Space Vector Modulation of a 3-Phase AC Induction Motor with the Z16FMC ZNEO Microcontroller

AN037602-0116

Abstract

Space Vector Modulation (SVM) techniques can be applied to AC induction motors (ACIM), permanent magnet synchronous motors, and BLDC motors. A 3-phase ACIM is controlled by creating a rotating voltage reference vector within a hexagon. The speed of rotation of this voltage reference vector determines the frequency of motor rotation. The Space Vector Modulation application discussed in this application note uses the Voltage per Hertz (V/F) control principle with or without a Hall sensor functioning as a tachometer for speed feedback to control an ACIM motor.

Continual cost pressures and increased consumer expectations have driven design engineers to seek minimal hardware solutions that extract maximum performance from motors used in consumer goods. This application note demonstrates how Zilog's Z16FMC MCU can implement an efficient and cost-conscious V/F vector modulation of an AC induction motor.

> **Note:** The source code file associated with this application note, AN0376-SC01, is available free for download from the Zilog website. This source code was tested with version 5.0.1 of ZDSII for ZNEO MCUs. Subsequent releases of ZDSII may require you to modify the code supplied with this application.

Z16FMC Series Flash Microcontrollers

The Z16FMC Series of Flash MCUs is based on Zilog's advanced 16-bit ZNEO CPU core. The MCUs in this series are optimized for motor control applications and support control of single- and multi-phase variable-speed motors. Target applications include consumer appliances, HVAC systems, factory automation, refrigeration, and automotive applications.

To rotate a 3-phase motor, three AC voltage signals must be supplied and phase-shifted 120° from each other. To control a 3-phase motor, the MCU must provide six Pulse Width Modulation (PWM) outputs. The Z16FMC Series Flash MCU features a flexible PWM module with three complementary pairs – or six independent PWM outputs – supporting deadband insertion and fault protection trip input. These features provide multiphase control capability for multiple motor types and ensure that the motor operates safely by effecting an immediate shutdown of the PWM during a fault condition.

Discussion

An electric motor consists of a stator and a stationary frame in which a rotating component, or *rotor*, is mounted on a shaft and bearings. In a 3-phase ACIM motor, the stator is laced with three sets of inductor windings energized by three AC voltage inputs that are phase-offset 120° from each other to produce a rotating field of magnetic flux. This stator flux field induces a voltage onto the rotor which also generates a rotor flux field which then interacts with the stator flux field, resulting in torque on the output shaft.

In a 3-phase motor control application, the input to the motor is produced by a 3-phase inverter bridge consisting of six switching devices. This inverter bridge forms three legs, each operating in complementary PWM. Each leg or MOSFET pair connects to either the ground voltage or the bus voltage depending on the ON/OFF state of the MOSFETS, which are controlled by the PWM signals from the ZNEO microcontroller. The microcontroller applies sinusoidal changing PWM signals to this inverter bridge to generate three approximately-sinusoidal AC waveforms on the bridge outputs to which the ACIM motor is connected, with the required 120° phase offset.

The duty cycle of each microcontroller's PWM output is varied, to control the period and amplitude of the generated AC signal, which in turn determines the speed and torque of the motor.

Theory of Operation

When a constant ratio of applied frequency and voltage is maintained, a constant flux throughout a wide operating range is created in the air gap between the rotor and the stator. This control method is referred to as *Voltage per Frequency*, or V/F control.

In this application, using the V/F method, space vector modulation is the means by which a rotating magnetic field is created in the stator, and via induction, ultimately in the rotor. Space vector modulation techniques utilize an additional fifteen percent of the available bus voltage, thereby increasing the efficiency of the motor. The space vector modulation scheme applied here is referred to as alternate-reverse switching. This technique minimizes inverter switching and therefore, linear switching power losses. Intrinsic to ACIM motors is the *slip frequency,* which is the difference between the synchronous speed of the stator and rotor flux fields. This slip frequency must be controlled with a V/F profiler as discussed later in this document.

Using ordinary sinusoidal PWM techniques, the neutral point of the phase voltages are confined to Vbus/2, as shown in Figure 1.
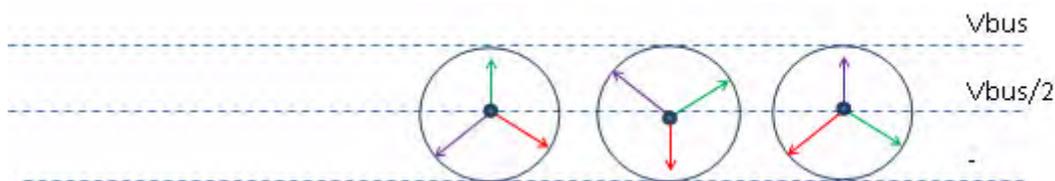
Figure 1. Neutral Point Confinement of Sinusoidal PWM Phase Voltages

The advantage of space vector modulation is that the neutral point of the phase voltages is not constrained to one-half of the bus voltage, as illustrated in Figure 2.
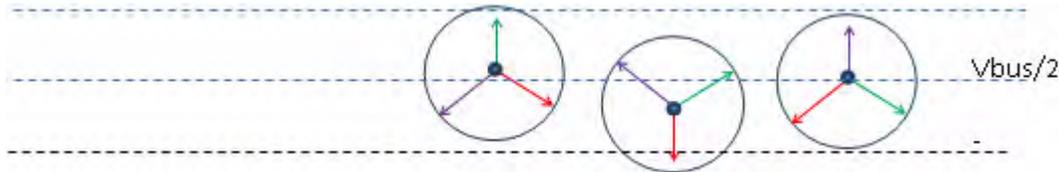
Figure 2. Space Vector Modulated Phase Voltages not Confined to a Neutral Point

Additionally, unlike sinusoidal PWM, which generates sinusoidal currents separately in each push/pull stage of the inverter, the Volt per Hertz (V/F) space vector modulation technique operates the entire inverter as a single unit to produce sinusoidal currents. In doing so, the inverter is operated in eight different states within the hexagon. Two of these states are referred to as zero vectors because they produce no voltages. The remaining six states produce non-zero voltages. The rotating reference voltage V_S within this hexagon, shown in Figure 3, is represented by a space vector V_S in Equation 1, which follows.
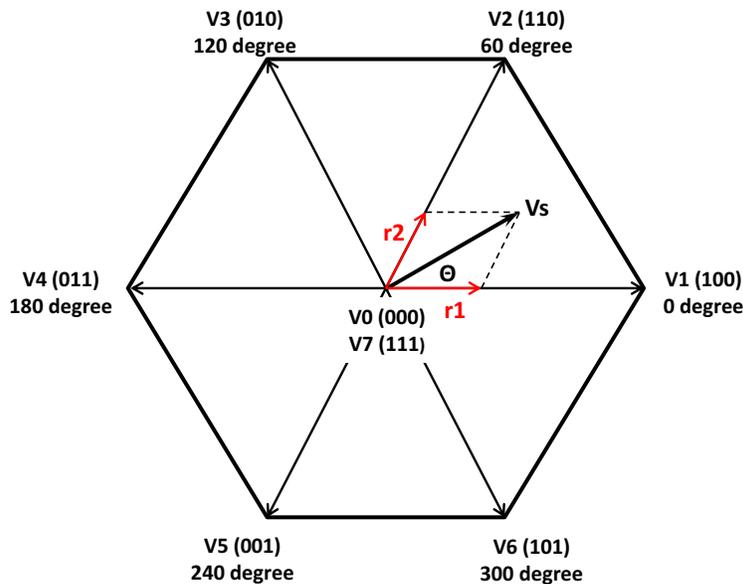
Figure 3. The Rotating Reference Vector V_{REF} Within The Hexagon

Equation 1

$$V_S = \frac{Vmag}{Vbus} \times e^{j\theta}$$

The $e^{j\theta}$ part of Equation 1 can be represented by Euler's identity in Equation 2, which states that the V_S vector is comprised of a real component and an imaginary component.

Equation 2

$$e^{j\theta} = \cos(\theta) + j\sin(\theta)$$

This V_S vector is formed, as shown in Equation 3, in which sinusoidal voltage changes present at each motor phase winding produce sinusoidal currents in each phase to generate magnetic flux fields, as shown in Equation 4.

