Freescale Technology Forum

Design Innovation.

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Motor Control Part 1 - Fundamentals and Freescale Solutions

PZ109

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Abstract

AC induction, brush permanent magnet, brushless DC and stepper motors. Freescale offers many excellent and familiar motor control solutions ranging from 8-bit to 32-bit ColdFire® MCUs, to 16-bit digital signal controllers and high-performance processors with 32-bit Power Architecture™ cores. How do you choose between them? Come learn about the key differentiators of each product family and how they help to lower system cost, power consumption and complexity for your target application.

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Benefits of Electronically Controlled Motors

- Improved end system performance
- Energy savings
- Quieter operation
- Improved EMI performance
- System cost savings
- Enhanced reliability

Appliance

Industrial

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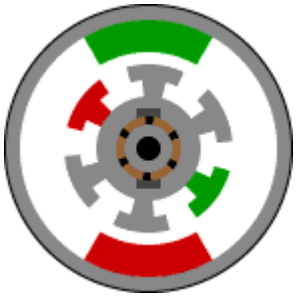
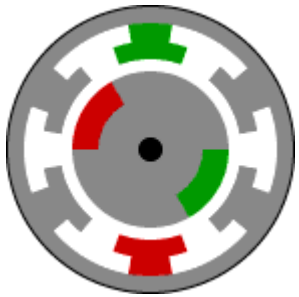
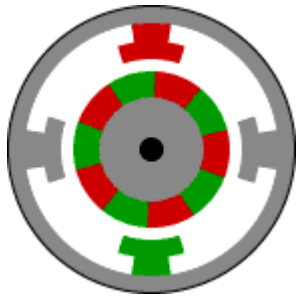
Many Different Motor Types …



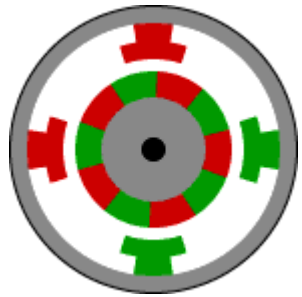
DC Motor



Brushless DC Motor (BLDC)



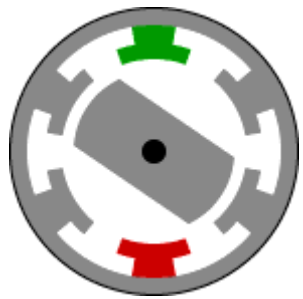
Stepper Motor (full step)



Stepper Motor (half step)

AC Induction Motor (ACIM)

Permanent Magnet Synchronous Motor (PMSM)



Switched Reluctance Motor

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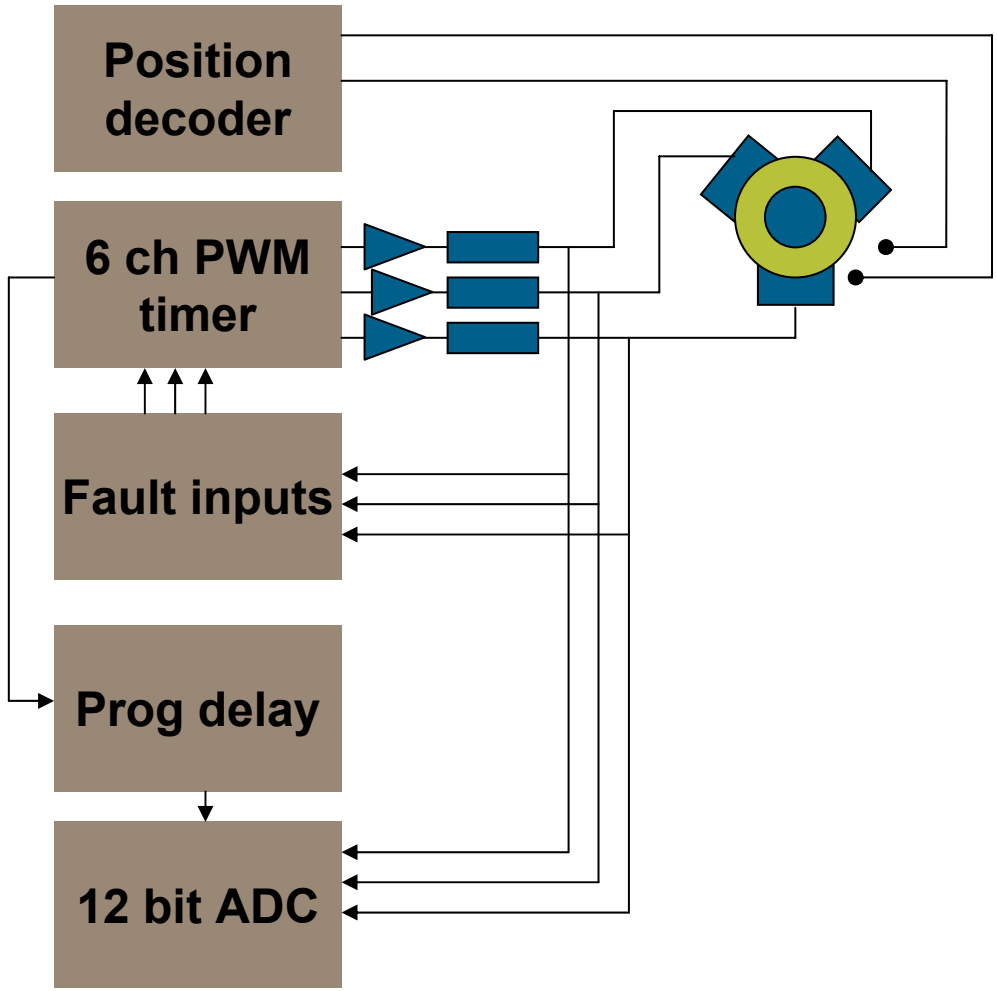
Global Motor Control Markets and Applications

	Typical Motor Type
Appliance	
• Washing machine/Dishwasher/Dryer	ACIM, PMSM
• Refrigerator/Freezer	BLDC
• Shaver	DC
• Drills	DC
• Vacuum Cleaner	SR
Industrial	
• Factory automation	Stepper
• Robotic systems	Universal, BLDC
• Compressors	ACIM, PMSM
• Fans	BLDC
• Air conditioning	ACIM, BLDC, PMSM
• Elevators	ACIM
• Shutters	BLDC
• Gates	DC
• Surveillance platforms	DC

Typical Motor Control MCU Peripherals Function

- Timer:
  - PWM signals < 20Khz
  - Dead time insertion
  - Commutation (mask-out)
  - ADC triggering
  - Fault control
- ADC
  - Measure current
- Delay block
  - Set ADC measurement at specific times
- Position decoder
  - Quadrature decoder inputs if not sensorless



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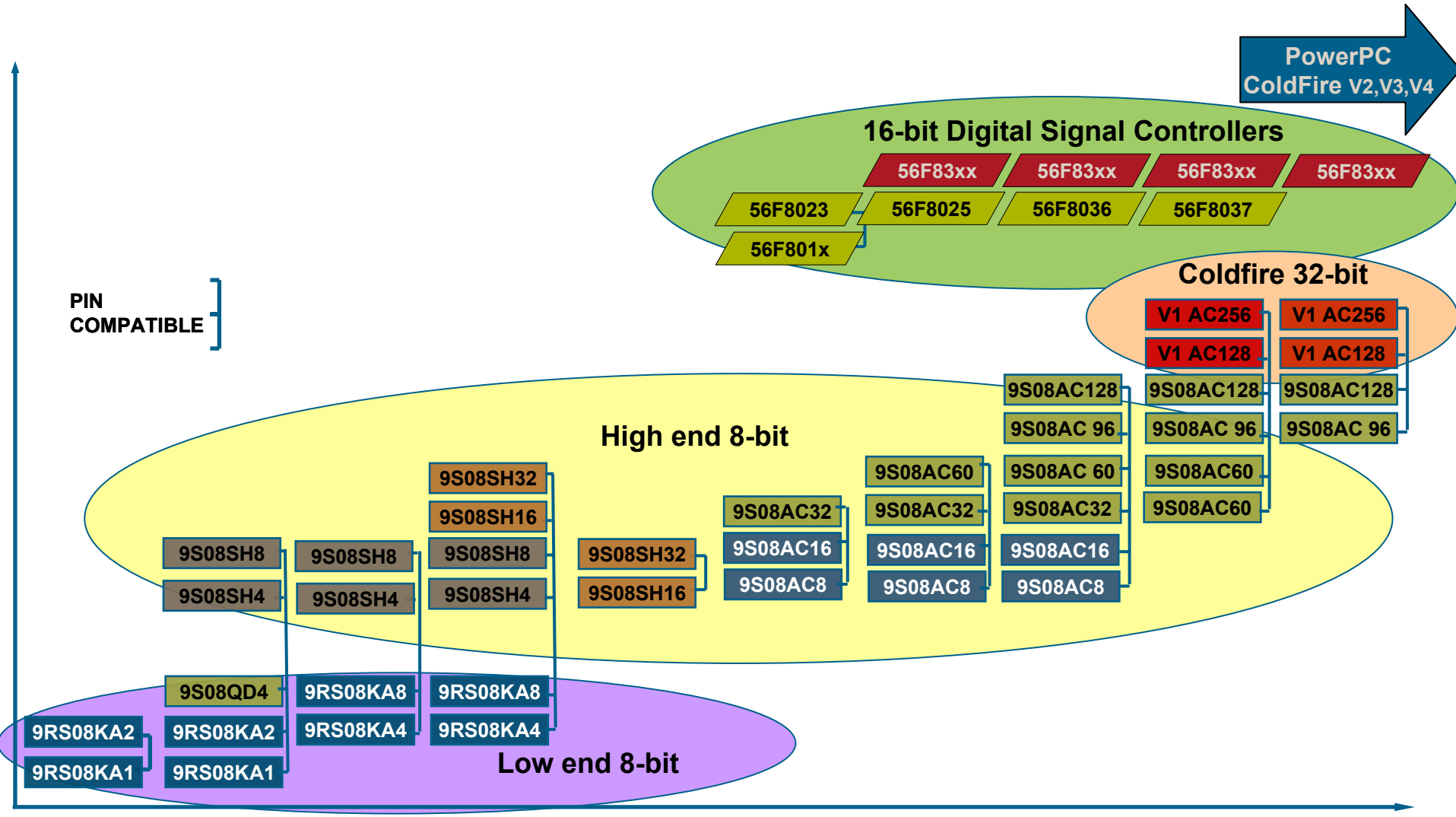
Freescale Motor Control MCU Devices



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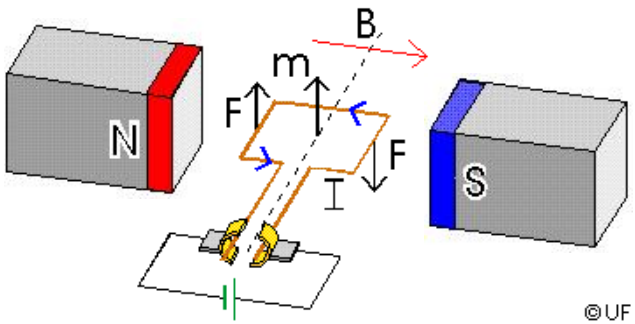
Choosing Your MCU Therefore Depends Upon …

- The **same application** may have **different performance** if implemented on **different MCUs**
- The **peripheral features** can significantly impact performance of target application, **not CPU only**
- **Application Features** should be considered
  - Type of motor
  - Type of load
  - Operational mode
  - Minimal speed
  - Maximal speed
  - Current control
  - Speed control and/or position control
  - Number of PID controllers
  - Fault control
  - **System Cost!**

Understanding the Motor Basics

DC Motor Torque Establishment



Left Hand Rule

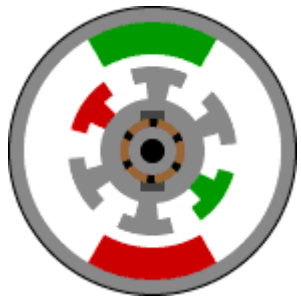
I = Current Flow

B = Magnetice Field

F = Force

DC Motor Principle

•The stator of a **Permanent Magnet DC Motor** is composed of two or more permanent magnet pole pieces



•The rotor is composed of windings which are connected to a mechanical commutator. In this case the rotor has three pole pairs

Brush DC motor control is simple:

Apply voltage → Commutation occurs mechanically

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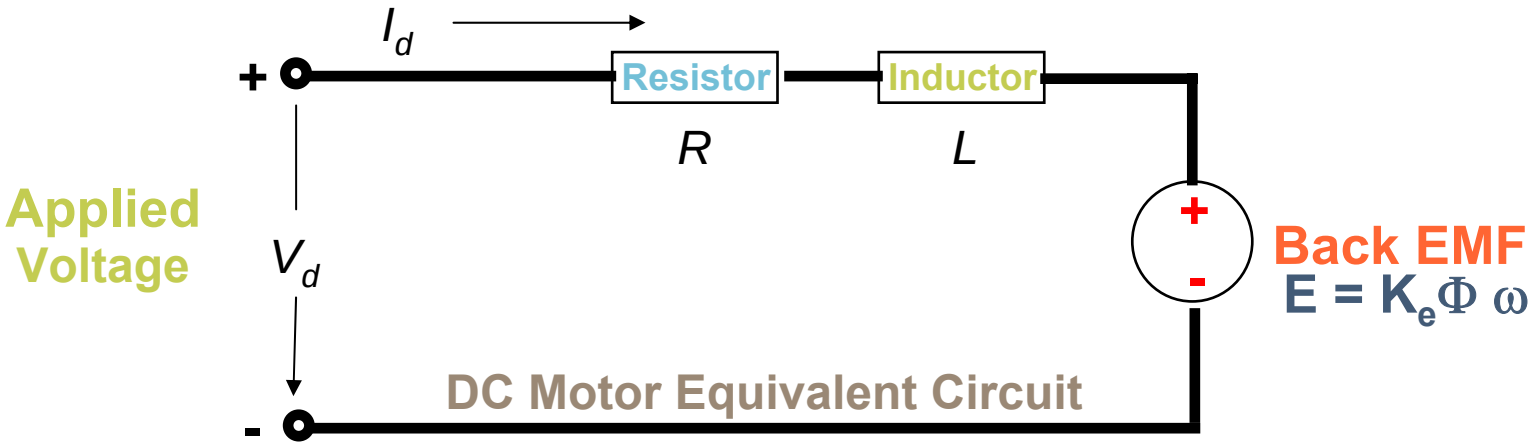
Simple Model of a DC Motor



Dynamic Motor speed:

$$\omega = \frac{V_d - I_d \times R - L\frac{dI_d}{dt}}{K_e \times \Phi}$$

- **Speed is increased by increasing the voltage**
- **Torque is controlled by controlling the current**
- **Direction is determined by the direction of the current**

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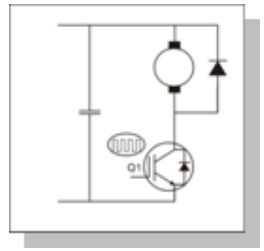
PWM Control of DC Motor

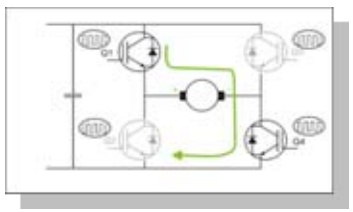
- Same motor can have different control configurations
  (i.e. Simple switch vs. H-Bridge)
- Same control configuration can have different operating modes
  (i.e. Bipolar PWM vs. Unipolar PWM, independent vs. complementary)
- Different modes have advantages and disadvantages

Simple Switch
(uni-directional operation)



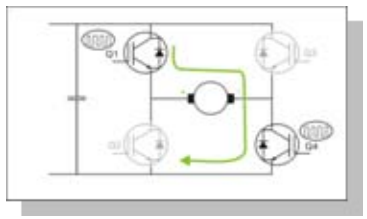
1- PWM

H-Bridge - Complementary PWM
(4 quadrant operation)



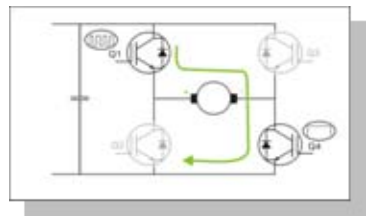
4 – PWMs with Deadtime

H-Bridge - Independent Bipolar PWM
(bi-directional operation)



2 – PWMs

H-Bridge - Independent Unipolar PWM
(bi-directional operation)



2 – PWMs
2 – GPIO

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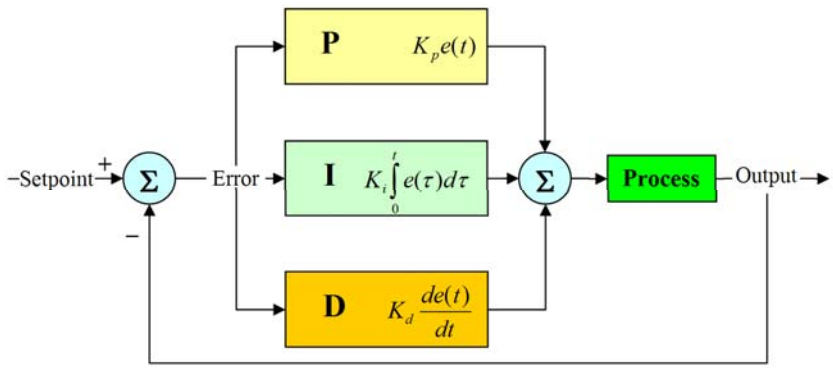
Proportional Integral Derivative (PID) Controller

- The PID controller corrects the error between a measured variable and a desired set-point
- The PID controller calculation involves 3 separate parameters
  - **Proportional** - determines the **reaction** to the **current** error
  - **Integral** - determines the **reaction** based on the **sum** of recent errors (i.e. steady state error)
  - **Derivative** - determines the **reaction** to the **rate** at which the error has been changing
- The **weighted sum** of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element or the voltage to a motor



A fast response may require rapid calculation of the PID output and this can force the use of a higher performing CPU core (i.e. DSC, ColdFire, or PPC)

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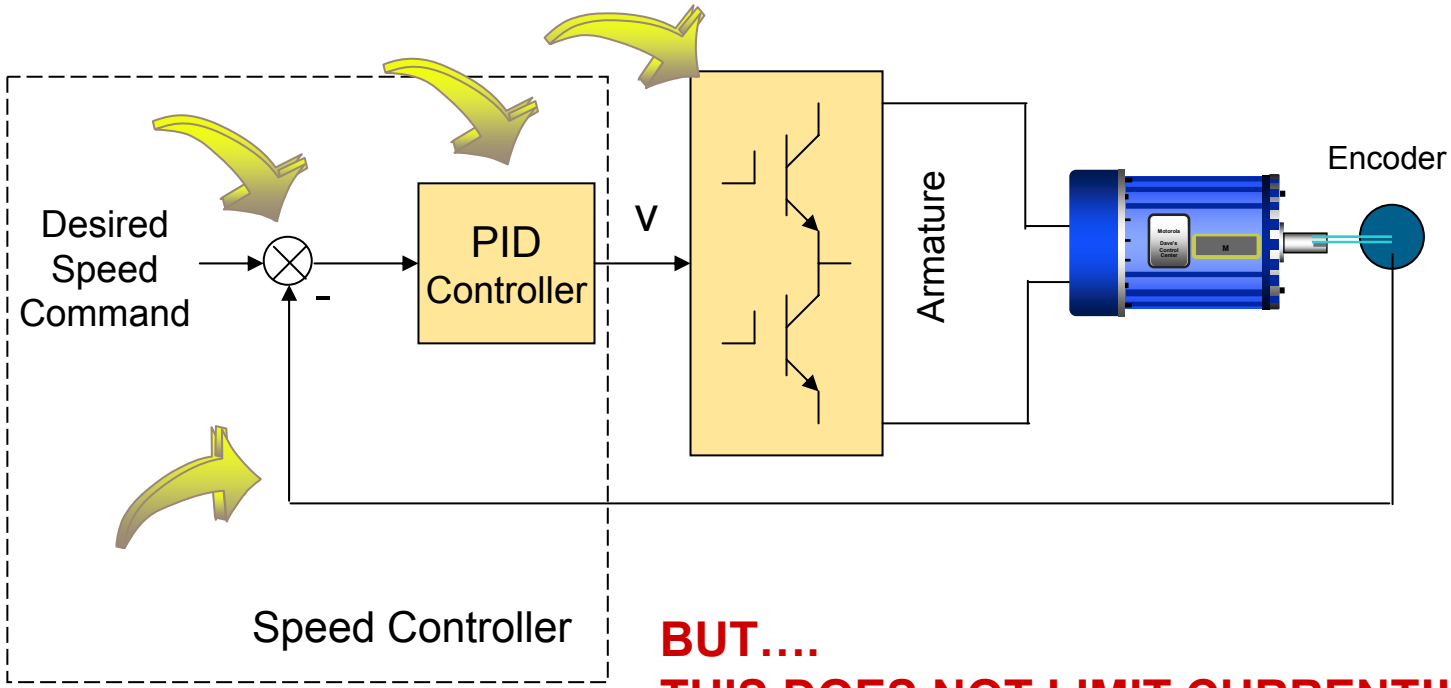
Simple Speed Control On A Brush DC Motor



BUT….
THIS DOES NOT LIMIT CURRENT!!

