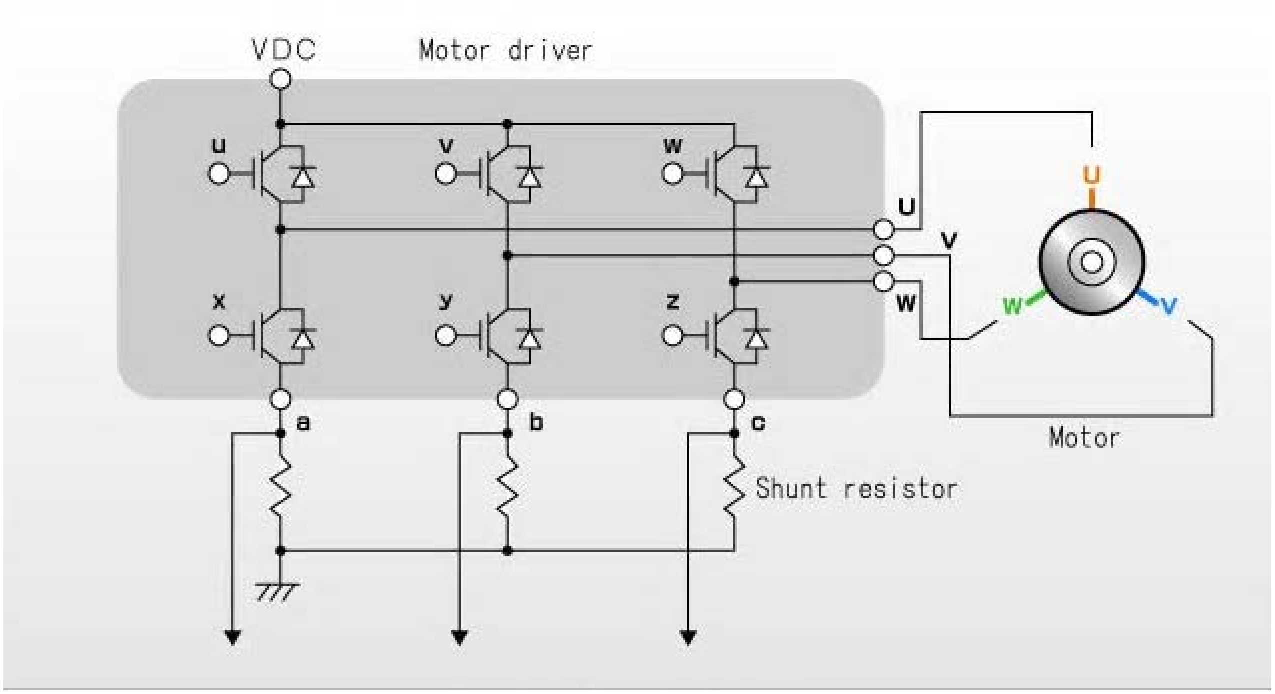
Motor Control Device vs. Motor Control MCU for Brushless Motor Control

Brushless motors offer highly efficient operation while providing excellent torque characteristics and high rotation speeds. The construction of stationary electro-magnets with a rotating permanent magnet, a brushless motor, enables the development of significant motor torque in a compact package. The operating parameters of brushless motors allow for a wide range of motor control and drive solutions with varying complexity.

The complexity of brushless motor control depends on the requirements of a given application and can range from the relatively simple motor control driver (MCD) to the more complex motor control specific microcontroller unit (MCU) with a variety of motor control techniques including field-oriented control (FOC) technology.

This white paper strives to explain the differences between the two motor control approaches and why certain applications are used with one over the other.