Equation 3

$$V_S(t) = V_a \times (t) \times e^{j0} + V_b \times (t) \times e^{j120} + V_c(t) \times e^{j240}$$

Equation 4

$$B_S(t) = \frac{N_S \times \mu_0}{2 \times L_g}\left(i_a(t) \times e^{j0} + i_b(t) \times e^{j120} + i_c(t) \times e^{j240}\right)$$

In Equation 4, N_S is the number of inductor turns, μ_0 is the permeability of space, and L_g is the air gap.

The reference vector V_S must be converted to the appropriate switching signals and applied to the inverter bridge using Equation 5.

Equation 5

$$V_S = (r1 \times v1) + (r2 \times v2)$$

As indicated in Equation 5, to generate this rotating vector V_S, the angular position within any two base vectors, the base vectors themselves, and the scalar coefficients r1 and r2 must be known, as shown in Figure 3.

After learning the angle theta of rotation and the adjacent base vectors within the hexagon, the scalar coefficients for the adjacent base vector r1 and r2 must be calculated to time-modulate the base vectors V1 and V2 to generate the rotating voltage reference vector V_S within the hexagon. This space vector can be located anywhere between any of the base vectors V1 to V6. This commutation scheme is different from the six-step commutation scheme which has six distinct commutation steps per electrical revolution.

Figure 4 shows the location of the reference vector V_S, which is located between base vectors V1 and V2.
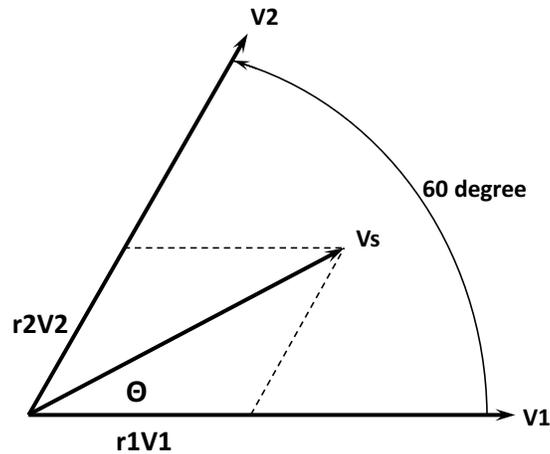
Figure 4. The Location of Reference Vector V_S Between Base Vectors V_1 and V_2

After the angular information is obtained, the scalar quantities r1 and r2 are calculated by equations 6 and 7.

Equation 6

$$r2 = m\sqrt{3} \times \sin(\Delta\theta)$$

Equation 7

$$r1 = m\sqrt{3} \times \sin(60 - \Delta\theta)$$

In the above equations, m is the magnitude of the rotating space vector V_S within the hexagon and θ is the angle of the reference vector V_S with respect to the base vectors V1 and V2.

The time duration for which the adjacent base vectors are modulated to obtain the reference vector is calculated by using equations 1, 2, and 3 to compute equations 8 through 10.

Equation 8

$$T0 = (1 - r1 - r2) \times T$$

Equation 9

$$T1 = r1 \times T$$

Equation 10

$$T2 = r2 \times T$$

In these equations, T is the sum of T0, T1, and T2 and cannot be greater than the time period of the PWM. Next, T0 becomes the time period for which either or both zero vectors are applied in combination with T1 and T2, as shown in Figure 5.
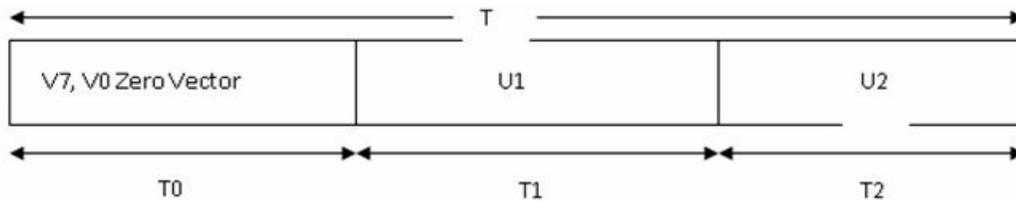
Figure 5. The Switching Times for Base Vectors V1, V2, and Zero Vectors

To find the time values T0, T1, and T2, the angles are determined by using V1 as the reference axis going counterclockwise to find the base vector angle to be subtracted from the angle of the reference vector.

For example, using Equation 1, if the bus voltage is 24 V and the desired reference vector magnitude is 12 V, then the reference vector V_S is calculated using Equation 11.

Equation 11

$$V_S = \frac{V_{mag}}{V_{bus}} \times e^{j190}$$

In Equation 11, the angle is 190° and the adjacent base vector is V4, which is 180°. Therefore, r1 and r2 are calculated by using equations 6, 7, and 8 to compute equations 12 and 13.

Equation 12

$$r1 = \sqrt{3} \times \frac{12}{24} \times \sin[60 - (190 - 180)] = 0.663$$

Equation 13

$$r2 = \sqrt{3} \times \frac{12}{24} \times \sin(190 - 180) = 0.15$$

If the PWM period is T = 50 µs, then the time duration for either zero vector V0, V7 is shown in equations 14 through 16.

Equation 14

$$T0 = (1 - r1 + r2) \times T = 9.3\mu s$$

The time duration for T1 is calculated using Equation 15.

Equation 15

$$T2 = r1 \times T = 33.2\mu s$$

The time duration for T2 is obtained from Equation 16.

Equation 16

$$T2 = r2 \times T = 7.5\mu s$$

Space vector modulation has an advantage over ordinary sinusoidal modulation because it allows for different switching combinations. For example, using T1 and T2 based on the choice of the null vectors which are applied for duration of time T0 and applying the zero vectors V0, V7, or both, results in different switching patterns to generate either less total harmonic distortion or to reduce linear switching power losses in the switching devices. V0, V7 zero vectors may be used to obtain the regenerative braking effect, especially when using ACIM.

For example, to reduce linear switching losses, either of the V0 or V7 zero vectors can be applied in sequence. V0 is applied as the zero vector in the sequence T1–T2–T0; the V7 zero vector is used in the same sequence. In either case, each of the three phases in the inverter does not switch for one third of the duration of a cycle.

Different combinations of switching sequences can be applied, but may have different, and perhaps undesirable effects on the inverter circuit, depending on the size of the boot-strap capacitors used for the high- and low-side drivers. However, space vector modulation allows for a variety of switching schemes to obtain the desirable effect and meet customer-specific requirements. This application note uses the alternate reverse switching mode, in which each column corresponds to vectors one through six, as shown in Figure 6.

PhaseA=T1+T2+0.5T0	PhaseA=T1+0.5T0	PhaseA=0.5T0	PhaseA=+0.5T0	PhaseA=T2+0.5T0	PhaseA=T1+T2+0.5T0
PhaseB=T2+0.5T0	PhaseB=T1+T2+0.5T0	PhaseB=T1+T2+0.5T0	PhaseB=T1+0.5T0	PhaseB=0.5T0	PhaseB=0.5T0
PhaseC= 0.5T0	PhaseC=0.5T0	PhaseC=T2+0.5T0	PhaseC=T1+T2+0.5T0	PhaseC=T1+T2+0.5T0	PhaseC=T1+0.5T0

Figure 6. Example of PWM Timings Using an Alternate-Reverse Switching Mode

In the reverse switching mode, only one inverter leg at a time switches to reduce linear power-switching losses. The null vectors are alternated upon each space vector modulation sequence in reversed order after each zero vector, as shown in Figure 7.

T1 - T2 - T0 - T0 - T2 - T1

Figure 7. space Vector Modulation Sequence

Application

To apply the space vector theory, the Z16FMC microcontroller's PWM module is configured to operate in three complementary output pairs. Each output pair controls one complementary source/drain transistor pair in the inverter bridge. The PWM module is configured to insert a deadband between ON states to prevent leakage that might occur if one transistor in a pair turns on before the other is fully off. Each PWM output pair produces a stream of complementary on/off pulses to activate the corresponding source or drain transistor in the inverter bridge. The voltage of each bridge output varies with the source/drain pulse duty cycle. The input to the space vector modulation software function is the angle and the magnitude.

The period of each PWM cycle is configured to be 50 μs and generates an interrupt request at the end of each cycle to process the speed integration to form the angle, the vector decomposition based on the angle, and the space vector modulation voltages based on the magnitude. This data is then loaded into the three PWM registers for Phase A, Phase B, and Phase C.

