Freescale Technology Forum

Design Innovation.

November 2008

Motor Control Part 3 - Solutions for Small Appliances and Health Care Applications

PZ106

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Application Engineer

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Abstract

Learn how cost-effective digital signal controllers (DSCs) and microcontrollers (MCUs) are the best choices for electric motor control in small appliances, such as toothbrushes, blenders and health care devices. The session will highlight several use cases and working demos that feature Freescale's S08SH8/4, S08QE8/4 and RS08KA8 8-bit MCUs, MCF51AC256 ColdFire® MCUs and 56F8013/23 DSCs.

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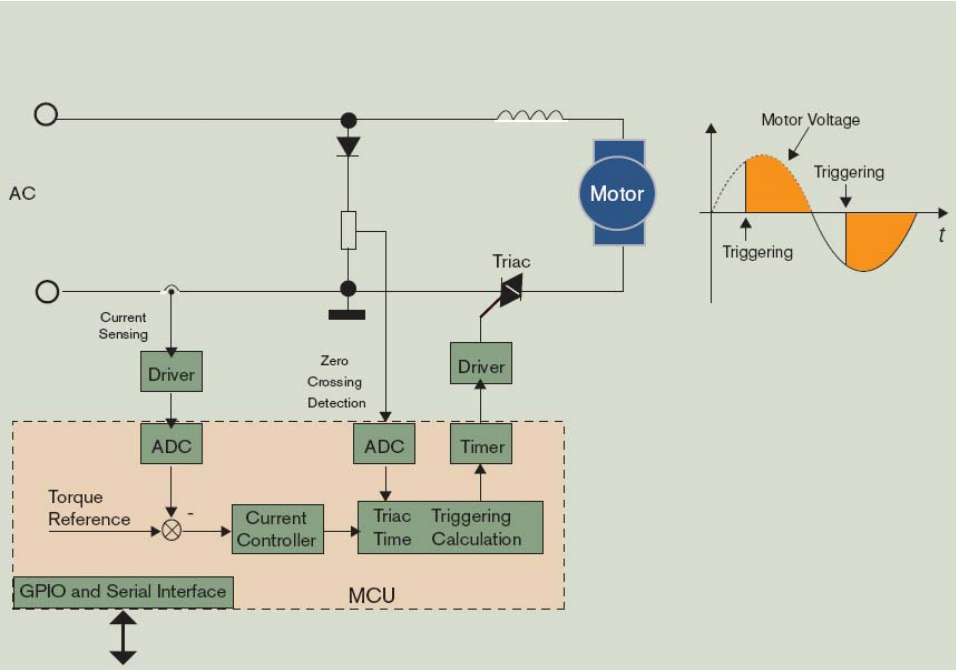
Universal Motor



Applications

- AC power tools
- Washers
- Dryers
- Garage openers
- Food mixers, blenders
- Vacuum cleaners
- Dishwashers
- HVAC
- Vibrating equipment
- Coffee makers
- Vending machines
- Pumps

Recommended Devices

8-bit MCU: HC908JK, JL, KX, MR, QT, QY, QB, GP, GR, GT;
HCS908AW, GB, GT, QG, QE, AC … any MCU with the right system features

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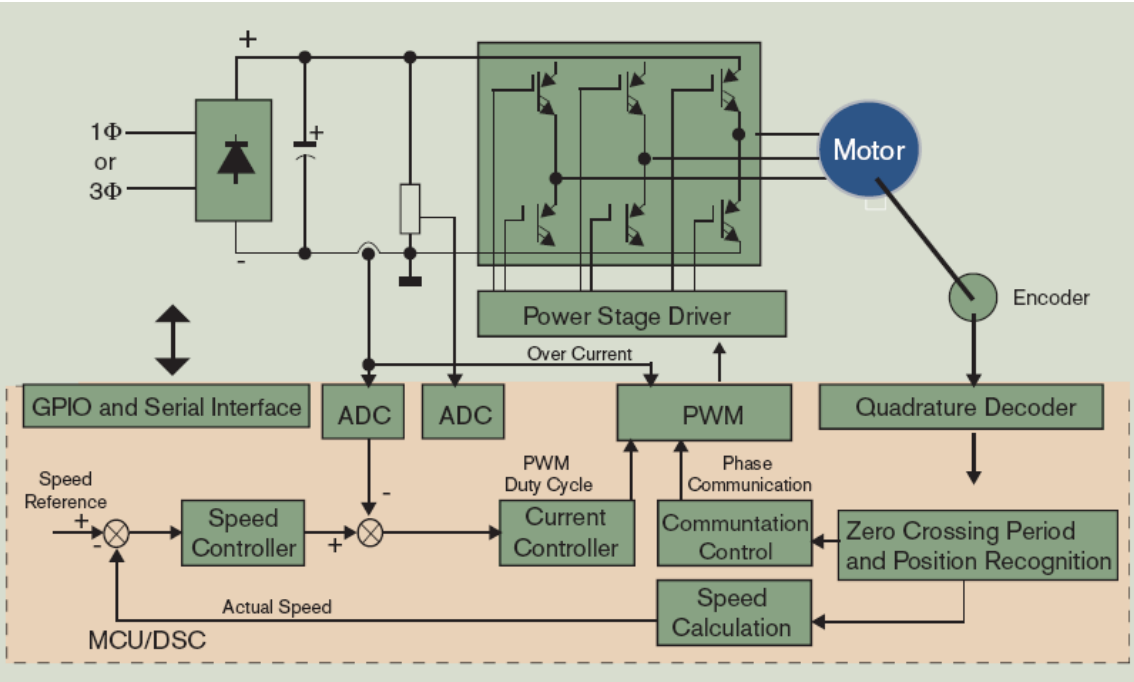
Brushless DC Motor (Encoder)



Recommended Devices

8-bit MCU: HC908MR, **HCS908**AW, GB, HCS908MP16

16-bit Digital Signal Controllers (DSC): MC56F80xx, MC56F83xx, Anguilla White

16-bit MCU: 9S12H, S12E, S12A, S12C, S12GC, S12X

32-bit MCU: MC51QE, MCF521x, MCF523x, MPC56x, MPC55xx

Analog/Mixed-Signal Power ASICs: MPC17510, MPC17529, MPC17531, MPC17533, MPC17550, MPC17559, MC34920, MC34921, MC34922, MC34923, MC33926, MC34710, MC34703

Advantages

- Enables bi-directional operation with fast-torque response, low noise and high efficiency
- High precision speed
- Torque control
- Position loop can be added

Applications

- Robots
- Traction control
- Servo systems
- Office equipment
- Sewing machines
- Fitness machines/treadmills
- Toys
- Industrial machines

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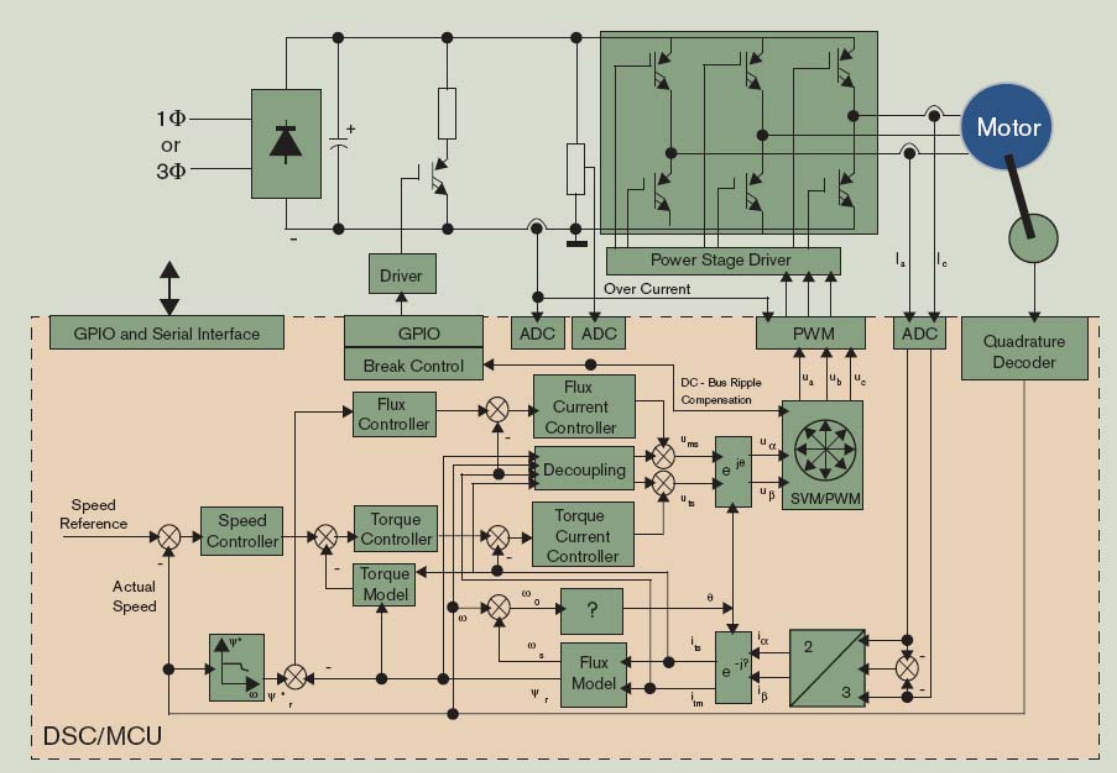
3-Phase AC Induction Motor (ACIM)—Vector Control



Advantages

- Very high precision speed/torque control
- Suitable for drives with high dynamic requirements
- Highly efficient

Applications

- Large appliances
- HVAC
- Blowers
- Fan, pumps
- Industrial controls
- Lifts, cranes, elevators
- Universal inverters
- Conveyors

Recommended Devices

16-bit Digital Signal Controllers (DSC): MC56F80xx, MC56F83xx, Anguilla White

32-bit MCU: MC51QE, MCF521x, MCF523x, MPC56x, MPC55xx

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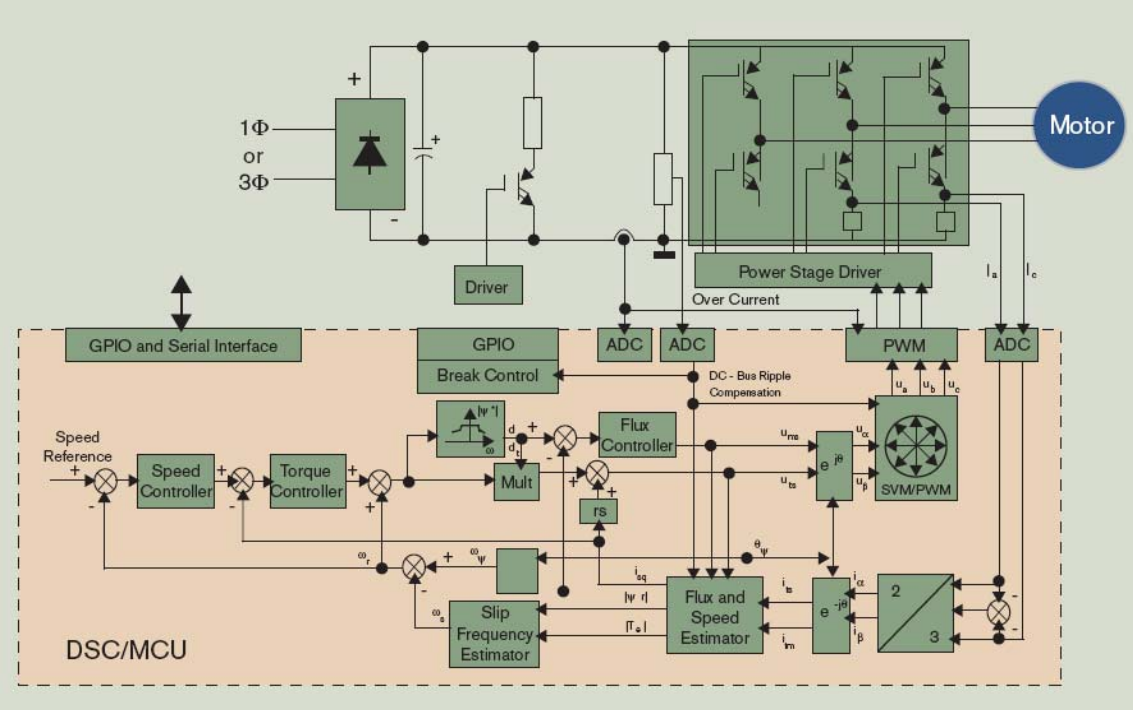
3-Phase Induction Motor (ACIM)—Sensorless Vector Control (Stator-Flux-Oriented)



Advantages

- High precision speed/torque control
- Suitable for drives with high dynamic requirements
- Removal of speed sensor

Applications

- Large appliances
- Industrial compressors
- Water pumps
- Construction machinery
- Universal inverters
- HVAC

- ***Recommended Devices***

- **16-bit Digital Signal Controllers (DSC):** MC56F80xx, MC56F83xx, Anguilla White

- **32-bit MCU:** MC51QE, MCF521x, MCF523x, MPC56x, MPC55xx

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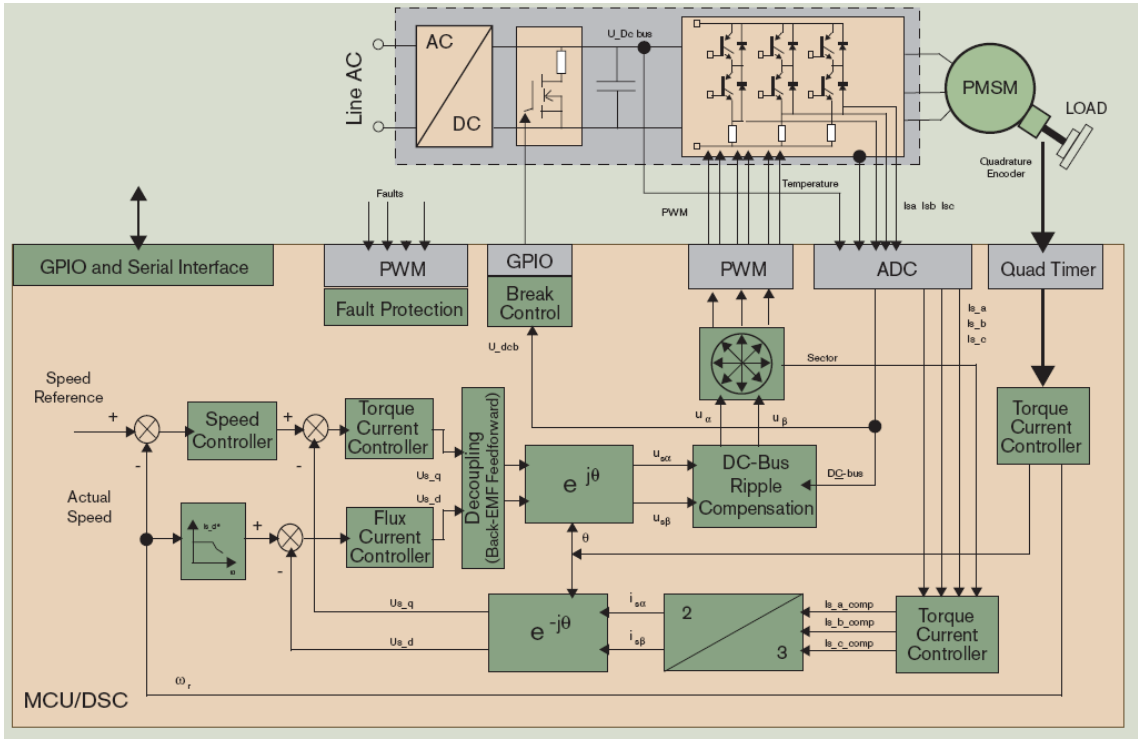
Permanent Magnet Synchronous Motor (PMSM)—Vector Control



Advantages

- Exceptionally low noise operation
- Outstanding drive efficiency
- Precise speed/torque control

Applications

- Robotics
- Elevators
- Servo drivers
- Traction systems
- Industrial motion control
- Automotive

Recommended Devices

16-bit Digital Signal Controllers (DSC): MC56F80xx, MC56F83xx, Anguilla White

32-bit MCU: MC51QE, MCF521x, MCF523x, MPC56x, MPC55xx

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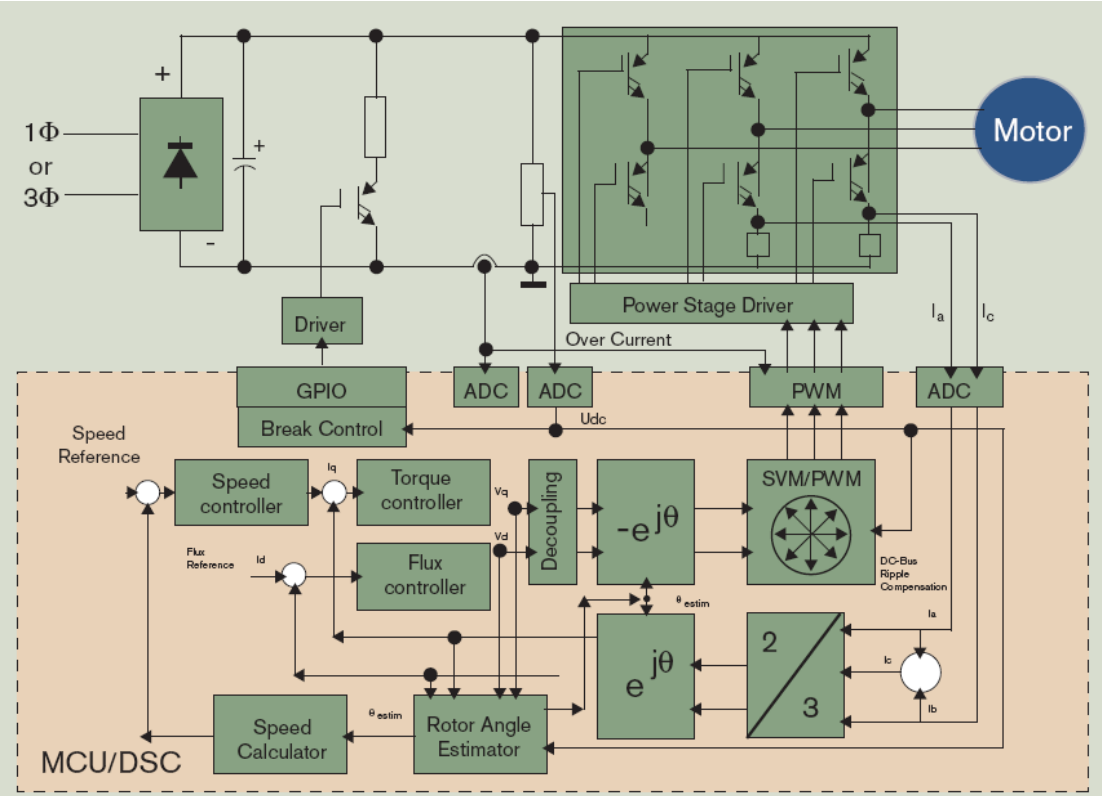
Permanent Magnet Synchronous Motor (PMSM)—Sensorless Sinusoidal



Advantages

- Very low noise operation
- Very high drive efficiency
- High precision speed/torque control
- Suitable for drives with high dynamic requirements
- Removal of speed sensor

Applications

- Appliances
- HVAC
- Compressors
- Blowers
- Industrial motion controls

Devices

16-bit Digital Signal Controllers (DSC): MC56F80xx, MC56F83xx, Anguilla White

32-bit MCU: MCF521x, MCF523x, MPC56x, MPC55xx

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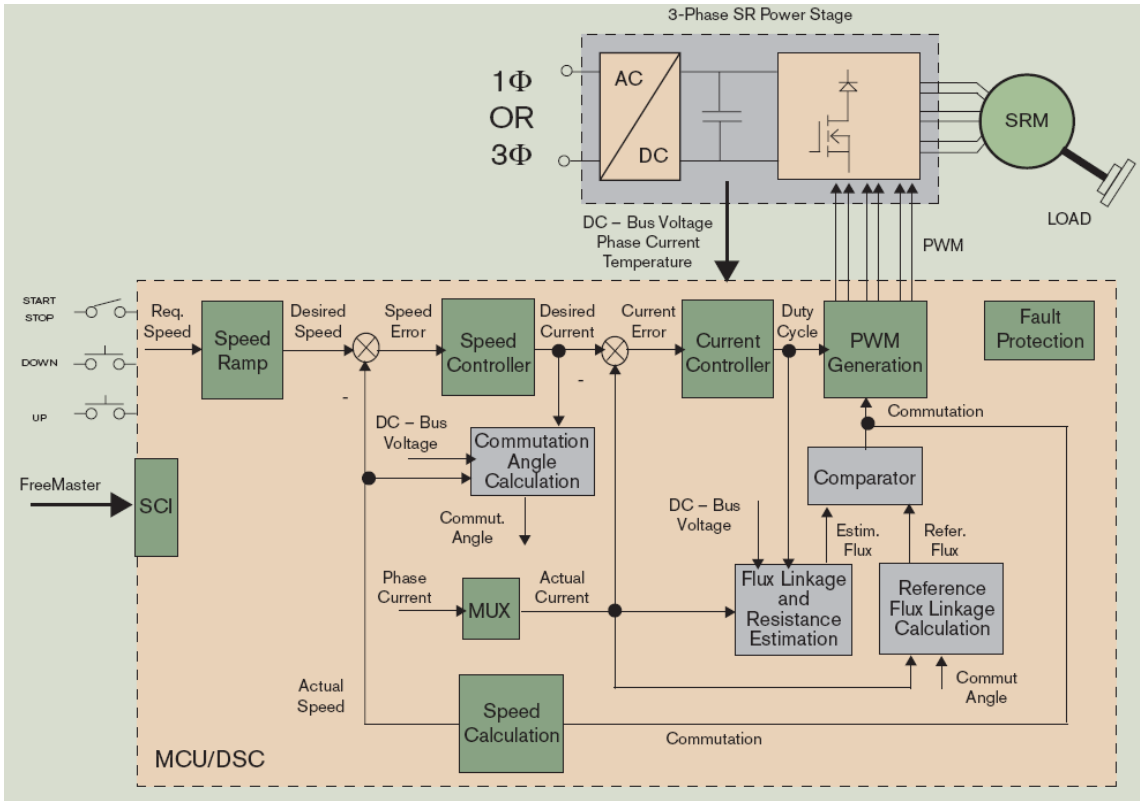
Sensorless Switch Reluctance Motor



