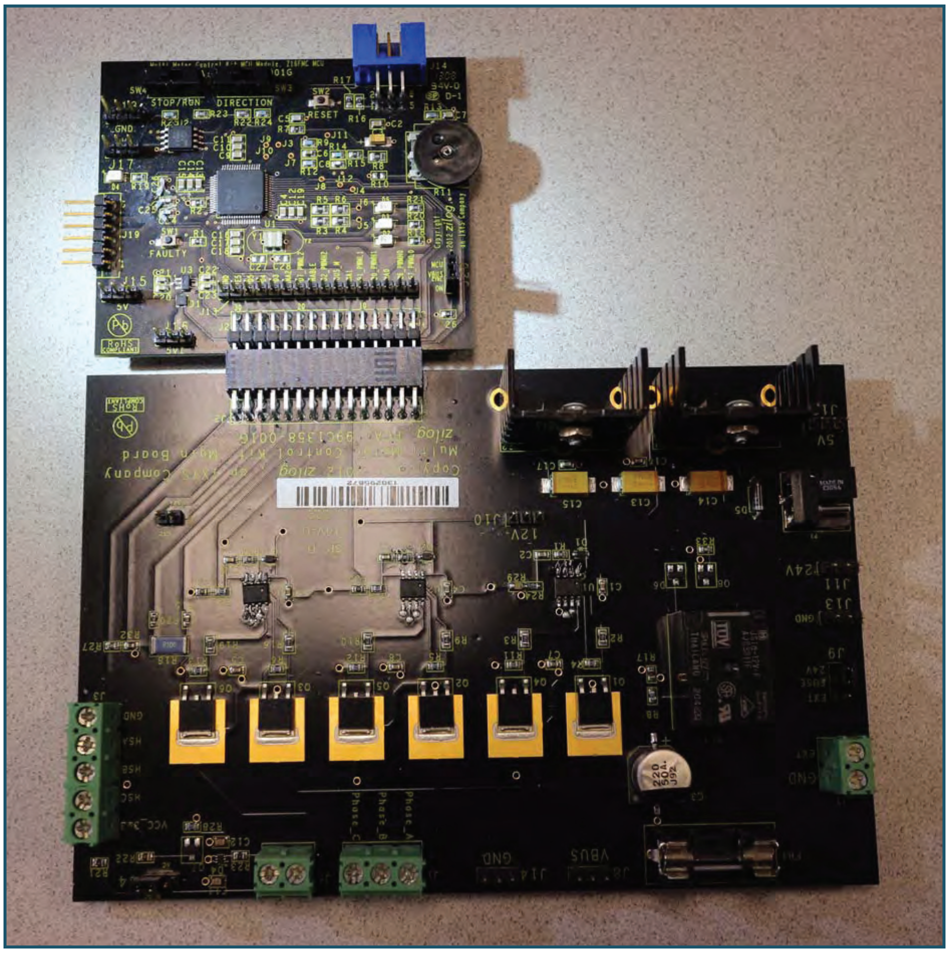
Zilog Motor Control Technologies

- **Optimized motor control strategies and solutions relevant to today's industry requirements**
- **Embedded software to leverage motor control capabilities**
- **Custom code development**

Demands on the efficiency and control of electric motors is increasing across every commercial sector, from white goods and electric vehicles to industrial installations and aerospace applications. ACIM machines have supported most commercial requirements for decades, but the ability to control them has often been very limited due to their typical operation via mains-supplied frequencies.

With the advent of affordable microcontrollers, control of ACIM motors has greatly increased because the mains voltage can be rectified and stepped down so that a microcontroller can be used to generate a sine wave pattern and control signals to operate the ACIM machine. Nevertheless, there is a slip factor intrinsic to ACIM machines known as *asynchronous speed*, a factor which makes an ACIM machine less efficient than its brushless DC (BLDC) counterparts, especially at smaller motor sizes. Meanwhile, permanent-magnet synchronous (PMSM) and synchronous AC motors are typically more efficient, and are suitable for even the most demanding of applications.

To evaluate suitable driving methods for BLDC, PMSM, or ACIM motors, Zilog has developed a comprehensive MultiMotor Series motor control kit featuring Zilog's Z32F128 ARM Cortex M3, which facilitates operation across these motor types with differing control schemes so that developers can choose the driver scheme that is most suitable for their application.



Zilog's MultiMotor Series Motor Control Development Kit

Topics Discussed Inside

- Motor Control Strategies
- Control Strategy by Motor Type
- Open- vs. Closed-Loop Speed Control
- Regenerative Braking Control
- Projected Market Share for Electric Motors
- Characteristics and Applications:
  - Single-Phase BLDC Motors
  - Three-Phase BLDC Motors
  - Trapezoidal Hall Sensor vs. Sensorless Commutation
  - Space Vector Modulation
  - Field Oriented Control
  - Stepper Motors

- The Z16FMC MCU and the Z32F128 ARM Cortex M3 MCU
- The MultiMotor Series Development Kit
- Zilog Motor Control Development Tools

Zilog-Supported Motor Control Strategies

The Difference Between Asynchronous and Synchronous Machines

Permanent Magnet Synchronous Motors (PMSM, PMAC) and brushless DC motors (BLDC) are synchronous machines because they contain permanent magnets whose flux fields interact immediately with the stator flux field to commutate the rotor. Therefore PMSM machines are typically more efficient than ACIM, typically greater than 90% and less than 100%.

AC Induction Motor Machines (ACIM) is an asynchronous electrodynamic machine with no permanent magnets. The current induced flux field in the windings has to build up a flux field in the air gap and iron of the rotor first before these two fields can interact and produce the torque to commutate the shaft. Therefore there is a lag between the iron flux and stator flux fields, commonly termed slip. Due to this slip, ACIM are less efficient, typically around 60 to 80%. Induction motor machines have an intrinsically poor transient performance between steady states but field-oriented control (FOC) motors address this issue.