The simplest way to control an ACIM is via the V/F method without any sensing feedback of the rotor. The speed demand comes from a potentiometer to calculate the frequency demand with a constant proportional frequency to voltage ratio. However, if the Hall sensing feedback option is desired, then a single Hall sensor is used as a tachometer to determine the speed of the motor. Additionally, the motor can be operated in either open loop or PI closed loop control. With the PI closed loop method, the Timer 0 ticks are captured at every rising edge of the Hall and compared to the requested speed received through a UART terminal or potentiometer, when in Standalone Mode. The frequency of the rotating vector is calculated as shown in Equation 17.

Equation 17

$$\text{Frequency} = \frac{\text{Look-Up Table offset}}{\text{PWM period} \times \text{Look-UpTable size}}$$

In the above equation, the Look-Up Table (LUT) offset value is a 16-bit integer index of which only the upper byte is used to select the LUT entries. The synchronous speed of the rotor is calculated as shown in Equation 18.

Equation 18

$$\text{RPM} = 120 \times \frac{\text{Frequency}}{\text{Poles}}$$

The Timer 0 ticks captured for the PI loop are calculated as shown in Equation 19.

Equation 19

$$TimerTicks = \cfrac{\cfrac{MCU\ clock}{Timer0\_prescaler}}{\cfrac{LUToffset}{PWM\ period \times LUTsize}}$$

To change the frequency of the motor, the upper byte of a 16-bit interpolating sine table index is used to fetch the next PWM sine value from the LUT. Assuming the sine frequency is 60 Hz, the offset value for the sine table pointer is calculated as shown in Equation 20.

Equation 20

$$SineIndexOffset = \frac{60 \times 65536}{20000} = 196$$

In the above equation, 20000 is the PWM frequency.

The (rounded) offset value represents the frequency demand, which is integrated to form the (theta) angle of the rotor. The upper byte of the theta value then becomes the index to the 256 sine value table.

Depending on the frequency demand, the values of the upper byte of the sine index can change with higher granularity, hitting each sine array value more or fewer times while the sine index continuously rolls over. Using this method, the lowest period using a16-bit pointer to a 256-element sine table is represented by Equation 21.

Equation 21

$$65535 \times 50\mu s = 3.277\ seconds$$

Because of the interpolating index method, the increment values in the upper byte of the sine table index will be small, changing only in fractions to achieve higher frequencies.

Speed Calculations

The angular time periods of the rotor are represented by elapsed timer ticks and are captured upon each rising edge of the Hall interrupt as described in the previous section. These timer ticks are then compared with the demand speed coming from a potentiometer in Standalone Mode, or from the UART when in Terminal Mode. The captured timer ticks period represents the actual speed of the motor and is compared with the demand value for closed-loop operation.

The angular speed is represented by Equation 22.

Equation 22

$$\omega = \frac{d}{dt} \times \theta$$

In the above equation, θ is $2 \times \pi \times f$

The RPM of the motor in this application is calculated using Equation 23.

Equation 23

$$RPM = \frac{120 \times F}{N}$$

In the above equation, N is the number of poles and F is the frequency. By substitution, use Equation 24 to obtain the RPM.

Equation 24

$$RPM = \frac{120 \times \dfrac{tableIndexValue}{PWMperiod \times SineTableSize}}{N}$$

Voltage per Hertz Control

As shown in Figure 8, the base frequency is at the maximum flux field with the speed at full armature current and voltage.
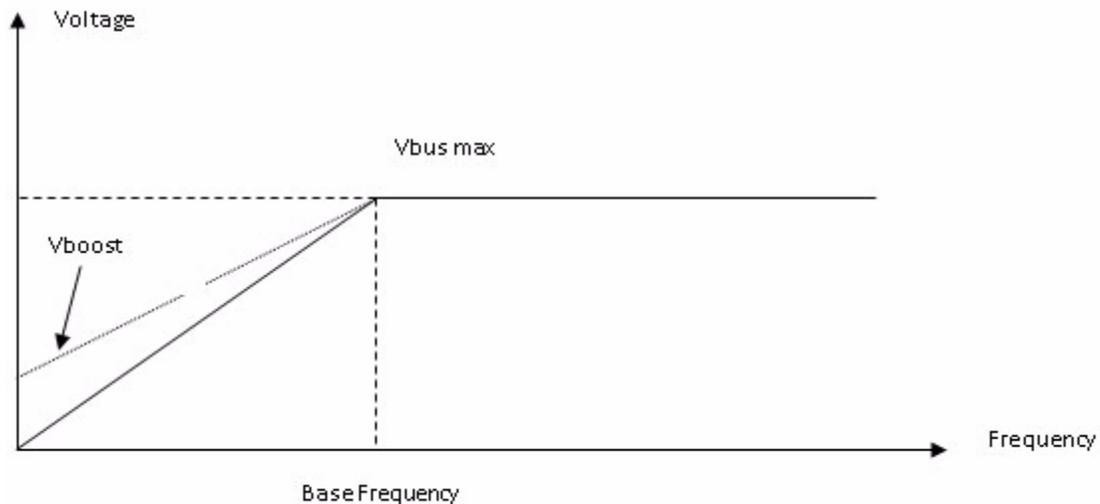
Figure 8. Voltage Per Hertz Control

The software algorithm ensures that the ratio of voltage and frequency remains constant over the full speed range to maintain a constant flux field in the air gap of the motor. A boost voltage, or minimum voltage and frequency limit, is implemented to avoid high currents through the motor windings at very low speeds in which the complex reactance of the motor windings is very low. In this application note, the total reactance of the motor is represented by Equation 25.

Equation 25

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

In the above equation, R is the real resistance and X_L and X_C are the inductor reactance and capacitive reactance, respectively.

V/F Profiler and Slip Frequency

Slip frequency is intrinsic to AC induction motors. In an AC induction motor, the stator flux field is rotating at synchronous speed according to the sinusoidal frequencies of the currents that produce this stator flux field. The resulting induced flux field in the rotor interacts with the stator flux field and causes a torque to rotate the motor at the synchronous speed minus a frequency that is referred to as *slip frequency*. In effect, the rotor frequency is always less than the stator field frequency, which is necessary because only an alternating current field can induce a voltage in the rotor. If the rotor frequency and stator frequency were the same (from the perspective of either stator or rotor), there is no alternating field and therefore no voltage is induced to cause a torque from the interacting rotor and stator force field. This electromagnetic behavior is depicted in Equation 26.

Equation 26

$$V_S = L_S \times \frac{d}{dt} \times I_S$$

In the above equation, the subscript S refers to the stator. This equation states that the rate of change of current through an inductor induces a voltage. This alternating stator voltage induces a voltage onto the rotor to cause an alternating current in the rotor, with a resulting rotating flux field in the rotor.

The interaction of rotor and stator flux fields must be controlled with a V/F profiler. If the Hall sensor option with closed loop feedback is enabled in the firmware, it is possible that the closed loop will adjust the stator frequency faster than the rotor frequency can respond, so that the stator frequency will run off, causing the slip frequency to become too large and subsequently stall the motor. Additionally, if the rate of deceleration is too high, the slip frequency becomes too large while the potentially damaging excessive Back-Electromotive Force (BEMF) voltage is fed back to the supply, unless the generated BEMF voltage is desired during deceleration for regenerative braking or battery-charging purposes. To control the slip frequency and its associated effects, a V/F profiler is implemented to control the rate of frequency changes.

If the option to operate the ACIM with Hall sensing feedback and no closed loop speed control is enabled, the slip frequency is dynamically calculated and optimized, based on the rotor frequency information which is provided by the Hall sensor.

> **Note:** The ACIM motor used for this application is a BOSCH 250 V, 2 A motor (500 W) shown in Figure 10 on page 14. However, for development purposes with Zilog's MultiMotor Control Development Kit, this software was designed to operate the motor at 30 V. Therefore,

the V/F profiler may require adjusting for acceleration and deceleration rates when operating a customer ACIM at higher voltages.

Equipment Used

The following equipment is used for the setup to demonstrate the V/F space vector modulation technique. The first four items are contained in the MultiMotor Development Kit (ZMULTIMC100ZCOG).