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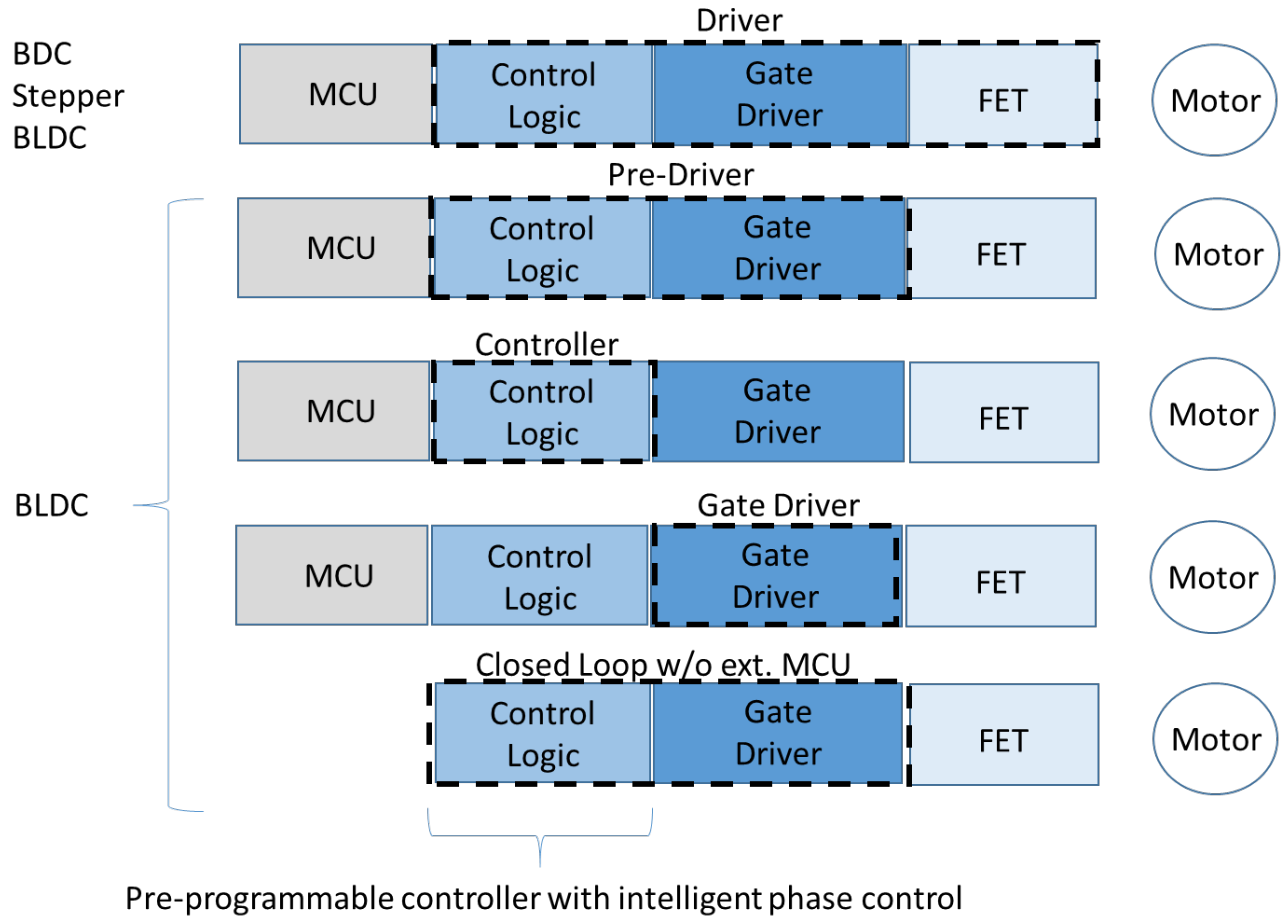
Caption: Basic three-phase brushless motor driver with control signal inputs U, V, W, X, Y, and Z

Background on MCDs for brushless motors

Motor driver ICs or motor control devices/drivers are control and driver circuits, often with 3 half-bridge inverter configurations, that are able to switch the supplied DC voltage in an appropriate way to achieve specified brushless motor operation. In order for the MCD and control algorithm to provide the required control signals to the inverter circuits driving the motor, feedback about the rotor position relative to the stator is required. There are MCDs for both sensor-based and sensorless brushless motors. Sensor-based MCDs have hall sensors in the motor that provide the rotor position feedback. In sensorless brushless motors, such deterministic position feedback mechanism is approximated by using the coil induced back electromagnetic force (BEMF) signals.