1. **Measure speed of the motor**
2. **Compare the measured speed with the desired speed and generate an error signal**
3. **Amplify the error signal to generate a correction voltage**
4. **Modulate the correction voltage onto the motor terminals**

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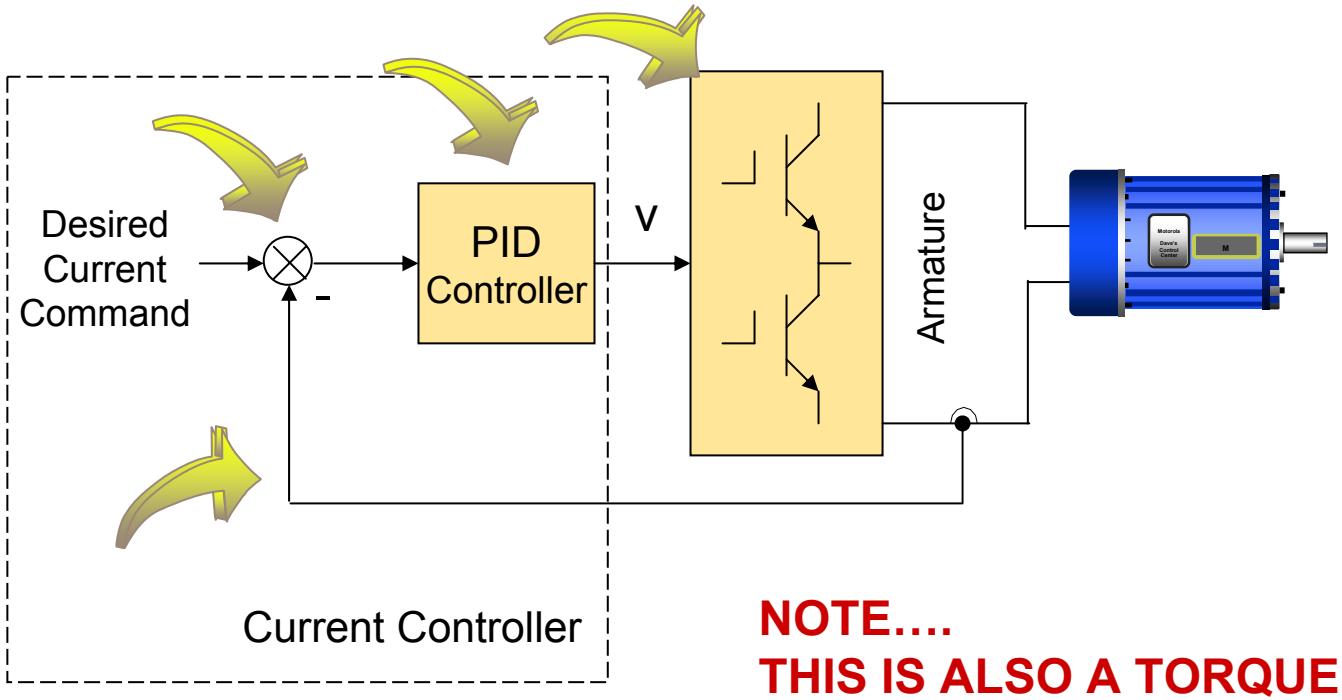
Control Current On A Brush DC Motor



NOTE….
THIS IS ALSO A TORQUE CONTROLLER!!

1. **Measure the current of the motor**
2. **Compare the measured current with the desired current and generate an error signal**
3. **Amplify the error signal to generate a correction voltage**
4. **Modulate the correction voltage onto the motor terminals**

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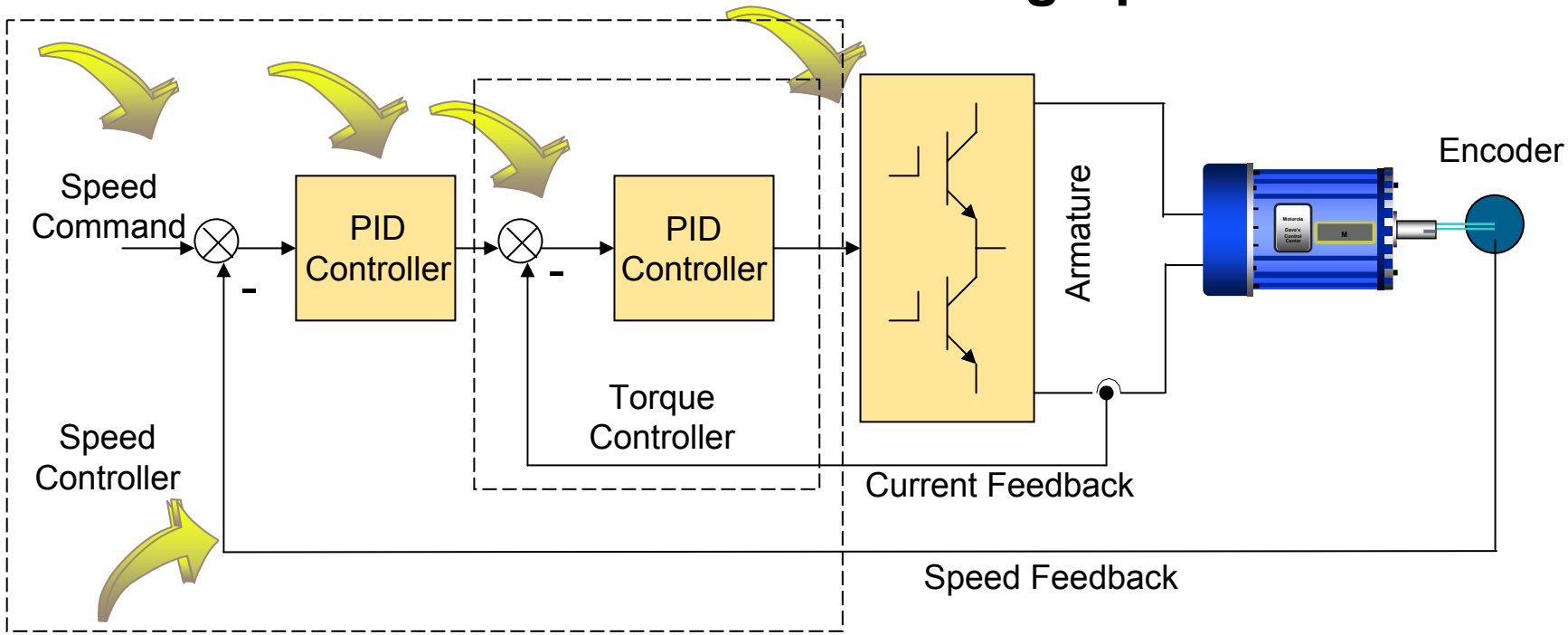
Controlling Speed and Current



1. **Measure speed from the motor shaft**
2. **Compare the measured speed with the desired speed and generate an error signal**
3. **Amplify the error signal to generate a correction to desired current**
4. **Input desired current into the torque controller**
5. **Modulate the correction voltage from the torque controller onto the motor terminals**

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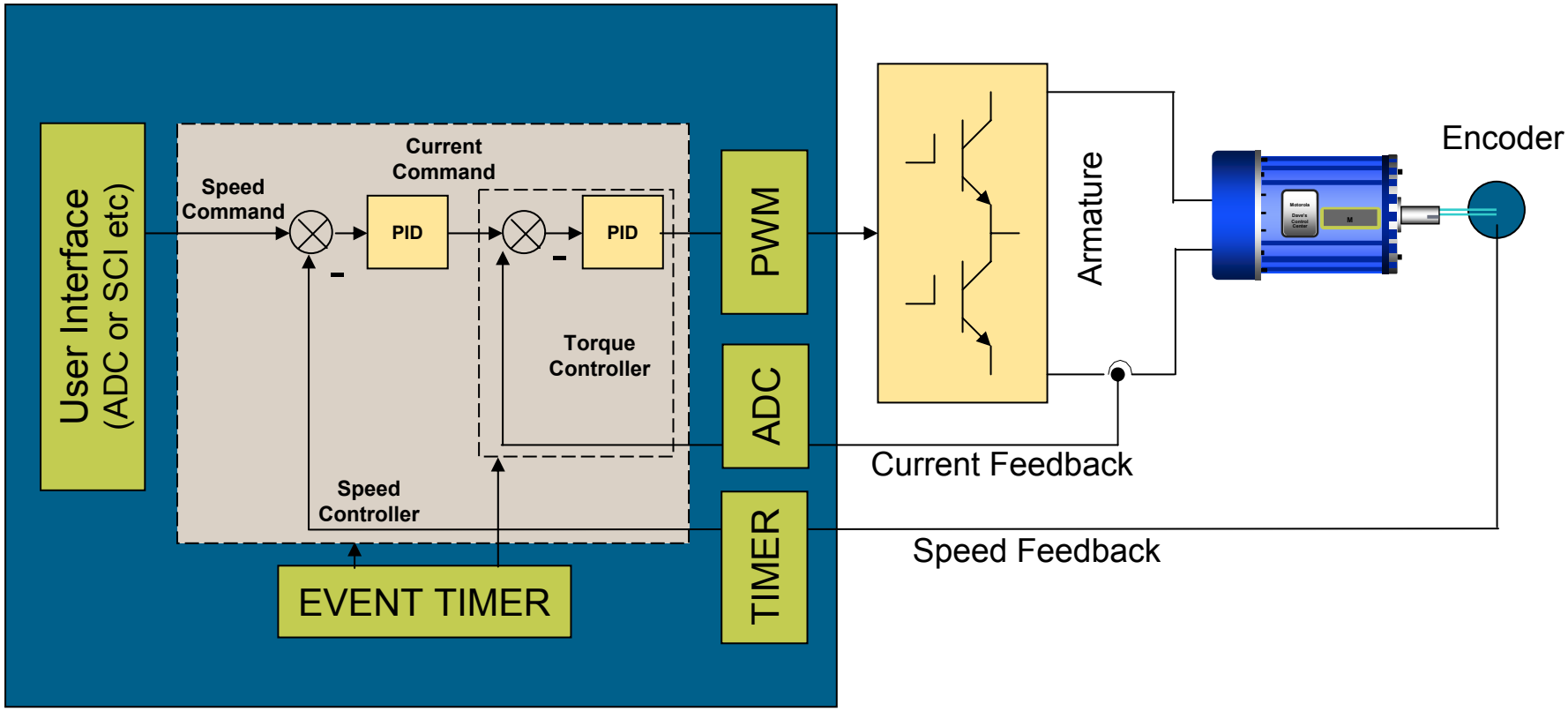
Simple DC Motor Control from the MCU's Perspective



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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

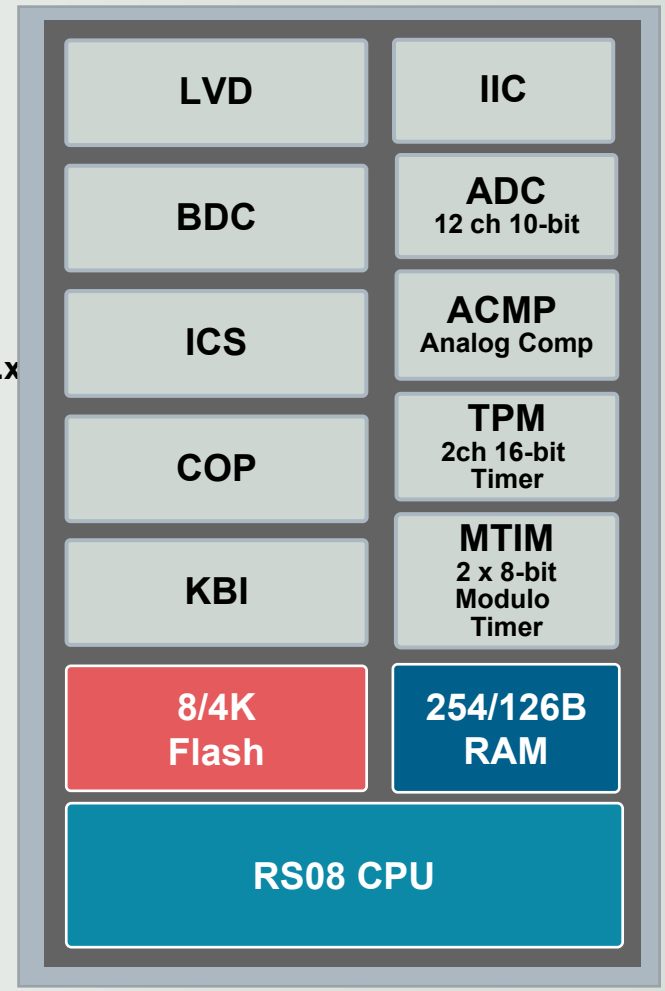
- 16 pin, 20 pin (SOIC/PDIP)

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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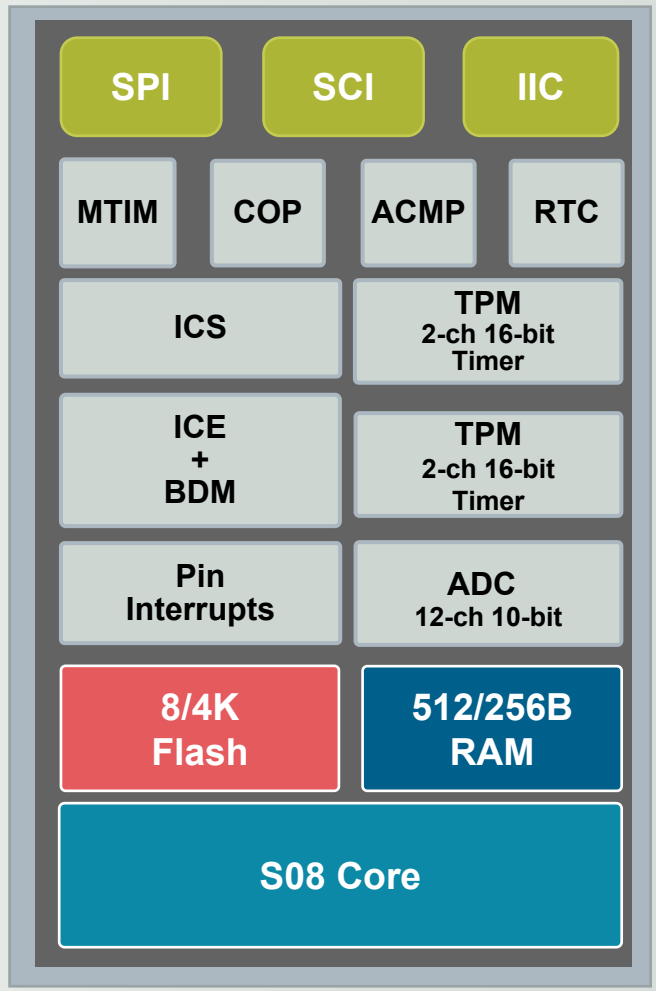
MC9S08SH8/4

- **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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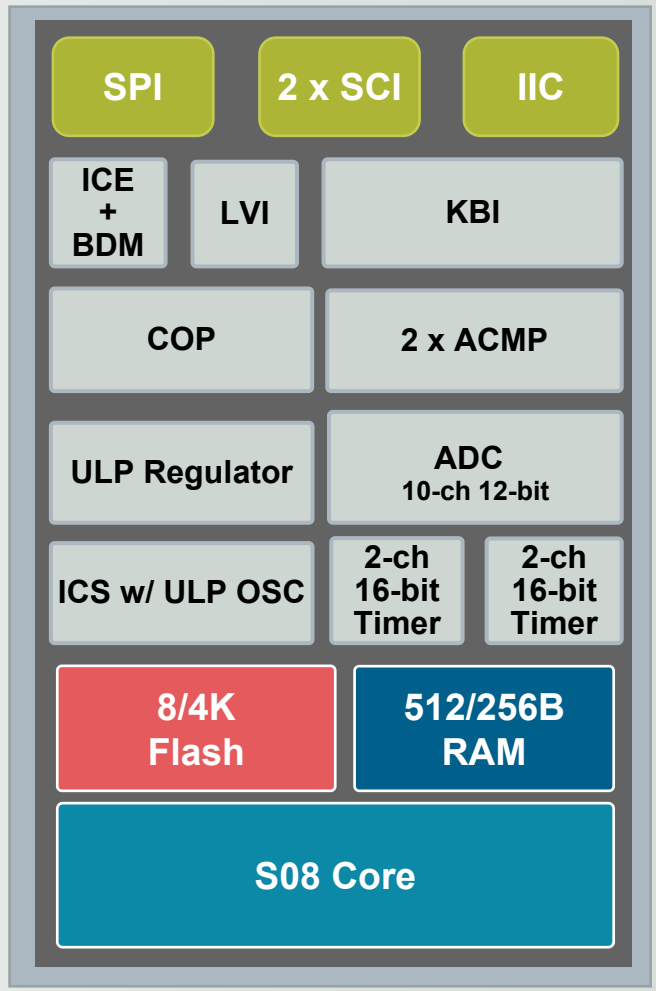
MC9S08QE8/4

- **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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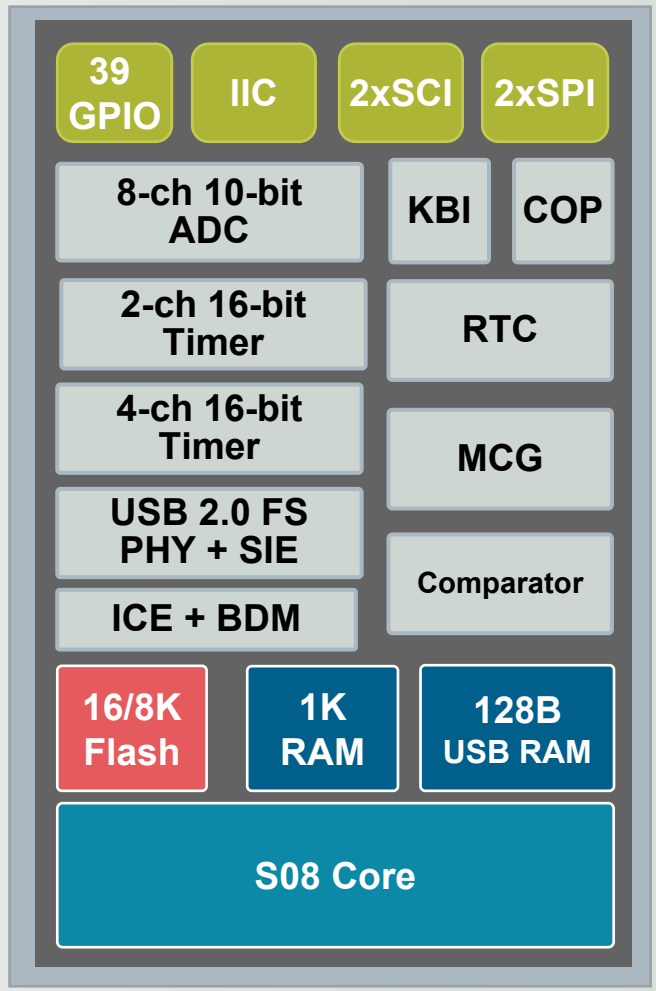
MC9S08JM16/8

- **Features / Benefits**
  - Timers – 1 x 2-ch, 1 x 6-ch
  - Upgraded SPI configurable for 8-bit or 16-bit data length
  - Analog comparator
  - 8-ch keyboard interrupt (KBI)
  - 8-bit 12-ch ADC
  - LVI
  - 39 (mux-ed) GPIOs for 48 pin package
  - Integrated USB 2.0 FS PHY and SIE
  - Multi-purpose clock generator (MCG)
    - PLL
    - On-chip oscillator
    - External crystal support
  - On-chip ICE and BDM
- **Supply Voltage / Performance**
  - 2.7 – 5.0 V operation
  - -40 to 85°C operation
- **Core**
  - 48 MHz HCS08 core
  - 24 MHz bus frequency
- **Memory**
  - 16K Flash, 1K RAM, 128B USB RAM
- **Communications**
  - SCI, SPI, IIC w/ broadcast mode feature
- **Packages**
  - 32 LQFP, 44 LQFP, 48 QFN



Last updated September 5, 2007

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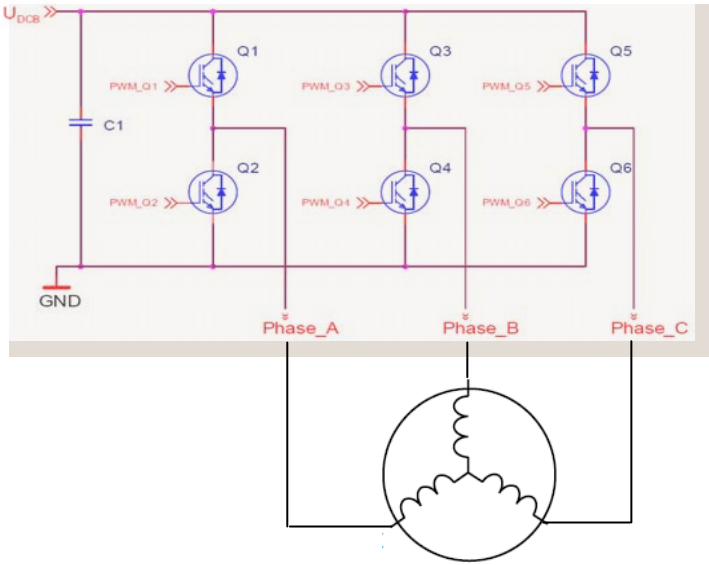
Brush DC Motor Summary

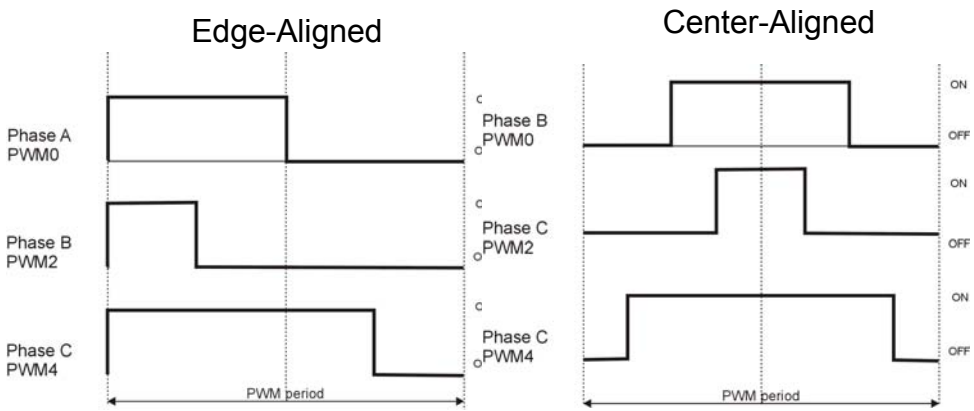
- Advantages
  - Ease of control (self commutating)
  - Low rotor inertia (coreless rotors)
  - Lowest total system cost for basic motion
  - Wound field motors exhibit high starting torque, (series wound) and can run with AC or DC
- Disadvantages
  - Higher maintenance cost due to brush wear
  - Electrical noise due to mechanical commutation
  - Maximal speed limited by commutator
  - Heat is generated in armature, which is difficult to remove
  - Friction losses associated with mechanical commutation
  - Not usable in “intrinsically safe” environments

NOTE: Brush DC motor control can be easily accomplished in a large variety of MCUs

3-Phase AC Motors (BLDC, PMSM, or ACIM)

- 3-phase motors require more control signals (i.e. 6 pins)
- These may or may not require dead-time based on motor type and control method (i.e. BLDC vs. PMSM or ACIM)
- Center-alignment may be desired





Center-aligned PWMs are better from an EMI and EMC point of view for sinusoidal generation

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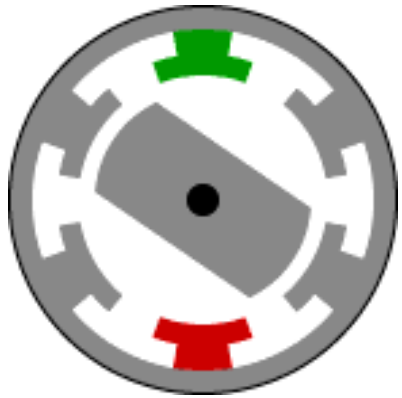
DC Brushless vs. DC Motor Principle

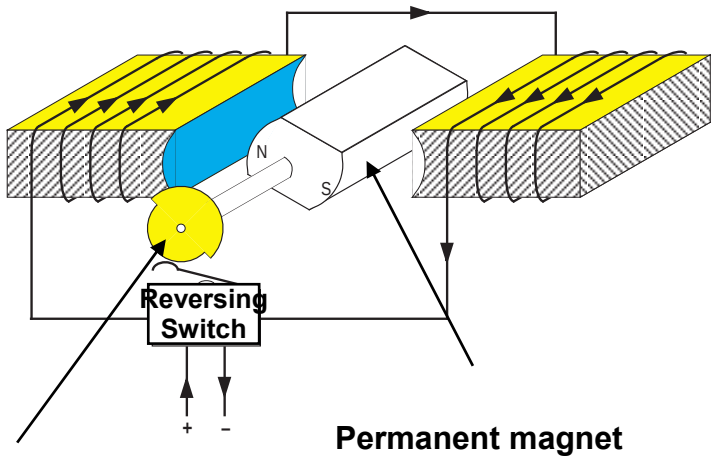
Permanent Magnet DC

- Magnets on the stator
- Windings on the rotor
- Commutation occurs automatically with the brushes



Brushless DC

- Magnets on the rotor
- Windings on the stator
- Stator Field Must be Commutated!