Recommended Devices

16-bit Digital Signal Controllers (DSC): MC56F80xx, MC56F83xx, Anguilla White

Advantages

- Reliable electronics
- High starting torque
- Removal of position sensor

Applications

- Industrial machines
- Medical scanners
- Computers, office equipment
- Toys
- Food processors
- Vacuum cleaners
- Machine tools
- Large appliances

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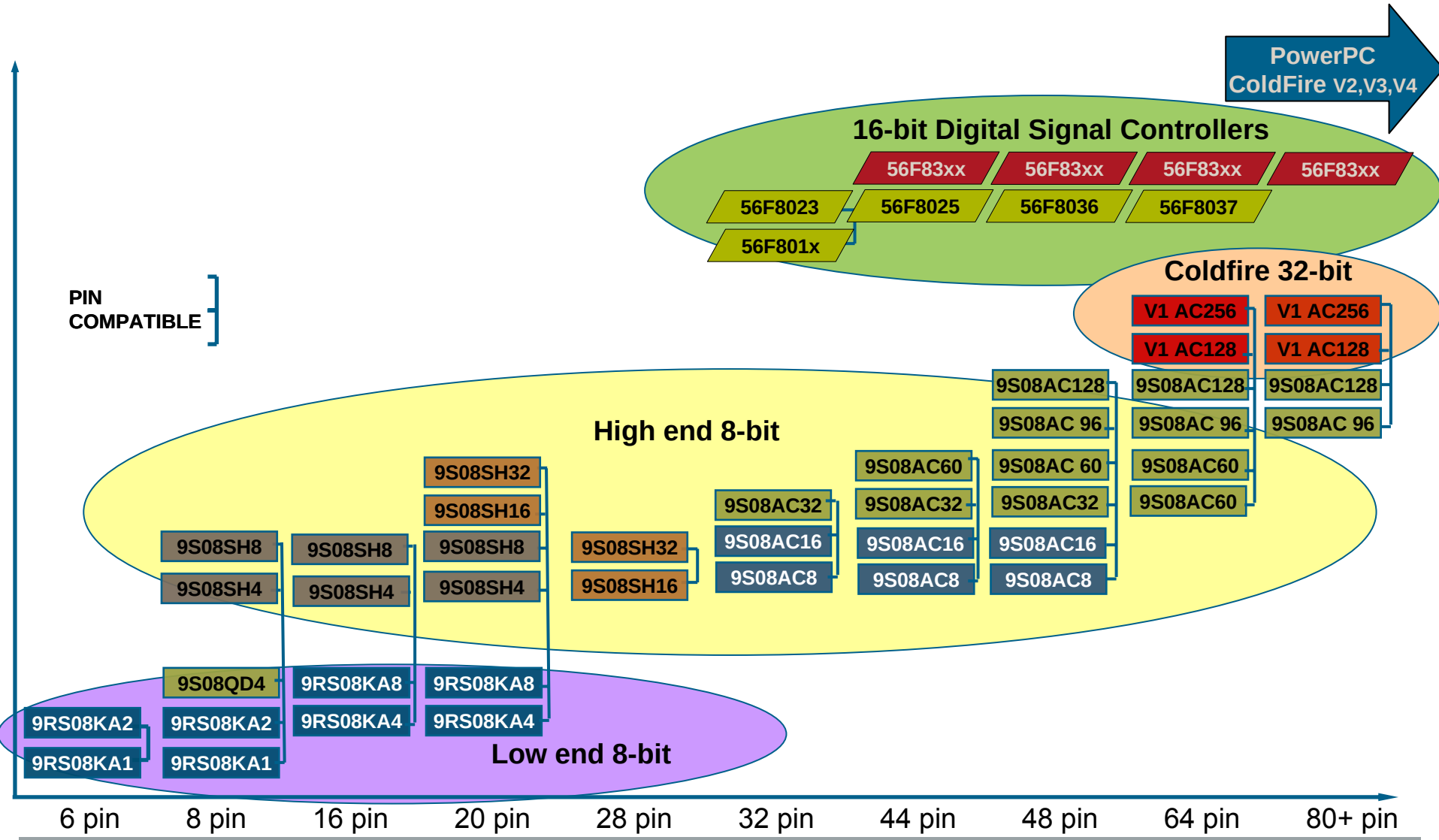
Freescale Motor Control MCU Devices



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MC9RS08KA8/4

Features / Benefits

- Full rail-to-rail supply operation
- Can operate in STOP mode
- Low Power Operation (<600uA @1MHz bus at 5V)
- Integrated clock source (ICS) - FLL, on-chip osc, ext crystal
- COP
- 2 x 8-bit Modulo Timers (MTIM)
- 2ch 16bit Timer (TPM)
- Analog Comparator (ACMP)
- 12 ch 10-bit Analog to Digital Converter (ADC)
- IIC
- 8 channel keyboard interrupt (KBI)
- Low voltage detect (LVD) with reset or stop wakeup
- External Vpp required for Flash programming
- Auto wakeup
- 14/18 GPIO

Supply Voltage / Performance

- 1.8 - 5.5 V operation
- -40 to 85°C operation

Core

- RS08 Core
- 10 MHz Bus (2% deviation over full temp and voltage range)

Memory

- 8K / 4K Flash
- 254 / 126B RAM

Packages

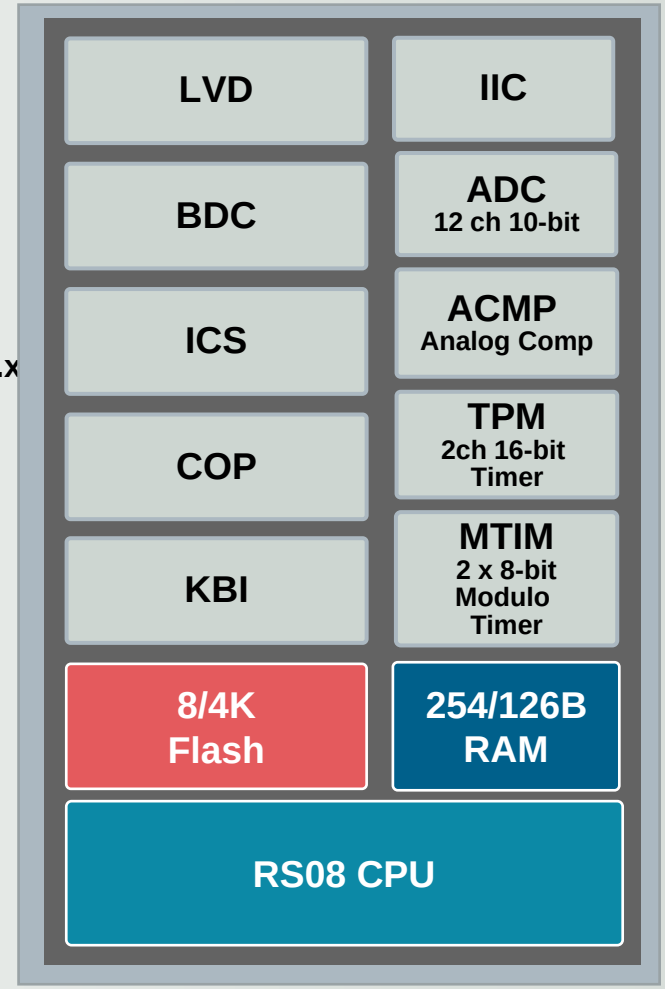
- 16 pin, 20 pin (SOIC/PDIP)

Target Applications

- **Small appliances**
- **Toys**
- **Simple analog comparator**
- **Simple logic replacement**
- **HB-LED**

Development tools

- **DEMO9RS08KA8**
- **Fast Track CodeWarrior® v6.x**



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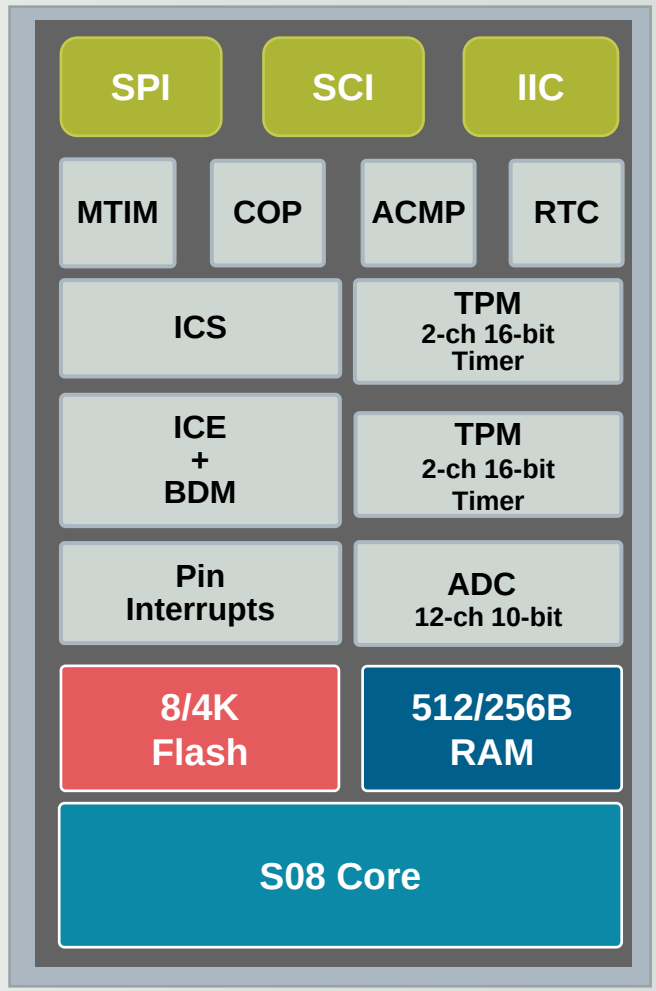
MC9S08SH8/4

- **Supply Voltage / Performance**
  - 2.7 – 5.5 V operation
  - -40 to 125°C operation
- **Core**
  - 40 MHz HCS08 core
  - 20 MHz bus frequency
- **Features / Benefits**
  - Multiple clock source options
    - 40 MHz ICS
    - XOSC for range of external clock sources
  - 2 x 2-ch 16-bit timer (TPM) & 8-bit modulo timer (MTIM)
  - 12-ch 10-bit ADC w/ built-in temp sensor
  - Analog comparator (ACMP) that can run in STOP3
  - LIN slave support
  - Low Voltage Detect (LVD)
  - Watchdog timer w/ multiple source options
  - Pin interrupts for selectable polarity
  - Hysteresis and configurable pull up device on all input pins
  - Configurable slew rate and drive strength on all output pins
  - Ganged output option to support high current drive
- **Memory**
  - 8/4K Flash, 512B/256B RAM
- **Communications**
  - SCI, SPI, IIC w/ broadcast mode
- **Packages**
  - 8 SOIC, 16 TSSOP, 20 PDIP, 20 TSSOP, 24 QFN



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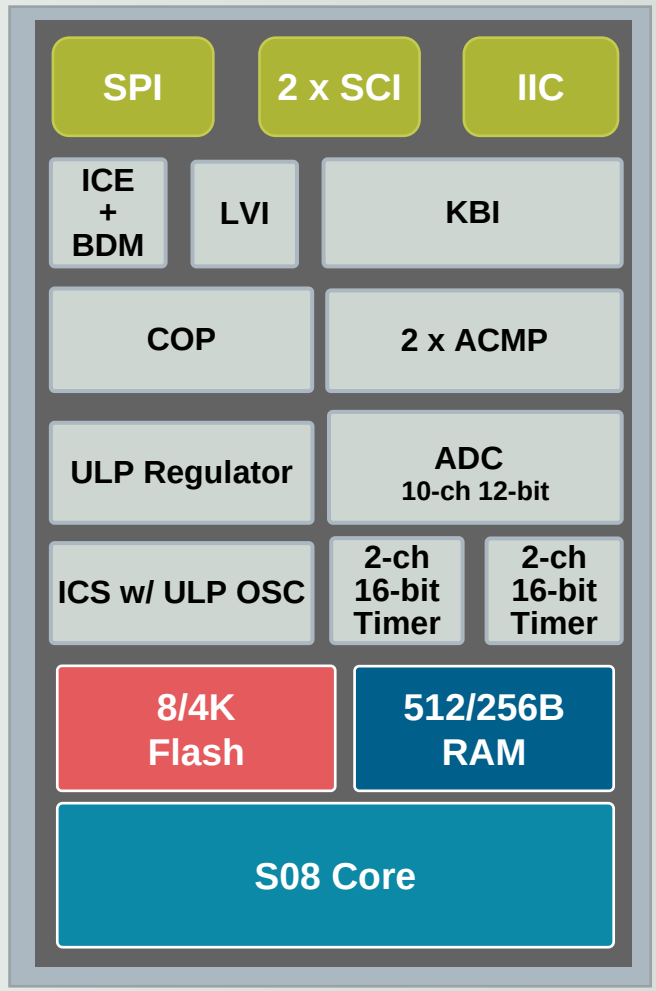
MC9S08QE8/4

- **Features / Benefits**
  - Internal clock source (ICS)
  - Vreg w/ fast start-up time and low-regulation voltage
  - Ultra- Low power 32 kHz oscillator (standby current 1.5 uA)
  - Optimized clock tree and clock gating techniques
- **Supply Voltage / Performance**
  - 1.8 – 3.3 V operation
  - -40 to 85°C operation
- **Core**
  - 20 MHz HCS08 core
  - 10 MHz bus frequency
- **Memory**
  - 8K Flash, 512B RAM
- **Communications**
  - 2xSCI, SPI, IIC w/ broadcast mode
- **Packages**
  - 16 TSSOP, 16 PDIP, 20 SOIC, 28 SOIC, 32 LQFP



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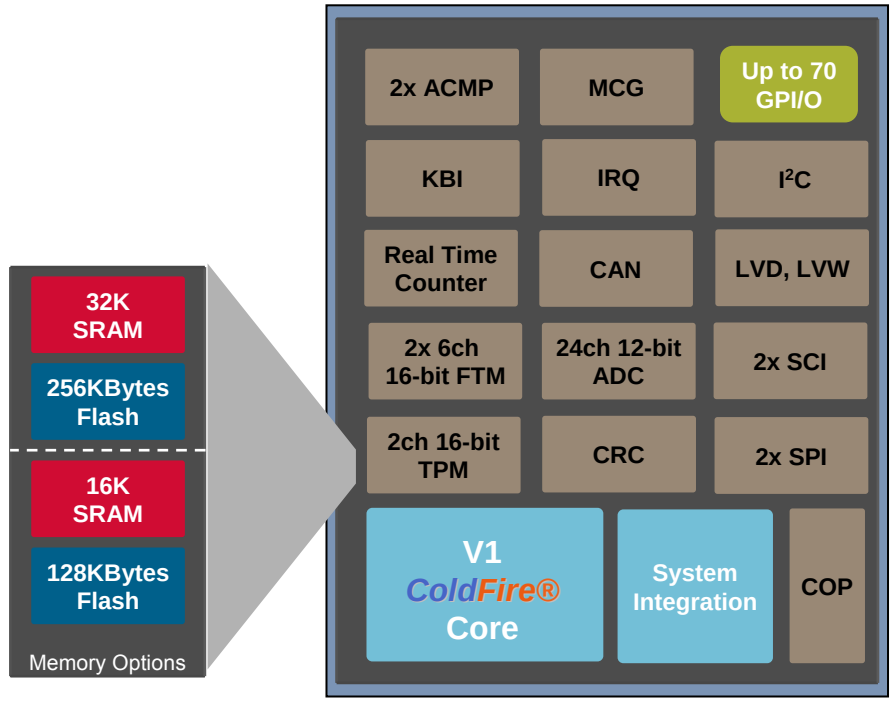
68K/*ColdFire*®: Celis MCF51AC

- **68K/ColdFire V1 Core: Up to 46 Dhrystone 2.1 MIPS @ 50 MHz**
- Up to 32K bytes SRAM / Up to 256K bytes Flash
- Single Supply **5 Volt Operation**
- High EMC (EMS) Performance
- Timer modules:
  - **2 x 6ch 16-bit FlexTimer Module (FTM)**
  - 1 x 2ch 16-bit TPM
- **24ch 12-bit ADC (2.5 us conversion)**
  - **ADC triggering from timer in addition to RTC**
- **msCAN Interface for Industrial Control**
- Real Time Counter (RTC)
- 2 x Serial Peripheral Interface (SPI), 2 x SCI
- I^2C bus interface with broadcasting mode
- Low Voltage Detect (LVD), Low Voltage Warning (LVW)
- Multi-Clock Generator (MCG)
- **Dual comparators (one linked to timer)**
- IEC60730 class C safety features
  - Cyclic Redundancy Check (CRC)
  - Watchdog option to run on independent clock source (LPO)
- Up to 70 General-Purpose I/O
- Offered at -40°C to +105°C @ 50MHz
- Packages:
  - 64LQFP, 64QFP, 80LQFP

New or Enhanced Module



Part Number	Flash	RAM	CAN	Price
Celis	256k	32k	Yes	$4.33
Celis	256k	32k	No	$4.23
Celis	256k	16k	Yes	$4.28
Celis	256k	16k	No	$4.13
Celis	128k	32k	Yes	$3.53
Celis	128k	16k	No	$3.33

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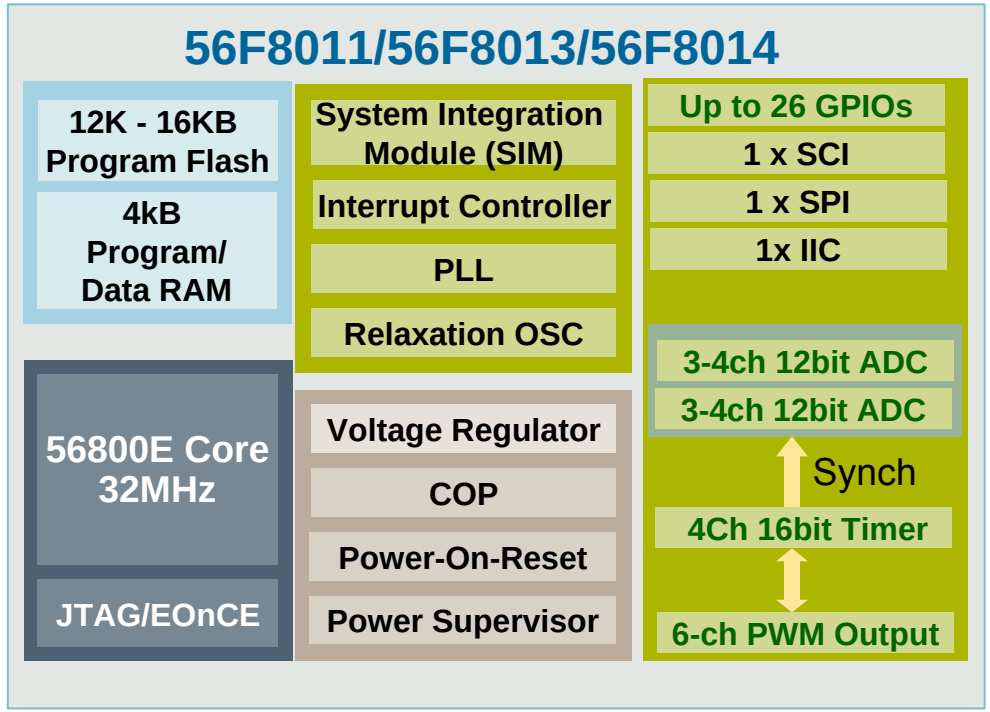
Cost Effective 56F8000 Solutions - 56F8011/56F8013/56F8014

- **32 MIPS Performance**
- 12K -16 K Bytes Program FLASH
- 4 K Bytes Program/Data RAM
- Tunable Internal Relaxation Oscillator
- Software Programmable Phase Locked Loop
- **Up to 96 MHz Peripherals – Timers and PWMs**
- **Up to 6-Output PWM Module with up to 4 Programmable Fault Inputs**
- **Selectable PWM frequency for each complementary PWM signal pair**
- **Two 12-bit ADCs with up to 8 Inputs , 1.125us conversion rate**
- **Synchronization between PWM and ADC**
- Four 16-bit General Purpose Programmable Timers
- Computer Operating Properly Timer
- Serial Ports: SCI, SPI, I2C
- Up to 26 GPIOs – Versatile pin usage
- Low Power Consumption – 59mA Max and .026mA Min
- JTAG/EOnCE™ Debug Port
- Industrial & Automotive temp
- Cost Effective



Package: 32LQFP

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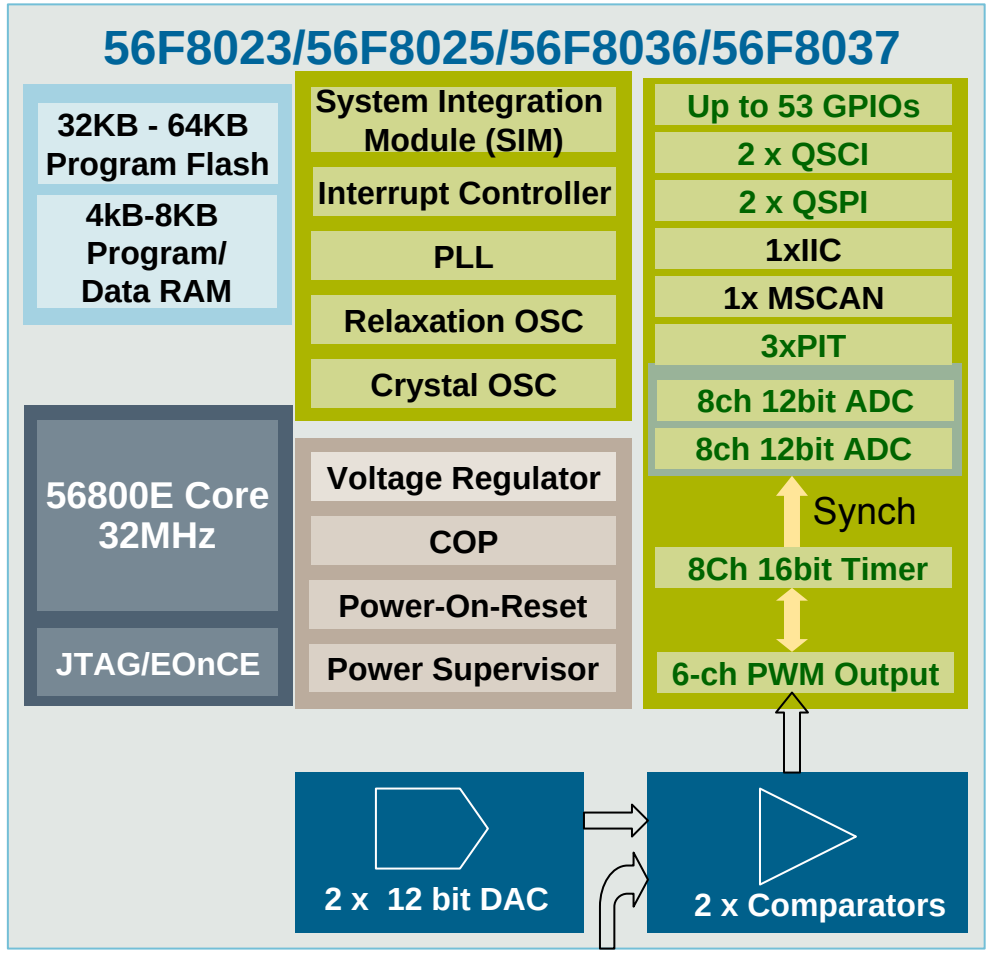
56F8000 Family Expansion - 56F8023/56F8025/56F8036/56F8037

