

56F8300 3-Phase Switched Reluctance Motor

Sensorless Control using Processor Expert

Targeting Document

MC56F8300
16-bit Digital Signal Controllers

8300SRMxxTD
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Document Revision History

Version History	Description of Change
Rev 0	Initial public release

3-Phase Switched Reluctance Motor Sensorless Control on Processor Expert

This application exercises sensorless control of the 3-phase Switched Reluctance Motor (SRM) using Processor Expert (PE), a 56F8346, 56F8357, or 56F8367 EVM boards, and a 3-phase SR High-Voltage (HV) Power Stage.

Applications developed for this demonstration board were not designed for the 56F8100 devices. The 56F8300 demonstration board does, however, fully support 56F8100 software development.

Note: The PC master software referenced in this document is also known as Free Master software.

1. Specifications

This application performs principal sensorless control of a 3-phase switched reluctance motor using a 56F8300 processor. The concept of the application is a speed closed-loop SRM drive using a flux linkage position estimation technique. The control technique compares estimated flux linkage and reference flux linkage, defined for the turn-off (commutation position). When the estimated flux linkage reaches the desired flux linkage it indicates that the commutation position has been reached. The actual phase and the following phase are both turned off.

Protection is provided against overcurrent, overvoltage, undervoltage, and overheating drive faults.

System Outline

The system is designed to drive a 3-phase switched reluctance motor. The application has the following specifications:

- Sensorless control of a switched reluctance motor
- Targeted for a 56F8346EVM, 56F8357EVM, or 56F8367EVM
- Runs on a 3-phase SR HV Power Stage, 180W
- Uses an optoisolation board for HV / Low Voltage (LV) isolation
- Speed control loop
- Motor mode in a single rotation direction
- Minimum speed of 600rpm
- Maximum speed of 2500rpm
- Manual interface (RUN / STOP switch, UP / DOWN push buttons control, LED indication)
- Overvoltage, undervoltage and overcurrent fault protection
- PC remote control interface (speed set-up)

- PC master software remote monitor provides information about:
 - Software monitor interface:
 - Applied voltage
 - Required voltage
 - Required and Actual Speed
 - START / STOP switch state
 - Fault status
 - Software speed scope:
 - Observes actual and desired speed
 - Currents:
 - Active
 - Desired
 - Discharge
 - Output duty cycle

Application Description

The sensorless control algorithm is calculated on Freescale's 56F8346EVM, 56F8357EVM, or 56F8367EVM. The algorithm generates 3-phase PWM signals for switched reluctance motor according to the user-required inputs and measured and calculated signals.

The SRM drive hardware components includes:

- Switched reluctance motor Type 40V, EM Brno s.r.o., Czech Republic
- Load Type SG 40N, EM Brno s.r.o., Czech Republic
- 3-phase SR HV Power Stage, 180W
- 56F8346, 56F8357, or 56F8367 EVM boards
- Legacy Motor Daughter Card (LMDC) board
- Optoisolation Board

Table 1-1 Motor Brake Specifications

Set Manufacturer	EM Brno, Czech Republic	
Motor	Motor Type	SR40V (3-Phase SR Motor)
	Stator / Rotor Poles	6 / 4
	Speed Range	< 5000rpm
	Nominal Voltage	3 x 30 V
	Nominal Current	1.2A
Brake	Brake Type	SG40N 3-Phase BLDC Motor
	Nominal Voltage	3 x 27V
	Nominal Current	2.6A

The drive can be controlled in two operating modes:

- In the **Manual operating mode**, the required speed is set by the UP / DOWN push buttons and the drive is started and stopped by the RUN / STOP switch on the EVM board
- In the **PC master software operating mode**, the required speed is set by the PC master software active bar graph and the drive is started and stopped by the START MOTOR and STOP MOTOR controls

Measured quantities:

- DCBus voltage
- Phase currents (charged and discharged phase)
- Power module temperature

The faults used for drive protection:

- Overvoltage (PC master software error message = *Overvoltage fault*)
- Undervoltage (PC master software error message = *Undervoltage fault*)
- Overcurrent (PC master software error message = *Overcurrent fault*)
- Overheating (PC master software error message = *Overheating fault*)

The following software tools are needed to compile, debug, and load to the EVM, and to use remote control and monitoring, and the RUN / STOP switch and UP / DOWN buttons:

- Metrowerks CodeWarrior v. 6.1.2
- PC master software
- Processor Expert v. 2.94

The 3-Phase Switched Reluctance Sensorless Motor Control Application demonstrates the sensorless Switched Reluctance Motor Control application using the flux linkage position estimation on the 56F8300 processor. An estimation of the phase resistance for low speed range is included.