Requires mechanism to sense rotor position to commutate field properly

This is usually a hall effect sensor array or an encoder

Permanent magnet
(usually ferrite, samarium cobalt, or neodymium iron boron)

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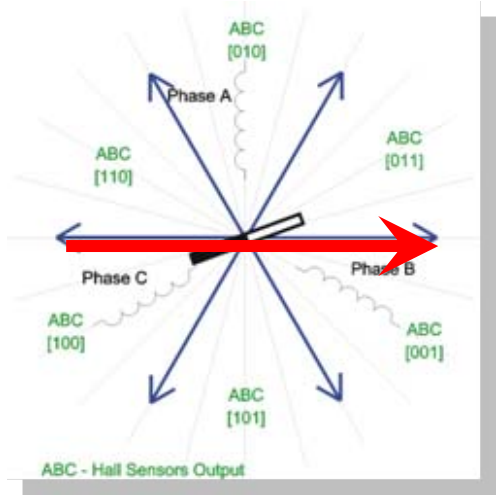
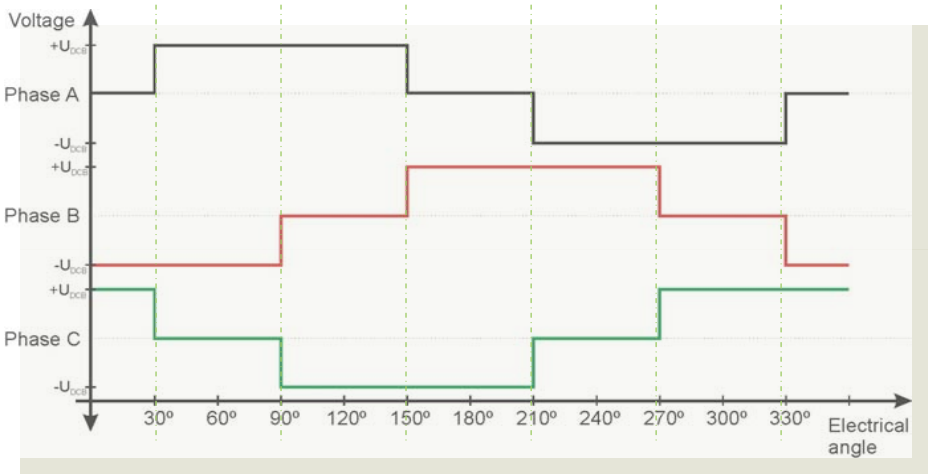
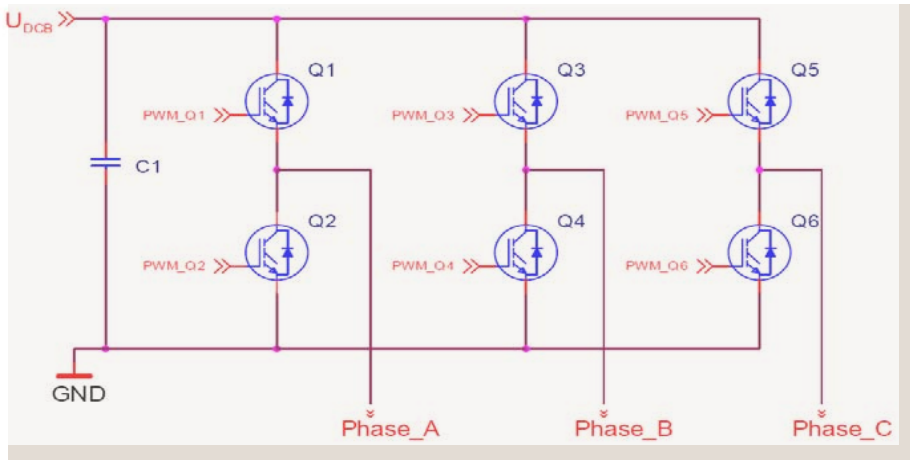
Commutation – 3-Phase Brushless DC Motor

- 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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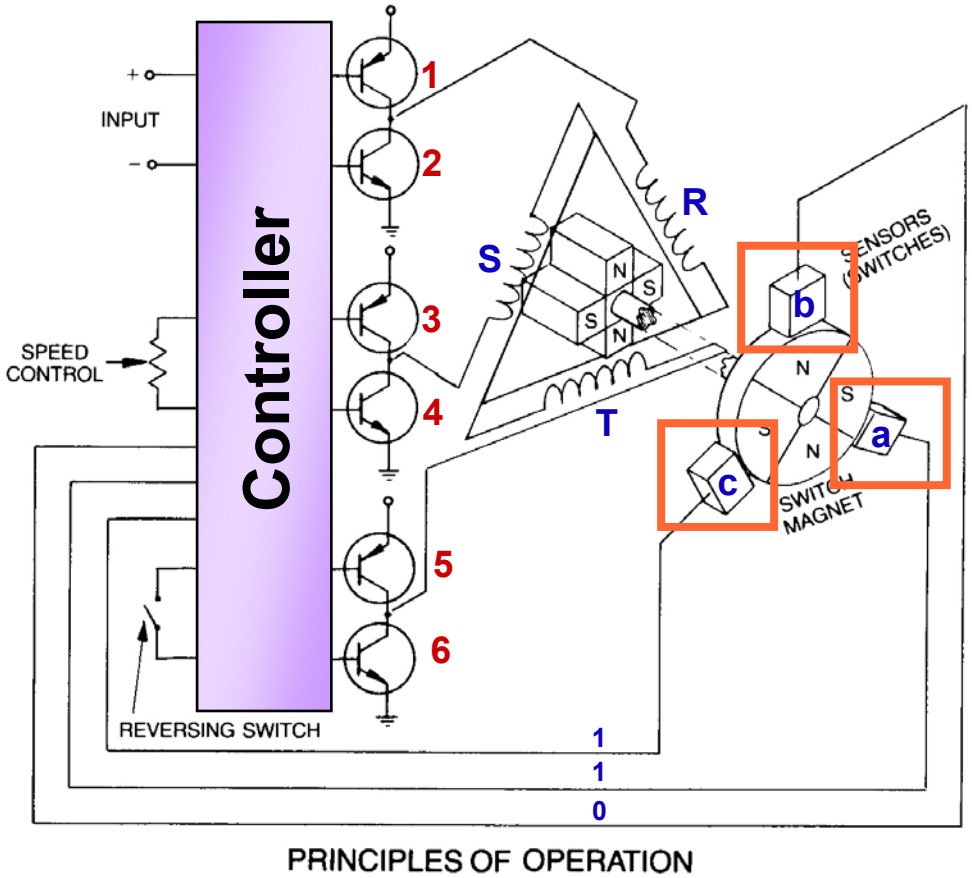
3-Phase Brushless DC Motor Control

Six Step BLDC Motor Control cont'd



PRINCIPLES OF OPERATION

- Hall sensors are used to sense the rotor field and therefore determines when to commutate the stator field

120 ^{0} hall spacing is preferred over 60 ^{0} spacing since unpowered or unconnected sensors produce 111 or 000 codes, which are discarded as illegal.

Source: Eastern Air Devices, Inc. Brushless DC Motor Brochure

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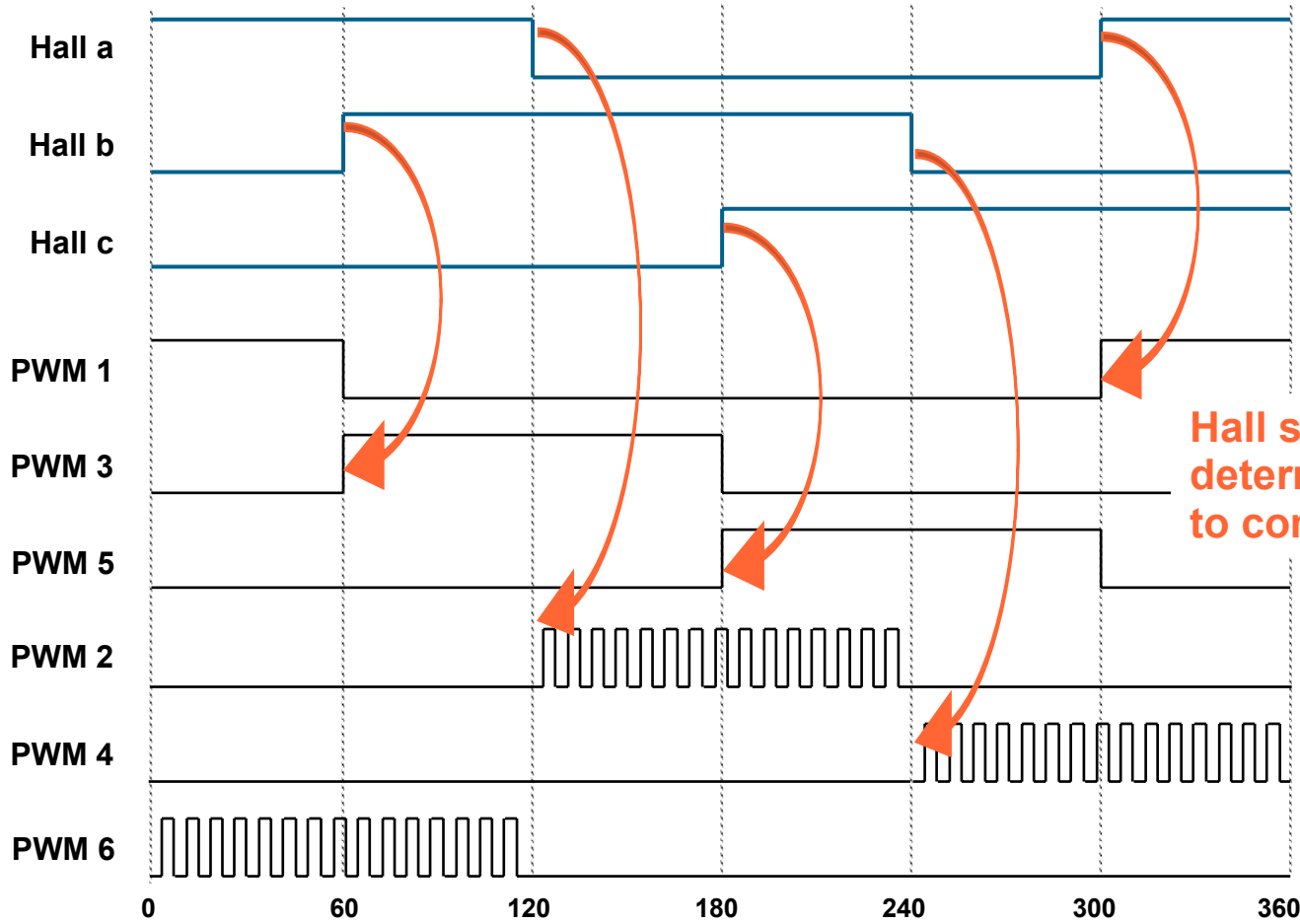
3-Phase Brushless DC Motor Control

- Six Step BLDC Motor Control cont'd



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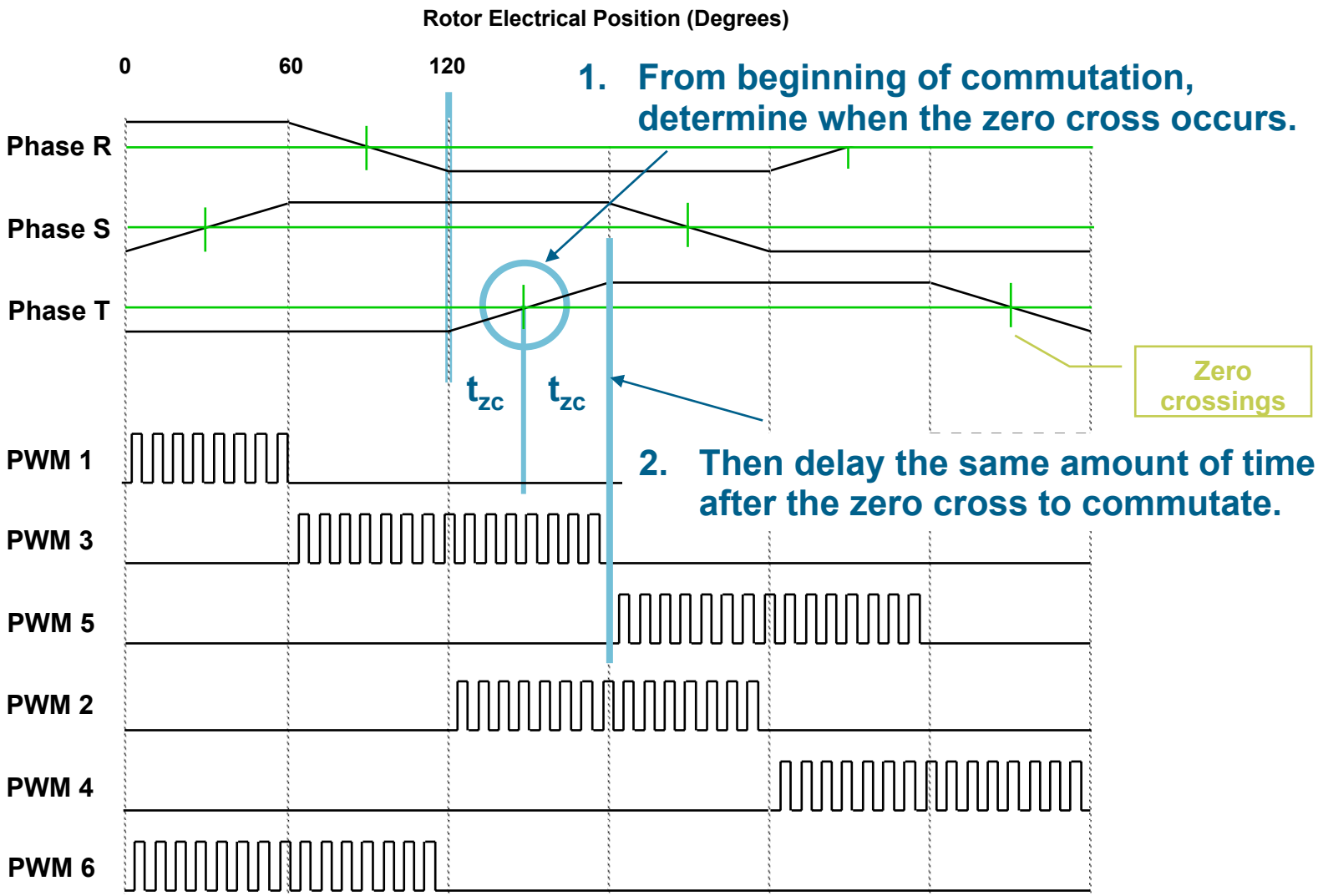
Sensorless Commutation



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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3-Phase Brushless DC Summary

- Advantages:
  - High reliability
  - High RPM possible
  - Can be used in intrinsically safe environments
  - High efficiency

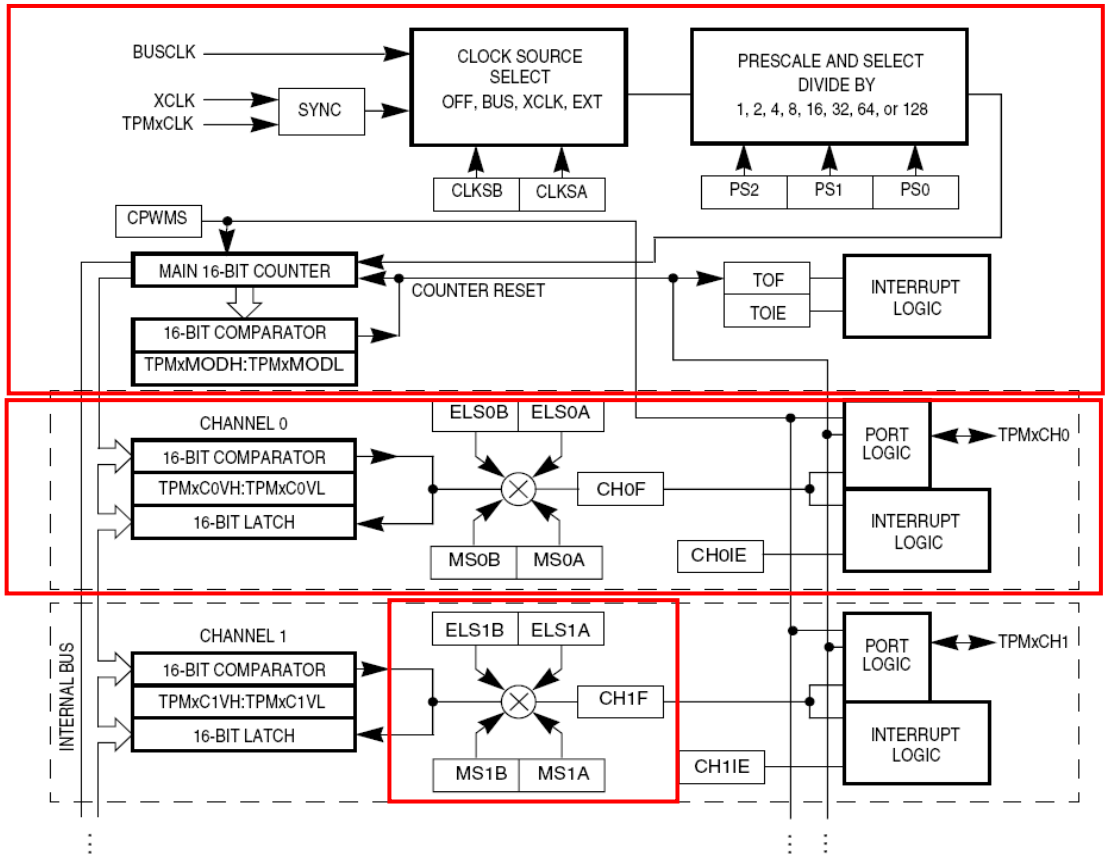
- Disadvantages:
  - Stator must be commutated (requires electronic control)
  - Can be demagnetized if not controlled properly.