- **32 MHz/32 MIPS 56800E Core**
- 3.0-3.6V Operation
- 32K-64K Bytes Program FLASH
- 4K-8K Bytes Program/Data RAM
- Flash security
- Tunable Internal Relaxation Oscillator
- Software Programmable Phase Locked Loop
- **Up to 96 MHz Peripherals – Timers and PWMs**
- 6 Output PWM Module with 4 Programmable Fault Inputs
- **Selectable PWM frequency for each complementary PWM signal pair**
- **Two 12-bit ADCs with up to 16 Inputs , 1.125us conversion rate**
- **Up to Two 12-bit Digital to Analog Converters**
- **Two Analog Comparators**
- Synchronization between PWM and ADC
- 4 or 8 16-bit General Purpose Programmable Timers
- **1 or 3 Programmable Interval Timers (PIT)**
- Computer Operating Properly Timer
- **2-Queued Serial Communications Interface**
- **2-Queued Serial Peripheral Interface**
- **Optional MSCAN**
- I^2C Communications Interface
- **Up to 53 GPIOs – Versatile pin usage**
- JTAG/EOnCE™ Debug Port
- Lead Free “Green” Packages
- Industrial & Automotive temp



Package 32 LQFP, 44LQFP, 48LQFP, 64LQFP

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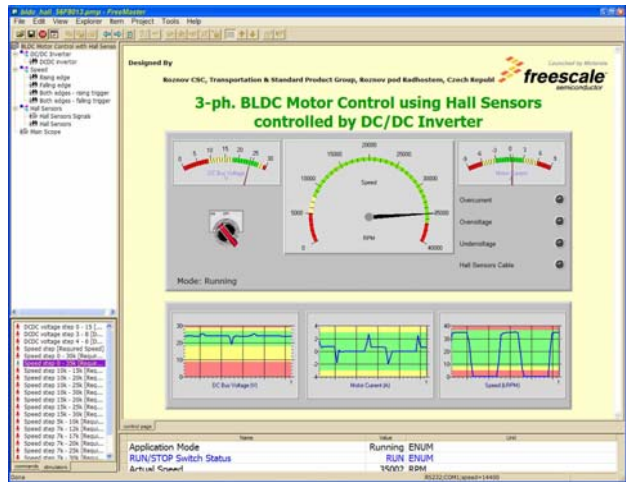
Very High Speed BLDC Control

DRM078

DRM078 - 3-Phase BLDC Drive Using Variable DC Link Six-Step Inverter

- Voltage control of BLDC motor using Hall sensors
- Targeted at the MC56F8013 controller board
- Running on 3-phase power stage with DC/DC inverter
- DC bus over-voltage and under-voltage, over-current, Hall sensors cable fault protection
- Control technique incorporating:
  - Voltage BLDC motor control using variable DC link six-step inverter with voltage closed loop
  - Closed-loop BLDC motor speed control
  - Both directions of rotation possible
  - Both motor and generator modes
  - Starting from any motor position without rotor alignment
  - Minimum speed – 300 RPM
  - Maximum speed – 38000 RPM
- FreeMASTER software control interface



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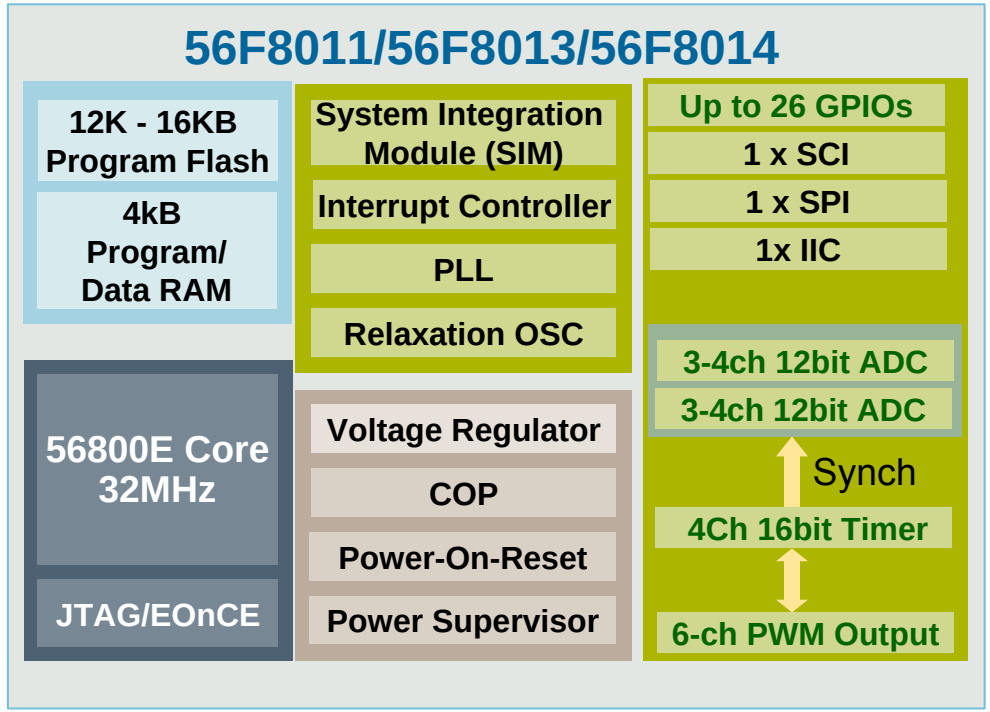
56F801x Key Features

DSC Key Features

- 32 MIPS performance
- Up to 96 MHz peripherals – timers and PWMs
- Up to 6-output PWM module with up to 4 programmable fault inputs
- Selectable PWM frequency for each complementary PWM signal pair
- Two 12-bit ADCs with up to 8 inputs, 1.125us conversion rate
- Synchronization between PWM and ADC
- Four 16-bit general purpose programmable timers



Package: 32LQFP

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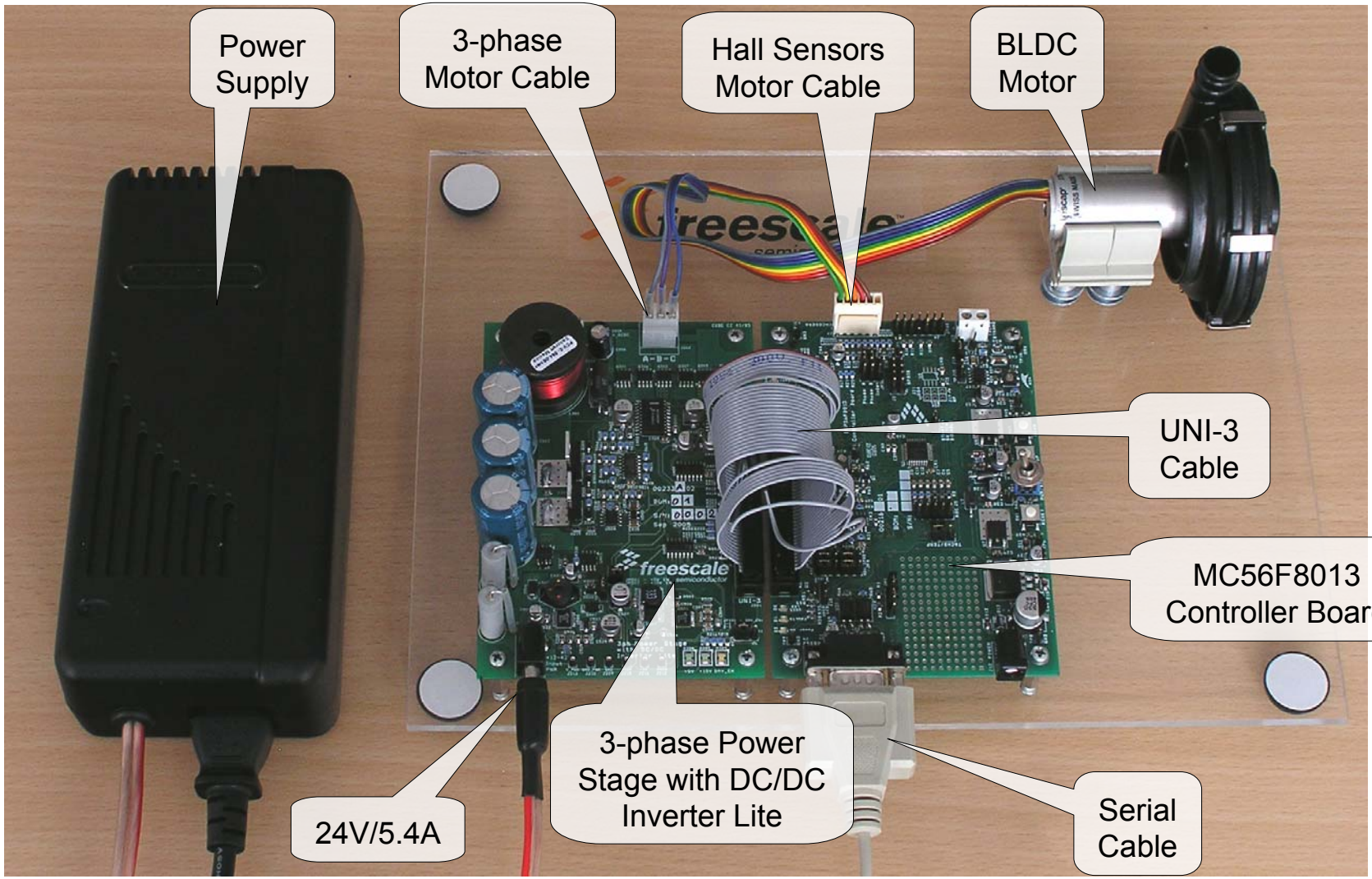
Demo Setup



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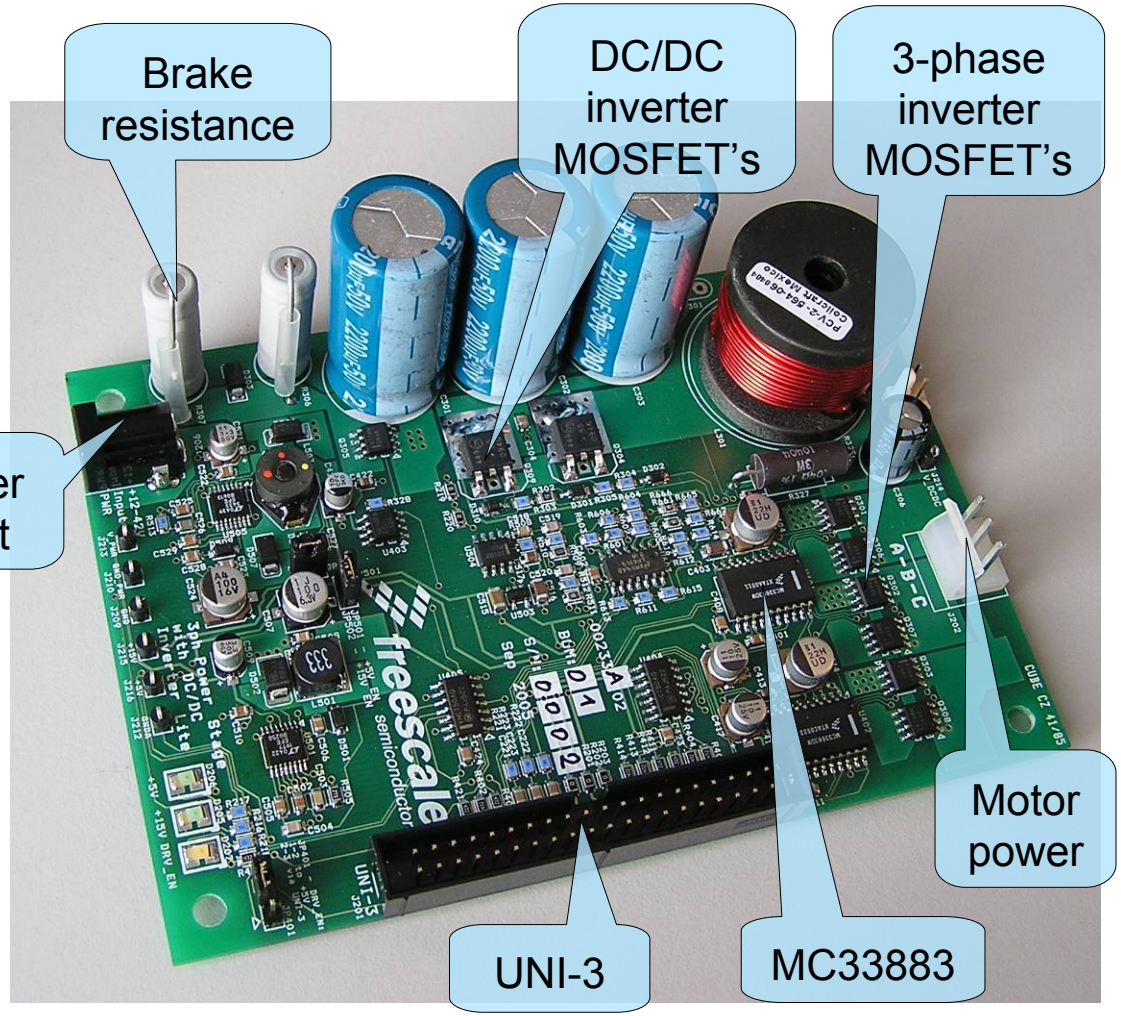
Power Board Features

- Power
  - 12 – 42V power supply
  - Up to 10A of current
  - 15V, 5V, 3.3V voltage generation
- Control
  - Controllable voltage on the 3-phase inverter by the DC/DC inverter
  - Energy recuperation
  - 10W of brake resistance
  - MC33883 MOSFET predrivers
- Connection
  - UNI-3 connector
  - 3-phase power connector
  - 2.1mm jack power input
- MOSFET's
  - 6x SO-8 for the 3-phase inverter
  - 2x DPAK or TO-220 for the DC/DC inverter
- Sensing
  - DC Bus voltage
  - DC/DC inverter output voltage
  - Motor current
  - BEMF voltage



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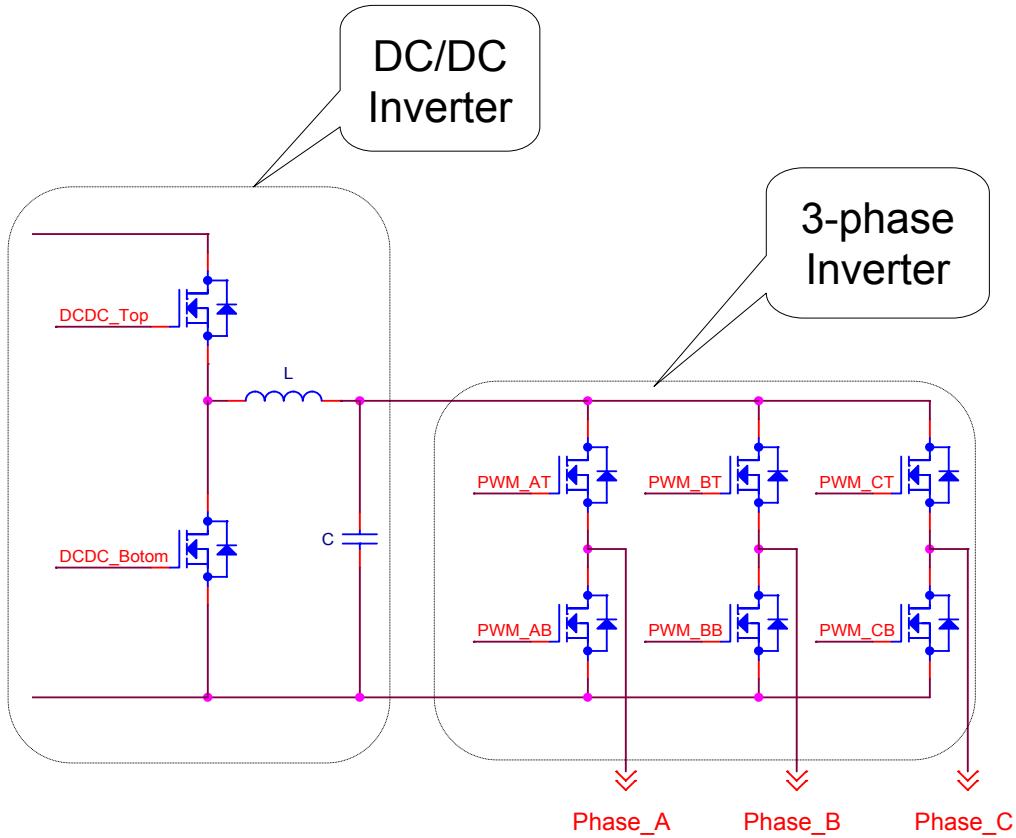
Board Outline

Two inverters on board:

- DC/DC Inverter
  - Converts one DC voltage level to different voltage level
  - Can operate in both direction, supply or brake
  - Provides voltage for the 3-phase inverter / motor
- 3-phase Inverter
  - Commutates the motor phases
  - Supplied (or braked) by the DC/DC inverter



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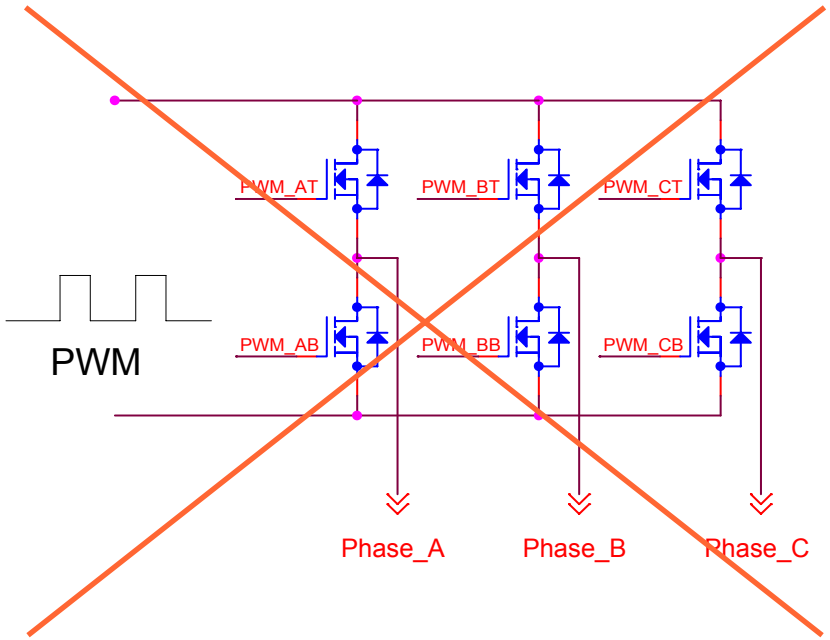
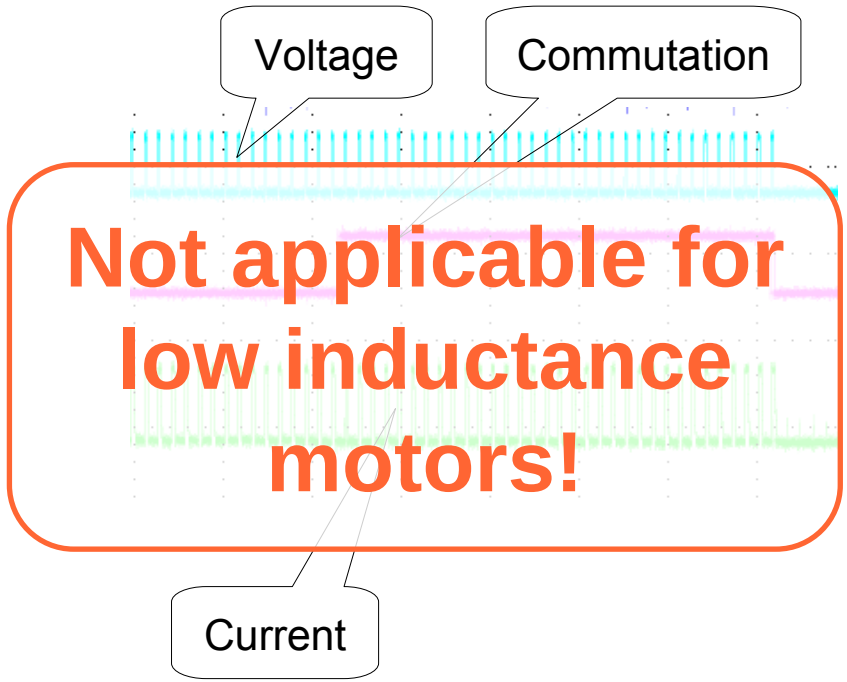
The Problem with High Speed BLDC Motor Control

- When PWM voltage is applied on a low inductance motor, the current does not get “filtered” and keeps the voltage PWM shape





- This switching of the current magnetizes and demagnetizes the motor iron with the same frequency as the PWM. This causes magnetic hysteresis losses that are observed by critical motor temperature