Control Process

After reset, the drive enters the INIT state in manual mode. When the RUN / STOP switch is detected in the STOP position (using the RUN / STOP switch or the PC master software command) and there are no faults pending, the STOP application state is entered. When the start command is detected (using the RUN / STOP switch or the PC master software Start button), the drive enters the RUN application state; the motor is started. The following start-up sequence with the rotor alignment is provided:

- MOTOR_STOPPED = Motor stopped
- ALIGNMENT_COMMAND = Alignment command accepted
- ALIGNMENT_STAGE_ONE = Alignment in progress; Phases B and C switched on
- ALIGNMENT_STAGE_TWO = Alignment in progress; Phase B switched on
- START_UP_COMMAND = Alignment finalized; start the motor
- START_UP_FINISHED = Motor running; start-up finalized

The rotor position is evaluated using the sensorless flux linkage estimation algorithm. The actual flux linkage is calculated using the PWM frequency rate and compared with the reference flux linkage for the given commutation angle. The commutation angle is calculated according to the desired speed, current and actual DCBus voltage. The commutation of the phases in the desired rotation direction is done when the actual flux linkage exceeds the reference flux linkage.

The flux linkage error is used for the phase resistance estimation in low speeds (US Patent Pending). The commutation instances are used for actual motor speed calculation. According to the control signals (RUN / STOP switch, UP / DOWN push buttons) and PC master software commands (during PC master software control), the reference speed command is calculated using an acceleration / deceleration ramp. The comparison between the actual speed command and the measured speed generates a speed error. Based on the error, the speed controller generates the desired phase current. When the phase is commuted, it is turned on with duty cycle 100% (or *Output_duty_cycle_startup* during motor start-up). Then during each PWM cycle, the actual phase current is compared with the desired current. As soon as the actual current exceeds the command current, the current controller is turned on. The procedure is repeated for each commutation cycle of the motor. The current controller generates the desired duty cycle. Finally, the 3-Phase PWM Switched Reluctance Motor Control signals are generated.

Drive Protection

The DCBus voltage, DCBus current and power stage temperature are measured during the control process. They protect the drive from overvoltage, undervoltage, overcurrent and overheating. Undervoltage and overheating protection is performed by software, while the overcurrent and overvoltage fault signals utilize a fault input of the hybrid controller. Line voltage is measured during application initialization and the application automatically adjusts itself to run at either 115V AC or 230V AC, depending on the measured value. If the line voltage is detected to be out of the -15% to +10% of nominal voltage, the fault *Out of the Mains Limit* disables the drive operation. If any of the previously mentioned faults occur, the motor control PWM outputs are disabled in order to protect the drive and the application enters the FAULT state. The FAULT state can be left only when the fault conditions disappear and the RUN / STOP switch is moved to the STOP position.

The application can run on:

- External RAM or Flash
- 3-Phase SR High-Voltage Power Stage powered by 115V AC or 230V AC
- Manual or PC master operating mode

The voltage level is identified automatically and the appropriate constants are set.

The 3-phase Switched Reluctance Motor Control Application can operate in two modes:

1. Manual Operating Mode

The drive is controlled by the RUN / STOP switch (S3) on the Legacy Motor Daughter Card (LMDC). The motor speed is set by the UP (S1) and DOWN (S2) push buttons on the LMDC; see **Figure 1-1**. In this application, the PWMA module output LEDs are used as USER LEDs. If the application runs and motor spinning is disabled (i.e., the system is ready), the GREEN USER LED (LED2, shown in **Figure 1-2**) will blink. When motor spinning is enabled, the USER LED is *On*. Refer to **Table 1-2** for application states; the actual state of the PWM outputs is indicated by PWMB output LEDs. If overcurrent, overvoltage or overheating occur, the GREEN USER LED (LED2) starts to flash quickly and the PC master software signals the type of fault identified. This state can be exited only by an application reset. It is strongly recommended that you inspect the entire application to locate the source of the fault before starting it again.

