

Sensorless BLDC Motor Control Using S08PT60 Based on Tower Board

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1 Introduction

This application note describes the design of a 3-phase sensorless BLDC motor drive with back-EMF zero crossing. It is based on Freescale's S08PT60 that can be effectively used for motor-control applications.

The concept of this application is that of a speed-closed loop drive using back-EMF zero crossing technique for positional detection. It serves as an example of a sensorless BLDC motor control system using Freescale's MCU and 3-phase BLDC/PMSM low-voltage motor control drive. It also illustrates the usage of general on-chip peripherals for motor-control applications, controller features, basic BLDC motor theory, system design concept, hardware implementation, software design including the FreeMASTER software visualization tool, application setup, and demo operation.

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2 S08PT60 features

On-chip modules available within the family include the following features:

- 8-bit S08L core
- Up to 20 MHz CPU at 2.7–5.5 V
- 60 KB flash, 4 KB RAM, 256 KB EE
- 12-bit ADC with 16 channels
- Analog comparator
- 16-channel, touch sensing input

- Multiple timers, FlexTimer module with 10 channels
- 57 GPIOs, including 8-pin, 20 mA drive and 2-pin true open-drain

3 BLDC motor control theory

The brushless DC (BLDC) motor is a rotating electric machine with a classic 3-phase stator like that of an induction motor; the rotor has surface-mounted permanent magnets. It is also referred to as an electronically-commuted motor. There are no brushes on the rotor and the commutation is performed electronically at certain rotor positions. The stator is usually made from magnetic steel sheets. A typical cross section of a BLDC motor is shown in [Figure 1](#). The stator-phase windings are inserted in the slots (distributed winding) or they can be wound as one coil onto the magnetic pole. Because the air-gap magnetic field is produced by permanent magnets, the rotor magnetic field is constant.

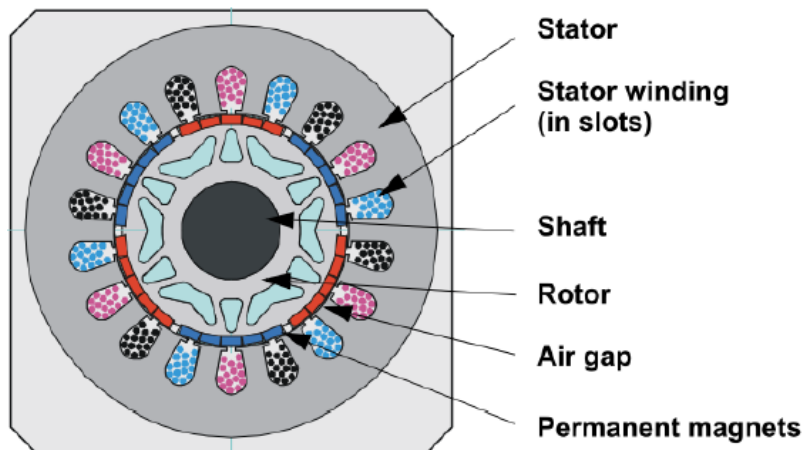


Figure 1. BLDC motor ontology

The magnetisation of the permanent magnets and their displacement on the rotor is chosen so that the shape of back-EMF, that is, the voltage induced on the stator winding due to rotor movement, is trapezoidal. This allows the DC voltage (see [Figure 2](#)) with a rectangular shape to be used to create a rotational field with low-torque ripples.

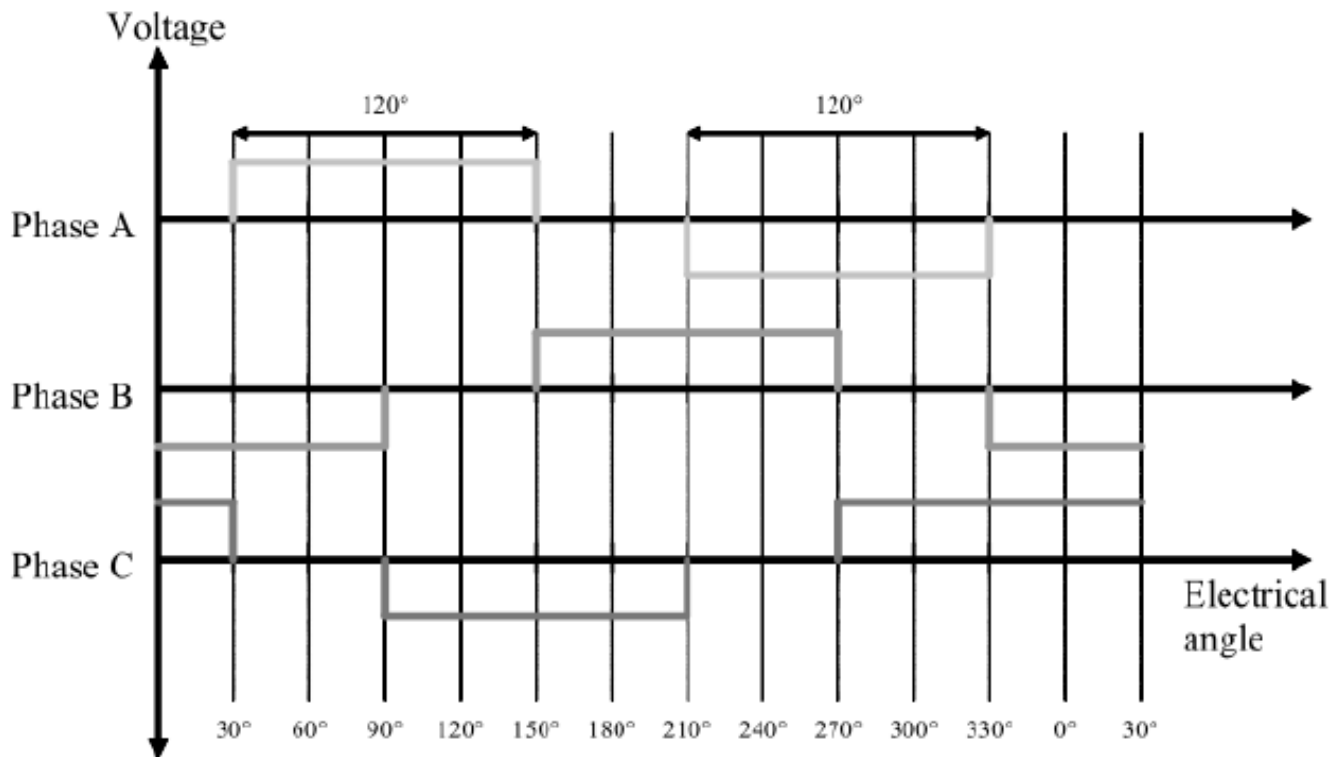


Figure 2. 3-phase voltage system of BLDC motor

4 System design concept

4.1 System specification

The motor-control system is designed to drive a 3-phase BLDC motor in a speed and torque-closed loop. The application meets these performance specifications:

- It has a sensorless BLDC motor control using back-EMF zero-crossing sensing.
- It is targeted at the MC9S08PT60 controller.
- The application is running on a 3-Phase BLDC/PMSM low-voltage motor control drive.
- Control technique incorporates:
 - Sensorless control with speed and torque-closed loop
 - ADC for zero-crossing sensing
 - Start from any motor position with rotor alignment
 - Manual interface (push-button control)
 - FreeMASTER software remote monitor

4.2 Sensorless drive concept

The concept shown in [Figure 3](#) is chosen. The sensorless rotor position technique developed detects the zero-crossing points of back-EMF induced in the motor windings. The phase back-EMF zero-crossing points are sensed while one of the three phase windings is not powered. The obtained information is processed in order to commutate the energized phase pair and control the phase voltage, using pulse width modulation (PWM).

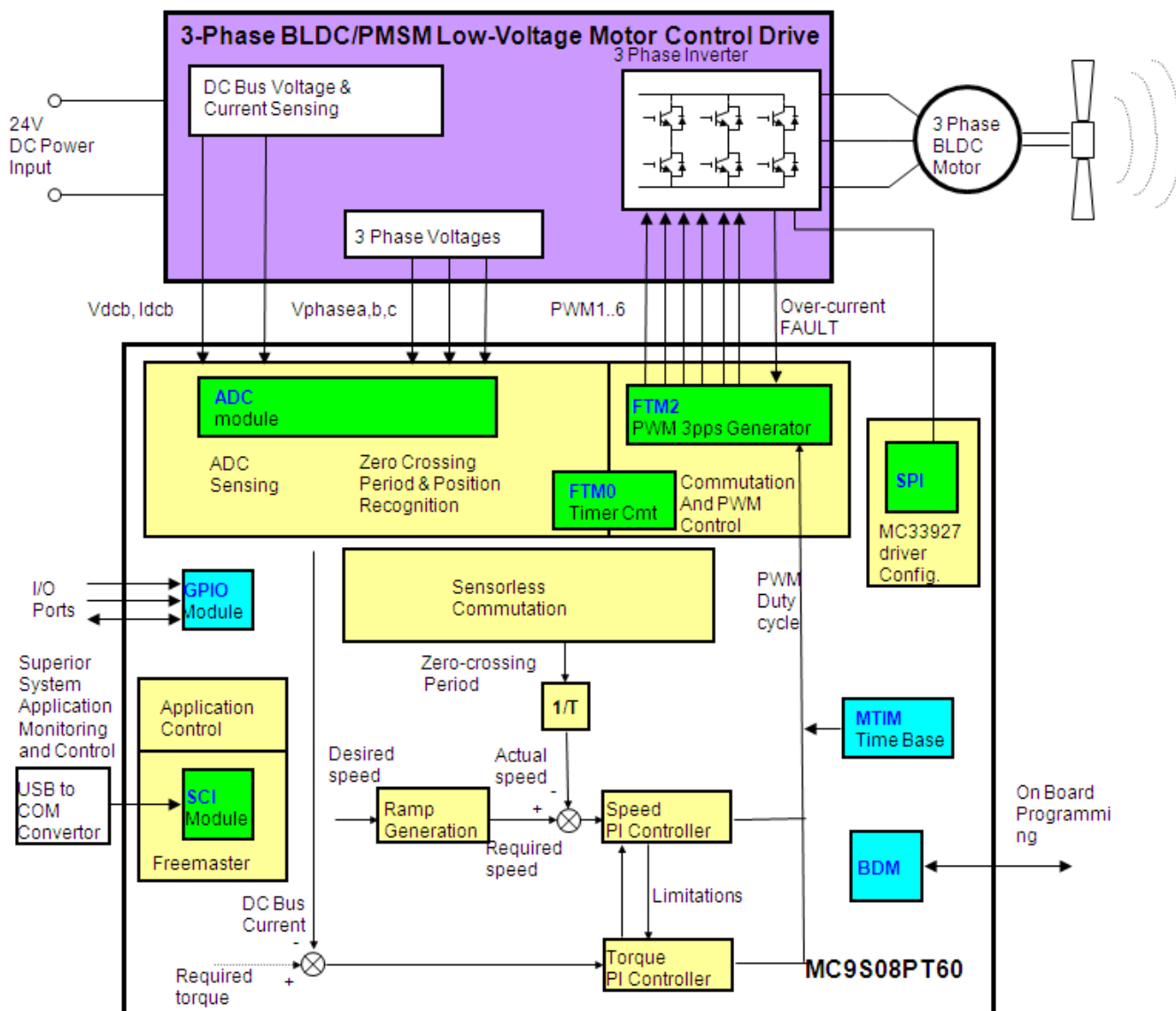


Figure 3. System configuration

5 Hardware

5.1 Hardware outline

The BLDC sensorless application runs on Freescale's MC9S08PT60 Tower Board and 45ZWN24-40 motor. See the following figure which depicts the configuration of the application.

