FTF FREESCALE TECHNOLOGY FORUM 2014

# Integrated Environment Motor Control

## FTF-IND-F0256

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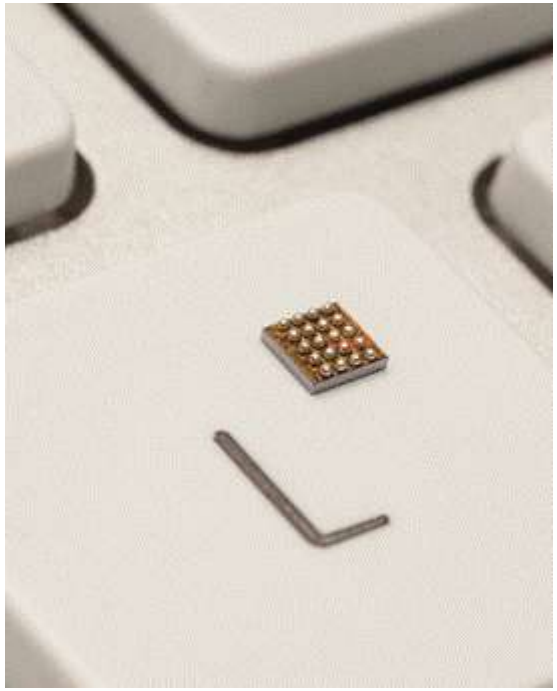
External Use

# Agenda

- Motor Control Introduction
- Motor Control Microcontrollers - DSC and Kinetis V
- Software Development Tools
- Motor Control Enablement

# Motor Control Introduction

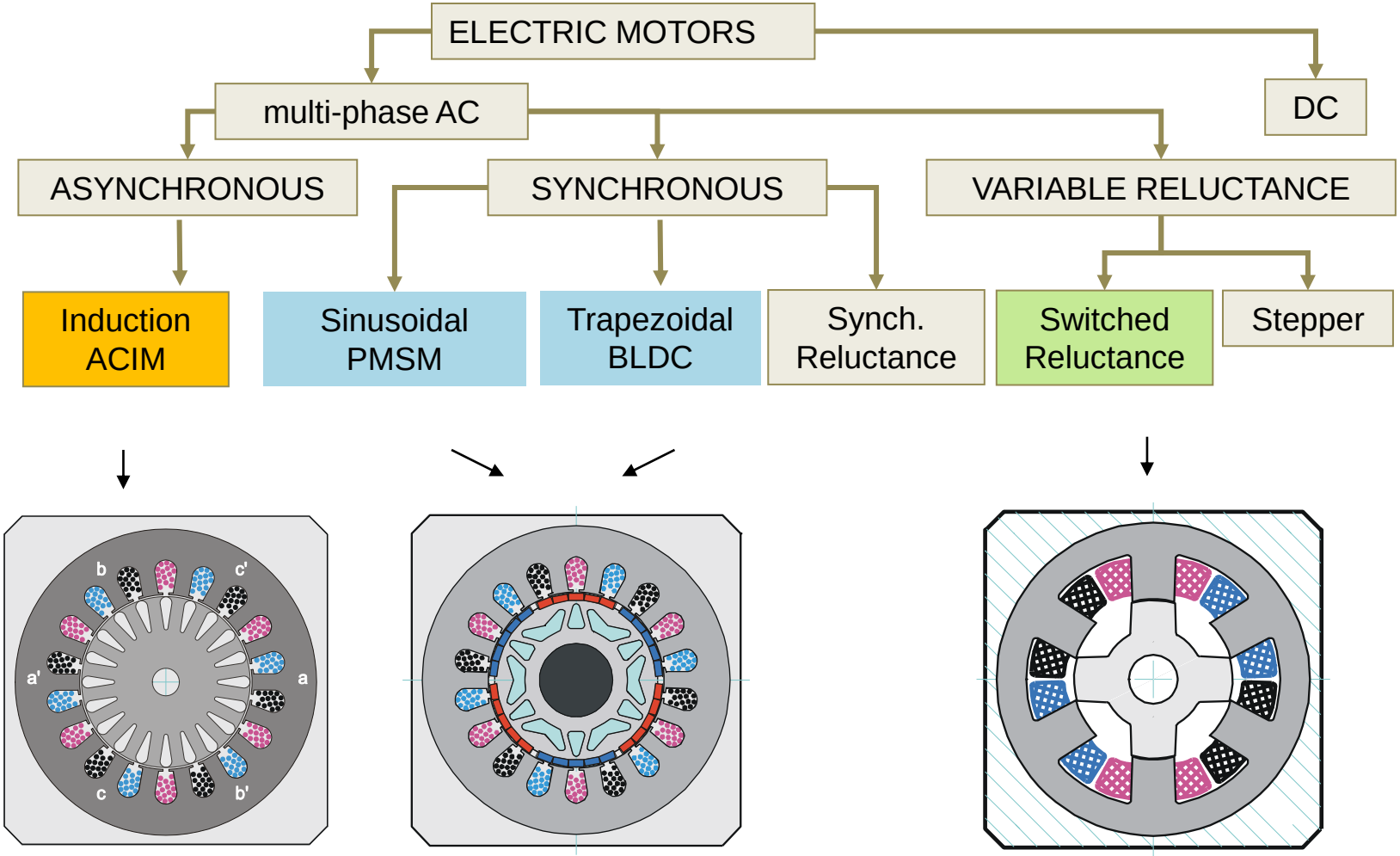


- Key Motors
  - Brushless DC (BLDC) Motors
  - Permanent Magnet Synchronous Motors (PMSM)
  - AC Induction Motors (ACIM)
  - Switched Reluctance Motor (SRM)
- Key Control Algorithms
  - Commutation Control (for BLDC Motor)
  - AC Scalar Control (for ACIM)
  - AC Vector Control (for ACIM and PMSM)
- Challenges in the motor control s/w design

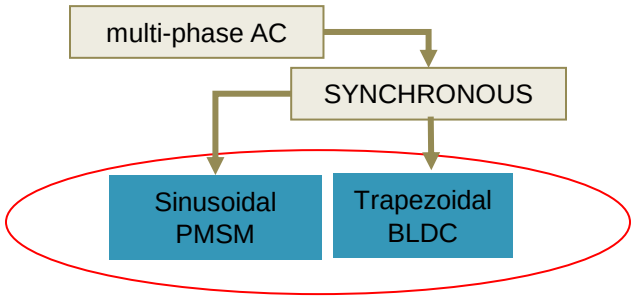
# Motor Control Target Applications

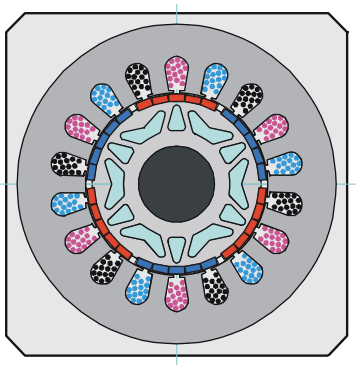
- **Pumps and fans** – pool pumps, factory systems, compressors
- **HVAC** – heating fans, air-conditioners
- **Industrial drives** – manufacturing assembly, robotics, wind turbines, printing presses
- **Appliances** – washers, dishwashers, dryers, fridges, power tools
- **Medical** – scanners, pumps, diagnostic and therapy equipment

# Electric Motor Type Classification



# Synchronous Motors: BLDC & PMSM



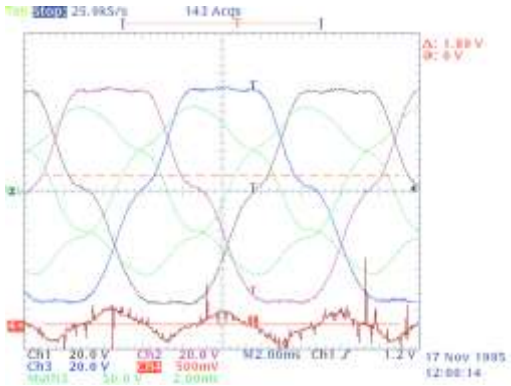



- BLDC & PMSM – Common features
  - Rotor with magnets, Winding on stator
  - Very high efficiency
  - High reliability
  - Quiet
  - Requires position information
  - Cost affected by cost of magnets (rare earth)
  - VERY popular today at low/medium power at both appliance / industrial drives

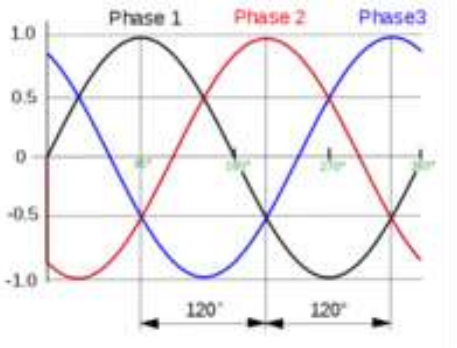
# BLDC vs. PMSM

- BLDC & PMSM differ in Back-EMF Shape
  - BLDC - Trapezoidal Back-EMF
  - PMSM - Sinusoidal Back-EMF

Trapezoidal BLDC



Sinusoidal PMSM

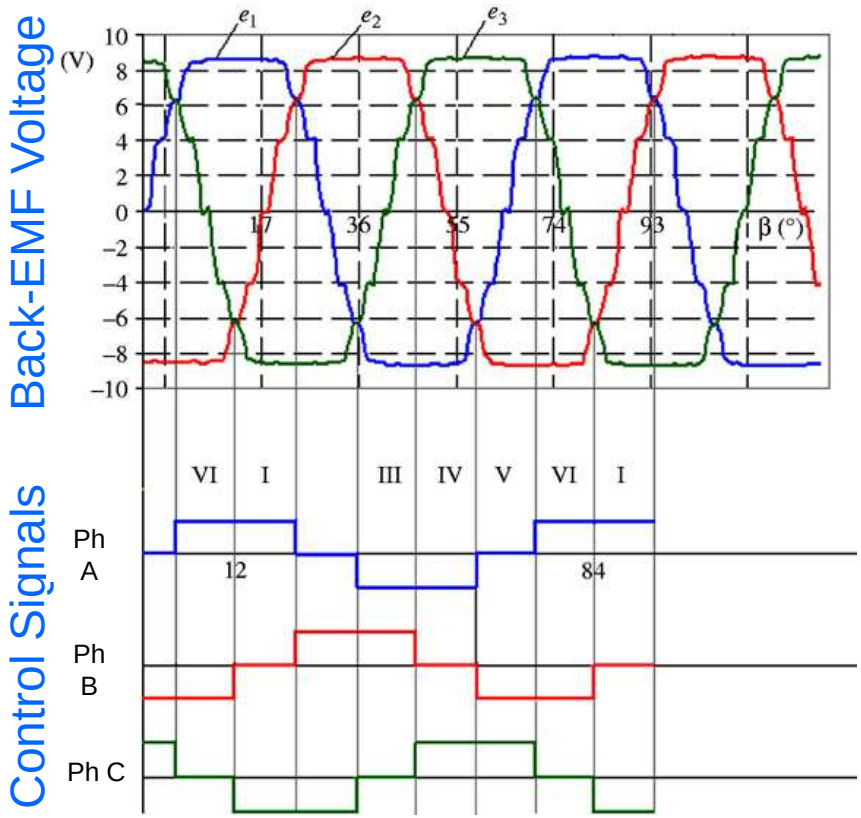



Back-EMF Recognition
- Rotate with motor shaft
- Observe generated voltage

# BLDC Motor Control

## BLDC motor

- **Trapezoidal** Back-EMF (flux distribution)
- Motor power **by commutation "square" voltage – more noisy**
- 2 of the 3 phases are excited at any time (Six-Step)
- Sensorless algorithm easy



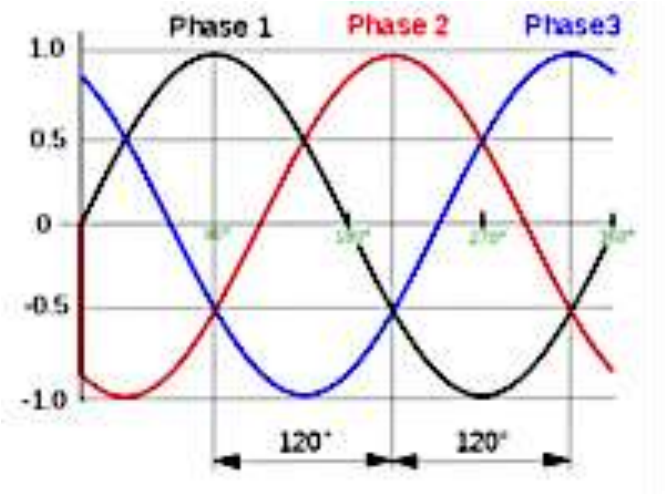

## BLDC Motor Control

- Phases are commutated according to the rotor position
- Hall sensors directly gives commutation instances
- Simple sensorless techniques help to avoid sensors

# Sinusoidal PMSM Control

- PMSM motor
  - **Sinusoidal** Back-EMF (flux distribution)
  - Motor power **by sine voltage - silent**
  - All 3 phases persistently excited at any time
  - Sensorless algorithm becomes complicated

- PMSM Motor Control
  - Phases are supplied by sine voltage according to rotor position
  - Requires known start-up position (alignment)
  - Position Information:
    - Using Hall Sensors – used rarely
    - Sensorless – several techniques are used
  - **Control Algorithm - Vector Control (FOC)**



# Trapezoidal BLDC vs. Sinusoidal PMSM

- **Important Note:**
  - Sometime customers calls both these motors as BLDC regardless of the back-EMF shape. This leads to the confusion since BLDC and PMSM are controlled differently.
  - It is important to always ask question:

**Is the motor TRAPEZOIDAL or SINUSOIDAL?**

# Various PMSM

Panckake PMSM for
Direct Drive Washers

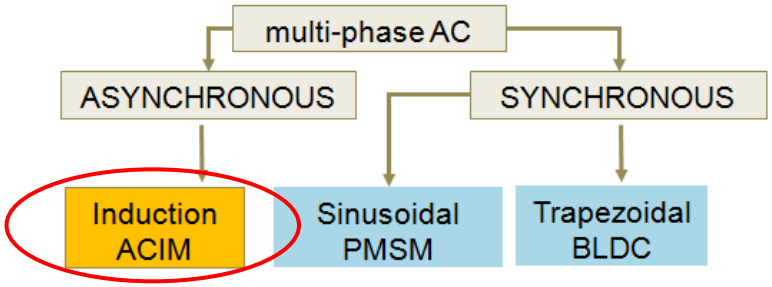
PMSM with external rotor

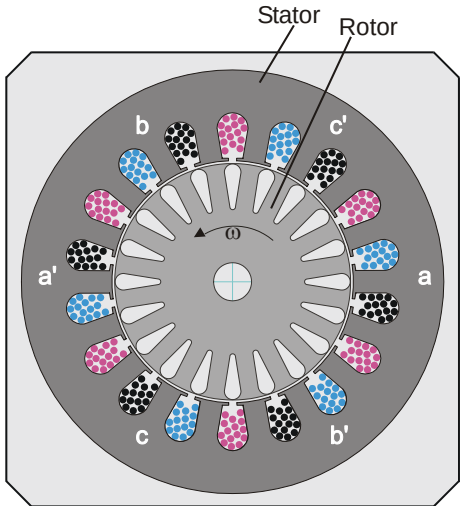
PMSM for belt-driven
Washers

# PMSM & BLDC Motors

- **Advantages**
  - High torque per frame size
  - Reliability due to absence of brushes and commutator
  - Highest efficiency.  Renewed interest for “white goods”
  - Good high speed performance (no brush losses)
  - Precise speed monitoring and regulation possible
  - Smooth torque
- **Drawbacks**
  - Position sensor or sensorless technique is required for motor operation
  - Difficult to startup the motor using sensorless technique
- **Typical Applications**
  - Appliance, washer, dishwasher, pump, compressor, dryer, medical, tools, HVAC, fan

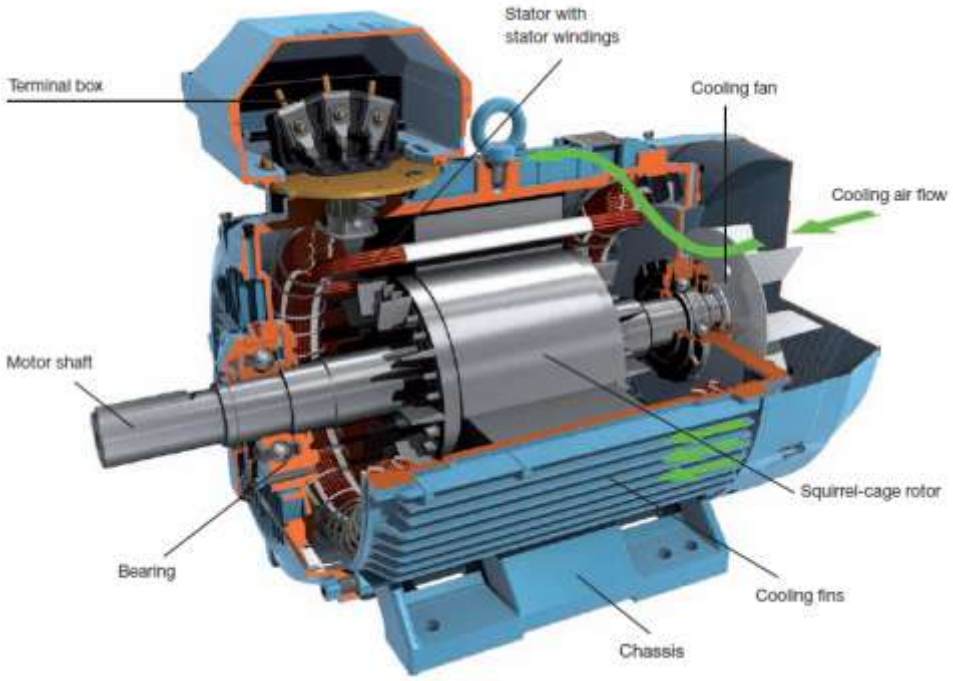
# AC Induction Motor (ACIM)




- 3-phase winding on the stator (sinusoidal)
- Key features
  - Squirrel cage (rugged, reliable, economical)
  - No brushes, no magnet –> low cost
  - Fed from 3-ph source of the AC voltage to the stator
  - Speed control requires varying stator frequency
  - High power drives

# Cutaway of Squirrel-Cage Induction Motor



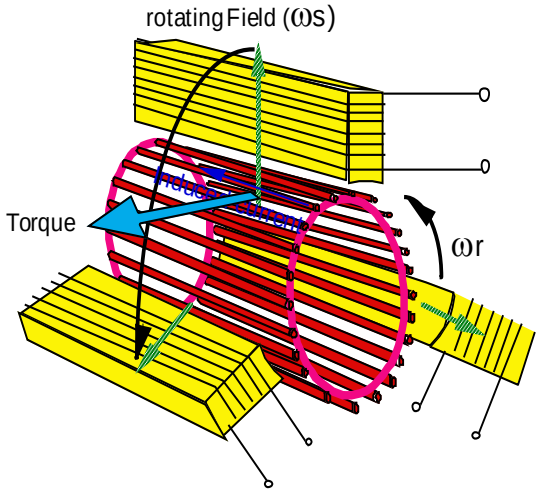
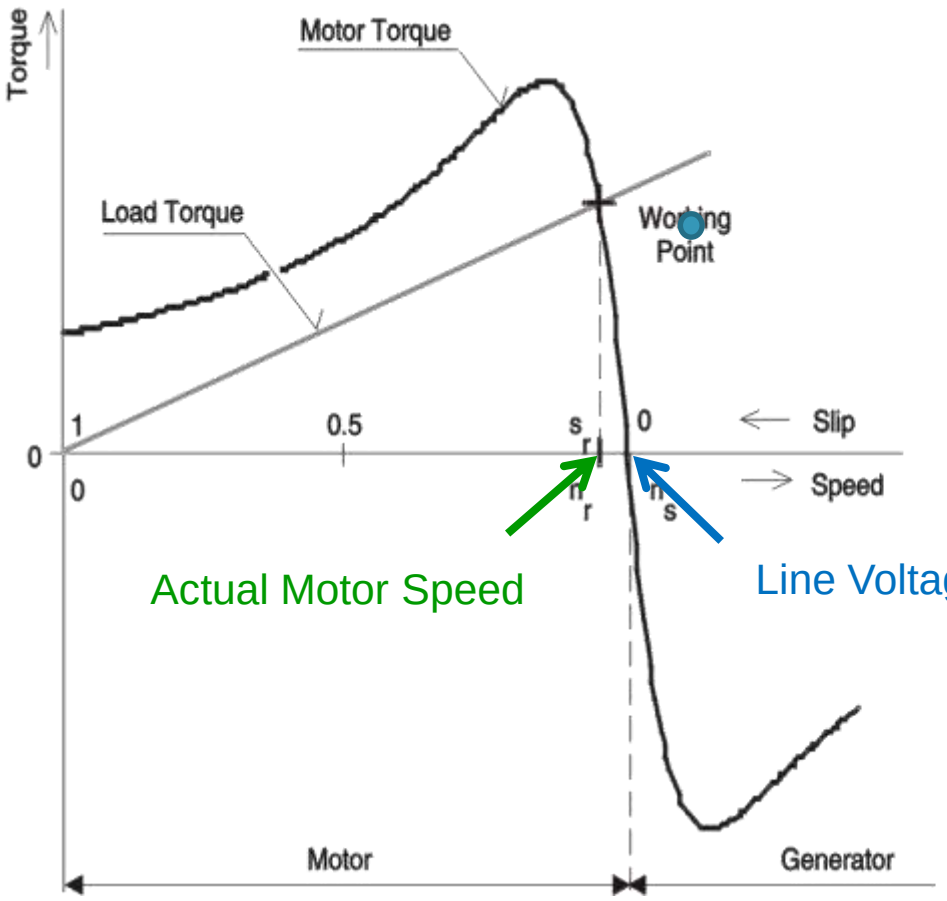




ABB -Technical application paper

# ACIM - Torque-Speed Profile



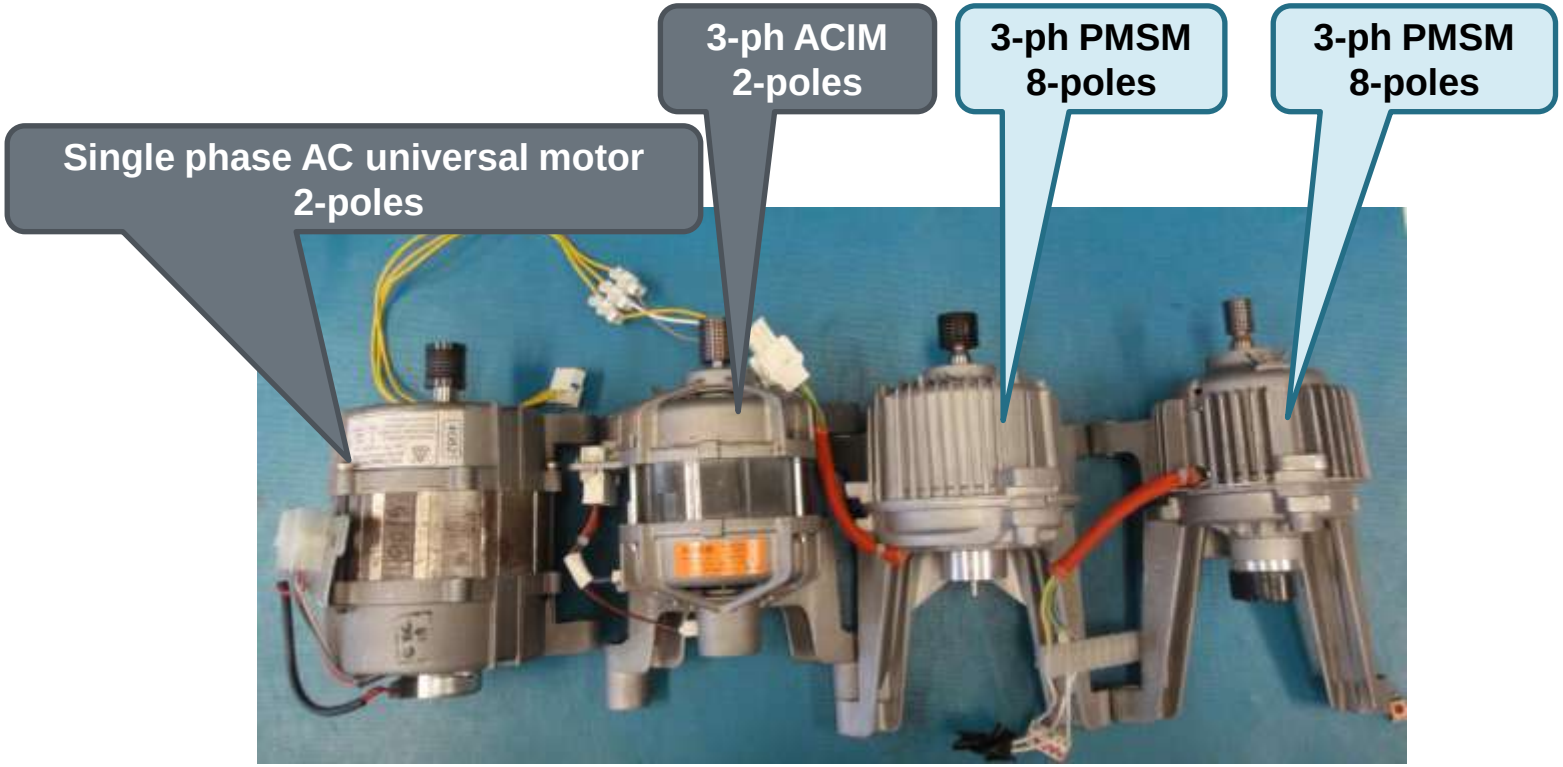

- Key Control Techniques:
  - Scalar (Speed) Control
  - Vector Control (Torque) Control
- For precise control motor speed information needed
  - Using sensor (Encoder, Tacho)
  - Sensorless

# AC Induction Motor

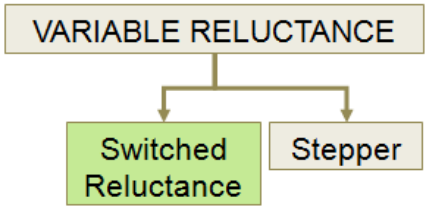
- **Advantages**
  - Low cost per horsepower
  - Inherent AC operation (Direct connection to AC line)
  - No permanent magnets (very rugged)
  - No brushes.  Very low maintenance
  - Available in wide range of power ratings
  - Low rotor inertia
- **Drawbacks**
  - Inefficient at light loads.
  - Speed control requires varying stator frequency.
  - Position control difficult (field orientation required).
- **Typical Applications**