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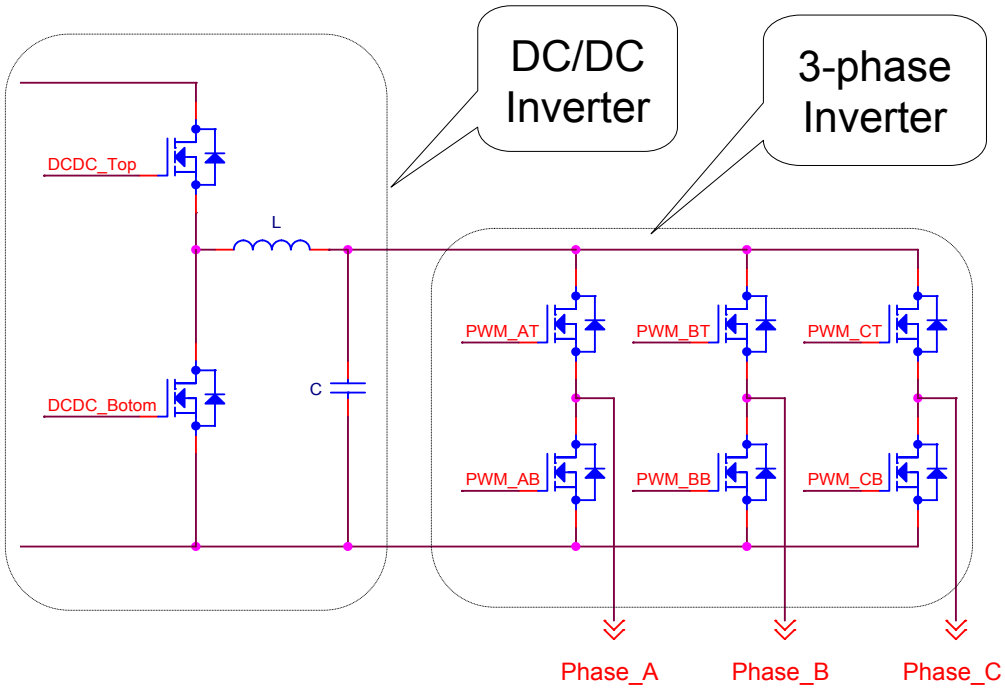
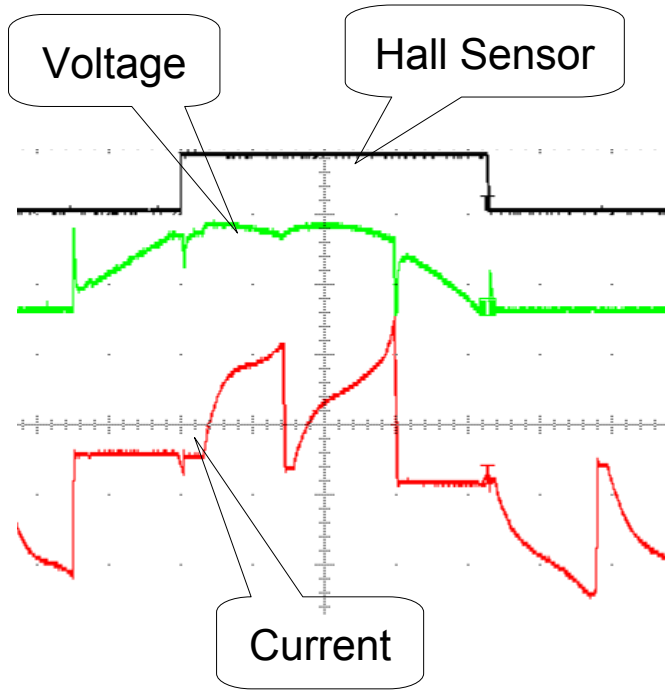
Solution - BLDC Motor Control using DC/DC Inverter

- Continuous voltage during commutation period creates continuous current along the commutation period ➔ low magnetic hysteresis losses ➔ motor is cool





- The DC/DC inverter generates the required voltage for the motor while the 3-phase inverter controls the commutation. MOSFET's of the 3-phase inverter are applied with 100% duty cycle

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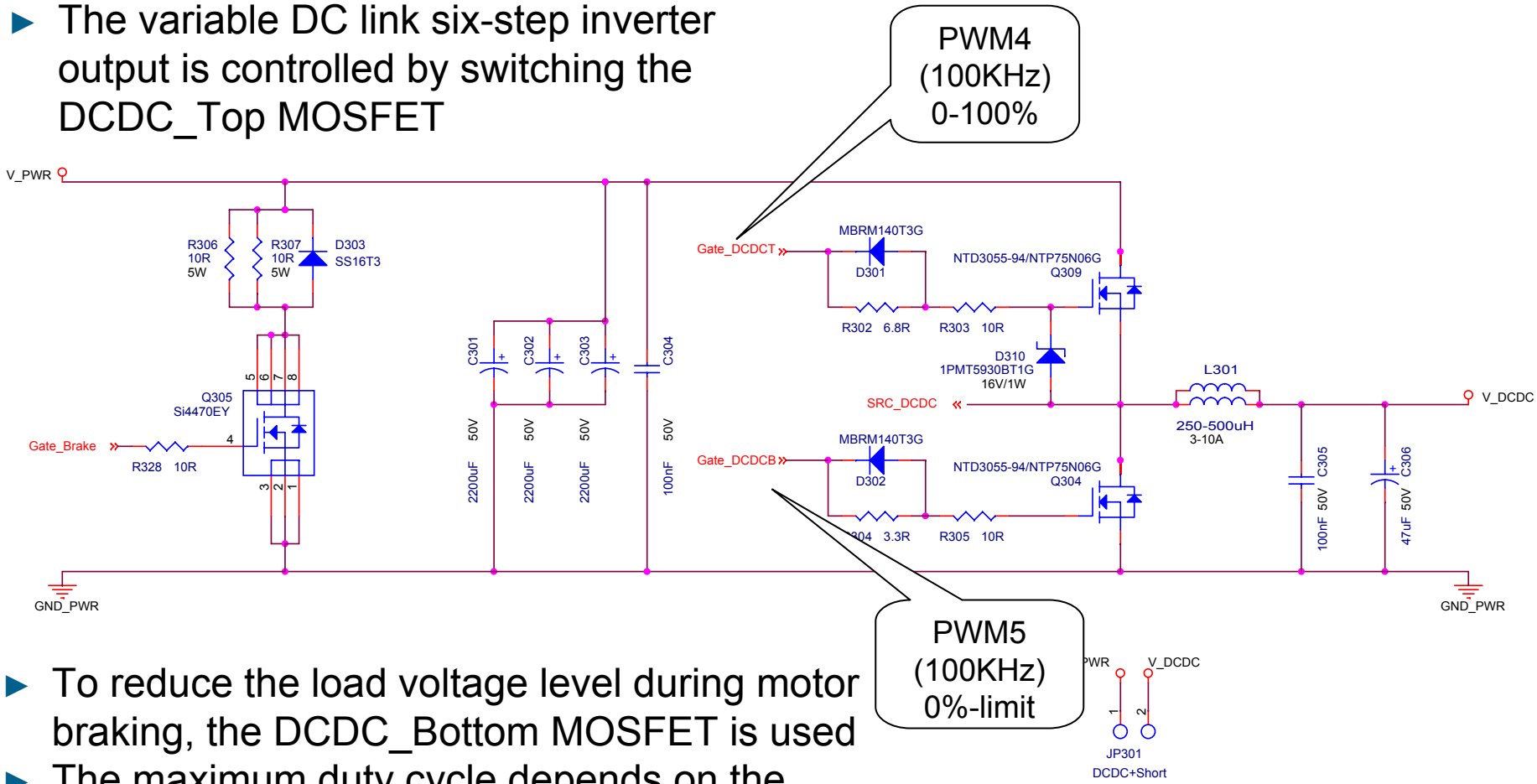
Schematics: DC/DC Inverter

- The variable DC link six-step inverter output is controlled by switching the DCDC_Top MOSFET



- To reduce the load voltage level during motor braking, the DCDC_Bottom MOSFET is used
- The maximum duty cycle depends on the voltages at both the input and the output

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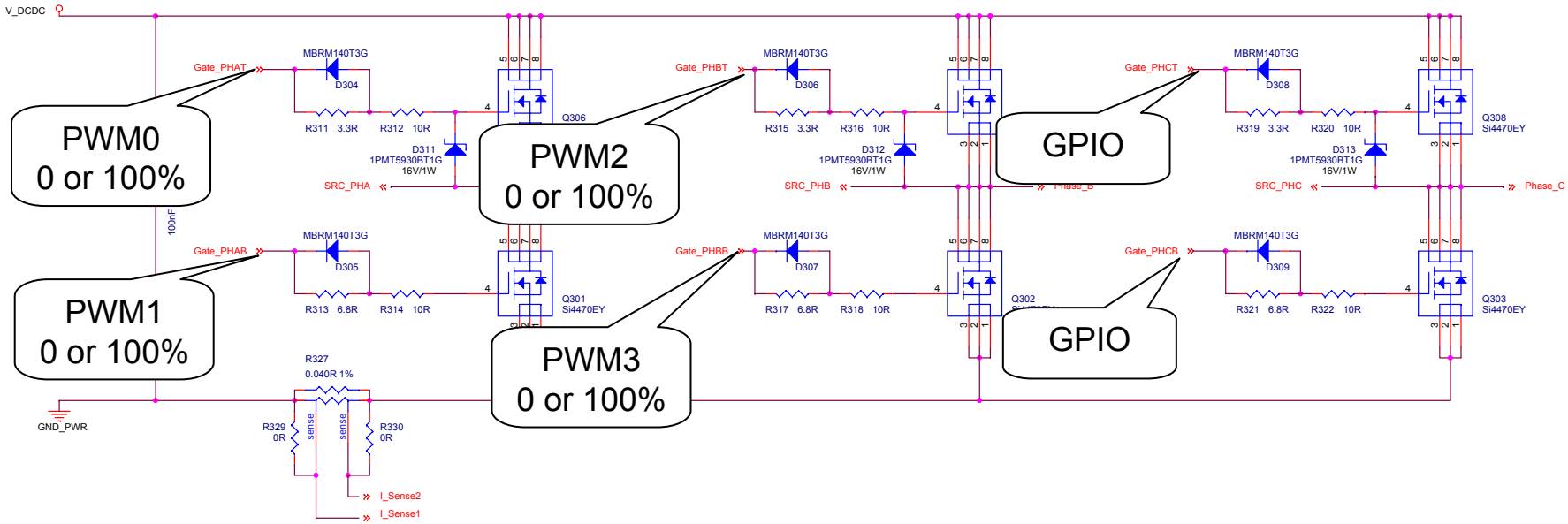
Schematics: 3-phase Inverter

- The 3-ph inverter uses the mask and swap logic of the 56F8013 to commutate the motor but does not use PWM signals



Clockwise Rotation

Hall Sensor A	Hall Sensor B	Hall Sensor C	Phase A	Phase B	Phase C
1	0	0	$-V_{DCB}$	$+V_{DCB}$	NC
1	0	1	NC	$+V_{DCB}$	$-V_{DCB}$
0	0	1	$+V_{DCB}$	NC	$-V_{DCB}$
0	1	1	$+V_{DCB}$	$-V_{DCB}$	NC
0	1	0	NC	$-V_{DCB}$	$+V_{DCB}$
1	1	0	$-V_{DCB}$	NC	$+V_{DCB}$

Counter Clockwise Rotation

Hall Sensor A	Hall Sensor B	Hall Sensor C	Phase A	Phase B	Phase C
1	0	0	$+V_{DCB}$	$-V_{DCB}$	NC
1	1	0	$+V_{DCB}$	NC	$-V_{DCB}$
0	1	0	NC	$+V_{DCB}$	$-V_{DCB}$
0	1	1	$-V_{DCB}$	$+V_{DCB}$	NC
0	0	1	$-V_{DCB}$	NC	$+V_{DCB}$
1	0	1	NC	$-V_{DCB}$	$+V_{DCB}$

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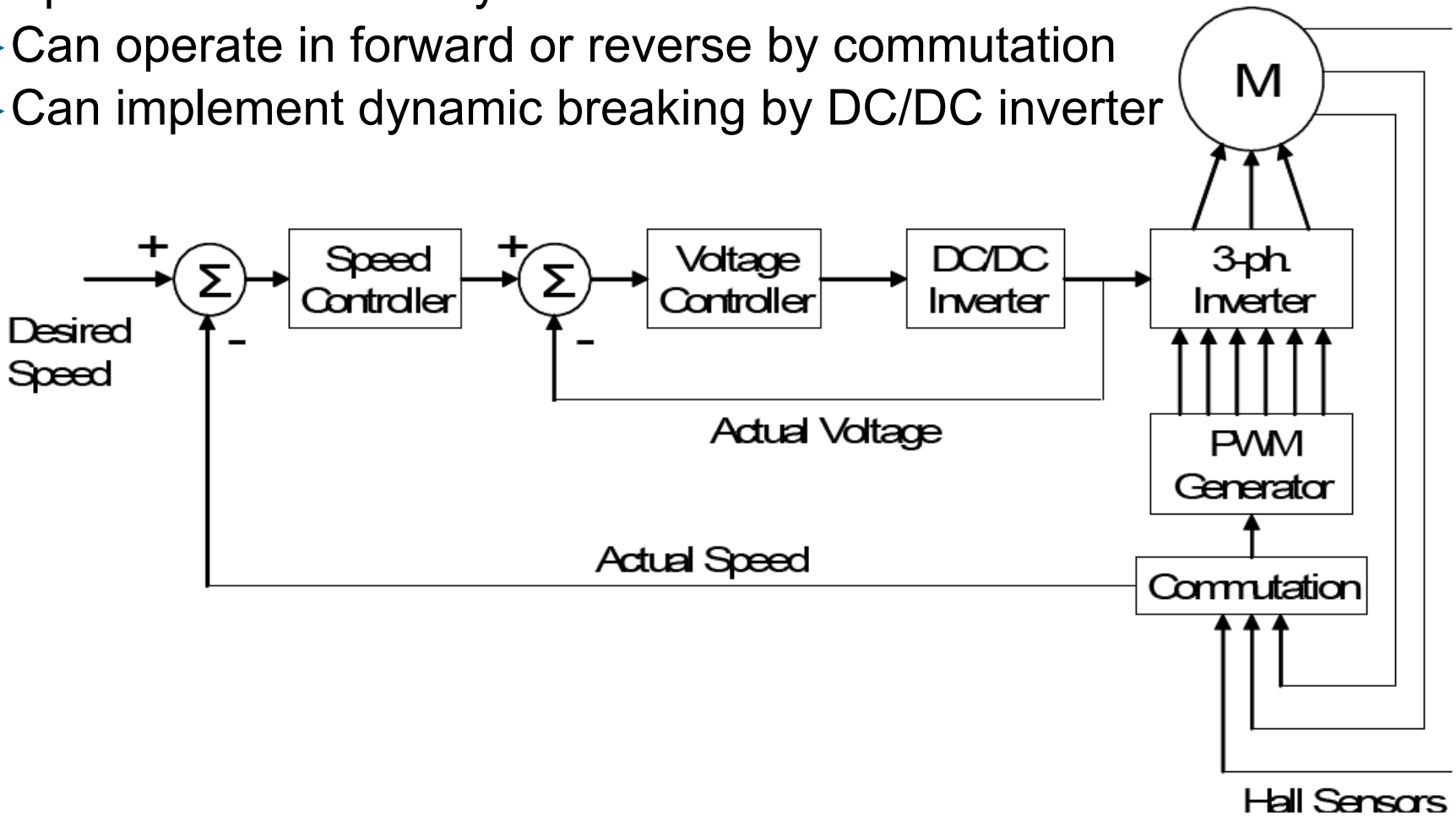
System Control

- Speed is controlled by the DC/DC inverter
- Can operate in forward or reverse by commutation
- Can implement dynamic breaking by DC/DC inverter



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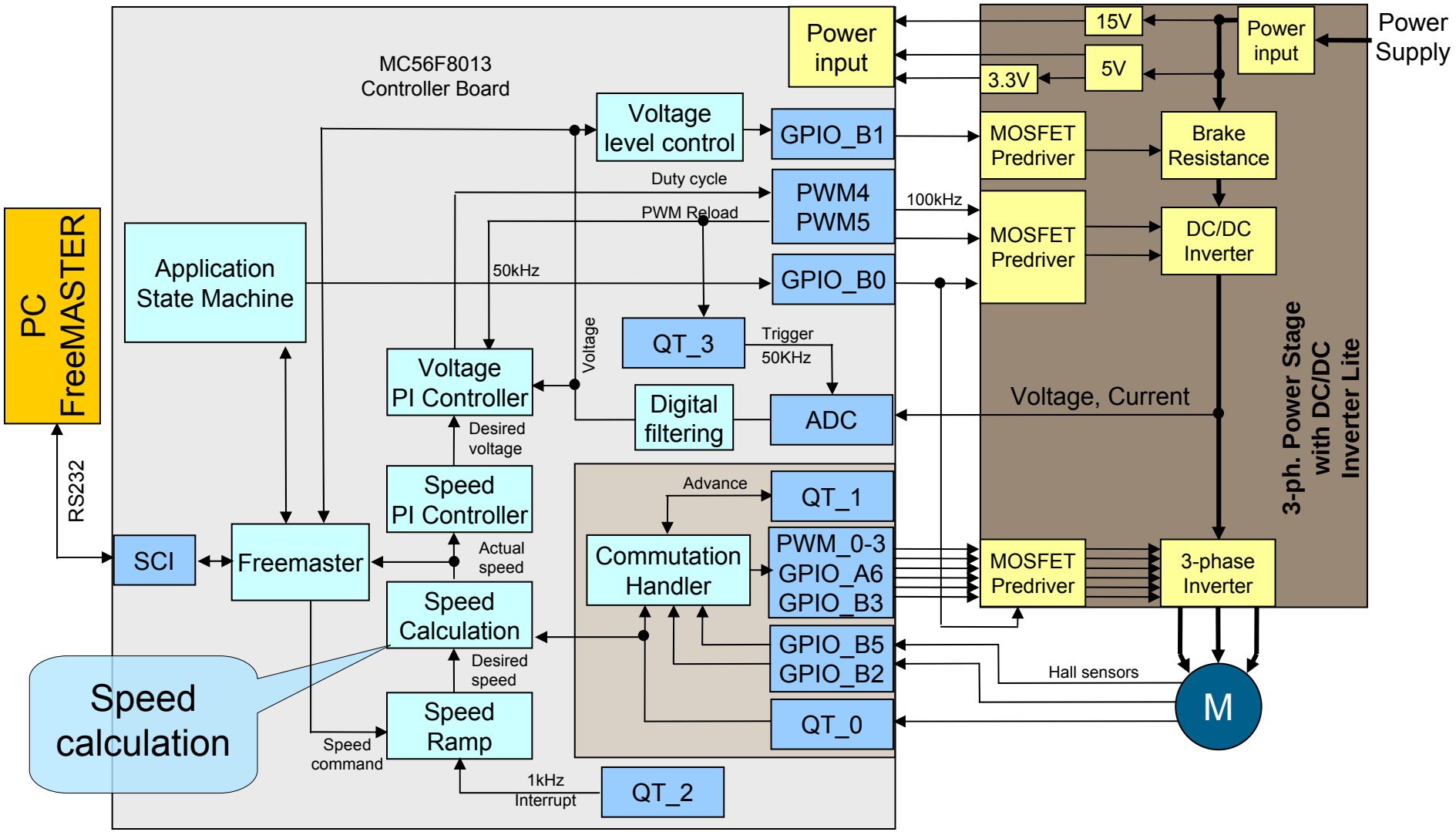
Block Diagram of the Application



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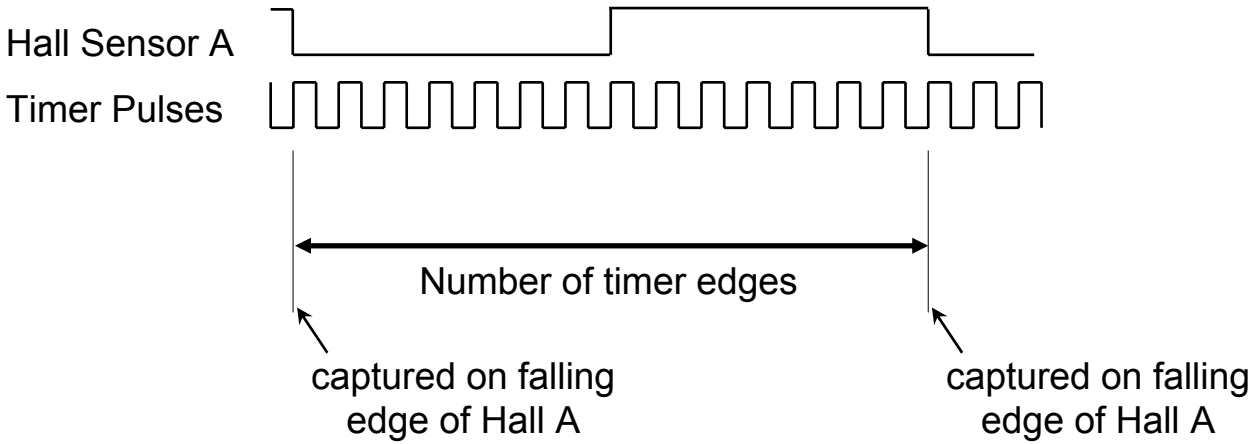
Speed Calculation

- Speed calculation is based off of Hall sensor input



$$speed = \frac{T}{K}$$

Speed Calculation

- **speed** calculated speed
- **T** scaling constant
- **K** number of timer edges