• MultiMotor Development Board (99C1358-0001G)

• 24V AC/DC power supply

• LINIX 3-phase 24VDC, 30W, 3200RPM BLDC motor (45ZWN24-30)

• Opto-Isolated UART-to-USB adapter (99C1359-001G)

• Z16FMC MultiMotor MCU Module (99C1357-001G) – Order separately

• Opto-Isolated USB SmartCable (99C0968) – Order separately

• BOSCH ACIM 2A/250V

• 30V AC/DC external power supply

• Yokogawa DL9140L and Tektronix DPO 2014B digital oscilloscopes

Hardware Setup

Figure 9 shows the application hardware connections required to operate the motor with the space vector modulation method.
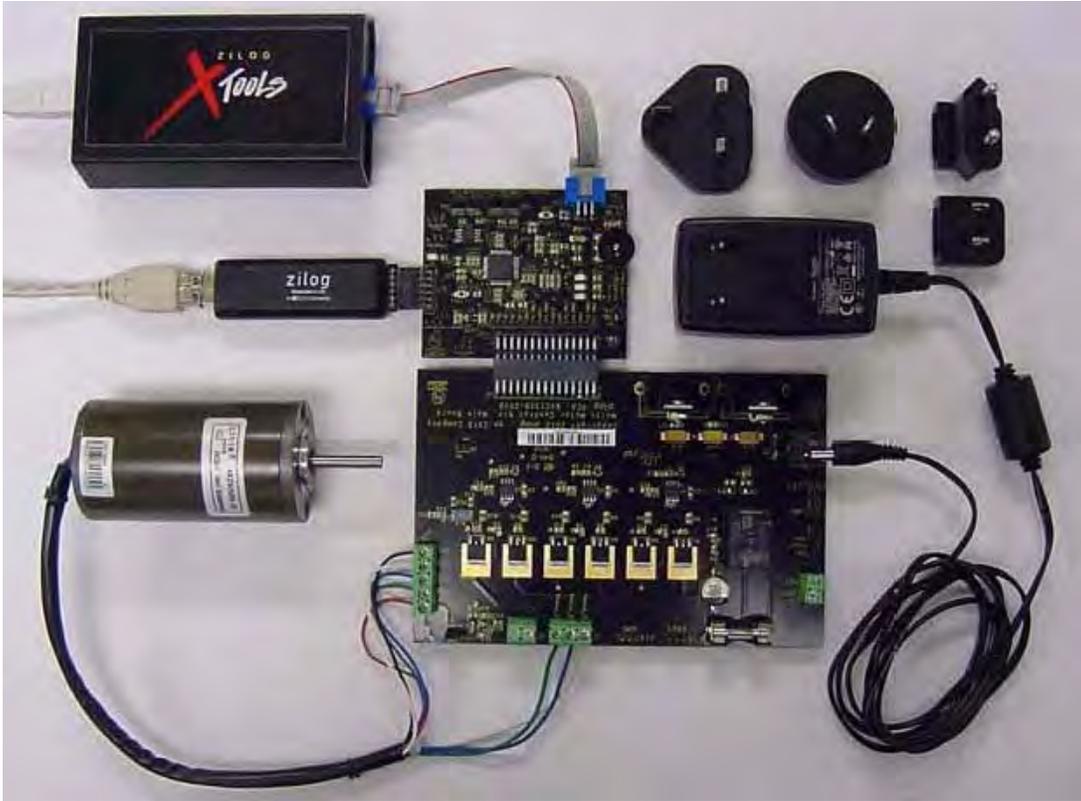
Figure 9. MultiMotor Demo Kit and Linix BLDC Motor

Figure 10 displays the BOSCH AC induction motor used for the development of the code for this application note.

Figure 10. BOSCH AC Induction Motor

Testing Procedure

Observe the following procedure to test the 3-phase Sensorless BLDC Motor Control demo program on the Z16FMC MultiMotor MCU Module.

1. Install the ZDSII–ZNEO version 5.0.1 (or newer) software on your PC.

2. Connect the Opto-Isolated USB SmartCable to the PC.
   – To install the driver of the Opto-Isolated USB SmartCable, refer to the Opto-Isolated USB Smart Cable User Manual (UM0195).

3. Connect the hardware as shown in Figure 9. To learn more, refer to the MultiMotor Series Development Kit Quick Start Guide (QS0091); however, disregard instructions regarding the BLDC motor connection.

4. Instead of connecting the included BLDC motor as shown in Figure 9, connect your ACIM motor phase wires to terminal J1 and the tachometer wires to J5. Then set jumper J4 to AC, as shown in Figure 11.
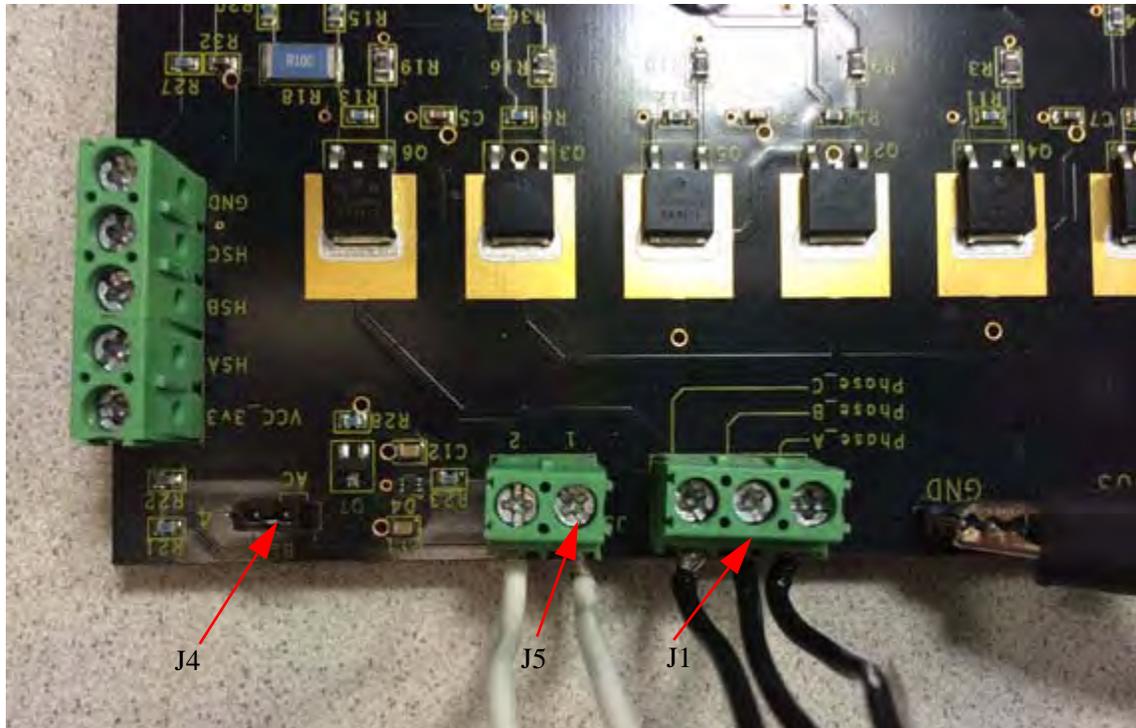
Figure 11. Motor Phase Wire Connections

> ➤ **Note:** The order of the phase wire connectivity affects the spin direction of the motor but is otherwise irrelevant. The 24 V power supply that is included in the kit may not suffice.

5. Power up the MultiMotor Series Development Board by connecting the 24 V DC adapter included in the kit to P1 on the Development Board.

6. Open the AN0376-SC01 project in ZDS II for ZNEO.

7. Download the code to the Z16FMC MultiMotor MCU Module.

8. In ZDS II, stop the Debug Mode. Unplug the power supply from the MultiMotor Series Development Board, then disconnect the Opto-Isolated USB SmartCable.

9. Ensure that the RUN/STOP switch on the MultiMotor MCU Module is in the STOP position.

10. Set Jumper J9 to the EXT position.

11. Reconnect the 24 V DC adapter to connector P1 on the Development Board. This will provide power to the control circuits.

12. Connect a 30 V supply source to the MultiMotor Series Development Board at J7 with ground (GND) and VDD (EXT) respectively. This will provide power to VBus.

13. Set the RUN/STOP switch on the MultiMotor MCU Module to RUN.

14. Set the direction of the rotation of the motor by changing the position of the direction switch on the MultiMotor Series Development Board.

