3-Phase BLDC Motor Control with Hall Sensors Using the MC56F8013

Targeting User Guide

56F8000
16-bit Hybrid Controllers

56F8013BLDCUG
Rev. 1
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About This Book

This manual describes the applications for 3-Phase BLDC motor control with Hall sensors using the 56F8013 device.

Audience

This document targets software developers using 3-Phase BLDC motor control for the 56F8013 processor.

Organization

- **Chapter 1, Introduction**—provides a brief overview of this document
- **Chapter 2, System Description**—describes the theory of BLDC motor control with Hall sensors for the 56F8013 processor
- **Chapter 3, Setting Up the Application**—explains how to set up the application
- **Chapter 4, Running the Application**—describes how the BLDC with Hall Sensor application operates

Suggested Reading

We recommend that you have a copy of the following references:

- *56F8013 Technical Data,* MC56F8013
- *56F8013 Motor Control Demonstration System using the 56F8013 Demonstration Board User Guide*, 56F8013MCSUG
- *3-Phase BLDC Motor Control with Hall Sensors using 56800/E Digital Signal Controllers*, AN1916
- *56F8000 Peripheral Reference Manual,* MC56F8000RM
- *Inside CodeWarrior: Core Tools*, Metrowerks Corp.

Conventions

This document uses the following notational conventions:

Typeface, Symbol or Term	Meaning	Examples
`Courier Monospaced Type`	Code examples	`//Process command for line flash`
Italic	Directory names, project names, calls, functions, statements, procedures, routines, arguments, file names, applications, variables, directives, code snippets in text	...and contains these core directories: *applications* contains applications software... ...CodeWarrior project, *3des.mcp* is... ...the *pConfig* argument.... ...defined in the C header file, *aec.h*....
Bold	Reference sources, paths, emphasis	...refer to the **Targeting DSP56F80x Platform** manual.... ...see: **C:\Program Files\Motorola\help\tutorials**
Blue Text	Linkable on-line	...refer to Chapter 7, License....
Number	Any number is considered a positive value, unless preceded by a minus symbol to signify a negative value	3V -10 DES^{-1}
ALL CAPITAL LETTERS	# defines/ defined constants	# define INCLUDE_STACK_CHECK
Brackets [...]	Function keys	...by pressing function key [F7]
Quotation marks, "..."	Returned messages	...the message, "Test Passed" is displayed.... ...if unsuccessful for any reason, it will return "NULL"...

Definitions, Acronyms, and Abbreviations

The following list defines the acronyms and abbreviations used in this document. As this template develops, this list will be generated from the document. As we develop more group resources, these acronyms will be easily defined from a common acronym dictionary. Please note that while the acronyms are in solid caps, terms in the definition should be initial capped ONLY IF they are trademarked names or proper nouns.

BLDC	Brushless DC Motor
PI	Proportional-Integral
PWM	Pulse Width Modulation

References

The following sources were used to produce this book:

1. *56F8000 Peripheral Reference Manual,* MC56F8000RM, Freescale Semiconductor, Inc.
2. *56F8013 Demonstration Board User Guide,* MC56F8013DBUG, Freescale Semiconductor, Inc.
3. *56F8000 Motor Control Board User Guide*, 56F8000MCBUG, Freescale Semiconductor, Inc.
4. *DSP56800E Reference Manual,* DSP56F800ERM, Freescale Semiconductor, Inc.
5. *56F8013 Technical Data,* MC56F8013, Freescale Semiconductor, Inc.
6. *3-Phase BLDC Motor Control with Hall Sensors using 56800/E Digital Signal Controllers*, AN1916, Freescale Semiconductor, Inc.
7. *56800/E Accelerated Development System Resource Pak* CD-ROM, CD342, Freescale Semiconductor, Inc. (available from the Literature Distribution Center)

Chapter 1
Introduction

1.1 Application Benefits

This document describes the design of a 3-phase BLDC (Brushless DC) motor control applciation with Hall Sensors, and explains how it is targeted for Freescale's 56F8013 dedicated motor control device. The software design takes advantage of the Processor Expert™ (PE) tool, included with CodeWarrior.