NOTE: 3-Phase Brushless DC motor control can be easily accomplished in a large variety of MCUs but performance may vary based on the selection

Key Peripherals

- ADC module
  - We need to measure DC bus voltage, Back-EMF voltage and DC bus current
- PWM/Timer module
  - We need to generate 6 PWM outputs for 3-phase bridge
  - Independent unipolar PWM modulation can use 3 PWM channels and 3 GPIO
- General timer for application timing and speed measurement
- Communication interface if required (SCI, SPI, CAN, I^2C)

S08 – Timer/PWM (TPM) Module



- Sets PWM Frequency
- Sets PWM Duty Cycle
- Sets PWM Polarity

- **The TPM can also do complementary PWMs but dead-time needs to be accomplished by software**

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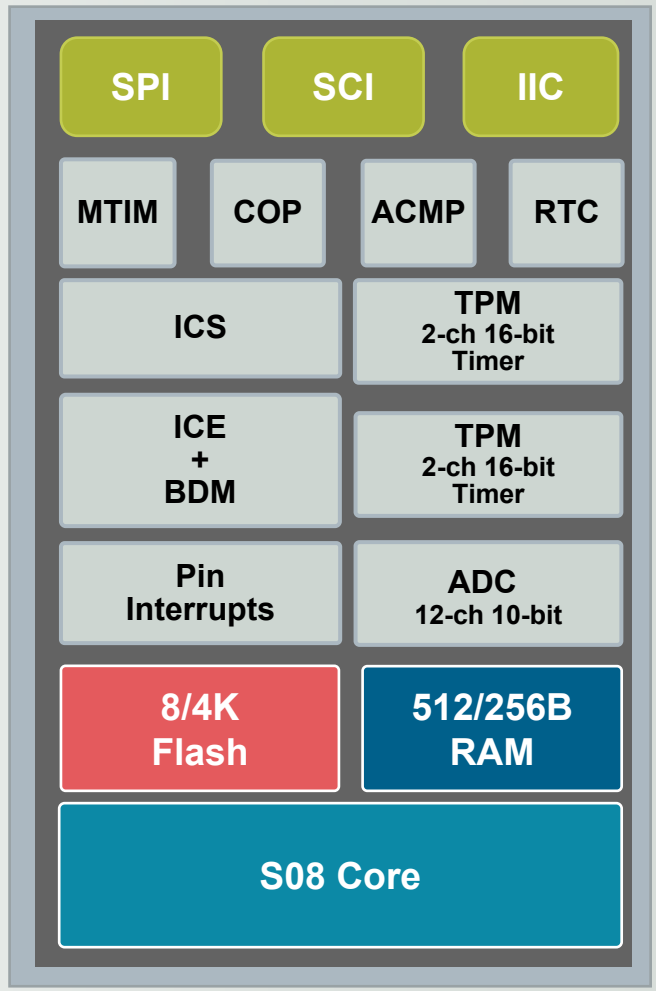
MC9S08SH8/4

- **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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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

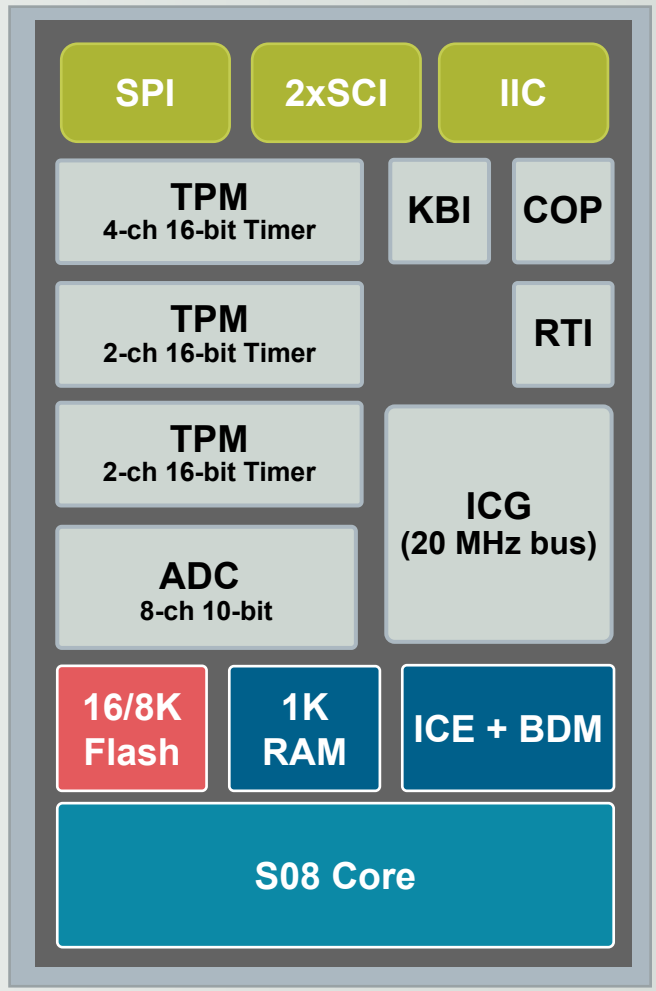
Memory
- 16/8K Flash
- Up to 1K RAM

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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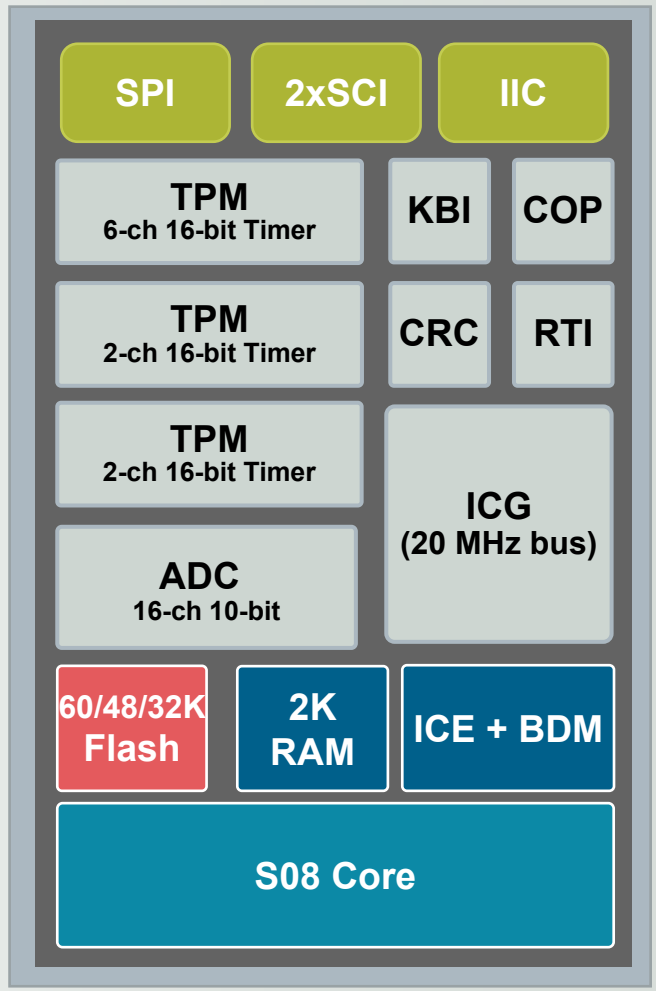
MC9S08AC60/48/32

- **Features / Benefits**
  - 40 MHz S08 core (20MHz Bus)
  - 3 independent clock modules
  - 16-ch 10-bit ADC
  - Pin-compatible with AW60/AW32
  - Internal clock generator (ICG)
  - Independently clocked COP
  - Cyclic redundancy check (CRC)
  - On-chip ICE and BDM
- **Supply Voltage / Performance**
  - 2.7 – 5.5 V operation
- **Memory**
  - 60/48/32K Flash
  - 2K RAM
- **Communications**
  - One (1) IIC w/ broadcast mode
  - Two (2) asynchronous SCI ports
  - One (1) synchronous SPI ports
- **Packages**
  - 32 LQFP, 44 LQFP, 48 QFN, 64 QFP, 64 LQFP
- **Pricing**
  - $1.84* MSRP at 10K units



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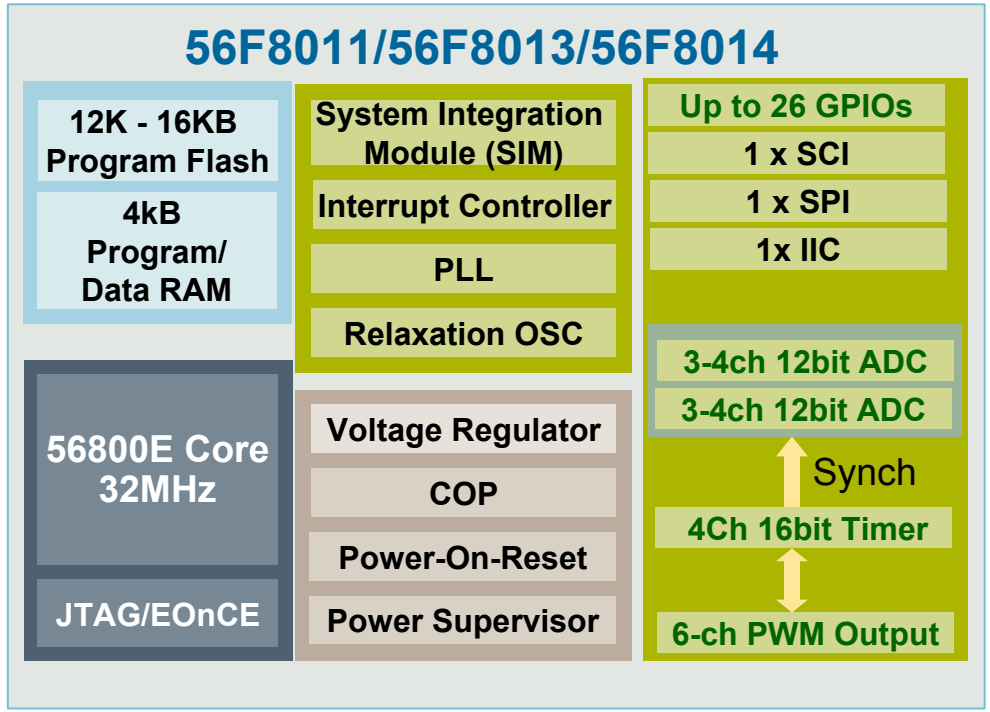
Cost Effective 56F8000 Solutions - 56F8011/56F8013/56F8014

- **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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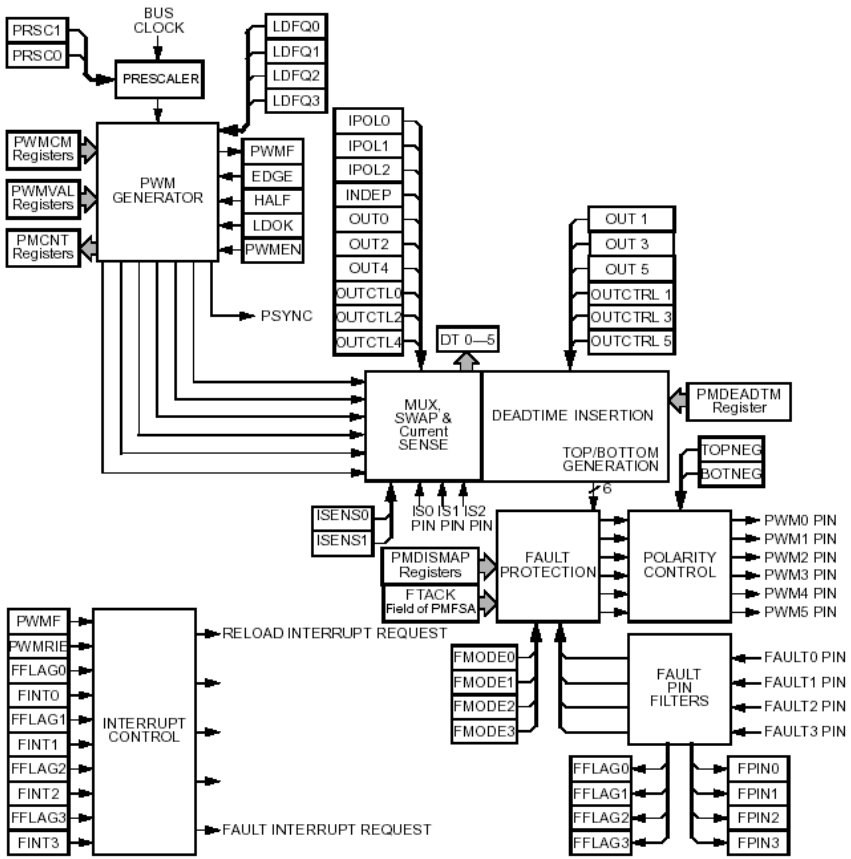
MC56F80xx – PWM Block



- Prescaler
- PWM Generator
- **MUX Swap & Current sense**
- **Deadtime Insertion Top/Bottom Generation**
- Software Output Control
- **Fault Protection**
- **Fault Pin Filters**
- Polarity Control
- Interrupt Control

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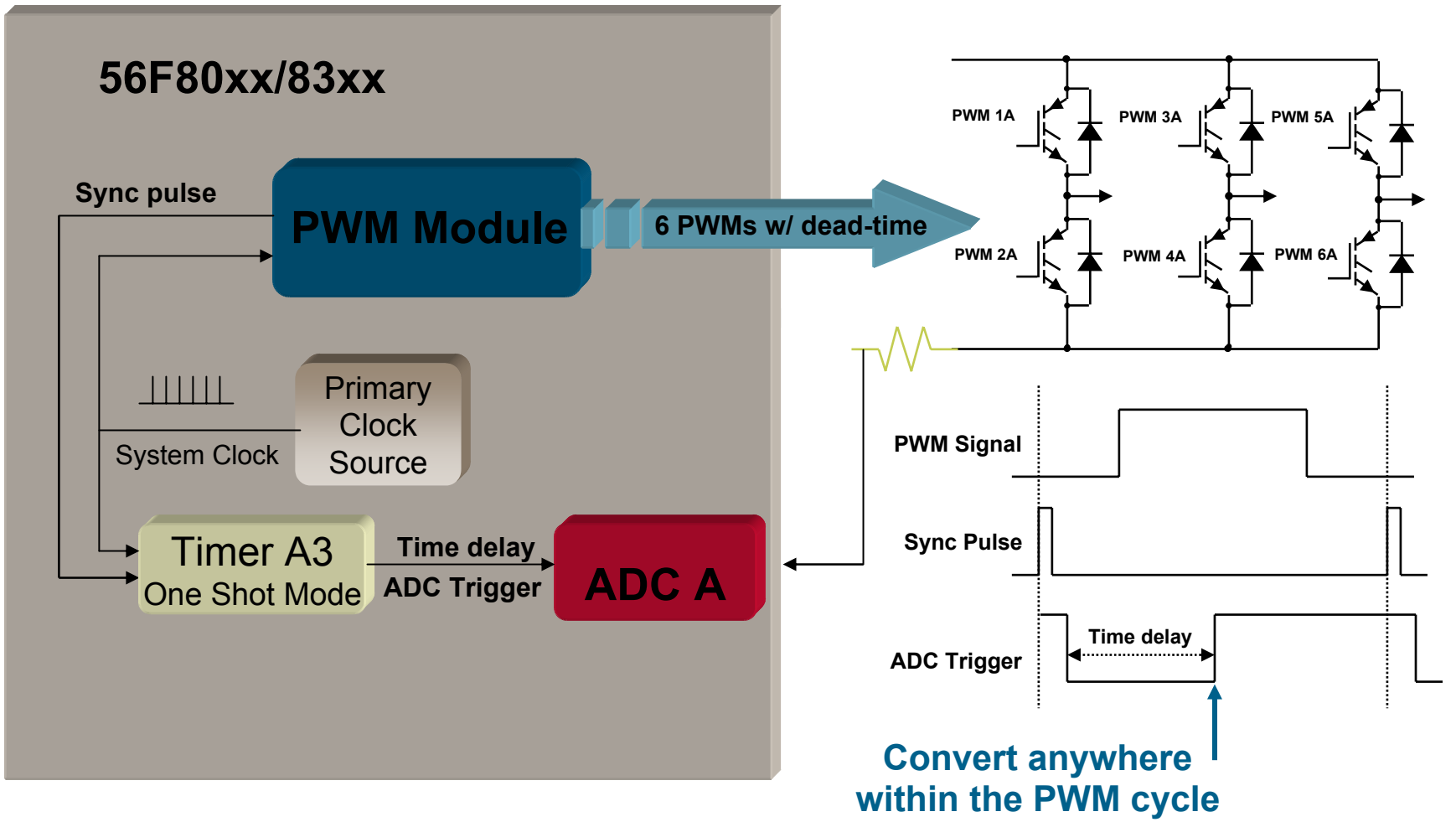
ADC Synchronization from the PWM Module



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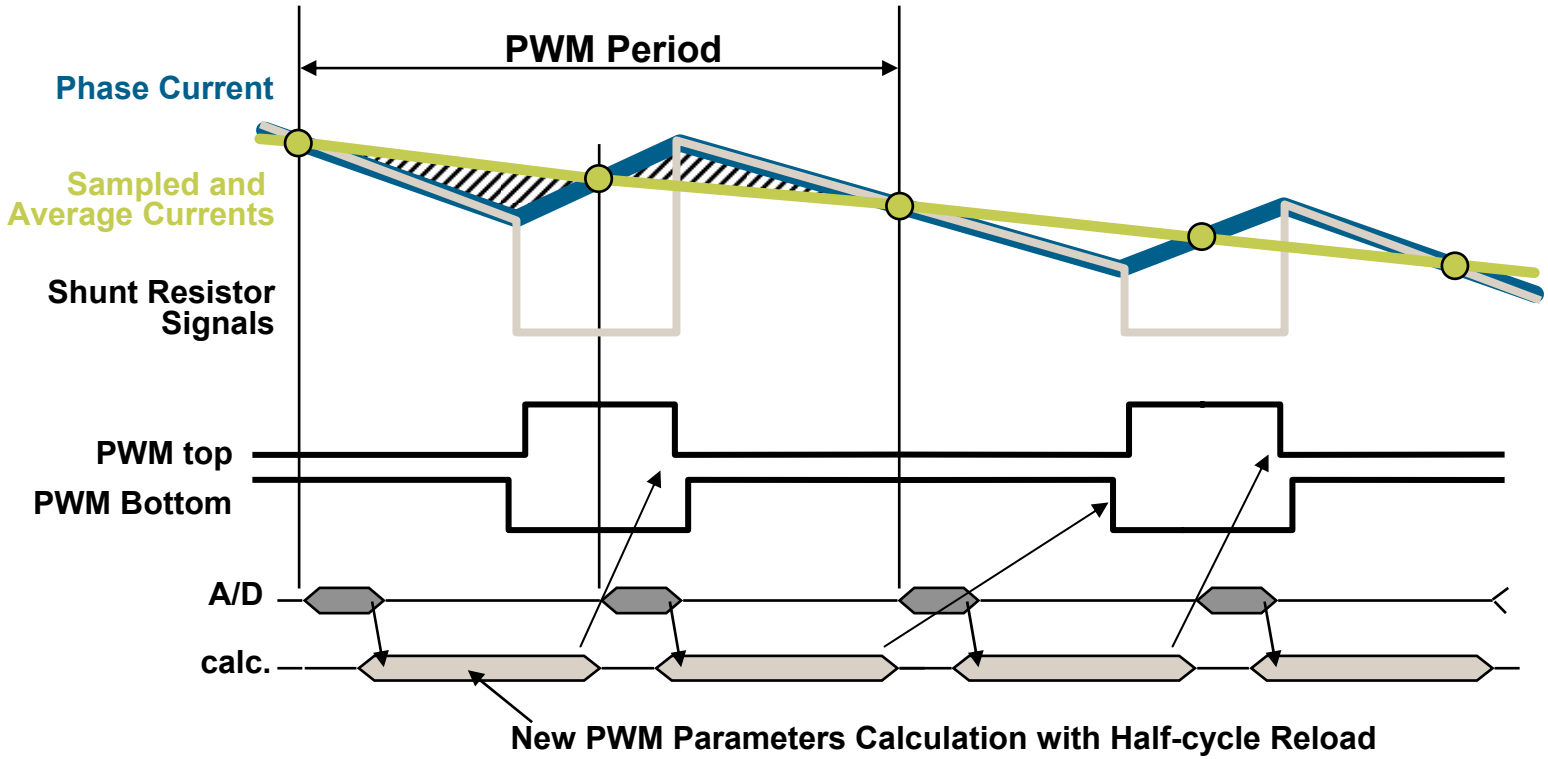
Benefits of ADC Synchronization with the PWM



- 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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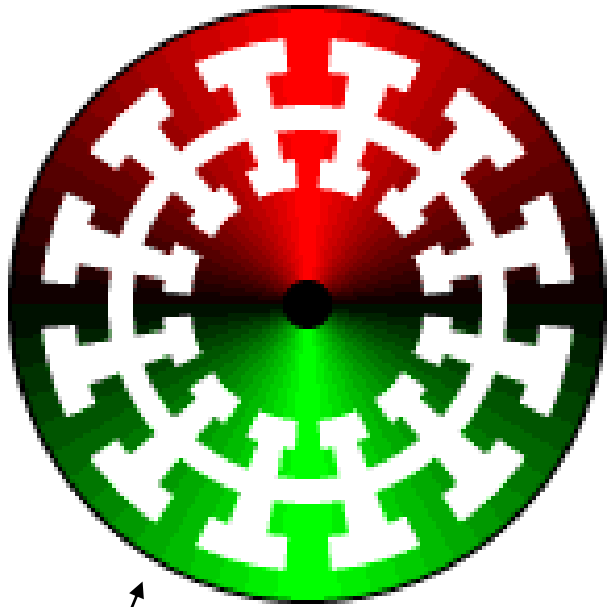
Which device is the right choice?

- The same application may have **different performance** if implemented on **different MCUs**
- The **peripheral features** can significantly **impact performance** of target application, **not only the CPU**

MC56F80xx implementation	MC9S08ACxx implementation
Safer PWM generation due to complementary and dead-time logic	Complementary signals and dead-time has to be generated by software
Lower minimal speed due to PWM->ADC synchronization	Minimal speed is limited by software PWM->ADC synchronization
Higher maximal speed due to faster ADC, more result registers, PWM->ADC synchronization, multiple sampling of Back-EMF allowed	Maximal speed is limited by capability of Back-EMF voltage detection. Only one Back-EMF sample can be taken during PWM period due to slower ADC and single result register
Current control can be easily implemented due to fast ADC, powerful CPU	Harder to implement due to slower ADC converter, no HW PWM->ADC synchronization and single result register
Fault control integrated in PWM module	There is no support for fault processing

AC Induction Motor

- The **STATOR windings** are distributed around the stator to produce a roughly **sinusoidal distribution**
- When three phase ac voltages are applied to the stator windings, a rotating magnetic field is produced
- The **ROTOR** also consists of windings or, more often, a **copper squirrel cage**
- An electric current is **induced** in the rotor bars which also produce a magnetic field

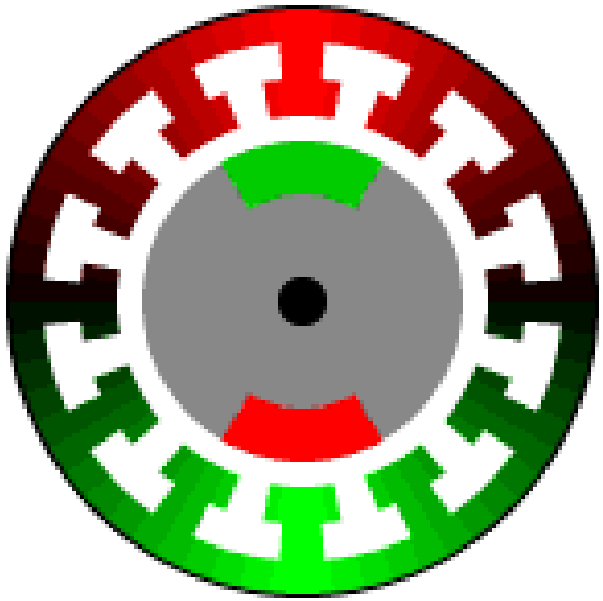


Notice the rotor slip!