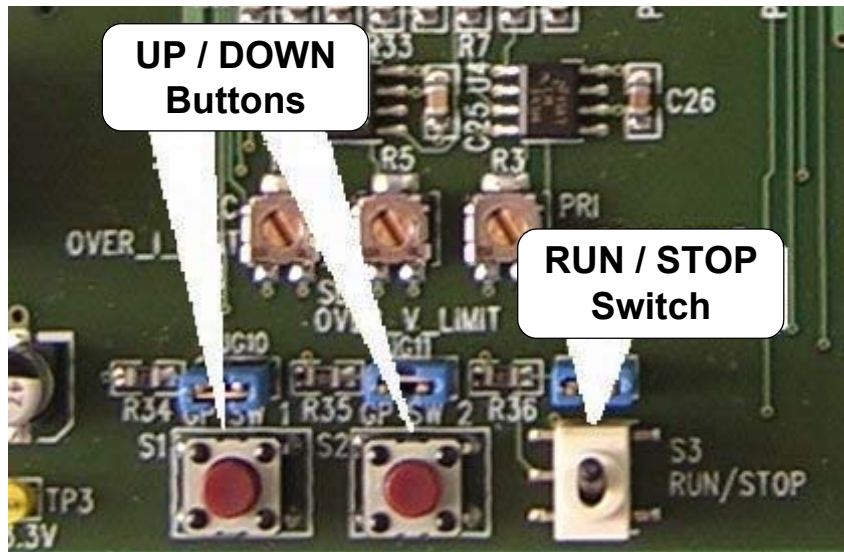


Figure 1-1 RUN / STOP Switch and UP / DOWN Buttons on the Legacy Motor Daughter Card (LMDC)