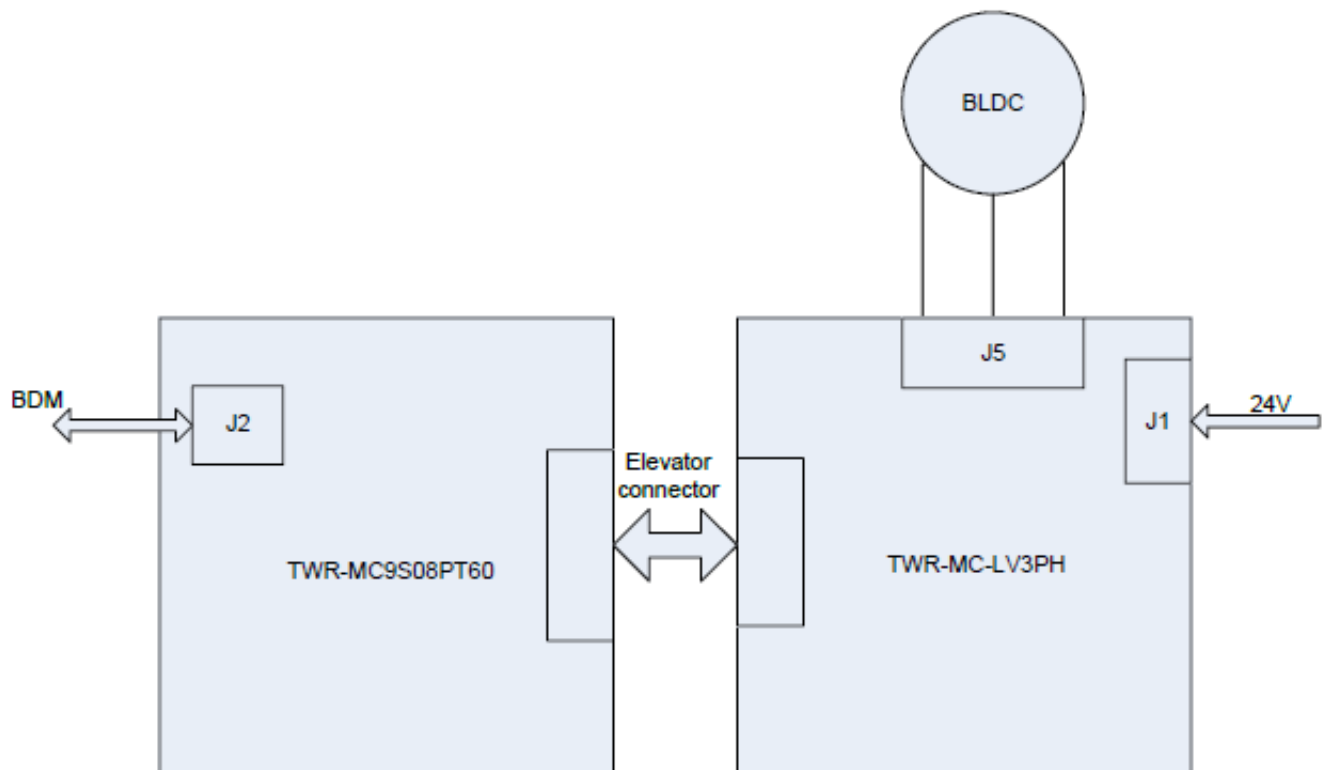


Figure 4. Application configuration

5.2 Component description

5.2.1 3-phase bridge inverter and DC_Bus overvoltage protection

Component description

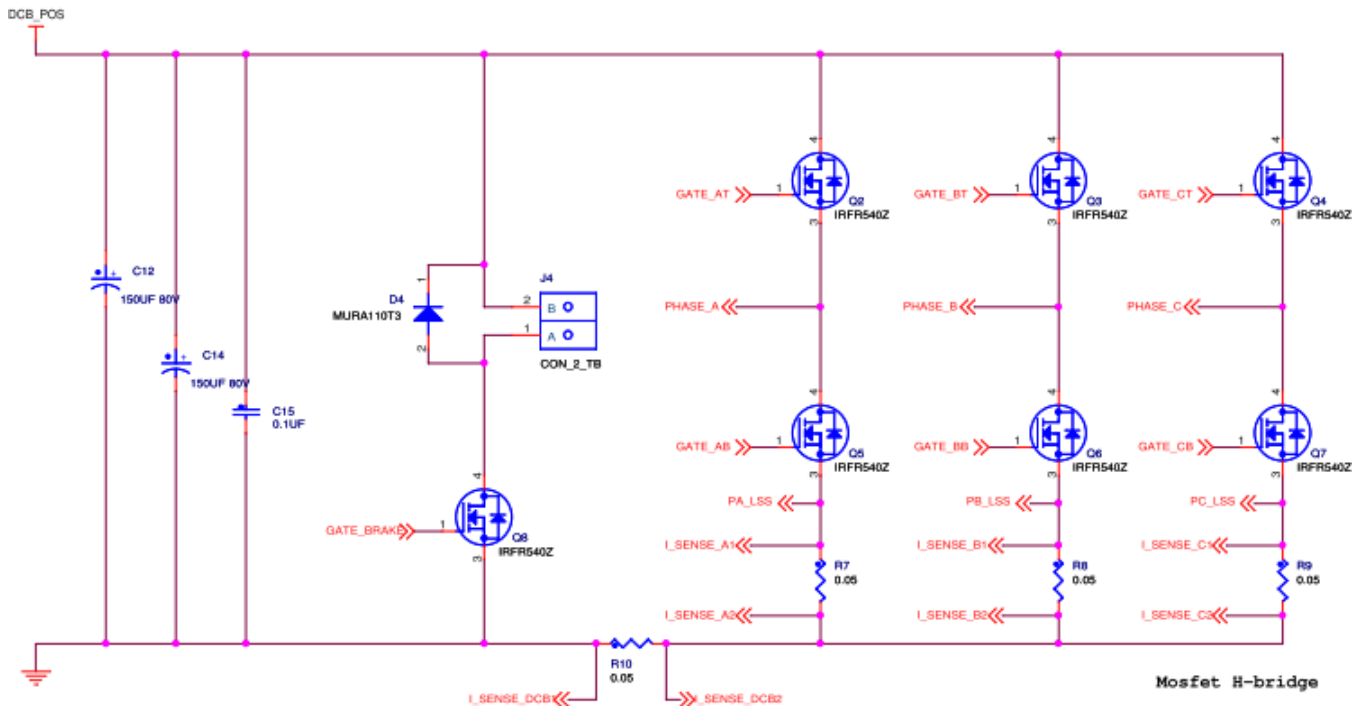


Figure 5. Three-phase bridge inverter and overvoltage protection

The 3-phase bridge inverter contains six MOSFETs, 3-phase current sample resistors, and one bus current sample resistor, as shown in [Figure 5](#).

Due to voltage fluctuation or motor stalling, or any other fault, the DC_Bus voltage can increase. Overvoltage can destroy the hardware board or motor; so the required action must be taken to avoid such conditions.

In this demo, a braking resistor and a MOSFET is installed in series between DCB_POS and GND (the red line range in [Figure 5](#)). If DC_Bus voltage is larger than preset maximum voltage, the MOSFET conducts, and energy is lost through the braking resistor, resulting in a decrease in the DC_Bus voltage. The hardware plays the role of over voltage protection.