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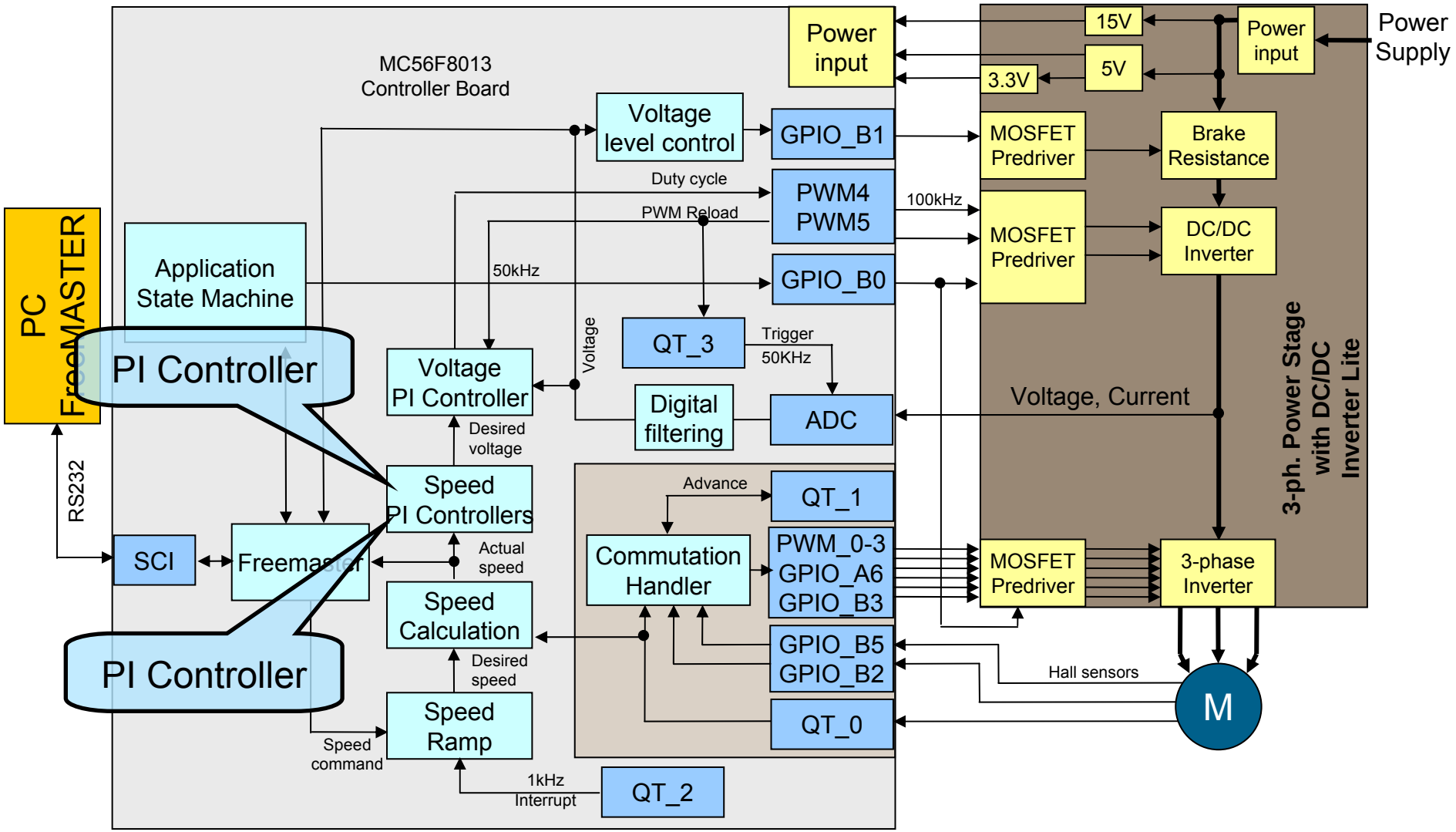
Block Diagram of the Application



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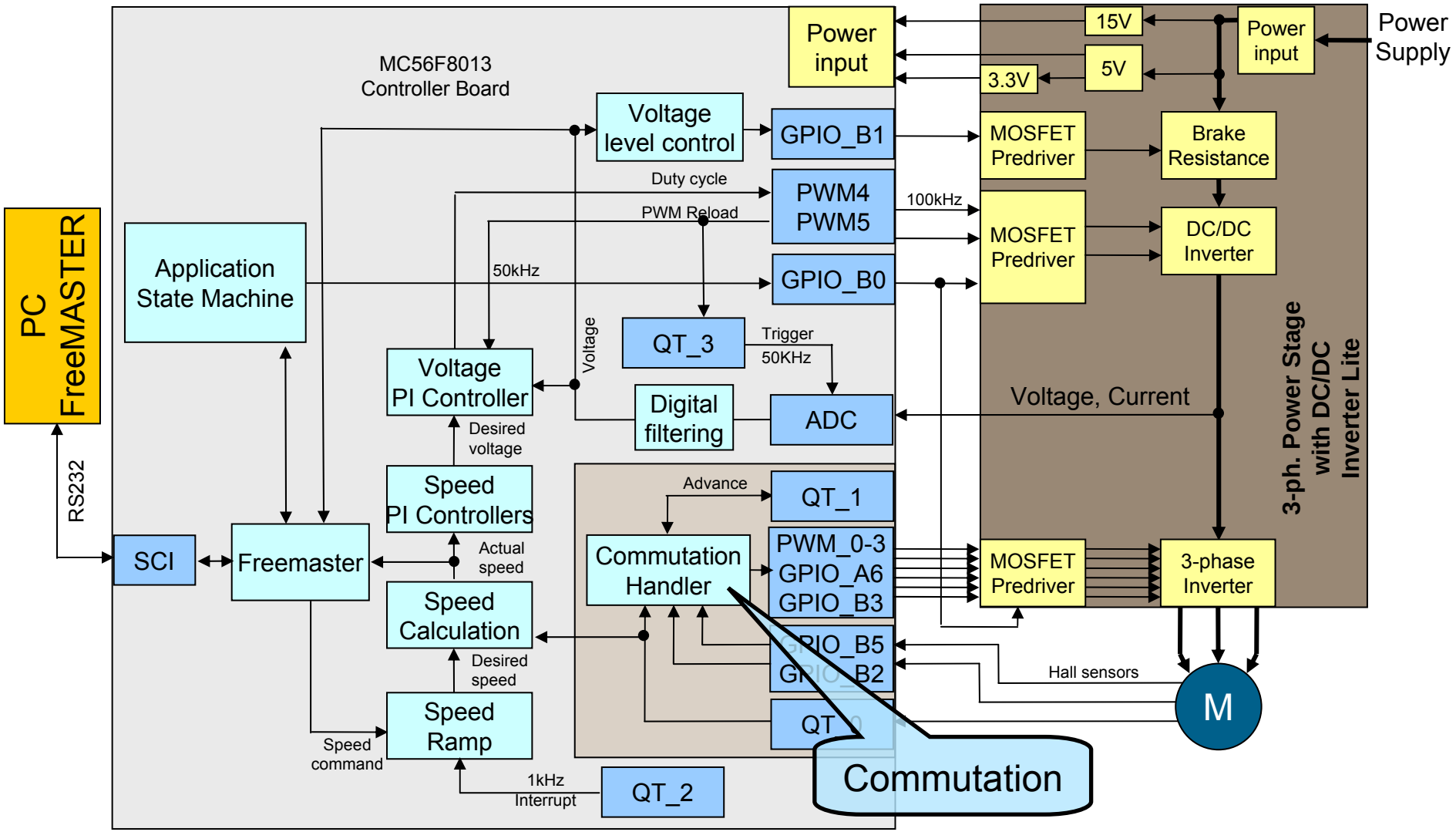
Speed PI Controllers

- The system contains two speed PI controllers
  - One for the range 15000 to 40000 RPM created for an acceleration of 15000 RPM per 100ms
  - A second for the range 0 to 15000 RPM constructed with an acceleration of 10000 RPM per 300ms
- The speed controller is calculated every 1ms
- The hysteresis between these two PI controllers is 1500 RPM
  - If the speed goes up, the higher speed PI controller is switched on at the threshold of 15000 RPM
  - When the speed goes down, the lower speed PI controller is switched on at a speed of 13500 RPM

Block Diagram of the Application



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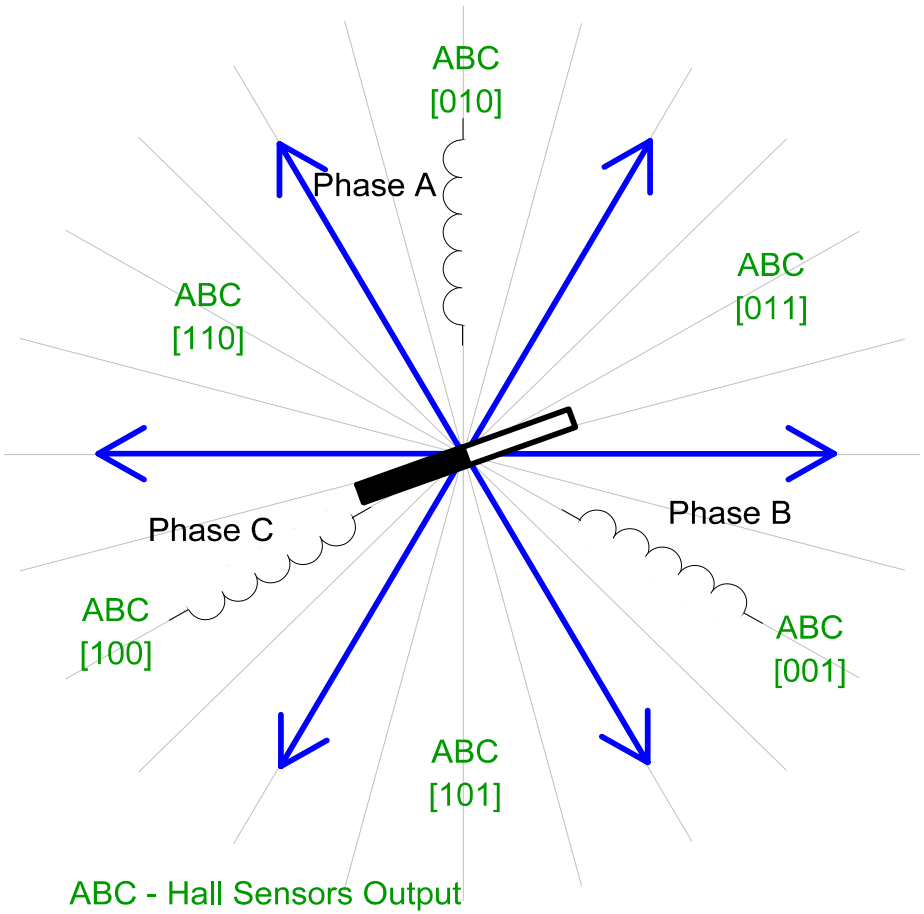
Commutation



- Hall sensors are read
- The system looks for the Hall sensor combination in the commutation table depending upon motor direction
- MOSFET's are turned on according to the Hall sensor

Clockwise Rotation

Hall Sensor A	Hall Sensor B	Hall Sensor C	Phase A	Phase B	Phase C
1	0	0	$-V_{DCB}$	$+V_{DCB}$	NC
1	0	1	NC	$+V_{DCB}$	$-V_{DCB}$
0	0	1	$+V_{DCB}$	NC	$-V_{DCB}$
0	1	1	$+V_{DCB}$	$-V_{DCB}$	NC
0	1	0	NC	$-V_{DCB}$	$+V_{DCB}$
1	1	0	$-V_{DCB}$	NC	$+V_{DCB}$

Counter Clockwise Rotation

Hall Sensor A	Hall Sensor B	Hall Sensor C	Phase A	Phase B	Phase C
1	0	0	$+V_{DCB}$	$-V_{DCB}$	NC
1	1	0	$+V_{DCB}$	NC	$-V_{DCB}$
0	1	0	NC	$+V_{DCB}$	$-V_{DCB}$
0	1	1	$-V_{DCB}$	$+V_{DCB}$	NC
0	0	1	$-V_{DCB}$	NC	$+V_{DCB}$
1	0	1	NC	$-V_{DCB}$	$+V_{DCB}$

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56800/E Solutions for V Control & Commutation – PWM

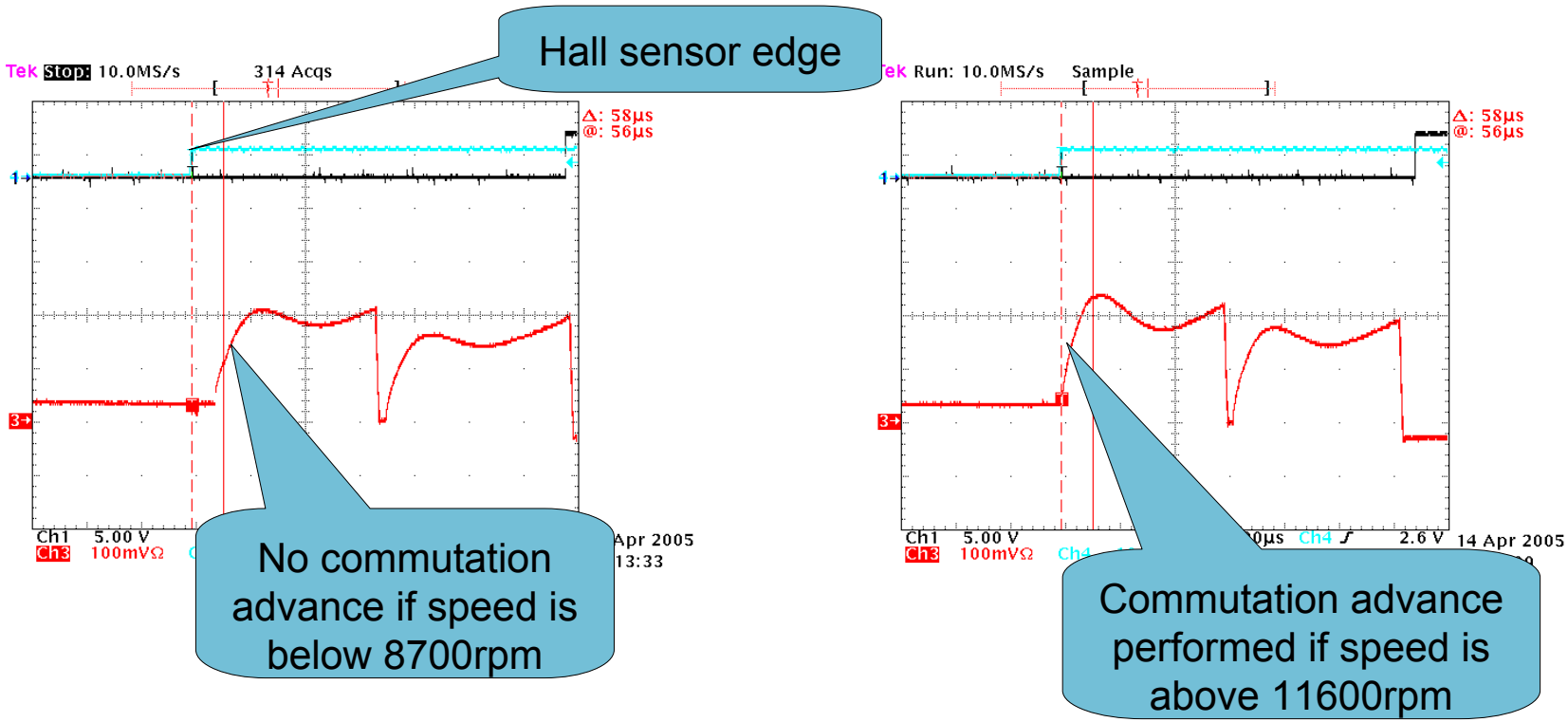
- Use single register for Mask and Swap operation
  - 56800/E PWM automatically generates complimentary waveforms with appropriate duty cycles

Base + $11	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Read	ENHA	nBX	MSK5	MSK4	MSK3	MSK2	MSK1	MSK0	0	0	VLMODE		0	SWP45	SWP23	SWP01
Write																
Reset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 10-46. Channel Control (CCTRL) Register

Commutation Advance

- Due to the delay between the Hall sensors edge and the phase current edge it is necessary to perform commutation advance that commutates sooner before the Hall sensor edge
- Commutation advance is accomplished by Timer 1



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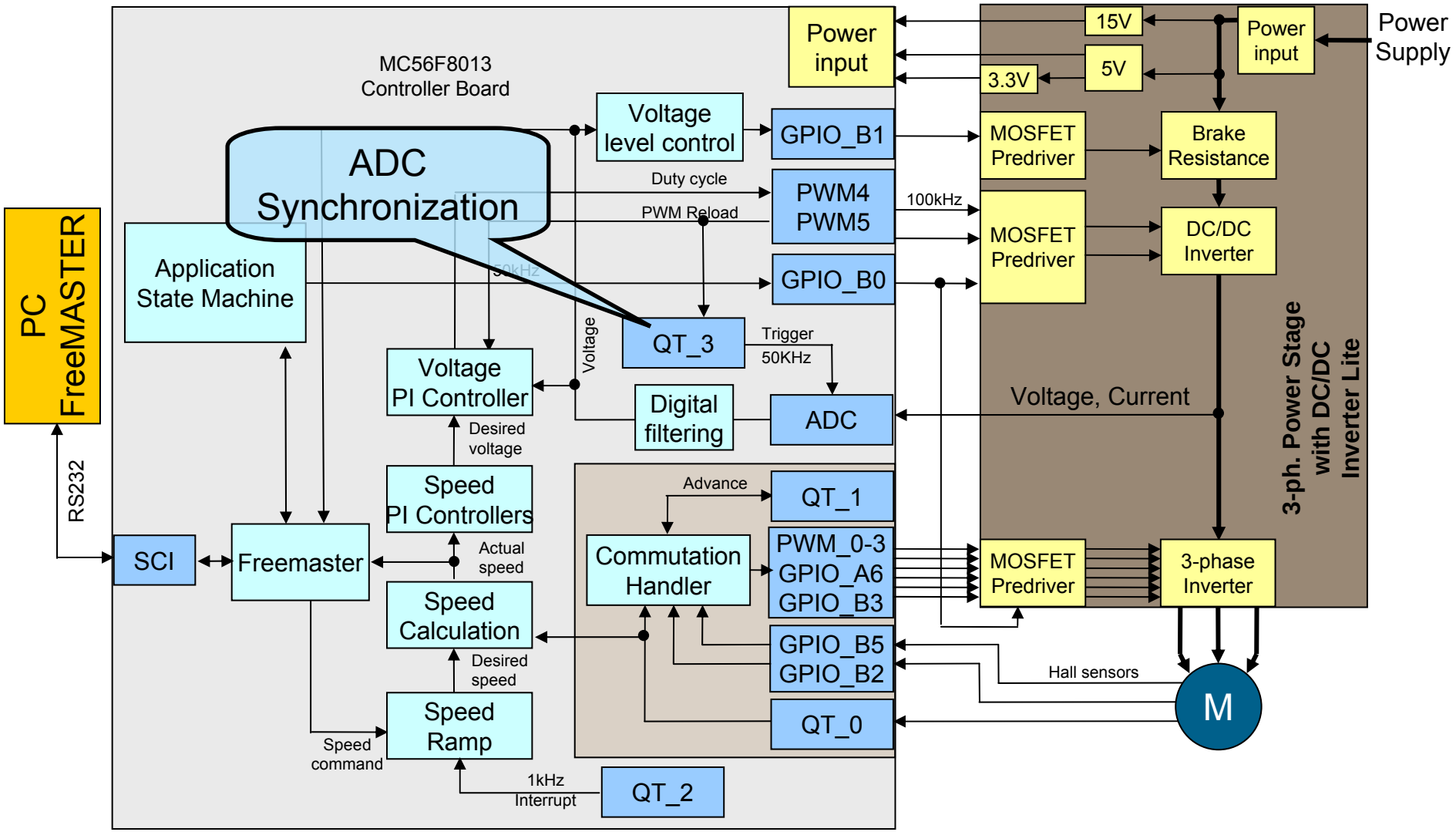
Block Diagram of the Application



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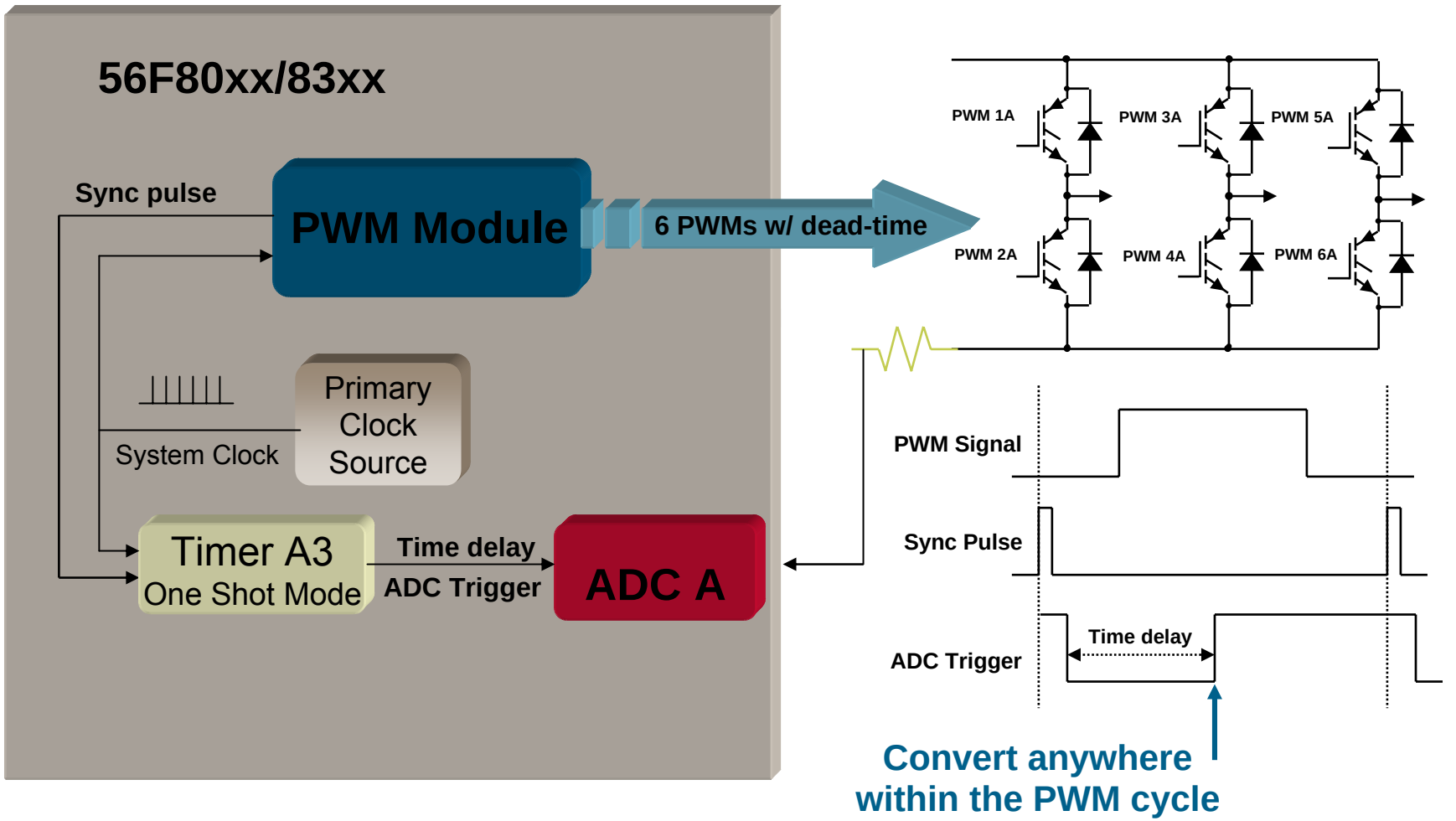
ADC Synchronization from the PWM Module