  - Washer, pool pump, industrial drives, HVAC, fan, compressor

# Washer Motors (about 750W)

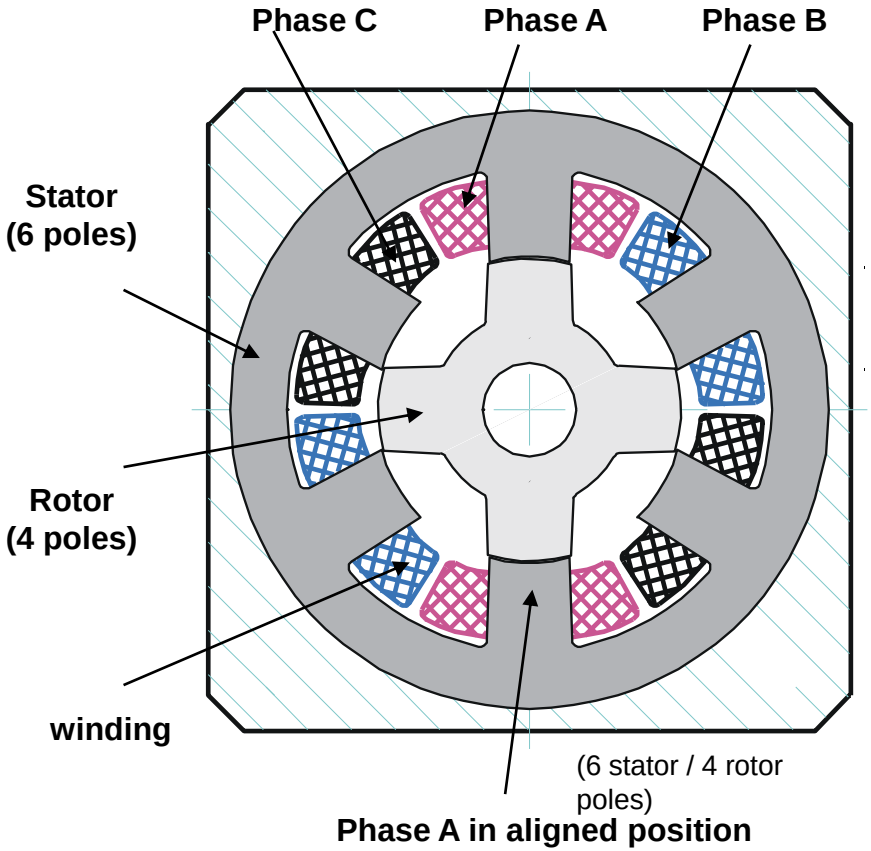


# Switched Reluctance Motor (SRM)

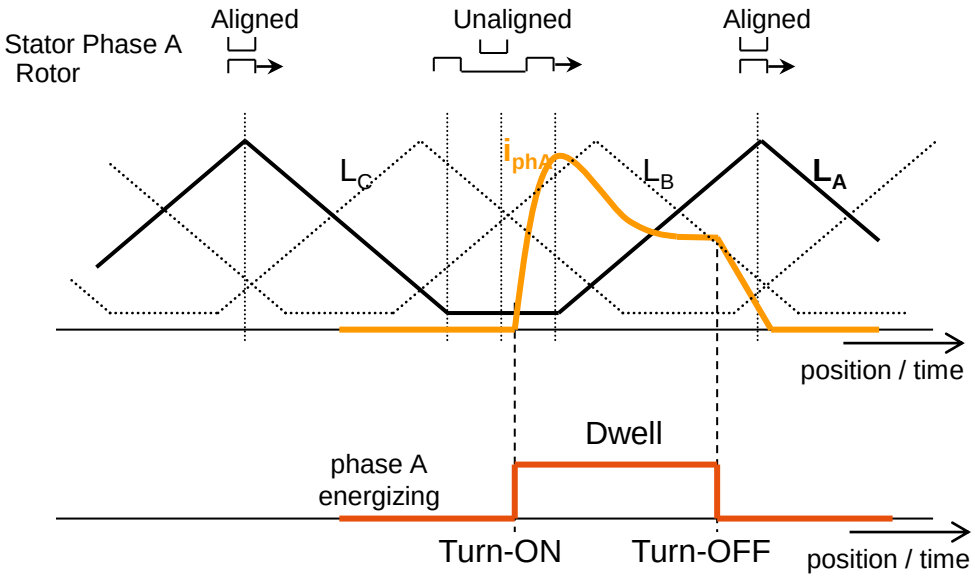


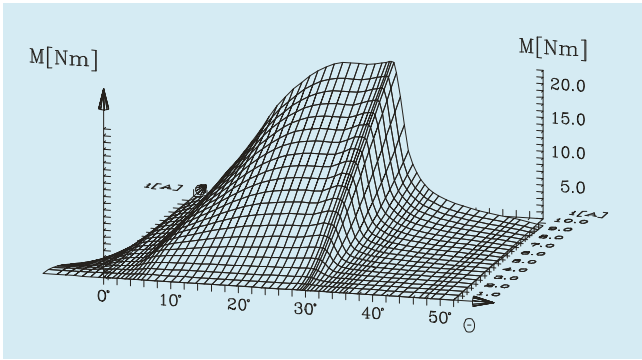

- Both stator and rotor have salient poles
- Winding on stator
- Characterized by magnetization characteristic $\Psi(i, \theta)$
- Inductance profile linked with rotor position
- Requires position information for phases commutation

- Suitable stator/rotor poles ratio configuration (the higher number of phases, the lower torque ripple):
  - 2-phase:4/2
  - 3-phase: 3/2, 6/2, 6/4, 6/8, 12/8, 2/10, 24/32
  - 4-phase: 8/6
  - 5-phase: 10/8
  - 7-phase: 14/12



# Phase Energizing



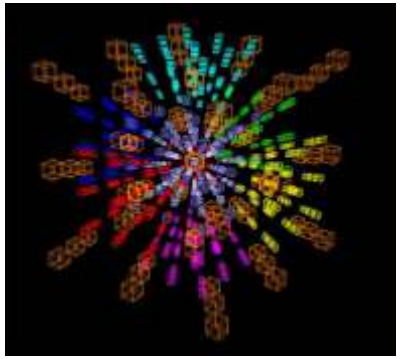



# SR Motor

- **Advantages**
  - Low cost resulting from simple construction
  - High reliability
  - High fault tolerance
  - Heat is generated in stator:  easy to remove
  - High speed operation possible (100,000 rpm)
- **Drawbacks**
  - Acoustically noisy
  - High vibration
  - Magnetic nonlinearities make smooth torque control difficult
  - Dependent on electronic control for operation
- **Typical Applications**
  - Vacuum cleaners, lawn movers, industrial drives

# Complexity of the Motor Control Solutions

- **Large Variety of MC Algorithm Structure**
  - Processor Dependent (variety of CPU's & peripherals…)
  - Motor Type Dependent (ACIM, PMSM, BLDC, DC, Stepper, SR, Linear)
  - Motor Parameters Dependent (variation of parameters with temperature & current, fluctuation during production, magnetic saturation curves, material of magnets ...)
  - Algorithm Dependent (FOC, scalar, sensorless, position servo…)
  - Application Dependent (industrial drive, fan, pump, washer,…..)
  - Hardware dependent (h/w topology, tolerance of components, noise ….)
  - Standard's Dependent (Safety, Autosar, ctm specific standards….)
  - Co-Existence with other applications (operating system, multi-motor control, PFC…)

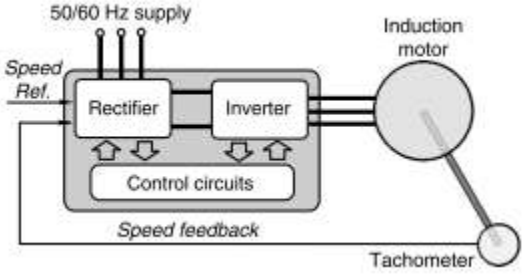


Multi-Dimensional Task

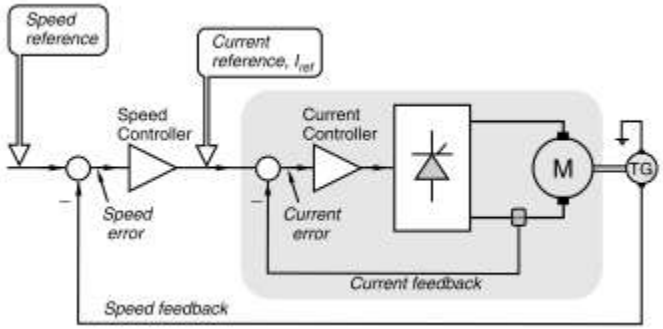
One "universal solution" does not work

# Speed/Torque Control

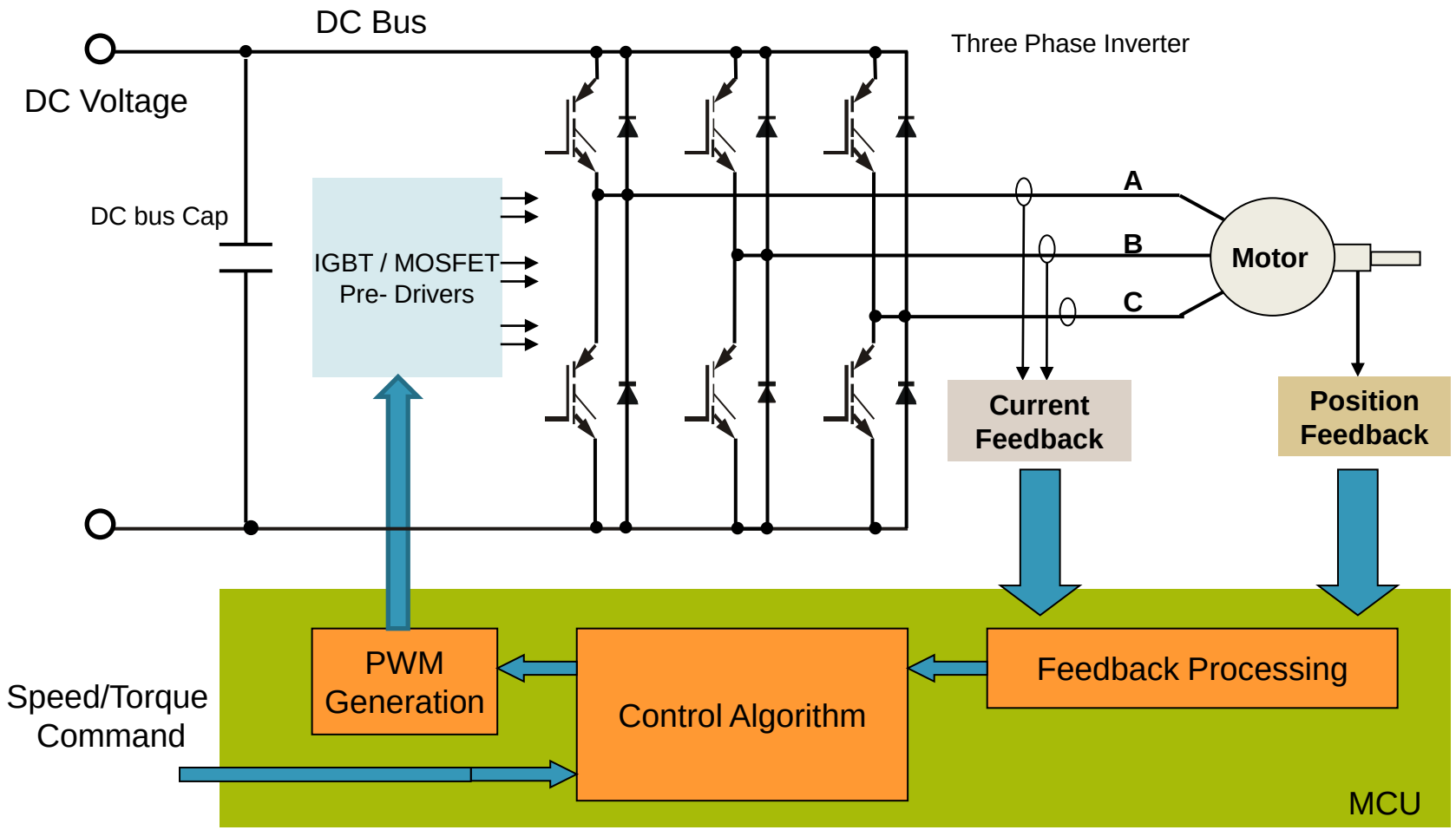
- Speed Control
  - Majority of variable speed drives
  - Speed directly control by applied voltage or by using inner control loop
  - Speed information necessary



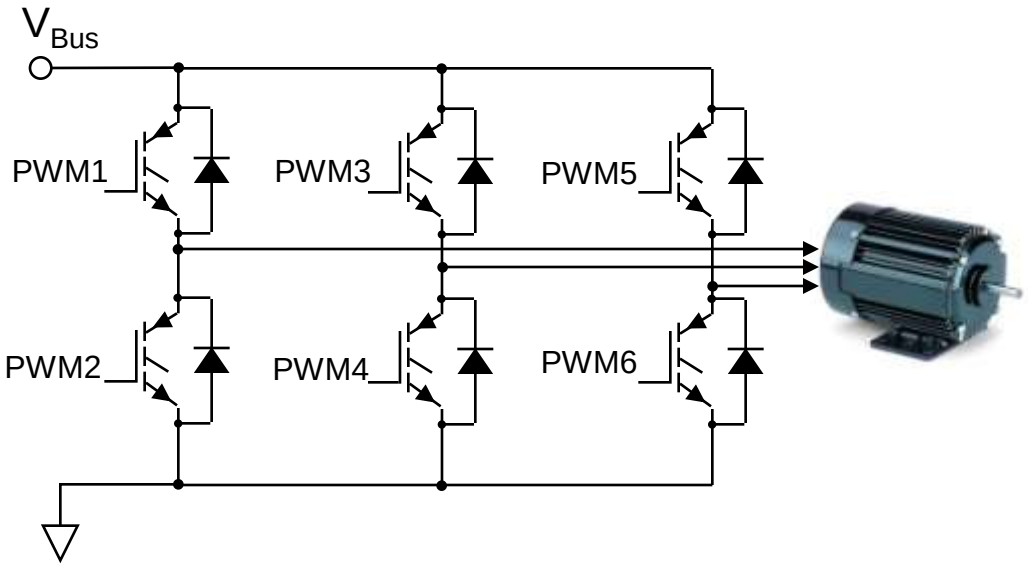

- Torque (Current) Control
  - Demanding applications (electrical power steering, electric braking, winding machine, lifts etc…)
  - Appliance applications (washers, pumps, industrial drives)
  - Applications requiring the motor to operate with a specified torque regardless of speed
  - Knowledge of speed & current must be present
  - Typical algorithm: Vector Control (Field Oriented Control)

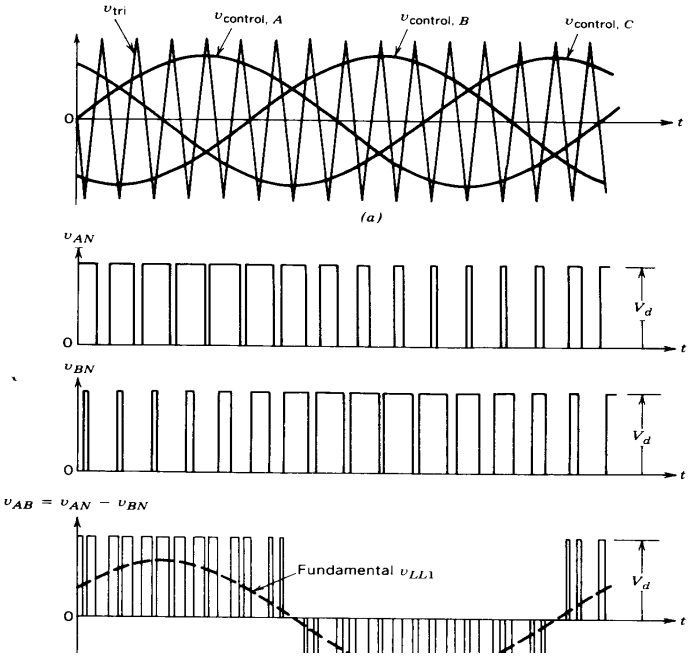


# Motor Control Topology



# Three Phase Inverter




Three-phase PWM waveforms.

**PWM frequency 10-20kHz**

-The higher frequency – the higher switching loses

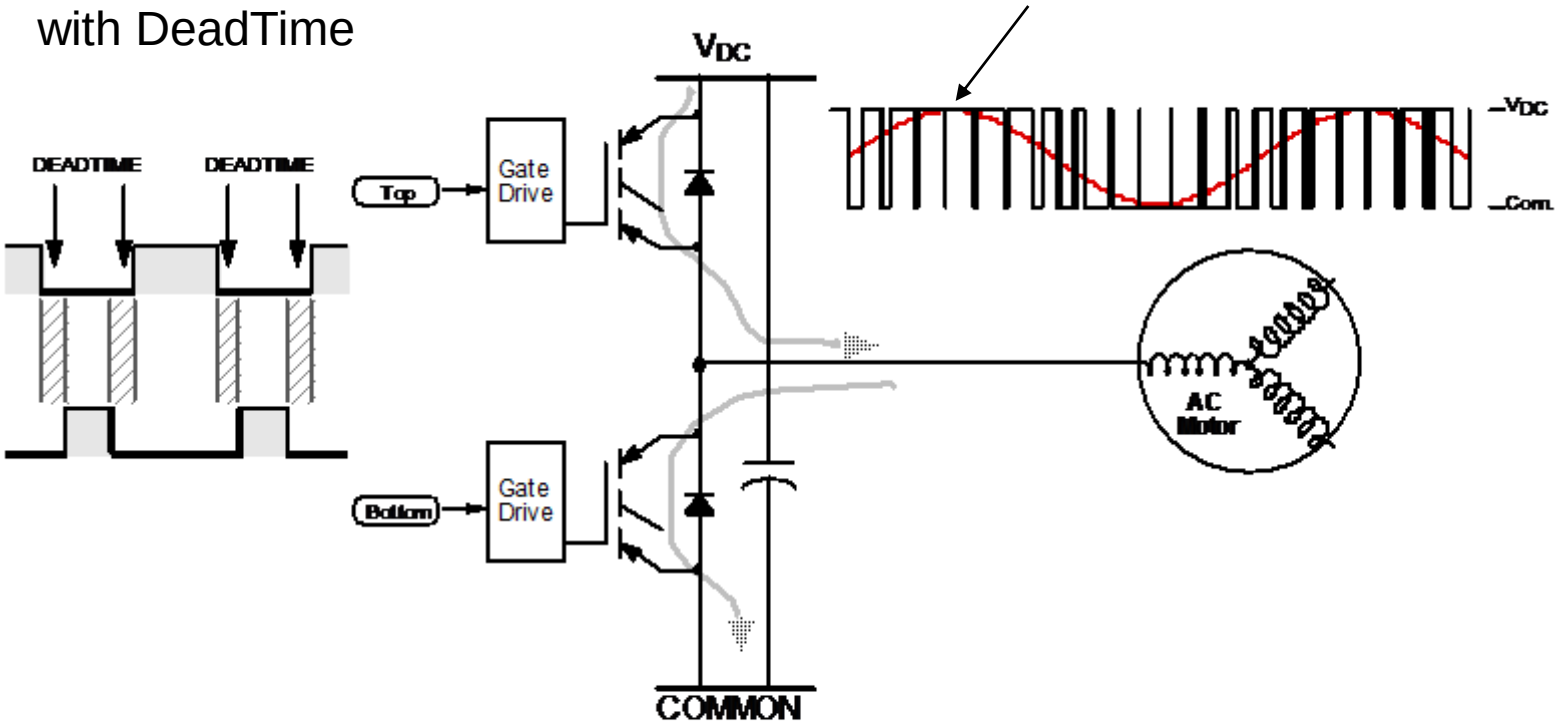
- The lower frequency, the higher audible noise

*Source: Power Electronics, by Ned Mohan, Tore Undeland, and William Robbins, John Wiley & Sons, 1995*

# PWM Applied to Electrical Systems

• Load inductance acts like a low pass filter to smooth current.

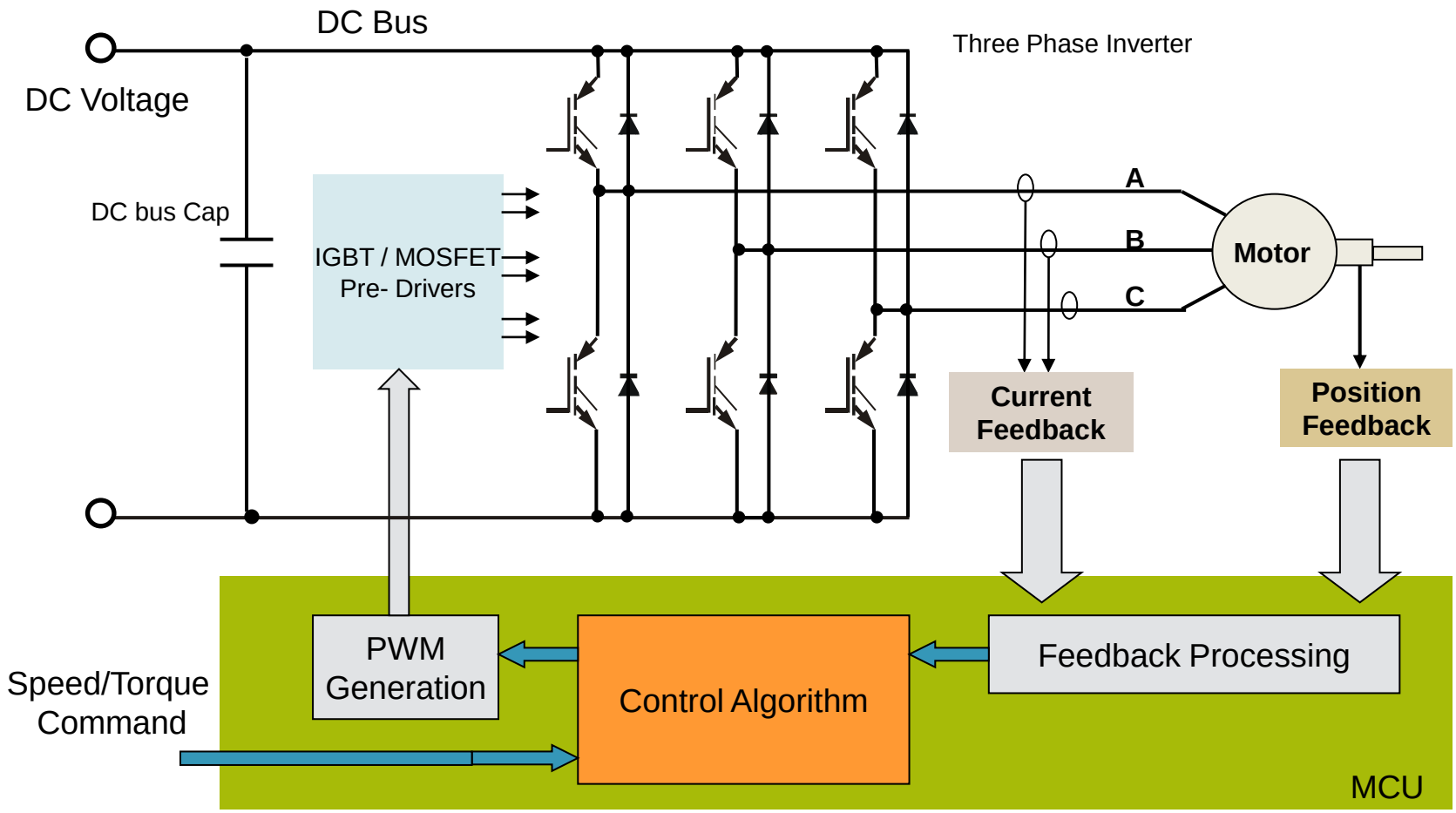
Complementary PWM with DeadTime




Half-h bridge (one of three)

*Peter Pinewski*

# Motor Control Topology – Control Algorithm

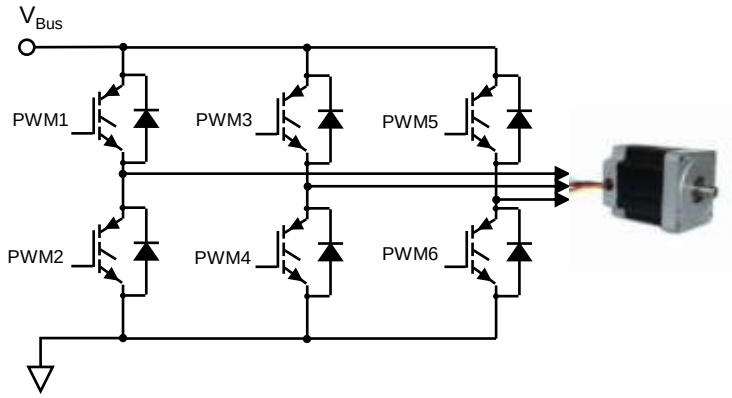


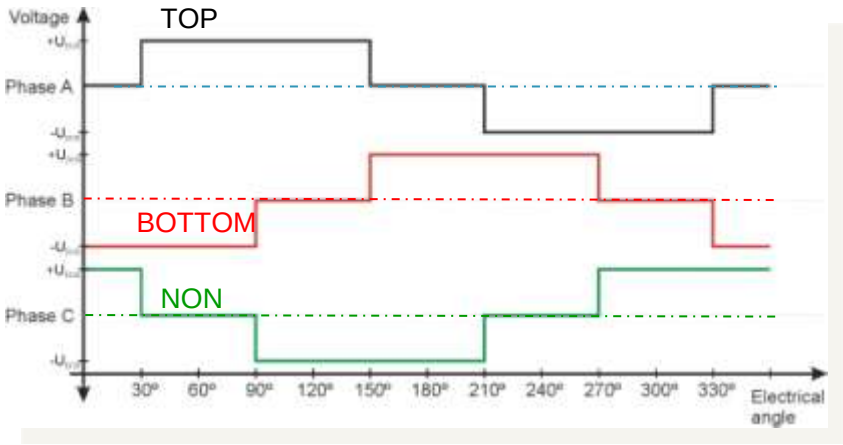
# Basic Types of Motor Control Algorithms

- Commutation Control (BLDC)
- Volt per Hertz Control (ACIM)
- Vector Control (ACIM, PMSM)

# Commutation Control (BLDC)

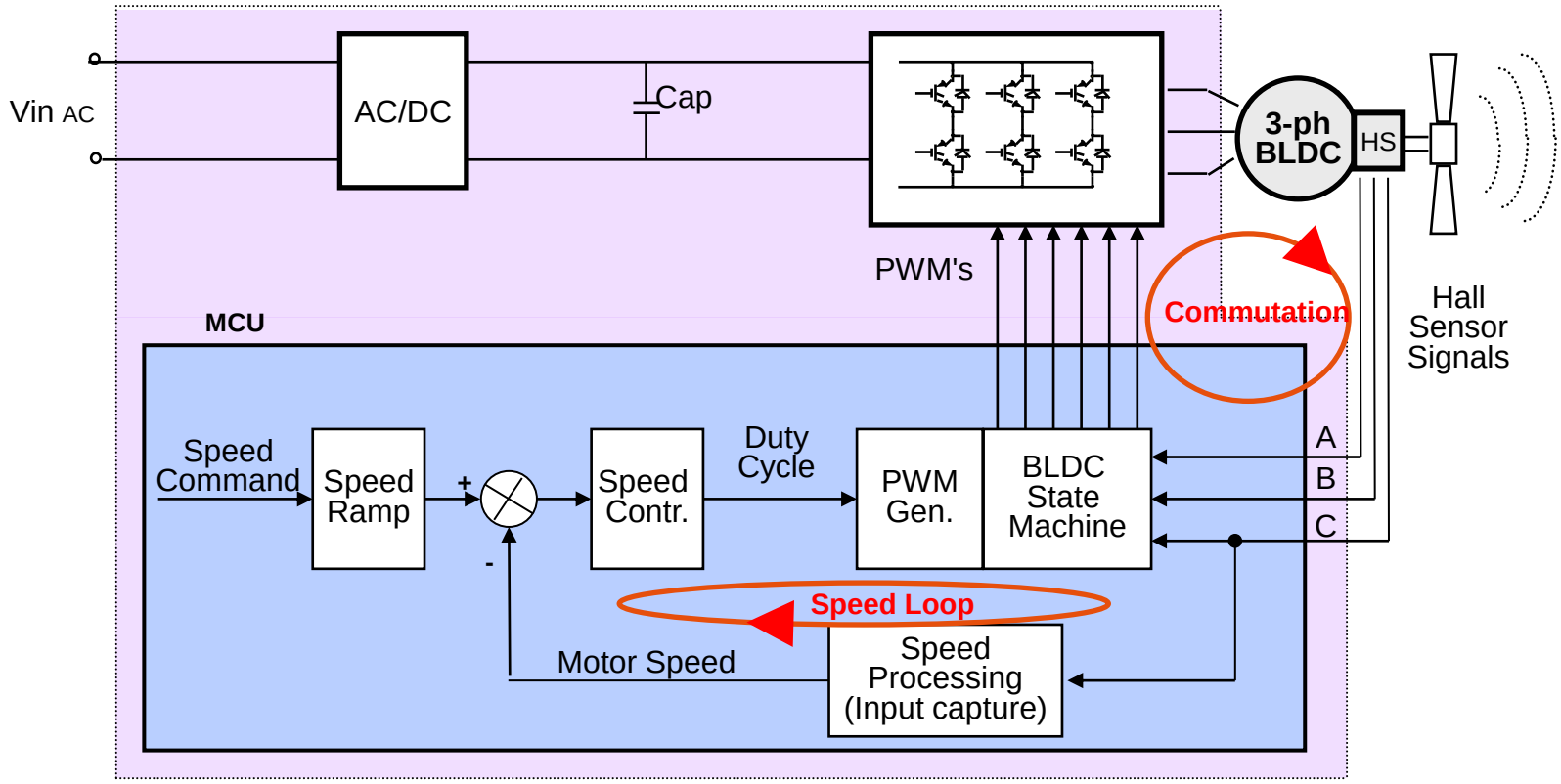
- Six Step BLDC Motor Control
  - Voltage applied on two phases only
  - It creates 6 flux vectors
  - Phases are power based on rotor position
  - The process is called Commutation
  - Speed defined by applied voltage
  - Sensorless control easy (position detection based on back-EMF Zero Crossing)