The theoretical concepts of this application are explained in an application note **3-Phase BLDC Motor Control with Hall Sensors using 56800/E Digital Signal Controllers**, found on the Freescale Semiconductor web site:

www.freescale.com

Chapter 2
System Description

The system is designed to drive a 3-phase BLDC motor. The application meets the following performance specifications:

- Speed/Voltage control of BLDC motor using Hall sensors
- Torque/Current control
- Start from any motor position without rotor alignment
- DCBus undervoltage fault protection
- Real-time application monitoring via the PC master software application

The BLDC drive introduced in this manual is designed to power a low-voltage BLDC motor equipped with Hall sensors, which is supplied with the Motor Control Daughter Card. The motor has the following specifications:

Table 2-1. Motor Information

M1		
Characteristic	**Typical Value**	**Units**
Power Rating	6	W
Nominal Voltage	9.0	Volt
No-Load Speed	8600	rpm
Stall Torque	20	mNm
Speed / Torque Gradient	479.0	rpm / mNm
No-Load Current	110	mA
Terminal Resistance Phase-to-Phase	4.50	Ohm
Maximum Permissable Speed	12000	rpm
Maximum Continuous Current at 5000rpm	1.03	A
Maximum Continuous Torque at 5000rpm	8.70	mNm
Maximum Efficiency	60.0	%
Torque Constant	9.5	mNm / A
Speed Constant	1007	rpm / v

Table 2-1. Motor Information (Continued)

M1		
Characteristic	**Typical Value**	**Units**
Mechanical Time Constant	70.0	ms
Rotor Inertia	13.9	gcm^2
Terminal Inductance Phase-to-Phase	1.070	mH
Thermal Resistance Housing Ambient	6.8	K / W
Thermal Resistance Winding-Housing	7.4	K / W
Thermal Time Constant Windings	3.7	s
Thermal Time Constant Stator	16.1	s

2.1 Application Description

A standard system concept is chosen for the drive; see **Figure 2-2**. The system incorporates the following hardware:

- 9V DC Power Supply
- 56F8000 Motor Control Daughter Card (Part #APMOTOR56F8000)
- Demostration board for MC56F8013 (Part #DEMO56F8013 or DEMO56F8013-E)

The 56F8013 runs the main control algorithm and generates 3-phase PWM output signals for a 3-phase inverter according to the user interface and feedback signals.