Motor Control Methodologies

These motor control parameters can be monitored with the following control driving schemes, all of which Zilog supports with corresponding application notes:

- Sensorless 3-phase trapezoidal commutation
- Hall sensor 3-phase trapezoidal commutation
- Sinusoidal PWM commutation with Hall sensor feedback
- Space vector modulation with Hall sensor feedback for BLDC motors
- Space vector modulation ACIM machine commutation with the V/F principle
- Single-shunt space vector control/FOC for ACIM using rectangular coordinates
- Dual shunt space vector control/FOC for ACIM using polar coordinates

Types of Electric Motors

- Brush-type BLDC motors
- Three-phase brushless BLDC motor (suitable for trapezoidal commutation)
- Permanent Magnet Synchronous (PMSM, PMAC) machines with sinusoidal wound stator wire distribution (suitable for sinusoidal-, space vector-, and FOC-controlled commutation due to less cogging torque)
- AC induction motor (ACIM): asynchronous machines suitable for sinusoidal, space vector modulation, and field-oriented control

Common Control Strategies

Block commutation adjusts the phase-angle every sixty degrees, thereby introducing a ± 30 degree error; however, this is acceptable for many motor drive applications. Sinusoidal control (including space vector modulation and field-oriented control) allows for adjustment of the commutation so that the rotor and stator flux fields are at 90 degrees to each other.

Common commutation schemes include:

- Single-phase trapezoidal commutation (Hall sensor)
- Three-phase trapezoidal commutation (sensored/sensorless)
- Sinusoidal PWM modulation (Hall, encoder)
- Space vector modulation (predominantly for ACIM and PMSM machines mostly sensor using encoders or Halls)
- Space vector control/FOC mostly used for ACIM but can be designed for PMSM

Choice of Control Strategy by Motor Type

Sinusoidal controls are suitable for BLDC type motors because this driving scheme utilizes more of the bus voltage and tends to run the BLDC machine more quietly, both electrically and accoustically. However, the current waveform may not be very sinusoidal because BLDC type machines have no sinusoidal wound stators and therefore, a higher detent. On the other hand, using trapezoidal motor control on PMSM or ACIM machines with sinusoidal wound stators does not utilize the benefits of these types of machines either.

Sinusoidal PWM, Field Oriented Control and Space Vector Modulation strategies are best suited for ACIM, PMSM or PMAC type machines because they have sinusoidal wound stators utilizing the benefits of these control strategies.

Open-Loop vs. Closed-Loop Speed Control

- To some extent, electric motors have self-governing closed-loop properties
- Closed-loop speed control operation may not be suitable for some types of applications
- In the case of air-moving fans and blowers, the pressure vs. flow characteristics are very different not only between radial and axial types of motors, but also under closed-loop and open-loop speed control (i.e., stall points). Depending on these cases, closed-loop control may or may not be desired
- Arguably, in the case of vehicular applications, closed-loop speed control may not be suitable unless when operated in a *cruise control mode*

- Closed-loop torque or speed (inner/outer control loops) controls are suitable for power tool applications because the torque will go up under higher load conditions
- Some motor control applications may require the motor to reach terminal speed at a defined acceleration rate and therefore require closed-loop operation

Regenerative Braking

- Depending on which qudrant the motor operates, an electric motor is in either motoring or generating mode
- One of the advantages of electrodynamic machines is the ability to produce regenerative voltages even without sophisticated inverter switching techniques
- In generating mode, the motor currents produce negative torque, causing a *plug braking* effect, which may be required for some applications.
- In conjunction with the motor inverter bridge and PWM switching techniques, regenerative energy can be efficiently channeled for battery charging purposes

Regenerative Braking Control

Type of Control/Motor	Sinusoidal Wound Stator (PMSM, PMAC and ACIM)	Nonsinusoidal Wound Stator (BLDC)
BLDC with block commutation	Yes, but not ideal	Ideal
BLDC with Sinusoidal PWM	Ideal	Yes, but not ideal
Space Vector Modulation	Ideal	Yes, but not ideal
Space Vector Control (FOC)	Ideal	Yes, but not ideal

Motor Types Suitable For Regeneration And Motoring

Type of Control/Motor	Motoring	Regeneration
Single phase	Yes	Not ideal
Three-phase block commutation	Yes	Yes
Sinusoidal and SVM/FOC using ACIM/PMSM	Yes	Ideally suited
Stepper motor (discrete steps)	Yes	No
Servo motor	Yes	Not ideal

MCU Resource Usage Comparison By Control Strategy

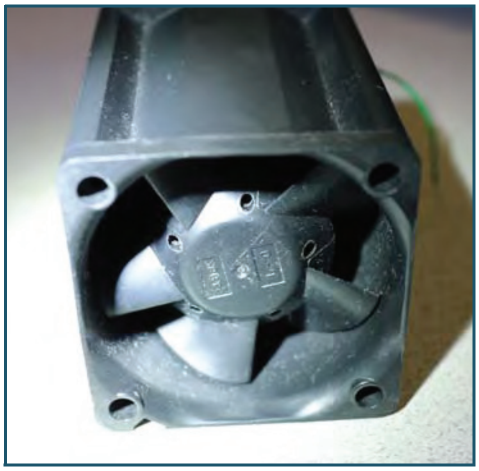
Type of Control	Performance	Cost	Code Complexity	Applications
Single phase	Low	Low	Low	Telecommunications, commercial
Three-phase sensor	Medium	Medium	Low	Telecommunications, commercial, vehicular
Three-phase sensorless	Medium	Low to Medium	Medium to high	Telecommunications, commercial, white goods
Sinusoidal PWM	Medium to high	Medium to high	Medium to high	White goods, industrial, commercial, vehicular
Space Vector Modulation	Medium to high	Medium to high	Medium to high	White goods, industrial, commercial, vehicular
Field Oriented Control	High	High	High	High performance, industrial, vehicular

Market Share by Motor Type

- AC Induction Motor type machines are projected to have the largest product segment of the market by 2017
- BLDC/PMSM machines are predicted to have the second highest market share by 2017
- Among major markets, BLDC machines for heating and cooling equipment are projected to be the fastest growing market sector

Single-Phase BLDC Motors

Single-phase BLDC motors consist of simple hardware and software requirements because they only require an H-bridge inverter to produce a single-phase voltage.



Single-phase BLDC motors are typically used in cost-sensitive applications, and are often used to control fan motors.

Single-phase designs can yield undesired effects and exhibit low efficiencies in fan applications – as little as 35 to 40% – and generally produce high ripple currents. Single-phase BLDC fan motors are found in every aspect of the industry, mainly when removing heat from electrical systems is a requirement.