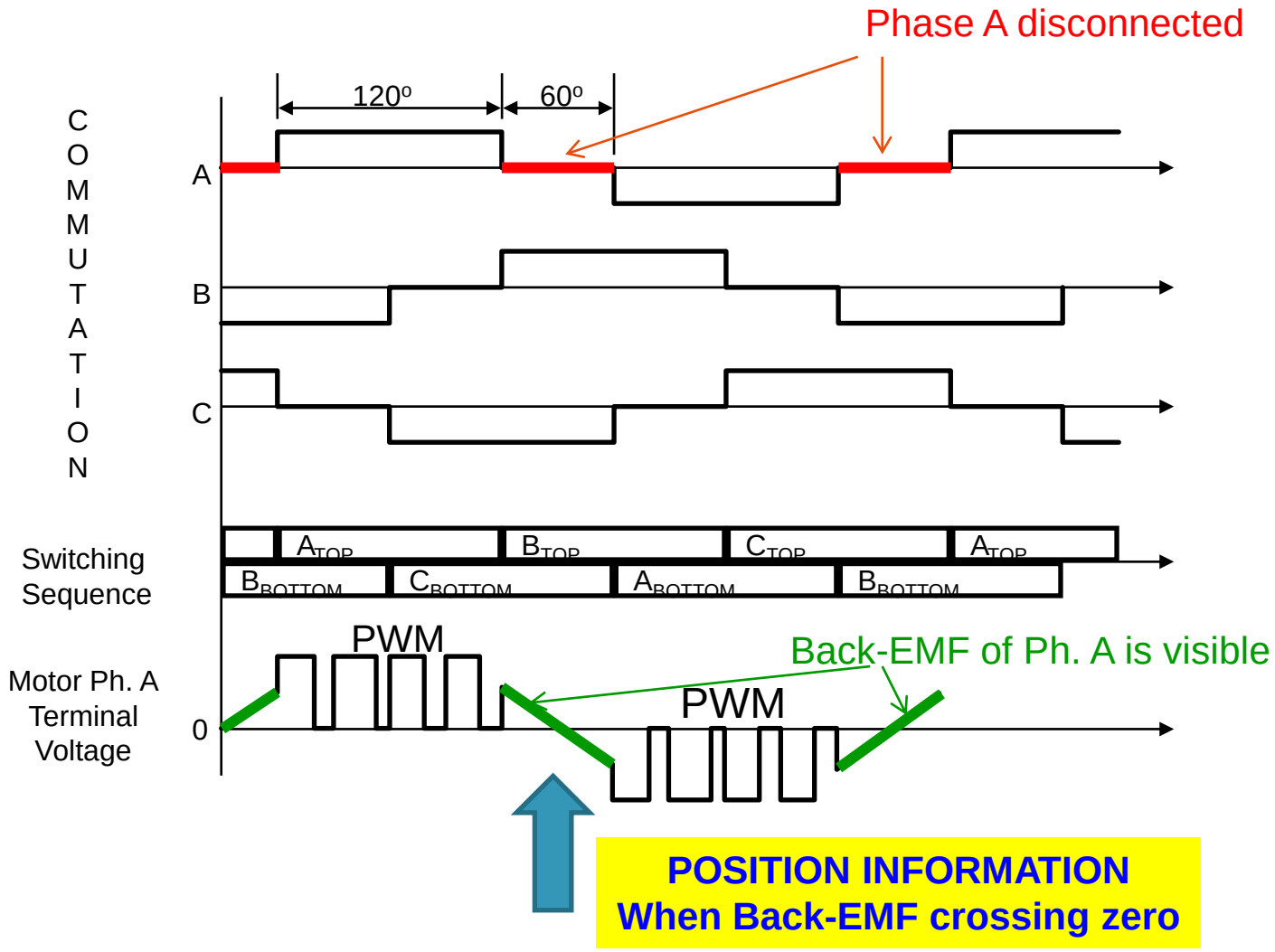

*Phase voltages*

# Commutation Control – BLDC with Sensors




8-bit/20MHz MCU satisfies the algorithm needs

# BLDC Sensorless Detection

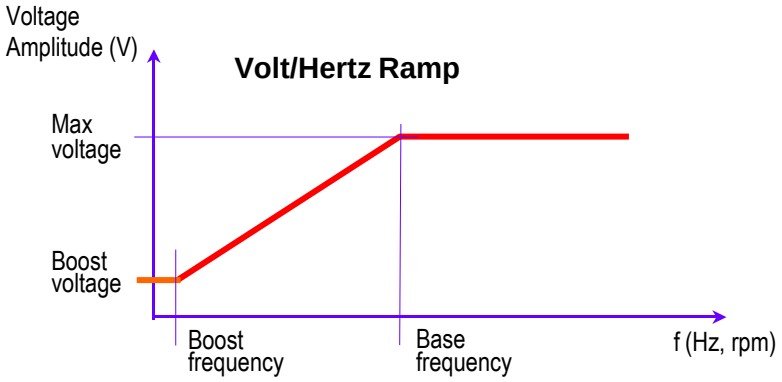


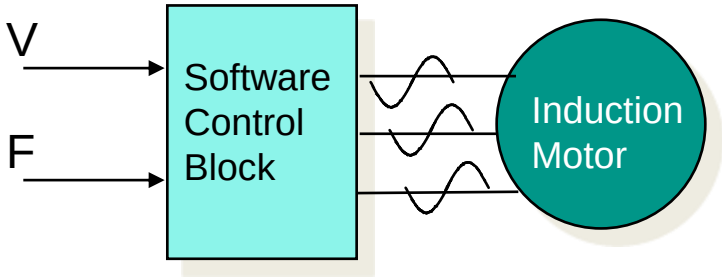
# Scalar Control (ACIM)
## Also called “Volt-per-Hertz”

USE: Low cost AC industrial drives.

CONTROL: VOLTAGE (Amplitude and Freq)

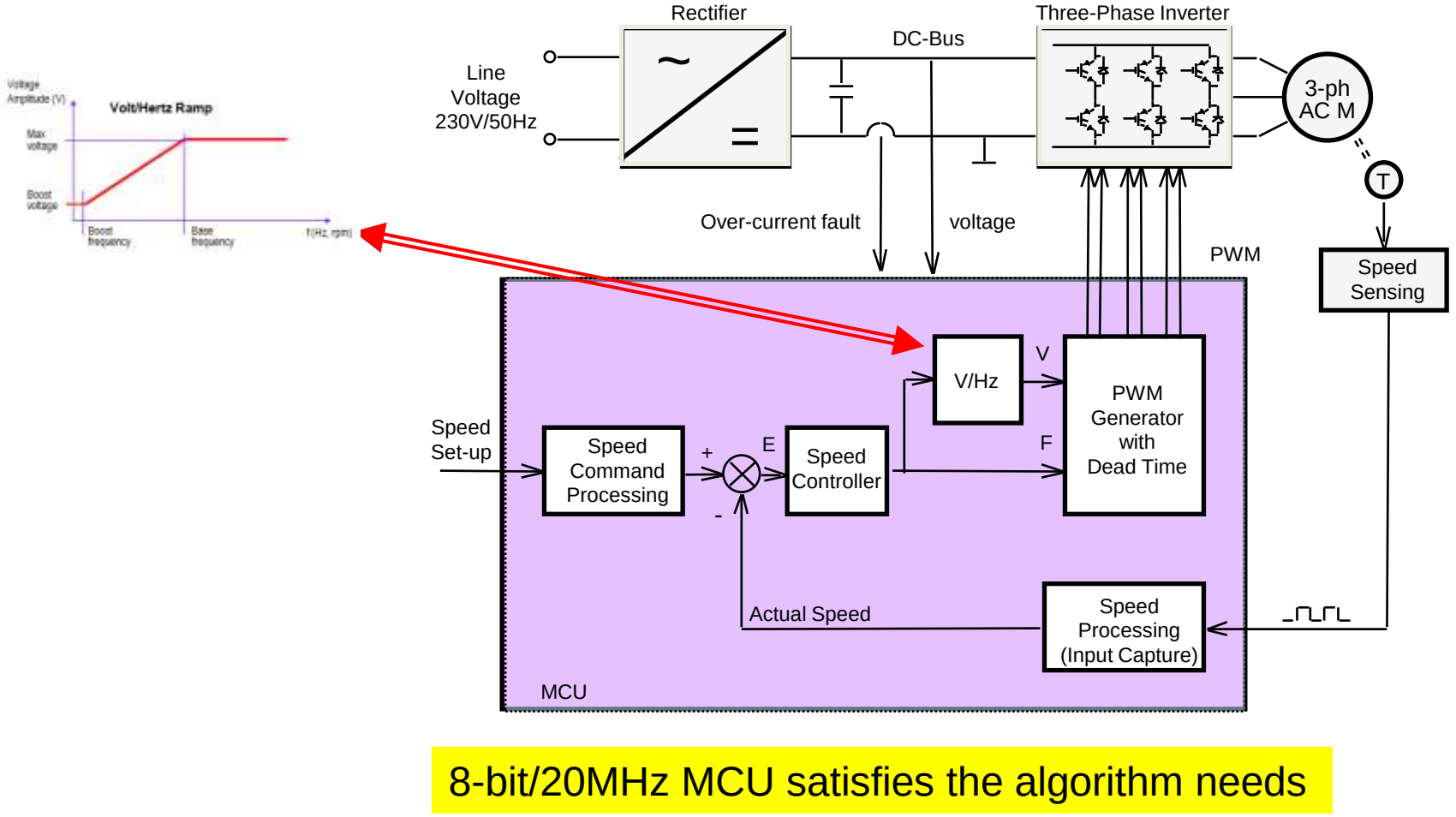
OPERATION: Attempts to keep magnetizing current constant by varying stator voltage with frequency.




*Pete Pinewski*

# V/Hz Control Block Diagram




8-bit/20MHz MCU satisfies the algorithm needs

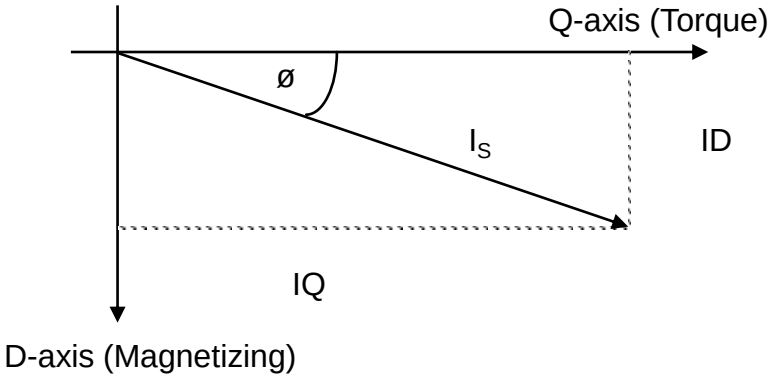
# Vector Control (PMSM, ACIM)

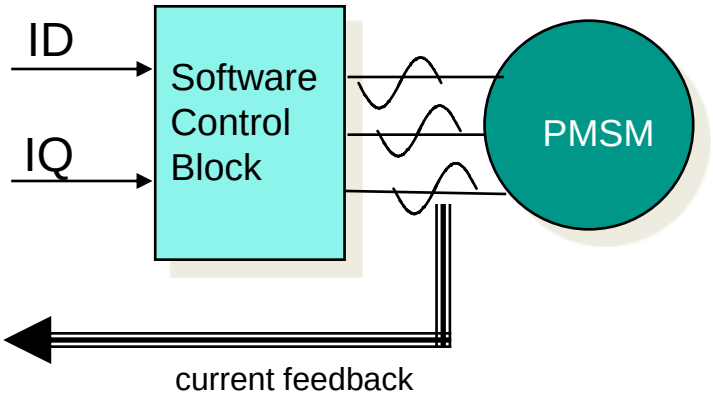
Also called Field Oriented Control - FOC

Vector control ~ control of **CURRENT vector** (Magnitude and Angle)

In special reference frame, the stator currents can be separated into

- Torque-producing component
- Flux-producing component




Pete Pinewski

# Vector Control for Sinusoidal Motors
## (PMSM, ACIM)

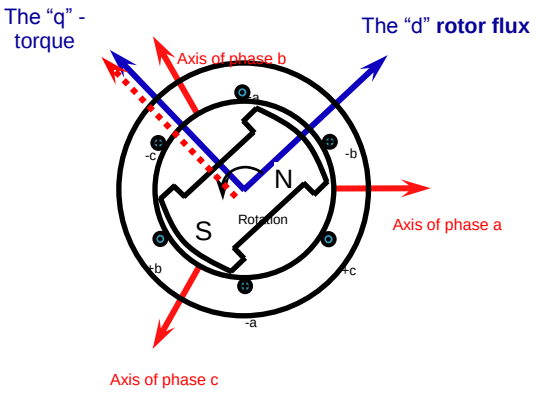
- Vector Control (Field Oriented Control - FOC) is popular technique for nowadays motor drives
- Advantages:
  - Excellent dynamic performance
  - Full motor torque capability at low speed
  - Higher efficiency for each operation point in a wide speed range
  - Decoupled control of torque and flux
  - Natural four quadrant operation (motor/brake/generator)
- Wide variety of control options

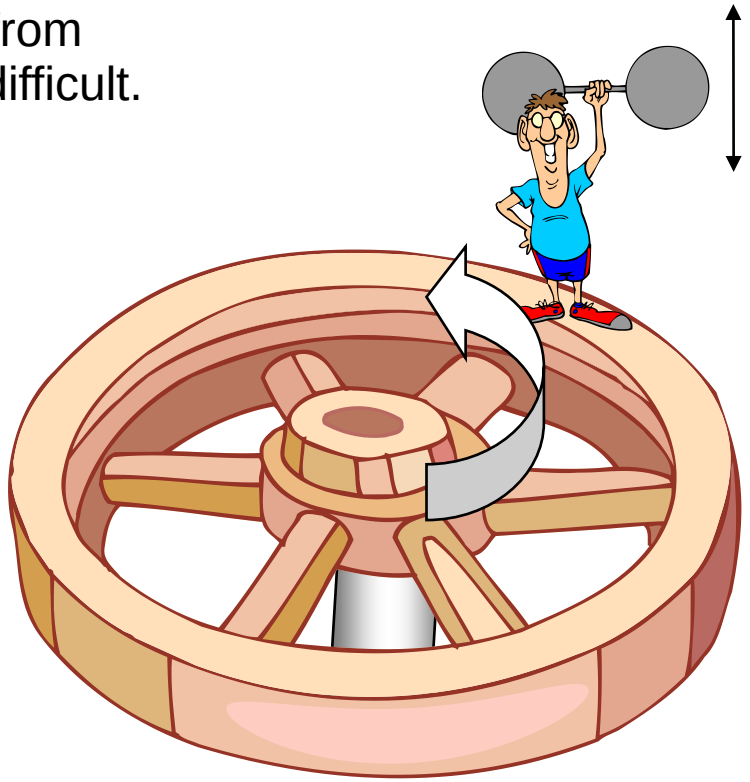
# How Difficult Is the Vector Control?

## It depends on your “point of view”!

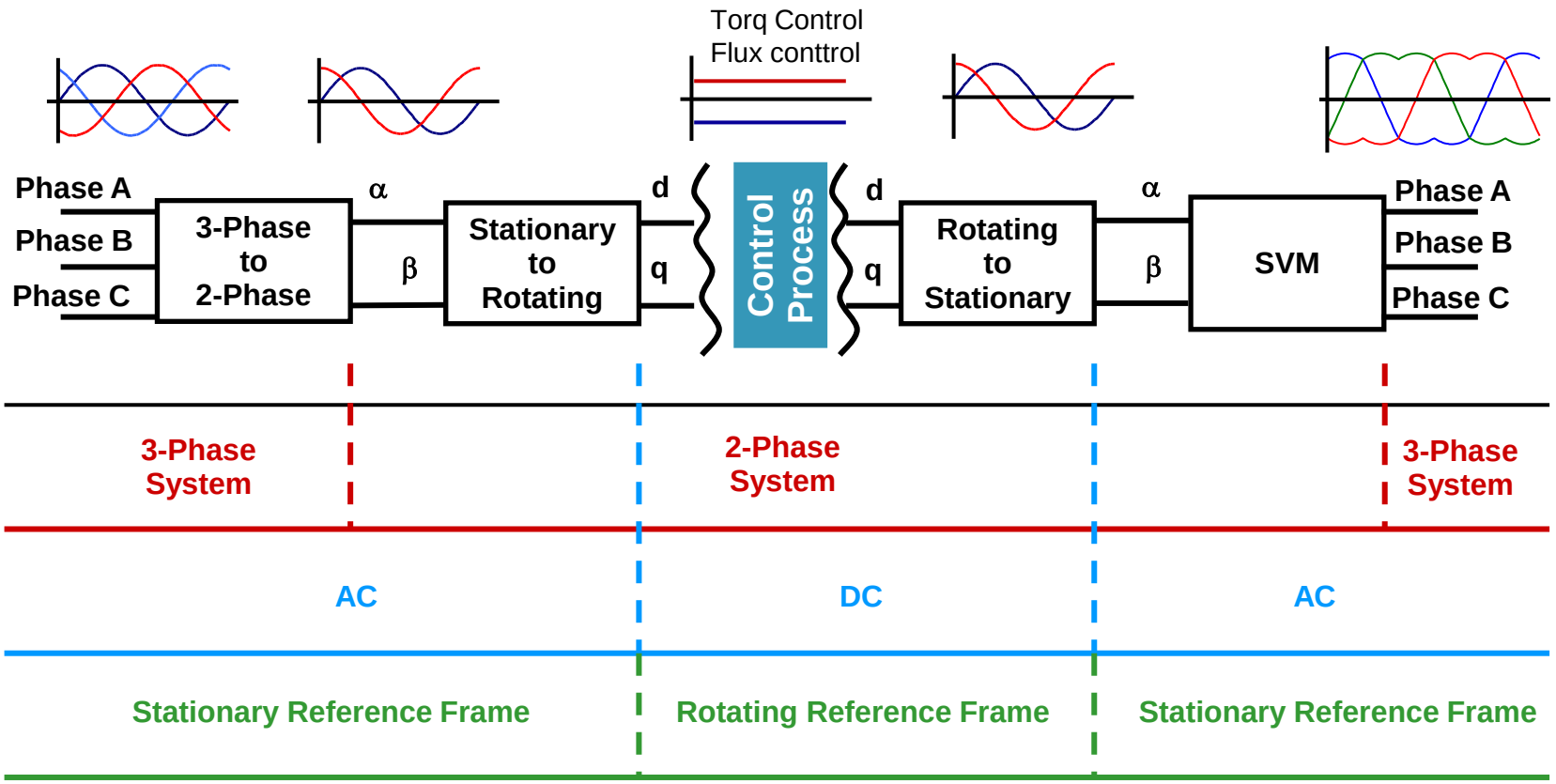
To mathematically describe barbell motion from a **stationary frame** of reference would be difficult.

However, by jumping on the wheel, and describing the motion from a **rotating frame** of reference, simplifies the problem immensely!



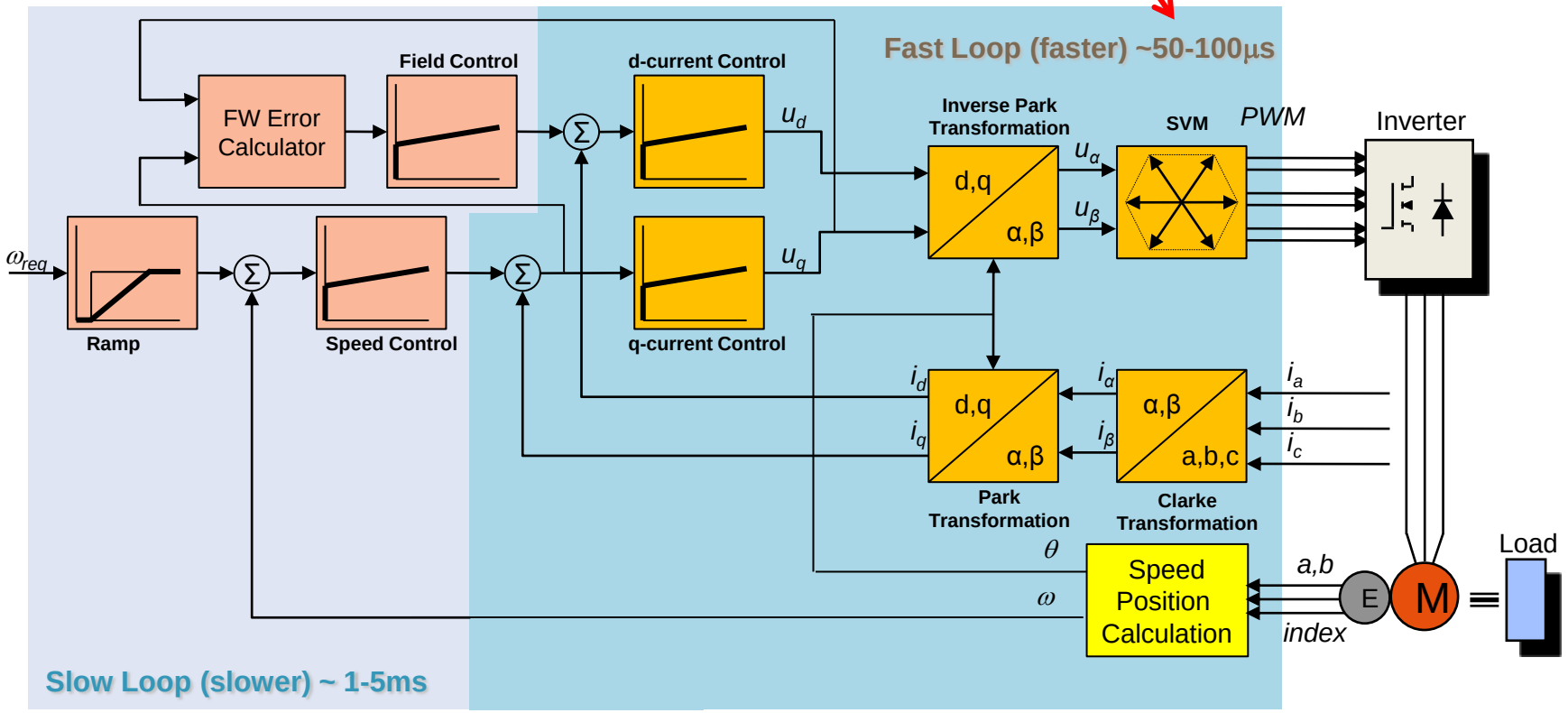



# Basic Principle of Vector Control



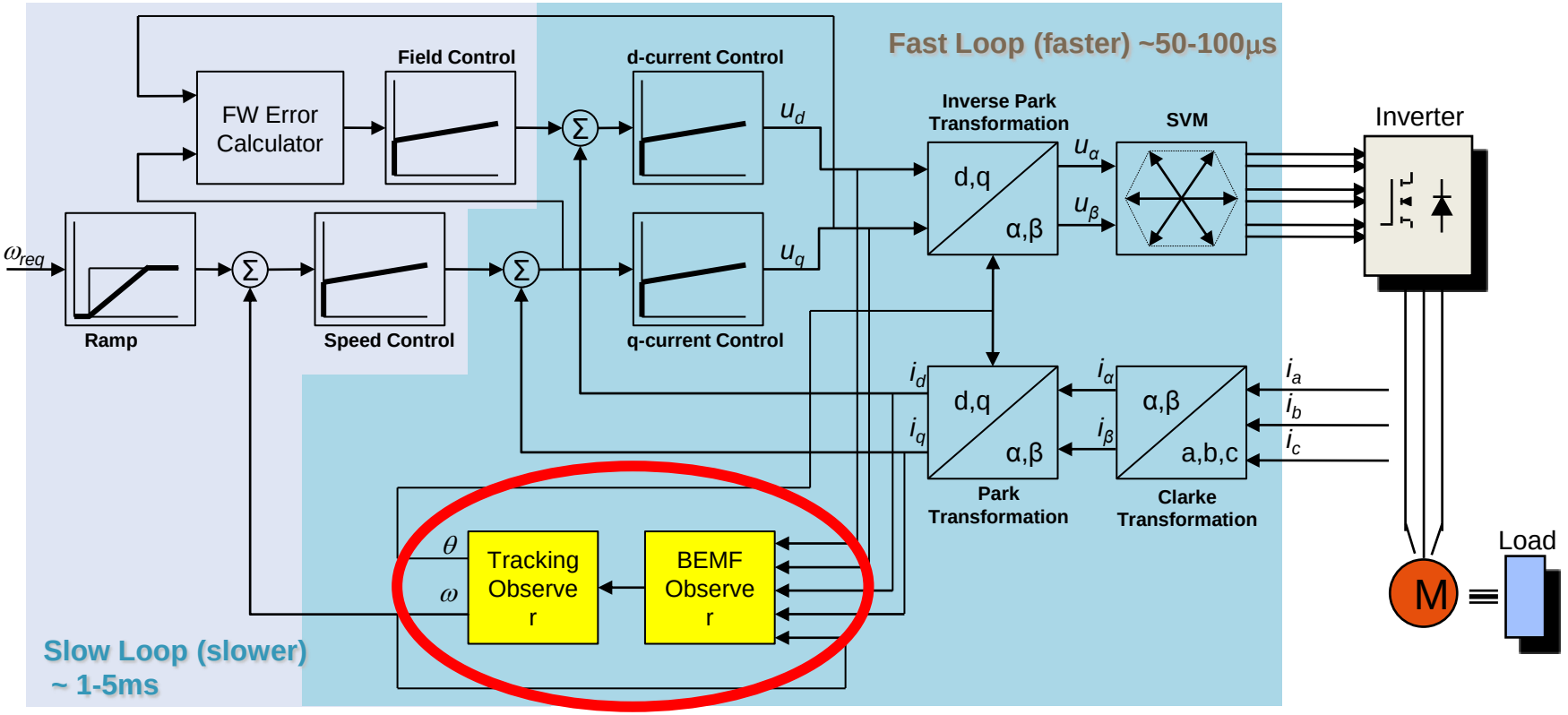
# Vector Control Implementation (PMSM)

Critical Loop executed each PWM pulse (10-20kHz)



