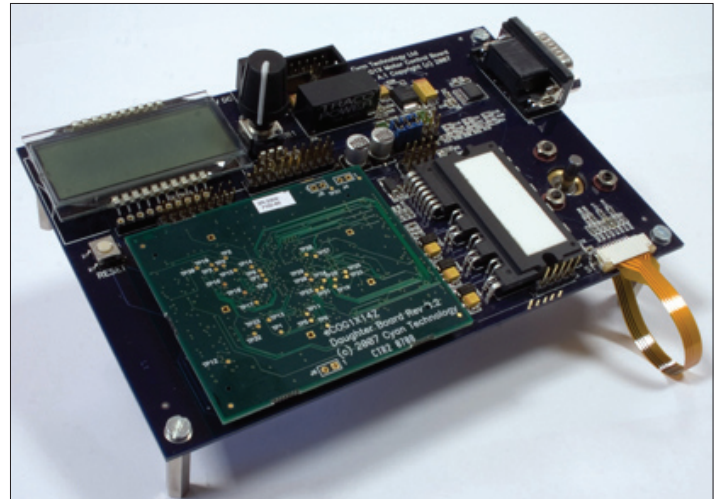


Figure 2: Control circuits for brushless DC motors and Permanent Magnet Synchronous Motors are increasingly being implemented using low cost, highly integrated microcontrollers.

Without current flow in the rotor, the motor also generates much less heat. The wound stator construct of BLDC motor and PMSM further allow any heat that is produced to be dissipated more efficiently, compared to dissipation via the AC induction motor air gap or the brushed DC motor shaft.

The inertia on the rotor is also less when compared to the squirrel-cage and wound rotor constructs of the AC induction motor and brushed DC motor respectively. This high torque to inertia ratios allows the BLDC motor and PMSM to provide a much better acceleration rate than the other motor types.

In the low power range and in applications requiring variable speed control, adopting BLDC motor and PMSM can lead to efficiency improvements of up to 10 per cent to 15 per cent when compared with AC induction motors, and allow the possibility of 90 per cent operating efficiency.

At the same time, BLDC motor and PMSM are also more energy-efficient than brushed DC motors. This arises because the motors eliminate the excitation circuit losses and does not suffer from friction due to the brushes. The enhanced efficiency is more apparent in the low-load region of the motors' performance curve.

In addition, both BLDC and PMSMs, for the same mechanical work output, will always be smaller than an AC induction motor and usually be smaller than a brushed DC motor. This arises because the motors' inherent construction facilitates better thermal efficiency. Thus, the motor body has less heat to dissipate. From this standpoint, BLDC and PMSMs require fewer raw materials to build and are potentially more cost-effective.

16bit microcontrollers such as the peripheral-rich Cyan eCOG1X naturally lend themselves to embedded motor control applications. These devices host a number of motor control specific peripherals that aid and simplify the motor control application software executed by the microcontroller processor core. These peripherals are as summarised in **Figure 1**.

The six channel MCPWM digital outputs can control directly the switching transistors of the power driver stage, which in turn applies the appropriate phase signals to the motor phases via the inverter bridge. Full four quadrant drive operation is possible, providing acceleration and deceleration torque with the motor running in either direction.

In applications where a potentiometer is used to input the speed demand and motor run-

ning direction, this can be monitored by one of the eCOG1X ADC channels. Another ADC channel can be used to observe the total stator current and check for over-current fault conditions.

Information on the rotor position and speed feedback can be

obtained by capturing changes in the motor Hall effect sensor outputs using the eCOG1X input capture timer.

To reduce design time, modular software blocks and hardware reference design are also provided, an example of the

latter is shown in **Figure 2**.

As we have shown, both brushless DC motors and PMSM are gaining widespread use in various consumer and industrial applications due to the high efficiency and linear speed/torque characteristics, which meet the

need to cut power and improve performance.

Modern microcontroller offerings have therefore evolved to ensure that products can be generated quickly and cheaply while meeting these requirements.