The **Rotor** does not quite keep up with the **Rotating Magnetic Field** of the stator.

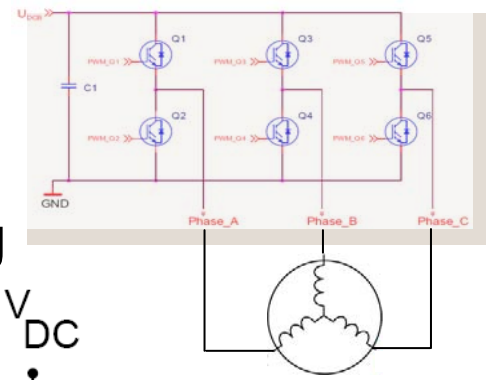
Permanent Magnet AC Motor

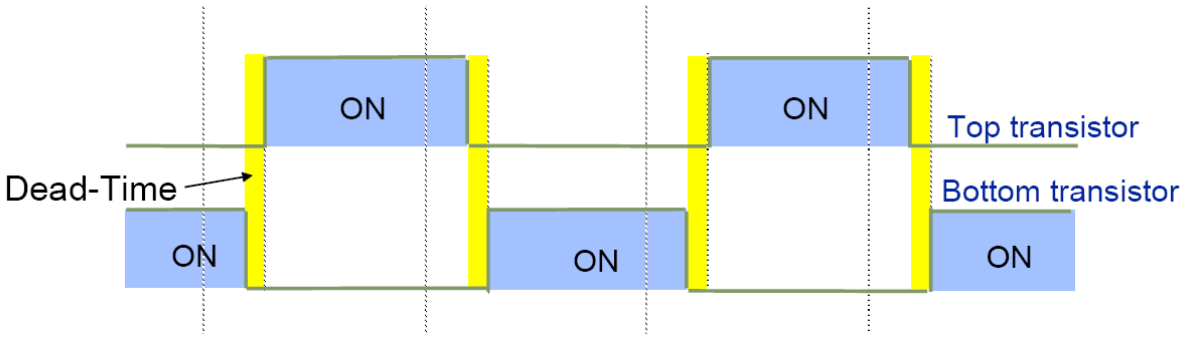
- This motor exhibits a smoothly rotating magnetic field where the magnetic gradient of the stator flux is illustrated by the color shading. There is no commutation to cause motor jerking. But how do you create such a smoothly rotating magnetic field?

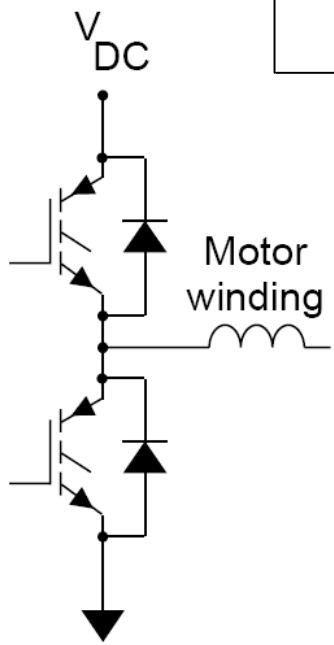


3-Phase AC Voltage Generation on a per Phase Basis

- Each phase is considered a "Half H-Bridge"
- Complementary PWMs are used
- Dead-time is needed to prevent shoot through
- 50% duty cycle → Zero voltage on phase winding







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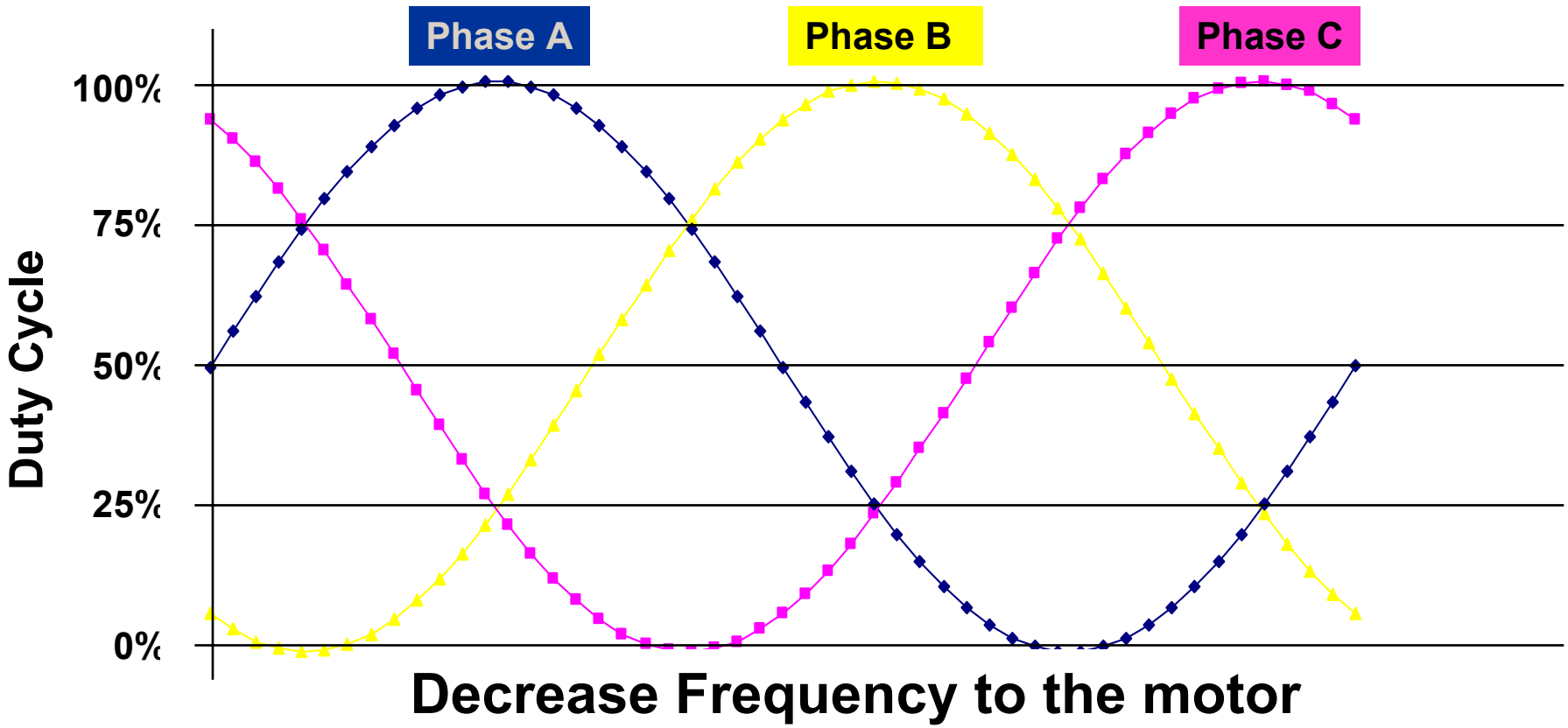
Sinusoidal PWM Generation – ACIM / PMSM



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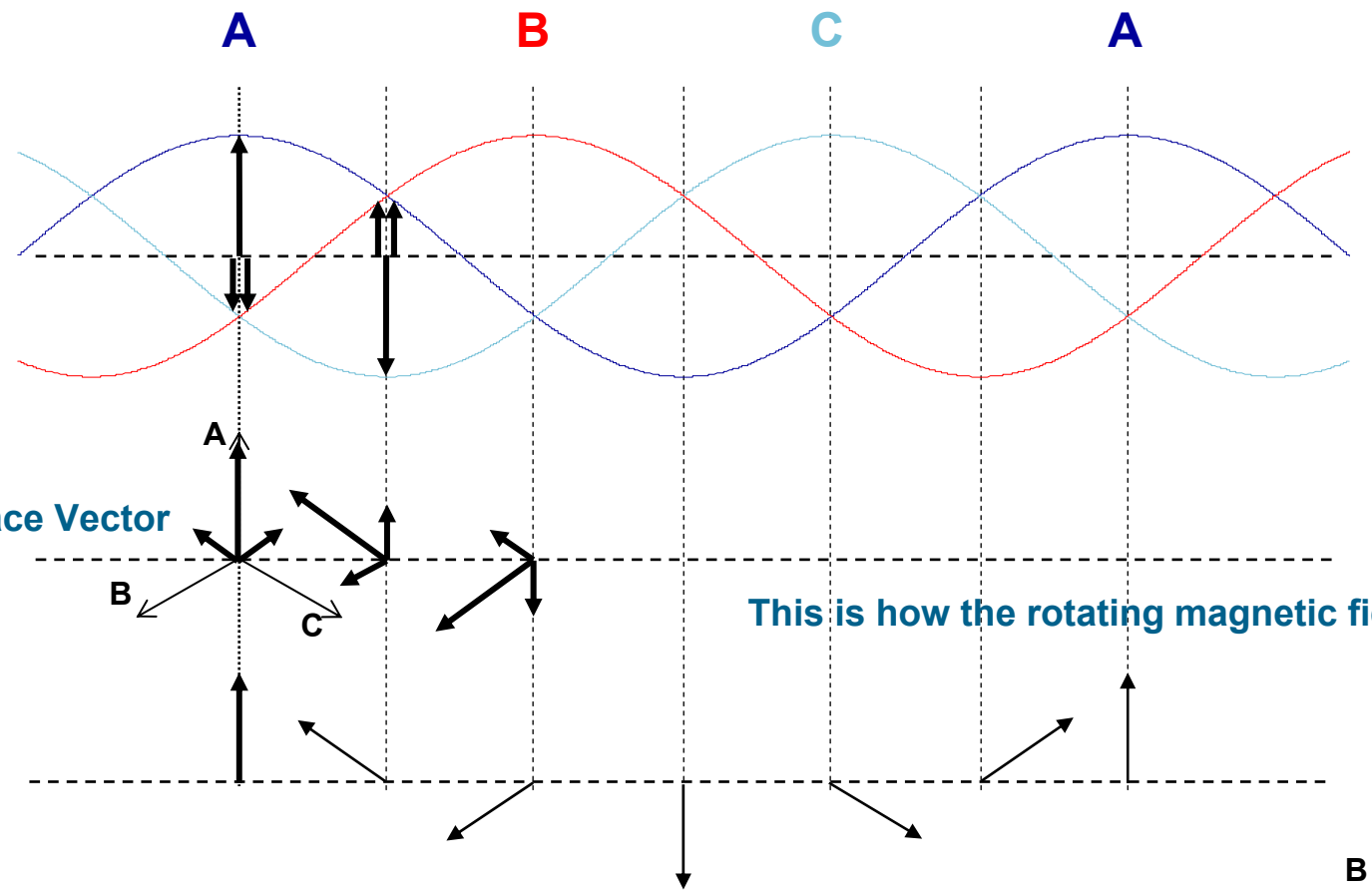
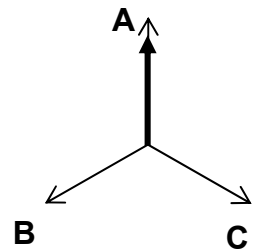
Space Vector Rotation Sequence



Rotating Space Vector

This is how the rotating magnetic field is made



- To reverse rotation direction, swap the connection of any two phases
  ….or sequence the field in the opposite direction

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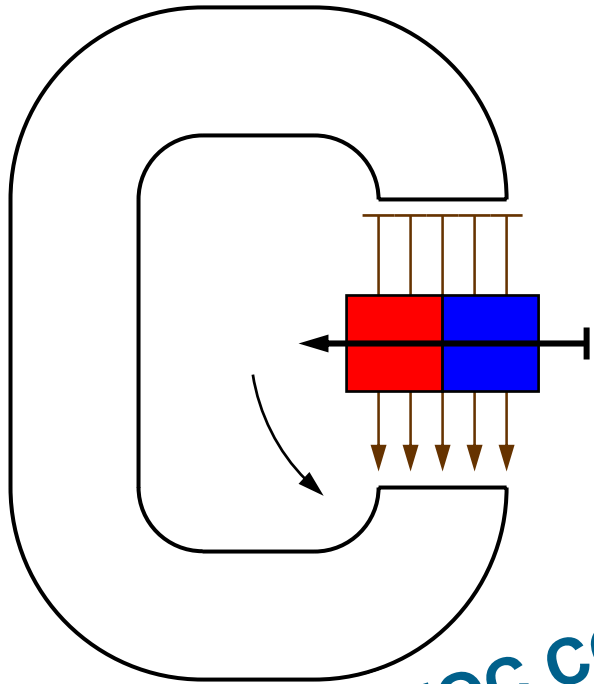
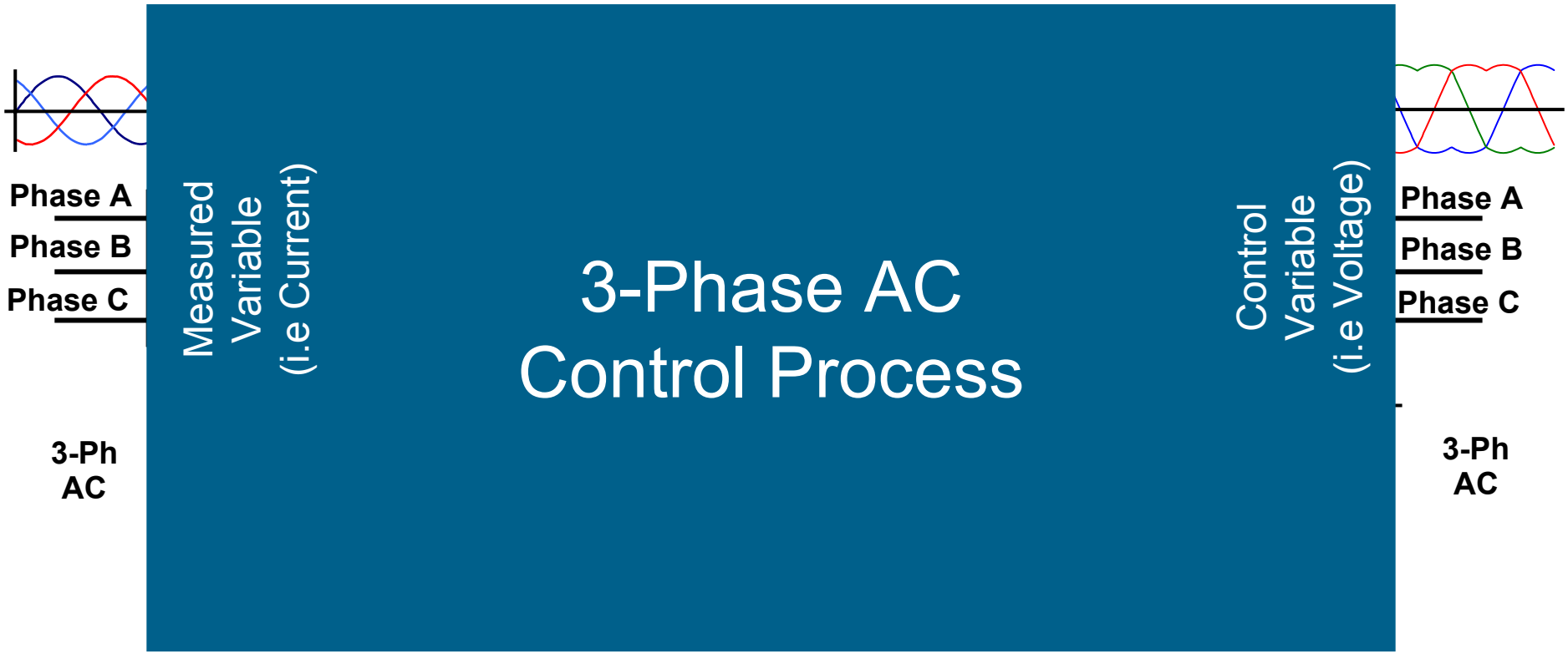
Principle of Field Oriented Control (Vector Control)

- All is about magnetic fields interaction
  - Rotor Magnetic field
  - Stator Magnetic field
- The torque/force is produced when both fields form an non zero angle
- Having the stator magnetic field leading the rotor magnetic field we form an electric motor
- Then FOC is to control the torque
  - By the field angle
  - By strength of the rotor magnetic field
  - By strength of the stator magnetic field



THE FOC CONCEPT IS SIMPLE

How Do We Control a 3-Phase AC Process?



Convert it to a 2-phase DC process!!

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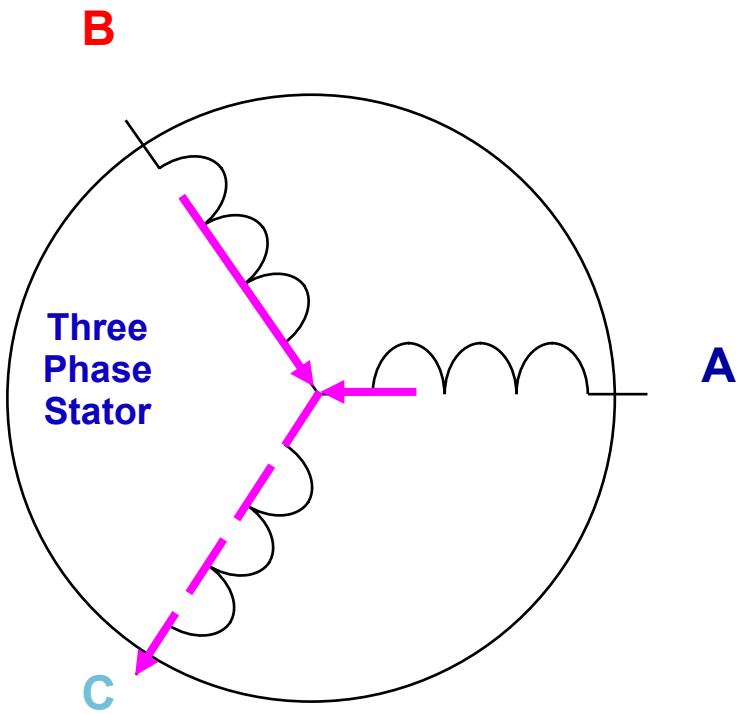
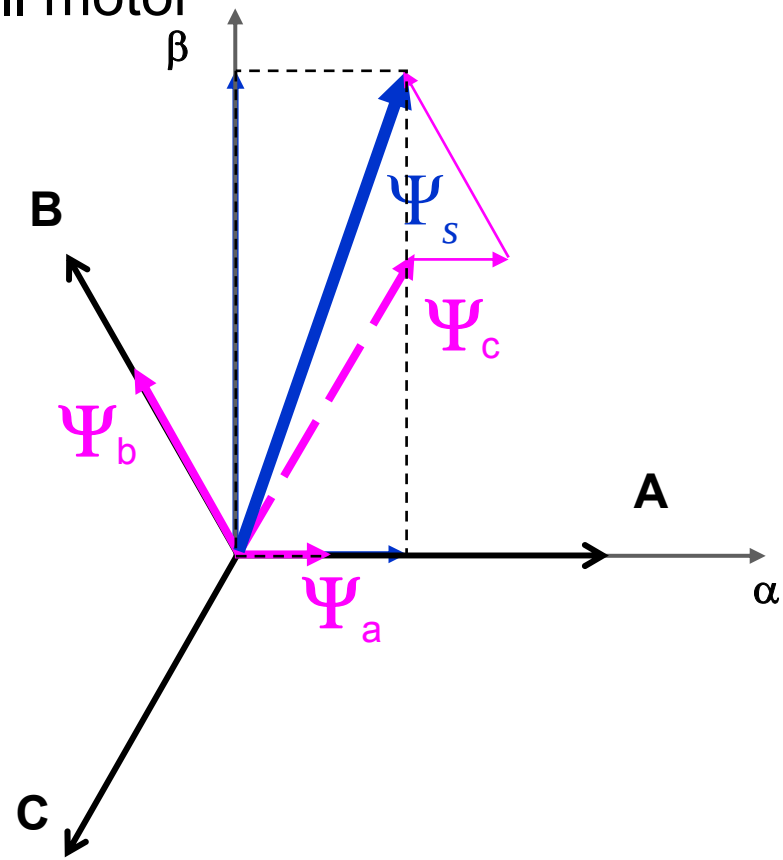
Creating Space Vector – (3ph – 2ph transformation)

- The space-vectors can be defined for all motor quantities





- Because the space vector is defined in the plain (2D), it is sufficient to describe space vector in 2-axis (α,β) coordinate system - some times also 2-phase system

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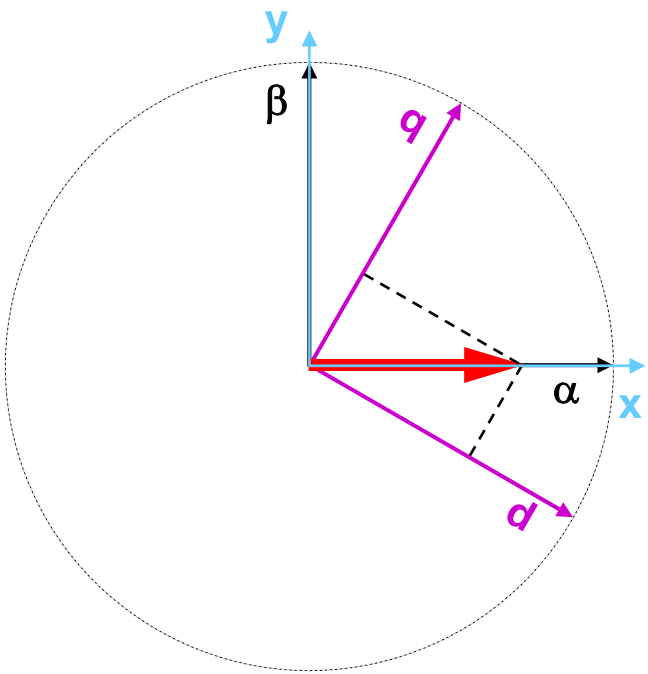
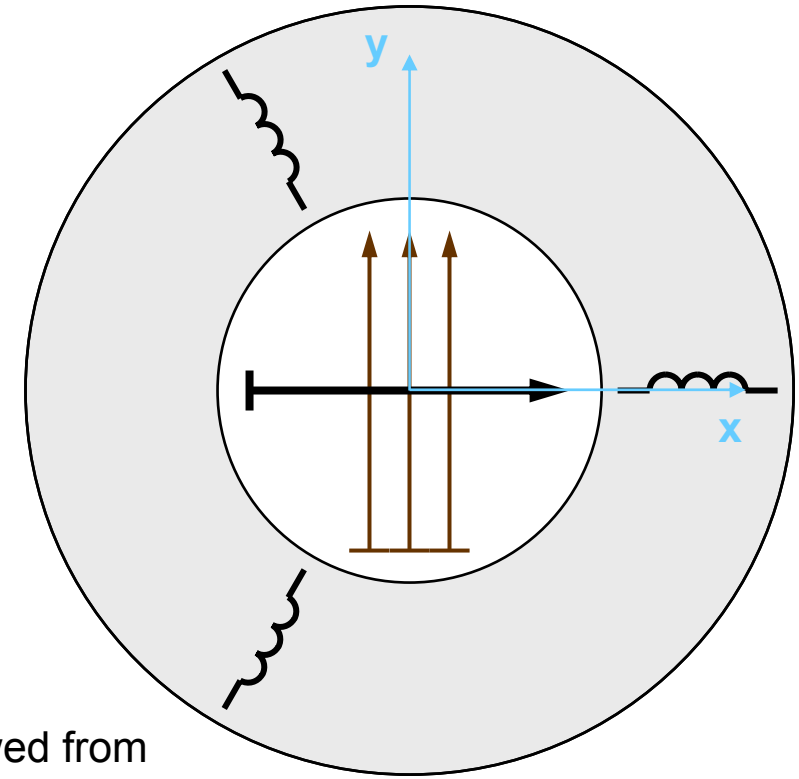
Reference Frames - The “Magic” to Convert AC to DC

- There are the following reference frames
  - Stationary - α, β
  - Rotating rotor speed - d, q





- All rotating quantities are “rectified” when viewed from reference frame that rotates synchronously with rotor

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Controlling the Fields

i_d and i_q are handled independently. Since the comparison is performed in the rotating frame, motor AC frequency is not seen. Thus, they are treated as DC quantities!