Applications that employ Single-Phase BLDC Motors

- Telecommunications, radial/axial fans for:
  - Servers
  - Fans
  - Fan trays
  - Blowers
- Automotive climate adjustment
- Water pumps
- Single-stator wire-wound for trapezoidal back electromotive force (BEMF) generation

Advantages of Single-Phase Control

- Simple H-bridge hardware design
- Simple software implementation
- Low resource demands on MCU
- Low BOM cost

Disadvantages of Single-Phase Control

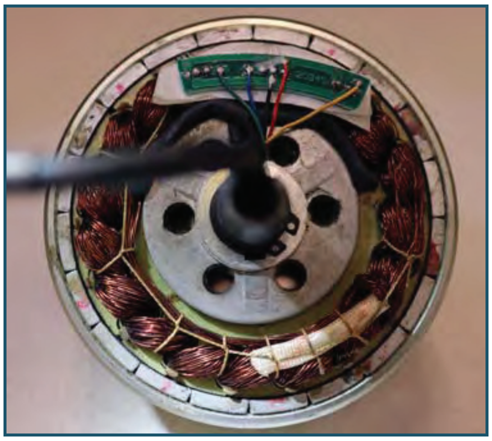
- High electrical noise signature
- High acoustical noise signature
- High total harmonics
- High ripple currents
- Higher stress on ripple current electrolytic capacitors
- Higher stress on ball bearings
- Typically less efficient than three phase machines

Zilog Single-Phase Motor Control Offerings

ZNEO32!	Z8 Encore!	ZNEO	Z8051	S3
Z32F128	Z8F0130, Z8F0230 Z8F0231, Z8F0430, Z8F0830 Z8FMC04, Z8FMC08, Z8FMC16	Z16FMC2 Z16FMC3 Z16FMC6	Z51F0410, Z51F0811 Z51F3220, Z51F3230 Z51F6412	S3F80P5,S3F80P9 S3F8S15, S3F8S19 S3F8S35, S3F8S39 S3F8S45

Three-Phase BLDC Motors

Trapezoidal commutation is also referred to as *block* or *six-step* commutation. Hall sensor feedback can provide binary information to commutate a 3-phase motor every 1/6th of an electrical revolution. With sensorless commutation, the BEMF is detected every 1/6th of an electrical revolution to commutate the motor.



The phase angle synchronization in six-step commutation is rather approximate, because the optimum commutation step occurs when the rotor is perpendicular to the stator field. However, this state cannot be achieved commonly with Hall or sensorless commutation; therefore, the phase angle is adjusted every sixty degrees, which introduces an error of ±30 degrees. Nevertheless, for most applications, this compromise is acceptable.

Applications that employ 3-Phase Trapezoidal Commutation

- Used in virtually every aspect in the industry
- Heavy use in vehicles (e.g., air movement, seat adjustment)
- Power tools
- Industrial
- Commercial

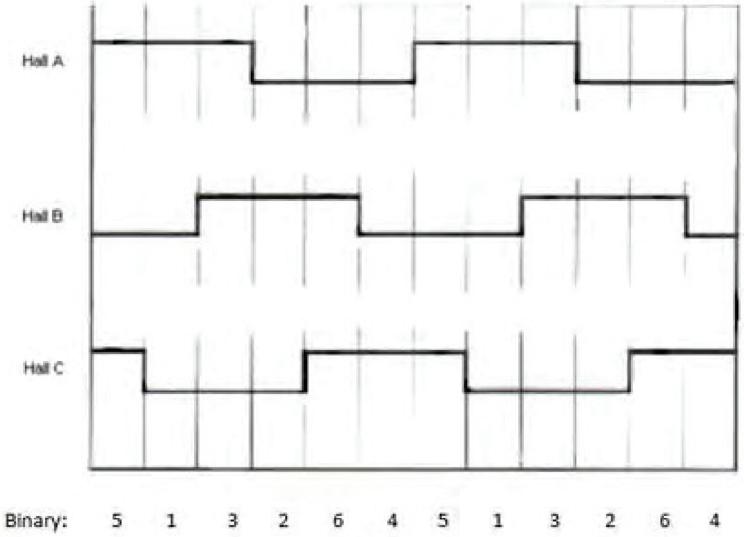
Advantages of Three-Phase Trapezoidal Motor Control

- Less acoustical noise

- Less electrical noise
- Generally higher life expectancy of electrical and mechanical components compared to single-phase machines
- Less cost if operated sensorless
- Generally higher torque than single phase
- Less cogging torque and ripple current than single phase machines

Disadvantages of Three-Phase Trapezoidal Motor Control

- Higher BOM cost if operated with Hall sensors
- Higher complexity of software for sensorless commutation mode
- Hardware design complexity higher than single phase
- Manufacturability
- Commutation angles are adjusted every 60 degrees as opposed to the ideal 90 degree commutation switching.



Phase Voltages with respect to Hall Binary States

Zilog Three-Phase Motor Control Offerings

Z8 Encore!	ZNEO	Z8051	S3
Z8FMC04 Z8FMC08 Z8FMC16	Z16FMC2 Z16FMC3 Z16FMC6	Z51F3220 Z51F3230	Only with additional software and discrete components; contact Zilog Sales

Trapezoidal Hall Sensor vs. Sensorless Commutation

To commutate a Hall sensor-operated BLDC machine, the rotor magnets pass across Hall sensors to generate the binary information required to commutate the rotor shaft. This information is available at power-up; therefore the motor is capable of running at very low speeds. Hall sensor-operated BLDC machines are often used for high torque requirements. Though not always the case with sensorless operation, Hall sensor information is always available and is independent of high load currents.

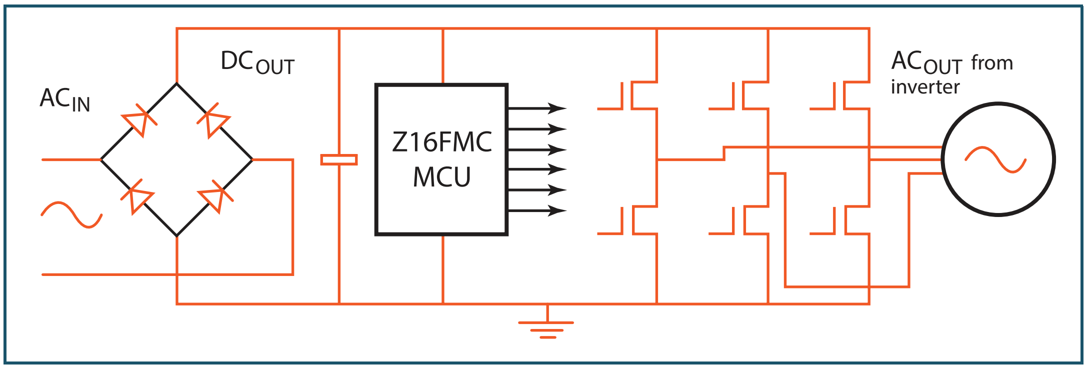
For smooth startup, a sensorless-commutated BLDC machine must have a defined startup ramp until the speed is high enough to detect the BEMF information required to commutate the motor, according to the equation EMF = B*L*v. This equation states that the generated BEMF is contingent on the flux field strength, the length of the inductor, and the velocity of motor rotation. Therefore, if the velocity of the rotor is low, sensorless machines may not be ideal candidates for low-speed applications and may not be as suitable for high-torque applications because the generated BEMF information may become lost at high currents. This loss can occur because stored magnetic energy in the motor windings will discharge in the form of inductive spikes every six commutation steps. Therefore, if the load current is high, the width of the inductive spike containing the stored energy of the windings can be wide enough to delay the rising BEMF signal so that it can no longer be detected.