5.2.2 Predriver (MC33937)

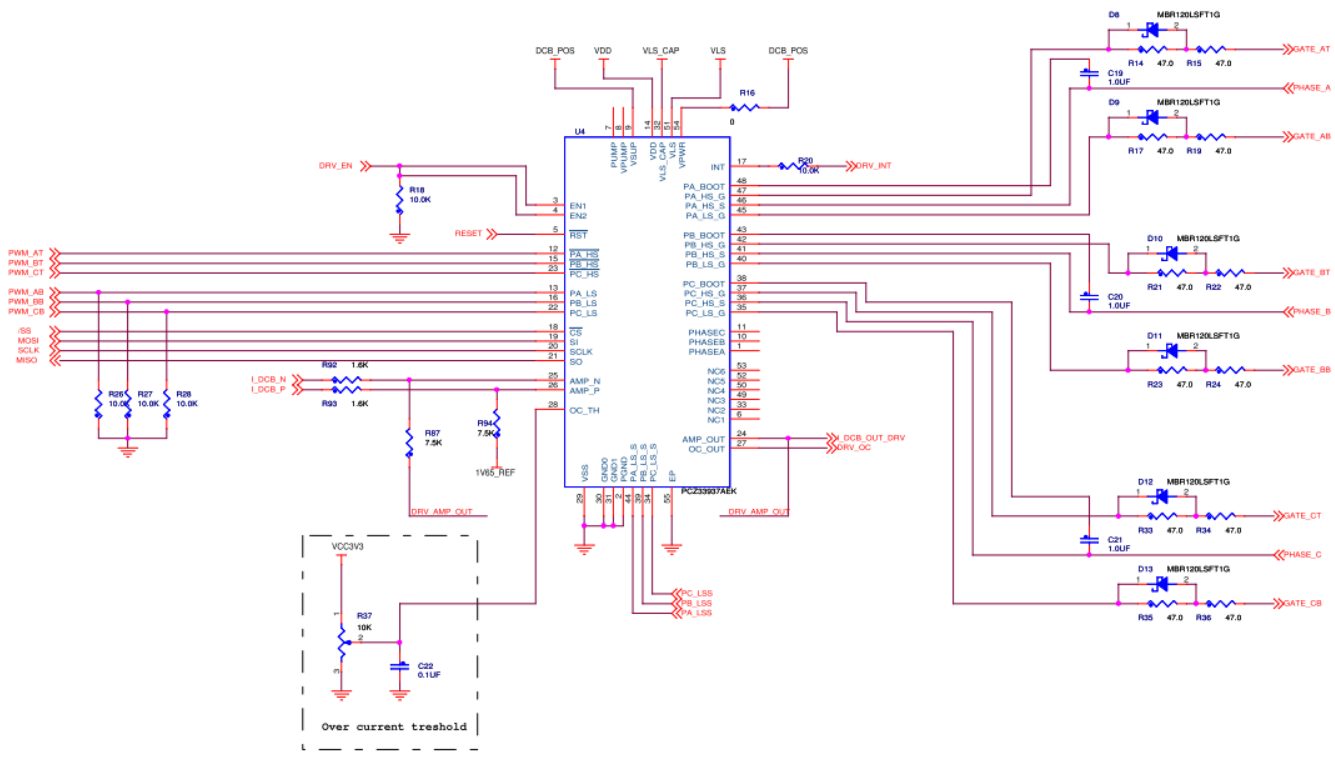


Figure 6. Predriver (MC33937)

MC33937 is a field effect transistor (FET) predriver designed for 3-phase motor control (See Figure 6). Three external bootstrap capacitors provide gate charge to the high-side FETs. The IC interfaces to an MCU via six direct input control signals, an SPI port for device setup and asynchronous reset, enable and interrupt signals. MC33937 integrates overcurrent detect circuit; if overcurrent occurs, DRV_OC port level changes to a high level.

5.2.3 BEMF & DC_Bus voltage sensing circuit

Figure 7 is the BEMF sensing circuit for phase A, while phase B and phase C are the same. According to the power supply voltage of MCU and preset maximum DC_Bus voltage, the divide resistance value can be selected. In this project, if DC_Bus voltage is preset to 36.3 V, and the power supply voltage of MCU is 3.3 V, the divide resistance value is 30 kΩ and 3 kΩ.

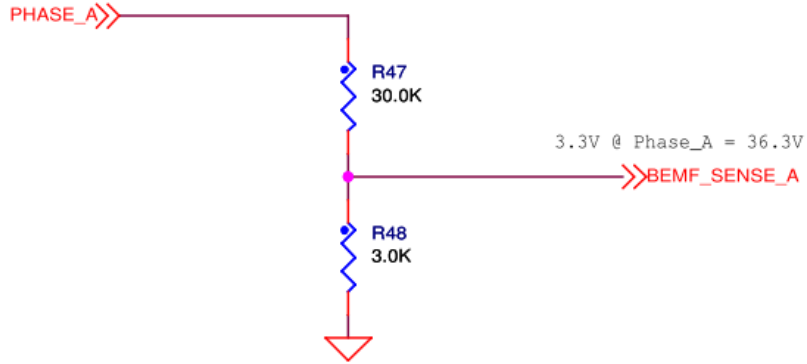


Figure 7. BEMF sensing circuit

Figure 8 is the DC_Bus voltage sensing circuit, which is similar to the BEMF sensing circuit.

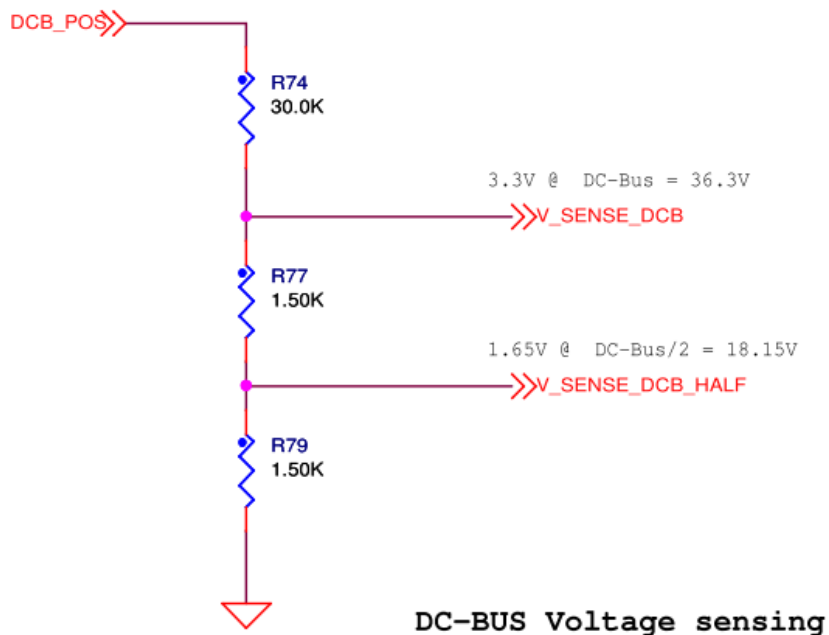


Figure 8. DC_Bus voltage sensing circuit

5.2.4 DC_Bus current sensing circuit

The following figure shows the DC_Bus current sensing circuit.