An MCD may supply square-wave drive (aka 120˚ energization) or sine-wave drive (aka 180˚ energization). Sine-wave drive presents better motor performance characteristics at the expense of more complex control circuitry. An MCU is needed in conjunction with an MCD to provide interfacing, communications, and higher-level operation control of the brushless motor, depending on the application requirements. However, there are MCDs on the market that are capable of standalone sinewave drive and relatively complex control.



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Caption: Brushless motor MCDs can be configured in a variety of ways with several typologies to realize a BLDC motor control solution.

Advantages of brushless motor MCDs

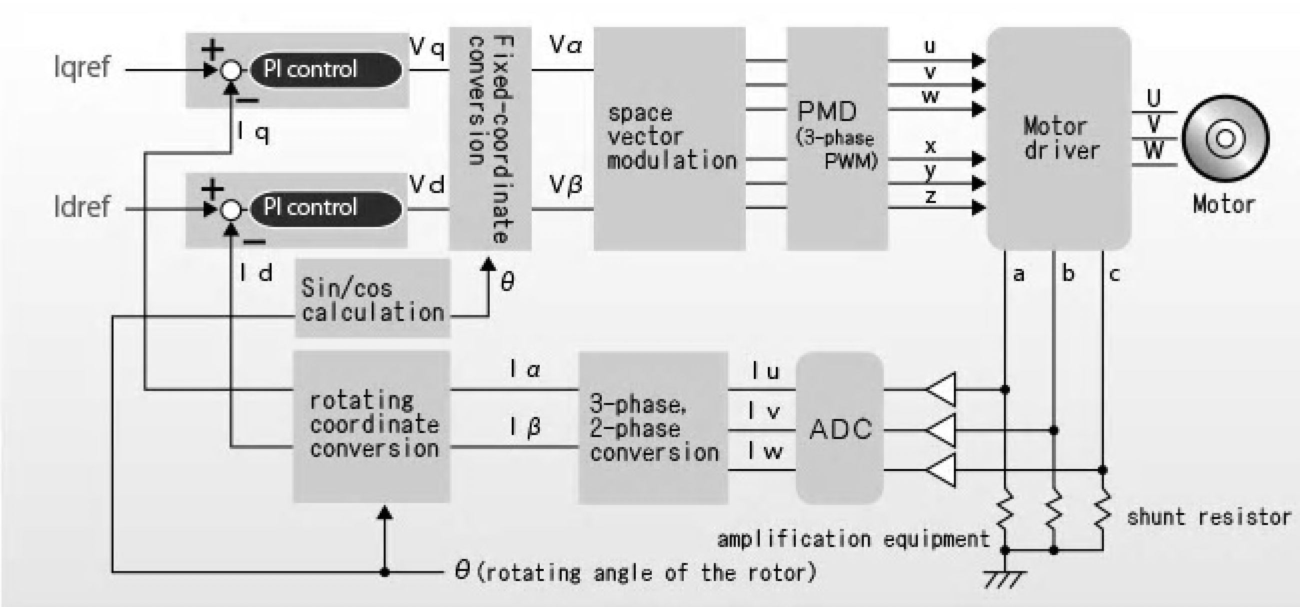
There are a wide range of MCDs to handle many brushless motor applications, which makes it easier to find a motor control solution suited to a given application. Some have special features such as intelligent phase control. Intelligent phase control allows the MCD to compensate for the phase delays between motor voltage and motor current caused by the brushless motor inductance, inertia, and the electronics for close loop control. An out-of-phase motor power supply can cause the brushless motor current to lag from the voltage and run inefficiently. The intelligent phase control forces the synchronization of motor voltage and motor current to run in phase. TC78B016FTG is an example, with of a sinewave drive Hall Effect sensored MCD with intelligent phase control.

The latest advanced MCDs for brushless motors also include features that may eliminate the need for external control and simplify the designs. For instance, some of Toshiba’s latest MCDs feature closed-loop speed control for maintaining the critical speed at various loads and intelligent phase control that improves motor efficiency (TC78B009FTG). Both intelligent phase control and close loop speed control technologies allow the ICs to handle brushless motor control without the need for the external MCU for processing complex parameters.