Characteristics of Sinusoidal Current Control of PMSM/ACIM Machines

To operate BLDC permanent-magnet synchronous and permanent-magnet AC machines, three 120-degree sinusoidal waveforms must be applied to the motor's windings. The simplified diagram below illustrates a conversion from AC to DC and back to the MCU-generated AC signals across the inverter bridge.

Applications that employ Sinusoidal PWM Modulation

- Automotive
- White goods



- Motion control (e.g., ceiling fans)

Advantages of Sinusoidal PWM Modulation

- Ideal for ACIM/PMSM and BLDC machine types
- All three phases are energized at any given time
- Near-constant torque
- Flux is sinusoidally distributed
- Virtually no ripple current
- Electrical and acoustical noise is significantly lower than in block-commutated machines due to absence of steep current transitions
- Generally higher lifetime and efficiency of electrical and mechanical components compared to single- or 3-phase block-commutated machines
- Simple V/F scaling operations (Volts per Hertz profiler)
- As with space vector modulation and field-oriented control, PWM sine modulations have 15% more bus voltage utilization and efficiency if a third harmonic-injected sine wave is implemented

Potential Disadvantages of Sinusoidal PWM Modulation

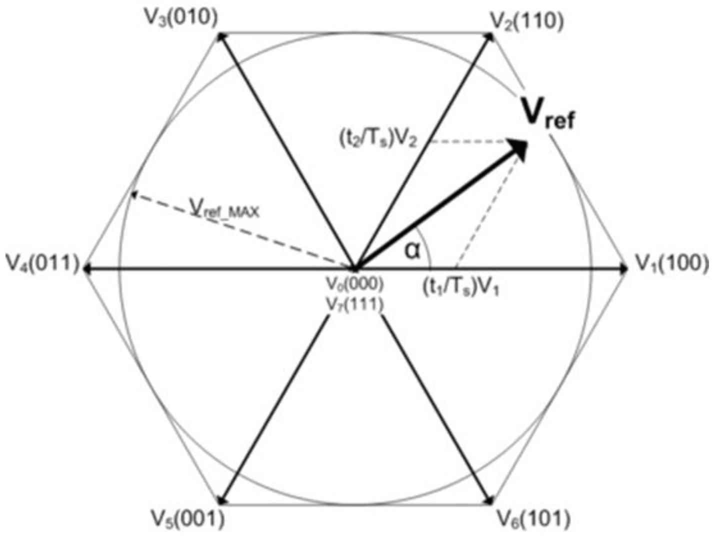
- Higher software complexity
- MCU cost potentially higher than block commutated machines due to higher resource demands
- If no third harmonic injected then sine wave then less efficient when compared to Space Vector Modulated machines
- Total linear switching power losses typically higher than block commutated machines, unless Space Vector Modulation is used, which allows 2/3rd phase switching.
- Torque and field producing components (d-q) are not controlled separately, meaning the orthogonal relationship of the d-q components can become distorted at high speeds, partially due to effects of the BEMF and lagging effects of the PI loops.

Zilog Sinusoidal PWM Motor Control Offerings

ZNEO32!	Z8 Encore!	ZNEO
Z32F128	Z8FMC04, Z8FMC08, Z8FMC16	Z16FMC2, Z16FMC3, Z16FMC6

Space Vector Modulation

Contrary to the PWM Sine Modulation strategy in which each leg in the inverter generates each phase sine wave independently, SVM strategy treats the entire inverter as a single unit to generate the rotating space vector, V_{REF}, and the three 120 degree-shifted waveforms, as illustrated in the hexagon below.



Rotating Reference Vector V_S within the Hexagon at Angle Theta

The rotating space vector V_{REF} rotates within this hexagon, according to the following equation.

$$V_{REF} = \frac{V_{MAG}}{V_{NOM}} \cdot e^{j\theta}$$

Therefore the magnitude and the angular position of the rotor must be known to determine which sector of the hexagon V_{REF} is to be generated by using the adjacent base vectors. The adjacent base vectors are then time-modulated together with the zero vectors V0 and V7 and scalar quantities r1 and r2 using the following two equations.

$$V_{REF} = r_1 \cdot V_1 + r_2 \cdot V_2$$

$$r_1 = \sqrt{3}\frac{u_s}{U_{dc}}\sin(60° - \Delta\theta)$$

$$r_2 = \sqrt{3}\frac{u_s}{U_{dc}}\sin(\Delta\theta)$$

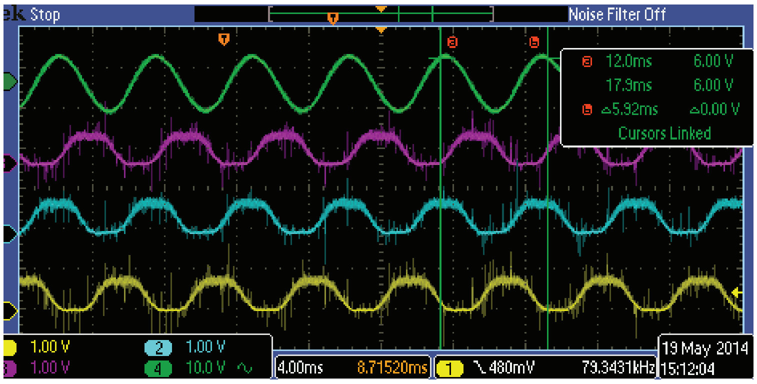
The T0, T1, and T2 space vector modulation periods are derived from r1 and r2 using the following three equations.

$$T_0 = (1 - r_1 - r_2)T$$
$$T_1 = r_1 T$$
$$T_2 = r_2 T$$

Using the equations above, a space vector can be generated at any angular position within the hexagon. V0 and V7 are called *zero vectors* because they produce no voltage across the inverter bridge. In the hexagon figure, the adjacent base vectors are V1 and V2, and the reference vector V_{REF} is located at approximately 40 degrees in the counterclockwise direction. The magnitude V_{MAG} determines the length of this reference voltage vector V_{REF}.