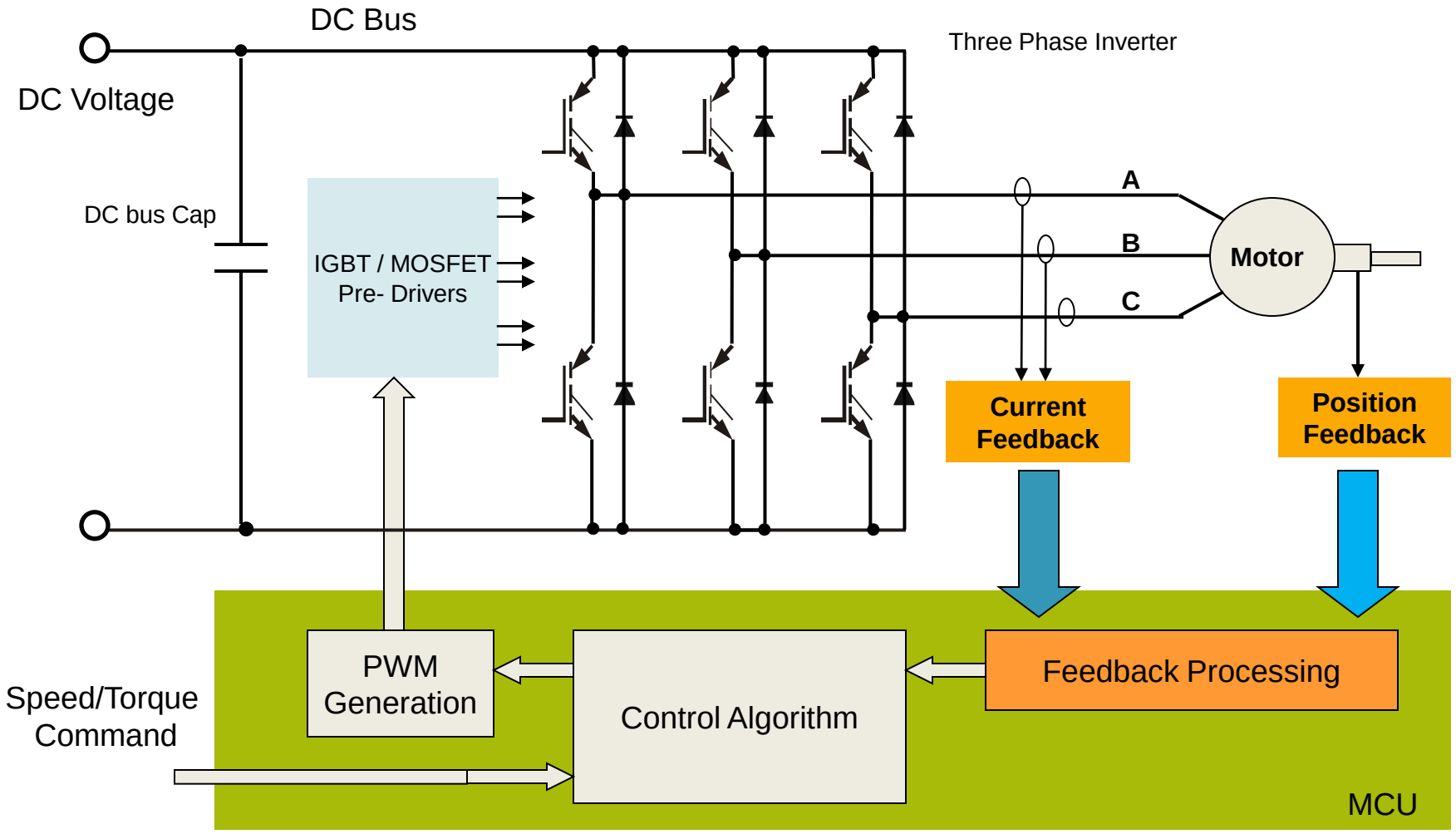

Algorithm requires powerful CPU with fast math

# Vector Control including Sensorless Estimator



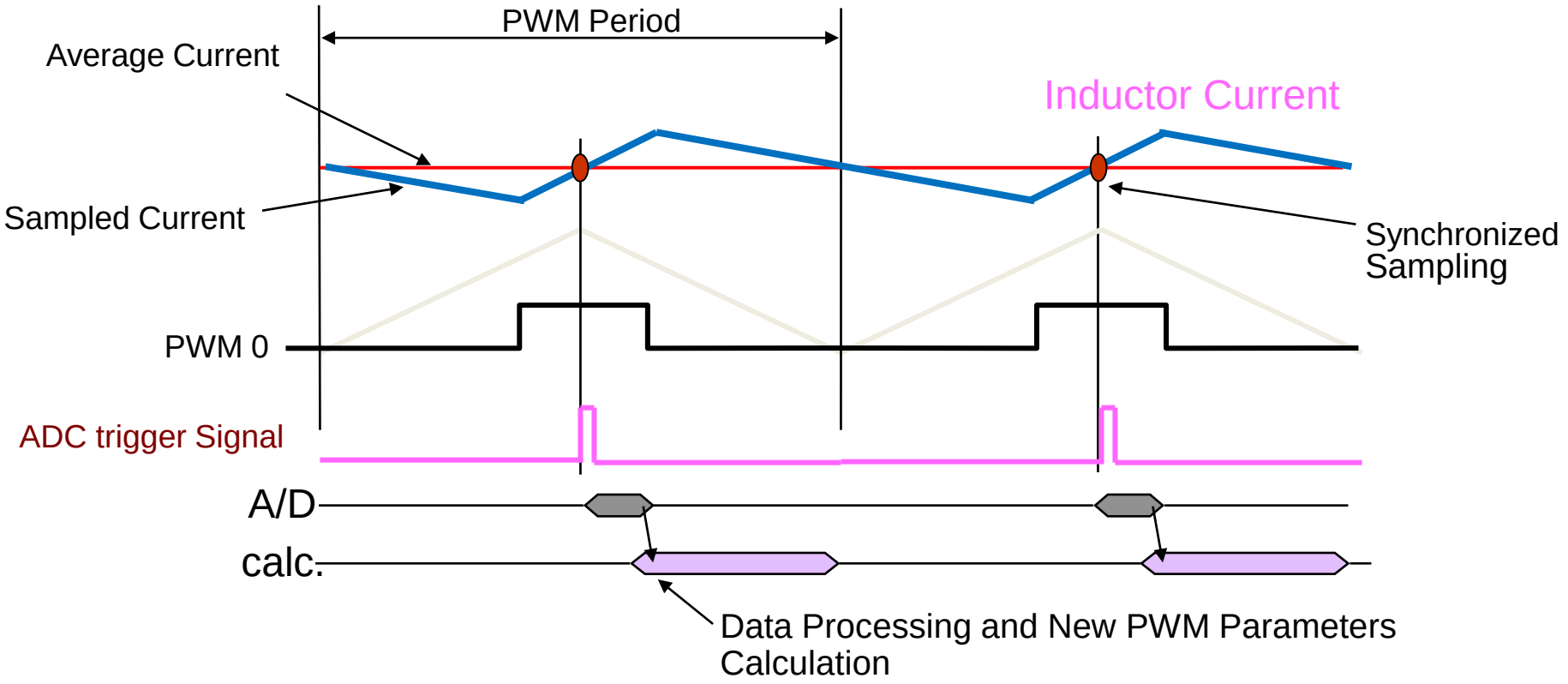

Sensorless Algorithms calculate speed/position

# Feedback Processing



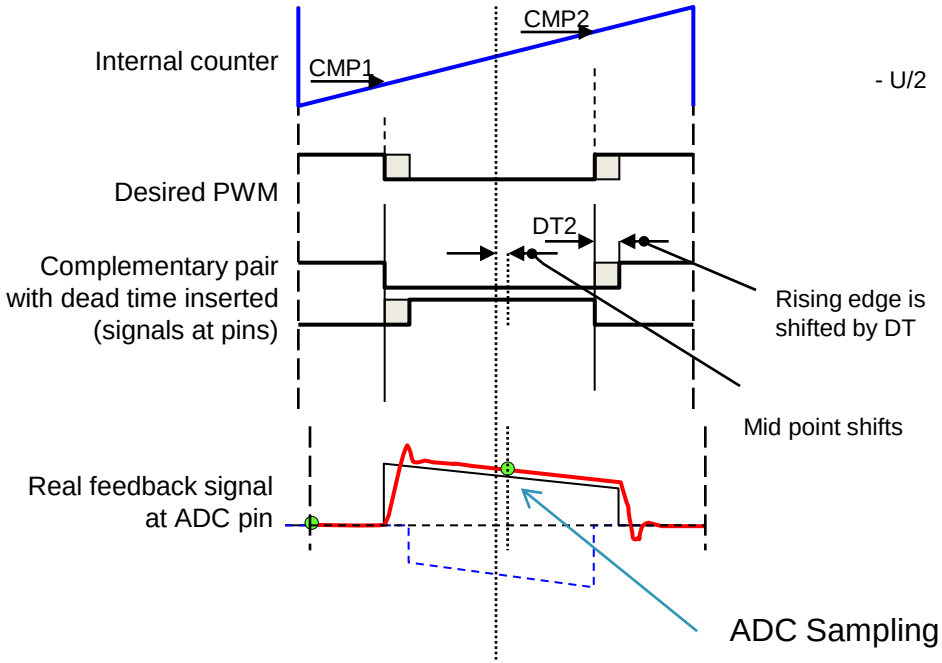
# Why ADC to PWM Synchronization is needed?

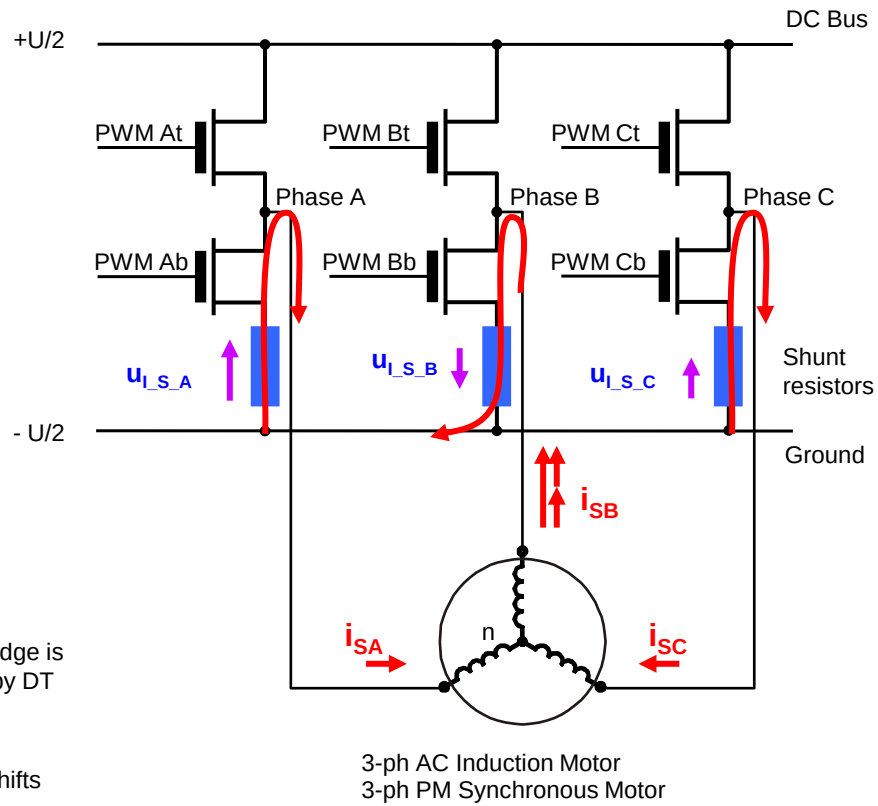
- ADC Sampling helps to filter the measured current



# Current Sensing with Shunt Resistors

- Shunt resistors voltage drop measured
- Dual-sampling required



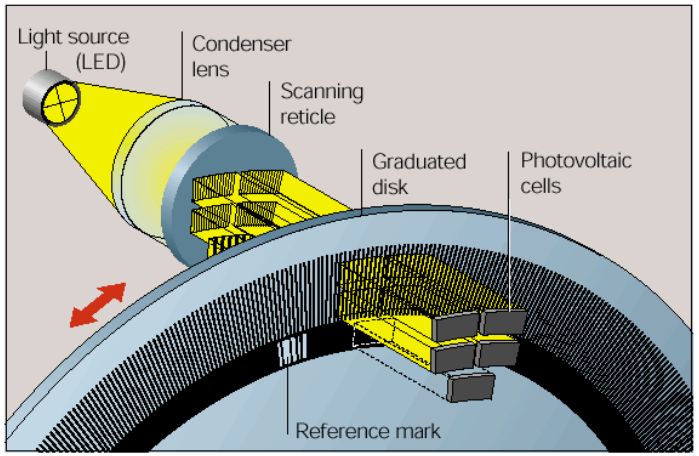
# Position Sensing

- Position and velocity measurement is often required in feedback loops
- Position measurement:
  - Potentiometers
  - Optical Encoders
  - Linear Variable Differential Transformer
  - Resolvers
  - Sin-Cos
- Velocity measurement:
  - Tachogenerator

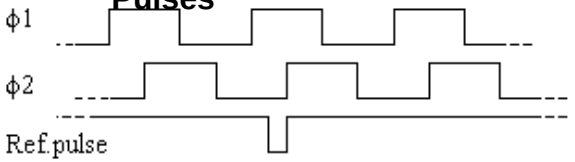
# Optical Encoders

- Encoders are digital Sensors commonly used to provide position feedback for actuators
- Consist of a glass or plastic disc that rotates between a light source (LED) and a pair of photo-detectors
- Disk is encoded with alternate light and dark sectors so pulses are produced as disk rotates
- The current position is calculated by incrementing/decrementing the pulse edges.
- The direction of counting is determined by phase shift of two quadrature pulses

**Scanning Principle**



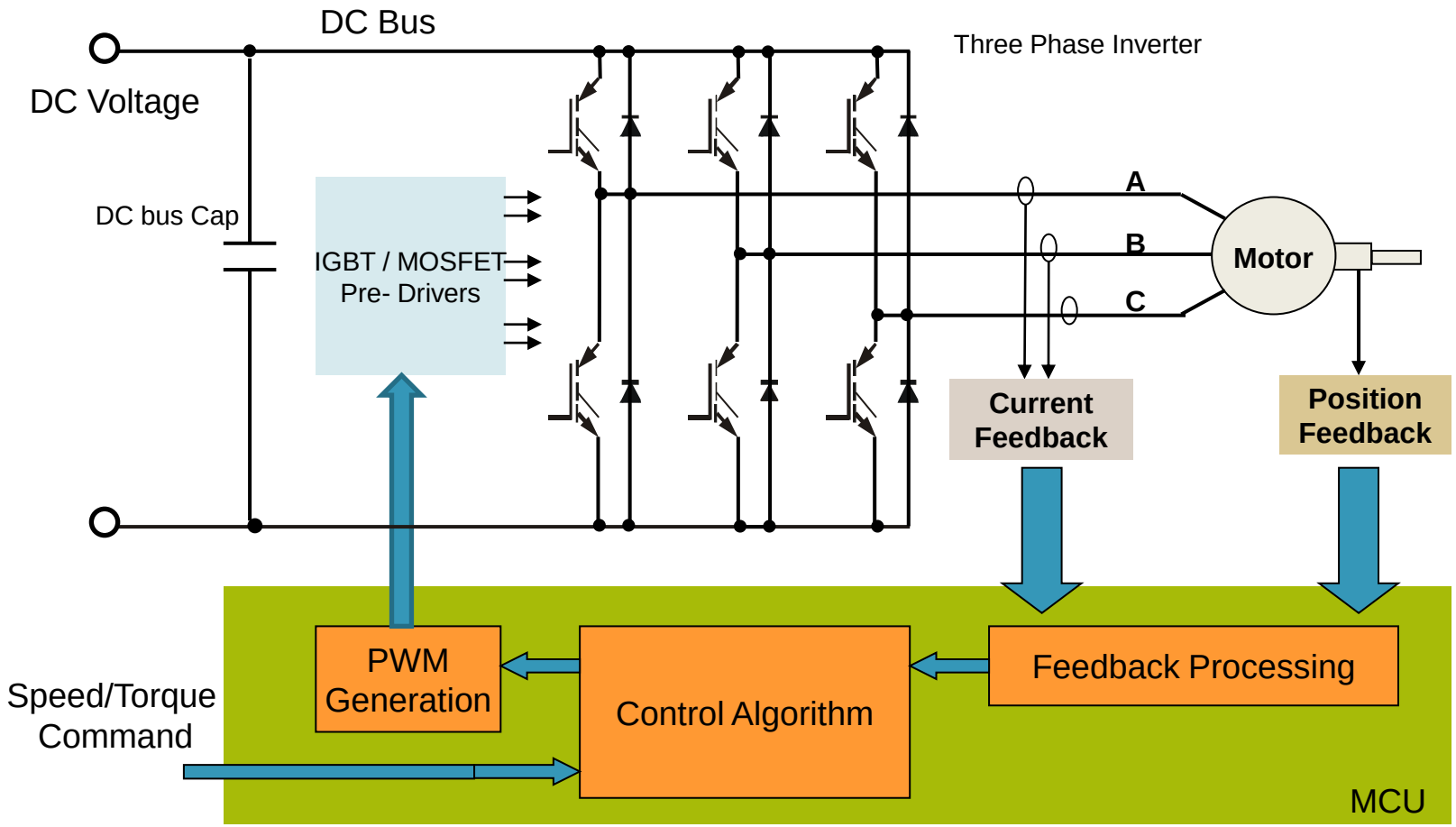

**Incremental Encoder Pulses**




There are 4 phases within one pulse cycle. You need for example (360/0.5)/4=180 pulses per rotation if 0.5deg resolution is wanted.

By courtesy of Heidenhain

# Motor Control Topology

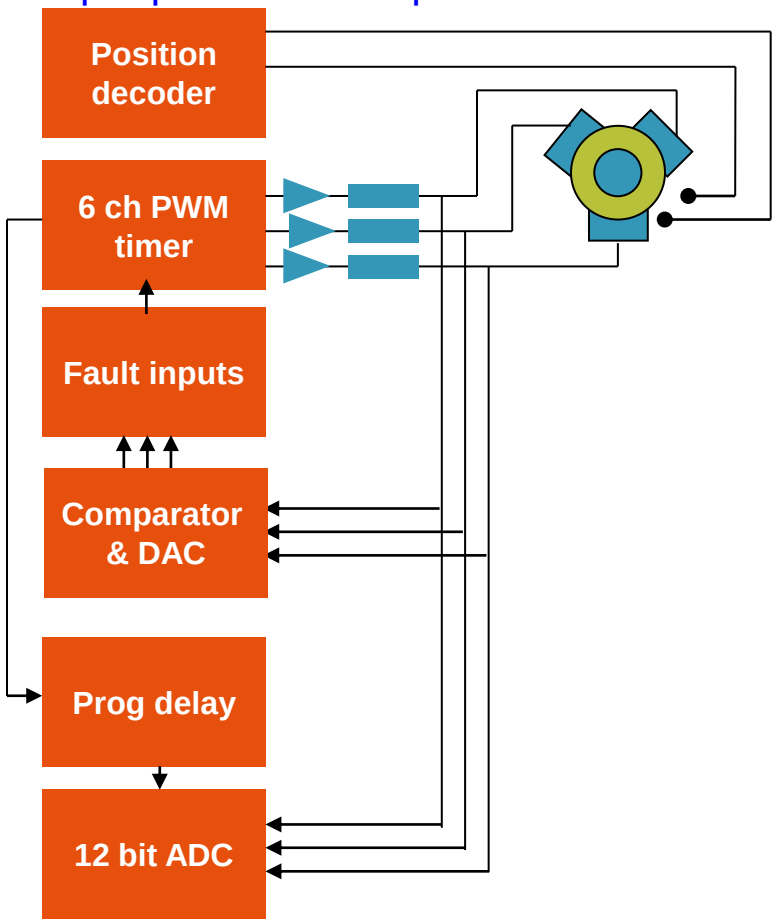


# Challenges in Motor Control Development

# Motor Control Challenges

Not just s/w, but combination of s/w algorithms and MCU peripherals with special features and mutual interconnection between them

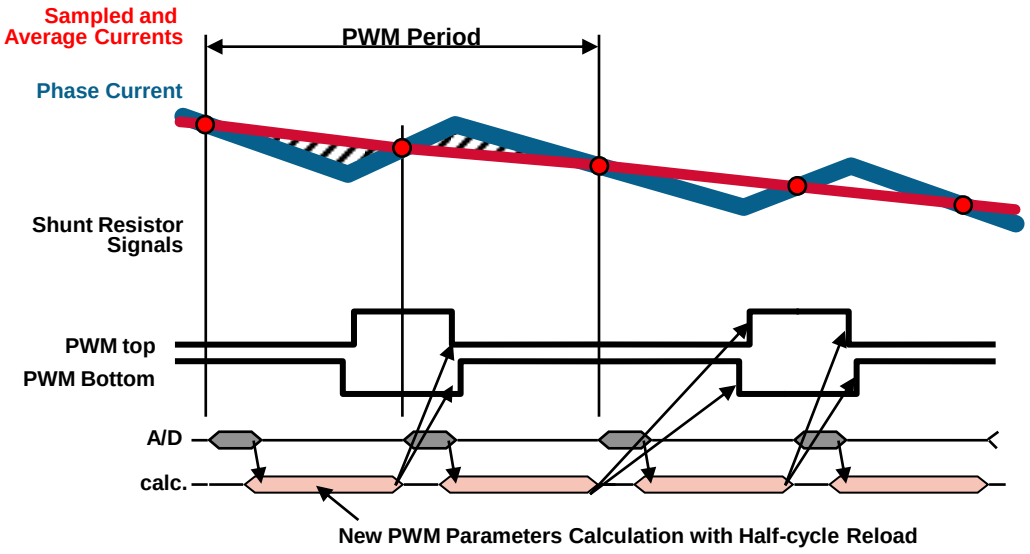
- **MC Timer**
  - PWM signals < 20Khz with dead time insertion
  - ADC triggering
  - Fault control
- **ADC**
  - Measure current, voltage, temperature
  - simultaneous sampling of two currents
  - ADC sampling synchronized with PWM
- **Delay block**
  - Set ADC measurement at specific times
- **Position decoder**
  - Quadrature decoder inputs if not sensorless
- **Comparator with DAC**
  - Eliminate need of external components



# Motor Control Challenges

Critical real time operation – interrupt each 25-125usec

- S/W must:
  - sample current, voltage at precise moment (synchronized with PWM)
  - calculate current control loop (filters, transformation, controllers, ripple elimination, estimators / observers)
  - calculate output values for PWM (SVM), update output registers
  - configure next ADC conversion
- Fast control loop for PMSM sensorless drive includes:
  - 63 MAC
  - 54 MUL
  - 6 DIV
  - 56 ADD/SUB
- Fast sensorless control loop takes:
  - 21 usec on 56800E core @ 100MHz



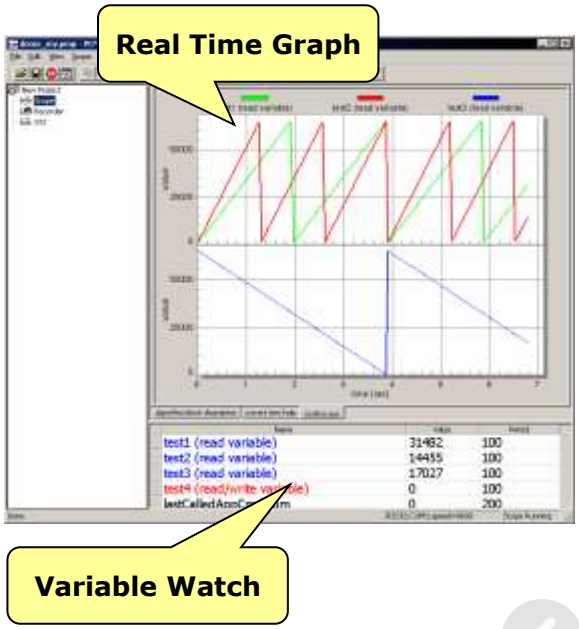
# Motor Control Challenges

- Electro- Mechanical System – debugging includes power h/w
  - Safety:
    - galvanic isolation between debugger and application required (opto, RF)
  - Debugging:
    - s/w cannot be just stopped during application debugging to see what's going on
    - Standard debugger not sufficient for motor control application debugging

FREEMASTER

**as a Real-time Debugger**

**- Variables**
**- Real-time waveforms**
**- High-speed recorded data**



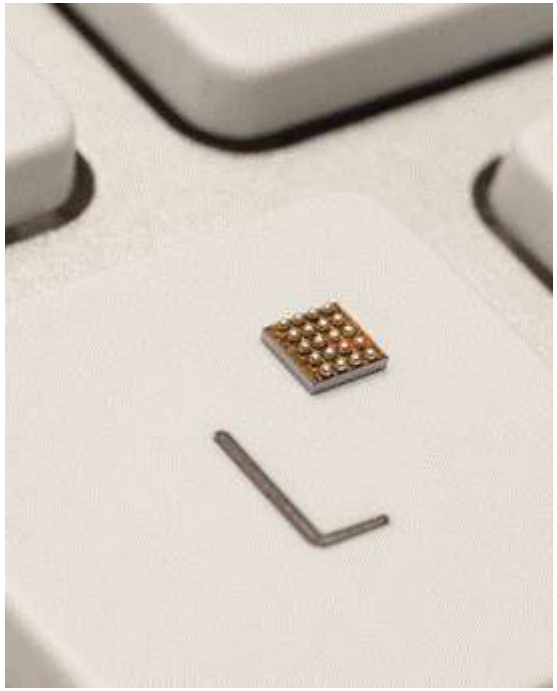
# Motor Control Challenges

## Solution at technical limits driven by cost

- Applications Complexity
  - low cost motors with wild parameters
  - low cost h/w, sensorless
  - limited CPU performance
  - low-cost MCU peripherals

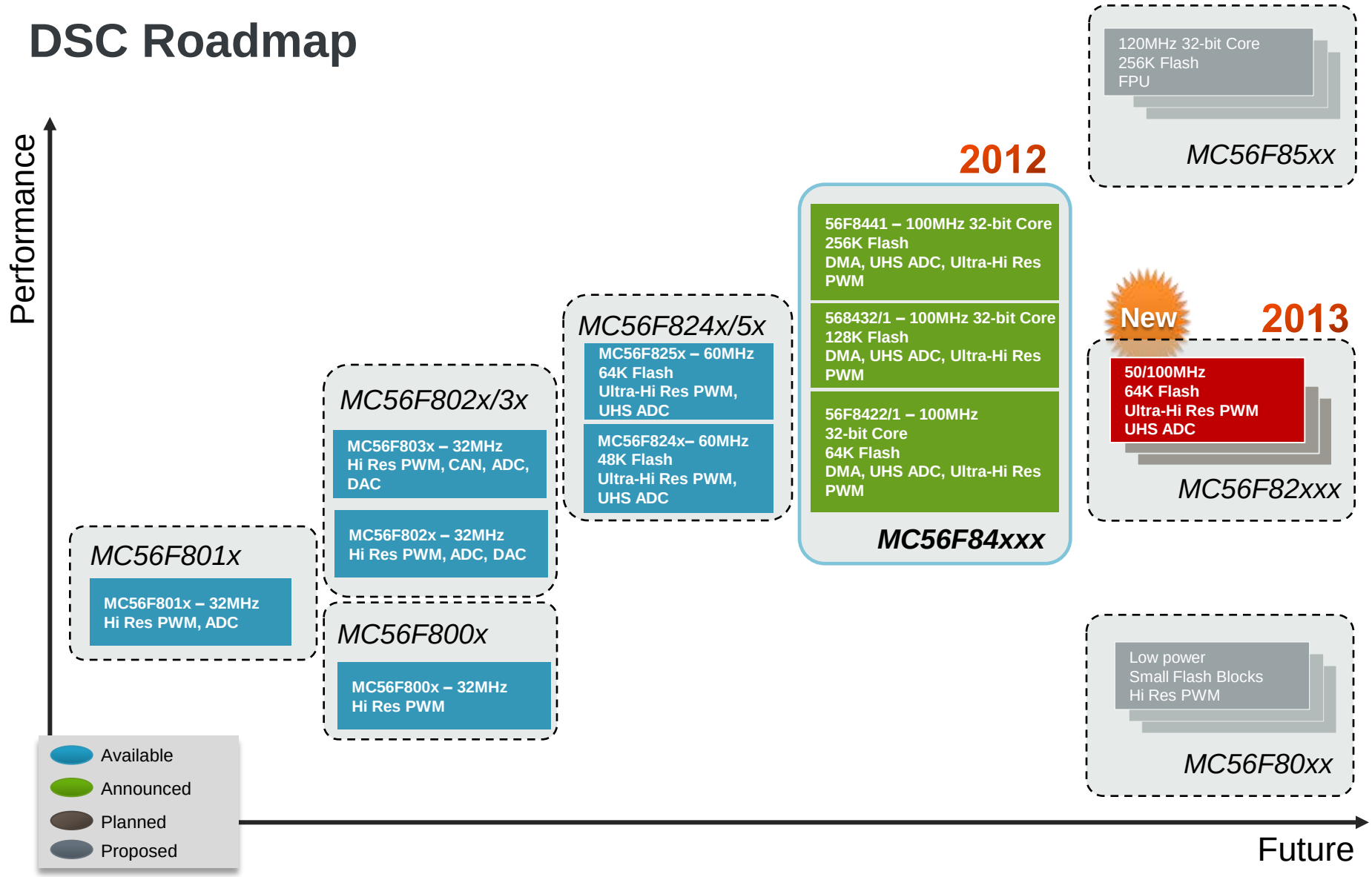
  - Applications development often requires expert MC know-how and experience