Primer on VEMCUs with FOC for brushless motors

There have been several advances in the control of brushless DC motors. One such advance is to use Vector Engine (VE) technology to optimize Field-Oriented Control (FOC) on a brushless motor. This is used in coordination with a dedicated MCU to provide enhanced brushless motor control even in conditions that dramatically vary the load and operating parameters of the motor.

VE technology has been used to efficiently control motor rotation across an ultra-wide range of rotation speeds and conditions. VE has been implemented so efficiently that brushless VE solutions can even enable smooth motor control at very low speeds, which used to be a challenge. In essence, a VE system uses the current and voltage states of the motor drive, applies Proportional Integral (PI) control to current vector components derived via three-phase to two-phase conversion followed by rotation coordinate conversion. Space-vector modulation is then performed on the resultant signals (Valpha and Vbeta) to convert the 2-phase signals back to 3-phase signals needed to drive a three-phase PWM circuit that supplies the U, V, W, X, Y, and Z signals to the motor driver. In other words, the function space vector modulation is to convert a 2-phase signal into a 3-phase signal that can be accepted by the three-phase PWM circuit driving the brushless motor. Additional PI controls can be added to enhance the speed and position controls, putting the burden on motor tuning as inaccurate tuning parameters can lead to motors not spinning nor operating efficiently.



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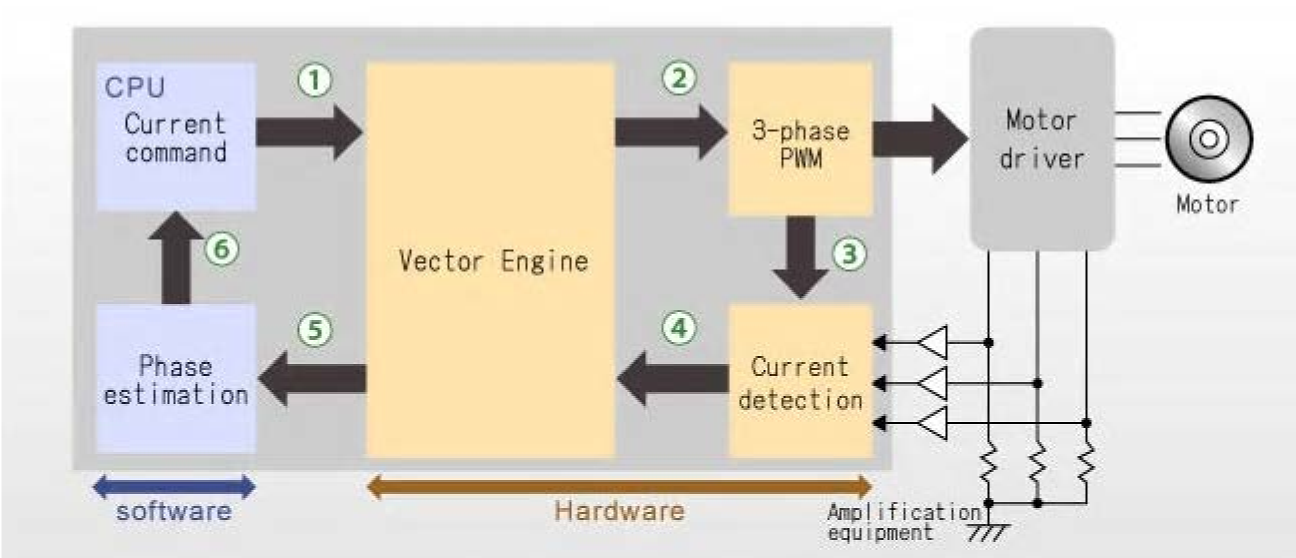
Caption: Vector control for a three-phase brushless DC motor

Given that the outputs of the motor driver current signals (a, b, and c) are very small, signal conditioning is used prior to analog-to-digital conversion (ADC) to ensure the values are accurately converted. As the three current signals are difficult to use in control and calculation simultaneously due to their mutual relations, a three-phase to two-phase conversion of the current signals is applied before control. This reduces the number of control signals and simplifies the rotational coordinate conversion circuitry needed for the operation. Using rotating coordinate conversions, the currents can be treated as DC instead of AC, and the subsequent calculations and control algorithms are simplified. The motor's rotation angle is needed for this calculation and to derive the motor control parameters, which can be computed from the induced back EMF or other forms of observers.