Space Vector Modulation Waveform

The following figure presents the typical Space Vector Modulation phase voltage and phase current on a PMSM machine.



Applications that employ Space Vector Modulation

- Automotive
- White goods (washing machines and dryers)
- Small home appliances
- Aerospace

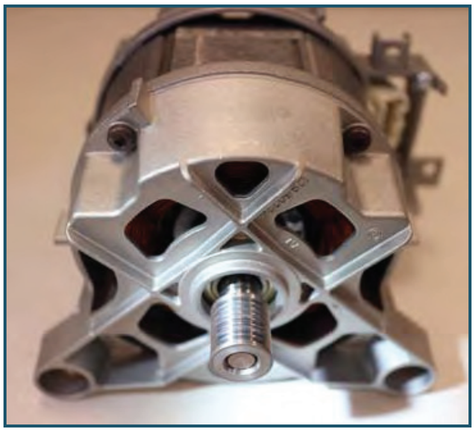
Advantages of Space Vector Modulation

- Higher life time of electrical components
- Suitable for ACIM and PMSM or BLDC machine operation
- The same hardware as used for Sinusoidal PMM modulation can be implemented for Space Vector Modulation
- Multiple Space Vector Modulation switching strategies can be applied to:
  - Reduce linear switching power losses
  - Reduce total harmonics
  - Combination of switching strategies
- Higher bus voltage utilization than non-third harmonic injected PWM sine modulation since center voltages can float around $V_{DD}/2$
- Simple V/F scaling operations (Volt per Hertz) where applicable

Disadvantages of Space Vector Modulation

- Higher code complexity
- Higher MCU cost due to resource demands
- As with sinusoidal PWM, torque and field producing components (d-q) are not controlled separately, meaning that the orthogonal relationship of the d-q components can become distorted at high speeds due to BEMF and PI loop lag effects.

Field Oriented Control



Field-oriented vector control (FOC) controls the *d-q* components of a brushless motor to mimic the d-q control characteristics of a brushed DC machine in which the orthogonal relationship between flux and torque is always maintained by the motor's contacts and brushes.

These d-q currents exist naturally in an orthogonal relationship; however, this relationship can become nonorthogonal at very high motor speeds due to BEMF and PI loop lag effects, so that this orthogonal relationship between rotor and stator field can no longer be maintained. As a result, the motor does not run as efficiently as it could.

Therefore the goal of field-oriented control is to separately control the d-q (i.e., torque- and flux-producing currents) of the machine to eliminate these detrimental effects while maintaining an orthogonal relationship between the rotor and stator flux, as governed by the following equation: Torque = Bs x Br, where Bs and Br are vector quantities.

Another beneficial aspect of field-oriented control is the transitioning performance in between steady states and instantaneous torque control.

To achieve this controllability, sophisticated transform functions are implemented, as follows:

Clarke Transform

$$Is\_\alpha = Ia$$

$$Is\_\beta = \frac{1}{\sqrt{3}} \times Ia + \frac{2}{\sqrt{3}} \times Ib$$

Park Transform

$$I\_ds = Is\_\alpha \times \cos(\theta) + Is\_\beta \times \sin(\theta)$$

$$I\_qs = -Is\_\alpha \times \sin\theta + Is\_\beta \times \cos\theta$$

Reverse Park Transform (for rectangular coordinates)

$$V\_ds = V\_dr \times \cos(\theta) - V\_qr \times \sin(\theta)$$

$$V\_qs = V\_dr \times \sin(\theta) + V\_qr \times \cos(\theta)$$

Reverse Clarke Transform (for rectangular coordinates)

$$V\_a = V\_ds$$

$$V\_b = \frac{1}{2}(V\_ds) + \frac{2}{\sqrt{3}}(V\_qs)$$

$$V\_c = \frac{1}{2}(V\_ds) - \frac{2}{\sqrt{3}}(V\_qs)$$

d-PI controller

q-PI controller

Applications that employ Field Oriented Control

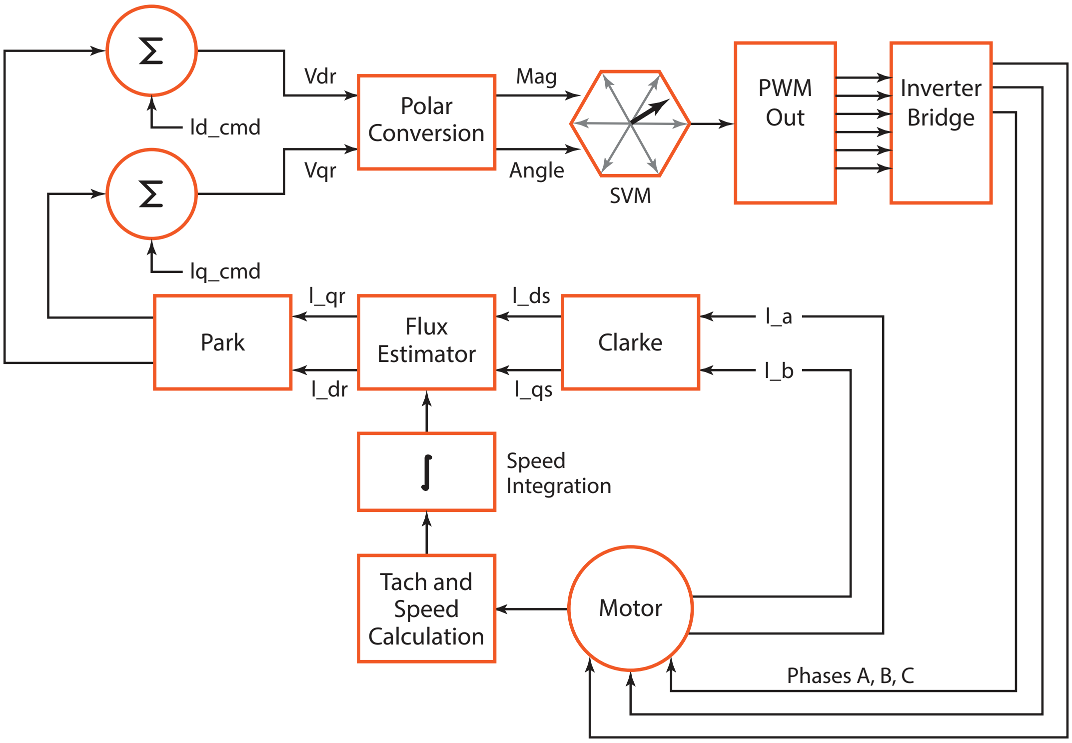
- High performance industrial applications
- Military
- Aerospace
- Machine tools spindle drives
- Automotive