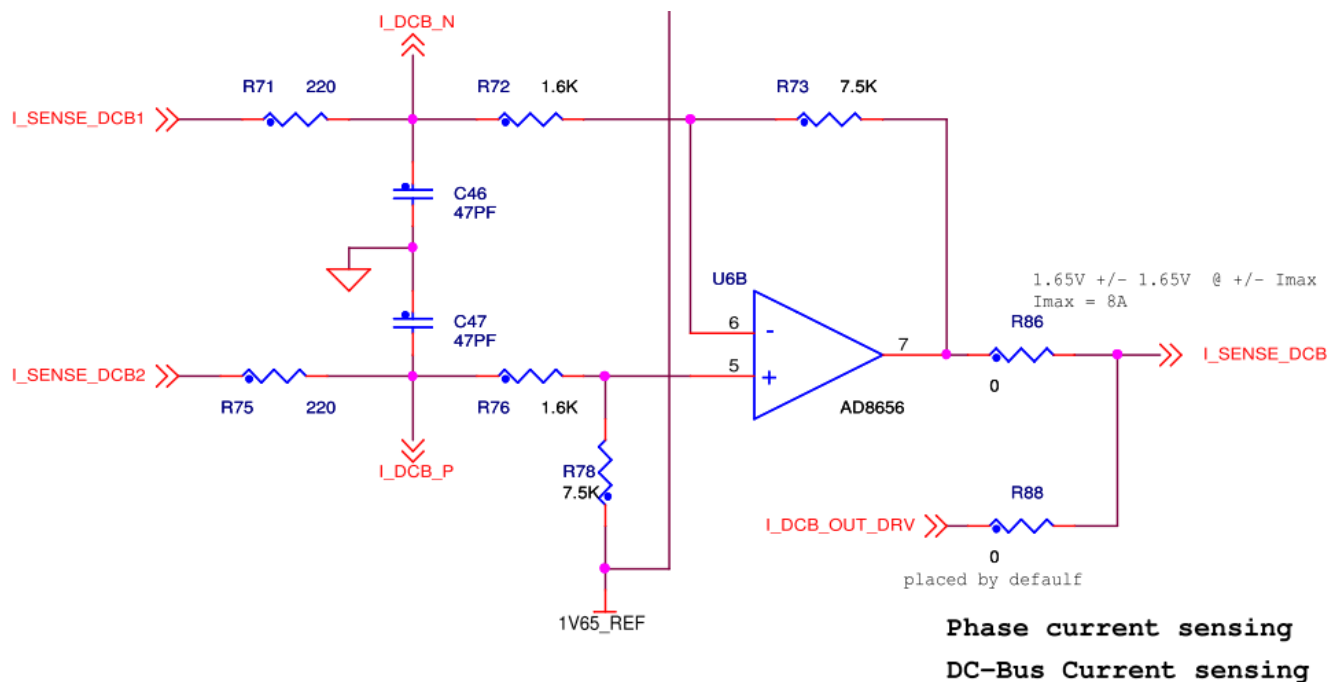


Figure 9. DC_Bus current sensing circuit

DC_Bus current sample is needed to conduct current loop PI regulator and/or over current software protection. In this demo board, the sample resistor is 0.05 Ω, and due to current’s positive and negative conduction, 1.65 V bias voltage is needed. The differential amplifier equation is given below.

$$I_DCBUS = 1.65 + \frac{R73}{R71+R72}(0.05*i)$$

Equation 1

Thus, the maximum current is 8 A.

5.2.5 Brake switch circuit

Figure 10 is a brake switch circuit. MIC4127YME is equivalent to a power amplifier, whose function is to drive MOSFET of overvoltage protection circuit. If the DC_Bus voltage is higher than preset maximum DC_Bus voltage value, the BRAKE_CONTROL and GATE_BRAKE are set to high level and the MOSFET conducts, thereby reducing the DC_Bus voltage.

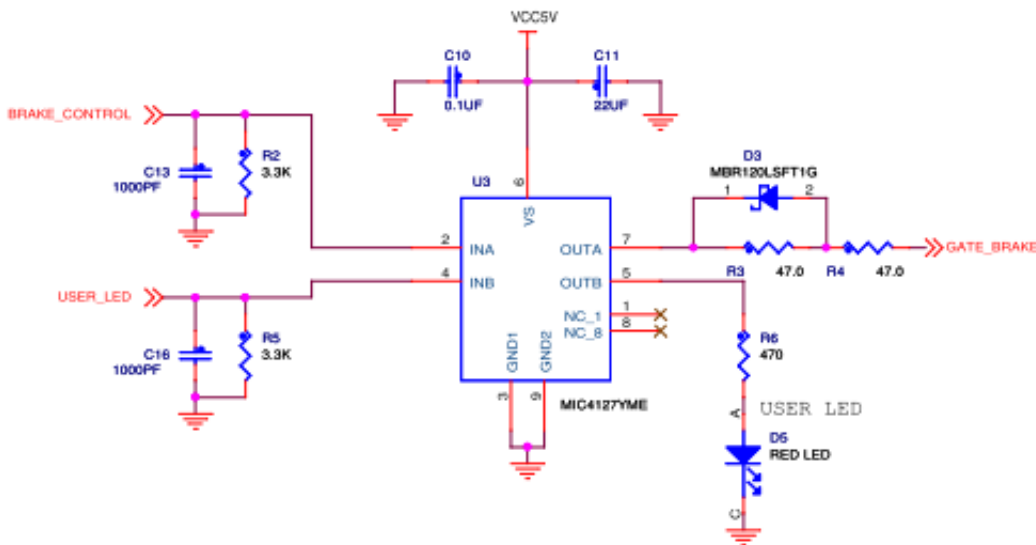


Figure 10. Brake switch circuit

5.3 LINIX 45ZWN24-40 motor

45ZWN24-40 motor from LINIX, is used for the BLDC motor sensorless control application, although other motors can also be adapted to the application, just by defining and changing the motor-related parameters. A detailed motor specification is shown in the following table.