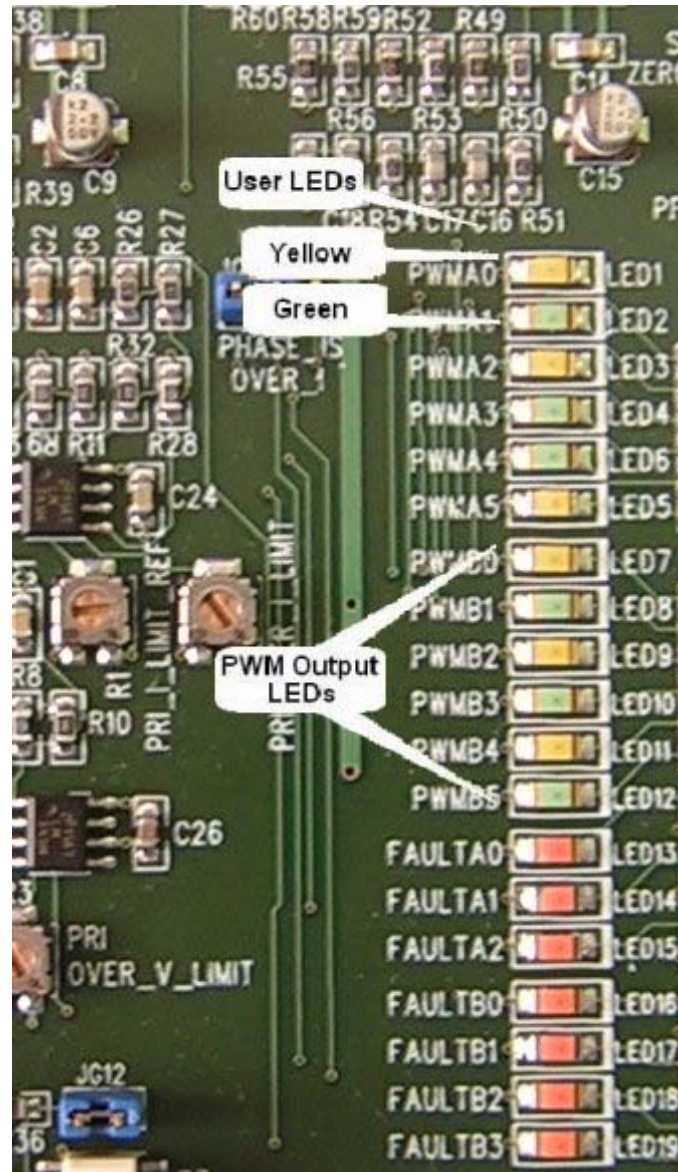


Figure 1-2 USER and PWM LEDS on the Legacy Motor Daughter Card (LMDC)

Table 1-2 Motor Application States

Application State	Motor State	Green LED State
Stopped	Stopped	Blinking at a frequency of 2Hz
Running	Spinning	On
Fault	Stopped	Blinking at a frequency of 8Hz

2. PC Master Software (Remote) Operating Mode

The drive is controlled remotely from a PC through the SCI communication channel of the hybrid controller device via an RS-232 physical interface. The drive is enabled by the RUN / STOP switch, which can be used to safely stop the application at any time. PC master software enables to the user set the motor's Required Speed.

The following PC master software control actions are supported:

- Set the motor control system's PC master software mode
- Set the motor control system's manual mode
- Start the motor
- Stop the motor
- Set the motor's Required Speed

PC master software displays the following information:

- The motor's Required Speed
- The motor's Actual Speed
- Application status:
 - Init
 - Stop
 - Run
 - Fault
- DCBus voltage level
- Identified line voltage
- Fault Status:
 - No_Fault
 - Overvoltage
 - Overcurrent
 - Undervoltage
 - Overheating

The Speed Scope monitors:

- Required Speed
- Actual Speed
- Desired phase current

The Start-up Recorder captures:

- Desired phase current
- Active phase current
- Reference flux linkage
- Active flux linkage
- Output duty cycle
- Encoder position reference

The Start-up Recorder is initiated only with motor start

The Flux Linkage Recorder captures:

- Active phase current
- Discharge phase current
- Active flux linkage
- Discharge flux linkage
- Reference flux linkage
- Encoder position reference

The Flux Linkage Recorder may be initiated any time during the motor run.

Current Controller Recorder captures:

- Desired Phase Current
- Active Phase Current
- Output Duty Cycle
- Encoder Position Reference

Current Controller Recorder may be initiated any time during the motor run.

Due to limited on-chip memory, the recorder can be used **only** when the application is running from **External RAM**. The length of the recorded window may be set in *Recorder Properties* => bookmark *Main* => *Recorded Samples*. It is limited by the dedicated memory space in Processor Expert's *PC_Master* bean. The recorder samples are taken every 64.5 seconds.

Start the PC master software window's application, *3ph_srm_sensorless.pmp*. **Figure 1-3** illustrates the PC master software control window after this project has been launched.

Note: If the PC master software project (*.pmp* file) is unable to control the application, it is possible that the wrong load map (*.elf* file) has been selected. PC master software uses the load map to determine addresses for global variables being monitored. Once the PC master software project has been launched, this option may be selected in the PC master software window under *Project / Select Other Map File Reload*.