# DSC & it's Peripherals

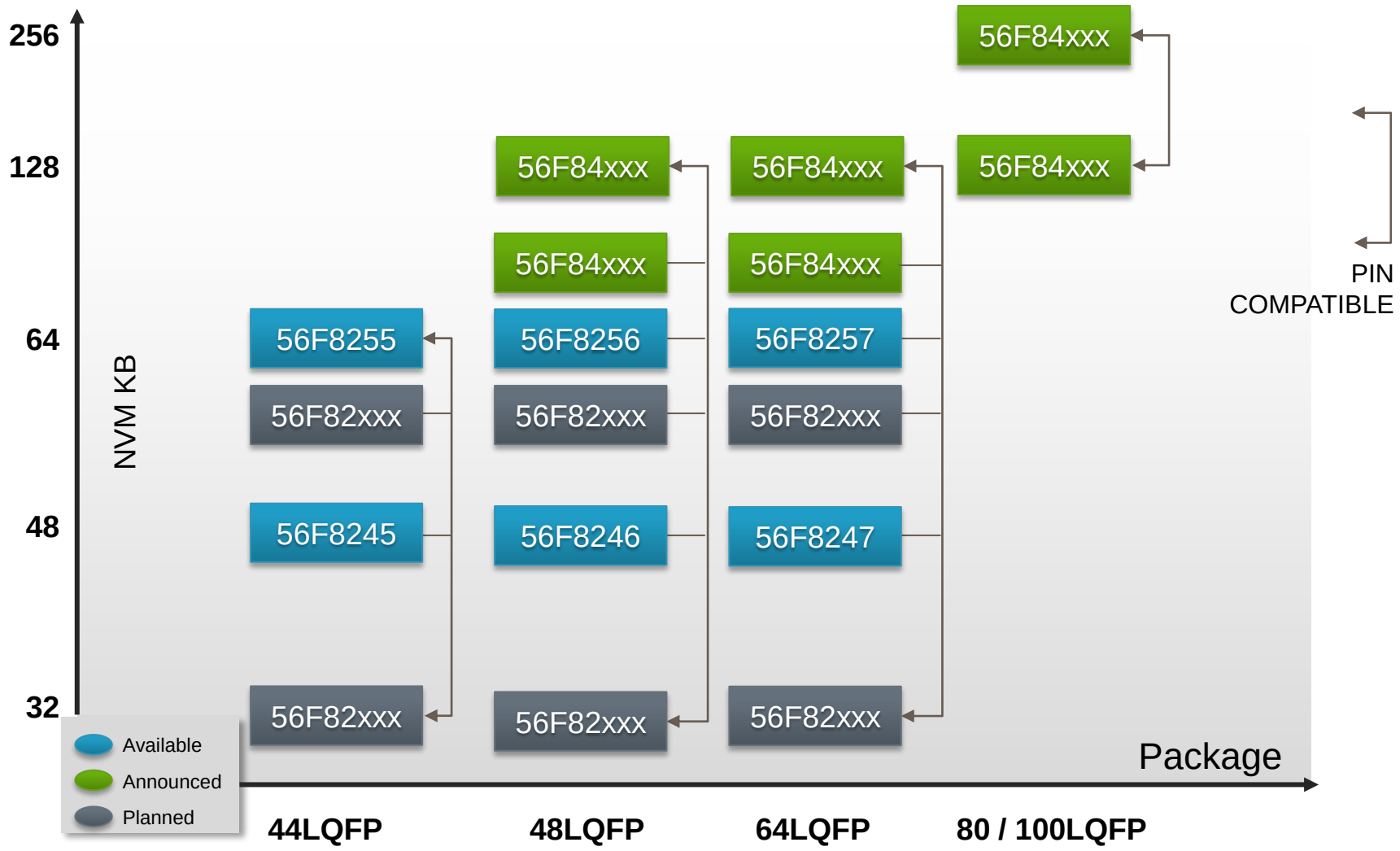


- For Motor Control and Power Conversion Applications

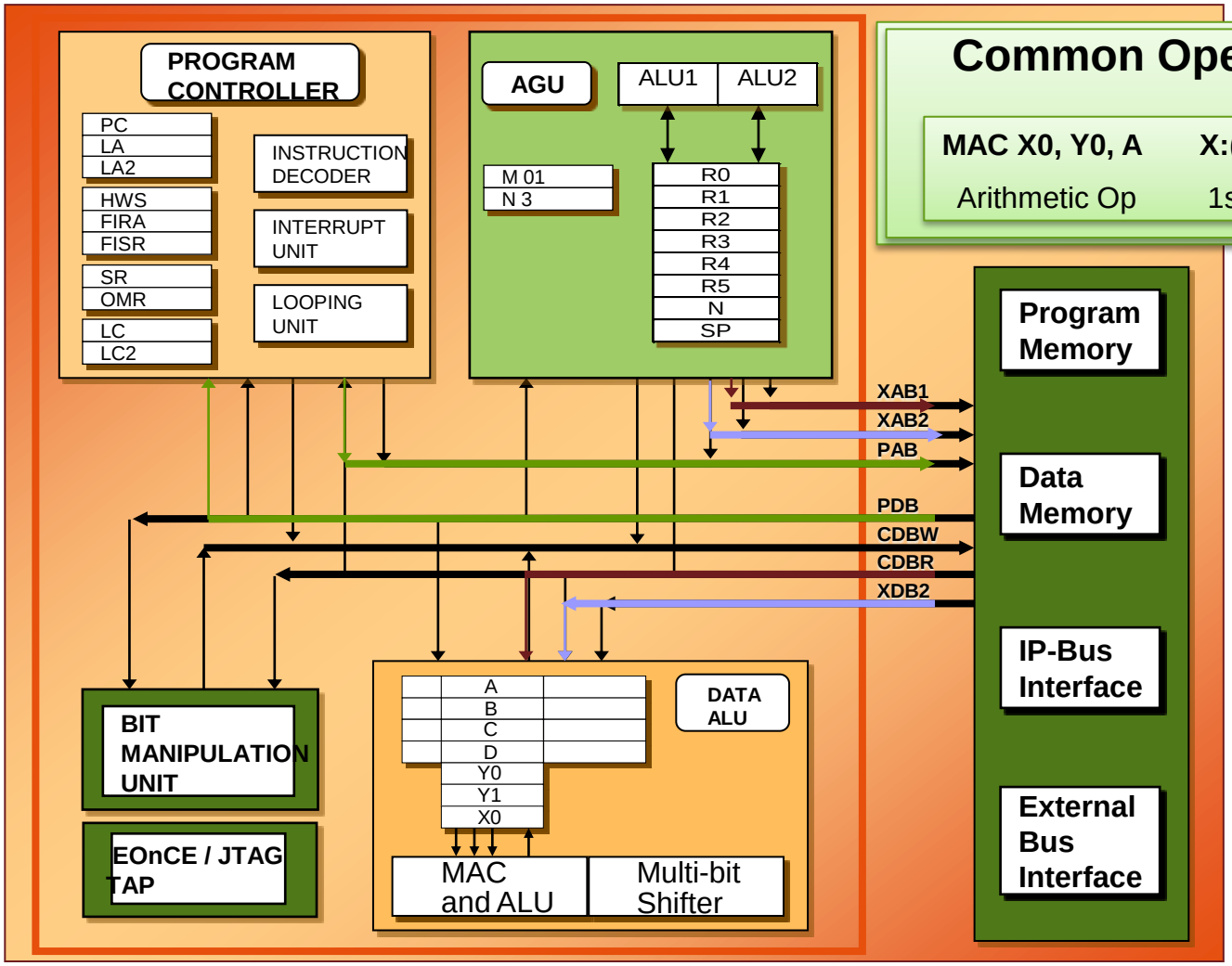
# DSC Roadmap


Performance
Future
2012
2013
New
MC56F801x
MC56F801x – 32MHz
Hi Res PWM, ADC
MC56F802x/3x
MC56F803x – 32MHz
Hi Res PWM, CAN, ADC, DAC
MC56F802x – 32MHz
Hi Res PWM, ADC, DAC
MC56F800x
MC56F800x – 32MHz
Hi Res PWM
MC56F824x/5x
MC56F825x – 60MHz
64K Flash
Ultra-Hi Res PWM, UHS ADC
MC56F824x– 60MHz
48K Flash
Ultra-Hi Res PWM, UHS ADC
56F8441 – 100MHz 32-bit Core
256K Flash
DMA, UHS ADC, Ultra-Hi Res PWM
568432/1 – 100MHz 32-bit Core
128K Flash
DMA, UHS ADC, Ultra-Hi Res PWM
56F8422/1 – 100MHz
32-bit Core
64K Flash
DMA, UHS ADC, Ultra-Hi Res PWM
MC56F84xxx
120MHz 32-bit Core
256K Flash
FPU
MC56F85xx
50/100MHz
64K Flash
Ultra-Hi Res PWM
UHS ADC
MC56F82xxx
Low power
Small Flash Blocks
Hi Res PWM
MC56F80xx
Available
Announced
Planned
Proposed

# Freescale DSC Family Compatibility



# Mapping the Architecture to DSP Algorithms




## Common Operation in DSP

| MAC X0, Y0, A | X:( R4)+, Y1 | X:( R3)+, C |
|---|---|---|
| Arithmetic Op | 1st Read | 2nd Read |

**Operations Performed:**

- Multiply-Accumulate
- 3 Memory Accesses
- 2 Address Additions

***Instruction Fetch:***

_PAB - 21 bits
PDB - 16 bits

***1st Data Access:***

XAB1 - 24 bits
CDBR - 32 bits

***2nd Data Access:***

XAB2 - 24 bits
XDB2 - 16 bits

# DSP56800E Version 3 Core Improvement

(the differences between V2 core and V3 core)

## New Instructions

- 32 x 32 -> 32/64 Multiply and MAC Instructions
  - ✓ IMAC32 - Integer Multiply-Accumulate 32 bits x 32 bits -> 32 bits
  - ✓ IMPY32 - Integer Multiply 32 bits x 32 bits -> 32 bits
  - ✓ IMPY64 - Integer Multiply 32 bits x 32 bits -> 64 bits
  - ✓ IMPY64UU - Unsigned Integer Multiply 32 bits x 32 bits -> 64 bits
  - ✓ MAC32 - Fractional Multiply-Accumulate 32 bits x 32 bits -> 32 bits
  - ✓ MPY32 - Fractional Multiply 32 bits x 32 bits -> 32 bits
  - ✓ MPY64 - Fractional Multiply 32 bits x 32 bits -> 64 bits

- Multi-Bit Clear-Set instruction to improve flexibility of peripheral register handling – BFSC (test bitfield and set/clear).

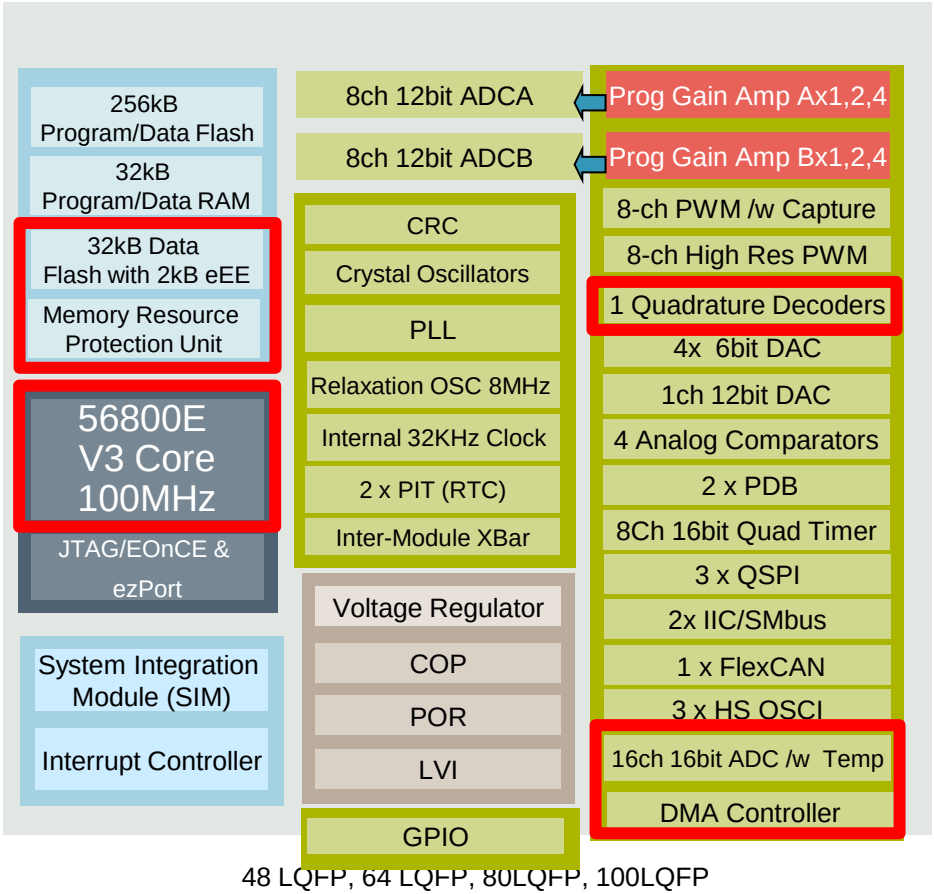
## Other Features

- Bit Reversed Address Mode For FFT algorithms.
- Swap all address generation Unit Registers with Shadowed registers to reduce Interrupt context switch latency.

# MC56F84xx Features

- 100 MHz/100MIPS 56800 V3 Core
  - Harvard architecture
  - 32 x 32bit MAC and 32bit arithmetic operation
- 2.7-3.6V Operation
- 256kB Program/Data FLASH
- 32kB Data Flash with up to 2kB of eEE
- 32kB Data/Program RAM
- Resource Protection Unit

- 3 HS-QSCI (8MBS) , 3xQSPI, 2xIIC/SMBus, 1xFlexCAN
- Multi-purpose timers
  - 2 Periodic Timers with Real Time Interrupt Generation
  - 2 Programmable Delay Blocks
  - 8Ch multifunction timers
- 8ch High Resolution PWM Channels
  - **312ps PWM and PFM resolution**
- 8ch PWM Channels with Input Capture
- 8ch x 2 12-bit ADC converter with built-in PGA
  - **300ns/3.33Msps conversion time with 12bit resolution**
- 8ch 16bit SAR ADC with built-in temperature sensor and band gap.
  - 2us conversion time.
- 4 Analog Comparators
- 1 Quadrature Decoder
- 1ch 12bit DAC with external outputs + 4ch 6bit DAC
- DMA controller
- Inter-Module Crossbar
- On-chip voltage regulator (Single 3.3V Power Supply)
- System Integration : Internal relaxation oscillator, PLL, COP, 32kHz , EWM, auxiliary Internal clock, low voltage detect, EZPort
- 5V tolerant I/O
- Temperature Range: -40°C to +105°C

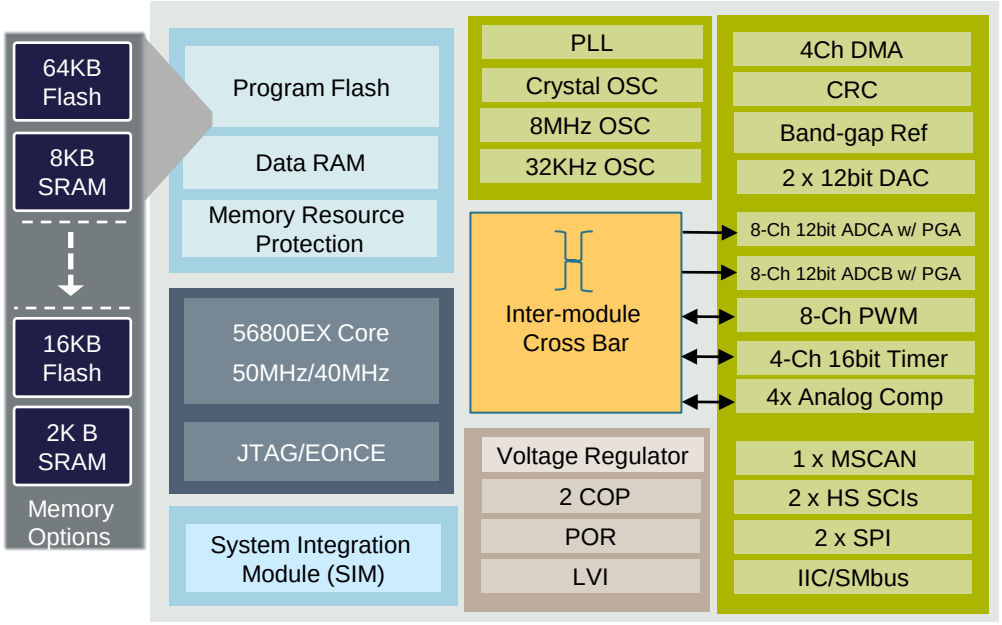



48 LQFP, 64 LQFP, 80LQFP, 100LQFP

# 56F8400 Series Feature Summary

| | Fully Featured Digital Control | | | | Digital Control | | | | | | Dual Motor | | | | Single Motor | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Part Number | | | | | | | | | | | | | | | | | | |
| Core MHz | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 80 | 80 | 80 | 80 | 60 | 60 | 60 | 60 |
| Flash Mem (kB) | 256 | 256 | 128 | 128 | 128 | 128 | 64 | 64 | 128 | 128 | 256 | 256 | 128 | 128 | 128 | 128 | 64 | 64 |
| SRAM Mem (kB) | 32 | 32 | 24 | 24 | 24 | 24 | 16 | 16 | 24 | 24 | 32 | 32 | 16 | 16 | 16 | 16 | 8 | 8 |
| Data Flash / EE Mem (kB) | 32/2 | 32/2 | 32/2 | 32/2 | 32/2 | 32/2 | 32/2 | 32/2 | 0 | 0 | 32/2 | 32/2 | 32/2 | 32/2 | 0 | 0 | 0 | 0 |
| Cyc ADC Chn | 2x8 | 2x8 | 2x8 | 2x8 | 2x8 | 2x8 | 2x8 | 2x8 | 2x5 | 2x5 | 2x8 | 2x8 | 2x8 | 2x8 | 2x8/2x5 | 2x8/2x5 | 2x8/2x5 | 2x8/2x5 |
| SAR ADC Chn | 1x16 | 1x16 | 1x16 | 1x16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PWM uE Chn | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 0 | 0 | 0 | 0 |
| PWM stnd Chn | 8 | 8 | 8 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| DAC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quad Decoder | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DMA | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| CMP | 4 | 4 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| QSCI | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| QSPI | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| I2C | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| FlexCAN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| Package | 100 | 80 | 100 | 80 | 80 | 64 | 80 | 64 | 64 | 48 | 100 | 80 | 100 | 80 | 64 | 48 | 64 | 48 |

# MC56F82xxx




32QFN, 32LQFP, (44LQFP), 48LQFP & 64LQFP

Packages will be pin compatible
with the MC56F824x/5x and MC56F84xx

**Breakthrough Features:**
**High speed ADC @ 800ns conversion time**
**Nano Edge PWM @ 512ps Resolution**
**Inter-module Cross bar**
**DMA**
**Memory Resource Protection Unit**

- **56800EX V3 Core @ 50MHz (100MHz from RAM)**
- 2.7-3.6V Operation

- Up to 64KB Program FLASH ,with Flash Security
- Up to 6KB Program/Data RAM
- **Memory Resource Protection Unit**

- Up to 100 MHz Peripherals – Timers and SCIs

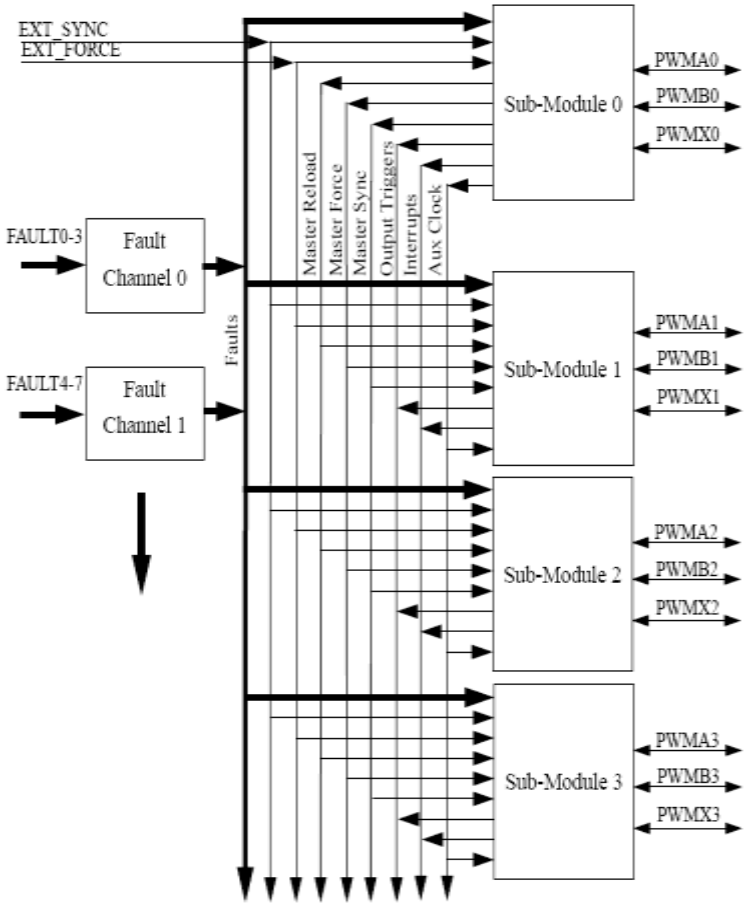
- **Eight Channel Nano Edge PWM (512ps resolution)**
  - Up to four programmable fault protection input
  - Dead-time insertion
  - Input Capture function
- **2 x12-bit ADCs with total 16 Inputs & PGAs 1x, 2x, 4x**
  - 800ns conversion rate
  - Band-gap reference
- **Four channel DMA controller**
- **Inter Module cross-bar**
- 4 x Comparators with a 6bit Voltage reference
- CRC Generator
- 2 x Windowed Watchdog
- External Watchdog Monitor
- 4 x 16-bit Enhanced Multifunction Programmable Timers
- 2 x 12b DAC
- 2 x High Speed SCI
- 2 x SPI
- 1x $I^2C$/SMbus Communications Interface
- Software Programmable Phase Locked Loop
- Multiple Clock sources
  - External Crystal/Resonator Oscillator
  - 8MHz/200KHz Tunable Internal Relaxation Oscillator
  - **32KHz Internal RC relaxation Oscillator**
- 5v Tolerant IO
- Error code correction
- Industrial temperature:-40C to 105C @ 50MHz

# 56F82xxx Series Feature Summary

| Part Number | MC56F82 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 748VLH | 746VLF | 743VLC | 743VFM | 738VLH | 736VLF | 733VLC | 733VFM | 728VLH | 726VLF | 723VLC | 723VFM |
| Core frequency (MHz) | 100/50 | 100/50 | 100/50 | 100/50 | 100/50 | 100/50 | 100/50 | 100/50 | 100/50 | 100/50 | 100/50 | 100/50 |
| Flash memory (KB) | 64 | 64 | 64 | 64 | 48 | 48 | 48 | 48 | 32 | 32 | 32 | 32 |
| RAM (KB) | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 6 | 6 | 6 | 6 |
| 12-bit Cyclic ADC channels | 2x8 | 2x5 | 2x3 | 2x3 | 2x8 | 2x5 | 2x3 | 2x3 | 2x8 | 2x5 | 2x3 | 2x3 |
| PWMA with input capture: | | | | | | | | | | | | |
| High-resolution channels | 1x8 | 1x6 | 1x6 | 1x6 | 1x8 | 1x6 | 1x6 | 1x6 | 1x8 | 1x6 | 1x6 | 1x6 |
| Standard channels | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12-bit DAC | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| DMA | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| CMP | 4 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 4 | 3 | 3 | 3 |
| QSCI | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| QSPI | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 |
| I2C/SMBus | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| MSCAN | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| GPIO | 54 | 39 | 26 | 26 | 54 | 39 | 26 | 26 | 54 | 39 | 26 | 26 |
| LQFP package pin count | 64 LQFP | 48 LQFP | 32 LQFP | 32 QFN | 64 LQFP | 48 LQFP | 32 LQFP | 32 QFN | 64 LQFP | 48 LQFP | 32 LQFP | 32 QFN |

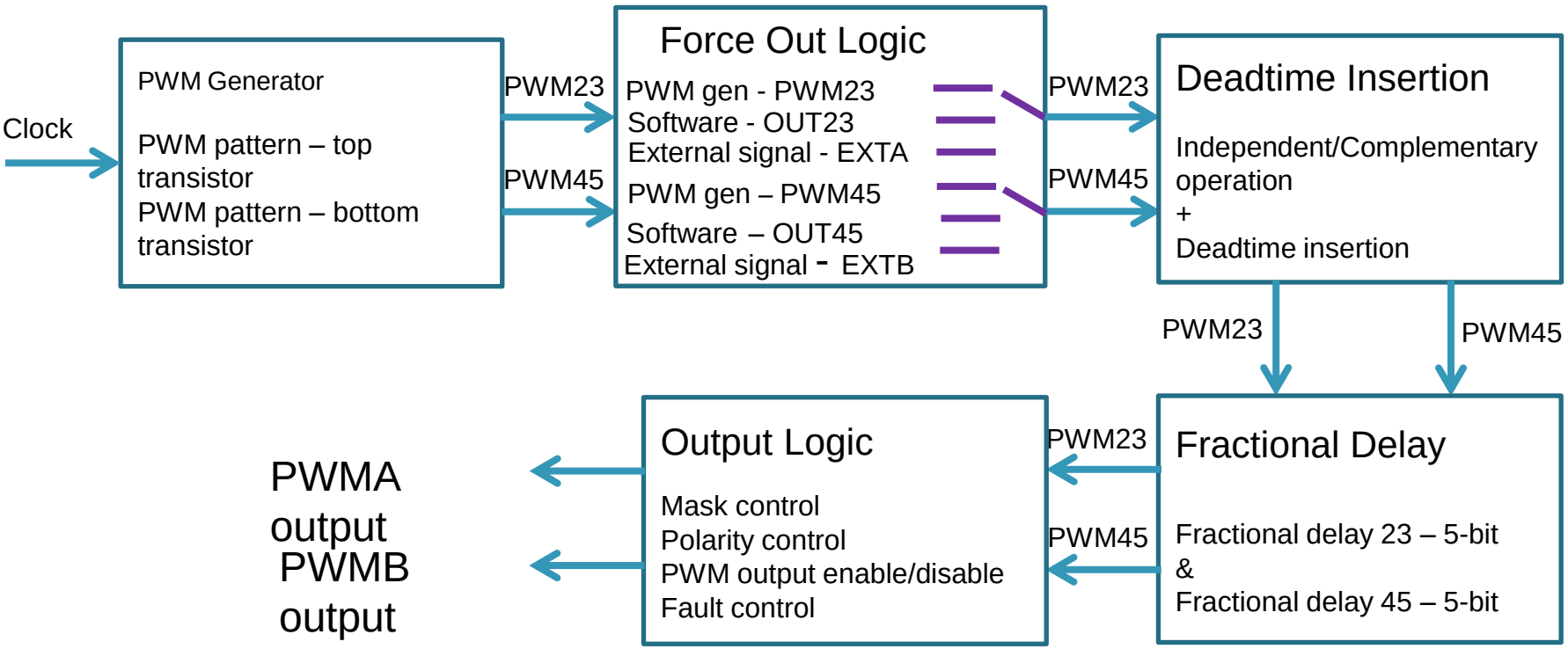
# Enhanced Flex Pulse Width Modulator (eFlexPWM)