15. Connect Zilog's Opto-Isolated UART-to-USB cable from J19 to the PC's USB port.

16. Open any terminal emulation software program such as RealTerm or HyperTerminal and select the USB port for communications to start the terminal mode. Figure 12 shows the console display in Hardware Control Mode.
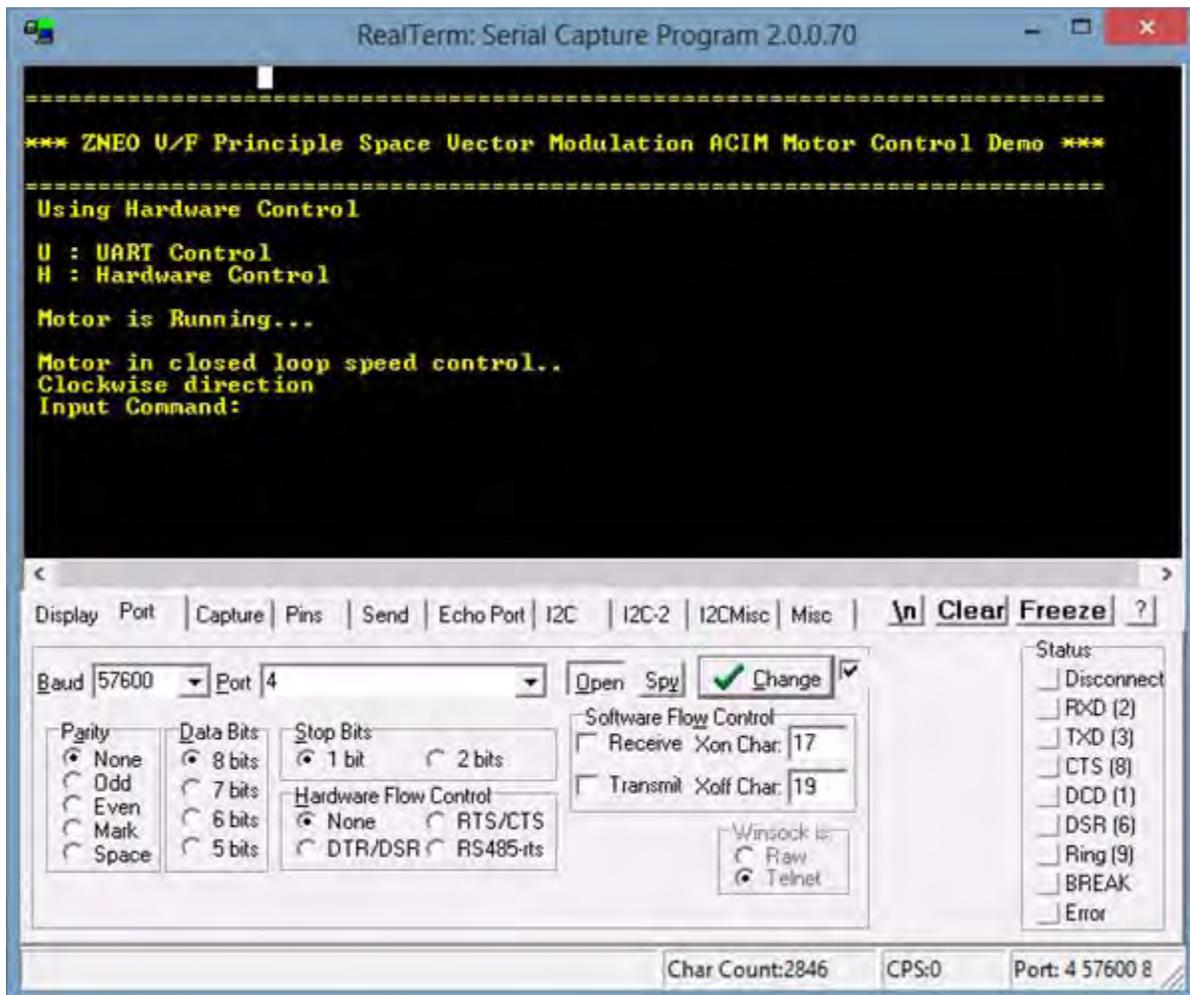
Figure 12. Console Display in Hardware Control Mode

17. On the open terminal window, enter the letter **U** on your keyboard to enter UART Control Mode to control the motor by entering commands on the computer keyboard. Figure 13 shows the console display in UART Control Mode.

Figure 13. Console Display in UART Control Mode

18. In the window that appears, enter the letter **S** to start the motor operation, and enter any of the available operation options.

19. A data logger is used to report vital motor control data, as shown in Figure 13. The data displayed includes:
    – Operating temperature
    – Speed
    – Operating current
    – Total run time
    – Spin direction

20. Upon entering **D**, recorded data is displayed in a continuous fashion. To stop this data display from continuing, enter a Ctrl+C command, as shown in Figure 14.
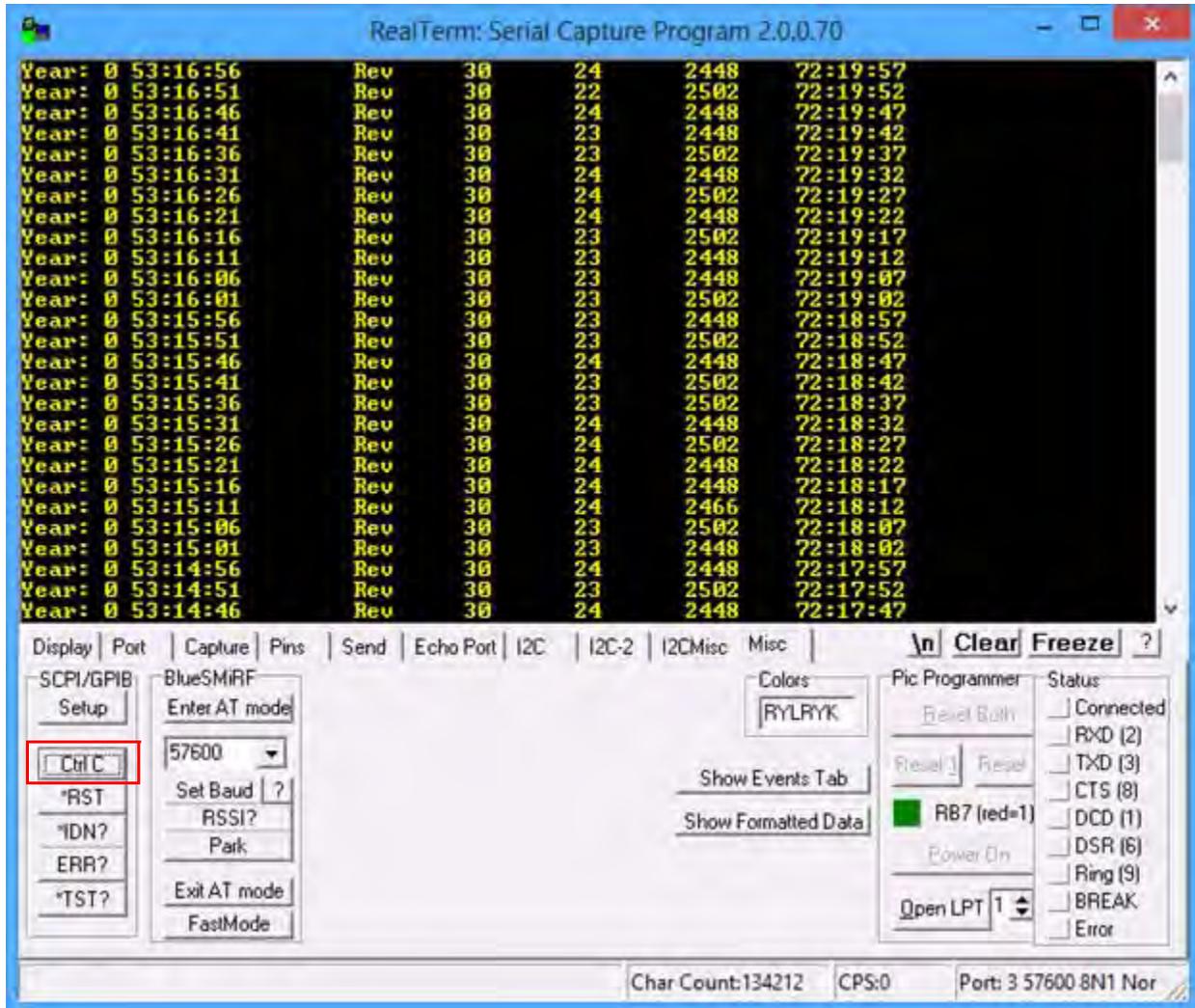
Figure 14. Enter a Ctrl+C Command to Stop the Display of Recorded Data

You can now add your application software to the main program to experiment with additional functions.