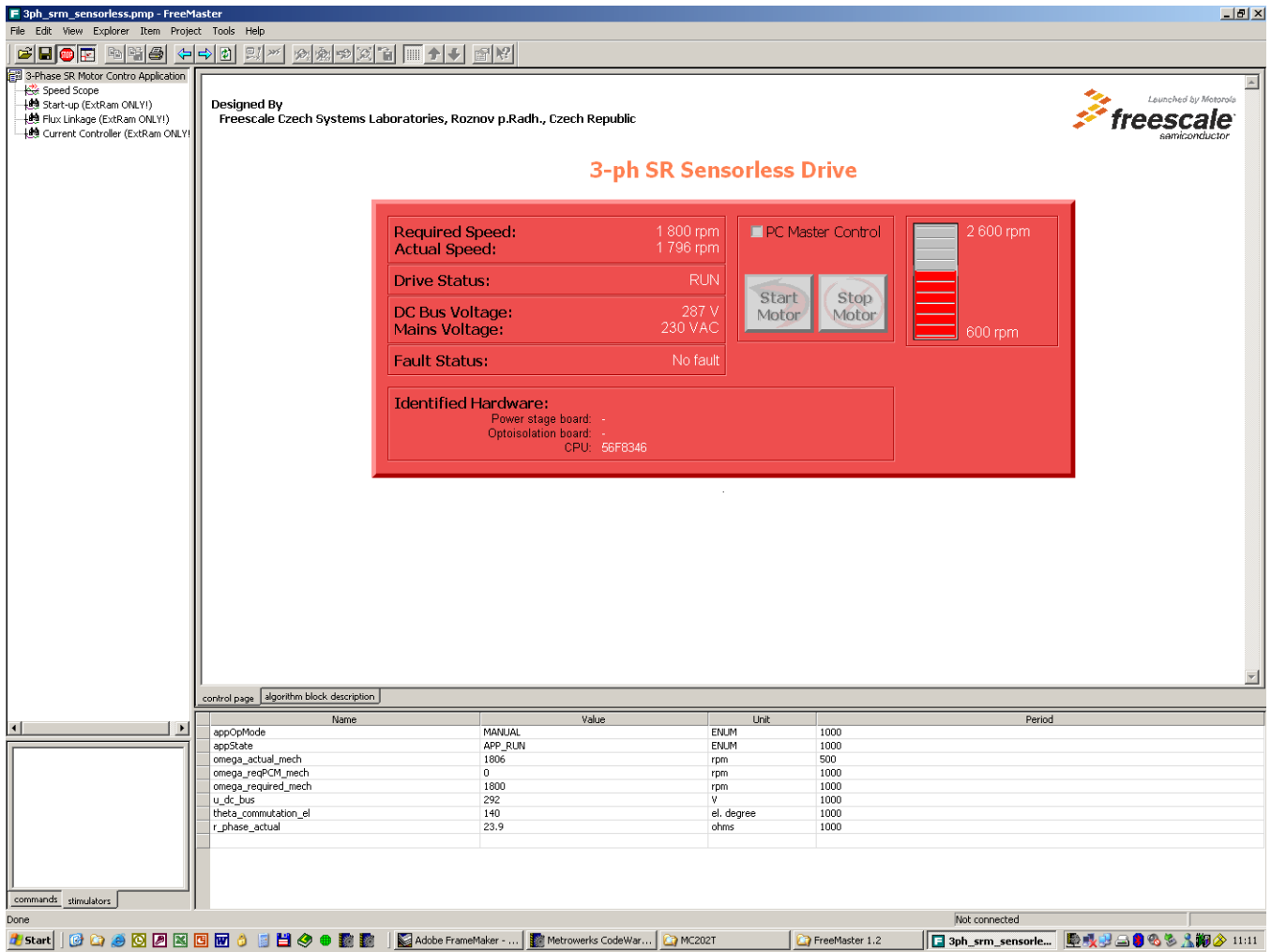


Figure 1-3 PC Master Software Control Window

2. Hardware Set-Up

Figure 2-1 illustrates the hardware set-up for the 3-phase Switched Reluctance Motor Sensorless Control Application.