Advantages of Field Oriented Control

- Fast transient control of flux and currents from one steady state to the next (direct torque control) especially in ACIM type machines
- ACIM machines have intrinsically poor steady state transient performance unless operated with sophisticated controls such as FOC
- Due to effects of the BEMF and the performance of current control loops at high speeds, the orthogonal relationship of the d-q axis becomes distorted unless the motor is operated with Field Oriented Control
- As with Space Vector Modulation and third harmonic PWM sine, FOC utilizes about 15% more of the available bus voltage, even at high speeds
- As with Space Vector Modulation, FOC generates less total harmonics, acoustical and electrical noise

Disadvantages of Field Oriented Control

- High code complexity
- Higher hardware design complexity
- MCU processing and resource demands are high



Block Diagram: Field Oriented Control Using Polar Coordinates

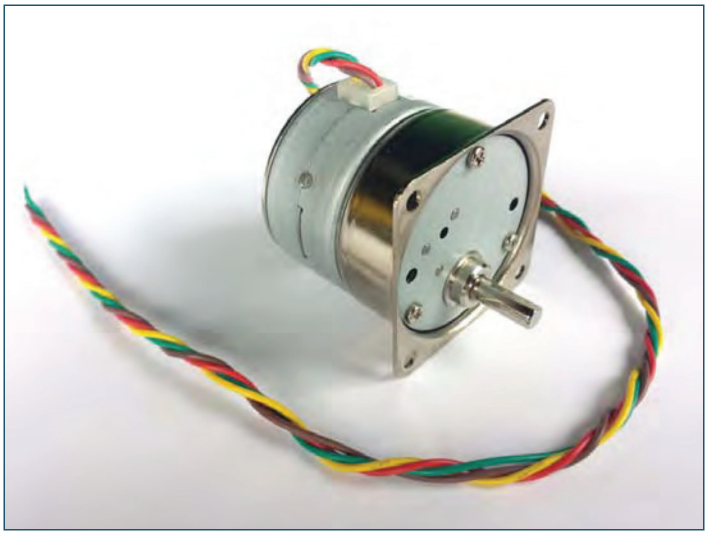
Zilog Space Vector Modulation & FOC Motor Control Offerings

Z8 Encore!	ZNEO	Z8051
Z8FMC04, Z8FMC08, Z8FMC16	Z16FMC2, Z16FMC3, Z16FMC6	Z51F3220, Z51F3230

Stepper Motors

A stepper motor is an electromagnetic brushless DC motor that divides its full rotation into a number of equal steps as it converts digital pulses into mechanical shaft rotation. The motor's position can then be commanded to move to and hold at one of these steps without a feedback sensor (i.e., an open-loop controller), as long as the motor is carefully sized to the application.

DC brushed motors rotate continuously when voltage is applied to their terminals. Stepper motors typically convert a series of square wave pulses into precisely-defined increments in the shaft position. Each pulse moves the shaft through a fixed angle. Stepper motors effectively have multiple toothed electromagnets arranged around a central gear. These electromagnets are energized by an external control circuit, such as a microcontroller. To make the motor shaft turn, an initial electromagnet is powered, thereby magnetically attracting the gear's teeth. When this gear's teeth are aligned to the first electromagnet, they are slightly offset from the next electromagnet. Therefore, when the next electromagnet is turned on and the initial one is turned off, the gear rotates slightly to align with the next one, and the process continues in a repeated rotating cycle. Each of these rotations is called a *step*, with an integer number of steps, to achieve a full rotation. With these steps, a motor can be turned at precise angles.



There are four main types of stepper motors:

- Permanent Magnet (PM)
- Variable Reluctance (VR)
- Hybrid synchronous
- Lavet-type

Permanent magnets in a motor's rotor operate on the attraction or repulsion between the rotor PM and stator electromagnets. Variable Reluctance motors often feature a plain iron rotor and operate based on the principle that minimum reluctance occurs with minimum gap; as a result, the rotor points are attracted toward the stator magnet poles. Hybrid synchronous stepper motors are so named because they use a combination of PM and VR techniques to achieve maximum power in a small package size.

Permanent-magnet stepper motors can be further subdivided into *tin can* and *hybrid* motor types. Tin can steppers are generally the cheaper of the two; hybrid motors generally include higher-quality bearings, smaller step angles, and higher power density.

Finally, Lavet-type stepping motors have widespread use as drives in electromechanical clocks and are a special kind of single-phase stepping motor.

Two-Phase Stepper Motors

Two basic winding arrangements exist for the electromagnetic coils in a two-phase stepper motor: *unipolar* and *bipolar*.

Unipolar Motors. A unipolar stepper motor features one center tapped winding per phase. Each section of windings is switched on for each direction of the magnetic field. In this arrangement, and because a magnetic pole can be reversed without switching the direction of the current, a simple commutation circuit (e.g., a single transistor) can be made for each winding. Typically, given a phase, the center tap of each winding is made common: by providing three leads per phase, or six leads, for a typical two-phase motor. Often, these two phase commons are internally joined so that the motor has only five leads.

A microcontroller or stepper motor controller can be used to activate the drive transistors in the right order, and this ease of operation makes unipolar motors popular with hobbyists; they are probably the cheapest way to obtain precise angular movements.

Bipolar Motors. A bipolar stepper motor features one winding per phase. The current in this winding must be reversed in order to reverse its magnetic pole; therefore the driving circuit must be more complicated – typically with an H-bridge arrangement. There are two leads per phase; none are common.

Because the windings in a bipolar stepper motor are better utilized, they are more powerful than a unipolar motor of the same weight due to the physical space occupied by the windings. A unipolar motor requires twice the amount of wire in the same space, but only half that wire is used at any one time; therefore a unipolar motor is 50% as efficient (or maintains approximately 70% of the available torque output). Though a bipolar stepper motor is more complicated to drive, the abundance of driver chips available on the market makes driving a bipolar stepper much less difficult to achieve.

Higher Phase-Count Stepper Motors

Stepper motors with multiple phases tend to produce much lower levels of vibration, though the cost of manufacture is higher. These motors tend to be called *hybrid* and feature more expensive machined parts and higher-quality bearings. Though they are more expensive, multiphase motors effect a higher power density and, with the appropriate drive electronics, are actually better suited to many types of applications in which single-phase steppers are currently used.