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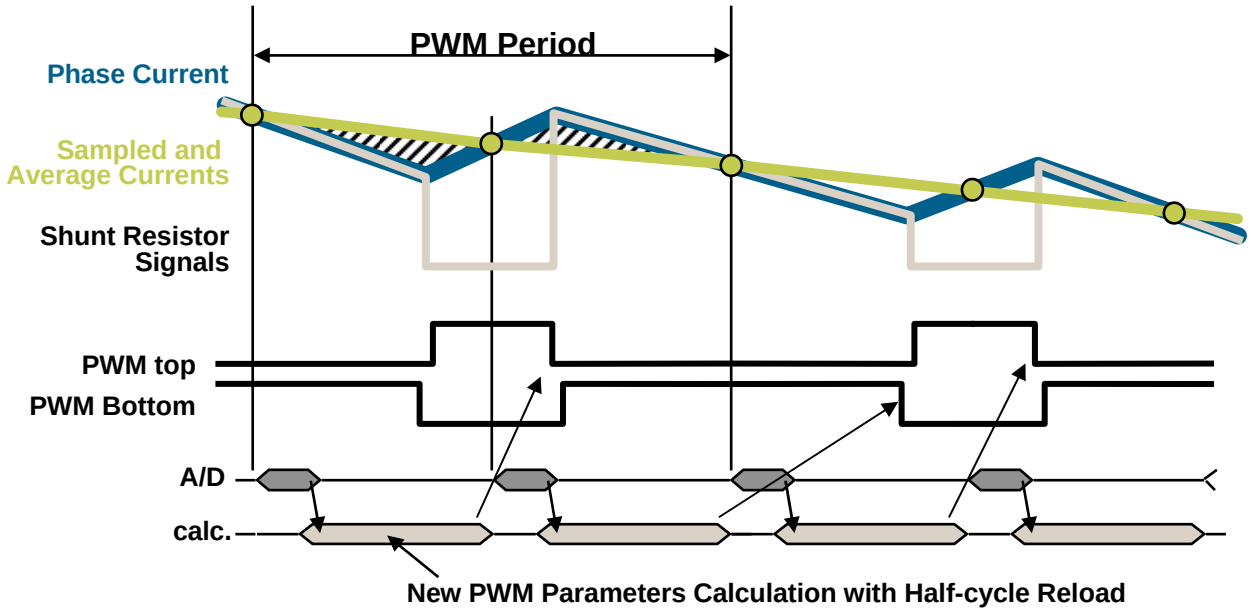
Benefits of ADC Synchronization With The PWM



- ADC sampling helps to filter the measured current - antialiasing
- Noise free ADC sampling when the power switch is not acting
- ADC sample is taken when current information is available

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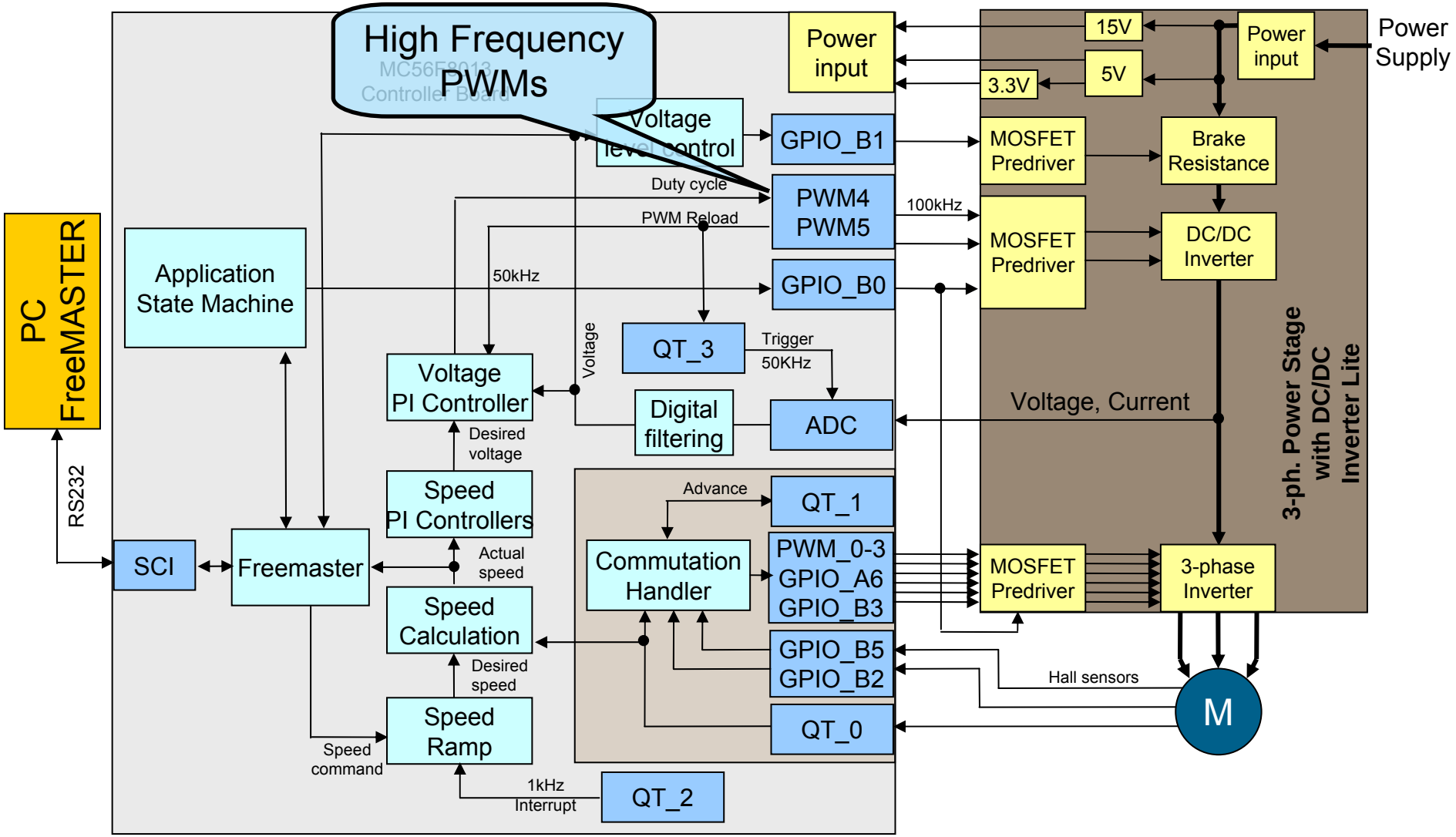
Block Diagram of the Application



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56F8000 Feature Highlights - Pulse Width Modulator (PWM)

- PWM clock set to 96Mhz (3x bus clock)
- PWM modulus set to 960
  - Defines the PWM frequency as **100kHz**
  - **Almost 10-bits**
- PWM module generates its reload signal every period (10us)
- Used to synchronize ADC to PWM edge

- The variable DC link six-step inverter output is controlled by switching the DCDC_Top MOSFET

- To reduce the load voltage level during motor braking, the DCDC_Bottom MOSFET is used. The maximum duty cycle depends on the voltages at both the input and the output

Summary

- MC56F801x Peripheral features designed specifically for motor control
- 32 MHz DSC core provides ample processing capabilities
- High frequency PWMs enable high resolution / high operation
- ADC synchronization allows scheduled ADC sampling
- Quad Timer provides good system timing

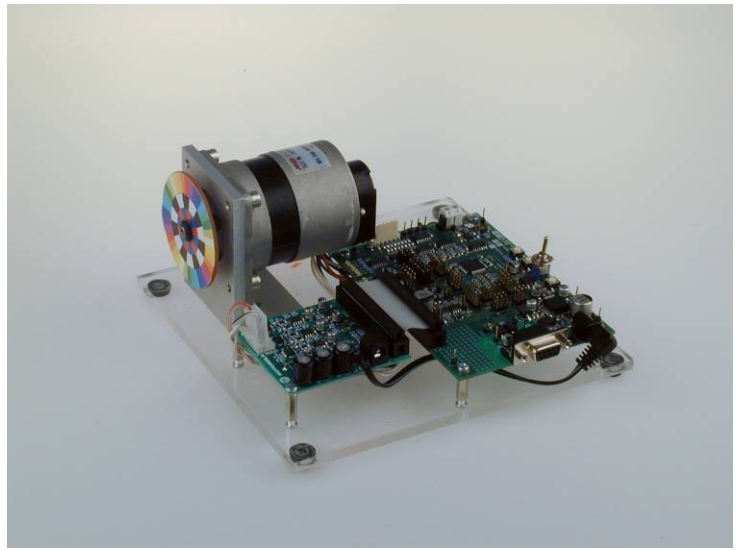
For more information go to www.freescale.com and search for DRM078

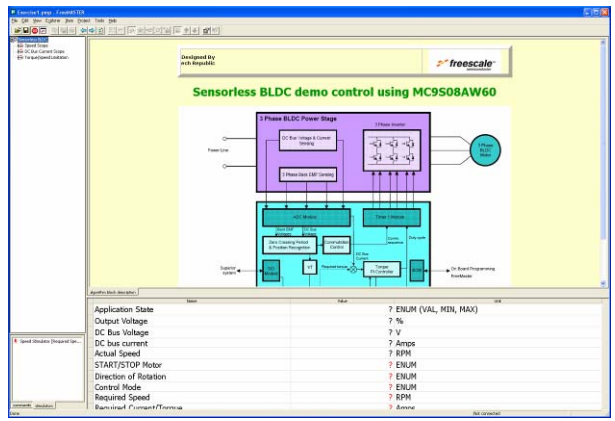
Sensorless BLDC control with MC9S08AW60

DRM086

Application Features

- Sensorless Back-EMF zero crossing algorithm implemented
- Controlled by MC9S08AW60
- Back-EMF sensing by ADC
- Full 4-quadrant operation
- Both direction of rotation
- Speed closed loop with PI controller
- Torque closed loop with PI controller
- Speed range: 100 – 1200 rpm (motor dependent)
- Manual interface
- FreeMaster interface





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MC9S08AC16/8

Features / Benefits
- 40 MHz S08 core (20MHz Bus)
- 3 independent clock modules
- 8-ch 10-bit ADC
- Pin-compatible with AW16/AW8
- Internal clock generator (ICG)
- Independently clocked COP
- On-chip ICE and BDM

Supply Voltage / Performance
- 2.7 – 5.5 V operation

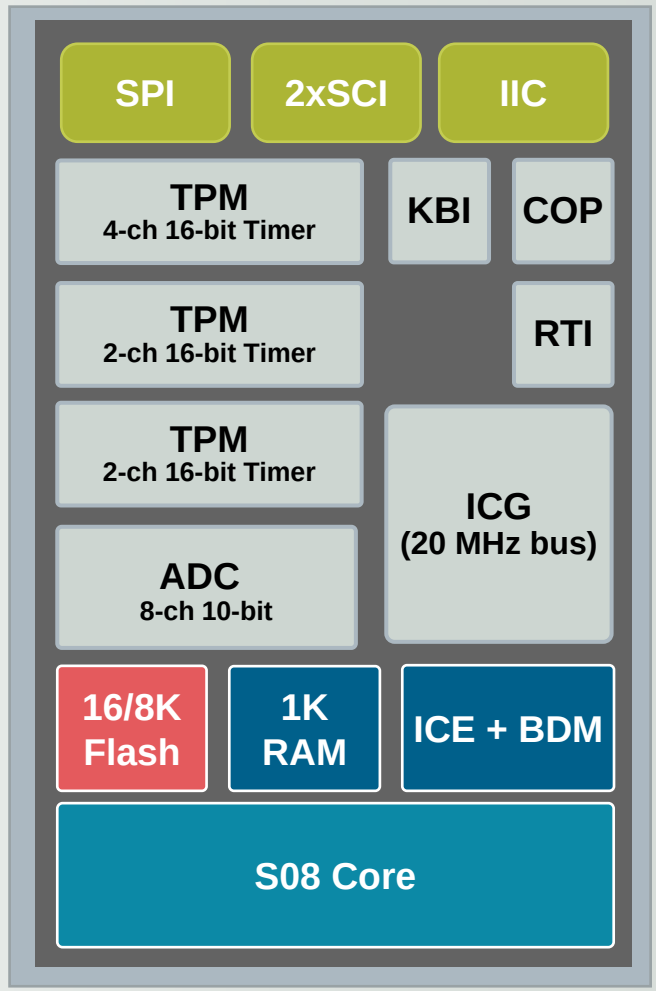
Memory
- 16/8K Flash
- Up to 1K RAM

Communications
- One (1) IIC w/ broadcast mode
- Two (2) asynchronous SCI ports
- One (1) synchronous SPI port

Packages
- 32 LQFP, 44 LQFP, 48 QFN

Pricing
- $1.45* MSRP at 10K units

*Varies by package



Last updated April 20, 2007

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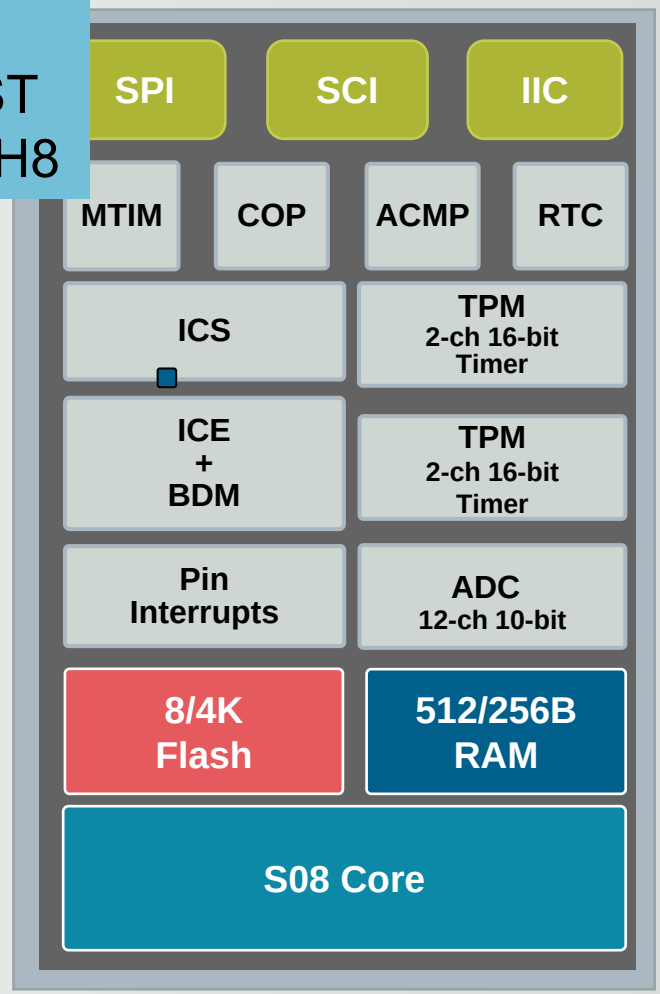
MC9S08SH8/4

- **Supply Voltage / Performance**
  - 2.7 – 5.5 V operation
  - -40 to 125°C operation
- **Core**
  - 40 MHz HCS08 core
  - 20 MHz bus frequency
- **Features / Benefits**
  - Multiple clock source options
    - 40 MHz ICS
    - XOSC for range of external clock sources
  - 2 x 2-ch 16-bit timer (TPM) & 8-bit modulo timer (MTIM)
  - 12-ch 10-bit ADC w/ built-in temp sensor
  - Analog comparator (ACMP) that can run in STOP3
  - LIN slave support
  - Low Voltage Detect (LVD)
  - Watchdog timer w/ multiple source options
  - Pin interrupts for selectable polarity
  - Hysteresis and configurable pull up device on all input pins
  - Configurable slew rate and drive strength on all output pins
  - Ganged output option to support high current drive
- **Memory**
  - 8/4K Flash, 512B/256B RAM
- **Communications**
  - SCI, SPI, IIC w/ broadcast mode
- **Packages**
  - 8 SOIC, 16 TSSOP, 20 PDIP, 20 TSSOP, 24 QFN

DRM086 CAN BE EASILY ADAPTED TO LOWER COST MCUs SUCH AS THE S08SH8



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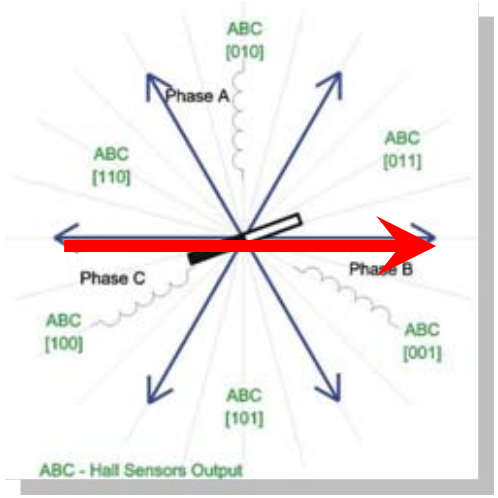
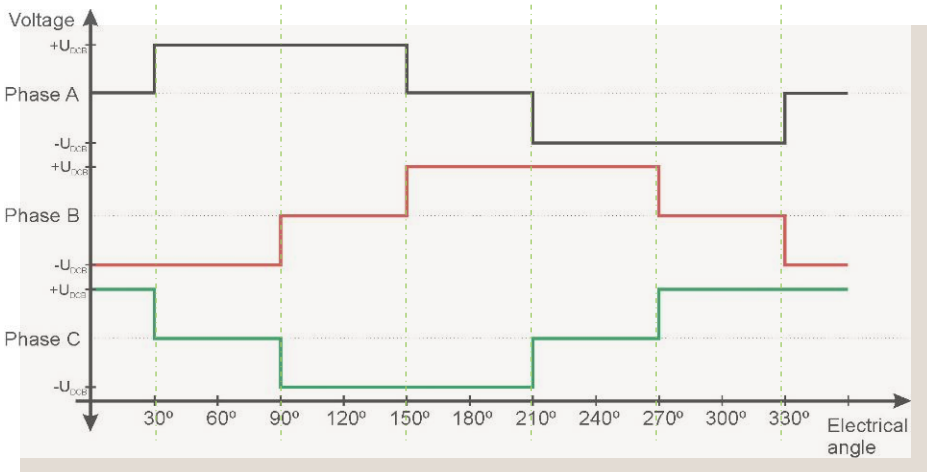
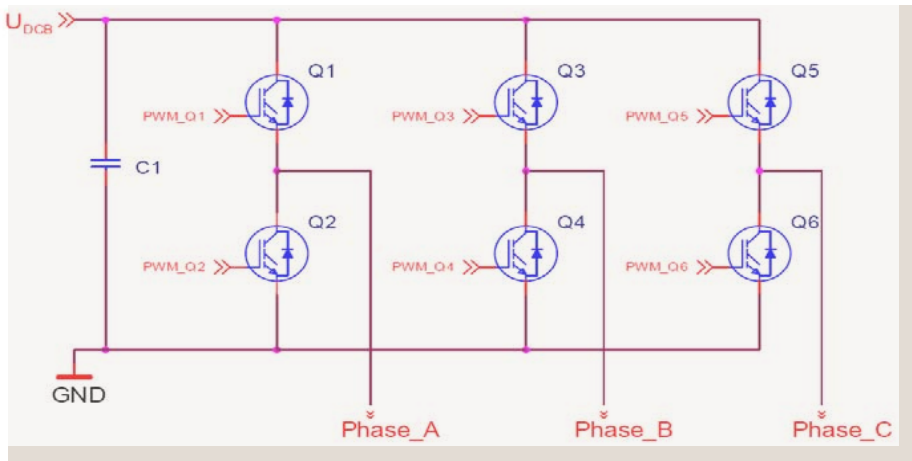
Commutation – 3-Phase Brushless DC Motor

- Six Step BLDC Motor Control (3-ph)
  - Voltage applied on two phases only
  - It creates 6 flux vectors
  - Phases are powered based on rotor position
  - This process is called commutation





Phases voltage



Power Stage

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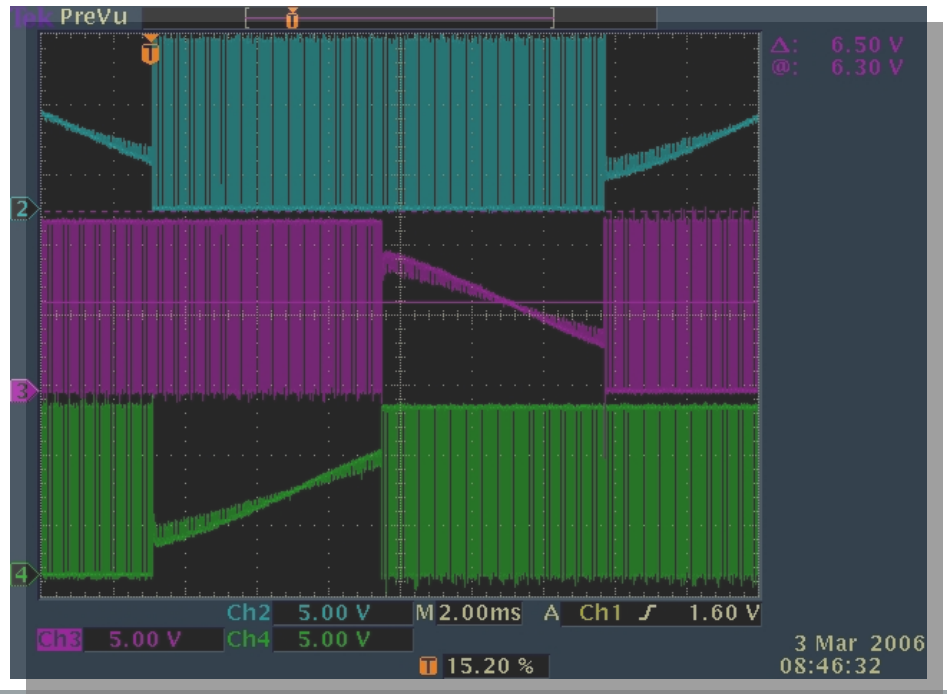
Sensorless BLDC Motor Control using MC9S08AW60

- Sensorless Back-EMF zero cross algorithm
  - Sensing voltage on disconnected phase
    - When sensed voltage crosses half of DC bus voltage, the rotor is in middle between two commutation
    - The detection of this zero crossing allows to detect rotor position