Results

Three oscilloscope probes were connected to the MultiMotor Series Development Kit to Phase A, Phase B, and Phase C to show three alternate reverse switching patterns. Scope probes were connected to the BEMF voltage dividers to monitor the generated BEMF voltages and to view the associated switching pattern waveforms.

Figures 15 through 17 show the alternate-reverse space vector modulation pattern on Phase A, Phase B, and Phase C at three different time instances.
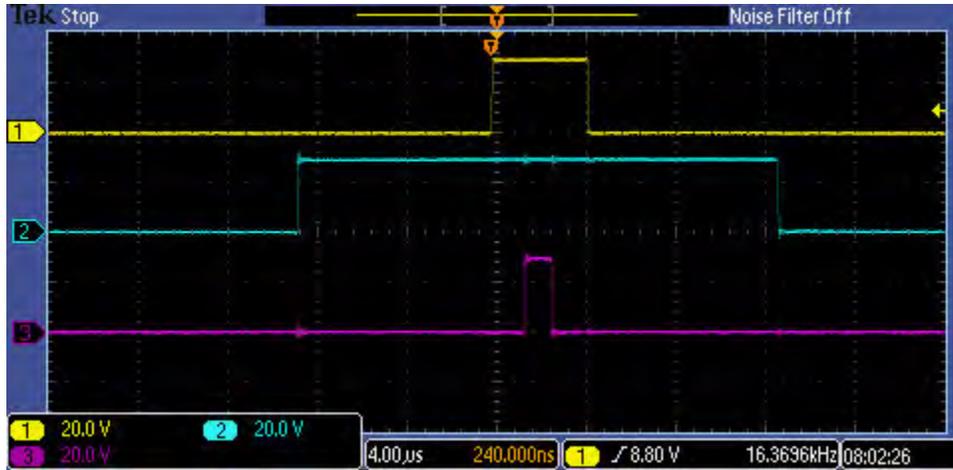
Figure 15. Alternate Switching Pattern at Time 1
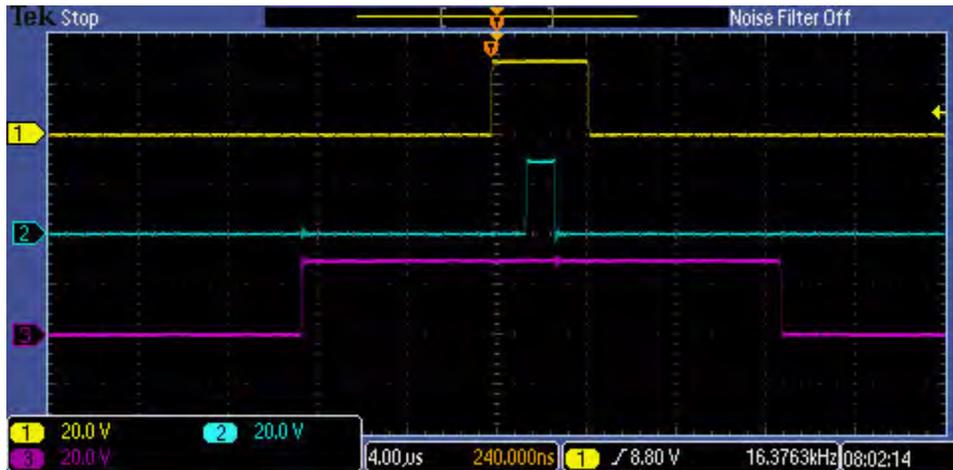
Figure 16. Alternate Switching Pattern at Time 2

Figure 17. Alternate Switching Pattern at Time 3

Figure 18 shows the three phase voltages and one of the three current wave forms (shown in green).
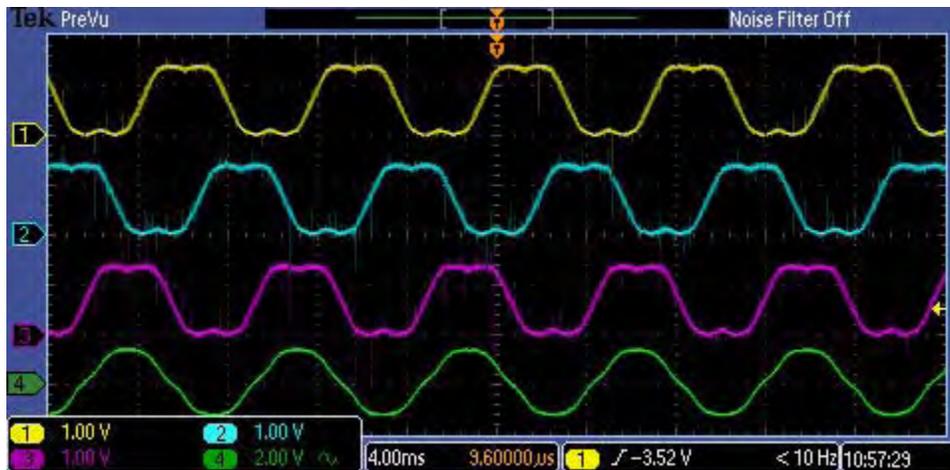
Figure 18. Three Phase Voltages and One Current Wave Form (Green)

Alternate-reverse voltage wave forms have been measured with the oscilloscope at the BEMF voltage dividers consisting of R24, R29, C30 (BEMF_A), R25, R30, C31 (BEMF_B), and R26, R31, C32 (BEMF_C).

Code Execution Time of Relevant Functions

The time required for code execution of relevant functions is listed in this section. Execution times are based on the external 20 MHz clock frequency.

PWM interrupt service code: 6.5 µs

Tachometer interrupt service: 6μs

SVM decomposition function call (SVM timing calculations): 2.5μs

Compiler Optimization Settings

Ensure that the following Compiler Optimization options are set:

- **Limit optimizations for easier debugging** box is not checked.
- **Use register variables** box is checked
- **Generate printfs inline** box is checked
- Default type of char is **Unsigned**

Code Size

The rounded-down code size is:

- Flash: 6K of 128K
- RAM: 2K out of 4K

Summary

The purpose of this application note is to demonstrate the operation of an ACIM-type machine using the Space Vector Modulation technique with the Voltage per Hertz (V/F) principle. To obtain a constant flux in the air gap, the ratio of voltage and frequency is held constant throughout the speed range of the motor. To generate sinusoidal voltages and currents, a voltage reference vector is rotated 360° within a hexagon. Each of the six sectors within this hexagon creates unique switching patterns for space vector modulation. Space vector modulation has the advantage of utilizing about fifteen percent more of the available bus voltage and the freedom to implement multiple forms of SVM switching patterns to meet design-specific requirements. The space vector modulation scheme discussed here uses an alternate-reverse switching pattern.

Formulas are shown to calculate the space vector modulation timings and resulting motor frequency. Because the frequency calculations include the PWM period, all space vector sinusoidal wave constructions are executed in the PWM interrupt service routine. The execution time for the sine wave reconstruction in the PWM interrupt service routine is approximately 6.5μs. The execution time of the tachometer interrupt service routine is approximately 6μs. Both of these execution times are based on a 20MHz external clock. The tachometer interrupt service routine captures the Timer 0 ticks upon each rising edge interrupt of the Hall for open- and closed-loop speed calculations. The calculated speed value from the timer ticks is integrated in the PWM interrupt service routine to form the interpolating 16-bit theta angle variable, of which only the high byte is used to fetch the next value from the sine LUT.

In essence, all speed calculation values are offset to the interpolating 16-bit sine LUT index. Depending on the demand speed, these values will increase or decrease the frequency of rotation of the reference vector. Space vector modulation has the advantage of

commutating the ACIM with less acoustical and electrical noise and, depending on the switching scheme, fewer linear power switching losses. The effects of total harmonic distortions and linear switching power losses can be further manipulated by applying different space vector modulation switching schemes. This technique allows for higher life expectancy of ripple current capacitors and ball bearings because the sinusoidal commutation approach causes virtually no torque or current ripple in an ACIM motor.

A simple V/F profiler and slip frequency is also discussed, and a V/F profiler is implemented to account for the rates of frequency increase and decrease to control the slip frequency.

The example application and techniques described in this document should prove helpful for anyone who intends to develop motor control applications based on the Z16FMC series of microcontrollers.

References

To learn more about this topic and the Z16FMC Series of motor control products, refer to the documents listed in Table 1.