- Four independent sub-modules with own time base, two PWM outputs + 1 auxiliary PWM input/output
- 16 bits resolution for center, edge aligned, and asymmetrical PWMs
- Fractional delay for enhanced resolution of the PWM period and edge placement
- Complementary pairs or independent operation
- Independent control of both edges of each PWM output
- Synchronization to external hardware or other PWM sub-modules
- Double buffered PWM registers
- Integral reload rates from 1 to 16 include half cycle reload
- Half cycle reload capability
- Multiple output trigger events per PWM cycle
- Support for double switching PWM outputs
- Fault inputs can be assigned to control multiple PWM outputs
- Programmable filters for fault inputs
- Independently programmable PWM output polarity
- Independent top and bottom deadtime insertion
- Individual software control for each PWM output
- Software control, and swap features via FORCE_OUT event
- Compare/capture functions for unused PWM channels
- Enhanced dual edge capture functionality



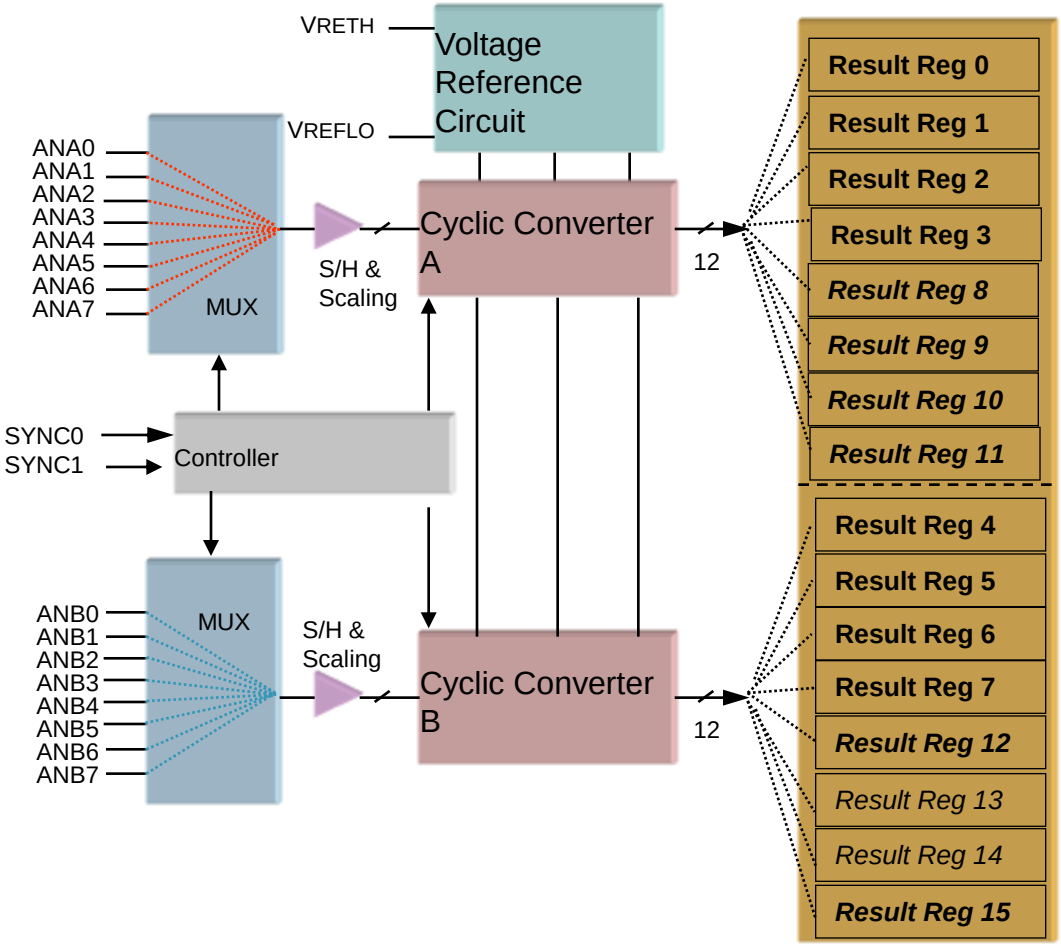
# eFlexPWM – 56F824x/5x – Block Diagram – Sub-ModuleX

## PWM generation – block diagram



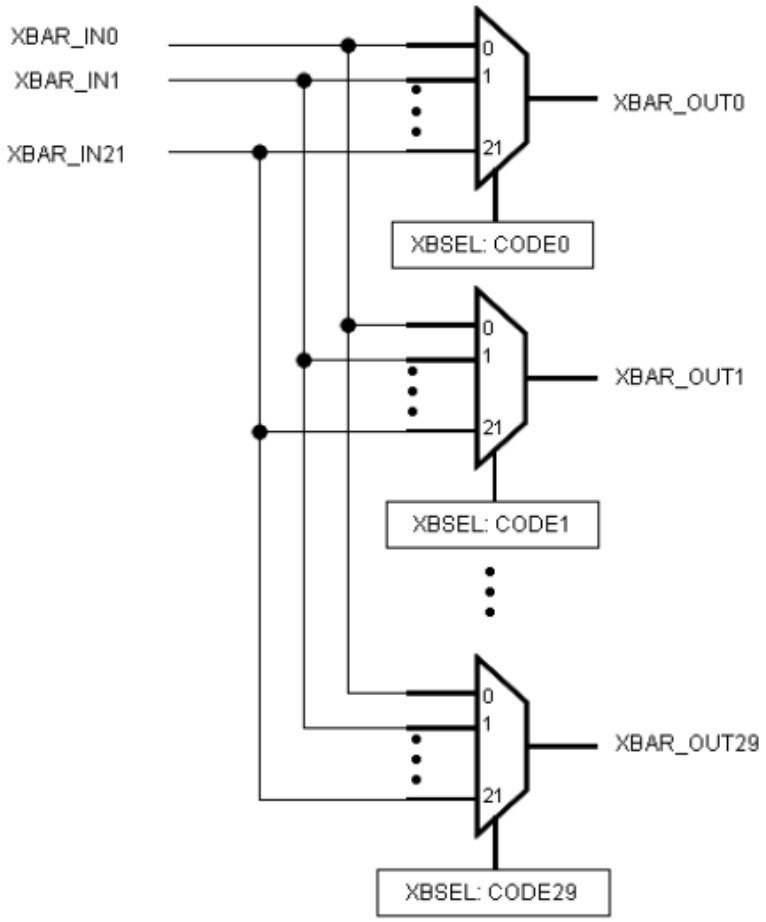
# A/D Converter

- 12-bit resolution
- Single conversion time of 8.5 ADC clock cycles (8.5 × 50 ns = 450 ns)
- Additional conversion time of 6 ADC clock cycles (6 × 50 ns = 300 ns)
- ADC to PWM synchronization
- Scans and stores up to eight measurements each on two ADC converters
- Multi-triggering support
- Gains the input signal by x1, x2, or x4
- Optional sample correction by subtracting a pre-programmed offset value

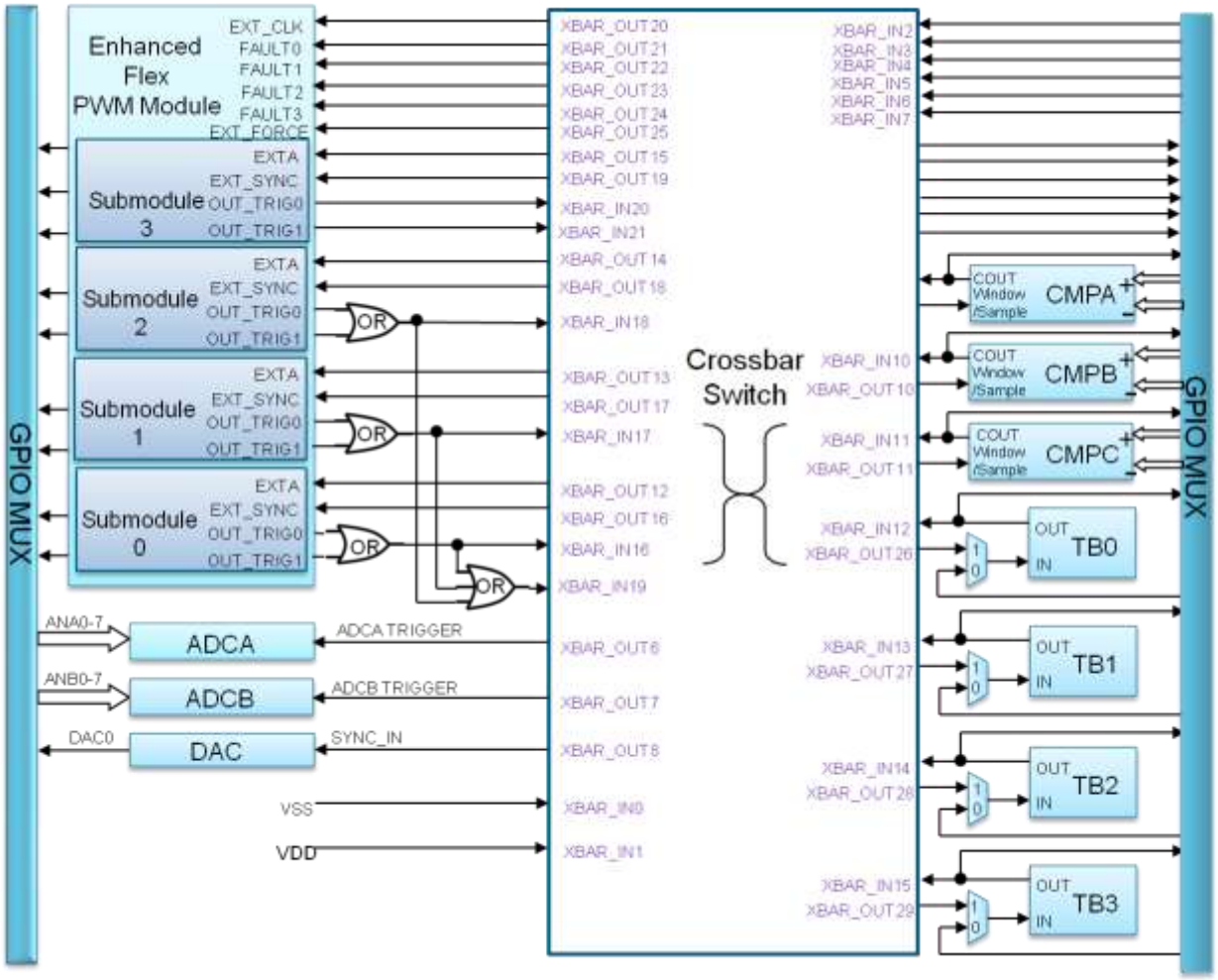


# Crossbar Switch – MC56F824x/5x

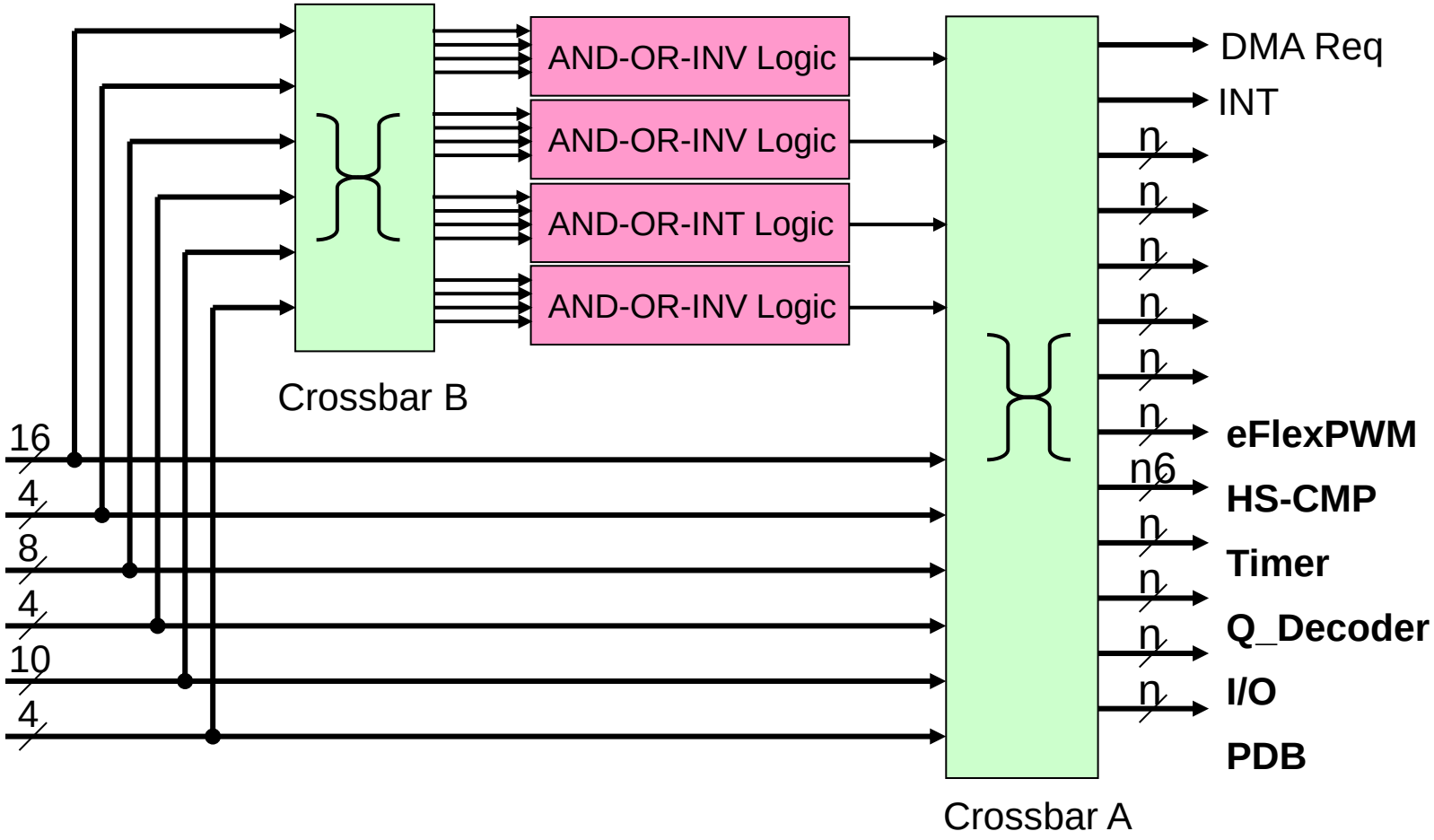
- Flexible signal interconnection among peripherals
- Connects any of 22 signals on left side to the output on right side (multiplexer)
- Total 30 multiplexers
- All multiplexers share the same set of 22 signals
- Increase flexibility of peripheral configuration according to user needs



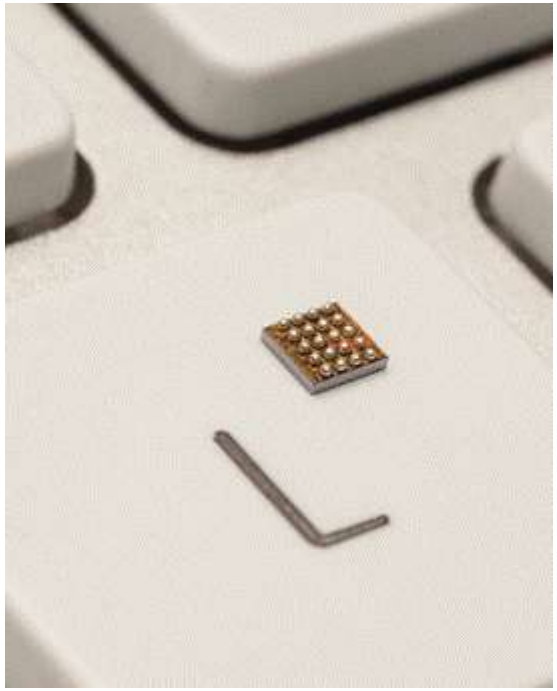
# Crossbar Inter-module Connection–MC56F824x/5x



# Crossbar Inter-module Connection – MC56F84xxx



# Kinetis V & it’s Peripherals

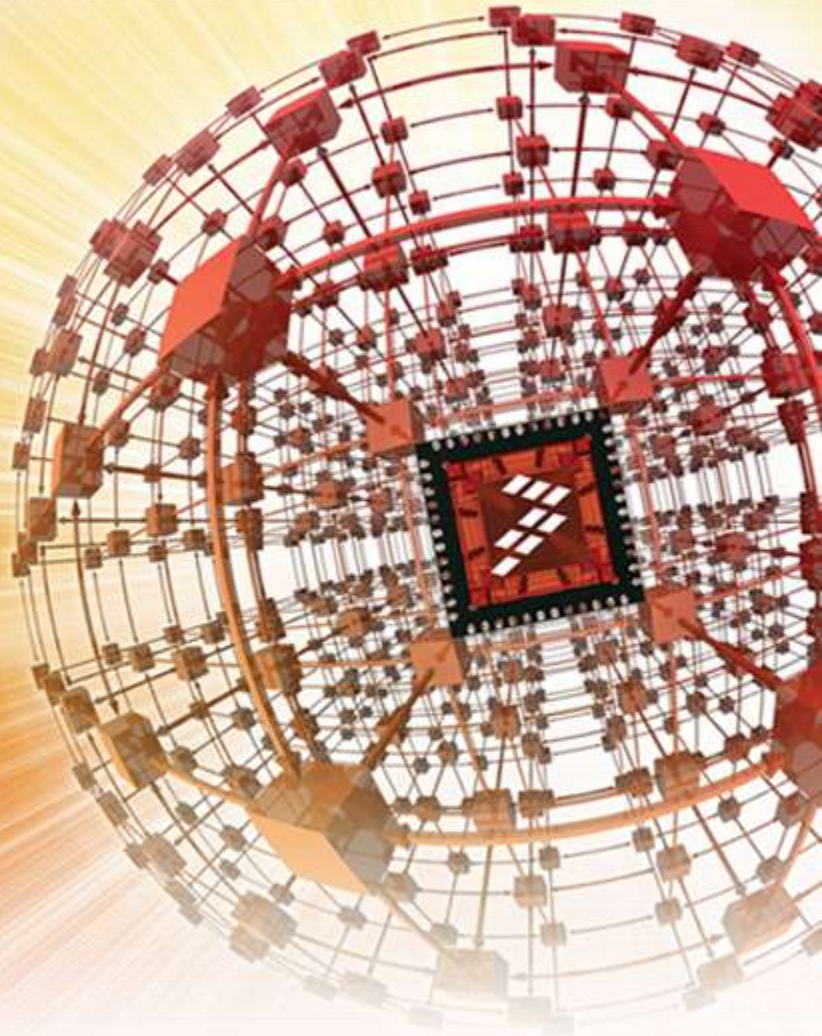


- For Motor Control Applications

# Kinetis V-Series

## Motor & Power Control

- **Full Kinetis portfolio compatibility** targeting low cost, stand alone motor control, to high performance digital power conversion
- **Optimized for processing efficiency** with performance ranging from 75MHz to beyond 200MHz
- ARM architecture with best in class, **high speed capture and control peripherals** for motor control and power management applications
- Enablement and tools built around reducing customer development time and cost, whilst increasing ease of use.



# Kinetis V Series Target Applications

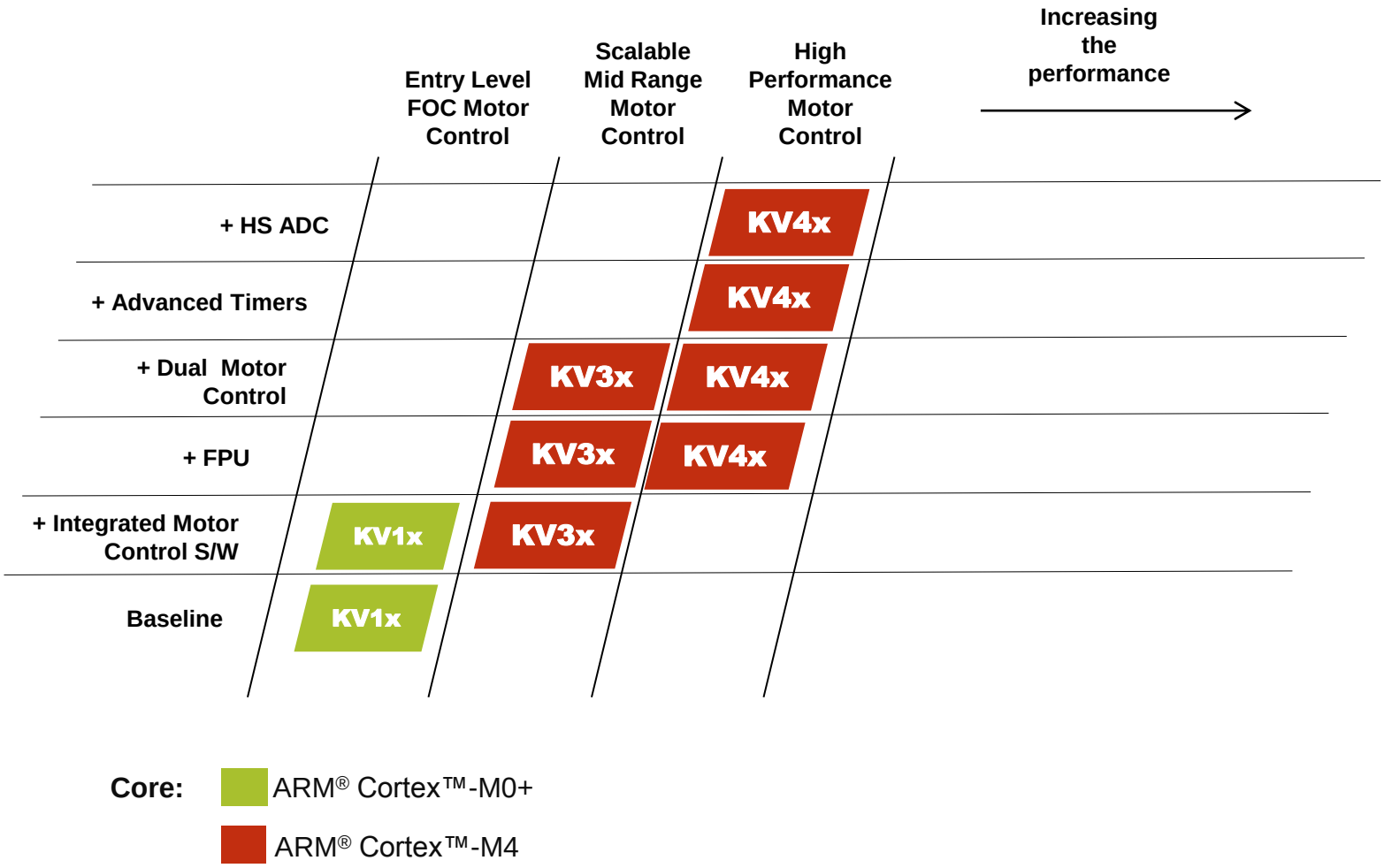
## Motor Control

- Sensored BLDC / PMSM
  - High Dynamic Control
- Sensored ACIM
- Sensorless VOC
  - PMSM/BLDC
  - High Dynamic Control
  - Low Dynamic Control
- Sensorless ACIM

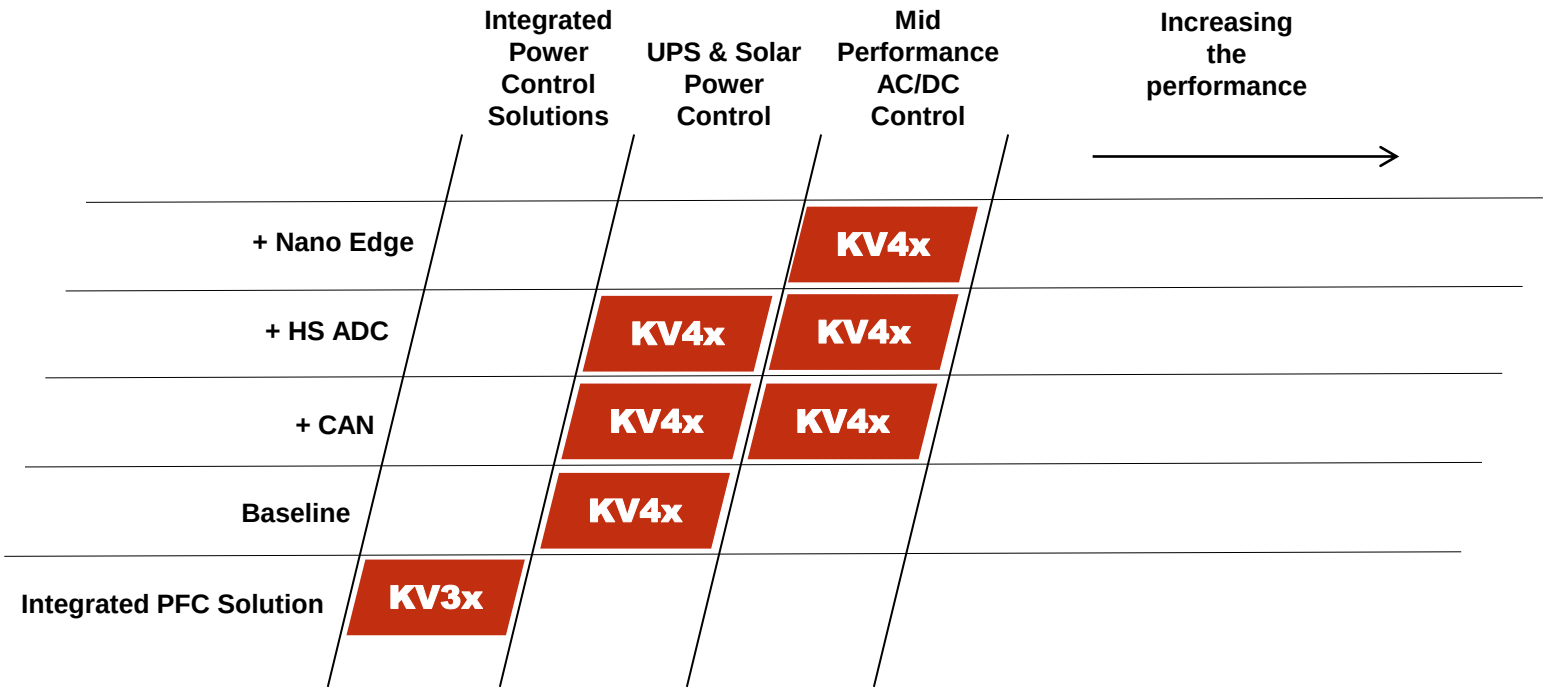
## Digital Power Conversion

- Solar Inverters
  - Grid-Tied
  - Non Grid Tied
- Power factor correction
- Switch Mode Power Supplies
  - AC/DC
  - DC/DC
- UPS
  - On-Line
  - Offline
- Inductive cooking
  - Multi cook plate