ACIM ($i_d \neq 0$)

Commanded i_d is set to induce a field in the rotor.

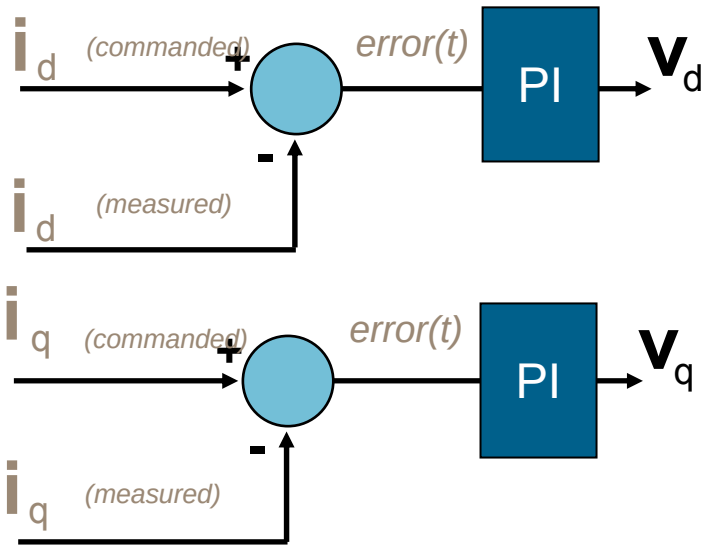
It is typically held constant unless field weakening is desired.

PMSM (id = 0)

Commanded i_d is set to zero since we have all the d-axis flux we need supplied by the permanent magnets in the rotor.

PMSM or ACIM

This is how much torque we want!



i_d can be used to weaken the field in both ACIM and PMSM machines
i_q controls amount of "instantaneous" torque generated by the motor

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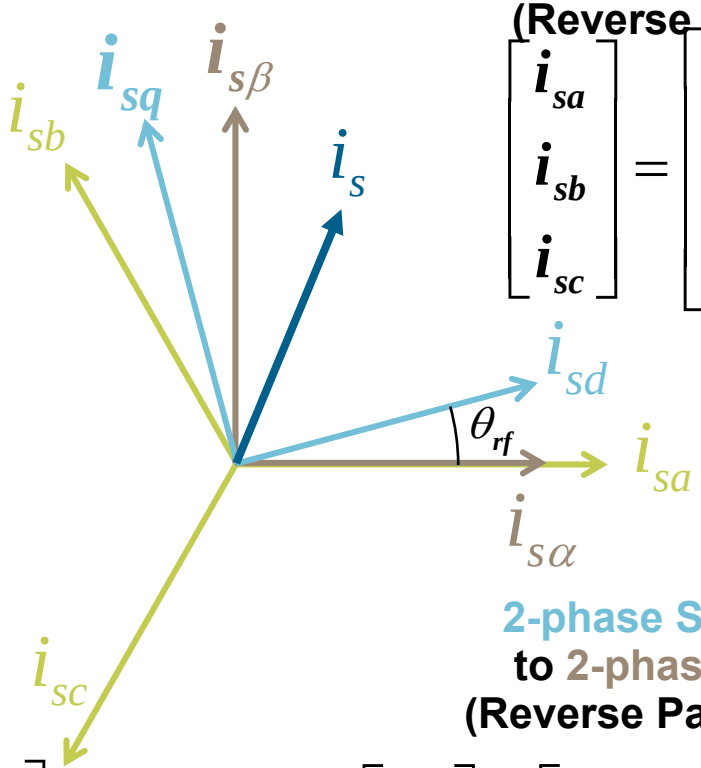
Transformation Calculations

3-phase Stationary to 2-phase Stationary (Forward Clark Transform)

$$\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} = \begin{bmatrix} \frac{3}{2} & 0 & 0 \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix}$$



2-phase Stationary to 3-phase Stationary (Reverse Clark Transform)

$$\begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & 0 \\ -\frac{1}{3} & \frac{1}{\sqrt{3}} \\ -\frac{1}{3} & -\frac{1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix}$$

2-phase Stationary to 2-phase Synchronous (Forward Park Transform)

$$\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = \begin{bmatrix} \cos\theta_{rf} & \sin\theta_{rf} \\ -\sin\theta_{rf} & \cos\theta_{rf} \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix}$$

2-phase Synchronous to 2-phase Stationary (Reverse Park Transform)

$$\begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} = \begin{bmatrix} \cos\theta_{rf} & -\sin\theta_{rf} \\ \sin\theta_{rf} & \cos\theta_{rf} \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix}$$

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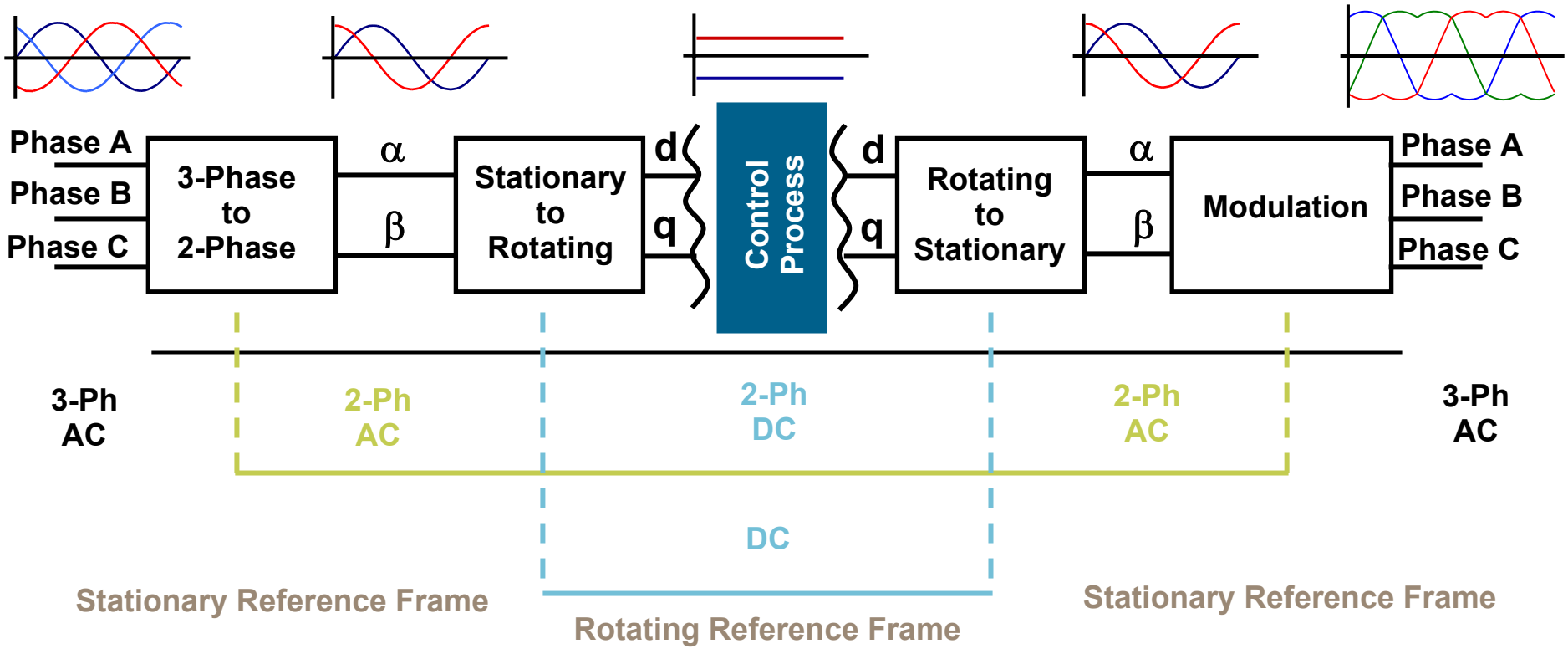
FOC Transformation Summary



ALL of these operations can be done on the 8300 family in about 20 uS!

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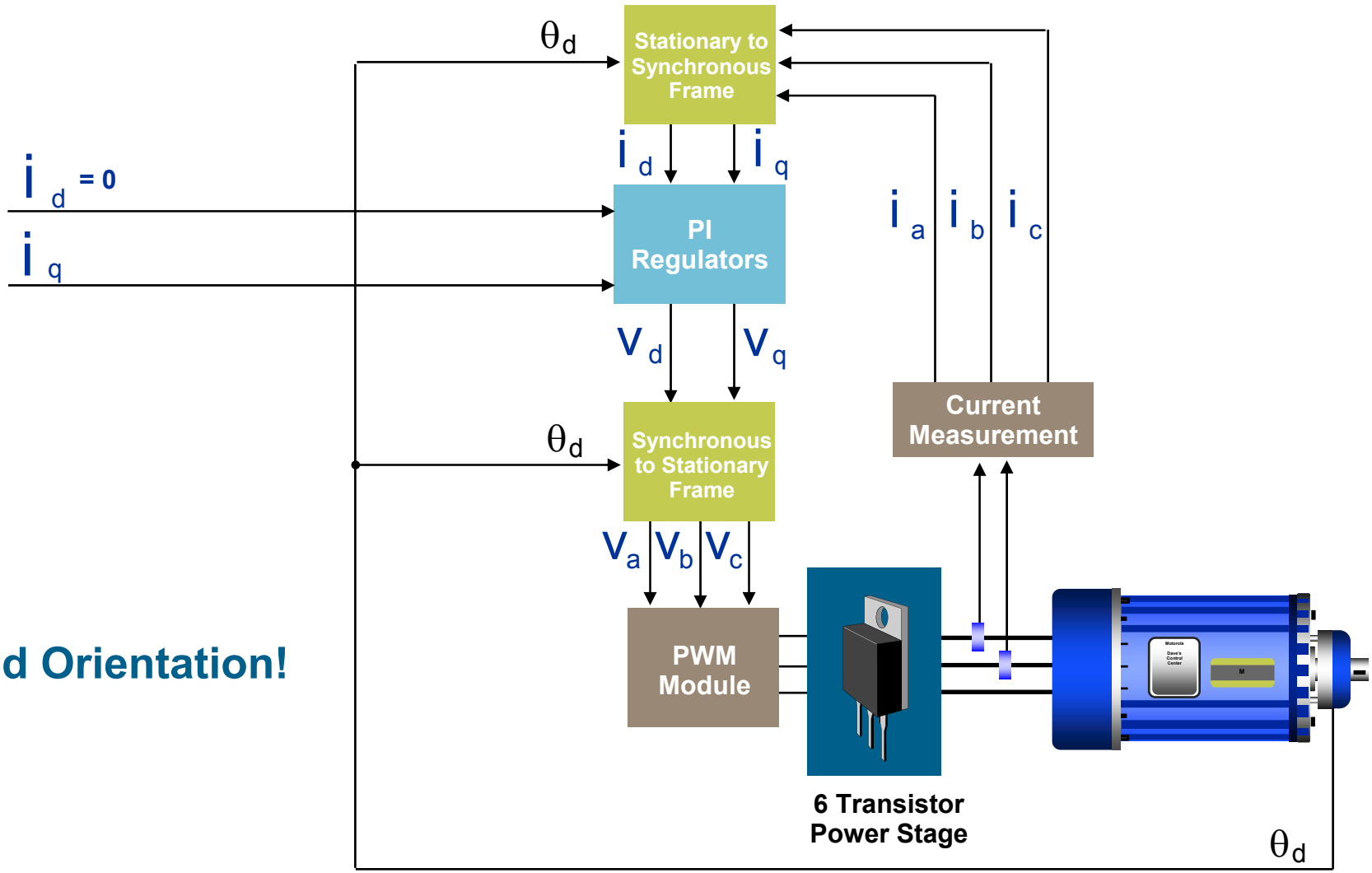
Put It All Together



Field Orientation!

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How Do We Know Where The Rotor is?

- Hall Effect Sensors
- Resolvers
- Quadrature Encoders
- Speed Sensors
- Sensor-less Techniques

Brushless DC vs PMSM Motor Control Summary

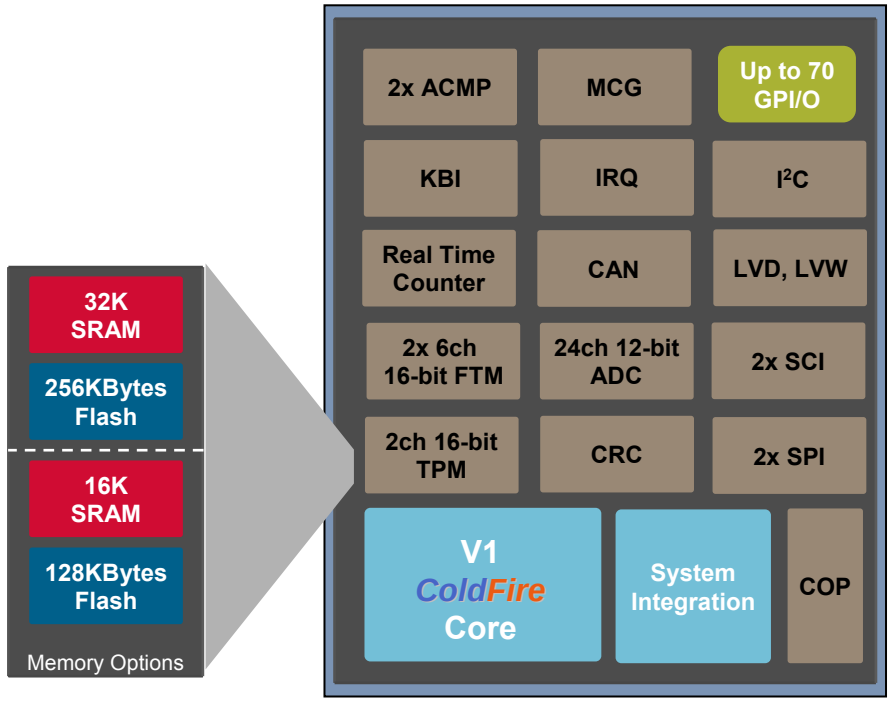
- Six step control versus sinusoidal control

Six step (BLDC) control	Sinusoidal (PMSM) control
+ Simple PWM generation	– More complex PWM generation (sinewave has to be generated)
– Ripple in the torque (stator flux jumps by 60°)	+ Smooth torque (stator flux rotates fluently)
– A little noise operation (due to ripple in the torque)	+ Very quite
+ Simple sensor (i.e Hall sensor)	– Requires sensor with high resolution

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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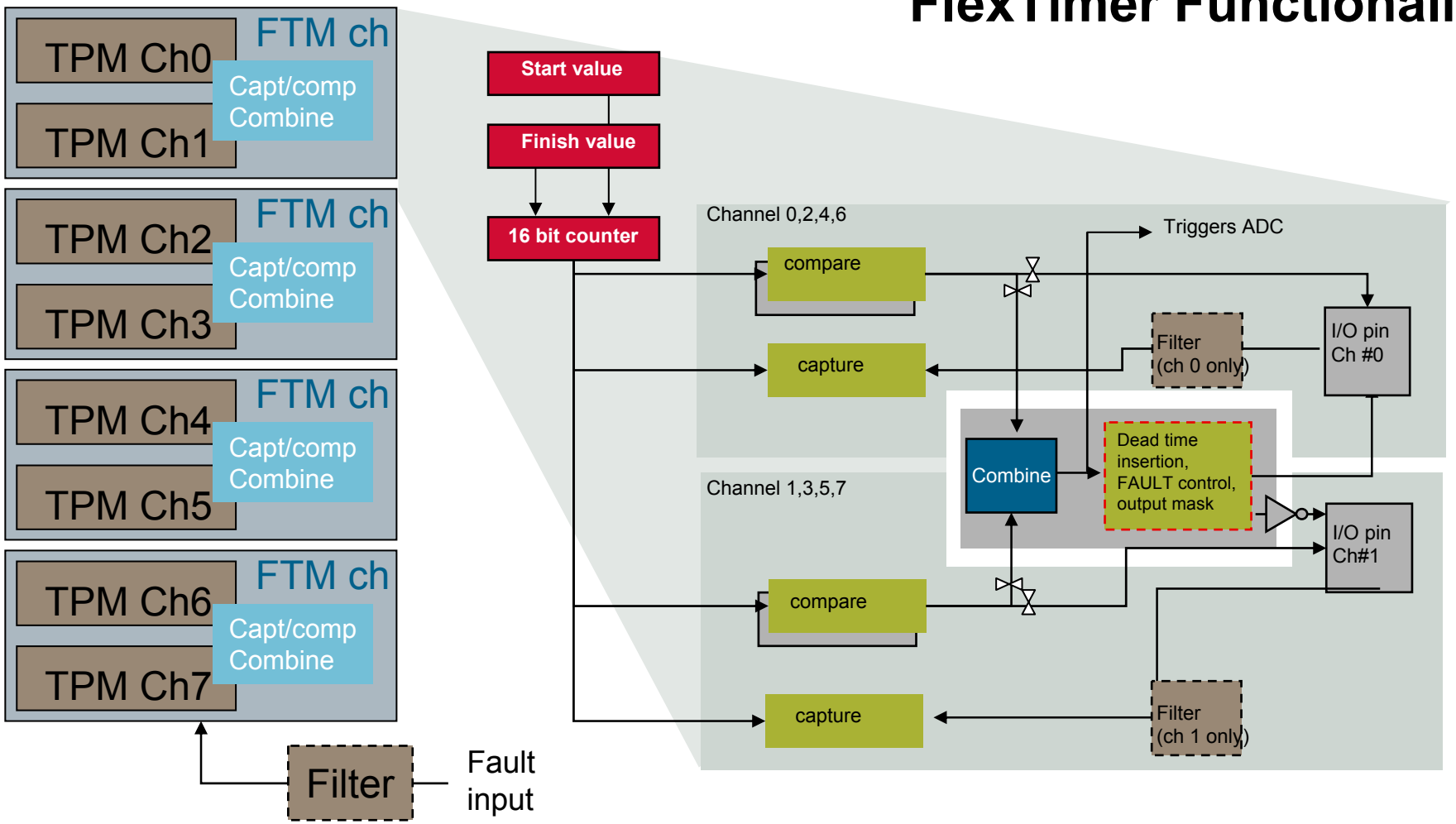
FTM Features Improve TPM for Motor Control

Additional (configurable) FTM Features:

- 16-bits of resolution for center, edge aligned and asymmetrical PWMs at maximum timer input clock speed
- PWM outputs can operate as complimentary pairs or independent channels
- Counter has a start and stop value to allow signed PWM generation
- Independent control of both edges of each PWM output
- Double buffered PWM registers
- Software definable dead time insertion post PWM edge generation
- Synchronized PWM load across all FTM channels
- Optional reset of counter from an on-board comparator
- Synchronization to external hardware or other PWM supported
- ADC trigger events can be generated per PWM cycle via hardware including counter reload
- Low pass filter for selected input capture channels
- Channels not used for PWM generation can be used for buffered output compare functions
- 4 fault inputs for global fault control with built in filter
- Fault control independently for up to 8 channels with predefined output
- Optional automatic clearing of fault condition
- Mask output function control for BLDC motor control with optional immediate new PWM period start
- Predefined output state for toggle function
- Write protection for critical registers
- ***Backwards compatible with the TPM***

The FlexTimer develops the TPM architecture to better support motor control.