FOC is relatively complex to calculate efficiently in real time without substantial computing resources. VE technology is used to handle a significant part of the FOC workload in hardware. Otherwise, software development and a substantial amount of central processing unit (CPU) resources would be needed to do all of the FOC calculations. With VE technology, the three-phase to two-phase conversion, rotating coordinate conversion, PI control, fixed-coordinate conversion, sine/cosine calculation, and space-vector modulation can all be handled in highly efficient and responsive hardware. Toshiba's VEMCUs are also programmable, and the functions the hardware performs are selectable for a given application.



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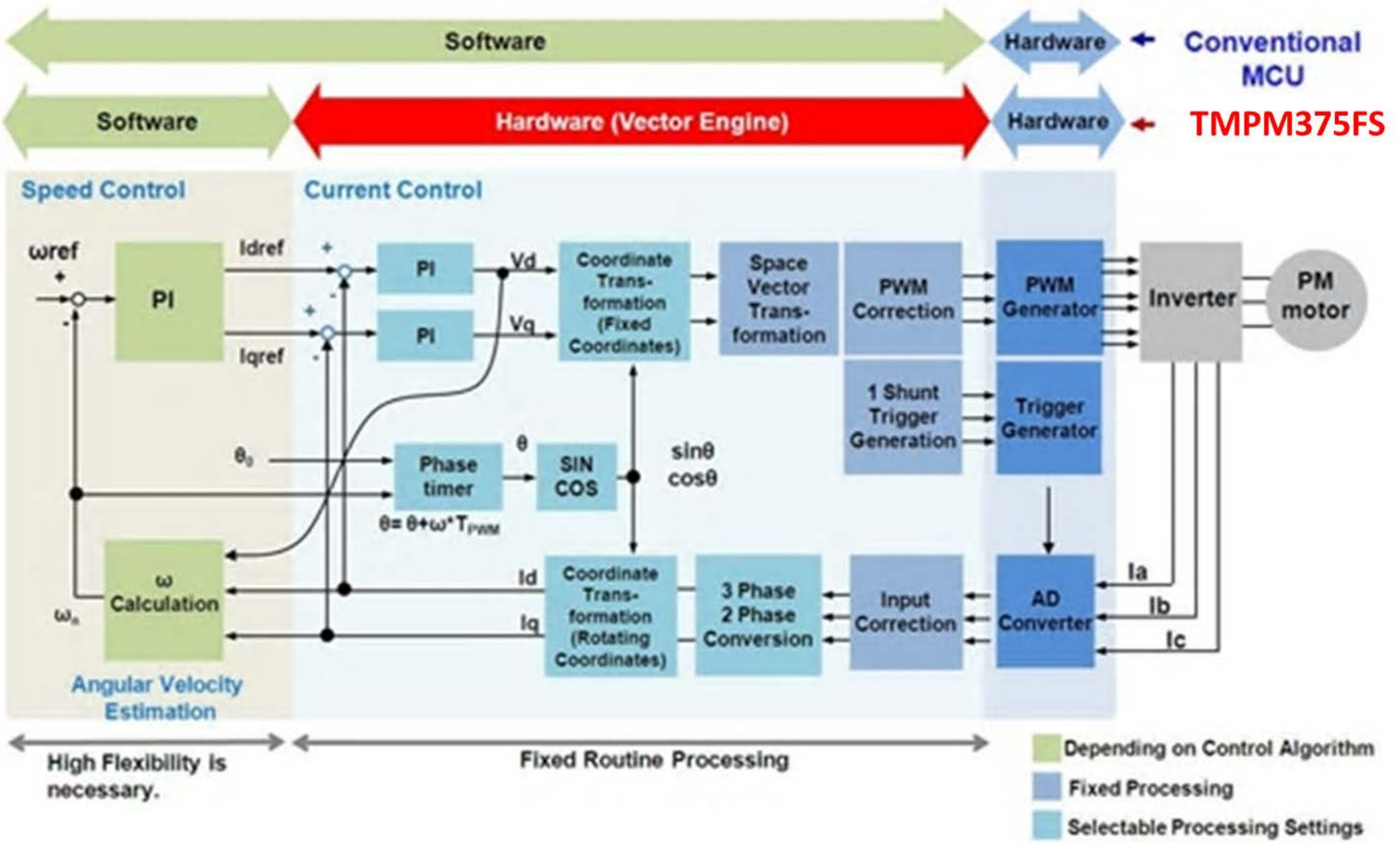
Caption: Vector engine block diagram for three-phase brushless DC motor control