# Kinetis V Series For Motor Control



# Kinetis V Series For Power Control



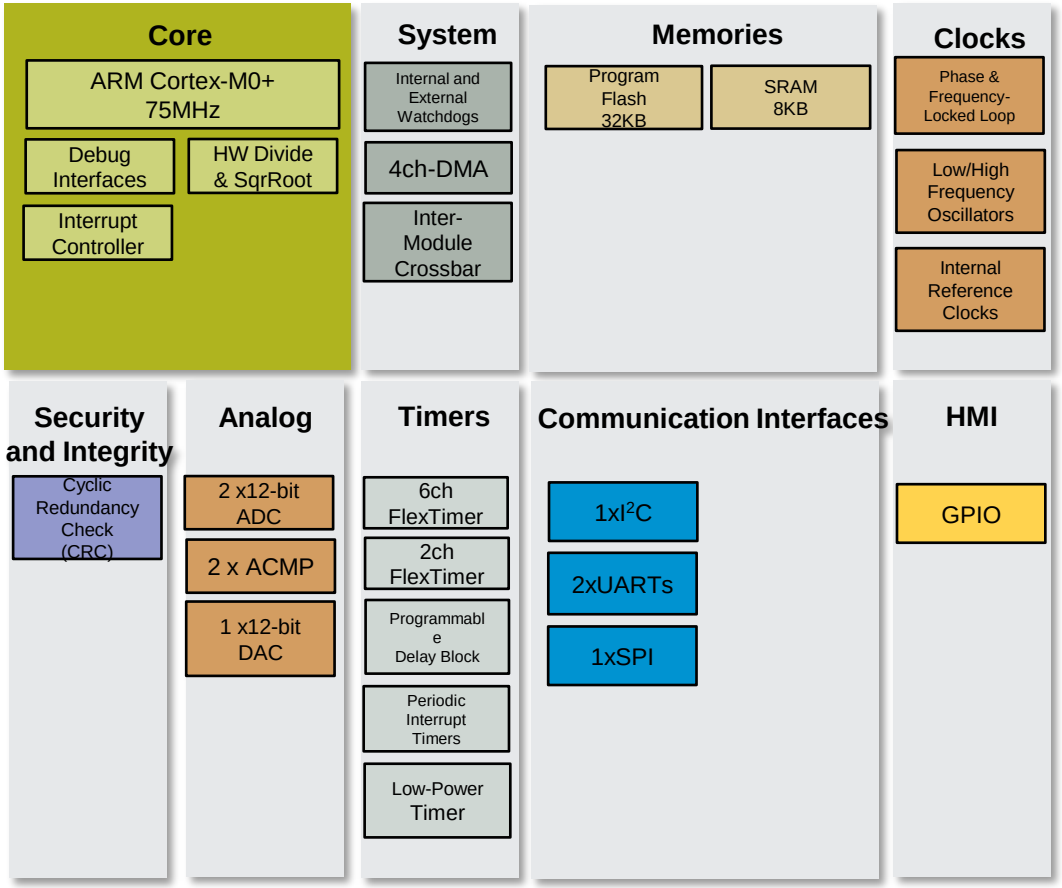

**Core:** ARM® Cortex™-M0+

ARM® Cortex™-M4

# KV1x: 75MHz Cortex-M0+

**Key Features:**

- **Core/System**
  - 75MHz **Cortex-M0+** with 4ch DMA
    - Hardware divide & SqrRoot
- **Memory**
  - 32KB Flash
  - 8KB SRAM
- **Communications**
  - Multiple serial ports
- **Analog**
  - 2 x 8ch 12-bit ADC (1uS conv)
  - 1 x12-bit DAC
  - 2 x ACMP w/ 6b DAC
- **Timers**
  - 1x6ch FlexTimer (PWM)
  - 1x2ch FlexTimer (PWM/Quad Dec.)
  - Programmable Delay Block
- **Others**
  - 32-bit CRC
  - Intermodule Crossbar Switch
  - Up to 35 I/Os
  - 1.71V-3.6V; -40 to 105oC
- **Packages**
  32QFN, 32LQFP, 48LQFP




*Typical applications:*

- *BLDC sensorless*
- *PMSM Sensorless FOC Low Dynamic*
- *ACIM V/Hz and FOC Low Dynamic*

# KV1xs 75MHz: Part Numbers

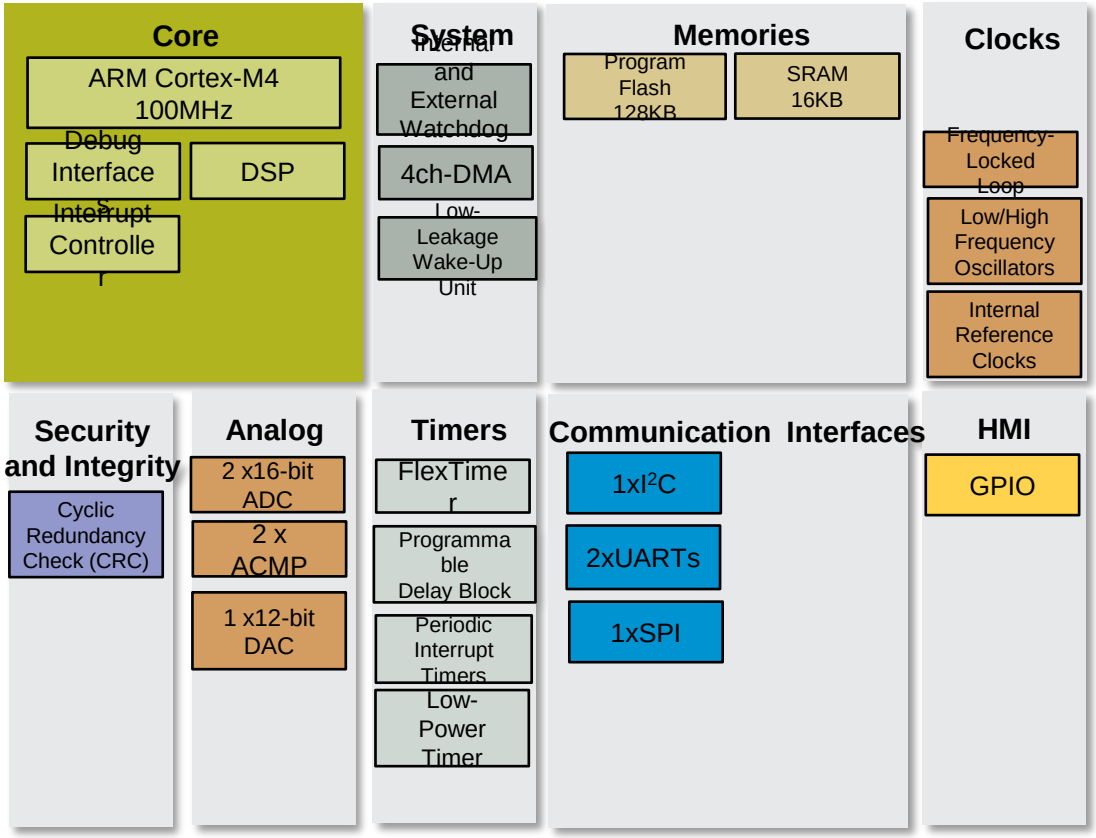
| MC Part Number | Max. Freq. | Pin Count | Package | Flash | SRAM | DMA | PLL | FTMs | DAC |
|---|---|---|---|---|---|---|---|---|---|
| MKV10Z32VLF7 | 75MHz | 48 | LQFP | 32K | 8KB | 4-ch | Yes | 1x6ch; 1x2ch | 1 |
| MKV10Z32VLC7 | 75MHz | 32 | LQFP | 32K | 8KB | 4-ch | Yes | 1x6ch; 1x2ch | 1 |
| MKV10Z32VFM7 | 75MHz | 32 | QFN | 32K | 8KB | 4-ch | Yes | 1x6ch; 1x2ch | 1 |
| MKV10Z16VLF7 | 75MHz | 48 | LQFP | 16K | 8KB | 4-ch | Yes | 1x6ch; 1x2ch | 1 |
| MKV10Z16VLC7 | 75MHz | 32 | LQFP | 16K | 8KB | 4-ch | Yes | 1x6ch; 1x2ch | 1 |
| MKV10Z16VFM7 | 75MHz | 32 | QFN | 16K | 8KB | 4-ch | Yes | 1x6ch; 1x2ch | 1 |

# KV3x – 128K Flash – 100MHz

**Key Features:**

- **Core/System**
  - Cortex-M4 @ 100MHz
- **Memory**
  - 128KB Flash,
  - 16KB SRAM
- **Communications**
  - Multiple serial ports
- **Analog**
  - 2 x16-bit ADC
  - 1 x12-bit DAC
  - 2 x ACMP
- **Timers**
  - 1x6ch FTM (PWM)
  - 2x2ch FTM (PWM/Quad Dec.)
  - Low Power Timer
- **Others**
  - Up to TBD I/Os
  - 6 high-drive I/Os (20mA) – SPI/I2C
  - 1.71V-3.6V; -40 to 105oC
- **Packages**

  32QFN, 48LQFP, 64LQFP



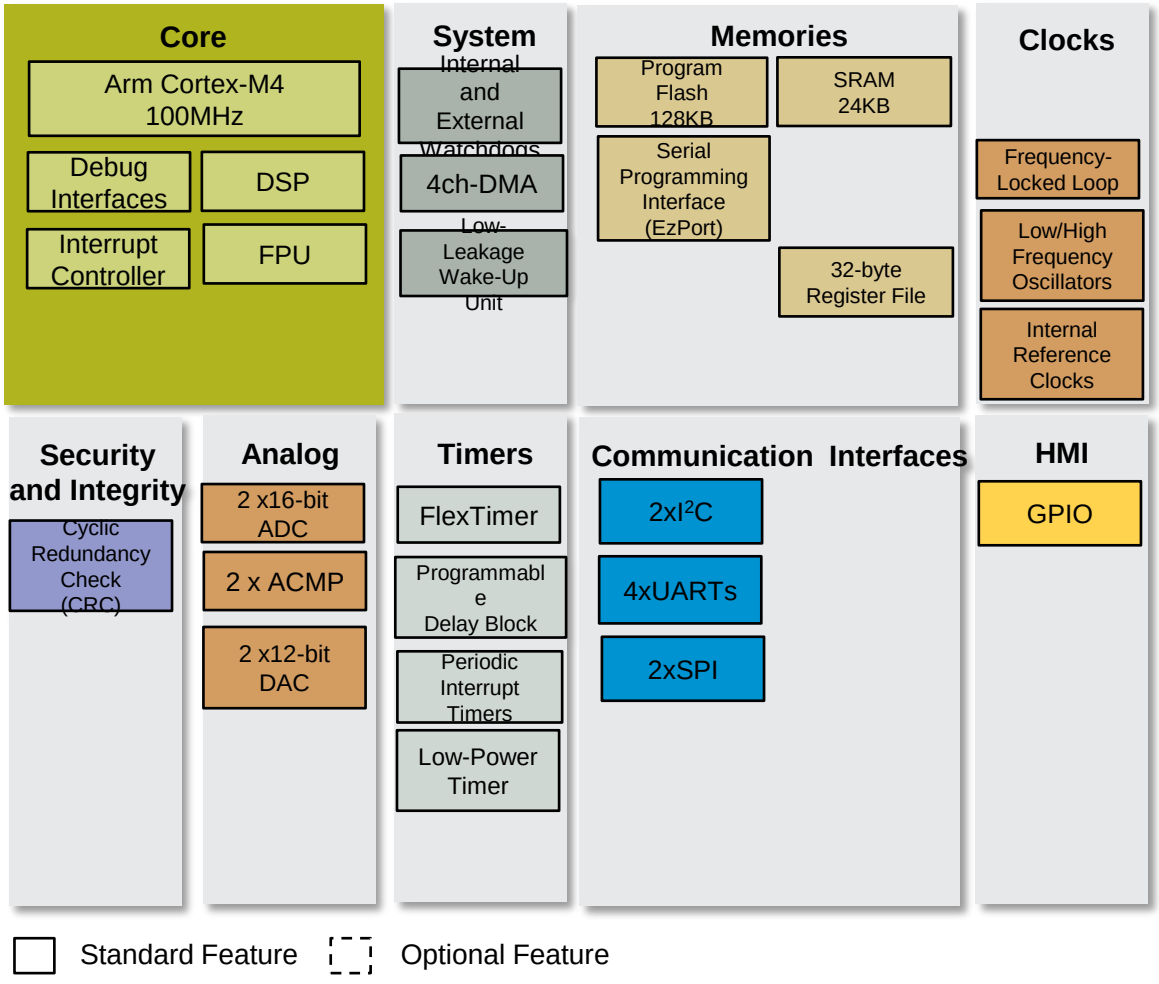

*Typical applications:*

- *PMSM Sensorless FOC*
- *ACIM FOC*
- *Dual MC*

# KV3x – 128K Flash – 100MHz / FPU

**Key Features:**

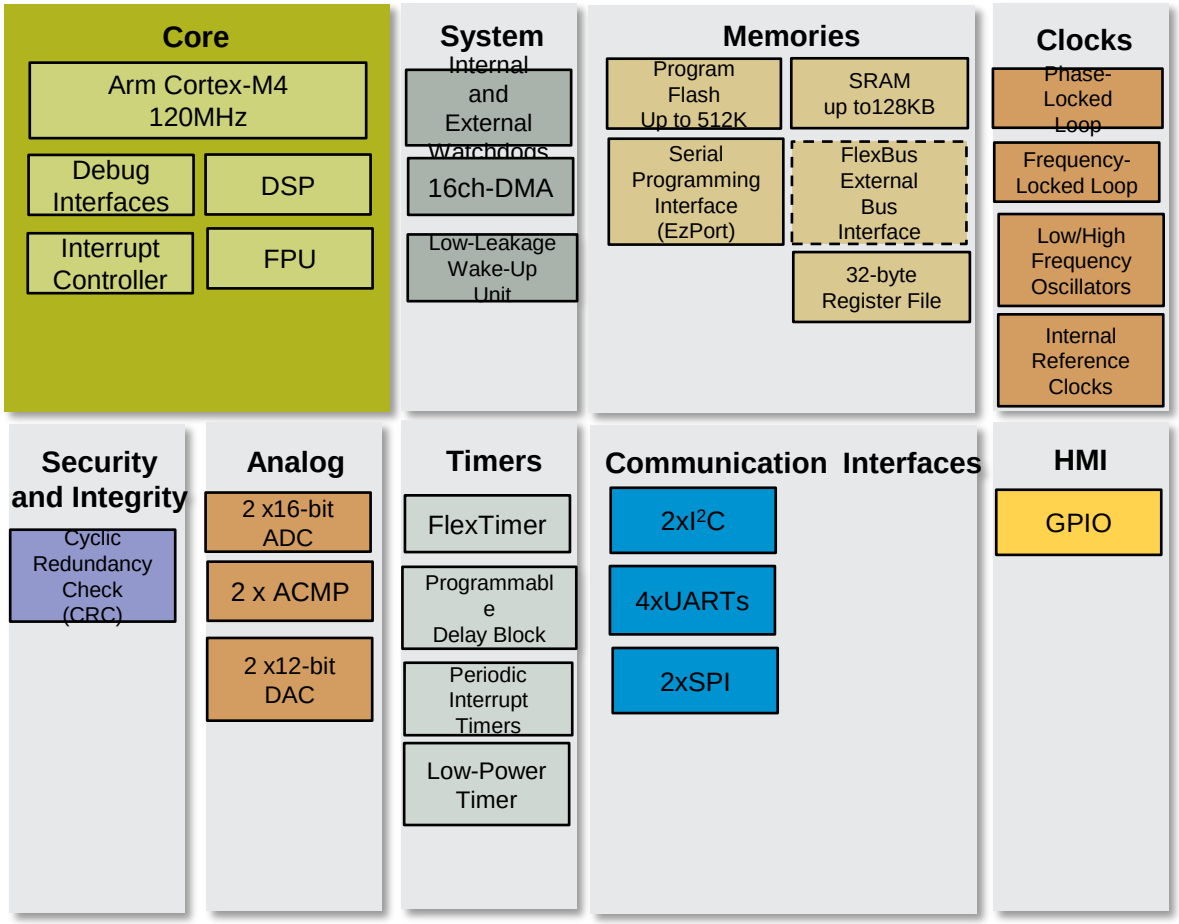
- **Core/System**
  - Cortex-M4 @ 100MHz / FPU
- **Memory**
  - 128KB Flash,
  - 24KB SRAM
- **Communications**
  - Multiple serial ports
- **Analog**
  - 2 x16-bit ADC
  - 1 x12-bit DAC
  - 2 x ACMP
- **Timers**
  - 1x8ch FTM (PWM)
  - 2x2ch FTM (PWM/Quad Dec.)
  - Low Power Timer
- **Others**
  - Up to TBD I/Os
  - 6 high-drive I/Os (20mA) – SPI/I2C
  - 1.71V-3.6V; -40 to 105oC
- **Packages**
  - 64LQFP, 100LQFP



# KV3x – 512K/256K Flash – 120MHz

**Key Features:**

- **Core/System**
  - Cortex-M4 @ 120MHz / FPU
- **Memory**
  - up to 512KB Flash,
  - up to 128KB SRAM
  - FlexBus (External Bus Interface)
- **Communications**
  - Multiple serial ports
- **Analog**
  - 2 x16-bit ADC
  - Up to 2 x12-bit DAC
  - 2 x ACMP
- **Timers**
  - up to 2x8ch FTM (PWM)
  - 2x2ch FTM (PWM/Quad Dec.)
  - Low Power Timer
- **Others**
  - Up to TBD I/Os
  - 6 high-drive I/Os (20mA) – SPI/I2C
  - 1.71V-3.6V; -40 to 105oC
- **Packages**
  - 64LQFP, 100LQFP



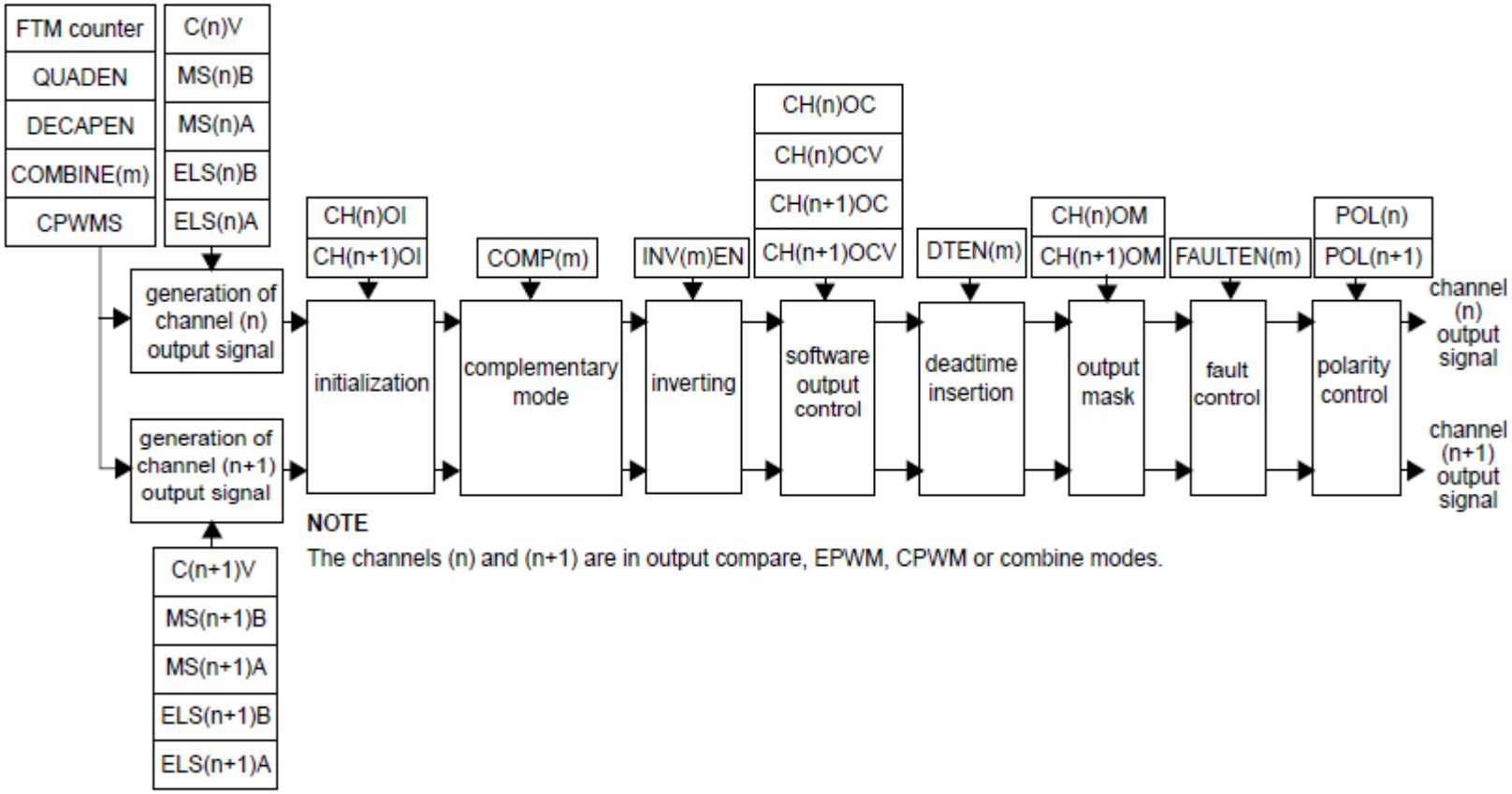
# KV3x -100/120MHz Part Numbers

| MC Part Number | Max. Freq. | Pin Count | Package | Flash | SRAM | Flex.Bus | DMA | PLL | FTMs | DAC | I/O w/ dig. Filters |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MKV10FN512VLL12 | 120MHz | 100 | LQFP | 512K | 96KB | Yes | 16-ch | Yes | 2x8ch; 2x2ch | 2 | 16 |
| MKV10FN512VLH12 | 120MHz | 64 | LQFP | 512K | 96KB | Yes | 16-ch | Yes | 2x8ch; 2x2ch | 2 | 16 |
| MKV10FN256VLL12 | 120MHz | 100 | LQFP | 256K | 48KB | No | 16-ch | Yes | 1x8ch; 2x2ch | 1 | 8 |
| MKV10FN256VLH12 | 120MHz | 64 | LQFP | 256K | 48KB | No | 16-ch | Yes | 1x8ch; 2x2ch | 1 | 8 |
| MKV10FN128VLL10 | 100MHz | 100 | LQFP | 128K | 24KB | No | 4-ch | No | 1x8ch; 2x2ch | 1 | 8 |
| MKV10FN128VLH10 | 100MHz | 64 | LQFP | 128K | 24KB | No | 4-ch | No | 1x8ch; 2x2ch | 1 | 8 |
| MKV10DN128VLH10 | 100MHz | 64 | LQFP | 128K | 16KB | No | 4-ch | No | 1x8ch; 2x2ch | 1 | 8 |
| MKV10DN128VLF10 | 100MHz | 48 | LQFP | 128K | 16KB | No | 4-ch | No | 1x8ch; 2x2ch | 1 | 8 |
| MKV10DN128VFM10 | 100MHz | 32 | QFN | 128K | 16KB | No | 4-ch | No | 1x8ch; 2x2ch | 1 | 8 |

# FlexTimer Module

- FTM source clock is selectable with prescaler divide-by 1, 2, 4, 8, 16, 32, 64, or 128
- FTM has a 16-bit counter
- **2 up to 8 channels** (inputs/outputs)
- The **counting** can be **up** or **up-down**
- Each channel can be configured for input capture, output compare, or
- Input filter can be selected for some channels
- **New combined mode to generate a PWM signal**
- **Complementary outputs, include the deadtime insertion**
- **Software control of PWM outputs**
- Up to **4 fault inputs** for global fault control
- **The polarity of each channel is configurable**
- The generation of an interrupt per channel input capture/compare, counter overflow, at fault condition
- **Synchronized loading of write buffered FTM registers**
- **Write protection for critical registers**
- Backwards compatible with TPM
- **Dual edge capture for pulse and period width measurement**
- **Quadrature decoder with input filters, relative position counting and interrupt on**
- Position count or capture of position count on external event

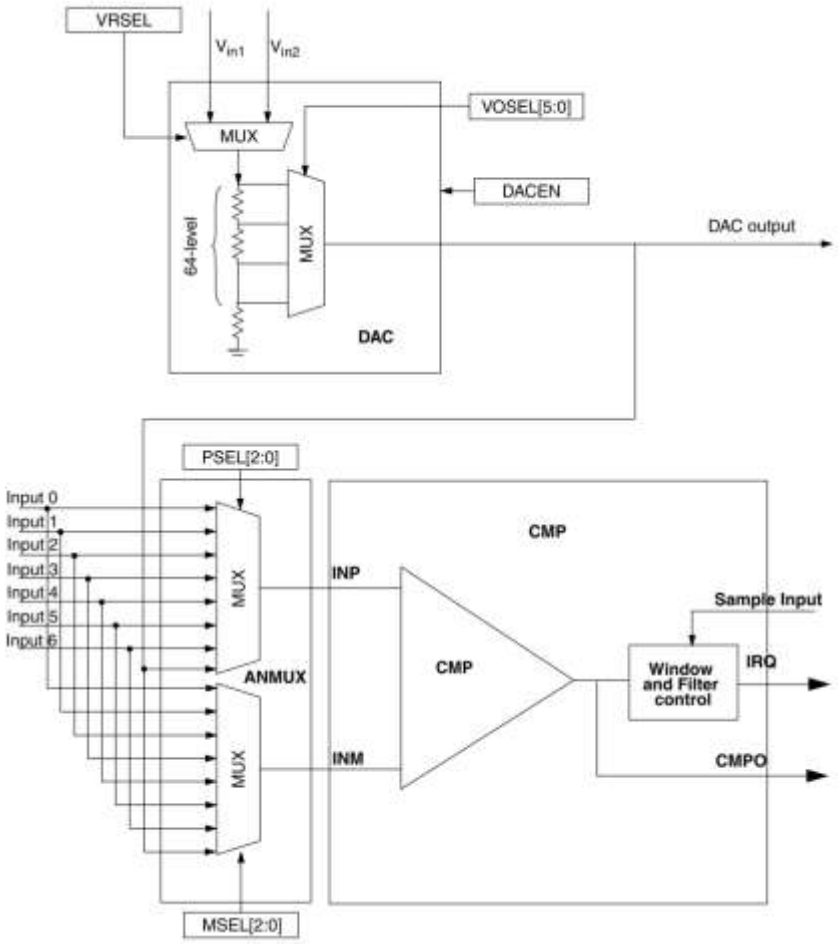
# FlexTimer Module Diagram




**NOTE**

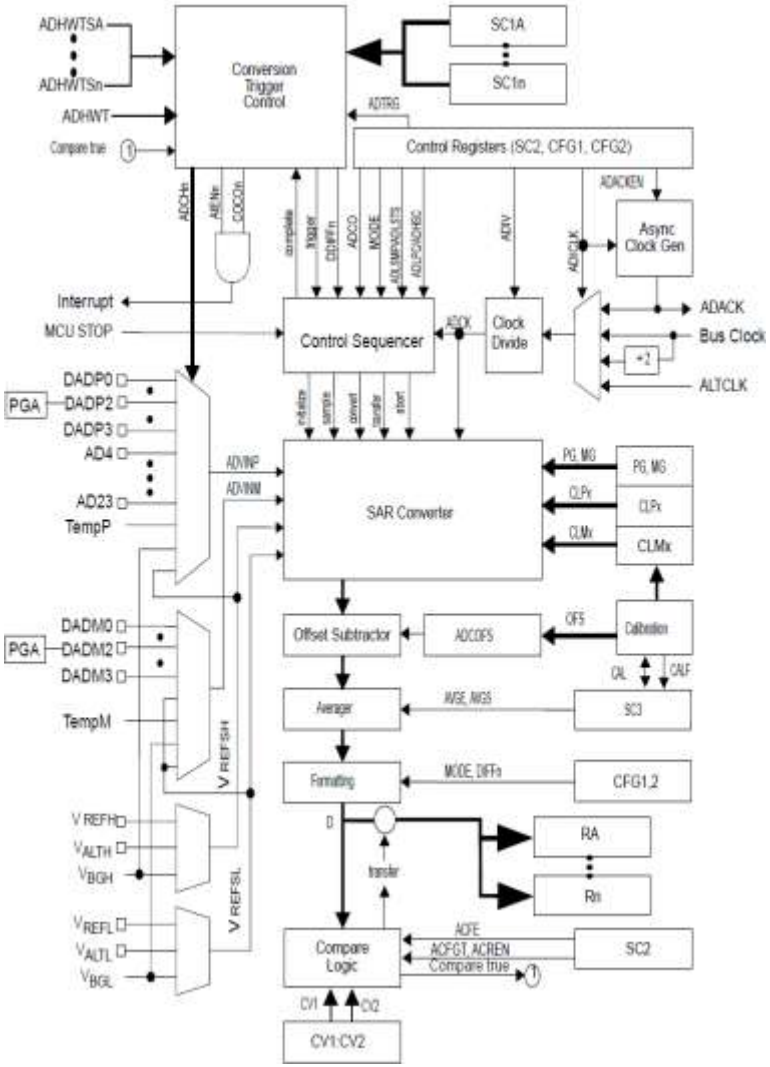
The channels (n) and (n+1) are in output compare, EPWM, CPWM or combine modes.