FlexTimer Functionality



- Combine adjacent TPM channels >>> paired dual edge control PWM

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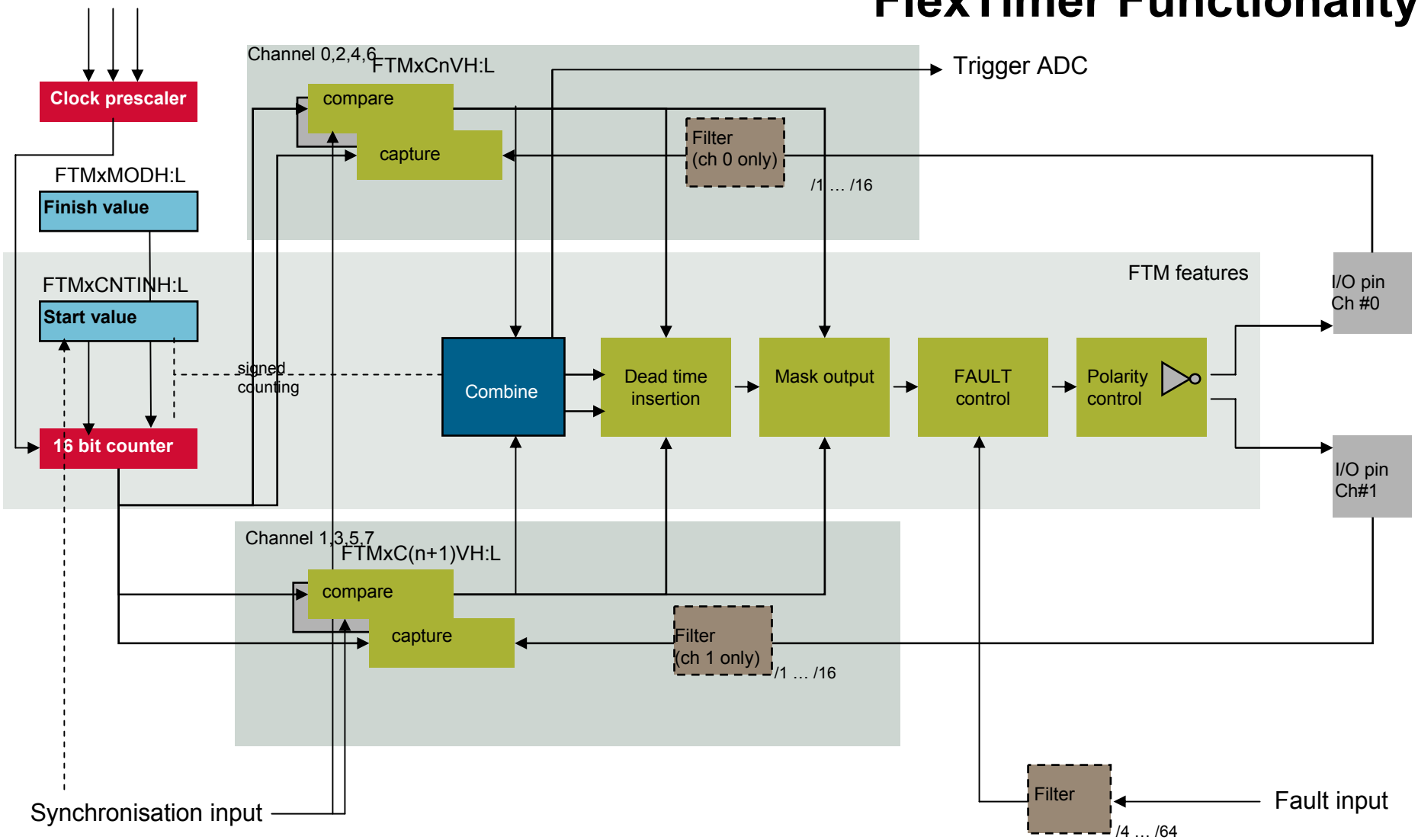
FlexTimer Functionality



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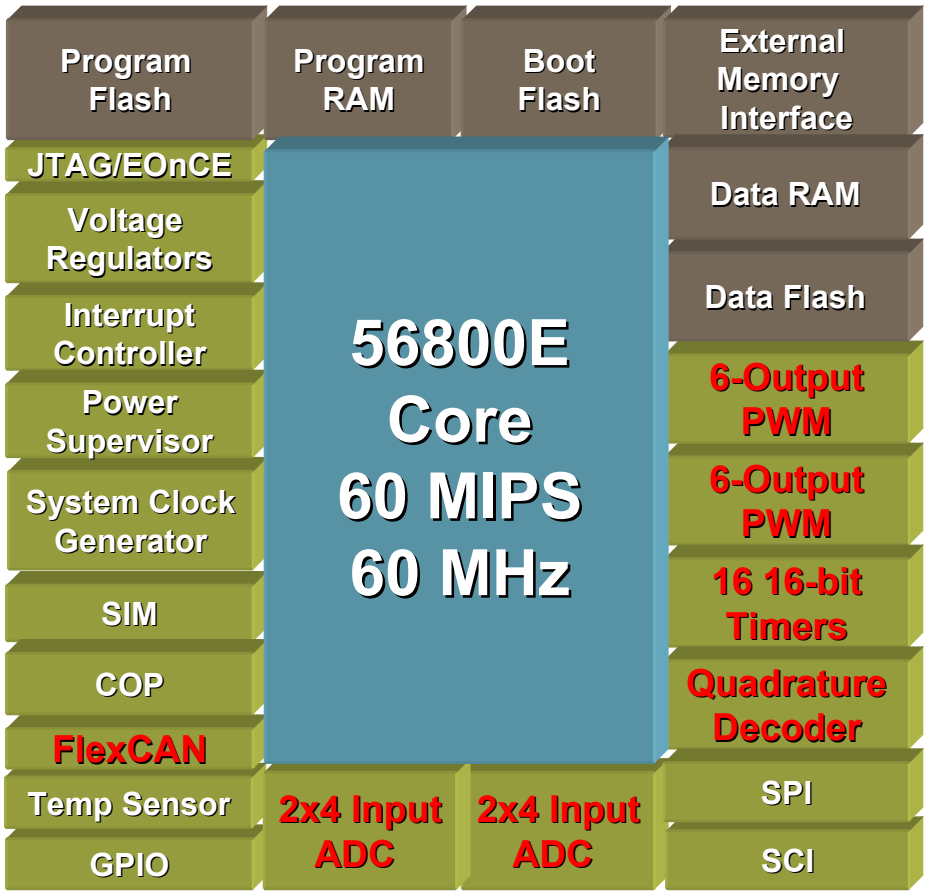
High Performance 56F8300 Solutions
56F836x/56F835x/56F834x/56F832x 60MHz/60MIPS



Packages: 48/64/128/144/160LQFP and 160 MBGA

Derivatives: 23 devices

Key Control Peripherals

- **60 MIPS Performance**
- Program Memory
  - Up to 512Kbytes FLASH
  - Up to 4Kbytes RAM
  - Up to 32Kbytes BootFLASH ™
- Data Memory
  - Up to 32Kbytes FLASH
  - Up to 32Kbytes RAM
- Serial Ports: SCIs and SPIs, **CANs**
- **Quad, 4 channel, 12-bit ADC**
- **Dual 6-Output PWM Modules**
- **Synchronization between PWM and ADC**
- **Up to Sixteen multifunction 16-bit Timers**
- External Memory Interface
- COP/Watchdog Timer
- Up to 76 GPIO – Versatile pin usage
- System Clock Generator
- On-chip temperature sensor
- On-chip Voltage Regulator and Power Supervisor
- Vectored Interrupt Controller
- JTAG/OnCE™ Debug Port

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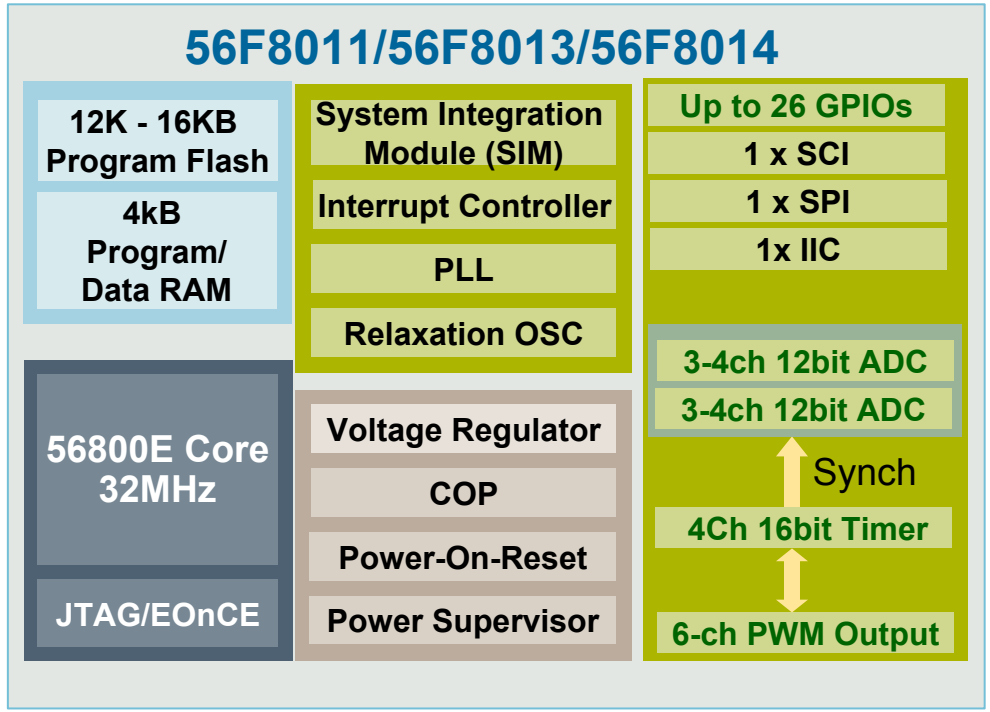
Cost Effective 56F8000 Solutions - 56F8011/56F8013/56F8014

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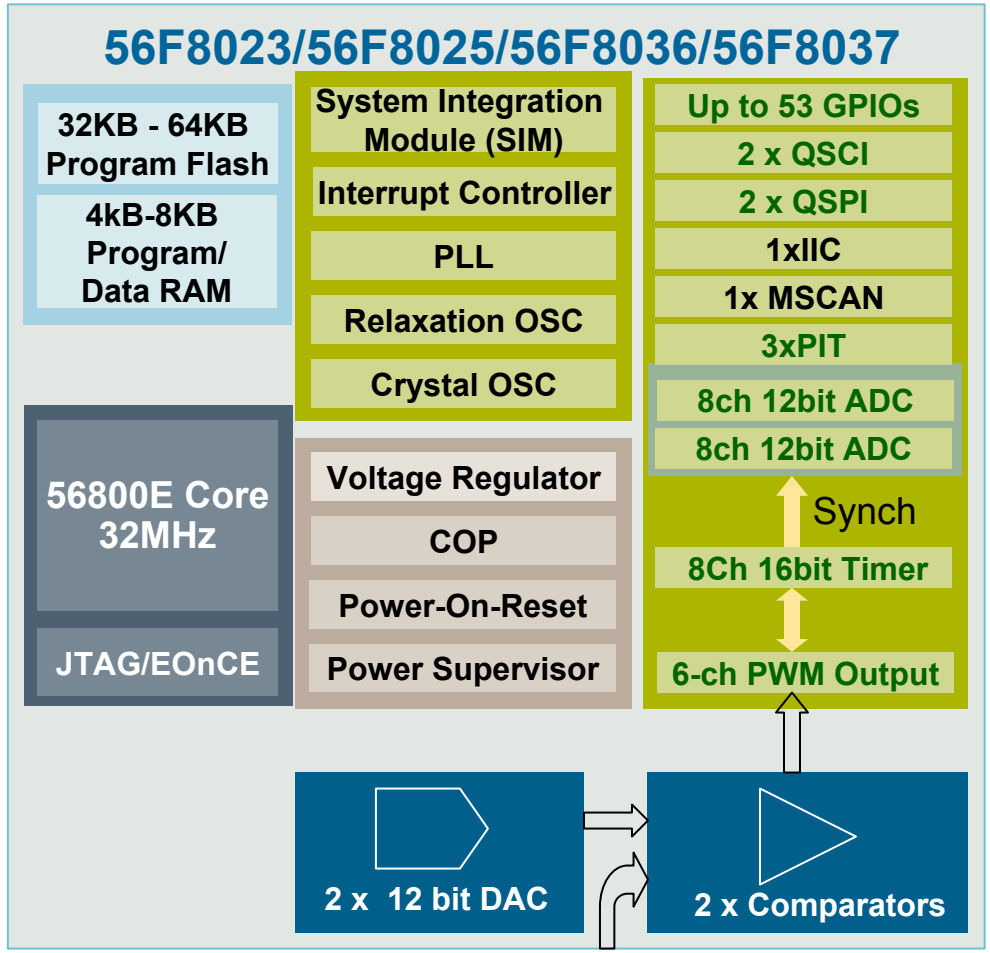
56F8000 Family Expansion - 56F8023/56F8025/56F8036/56F8037

- **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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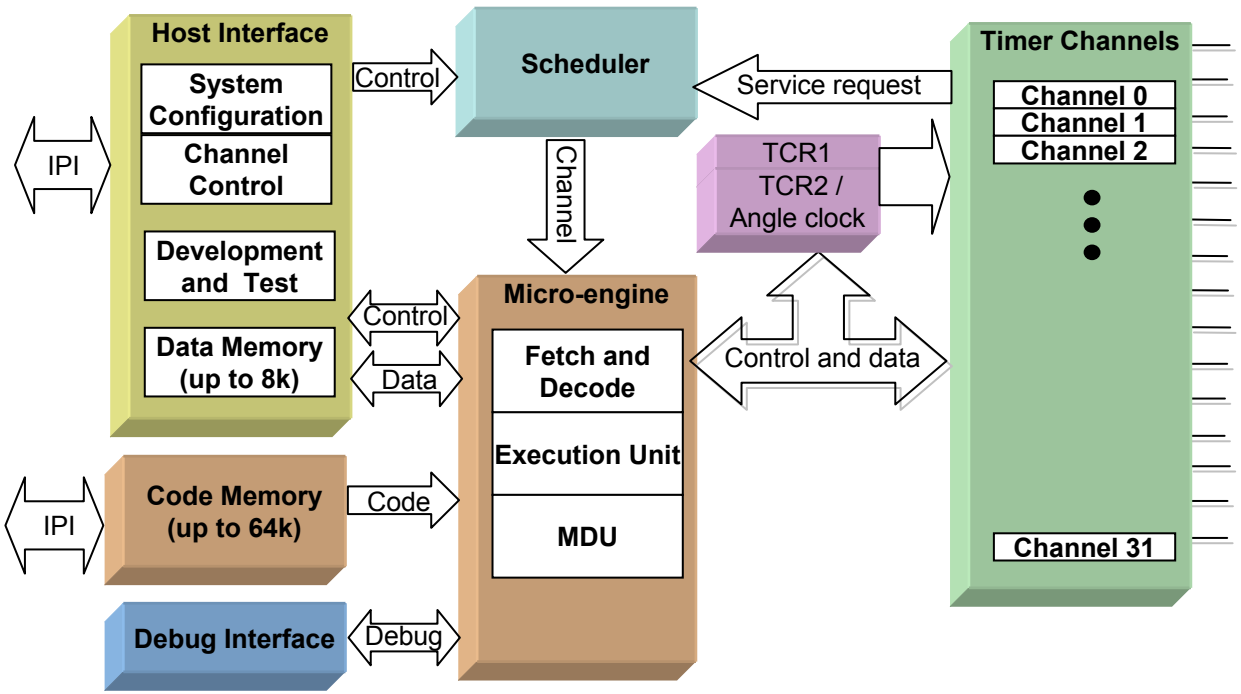
Motor Control with the eTPU?

The (e)*enhanced (T)time (P)processor (U)unit* is a programmable I/O controller with it's own core and memory system, allowing it to perform complex timing and I/O management *independently* of the CPU. The eTPU is essentially a microcontroller all by itself!



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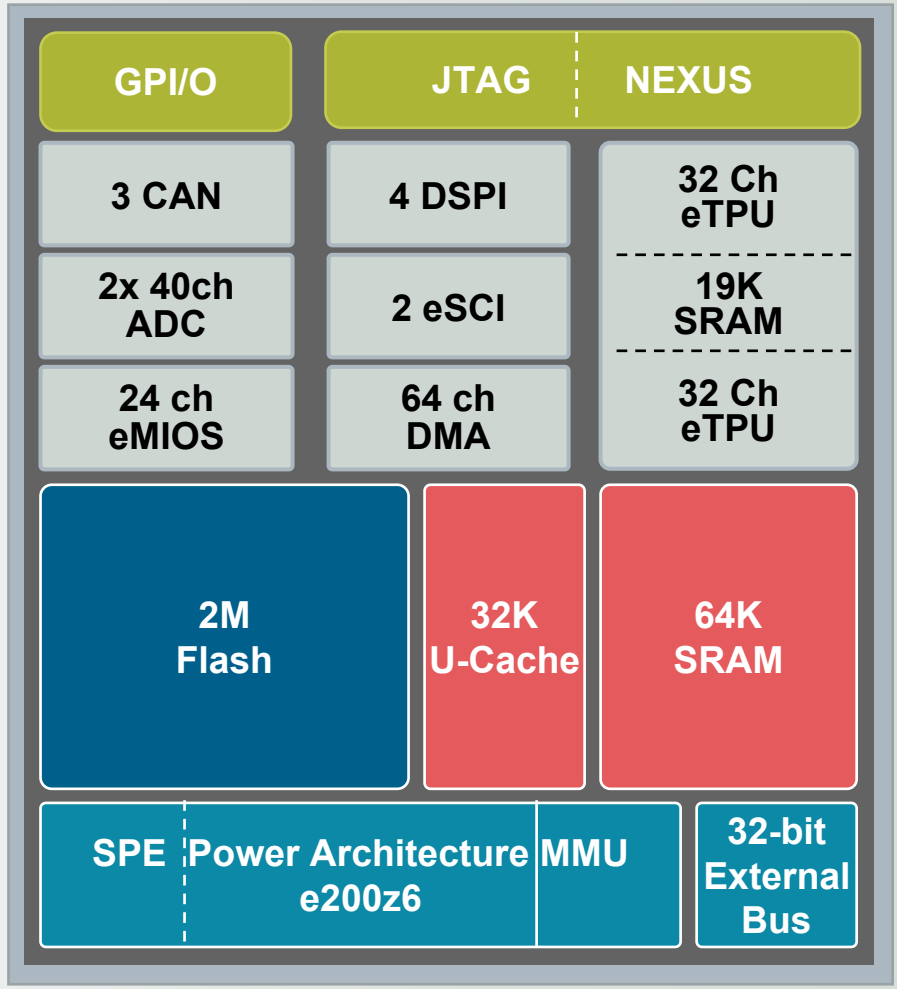
MPC5554

- **Power Architecture™ Technology e200z6 Core**
  - **132MHz performance**
  - SPE (signal processing extension): DSP, SIMD and floating point capabilities
  - Memory Management Unit (MMU)
- **Memory**
  - 2Mbyte RWW Flash with ECC
  - 64k SRAM (including 32K with standby) with ECC
  - 32k unified-cache (with line locking)
- **eTPU**
  - **2 x 32 I/O channels**
  - 19k designated SRAM (16k code & 3k parameters)
- **I/O**
  - 24 channel EMIOS with unified channels
  - 3 x CAN - 64 buffers each
  - 2 x eSCI
  - 4 x DSPI 16 bits wide up to 6 chip selects each
  - **40 channel dual ADC - up to 12 bit resolution and up to 1.25µs conversions, 6 queues with triggering and DMA support.**
- **System**
  - FM-PLL
  - 64 Channel DMA Controller
  - 300 Source Interrupt Controller
  - Nexus IEEE-ISTO 5001-2003 Class 3+
  - MPC500 compatible External Bus Interface
  - 5/3.3V IO, 5V ADC, 3.3V/1.8V bus, 1.5V core
  - **416 PBGA package**
  - Temperature Range: -40 to 125ºC



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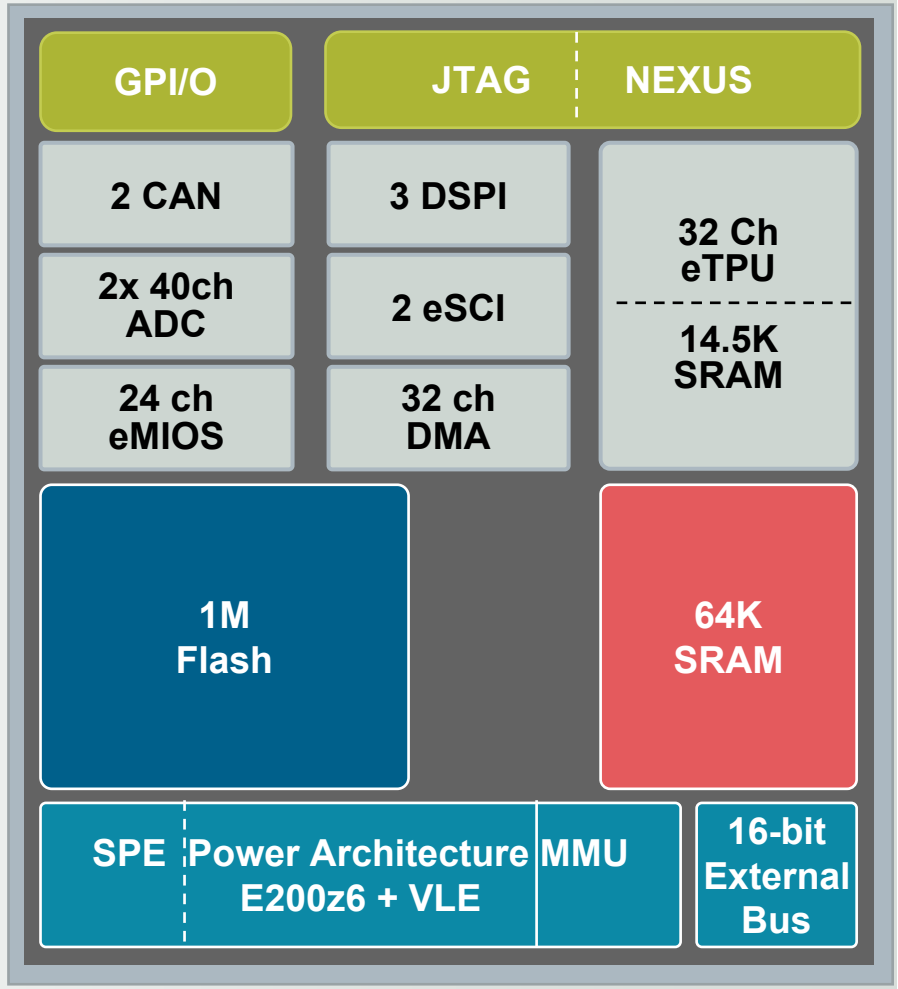
MPC5534