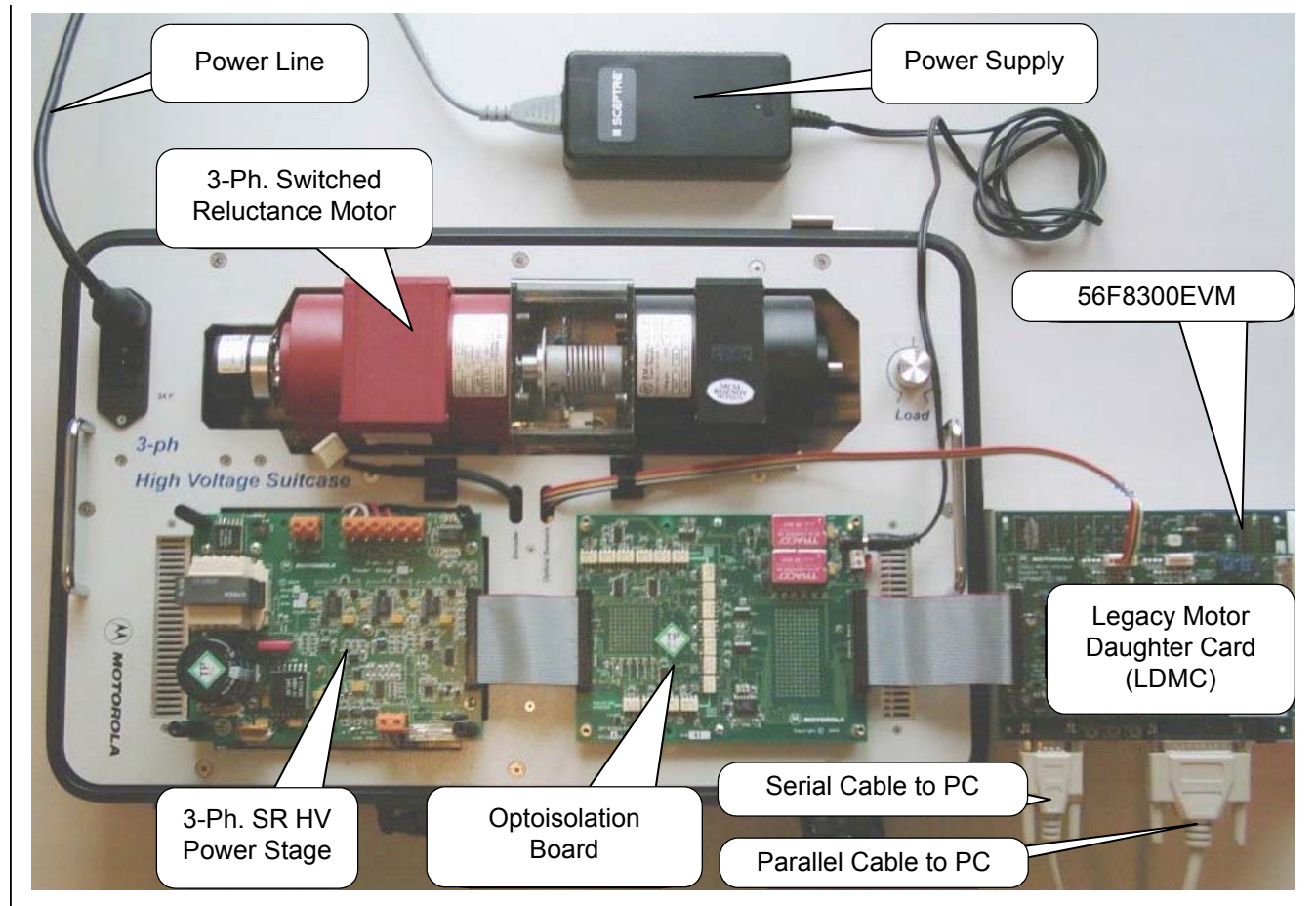


Figure 2-1 Application Setup

The correct order of phases for the switched reluctance motor shown in **Figure 2-1** is:

- Phase A = white wire
- Phase B = red wire
- Phase C = black wire

When facing a motor shaft, the phase order is: Phase A, Phase B, Phase C; the motor shaft should rotate clockwise (i.e., positive direction, positive speed).

For detailed information, see the **56F83xx Evaluation Module Hardware User's Manual** for the device being implemented. The serial cable is needed only for the PC master software debugging tool.

2.1 EVM Jumper Settings

For jumper settings, see the **56F8346 Evaluation Module Hardware User’s Manual**, **56F8357 Evaluation Module Hardware User’s Manual** or **56F8367 Evaluation Module Hardware User’s Manual**.

Note: When running the EVM target system in a stand-alone mode from Flash, in the **56F8346EVM**, the **JG9** jumper must be set in the 1-2 configuration to disable the command converter parallel port interface. In the **56F8357EVM** or the **56F8367EVM**, the **JG3** jumper must be set in the 1-2 configuration to disable the command converter parallel port interface.