Table 1. List of References

Topic	Document
ZNEO CPU	ZNEO CPU User Manual (UM0188)
Z16FMC MCU	Z16FMC Series Motor Control Product Specification (PS0287)
Motor Control	*Motor Control Electronics Handbook*; Richard Valentine, McGraw Hill
	Short Course on Electric Drives: Understanding Basics to Advanced Control & Encoderless Operation: a recording of the Internet-based short course presented on May 12, 2005 by Professor Mohan and edited to fit on a DVD; Ned Mohan, University of Minnesota, 2005.
	Lehrstuhl fuer Elektrische Antriebssysteme und Leistungselectronik; Ralph Kennel, Technische Universitaet Muenchen.
	Electric Machinery; Peter F. Ryff.

Appendix A. Schematic Diagrams

Figures 19 and 20 show the schematic diagrams for the Z16FMC MCU Module.
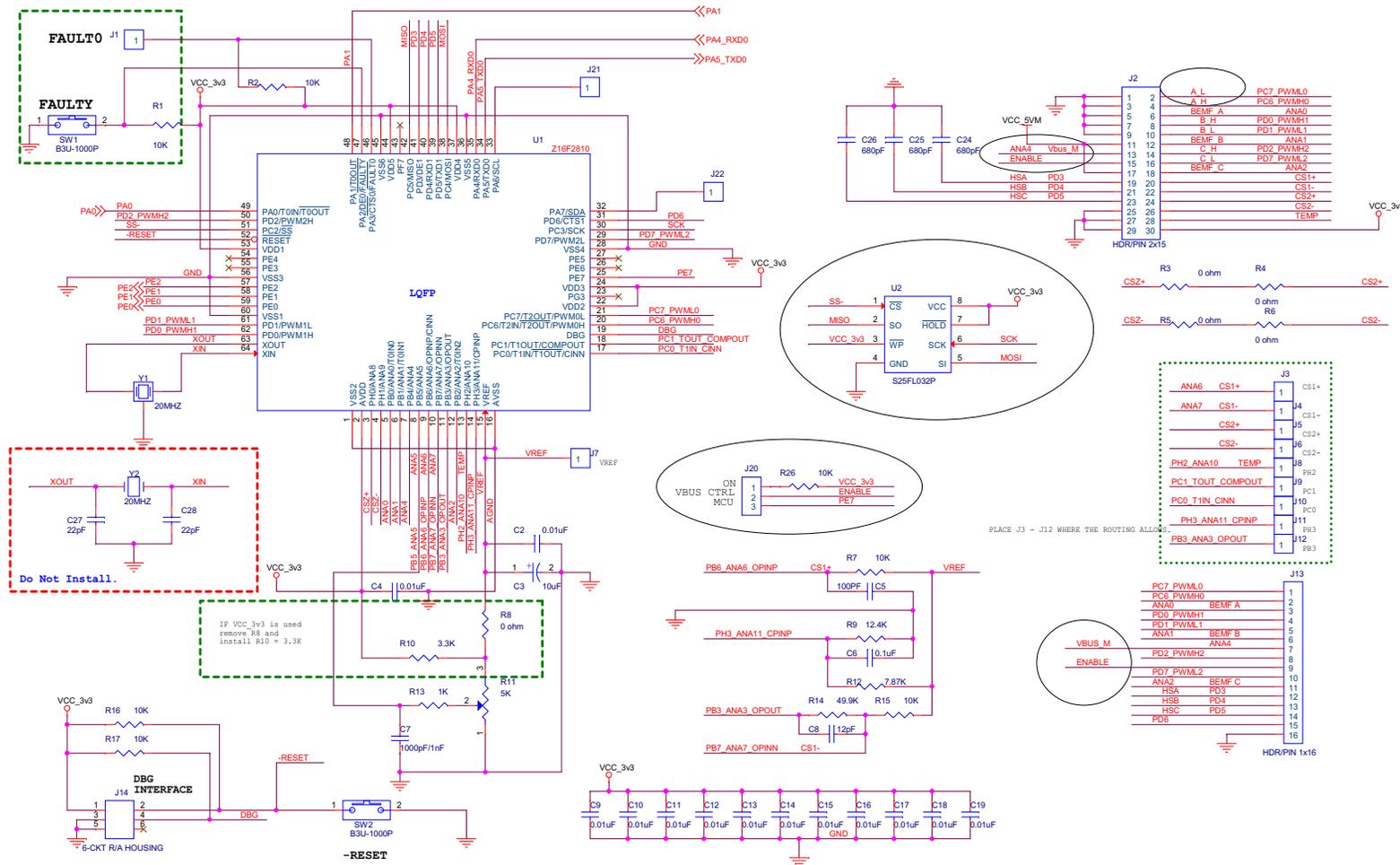
Figure 19. Z16FMC MultiMotor MCU Module, #1 of 2
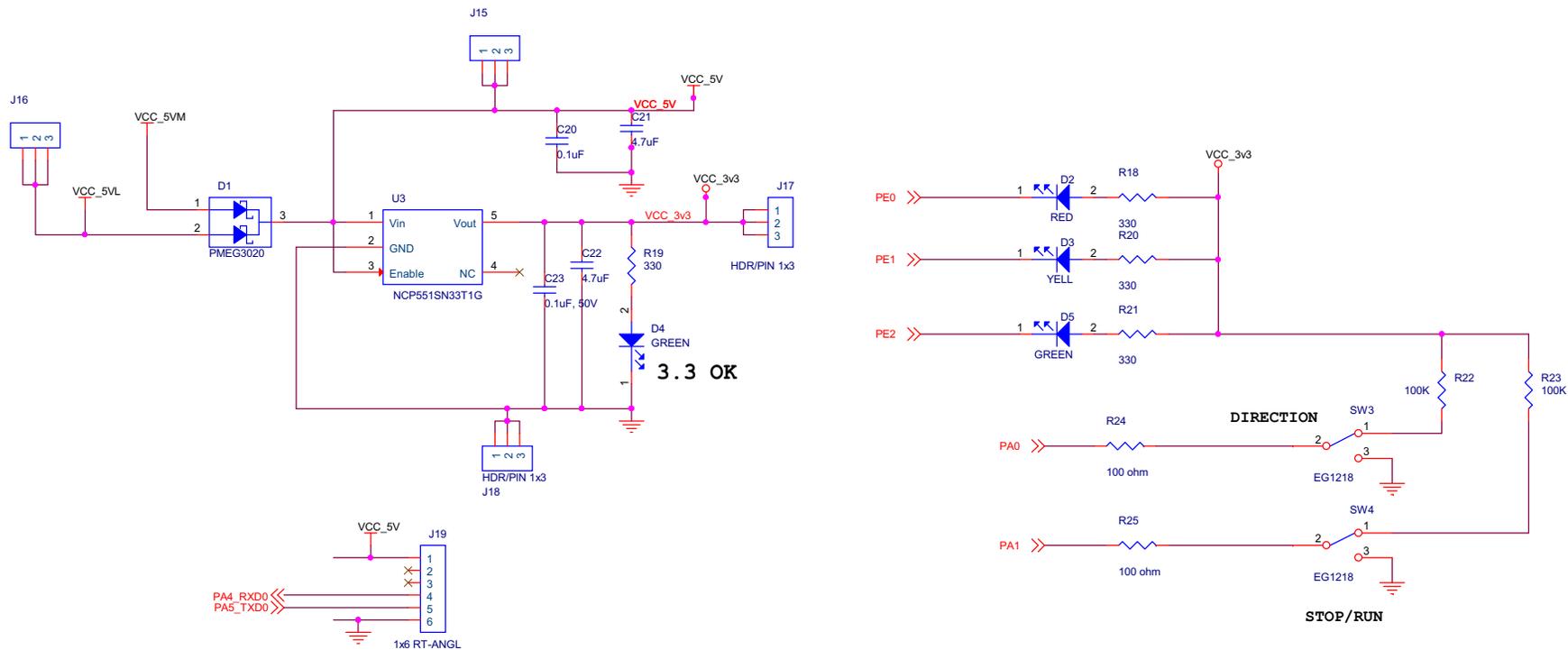
Figure 20. Z16FMC MultiMotor MCU Module, #2 of 2