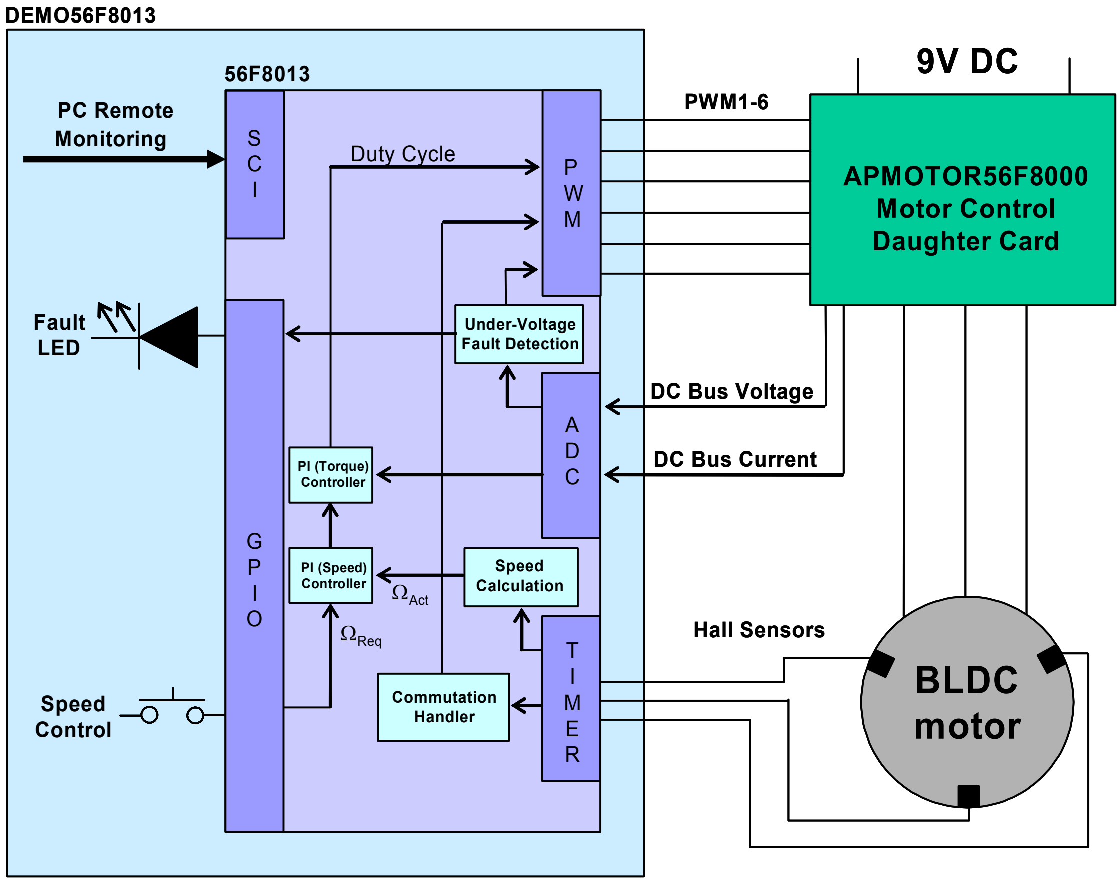

Figure 2-2. System Concept

The **control process** is as follows:

The state of the user interface is periodically scanned, while the speed of the motor is measured with each new edge from the Hall sensors; only one phase is used for speed measurement. The speed command is calculated according to the state of the control signals. The comparison between the actual speed command and the measured speed generates a speed error, which is input to the PI Speed controller that acts as an input to the PI Torque controller. Together with measured current, it forces the PI Torque controller to generate a new corrected duty cycle. The duty cycle value, together with the commutation algorithm, creates the PWM output signals for the BLDC power stage.

The Hall sensor signals are scanned independently of speed and torque controls. Each new coming edge of any Hall sensor signal calls the interrupt routine, which executes the commutation algorithm.

If undervoltage occurs, the PWM outputs are disabled and the fault state is displayed.

2.2 Hardware Design

This application utilizes the following HW modules:

- 56F8000 Motor Control Daughter Card (Part #APMOTOR56F8000)
- Demostration board for 56F8013 (Part #DEMO56F8013 or DEMO56F8013-E)

Refer to corresponding User Manual for more information on these boards.

2.3 Software Design

This section descibes the design of software blocks.

2.3.1 Data Flow

The control algorithm of a closed-loop BLDC drive is described in **Figure 2-3**. The individual processes are described in the following sections.

Figure 2-3. Main Data Flow

The main data flow can be divided into five parts:

- Speed control
- Torque control
- Velocity calculation
- Rotor commutation
- DCBus voltage measurement

Speed control starts with the *DesiredVoltageFraction* variable, which is set by the user button. This variable is used as one of the inputs to a Speed PI controller. The second input to the Speed PI controller is the *MeasuredVoltageFraction* variable, which is derived from the Velocity Calculation algorithm.

Velocity calculation is done by counting CPU clocks between the edges on one of the Hall Sensor phases (phase A). With a 4-pole motor, there are eight speed captures per one mechanical revolution, as shown in **Figure 2-4**:

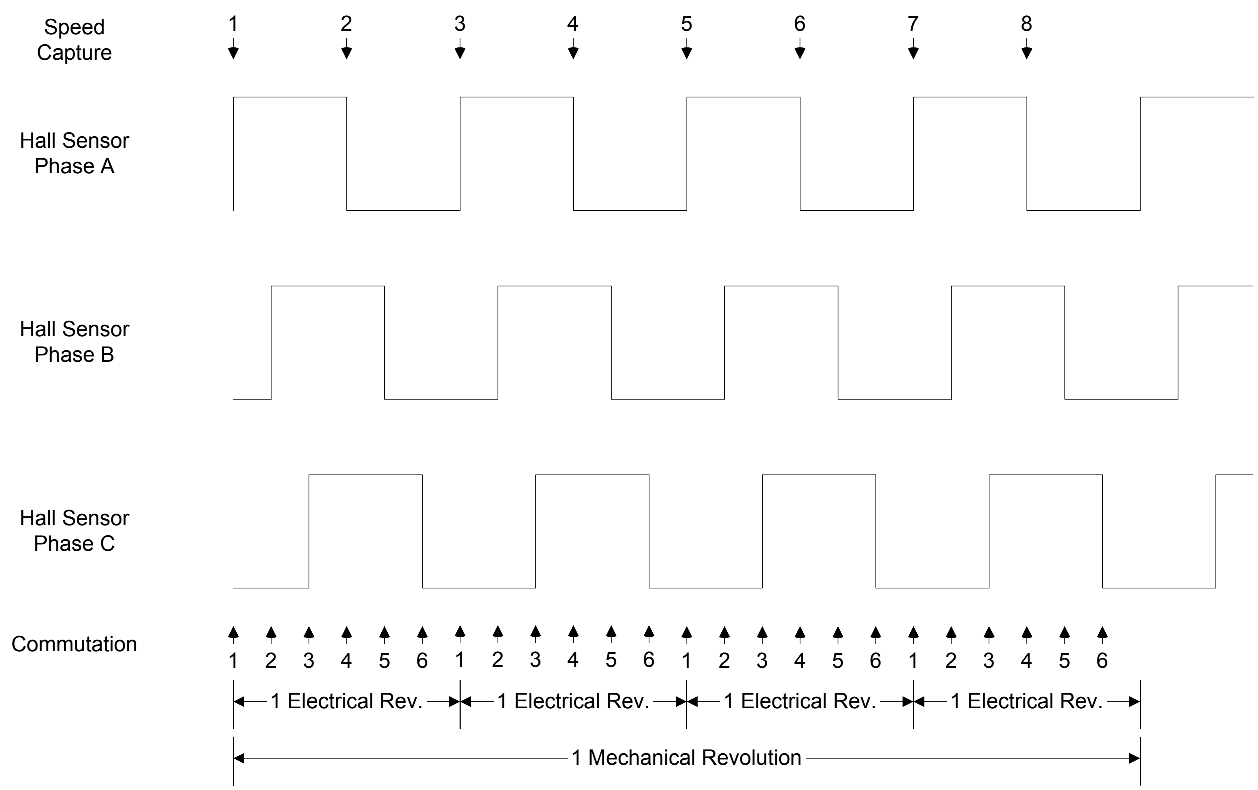

Figure 2-4. Speed Capture

At a maximum speed of 8600rpm, each timer capture should have a count of 218, calculated as follows:

9V = 8600rpm or 143.3 revolutions per second

By performing eight speed captures per revolution, there are 1146.6 captures per second, which translates to 872µsec per capture.

Since the capture timer is running at 250KHz or 32MHz / 128, a maximum rate of 8600 rpm will translate to 218 timer ticks for each capture.

To find the actual voltage fraction, divide 218 by the measured timer ticks. For example, if 218 timer ticks are measured, the voltage fraction is 1, or 100% (9V). If 436 timer ticks are measured, the voltage fraction is 0.5, or 50% (4.5V)

The output from the Speed PI controller is used as one of the inputs to a Torque PI controller. The second input to the Torque PI controller is the *ADCAvg* variable, which is derived from the DCBus current's moving average algorithm. The Torque PI controller's output determines the duty cycle of the generated PWM output signals.

The rotor commutation process performs mask and swap calculations' control. The proper PWM output can be generated by changing the PWM value (duty cycle) registers only. This has two disadvantages: The first is that the speed controller, which changes the duty cycle, affects the commutation algorithm (performed by changing the duty cycle). The second disadvantage is that a change in the duty cycle is synchronized with PWM reload, which may cause a delay between a proper commutation moment and the PWM reload. This is especially pronounced at high speed when the commutation period is very short.