Microstepping a Stepper Motor

Microstepping, or *sine/cosine microstepping*, is a stepper motor drive technique in which the current in the motor windings is controlled to approximate a sinusoidal waveform. Microstepping produces a much smoother rotation than a full step drive and provides greater resolution and freedom from resonance problems, due to there simply being more steps per revolution. In a conventional full step drive, an equal amount of current is applied to each of a motor's stator coils. The magnetic rotor aligns itself in the coil's magnetic field. With each motor step, current is reversed in one of the coils, and the rotor realigns to the new magnetic field to move the rotor one motor step, or 90 degrees.

In microstepping, varying amounts of current are applied to a motor's coils so that the magnetic field smoothly transitions from one polarity to the next. Each full step is now divided into several *microsteps* of varying current to produce a larger number of magnetic fields that the rotor can align with. The result is smoother motor rotation, quieter operation, and greater motor resolution.

Applications that employ Stepper Motors

- Consumer electronics
- Automotive and aircraft
- Office printers and equipment
- Medical
- Industrial machines
- Scientific instrumentation
- Chemical
- Security
- Gaming

Advantages of Stepper Motors

- Low cost
- High reliability
- High torque at low speeds
- Simple, rugged construction that operates in almost any environment
- Precise 360-degree positioning control
- Smooth rotation at high speeds

Disadvantages of Stepper Motors

- Resonance effect often exhibited at low speeds
- Decreasing torque with increasing speed

Zilog Stepper Motor Control Offerings

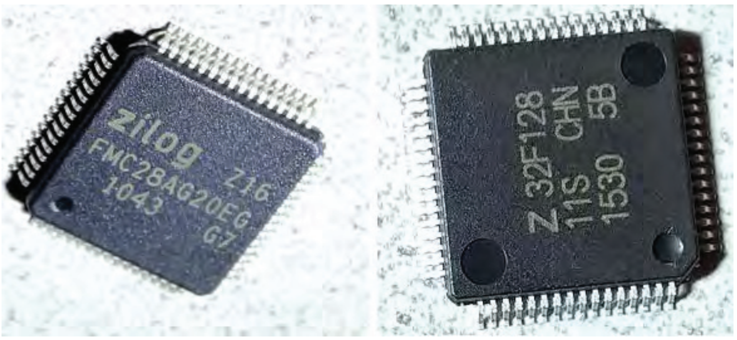
Z8 Encore!
Z8F2480, Z8F1680, Z8F0880

The Z32F128 ARM Cortex M3 and Z16FMC Architectures

Zilog's Z16FMC 16-bit and Z32F128 32-bit Cortex M3 architecture MCUs are optimized for multiphase AC and DC variable speed motor control to provide the power, punch, and performance to satisfy the most demanding application requirements.

The ZNEO CPU boasts a highly-optimized instruction set that achieves higher performance per clock cycle with less code space and lower overhead than competing architectures.

This powerful yet simple core with sixteen 32-bit general-purpose registers supports complex CISC addressing modes and a single-cycle instruction set that includes frame pointer support, multibit shift, and multiregister push/pop in addition to powerful 32-bit math operations.



Z16FMC and Z32F128 MCUs

The Z16FMC Series features a flexible multichannel pulse width modulator (PWM) timer module with three complementary pairs or six independent PWM outputs supporting deadband operation and fault protection trip input. These features provide multiphase control capability for a variety of motor types and ensure safe operation of the motor by providing pulse-by-pulse or latched fast shutdown of the PWM pins during fault conditions.

The Z16FMC Series also features up to twelve single-ended channels of 10-bit analog-to-digital conversion with a sample-and-hold circuit, plus one operational amplifier for current sampling and one comparator for overcurrent limiting or shutdown.

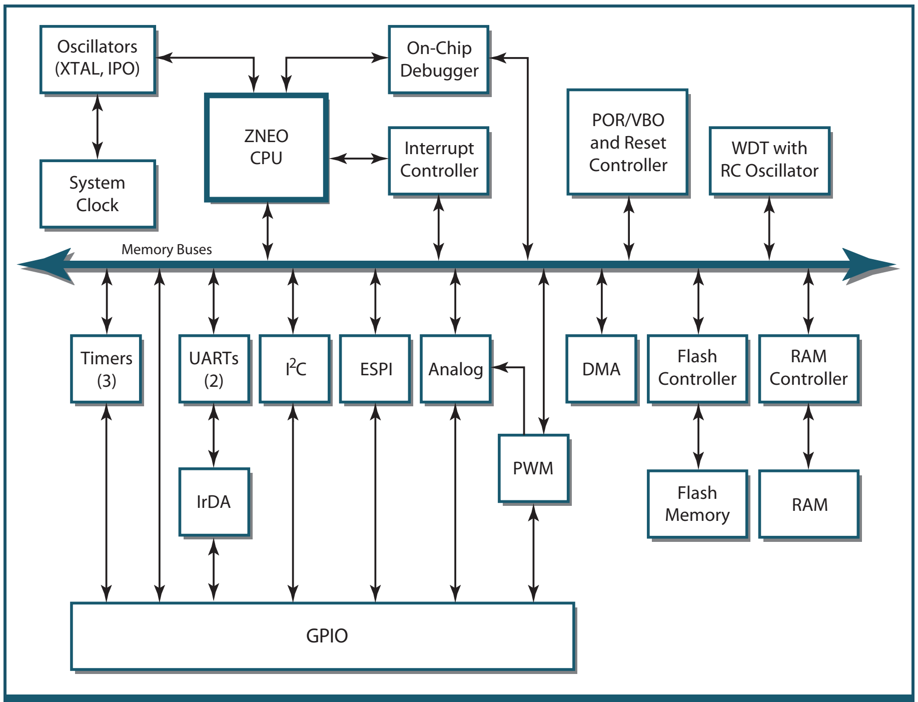
A high-speed analog-to-digital converter (ADC) enables voltage, current, and back-EMF sensing, while dual-edge interrupts and a 16-bit timer provide a Hall-effect sensor interface.

Two full-duplex 9-bit UARTs provide serial asynchronous communication and support the LIN serial communications protocol. The LIN bus is a cost-efficient Single Master, Multiple Slave organization that supports speeds up to 20 Kbps.