Table 1. Electrical characteristics of Linix 45ZWN24-40 motor

Characteristic	Symbol	Min	Typ	Max	Unit
Reference winding voltage	V_t	Jm		24	V
Speed @ V_t		–	–	4000	rpm
Torque constant	K_t	–	–	–	Nm/A
Voltage constant	K_e	–	–	–	V/RPM
Terminal resistance	R_t	–	–	–	Ω
Winding inductance	L	–	–	–	mH
Continuous current	I_{cs}	–	–	–	A

Table continues on the next page...

Table 1. Electrical characteristics of Linix 45ZWN24-40 motor (continued)

Characteristic	Symbol	Min	Typ	Max	Unit
Number of pole pairs		–	2	–	
Temperature rating		–	–	–	°C

The TWR-MC9S08PT60 and TWR-MC-LV3PH use tower elevator to interconnect. For more detailed information about these two demo boards, see TWR-S08PT60 User Manual and TWR-MC-LV3PH User’s Manual, available on freescale.com. The BLDC demo board needs jumper setting before the first usage. For more information, see Sensorless BLDCM Control Based on MC9S08PT60 Tower Board User Manual, available on freescale.com.

6 Software

The software was ported from MC9S08MP16. The main software flow chart is shown in the figure given below.

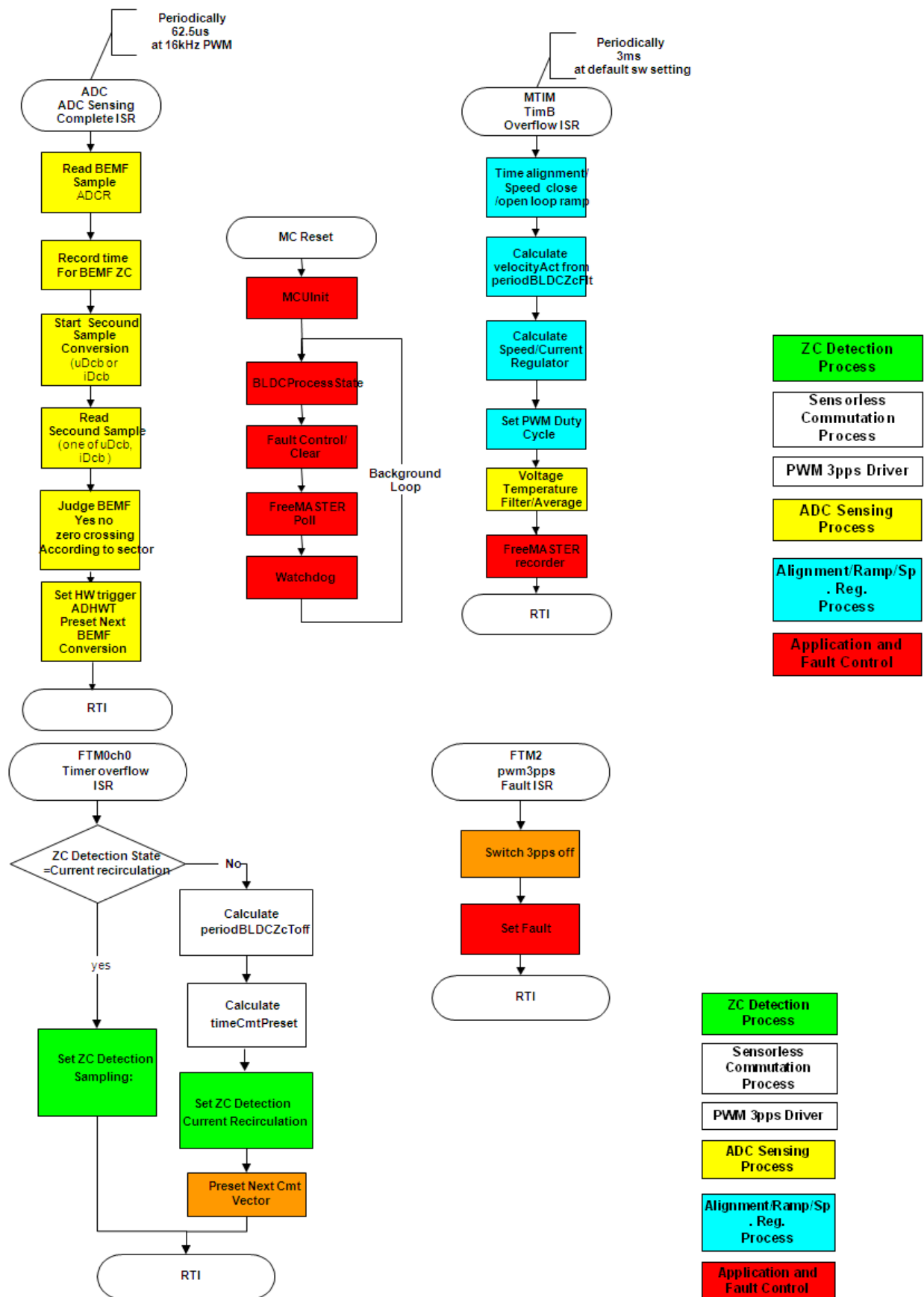


Figure 11. Main software flow chart

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6.1 MOSFET driver configuration

For the correct operation of the MC33937, the predriver must be configured. This driver is able to configure only via SPI communication. There are two files providing SPI communication between the MCU and the driver, and configuring the MOSFET driver.

- The spi_comm.h header file contains configuration and status constants defined for the MC33937 driver.
- The spi_comm.c file contains SPI communication functions and configuration function for the MC33937 driver.

The SPI communication is not only used for driver configuration, but also for detecting this driver.

6.2 PWM generation and timers

The FTM module of MC9S08PT60 has three submodules.

- FTM0, having two PWM channels
- FTM1, having two PWM channels
- FTM2, having six PWM channels

In this application, FTM0 channel 0 is used to serve as output compare function for commutation. FTM2 channel 0 to channel 5 are used to generate PWM signals to drive the motor.

In this application, the PWM frequency is 16 kHz, PWM resolution is 0.1%, and PWM mode is edge-aligned.