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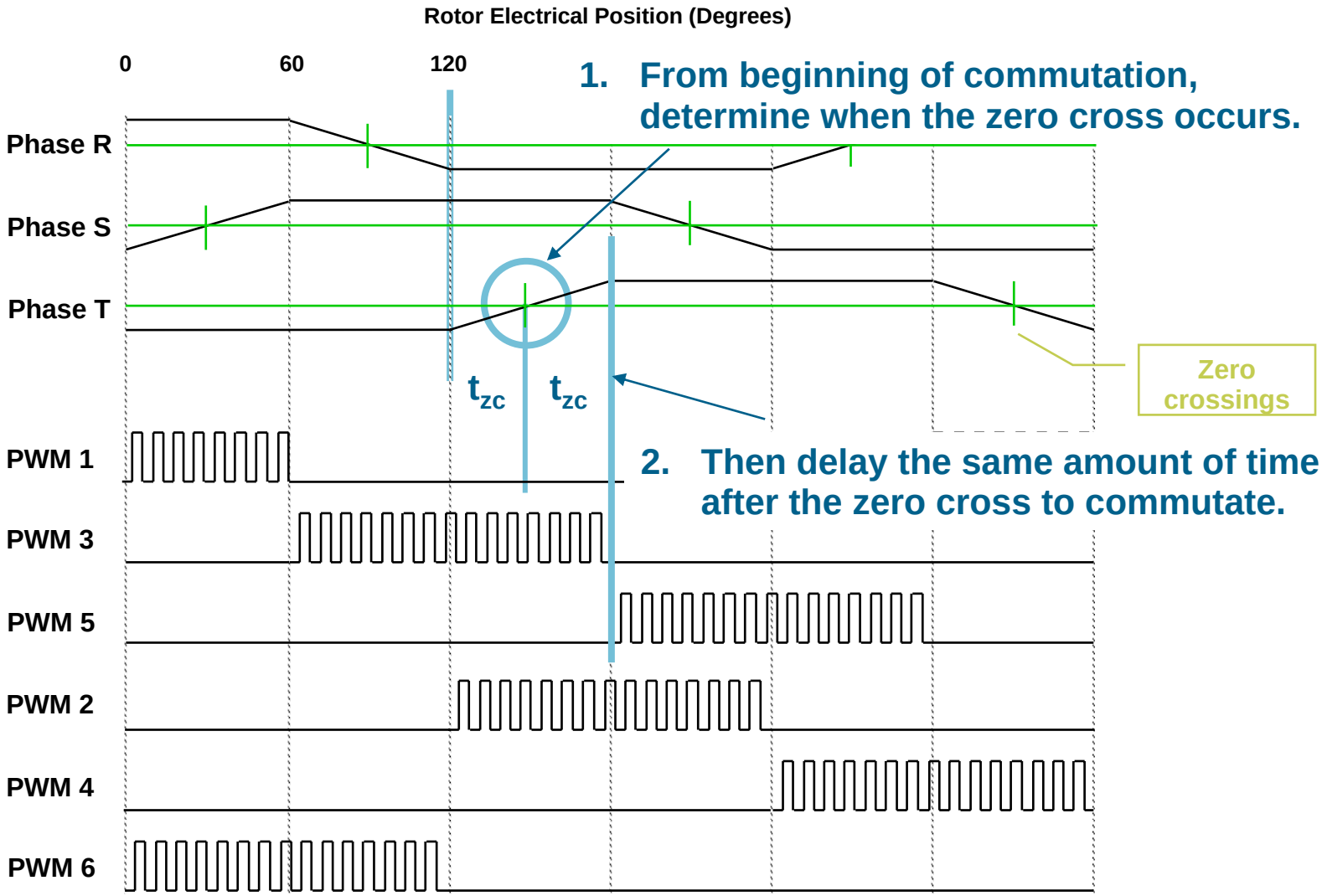
Sensorless Commutation



1. From beginning of commutation, determine when the zero cross occurs.

2. Then delay the same amount of time after the zero cross to commutate.

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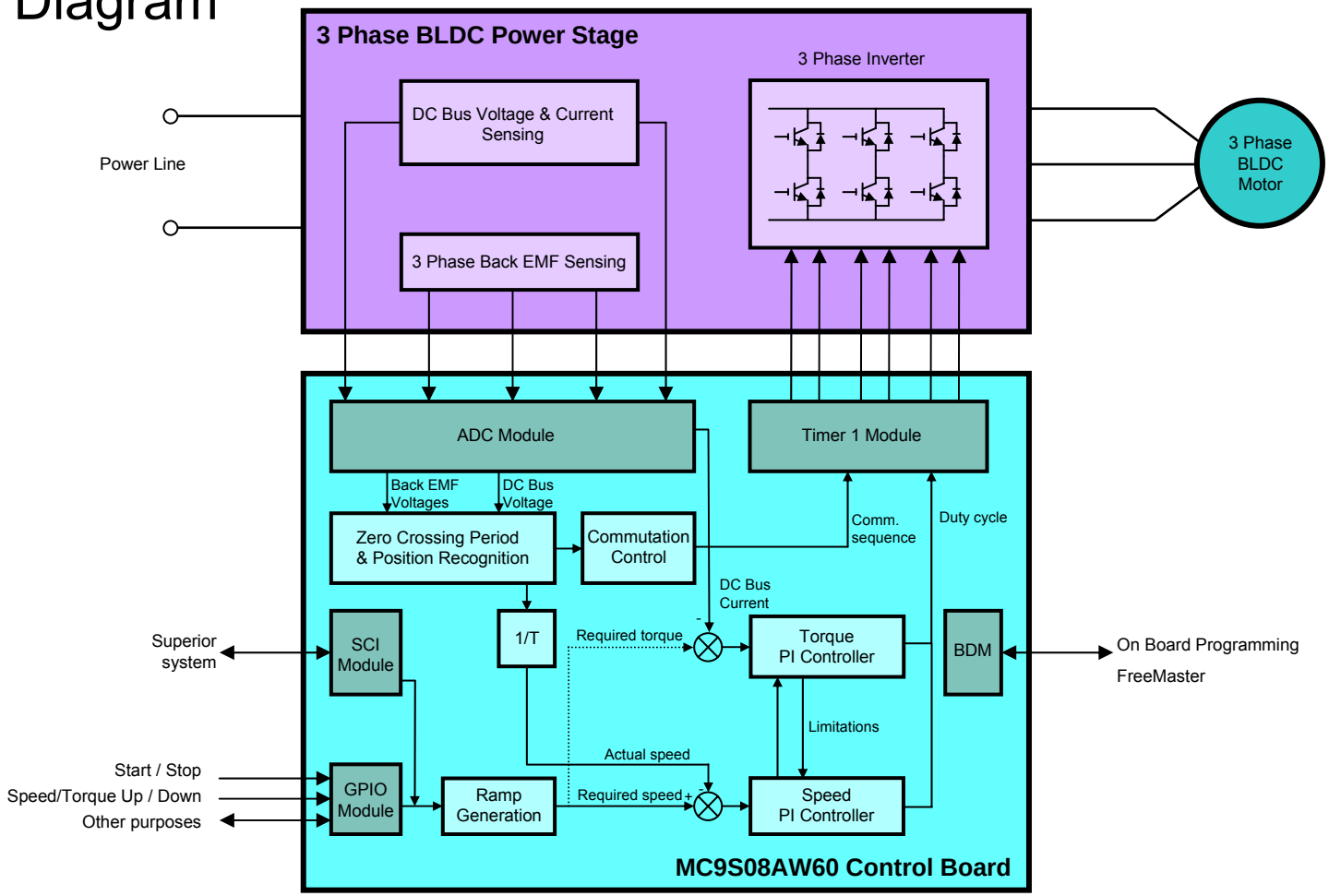
Sensorless BLDC Motor Control using MC9S08AW60

Application Diagram



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Sensorless BLDC Motor Control using MC9S08AW60

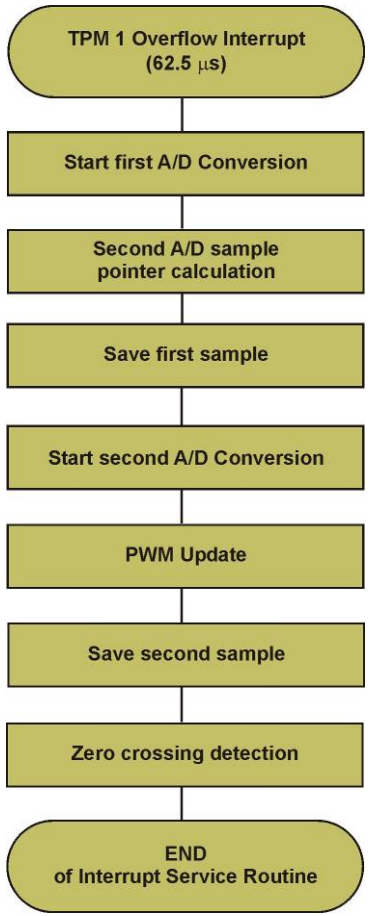
- MC9S08AW60 Peripheral Utilization
  - Timer 1
    - 6 channels: PWM modulation for BLDC motor (complementary bipolar)
  - Timer 2
    - Time base for commutation period measurement
    - Channel 0: commutation
    - Channel 1: timing of application
  - A/D Converter
    - DC Bus voltage, DC Bus current, Phase voltages, Heat sink temperature

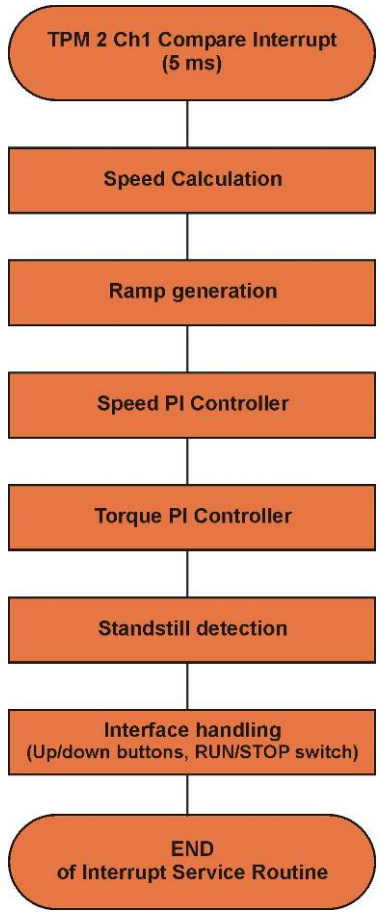
Sensorless BLDC Motor Control using MC9S08AW60

- Software Structure
  - 2x periodical interrupts (1x 62.5 μs, 1x 5ms)
  - 2x event interrupt (1x Commutation, 1x Over current fault)
  - Background loop
  - Written in C language
  - Some arithmetic functions written in assembler

Sensorless BLDC Motor Control using MC9S08AW60

- Software Structure (Periodic ISR)





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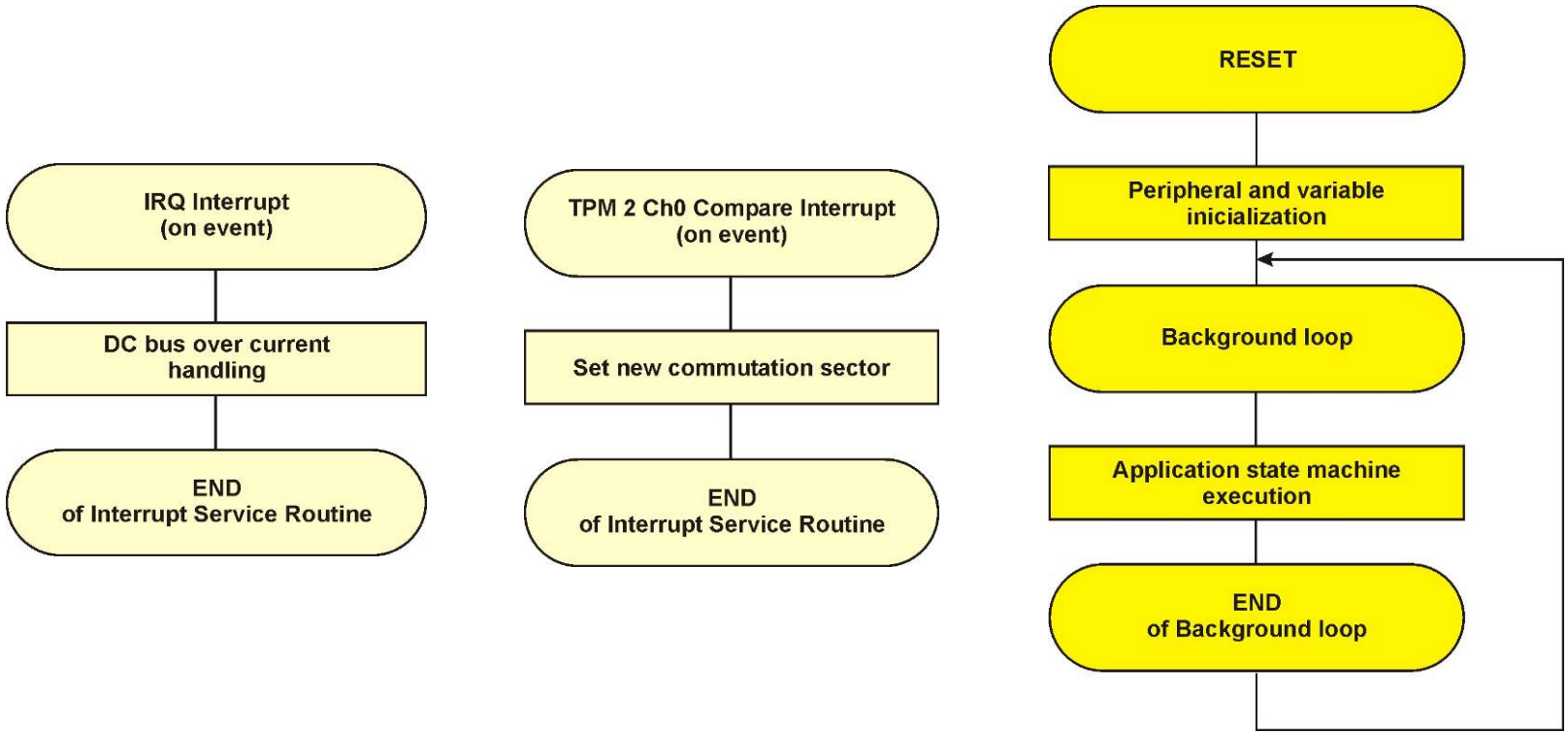
Sensorless BLDC Motor Control using MC9S08AW60

- Software Structure (Event ISR, background)



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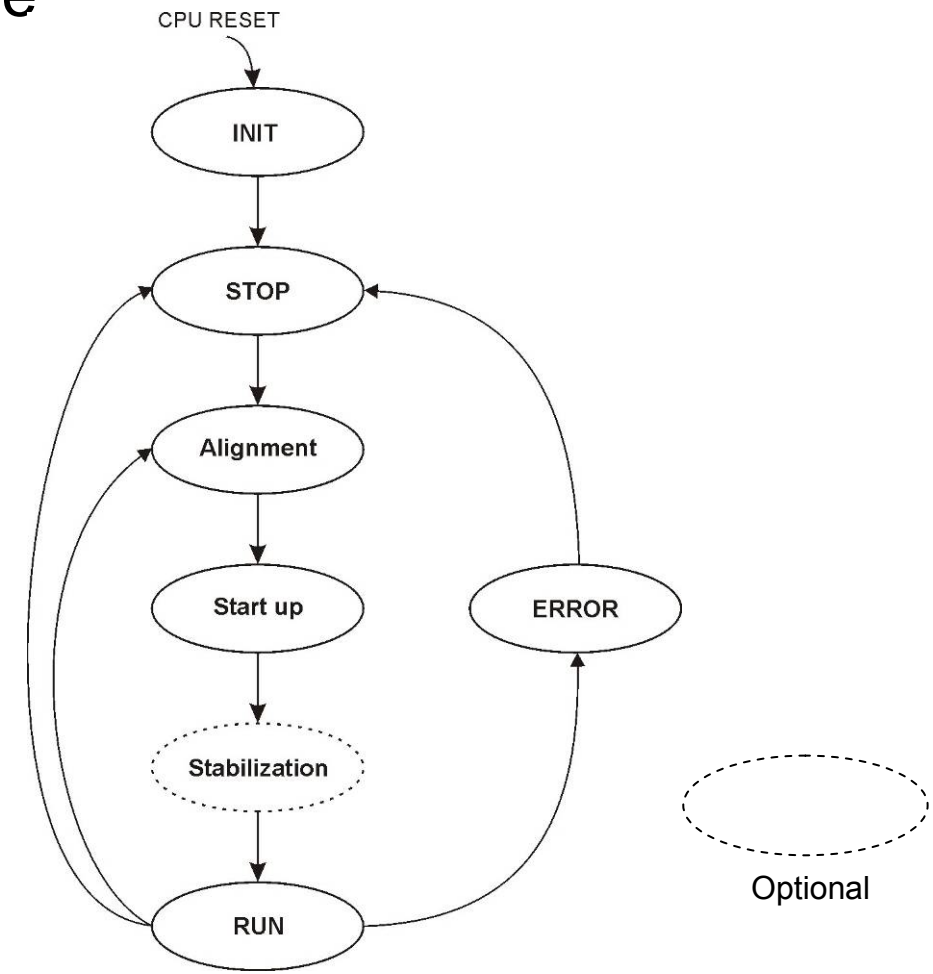
Sensorless BLDC Motor Control using MC9S08AW60

- Application State Machine



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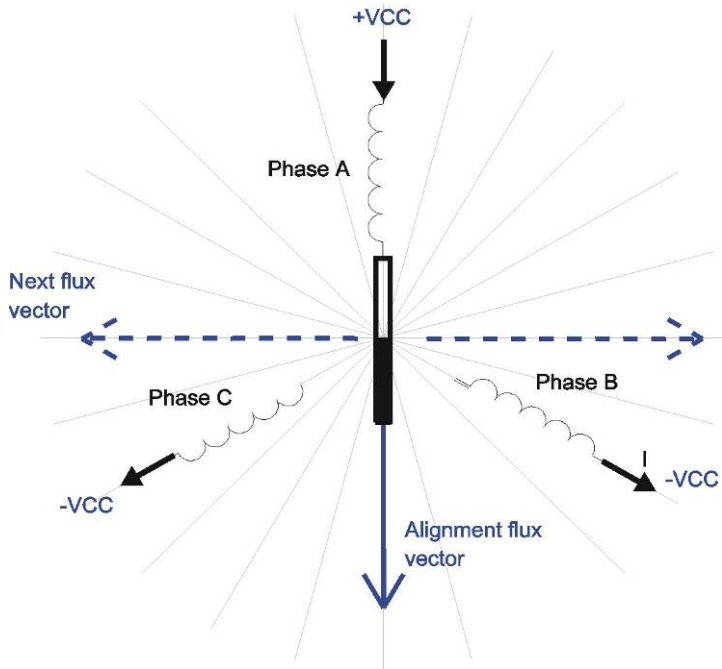
Sensorless BLDC Motor Control using MC9S08AW60

Motor Start Up

- Alignment
  - The rotor is aligned to known position (all phases are powered)
- Start up
  - Six forced commutation with predefined timing. Then transition to sensorless mode
- Run
  - Motor is running sensorless in closed loop



Rotor alignment

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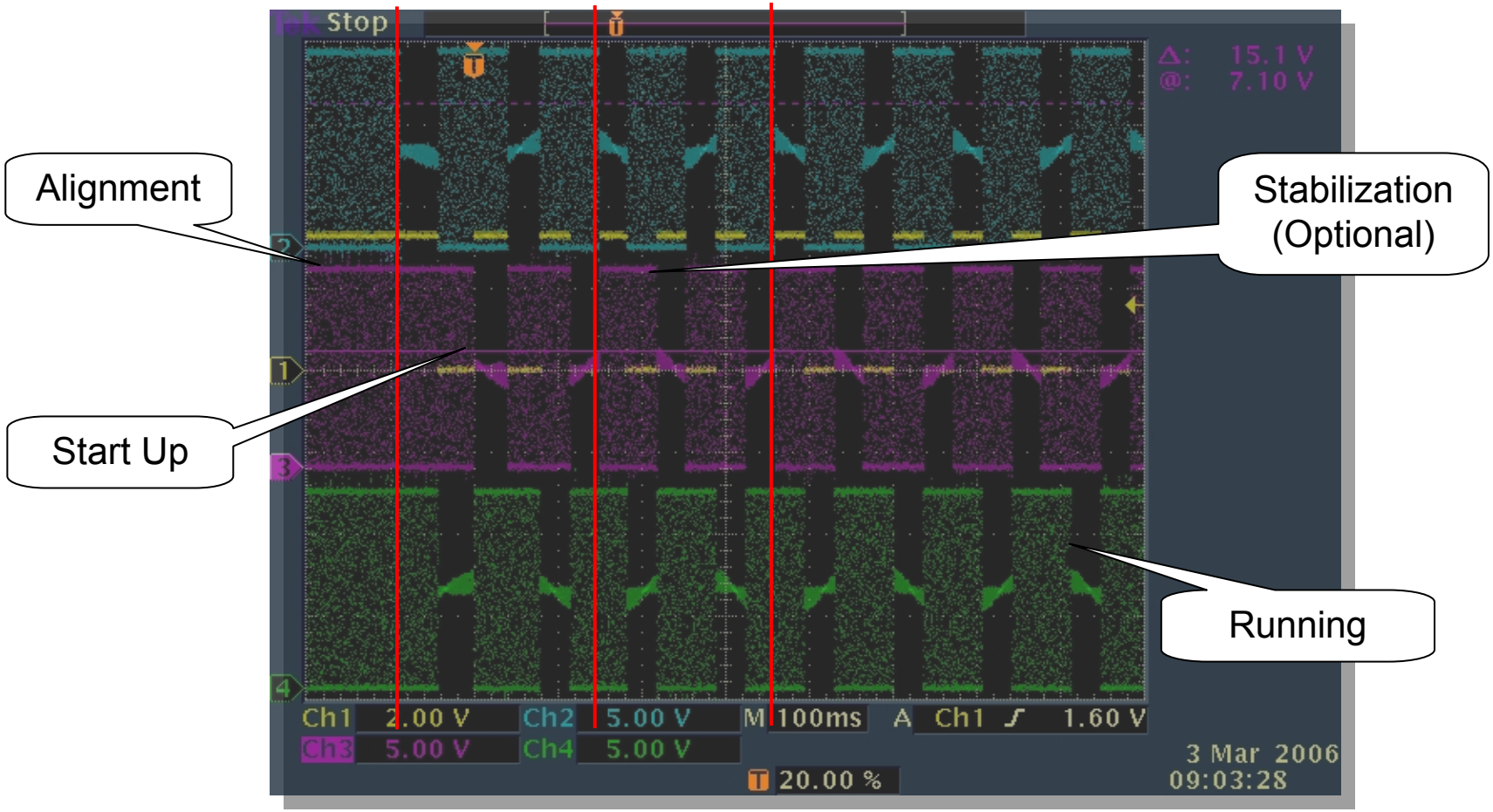
Sensorless BLDC Motor Control using MC9S08AW60