Features

The Z16FMC MCU offers the following key features:

- Up to 128 KB internal Flash memory with 16-bit access and In-Circuit Programming (ICP)
- 4 KB internal RAM with 16-bit access
- 12-channel, 10-bit Analog-to-Digital Converter (ADC)
- Operational Amplifier



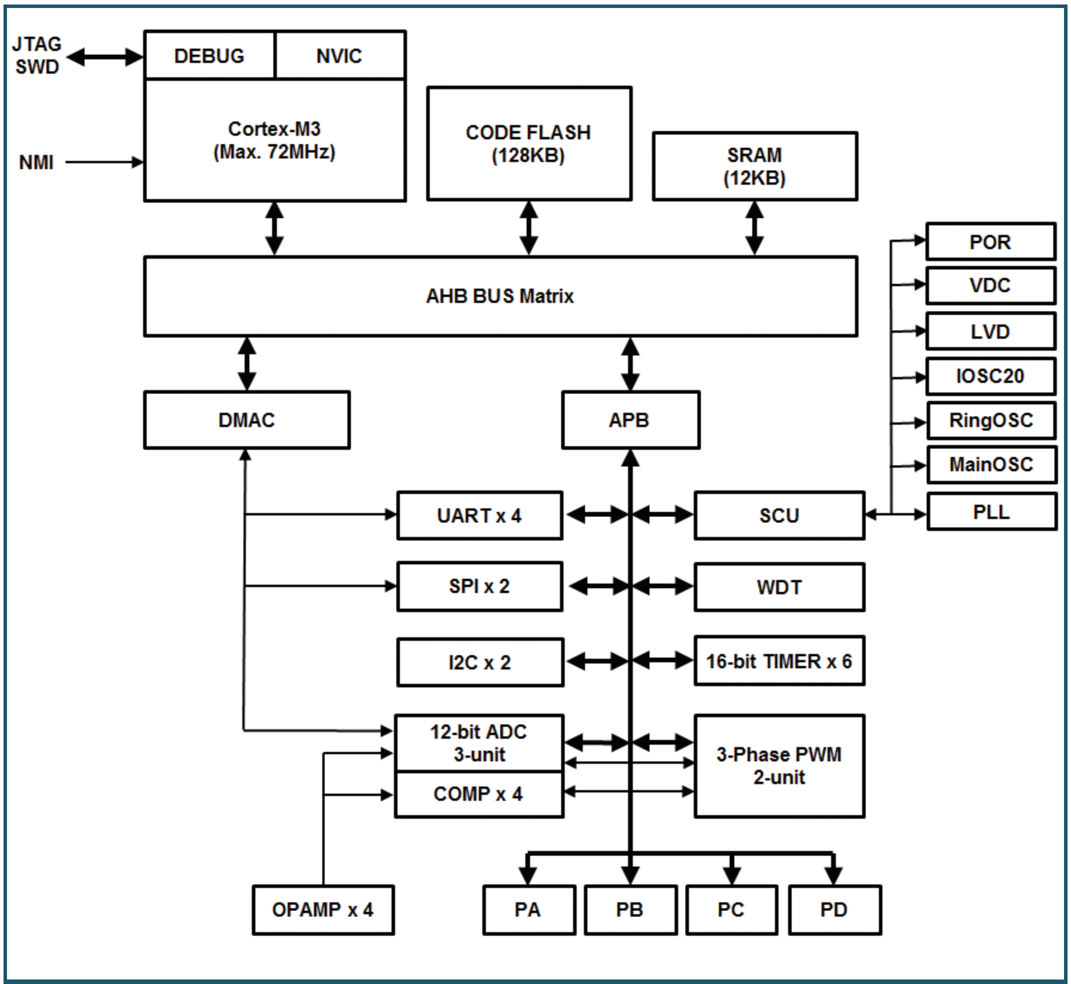
A Block Diagram of the Z16FMC MCU

- Analog Comparator
- 4-channel Direct Memory Access (DMA) controller
- Two full-duplex 9-bit Universal Asynchronous Receiver/Transmitters (UARTs) with LIN and IrDA support
- Internal Precision Oscillator (IPO)
- Inter-Integrated Circuit (I^2C) master/slave controller
- Enhanced Serial Peripheral Interface (ESPI)
- 12-bit Pulse Width Modulation (PWM) module with three complementary pairs or six independent PWM outputs with deadband generation and fault trip input
- Three standard 16-bit timers with Capture, Compare, and PWM capability
- Watchdog Timer (WDT) with internal RC oscillator
- 46 General-Purpose Input/Output (GPIO) pins
- 24 interrupts with programmable priority
- POR and VBO protection

The Z32F128 ARM Cortex M3 series has an RISC architecture with single cycle instructions particulary designed for motor control.

Features

- High performance low power MCU20Mhz internal oscillator up to 80Mhz used with PLL
  - 128K Flash
  - 12K SRAM
- Two inverter bridges six channel each for motor control applications configurable for:
  - ADC triggering functions
  - PWM interrupts on period and duty cycles
  - Edge aligned complementary mode
  - Center aligned complementary mode
  - Independent PWM (up count mode)
  - Over voltage and over current protection
- 1.5Msps high-speed ADC featuring up to three units with 16 channels and burst conversion function.



A Block Diagram of the Z32F128 MCU

- Analog Front End Peripheral
    - 4x OPAMPs
    - 4x Comparators
    - 6x General purpose 16-bit timers configurable for:
        - Capture compare
        - Continuous mode
        - PWM mode
- Serial communications:
    - 4x UART
    - 2x SPI
    - 2x I^2C
- Quadrature Encoder for four quadrant motor operation using 4 timers

MultiMotor Series Development Kit

Zilog's MultiMotor Series Development Kit is built upon the Z32F128 ARM Cortex and Z16FMC MCUs, yet is designed to allow additional MCU modules to be affixed to it for evaluation and development. These Z32F128, Z16FMC, Z8FMC 16100, and Z8051 MCU modules facilitate selection between terminal or hardware control of the motor and a number of driving schemes for its operation, plus the ability to monitor important motor parameters such as:

- Temperature
- Speed (in RPM for trapezoidal commutation, and in frequency for sinusoidal commutation)
- Current
- Bus voltage
- Total motor run time for maintenance-scheduling events
- Direction of shaft rotation
- Speed control (open or closed loop)

The MultiMotor Series Kit includes a Linix BLDC Motor

Zilog Motor Control Development Tools

ZNEO32!	Z8 Encore!	Z8051	S3
Keil MDK ARM Cortex IAR GCC for ARM Embedded Third Party	ZDSII – ZNEO ZDSII – Z8 Encore!	Keil µVision IDE Third Party	Third Party

Zilog Motor Control Solutions

To learn more about Zilog's MultiMotor Series products, navigate your browser to http://zilog.com/mc, or contact your nearest Zilog Sales Office at http://zilog.com/sales.