The BLDC motor uses only one timer. The Timer Module serves as 3 ms timer interrupt, which is used as speed loop regulator and current loop regulator timebase.

6.3 PWM deadtime calibration

MC33937 is FET predrivers designed for three-phase motor control. The MC33937 interfaces to an MCU via six direct input control signals, and SPI port for device setup, etc.

The deadtime is set by sending the deadtime command (100x xxx1).

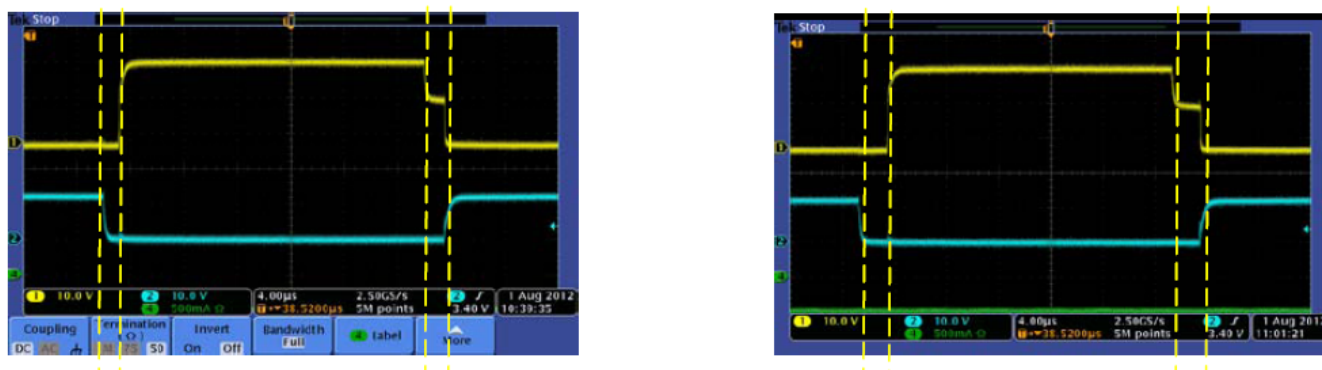


Figure 12. PWM deadtime calibration comparison diagram

Figure 12 is PWM deadtime calibration diagram. Referring to the left and right parts of Figure 12, it can be seen that:

- When the calibration value is 600 (left part), the left deadtime is 1.28 μ s, and the right deadtime is 1.76 μ s.
- When the calibration value is 2000 (right part), the left deadtime is 2.28 μ s, and the right deadtime is 2.32 μ s.

Usually, the deadtime set for MOSFET is about 1 μ s, so the calibration value is set to 600.

6.4 Analog-to-digital conversion

Following is the configuration of analog-to-digital conversion channel:

- Single conversion mode
- Left-justified result data
- External trigger control
- 12-bit resolution
- 8 MHz ADC clock

The ADC sample channel is non-conduct phase according to the sector of BLDC motor. The task of analog-to-digital interrupt program is to save the corresponding non-conduct phase voltage value and start second conversion (DC_Bus voltage or DC_Bus current) using polling, zero-crossing point detection, and analog-to-digital sample channel mapping. The analog sample of BEMF which is to be converted to digital sample must be synchronized with PWM due to mutual inductance of stator windings.

6.5 Fault handling

Fault handling is important for motor control. The main faults occurring during motor control include overvoltage, undervoltage, overcurrent, and overtemperature, among others. In this application, overvoltage protection and undervoltage protection are implemented by the software using polling mode.

6.6 FreeMASTER communication

Serial communication using the SCI module was implemented for remote control using FreeMASTER. The host computer is connected to the controller via a USB cable. The computer USB port works as a virtual COM port. Signal conversion from USB form to SCI form, and vice versa, is done by the USB/SCI bridge. More information can be found in LVMCDBLDCPMSMUG: 3-Phase BLDC/PMSM Low-Voltage Motor Control Drive, available on freescale.com.

6.7 Others

Finally, motor parameters, alignment and starting constants are stored in the main.h file. The motor used in this application is same as that used in the reference design of MC9S08MP16; so the motor parameters are same.

7 Demo setup and operation

For demonstrating the operation, this demo was built and is available for customers. See the following subsections.

7.1 Hardware setup

The hardware includes one BLDC motor, and MC9S08PT60 tower board (see the figure below).



Figure 13. MC9S08PT60 tower board

The following steps must be followed to run the sensorless BLDC motor.

1. Plug the power supply jack connector to the low-voltage motor control board connector J1.
2. Connect the USB BDM cable to the PC and to the PT60 central control board connector J2.
3. Check the settings of jumpers J2, J3, J10, J11, J12, J13, and J14 on the TWR-MC-LV3PH board as follows.
 - J3 (pins 2 and 3 shorted) is elevator analog supply.
 - J10, J11, J12 (pins 2 and 3 shorted) represent BEMF sense phase A, BEMF sense phase B, and BEMF sense phase C.
 - J13 (pins 2 and 3 shorted) represents the DC_Bus current sense.
 - J14 (pins 2 and 3 shorted) represents DC_Bus half voltage sense.
4. Check the settings of jumpers J26, J27, J29, and J7 on the TWR-S08PT60 board.
 - J7 must be open, because it shares one analog-to-digital conversion channel with DC_Bus current sense.
 - J26 (pins 1 and 2 shorted) represents 3.3 V from elevator connector.
 - J27 (pins 2 and 3 shorted) represents 3.3 V to processor VDD pin.
 - J29 (pins 1 and 2 shorted) represents 3.3 V to VDD_PULL.

Figure 14 is PT60 central control tower board and Figure 15 is low-voltage motor control tower board.