For a detailed description for jumper settings, see the appropriate **56F83xx Evaluation Module Hardware User’s Manual** for the device being implemented.

2.1.1 Legacy Motor Daughter Card (LMDC) Jumper Settings

To execute the 3-Phase Switched Reluctance Motor Sensorless Control Application, the 56F8300 LMDC requires the strap settings shown in [Figure 2-2](#) and [Table 2-1](#).

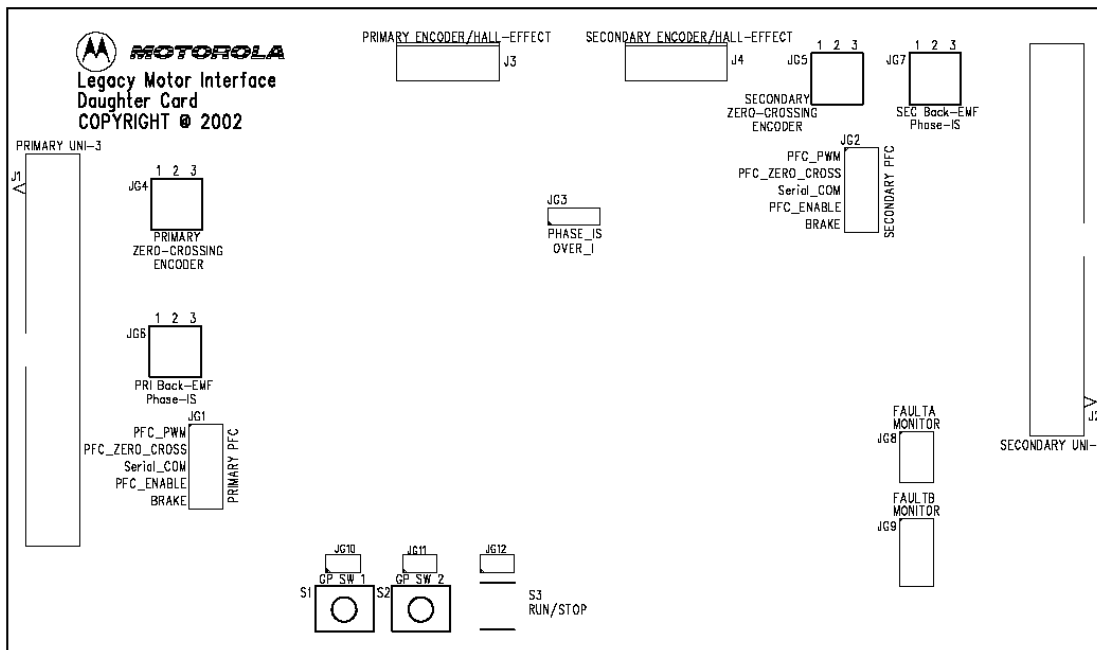


Figure 2-2 56F8300EVM LMDC Jumper Reference

Table 2-1 56F8300EVM LMDC Jumper Settings

Jumper Group	Comment	Connections
JG1	Primary PFC	1-2 & 3-4 & 5-6 & 7-8 & 9-10
JG2	Secondary PFC	NC
JG3	Phase_IS / Over_I	2-3
JG4	Primary Zero-Crossing / Encoder	2-3 & 5-6 & 8-9
JG5	Secondary Zero-Crossing / Encoder	2-3 & 5-6 & 8-9
JG6	Primary Back-EMF / Phase-IS	1-2 & 4-5 & 7-8
JG7	Secondary Back-EMF / Phase-IS	1-2 & 4-5 & 7-8
JG8	Fault A Monitor	1-2 & 3-4 & 5-6
JG9	Fault B Monitor	1-2 & 3-4 & 5-6
JG10	Switch 1 (Up)	1-2
JG11	Switch 2 (Down)	1-2
JG12	Switch 3 (Run / Stop)	1-2

3. Build

To build this application, open the *3ph_srm_sensorless_56F83xx_onPE.mcp* project file and execute the *Make* command, as shown in **Figure 3-1**. This will build and link the 3-phase Switched Reluctance Motor Sensorless Control Application and all needed Metrowerks and Processor Expert libraries.