- Motor Start Up



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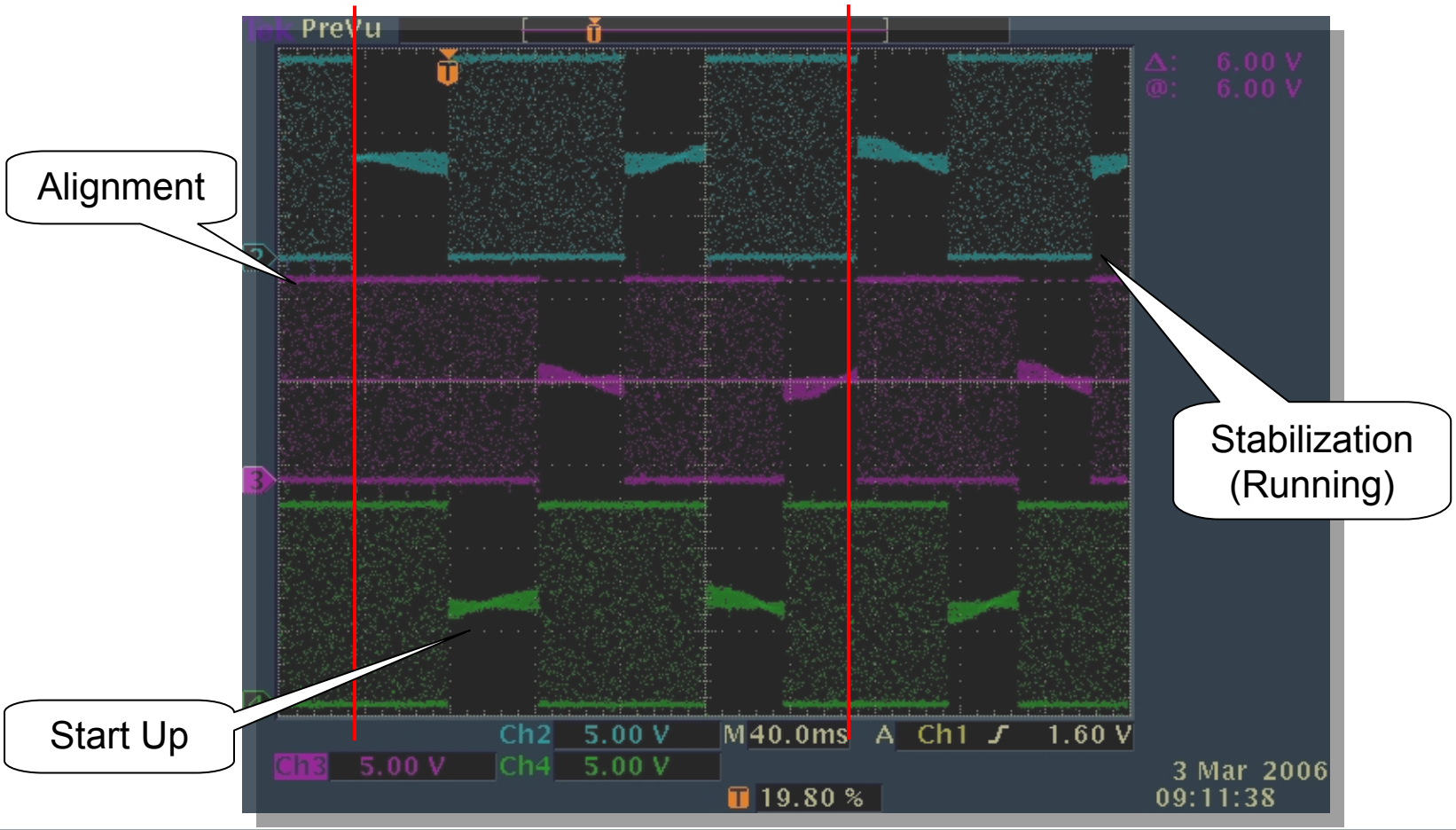
Sensorless BLDC Motor Control using MC9S08AW60

- Motor Start Up - detail



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Sensorless BLDC Motor Control using MC9S08AW60

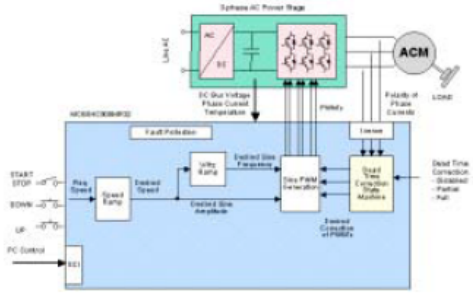
- Software Measurements
- Code Length
  - FLASH memory: 4600 bytes
  - RAM memory: 356 bytes (include stack 128 bytes)
- MCU load: 36 %
  - TPM1 Overflow ISR 19.2 μs (period 62.5 μs)
  - TPM2 Ch1 OC ISR 216 μs (period 5 ms)
  - TPM2 Ch0 OC ISR2.8 μs (on event)

Reference designs

BLDC Motor Control Board for Industrial and Appliance Applications

This Freescale reference design is a single PCB implementation of a 3-phase BLDC (brushless dc motor) control board for an appliance washing machine. This Reference Design is based on the Freescale's MC68HC908MR8 8-bit microcontroller unit (MCU). There are two board versions available, one for operating at 110-127 VAC and the other for operating at 220-240 VAC. The 3-phase inverter of the 110-127 VAC board operates at a nominal voltage of 180 VDC and 8 A RMS with 11 A peak. The inverter of the 220-240 VAC board operates at a nominal voltage of 320 VDC driving the same current. The reference design employs discrete three-phase inverter components and sensing circuitry for current, voltage and temperature Other features included are: user interface consisting of 16 x 2 character display and two push buttons, Opto-isolated RS-232 interface for external microcontroller communication and for in-application programming. The example software consists of a PI speed controller for closed loop control and Six-step BLDC commutation control based on three Hall-effect position sensors, and can be easily modified to perform other process cycles. The PI speed controller operates in the 200 rpm up to 4000 rpm range Also included are two washing machine algorithms, Wash and Spin. Wash process consists of generating a sine wave of speed references, including positive and negative reference speeds. Spin process consists of generating a start up curve of reference speeds and maintaining a fixed reference speed for a certain time. This single PCB design can be easily employed for Industrial applications that required 3 phase BLDC motor control.

3-Phase AC Induction Motor Drive with Dead Time Distortion Correction Using the MC68HC908MR32



This Reference Design describes the construction of a 3-phase AC induction motor drive. The Volt-per-Hertz algorithm with dead time distortion correction is implemented. The application is based on Freescale's MC68HC908MR32 microcontroller which is dedicated for motor control applications. The system is targeted for applications in both industrial and appliance fields (e.g. washing machines, compressors, air conditioning units, pumps or simple industrial drives). The AC induction motor is controlled using a Volt-per-Hertz algorithm with two selectable dead time correction techniques, Partial (detects the polarity of the phase currents) and Full (detects the polarity and the magnitude of the phase currents). The PWM frequency of the motor drive can be changed on the fly (4kHz, 8kHz, 16kHz, 32kHz). Also included is PC Master software to allow users to monitor motor control characteristics in real time.

Vacuum Cleaner Reference Design

This reference design shows how Freescale's HC08 low cost family of microcontrollers can implement a domestic vacuum cleaner application by controlling an ac universal motor via a triac, monitoring the zero cross of the mains power, and providing variable speed. This design has been implemented on the MCHC908KX8, but can be converted easily to other microcontrollers such as the MCHC908QT/QY and MC68HC908JL/JK devices. The reference design discusses the soft start to reduce power-on currents and techniques to control the speed and phase of the motor. Features of this reference design include Controlled power-on s/w to reduce surge current, Zero Cross Detect of ac mains, and Easy Speed Control via 8bit A/D Channel.

Sine Voltage Powered 3-Phase Permanent Magnet Synchronous Motor with Hall Sensors

This reference design describes control of a 3-phase PMS (Permanent Magnet Synchronous) motor with Hall sensors controlled using sinusoidal voltage. It is based on Freescale's 68HC908MR32 microcontroller dedicated for motor control applications. The motor is powered with a sinusoidal voltage to achieve a low audible noise. The position of the rotor is sensed by means of Hall-effect sensors. The generated voltage waveform is synchronized with the rotor position by a phase-locked loop algorithm (PLL). The motor speed is controlled by means of the voltage amplitude. The voltage frequency is generated to match the actual speed of the motor. It allows both closed and open loop. The reference design demonstrates high motor efficiency employing control techniques such as motor deceleration (energy is returned to the dc-bus), limitation of dc-bus over-voltage during deceleration, recognition of the spinning motor after CPU reset, dc-bus voltage ripple cancellation. Over-voltage and current protection, dc-bus voltage sensing and PC master software which allows users to monitor the motor control characteristics in real time are also incorporated.

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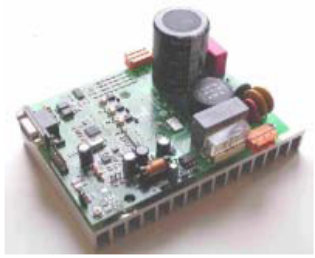
More reference designs

High-voltage BLDC Drive for Domestic Appliances using the MC68HC908MR8



This reference design is a low-cost compressor drive using sensorless 3-phase BLDC (brushless direct current) motor control with back-EMF zero-crossing sensing.
It is built around the MC68HC908MR8, a Freescale microcontroller designed specifically for appliance applications.
The design is a motor drive system for low-power 3-phase BLDC motors, and is aimed at applications in the automotive, industrial and appliance fields in, for example, fridge compressors, air conditioning units, pumps, and simple industrial drives. The reference design focuses on the motor control part of the refrigeration system. The cooling control algorithms, which are the intellectual property of the fridge manufacturers, can be resolved using different approaches. These algorithms can be programmed into the system according to the requirements of the application. Features include: Sensorless closed-loop speed control using back-EMF sensing

- Single board solution with MC68HC908MR8 microcontroller
- Power supply voltage: +230 VAC
- Maximum output power: 400 W
- One direction of rotation
- Start from any motor position with rotor alignment
- Pre-charging of IGBT pre-driver bootstraps before each motor start
- Speed range: 500 to 5000 RPM (depending on the motor used)
- Manual interface
- Option to connect user's interface through terminals
- Fault protection:
  - DC-bus over-current fault protection
  - DC-bus under-voltage fault protection
  - DC-bus over-voltage fault protection
- Common mode EMI filter

MC68HC908QT2 BLDC Fan for PCs Reference Design

This reference design features a brushless DC (BLDC) fan controlled by an MC68HC908QT2 MCU.
The reference design covers two systems:
An evaluation system, which includes a trimming potentiometer and an in-circuit programming feature, for customer evaluation purposes.
A demo system, which omits the in-circuit programming feature and uses pulse width modulation to drive a surface mount technology transducer, instead of the buzzer in the evaluation system.
In the evaluation system, the speed can be changed using the trimming potentiometer or the thermal sensor, and the firmware can be modified using the in-circuit programming capability.
In the demo system, the speed can be altered only by the thermal sensor, and the in-circuit programming capability has been omitted to keep the size to a minimum.

RD68HC908BLDCFPC Features
Automatic temperature-speed adjustment
Motor locking protection
Over-temperature and motor locking alarms
In-circuit programming for firmware upgrade (evaluation system only)
Manual speed adjustment (evaluation system only)

LIN-bus HID Lamp Levelling Stepper Motor Control Using the Freescale 908E625

This reference design describes a car High Intensity Discharge (HID) lamp leveling system with a LIN-bus interface. An essential part of the system is a stepper motor controller operating as a LIN-bus slave (LIN Stepper Controller). All functionality is provided by a general purpose LIN-bus IC MM908E625 and LIN Stepper software (HC08 software). The LIN Master consists of a master control board, based on an MC9S12DP256 CPU, and a personal computer with a graphical user interface (GUI), running in a master software environment. The LIN-bus Stepper Controller can be used for any kind of stepper motor control using the LIN-bus serial communication protocol. Features include:

- LIN bus Interface rev 1.2
- Bus speed 19.2 kbps
- Slave IC without external crystal or resonator
- Slave node clock synchronization ±15%
- Each LIN slave controls one bi-phase bipolar stepper motor
- Motor phase current limitation up to 700 mA
- Supply voltage 12 V d.c.
- Stepper motor control with stepping acceleration and deceleration ramp
- Stepping frequency up to 2,500 Hz
- Slave parameter configuration via LIN-bus
- Slave LIN signal reconfiguration via LIN-bus
- Code written in C-language

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Yet more reference designs

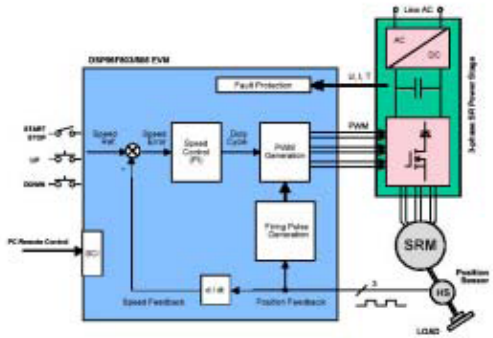
Low Power BLDC Drive for Fans Using the MC68HC908QY4 MCU

This Reference Design describes a low-power three-phase BLDC (brushless direct current) motor drive application based on Freescale's low-cost MC68HC908QY4 microcontroller.
The concept of this application is a high-speed closed-loop BLDC drive using a Hall position sensor for a low-voltage fan application. The power stage is designed for 48 V DC line voltage and 400 W output power. The design is focused on minimum cost and maximum component integration, for low-cost applications. Features include:

- Control technique incorporating:
  - Voltage control of 3-phase BLDC motor
  - Position sensing using Hall sensor signals
  - High-speed closed-loop with PI controller
  - Speed measurement based on Hall sensors
  - One direction of rotation
  - Starting from any motor position without rotor alignment
  - Pre-charging of MOSFET pre-driver bootstraps before each motor start
  - 750-4000 RPM (according to the motor used)
- Manual interface (run/stop switch, speed potentiometer, power-on LED indication)
- Fault protection (DC-Bus overcurrent, DC-Bus undervoltage, DC-Bus overvoltage, loss of Hall sensors)
- MCU in-circuit reprogramming using Developer's Serial Bootloader for M68HC08
- Transient voltage suppressor 60 V
- Power line choke

3-Phase SR Motor Control with Hall Sensors Reference Design

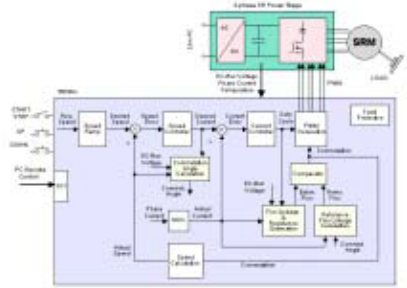
This reference design demonstrates speed control of the 3-Phase Switched Reluctance (SR) motor with Hall position sensor using Hybrid Controller 56F80x. This application demonstrates the SR motor drive and serves as an example of a motor control system design using a Freescale Hybrid Controller 56F80x. The 56F80x runs the main control algorithm. When the start command is accepted, the state of the Hall sensors position signals is sensed and the individual motor phases are powered in order to start the motor in the requested direction of rotation without rotor alignment. When the motor starts to rotate, the edges of the Hall sensors' position signals are captured by the 56F80x, the switching pattern for the PWM control signals is determined. The actual speed of the motor is determined by the Hall sensor signals. Based on the speed error, the speed controller generates the desired PWM duty cycle. According to the determined switching pattern and the calculated duty cycle, the on-chip PWM module generates the PWM signals for the SR motor power stage.



Open Loop Universal Motor Chopper based on the MC68HC908QT4

This Reference Design deals with a low-cost, open loop universal motor chopper control drive system, based on Freescale's MC68HC908QT4 microcontroller. Pulse Width Modulation (PWM) is used to adjust the duty cycle of the voltage applied to the motor, allowing the average value of voltage to be varied. Compared to a phase angle drive, the chopper drive has the advantage of higher efficiency, with less acoustic noise and better EMC behaviour. The design focuses on providing minimal cost and maximum component integration for low-cost applications.

- Able to drive universal/DC motors
- Variable output voltage: 0-230V AC rms, with defined step and delay ramp
- Maximum output current: 6.52A AC rms (1500W @ 230V) (short time peak current: 8A)
- Uses PWM to modulate output voltage (5.882 kHz switching frequency)
- Capable of supplying general DC inductive/resistive loads
- Electronic switch on/off PWM generation



3-Phase SR Motor Sensorless Control Reference Design

The reference design demonstrates sensorless control of the 3-Phase Switched Reluctance (SR) motor using Hybrid Controller 56F80x. The concept of this application is that of a sensorless speed closed loop SR drive using flux linkage position estimation. An inner current loop with PI controller is included. The change in phase resistance during motor operation due to its temperature dependency creates errors in the position estimation and significantly affects the performance of the drive. Therefore, a novel algorithm for on-the-fly estimation of the phase resistance is included. Rotor position is evaluated using the sensorless flux linkage estimation algorithm. Flux linkage error is used for estimation of the phase resistance at low speeds (US Patent No.: 6,366,865). Other Features included are: Phase resistance measurement during start-up, Phase resistance estimation at low speeds, Motor starts from any position with rotor alignment, PC master software control interface and monitor for examining SR motor control characteristics.

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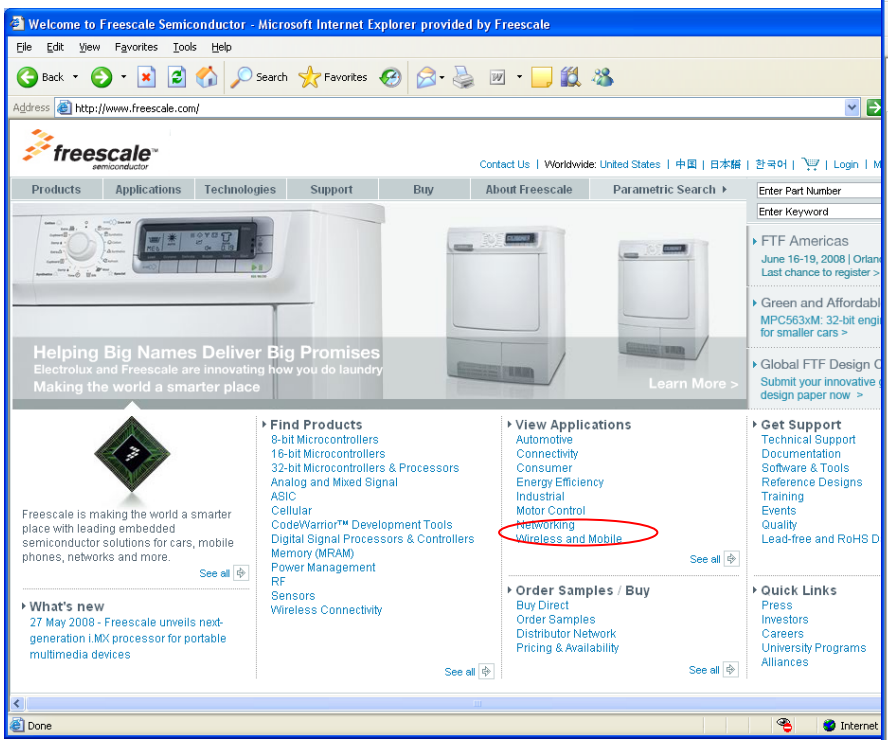
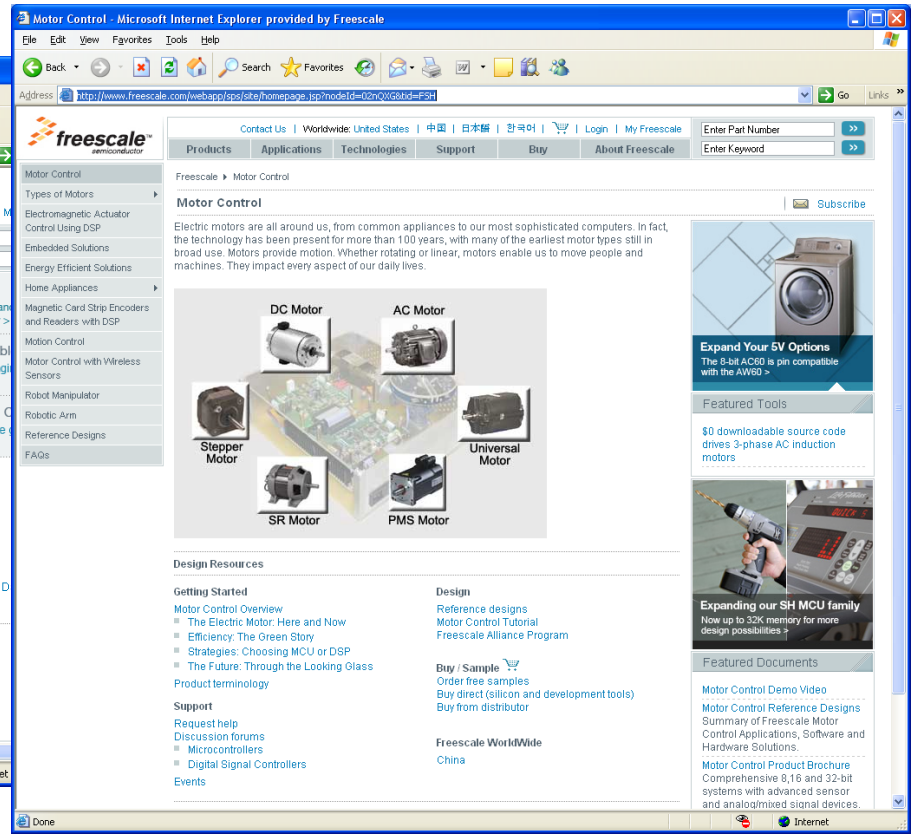
Freescale Motor Control WebSite

- For more reference designs or motor control information go to www.freescale.com/motorcontrol





http://www.freescale.com/webapp/sps/site/homepage.jsp?nodeId=02nQXG&tid=FSH

Related Session Resources

Session Location – Online Literature Library

http://www.freescale.com/webapp/sps/site/homepage.jsp?nodeId=052577903644CB

Sessions

Session ID	Title
PZ109	Motor Control Part 1 - Fundamentals and Freescale Solutions
PZ107	Motor Control Part 2 - Solutions for Large Appliances and HVAC
PZ104	Hands-on Workshop: Motor Control Part 4 - Brushless DC Motors Made Easy

Demos

Pedestal ID	Demo Title
704	Flexis™ AC Face-Off - Air Hockey Demonstration featuring the Flexis AC Products

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