The 56F801x device has two features dedicated to BLDC motor control: the ability to swap odd and even PWM generator outputs and the ability to mask (disable) any PWM generator outputs. These two features allow creation of a rotational field without changing the contents of the PWM value registers. The commutation algorithms calculate PWM mask and swap values based on the *SensorState* variable and the *ClockWiseCommTable* look-up table. The mask and swap values are written into the PWM Channel Control Register.

The DCBus voltage measurement acts as a fault detection, which disables PWM if voltage drops below 7V.

Chapter 3
Setting Up the Application

3.1 Required Parts and Instructions

To run this application, the user will need the 56F8013 Demonstration Board (DEMO56F8013 or DEMO56F8013-E) and the 56F8000 Motor Control Daughter Card (APMOTOR56F8000). These parts can be ordered through the Freescale website.

Please follow the instructions printed in the kit installation guide included in each kit to install and connect both boards, as well as to install CodeWarrior development tools.

The final set up should look like in the picture in Figure 3-1. Please the use default settings shown in the **56F8013 Demonstration Board User Guide**.

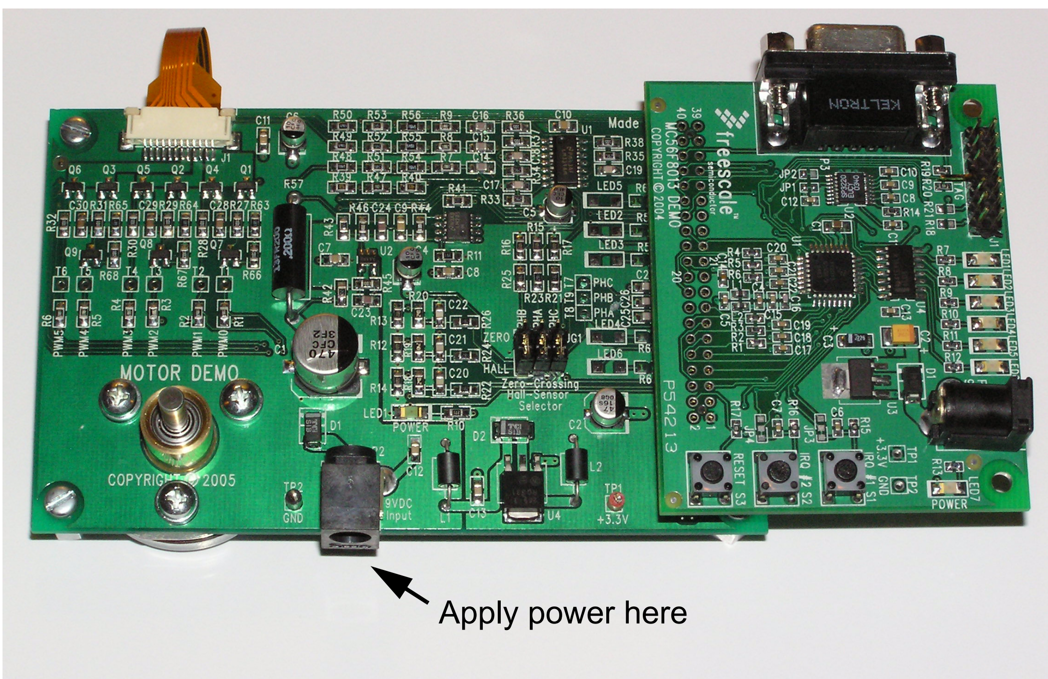

Figure 3-1. 56F8000 Motor Control Daughter Card and 56F8013 Demonstration Board

Chapter 4
Running the Application

4.1 BLDC with Hall Sensor Demonstration

Once this demonstration application is downloaded into the 56F8013 Demonstration Board, (DEMO56F8013), the user can control the speed of the BLDC motor by pressing and releasing the IRQ #2 button (S2) located on the demonstration board. Button control works as follows:

- Initially pressing and releasing the IRQ #2 button increases rotation speed
- Motor speed increases each time the IRQ #2 button is pressed, until the motor reaches maximum speed
- Once maximum speed is reached, motor speed decreases each time the IRQ #2 button is pressed, until the motor stops

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