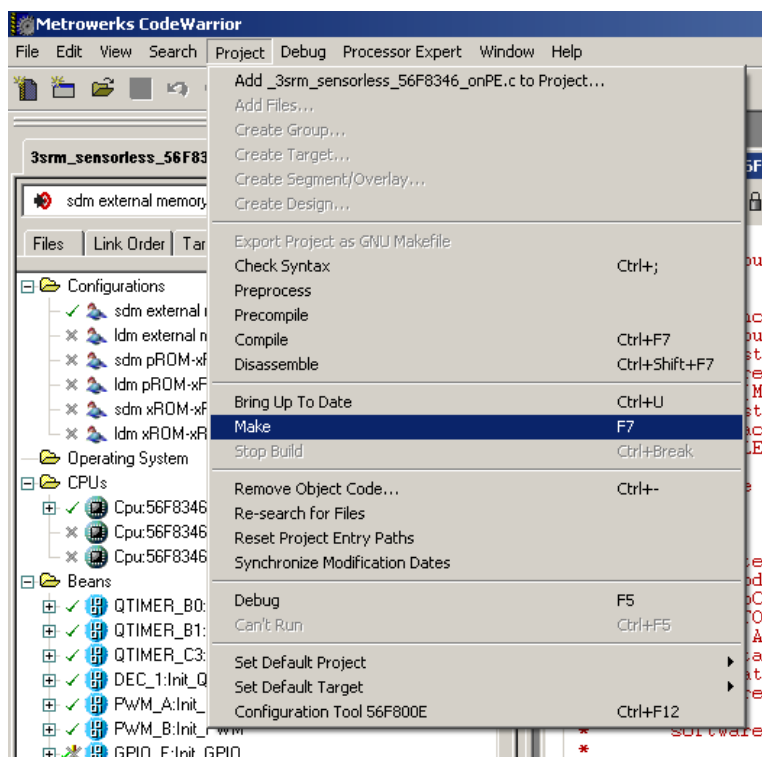


Figure 3-1 Execute *Make* Command

4. Execute

To execute the 3-phase Switched Reluctance Motor Sensorless Control Application, select *Project / Debug* in the CodeWarrior IDE, followed by the *Run* command.

If the *Flash* target is selected, CodeWarrior will automatically program the internal Flash of the hybrid controller with the executable generated during *Build*. If the *External RAM* target is selected, the executable will be loaded to off-chip RAM.

To execute the 3-phase Switched Reluctance Motor Sensorless Control Application's internal Flash version, choose the *Program / Debug* command in the CodeWarrior IDE and when loading is finished, in the **56F8346EVM**, set jumper **JG9** to disable the JTAG port and **JG3** to enable boot from *internal Flash*, then push the RESET button. In the **56F8357EVM** or the **56F8367EVM**, set jumper **JG3** to disable the JTAG port and **JG4** to enable boot from internal Flash, then push the RESET button.

For more help with these commands, refer to the CodeWarrior tutorial documentation in the following file, located in the CodeWarrior installation directory:

<...>\CodeWarrior Manuals \ PDF \ Targeting_56800E.pdf

For jumper settings, see the appropriate **56F83xx Evaluation Module Hardware User's Manual** for the device being implemented.

Once the application is running, move the RUN / STOP switch to the RUN position and set the required speed with the UP / DOWN push buttons. Pressing the UP / DOWN buttons should incrementally increase the motor speed until it reaches maximum speed. If successful, the 3-phase AC induction motor will be spinning.

Note: If the RUN / STOP switch is set to the RUN position when the application starts, toggle the RUN / STOP switch between the STOP and RUN positions to enable motor spinning. This is a protection feature that prevents the motor from starting when the application is executed from CodeWarrior. You should also see a lighted green LED, which indicates that the application is running. If the application is stopped, the green LED will blink at a 2Hz frequency. If an undervoltage, overvoltage, overcurrent, or overheating fault occurs, the green LED will blink at a frequency of 8Hz.



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