Incorporating VE technology in an MCU, along with an ADC and a three-phase PWM circuit, means that a single MCU can be used to provide advanced FOC technology to a brushless motor application without the need for other MCU, motor control components (other than the motor driver and external amplifiers if needed), and even the Hall Effect sensors. This solution improves significantly over a software-only implementation of FOC, as the software development for FOC is complicated and typically larger and more expensive CPUs are needed to handle the calculations in the timescale desirable for brushless motor control applications.



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Caption: Conventional MCU vector control approach compared with a vector-engine–equipped MCU for brushless motor control applications.

VE technology has also recently been augmented with the inclusion of FOC technology used to control the variable frequency sinusoid and keep the rotor and stator magnetic fields within the motor spaced 90˚ phase separation under all conditions. Both field flux linkage and torque need to be derived and optimally controlled to achieve this. For brushless motors, several mathematical transforms are needed to determine these parameters from the current in the three brushless motor windings. Hence, a VEMCU such as the TMPM375FS is able to provide advanced FOC for both sensor-based and sensorless brushless motors without the need for bulky and costly external components or substantial software development.

Advantages of brushless motor vector engine MCUs

VEMCUs with FOC are able to service an expansive range of applications, such as power tools, garage door openers, pumps, trolling motors, electric vehicles, and many more. These VEMCUs exhibit high motor efficiency and can be used to control motors that operate at even high power, high speeds, or the full range of optimum torque versus a given speed region. Another necessary aspect of motor control for demanding applications is the ability to respond rapidly to load changes and supply the appropriate voltage changes, and VEMCUs are ideal for this. There are typically hundreds of PWM pulses for sensing as opposed to using a six-Hall sensor based architecture therefore sensorless FOC can be more accurate and can respond faster than Hall sensor-based square wave or sine wave brushless motor control. Moreover, VEMCUs are excellent at maintaining low torque ripple, thus reducing motor vibration/noise and enhancing motor reliability and efficiency. Furthermore, VEMCUs are efficient enough that they are able to perform motor control with extra computation resources available for other application requirements, such as housekeeping and other control functions.

MCDs versus VEMCUs for brushless motors

Though MCDs and VEMCUs with FOC are both excellent solutions to modern brushless motor control applications, there are tradeoffs for each solution. Generally, MCDs offer a limited range of operation/choices and may not be well-suited for various load applications. Simple MCDs also require a minimum communication of speed and direction control from an external MCU when faced with changing operating requirements or conditions. Hence, MCDs are best used in relatively constant speed applications with consistent loading, such as fans, blowers, vacuums etc.

For more complex motor control applications with varying loads, high power or rotation speed requirements, VEMCUs may be the better choice. However, VEMCUs do take additional design effort to implement, especially if complex motor tuning is needed for optimized FOC operation.

Here are the flagship products from Toshiba that feature the technologies described in this article for reference:

Intelligent Phase Control	- TC78B016FTG
Close Loop Speed Control	- TC78B009FTG
Field Oriented Control	- TMPM375FSDMG

Resources

1. Motor Driver ICs (Motor Control Devices)
2. Brushless DC Motor Drive Examples
3. Brushless DC Motor Driver ICs
4. Toshiba TC78B009FTG Brushless Motor Driver IC
5. Toshiba Vector Engine and Vector Control
6. Toshiba Vector Engines
7. Making Field-Oriented Control of motors simple
8. Field-Oriented Control of Brushless Motors without the Math