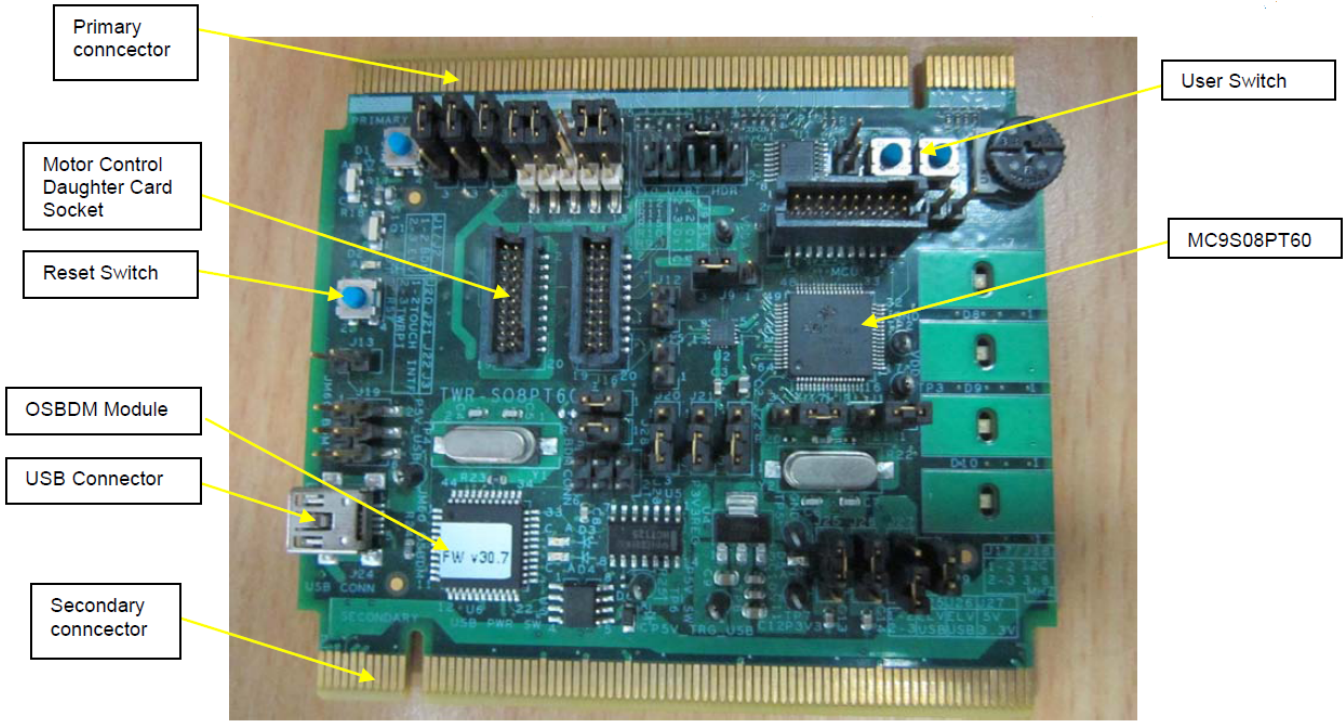


Figure 14. PT60 central control board

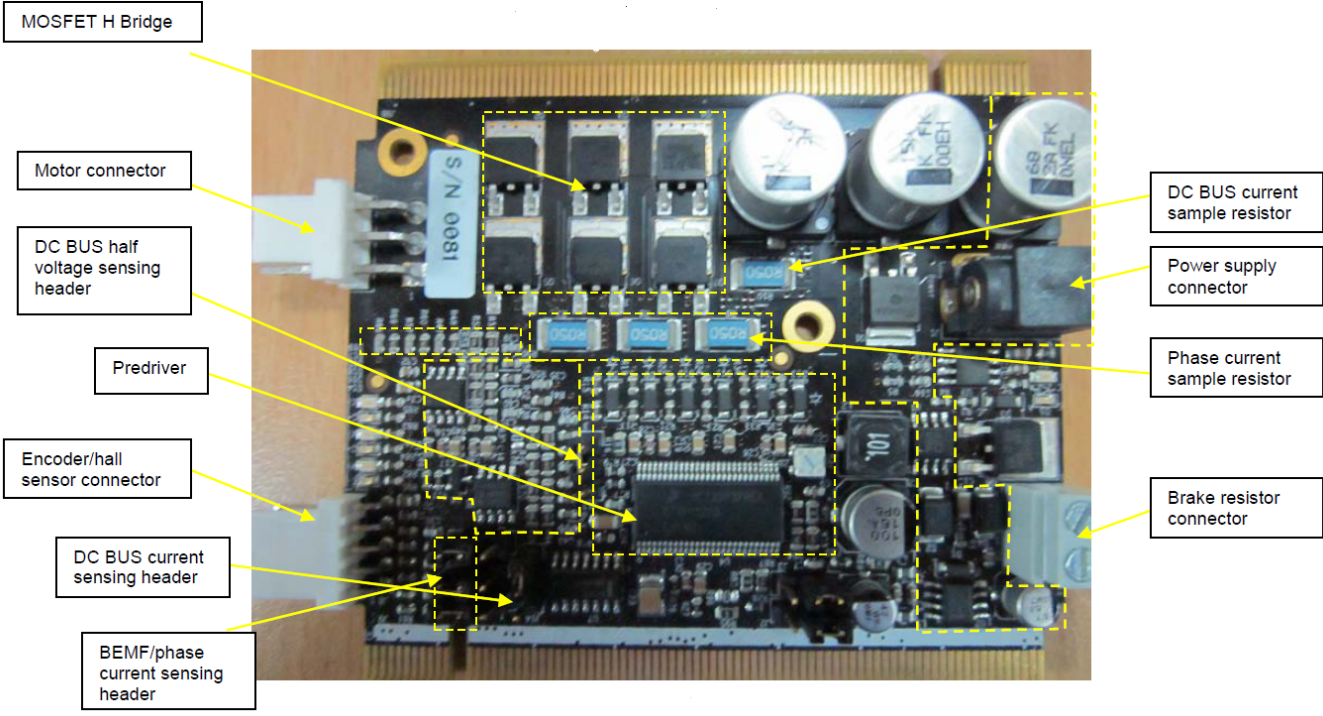


Figure 15. Low-voltage motor control demo board

7.2 Software setup

The software developing environment is CodeWarrior v.10.1. USB/SCI driver installation is required prior to the first usage of FreeMASTER. Driver installation is described in the MS Word file Installation USB/SCI Bridge manual. After successfully installing the driver, select a virtual COM port attached to the USB port, and then FreeMASTER is ready to use.

8 Reference documents

For the latest revision of all the Tower documents listed below, visit freescale.com.

- TWR-S08PT60 Design Package
- TWRS08PT60QSG: TWR-S08PT60 Quick Start Guide
- TWRS08PT60UM: TWR-S08PT60 User Manual
- MC9S08PT60RM: MC9S08PT60 Reference Manual
- MC9S08PT60: MC9S08PT60 Series Data Sheet
- TWRMCLV3PHUG: TWR-MC-LV3PH User's Guide
- TWR-MC-LV3PH Schematics

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