Figures 21 and 22 show the schematic diagrams for the MultiMotor Development Board.
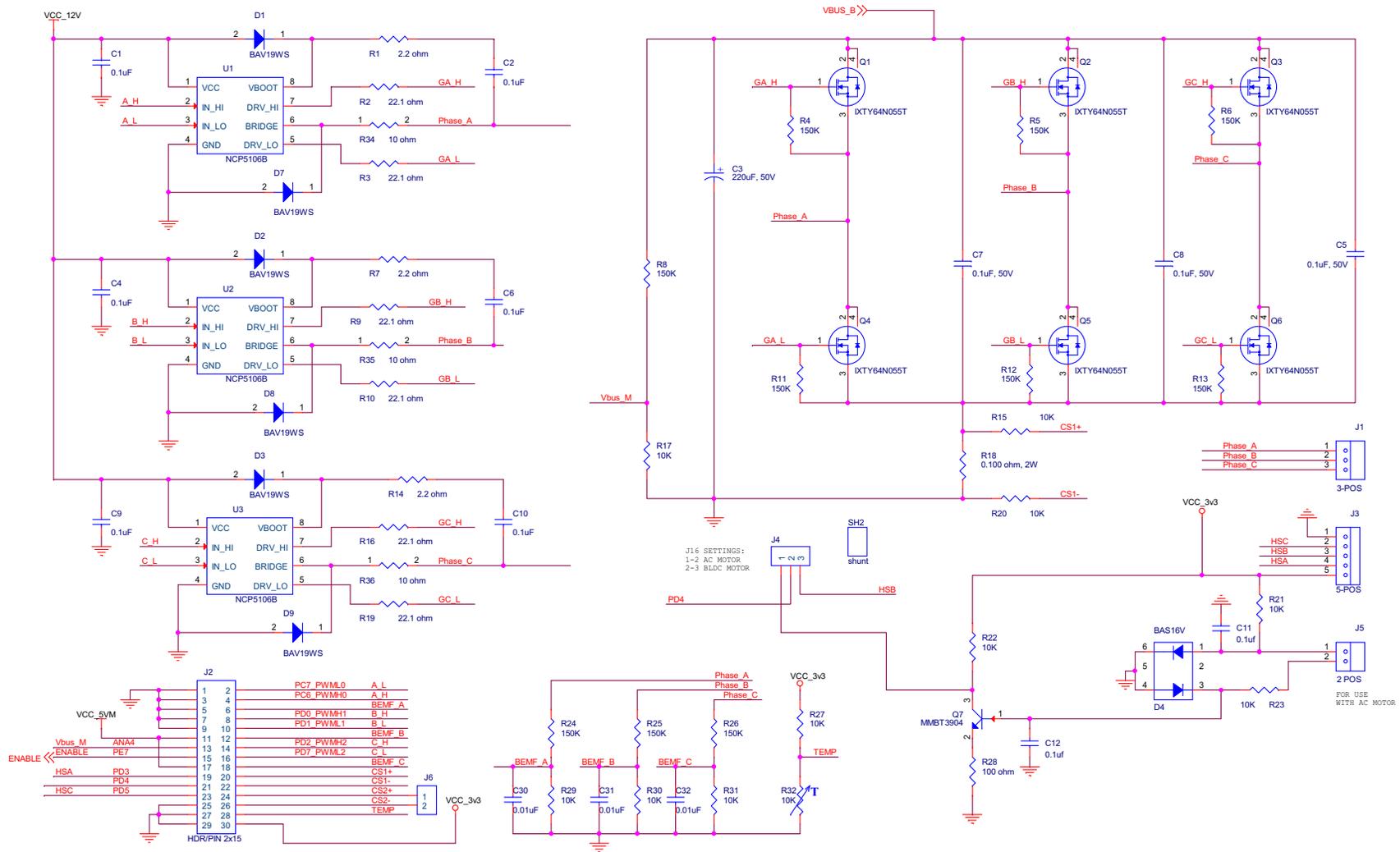
Figure 21. MultiMotor Series Development Board, #1 of 2

Figure 22. MultiMotor Series Development Board, #2 of 2

Appendix B. Flow Charts

Figure 23 presents the flow of the space vector modulation routine.
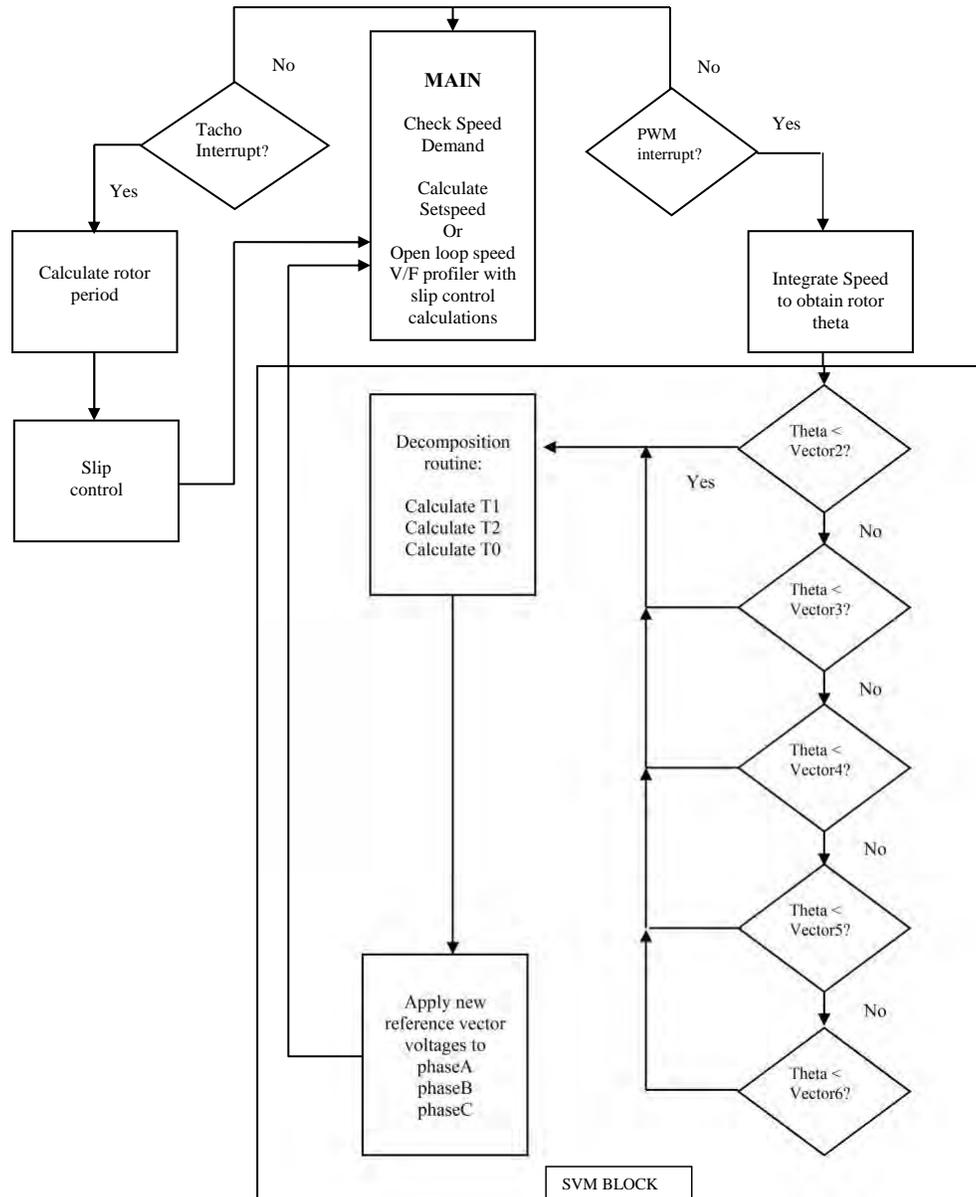
Figure 23. Space Vector Modulation Flow Chart

> **Note:** The Hall sensor for Tacho feedback can be disabled for sensorless V/F control.

Customer Support

To share comments, get your technical questions answered, or report issues you may be experiencing with our products, please visit Zilog's Technical Support page at http://support.zilog.com.

To learn more about this product, find additional documentation, or to discover other facets about Zilog product offerings, please visit the Zilog Knowledge Base at http://zilog.com/kb or consider participating in the Zilog Forum at http://zilog.com/forum.

This publication is subject to replacement by a later edition. To determine whether a later edition exists, please visit the Zilog website at http://www.zilog.com.

⚠ **Warning:** DO NOT USE THIS PRODUCT IN LIFE SUPPORT SYSTEMS.