- **Power Architecture™ Technology e200z3 Core + VLE**
  - **80MHz performance with Variable Length Encoding (VLE)**
  - SPE (signal processing extension): DSP, SIMD and floating point capabilities
  - Binary User mode compatible with RCPU (MPC500) and e200z6
  - Memory Management Unit (MMU)
- **Memory**
  - 1Mbyte RWW Flash with ECC
  - 64k SRAM (including 32K with standby) with ECC
- **eTPU**
  - **1 x 32 I/O channels**
  - 14.5k designated SRAM (12k code & 2.5k parameters)
- **I/O**
  - 24 channel EMIOS with unified channels
  - **2 x CAN - 64 buffers each**
  - 2 x eSCI
  - 3 x DSPI 16 bits wide up to 6 chip selects each
  - **40 channel dual ADC - up to 12 bit and up to 1.25µs conversions, 6 queues with triggering and DMA support**.
- **System**
  - FM-PLL
  - **32 Channel DMA Controller**
  - 210 Source Interrupt Controller
  - Nexus IEEE-ISTO 5001-2003 Class 3+
  - MPC500 compatible External Bus Interface
  - 5/3.3V IO, 5V ADC, 3.3V/1.8V bus, 1.5V core
  - **324 PBGA package (36 ADC)**
  - Temperature Range: -40 to 125ºC



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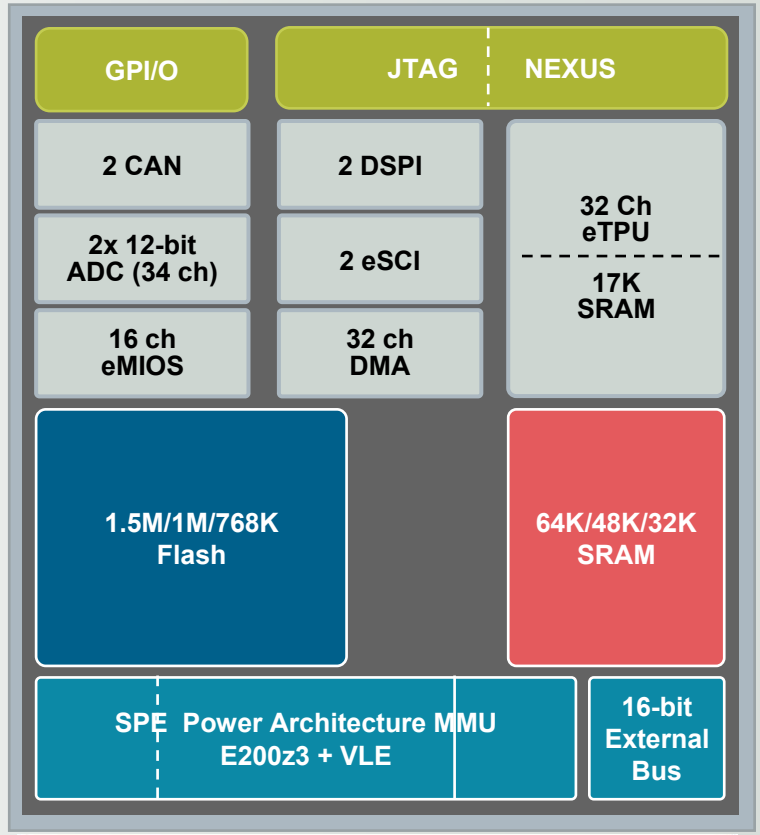
Powertrain Product Families Currently In Production

Device	MPC5533	MPC5534	MPC5553	MPC5554	MPC5565	MPC5566	MPC5567
Core Platform	Power e200z3	Power e200z3	Power e200z6	Power e200z6	Power e200z6	Power e200z6	Power e200z6
Program Flash	768 KB	1 MB	1.5 MB	2 MB	2 MB	3 MB	2MB
SRAM	48 KB	64 KB	64 KB	64 KB	80 KB	128 KB	80 KB
DMA	32 Ch	32 Ch	32 Ch	64 Ch	32 Ch	64 Ch	32 Ch
EEPROM	Emulated in program Flash	Emulated in program Flash	Emulated in program Flash	Emulated in program Flash	Emulated in program Flash	Emulated in program Flash	Emulated in program Flash
eSCI	1	2	2	2	2	2	2
DSPI	2	3	3	4	3	4	3
CAN	2	2	2	3	3	4	5
Flexray							✓
Ethernet (100BaseT)			✓			✓	✓
MLB							emulated via eTPU
External Bus	✓	✓	✓	✓	✓	✓	✓
Nexus	3	3	3	3	3	3	3
ETPU	32-Ch.,	32-Ch.,	32-Ch.,	2x32-Ch.,	32-Ch.,	2x32-Ch.,	32-Ch.,
eMIOS		24-Ch., 24-bit	24-Ch., 24-bit	24-Ch., 24-bit	24-Ch., 24-bit	24-Ch., 24-bit	24-Ch., 24-bit
GPIO	192	192	220	256	192	256	238
ADC	40-Ch., 1 x 12-bit	40-Ch., 1 x 12-bit	40-Ch., 1 x 12-bit	40-Ch., 1 x 12-bit	40-Ch., 1 x 12-bit	40-Ch., 1 x 12-bit	40-Ch., 1 x 12-bit
Voltage	3.3V & 5V	3.3V & 5V	3.3V & 5V	3.3V & 5V	3.3V & 5V	3.3V & 5V	3.3V & 5V
Temp. Range	M	M	M	M	M	C,M	C,M
Frequency Range	40-80MHz	40-80MHz	80-132MHz	80-132MHz	80-132MHz	80-132MHz	80-132MHz
Package Options	208 MAPBGA, 324 PBGA	208 MAPBGA, 324 PBGA	208 MAPBGA, 324 PBGA, 416 PBGA	416 PBGA	324 PBGA	416 PBGA	324 PBGA, 416 PBGA

MPC563x

- **Power Architecture Technology e200z3 Core + VLE**
  - **80MHz performance with Variable Length Encoding (VLE)**
  - SPE (signal processing extension): DSP, SIMD and floating point capabilities
  - Binary User mode compatible with RCPU (MPC500) and e200z6
  - Memory Management Unit (MMU)
- **Memory**
  - Family includes 768 KB, 1 MB and 1.5 MB flash memory options with ECC
  - Up to 81 KB SRAM
- **eTPU**
  - **1 x 32 I/O channels**
  - 17k designated SRAM (14k code & 3k parameters)
- **I/O**
  - 24 channel EMIOS with unified channels
  - **2 x FlexCAN compatible with TouCAN, 64 + 32 buffers**
  - 2 x eSCI
  - 2 x DSPI 16 bits wide up to 6 chip selects each
  - **Up to 34-channel dual analog-to-digital converter (ADC) with differential channels and input variable gain amplifiers.**
  - Die temperature sensor
- **System**
  - FM-PLL
  - **32 Channel DMA Controller**
  - 196 Source Interrupt Controller
  - Nexus IEEE-ISTO 5001-2003 Class 2+ (eTPU2 Class 1)
  - MPC500 compatible External Bus Interface
  - **Single 5V supply**
  - **100 LQFP, 144 LQFP, 176 LQFP, 208 MAPBGA and VertiCal Calibration System package options**
  - Temperature Range: -40 to 125ºC



Selector Guide

Product	Frequency Options	Flash	RAM	eTPU2	eMIOS	ADC	Package Options
MPC5634M	40 MHz, 60 MHz, 80 MHz	1.5 MB	64K	1 x 32-ch.	1 x 16-ch.	34-ch. dual 12-bit	144 LQFP, 176 LQFP, 208 MAPBGA
MPC5633M	40 MHz, 60 MHz, 80 MHz	1 MB	48K	1 x 32-ch.	1 x 16-ch.	32-ch. dual 12-bit	100 LQFP, 144 LQFP, 176 LQFP, 208 MAPBGA
MPC5632M	40 MHz, 60 MHz	768K	32K	1 x 32-ch.	1 x 8-ch.	32-ch. dual 12-bit	100 LQFP, 144 LQFP

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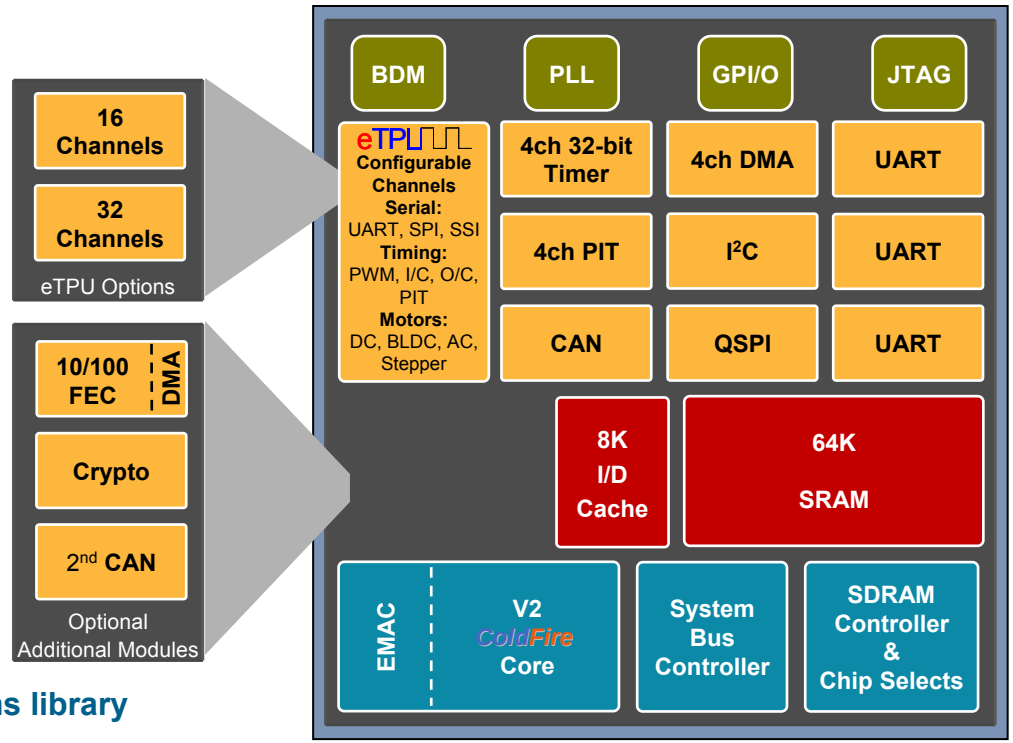
68K/ColdFire V2 Core

- **Up to 144 Dhrystone 2.1 MIPS @ 150 MHz**
- Enhanced MAC Module and HW Divide
- **150/75, 100/50, and 80/40 MHz core/bus speed grades**
- 8K bytes I/D-Cache
- 64K bytes SRAM
- **Optional 10/100 Ethernet MAC (external PHY)**
- Optional Hardware Accelerated Encryption
  - Random Number Generator
  - DES, 3DES, AES, Block Cipher Engine
  - MD5, SHA-1, HMAC, Hash Accelerator
- **CAN 2.0B Controller**
- 3 UARTs (optional 2nd CAN muxed with UART3)
- Queued Serial Peripheral Interface (QSPI)
- I²C bus interface
- 32-bit non-multiplexed data bus with 8 Chip Selects
  - Chip select support for paged mode flash memories
- **16 or 32 ch. Enhanced Time Processing Unit (eTPU)**
  - **Programmable I/O system supported by a functions library**
- 4 ch. 32-bit timers with DMA support
- 4 ch. Periodic Interrupt Timer
- 4 ch. DMA controller
- **SDRAM Controller**
- Up to 113 General-Purpose I/O
- System Integration (PLL, SW Watchdog)
- 1.5V Core, 3.3V I/O
- Temperature Range: -40°C to +85°C



Part Number	eTPU	10/100 FEC	Crypto	CAN	Speeds MHz	Packages	
MCF5235	16 ch	Yes	Yes	2	100, 150	256 MAPBGA	
MCF5234	16 ch	Yes	No	1	100, 150	256 MAPBGA	
MCF5233	32 ch	No	No	2	100, 150	256 MAPBGA	
MCF5232	16 ch	No	No	1	80 100, 150	160 QFP 196 MAPBGA	

Updated: 14 Apr 06

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Industrial Applications for Electric Motors

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Motor Control Example Devices

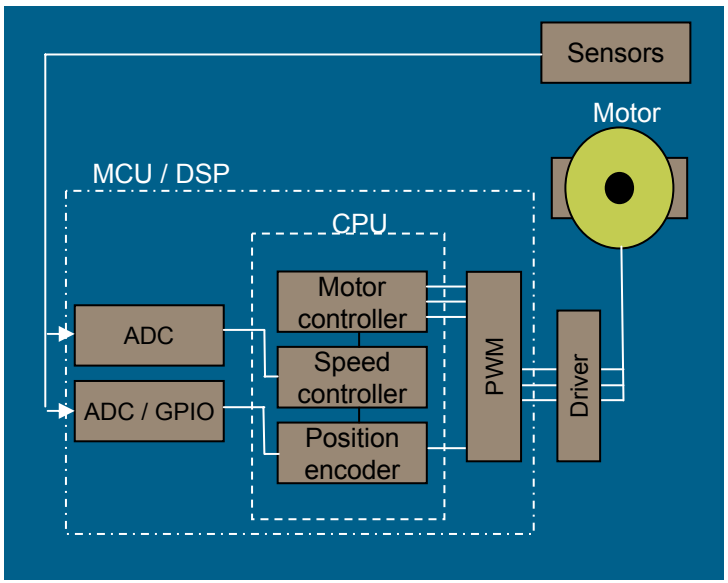
The DSC Family and ColdFire Family of Products

Motor Control Peripherals: PWM, ADC, Quadrature Decoder and eTPU

Connectivity: SCI, CAN, I2C, SPI

Performance: S08 6MIPs, DSC up to 60 MIPS, ColdFire up to 266MHz

Software Support: Motor Control Libraries, Low-level peripheral drivers provided by application experts, Free Master Monitoring Software, eTPU Software Libraries



Feature	9S08MP16	MC56F8037	MCF5232
Core / MIPS	S08 core, 6MIPS	56800E Core, 32MIPS	ColdFire V2, 144MIPS
Program Flash/Ram	16kB flash	64kB/0kB	MPU
Data Flash/Ram	1kB RAM	0kB/8kB	72Kb
QuadTimers/PIT	FTM 6+2 channels	2x4ch/3ch	4ch
PWMs	8 @ 50MHz	6ch @ 96MHz	16 Channel eTPU
12-Bit A/D	12 ch / 0.3M SPS	2x8ch/1.78MSPS	16 Channel eTPU
12-Bit DAC	none	2ch	16 Channel eTPU
SCI/QSCI	1 / 1 (SPI)	0/2	3 UART
CAN	0	1	1
I2C	1	1	1
I/O Pins	40	53	113
Package	48 pin LQFP, 32 pin LQFP 28 Pin PDIP, 28 pin SOIC	64-LQFP	160QFP
SRP @ 10K	$2.00	$4.11	$10.00

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Networked Actuators and Sensors

- Communications, I/O, ADC and Motor Control PWM capabilities are needed in these applications, and in the majority of applications medium performance. Support for industrial busses such as CAN and Ethernet are also essential making the Coldfire® V1 and V2 parts ideal products

Segment	Increasing Performance Requirement →		
Networked Actuators and Sensors	S08	Coldfire	Coldfire

Networked Actuators and Sensors example devices

The ColdFire Family of Products

Connectivity: 10/100 Ethernet MAC + PHY, CAN, I2C, SPI, SCI

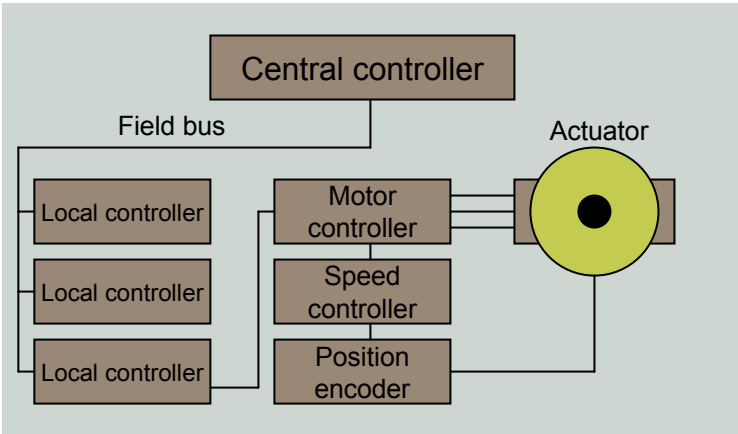
Performance: up to 80MHz

Software Support: TCP/IP Stack, USB Stack

Field Bus Support: via 3rd party software provided by IXXAT and Port

The S08DZ Family of Products

Highly integrated, Scalable solutions, from 32 to 64pin, with CAN, I2C, SPI, SCI



Feature	S08DZxxx	MCF52232	MCF52231
Core	S08 CPU 20MHz @ 5V	ColdFire V2, 50MHz	Coldfire V2, 60MHz
Flash	16Kb – 60Kb	128Kb	128Kb
RAM	1Kb – 4Kb	32Kb	32Kb
Ethernet	No	MAC + PHY	MAC + PHY
CAN	1	No	1
Timer	2 x 16-bit	4 x 32 bit, 4 x 16bit	4 x 32-bit, 4 x 16bit
USB	No	No	no
I/O	Up to 53	Up to 56	up to 55
PWM	See Timer	8/4ch	8/4ch
ADC	24ch, 12-bit	8ch, 12 bit	2 x 4ch 12 bit
SRP @ 10K	$3.36	$5.49	$8.79
Ecosystem			

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Robotics Control

- If we look more to the control aspects rather than the motor drive aspects then connectivity, CAN and Ethernet as well as performance are key factors
- Low to mid end systems can be implemented with Coldfire® with mid to high end systems being based on Power Architecture™
- The trend going forward will be for real time communications with 1588 becoming a necessity. This is available today on high end Power Architecture in hardware and implemented in Software on the Coldfire

Segment	Increasing Performance Requirement →		
Robotics Control	Coldfire	Power	Power

Robotics Control example devices

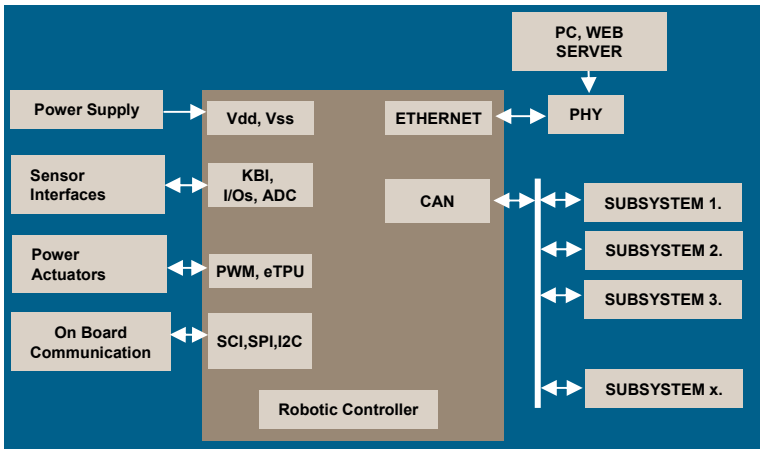
The ColdFire® Family and Power Architecture™ Products

Motor Control Peripherals: PWM, ADC, eTPU

Connectivity: SCI, CAN, I2C, SPI, 10/100 Ethernet MACs

Performance: up to 150MIPS, FPU, MMU

Software Support: eTPU libraries, TCP/IP Stack, µcLinux and Linux OS, IEEE 1588



Feature	MCF5235	MPC5554	MPC8349E
Core	V2 ColdFire / 144MIPS	132 MHz 32-bit PowerPC core	e300 up to 667MHz
Program Flash	no	2MB (ECC correction)	No
Static RAM	64kB	64kB	No
Ext Bus Interface	yes	yes	yes
MMU/FPU	no	yes	Double Precision Float
eTPU/SRAM	64ch/19kB	32ch/17.5kB	NA
10-Bit A/D	no	80ch/800kSPS	No
Timers	4ch - PIT	24ch - EMIOS	Real Time Clock
SCI/SPI/I2C	3xUART/1xQSPI/1ch	4xeSCI/4xDSPI/-	DUART, 2 x I2C, SPI
FlexCAN	2ch	3ch	No
Ethernet MAC	yes	no	2 x up to Gigabit
Package	256-MAPBGA	416-BGA	672 TBGA
SRP @ 10K	$19.78 @ 10k qty	$43.40 @ 10k qty	$42.91 for 400MHz

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Related Session Resources

Session Location – Online Literature Library

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

Sessions

Session ID	Title
PZ107	Motor Control Part 2 - Solutions for Large Appliances and HVAC
PZ106	Motor Control Part 3 - Solutions for Small Appliances and Health Care Applications
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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