# Build-in Comparator



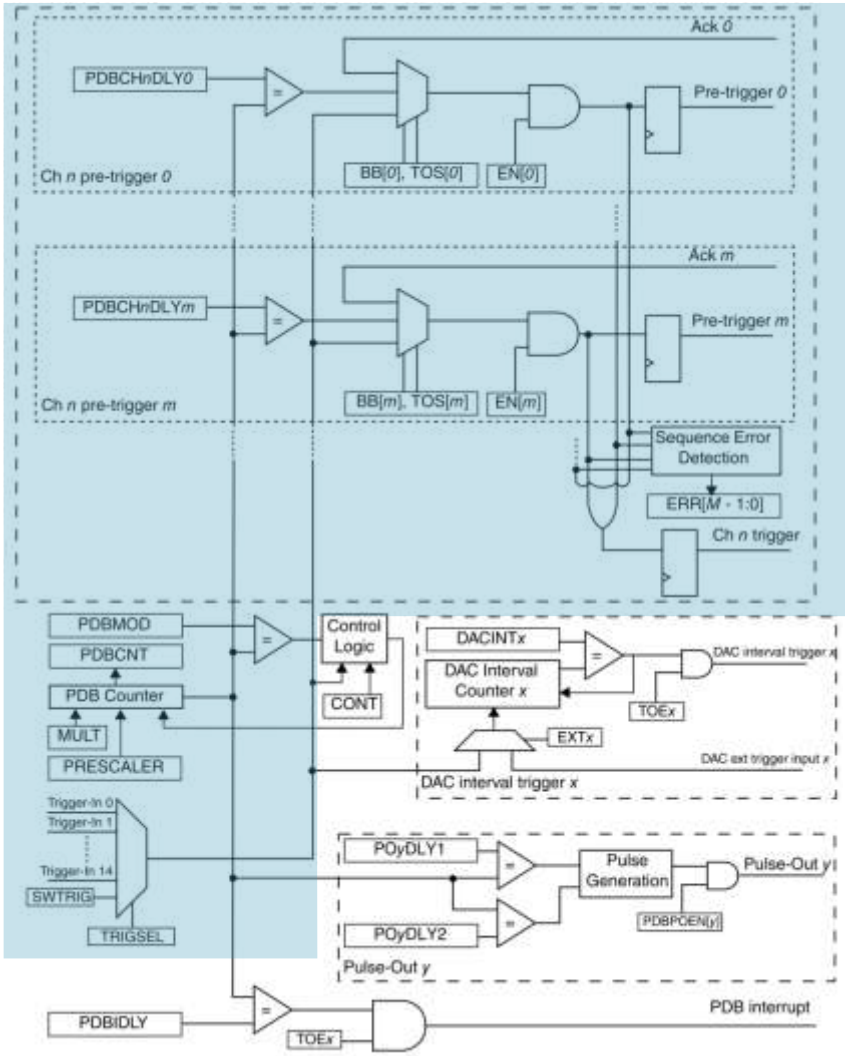

- Continuous, Sampled, Windowed modes
- Programmable filter and hysteresis
- Up to eight independently selectable channels for positive and negative comparator inputs
- External pin inputs and several internal reference options including 6-bit DAC, 12-bit DAC, bandgap, VREF, OpAmp,
- 6-bit DAC
  - Output range (Vin/64) to Vin
  - VREF or VDD selectable as DAC reference

# 16-bit ADC – Analog Quantities Measurement



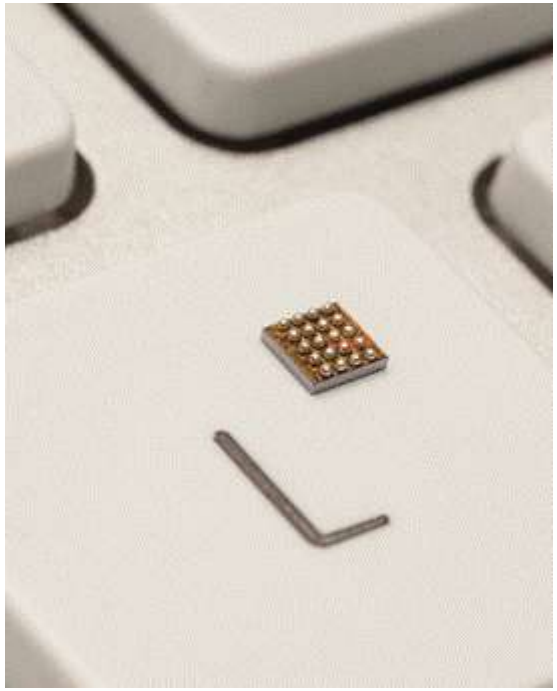

- Up to 4 pairs of differential and 24 single-ended external analog inputs
- Single or continuous conversion (automatic return to idle after single conversion)
- Configurable sample time and conversion speed/power
- Input clock selectable from up to four sources
- Operation in low power modes
- Asynchronous clock source for lower noise operation
- Selectable hardware conversion trigger with hardware channel select
- Automatic compare with interrupt for less-than, greater-than or equal-to, within range,or out-of-range, programmable value
- Temperature sensor
- Hardware average function
- Selectable voltage reference: external or alternate
- Self-calibration mode
- Programmable Gain Amplifier (PGA) with up to x64 gain

# Programmable Delay Block (PDB)




- The PDB provides delays between input and output triggers
- Up to 4 channels available (one for each ADC) with two pretriggers
- Trigger 0 => Sample A
- Trigger 1 => Sample B

# S/W Development Tools

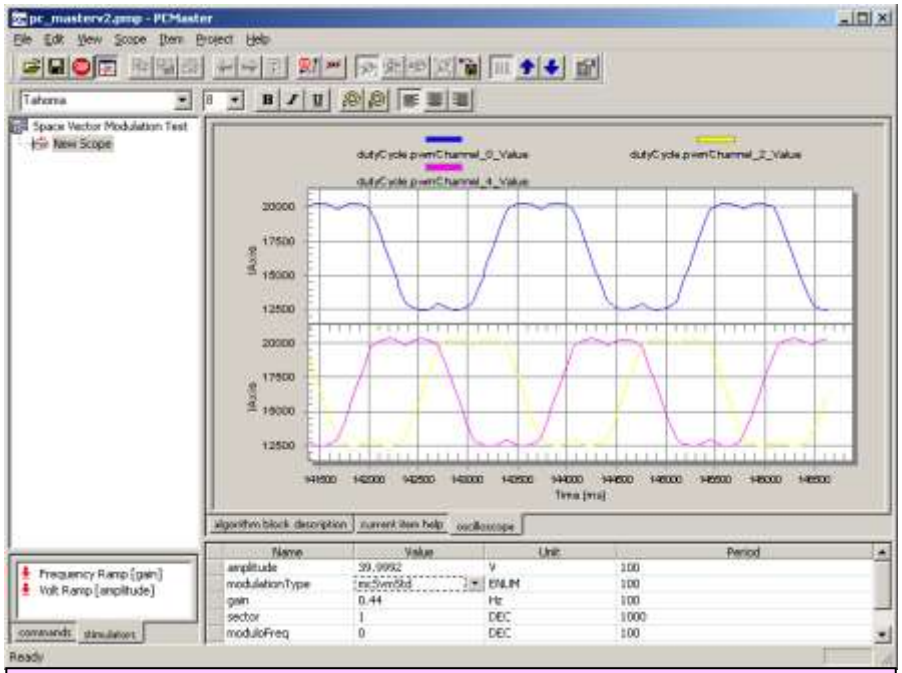


- FreeMASTER
- QuickStart

# FREEMASTER

## as a Real-time Monitor

# FreeMASTER




The Communication Library

Communication through:

- SCI, UART
- JTAG/OnCE (DSC, Kinetis)
- BDM (HCS08, HCS12)
- CAN
- Ethernet, TCP/IP
- Bluetooth

**Link**

PC Master functionality categories:

– Monitor functions:

watching on-board memory locations (board application variables) in various formats:

- textual in the tabular form
- real-time charts of the values (oscilloscope via RS232)
- graphs of high-speed recorded data (on board memory oscilloscope)

– Control functions:

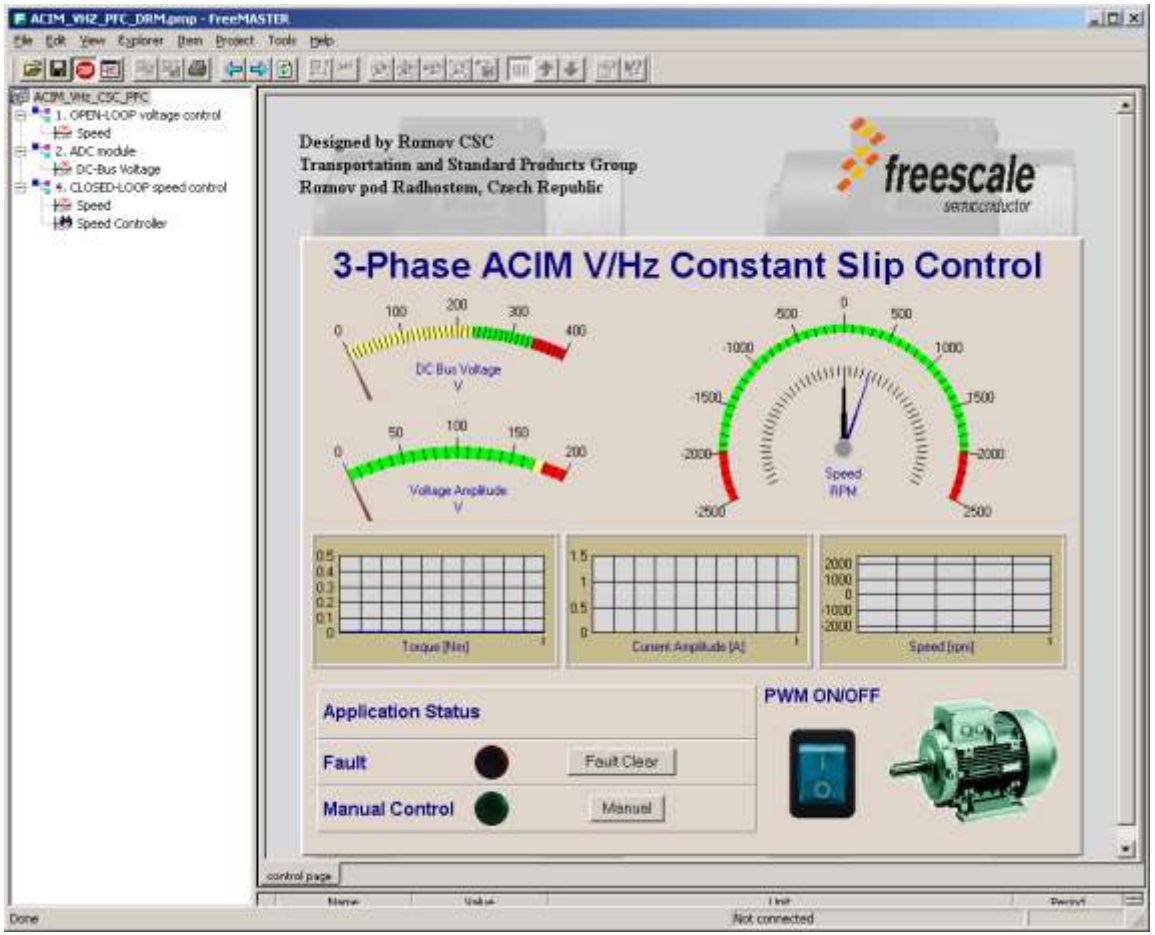
- setting the variable values asynchronously to the on board application
- stimulating the variable values according to specific time-table
- sending “user commands” as an official message to the board application

Protocol Implementation Module

# FREEMASTER as a Real-time Monitor

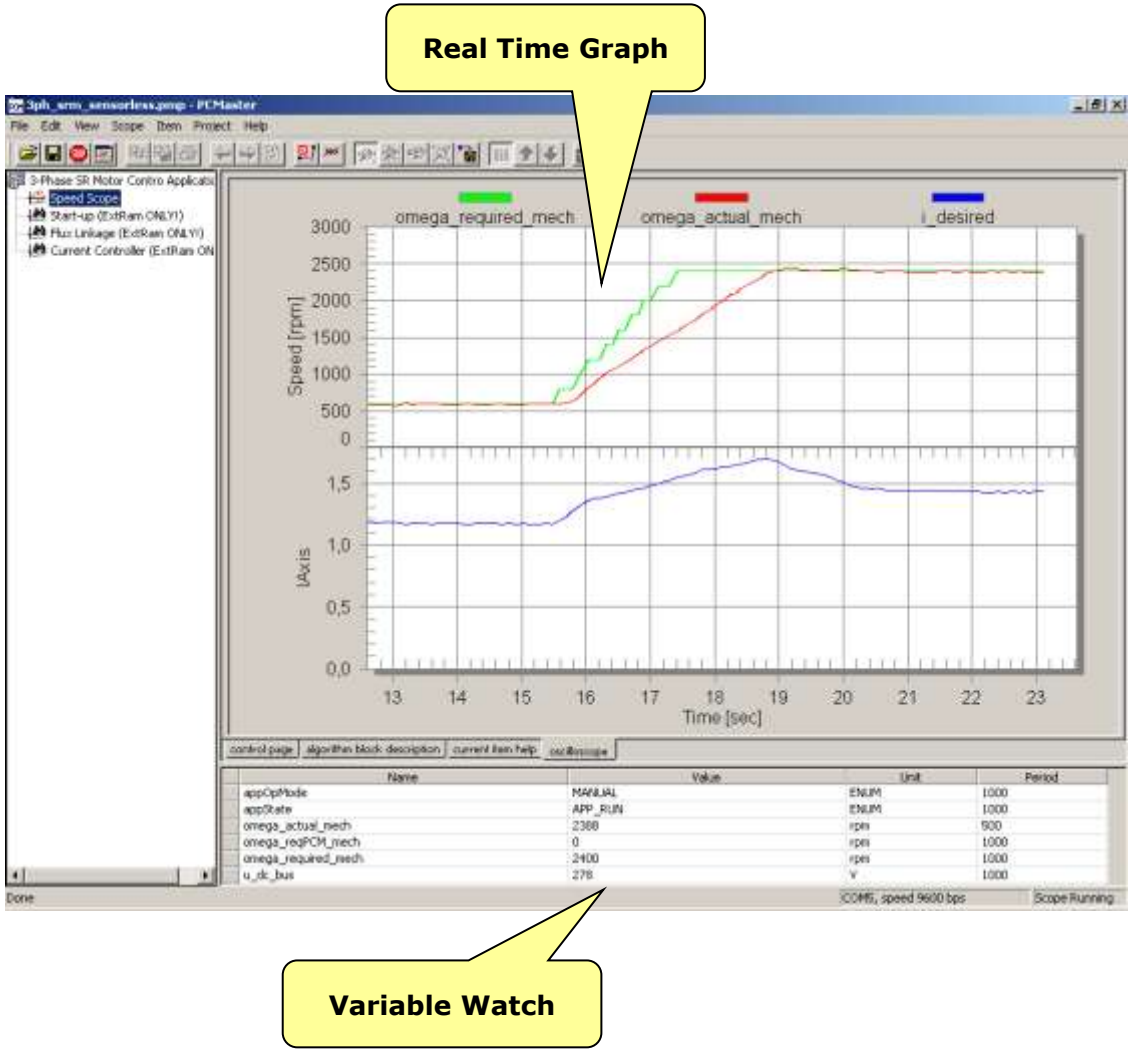
- Connects to an embedded application
  - SCI, UART
  - JTAG/EOnCE (DSC, Kinetis)
  - BDM (HCS08, HCS12)
  - CAN Calibration Protocol
  - Ethernet, TCP/IP
  - Any of the above remotely over the network
- Enables access to application memory
  - Parses ELF application executable file
  - Parses DWARF debugging information in the ELF file
  - Knows addresses of global and static C-variables
  - Knows variable sizes, structure types, array dimensions etc.

# Control Page Example



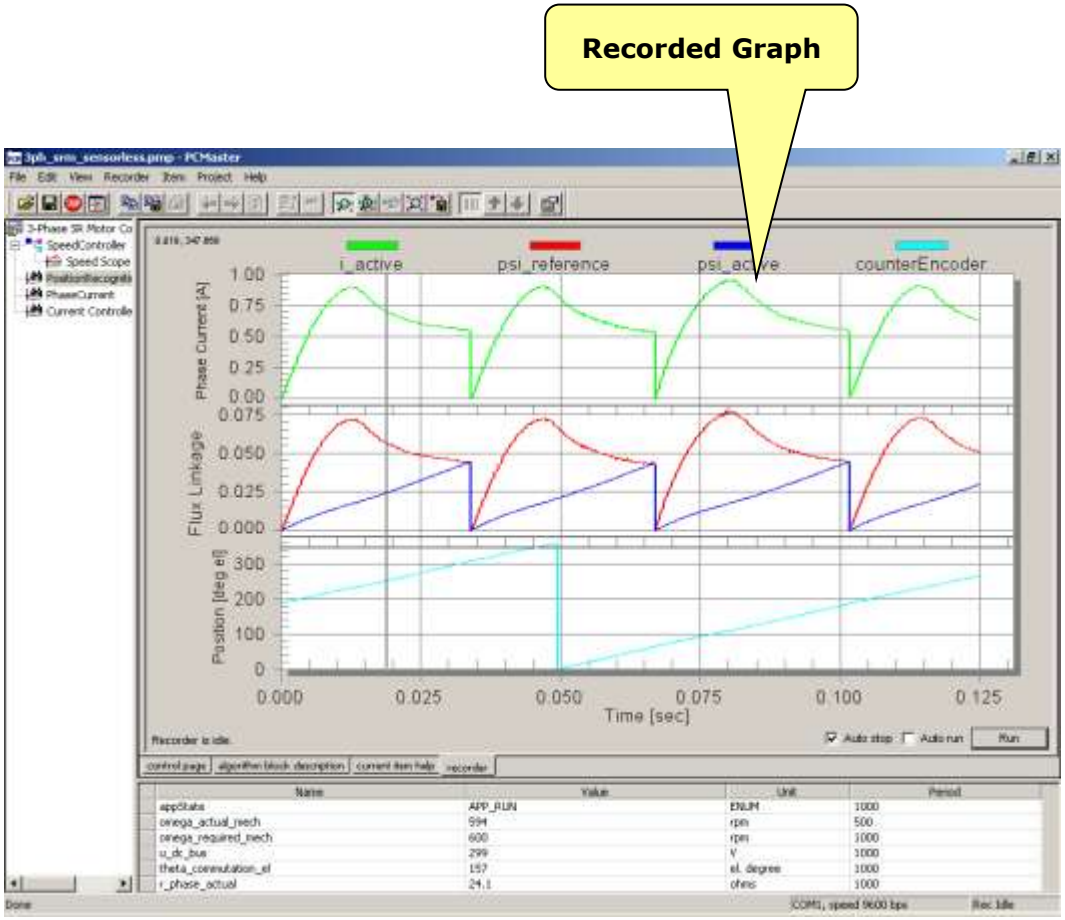
# Scope Example

- Similar to the classical hardware oscilloscope
- Variables read in real-time
- Sampling time limited by communication data link

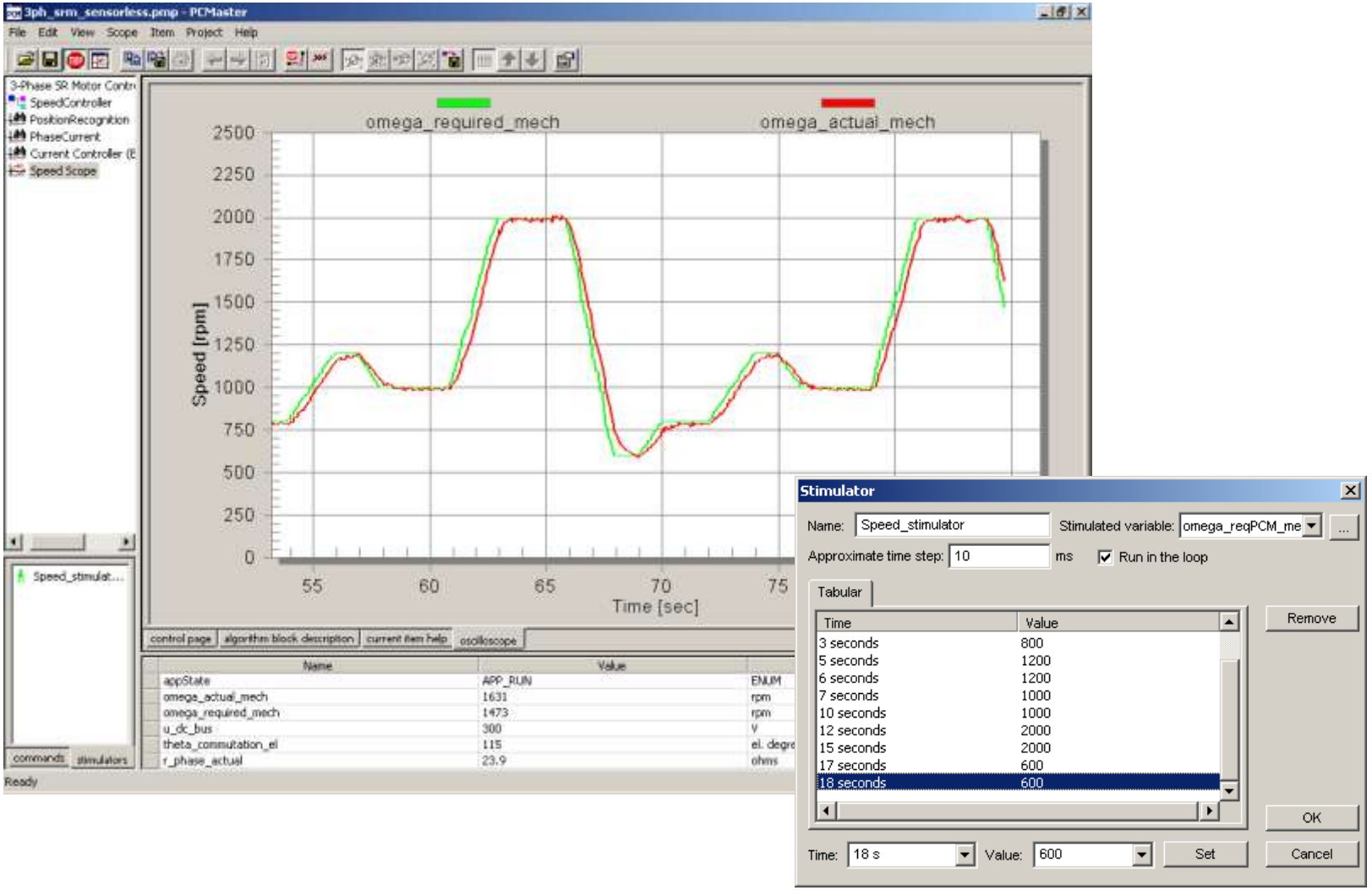


# Recorder Example

- Variables recorded by the embedded-side timer periodic ISR
- After requested number of samples data stored in Recorder buffer
- Sample very fast actions
- Buffer download can be defined



# Stimulator Example



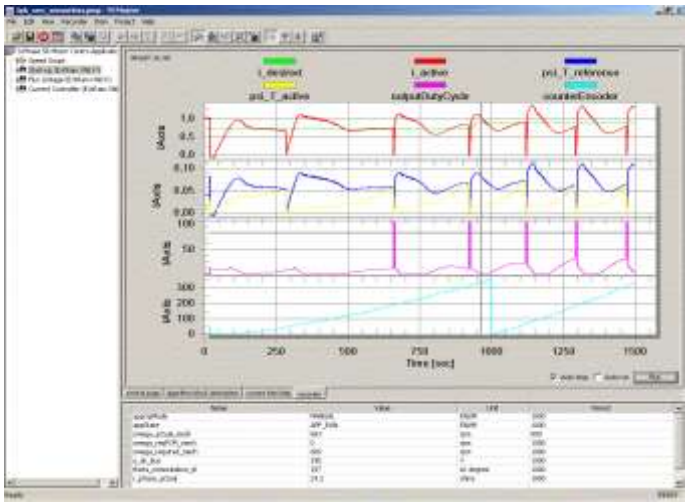
# What is FREEMASTER?

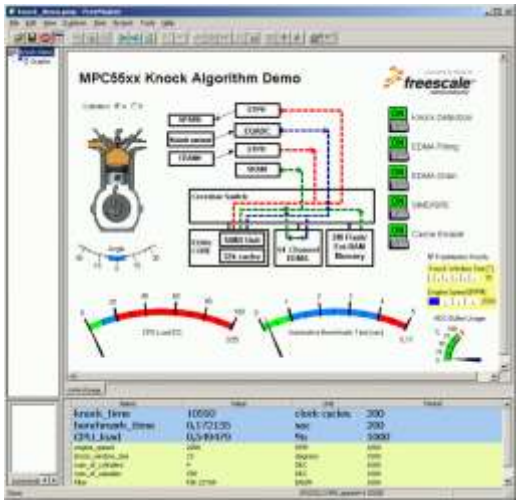
Application control and monitor

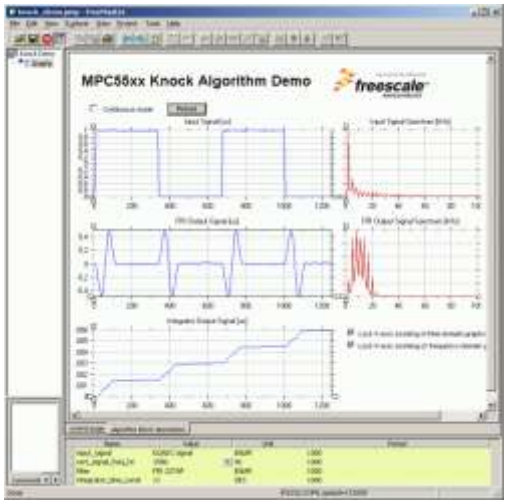
Live graphs, variable watches, and graphical control page

Real-time operation monitor

S08 S12
Kinetis Power Arch.
DSC ColdFire….





# QuickStart

# What is QuickStart?

## Quick Start = Easy-to-use SW Development Environment for DSC

- **QuickStart includes**
  - Set of Low-level Drivers for all Peripheral Modules
  - Ready-to-use Project Templates (“Project Stationery”)
  - Graphical Configuration Tool
  - Sample Applications
  - User Manual
- **QuickStart**
  - Designed according to customer needs
  - Supports all DSC’s including latest 56F82xxx/4xxx
  - Mandatory development tool for key appliance customers (Electrolux, Indesit, Miele, DiehlAKO, Emerson, PowerOne, etc)

# Low-level Drivers

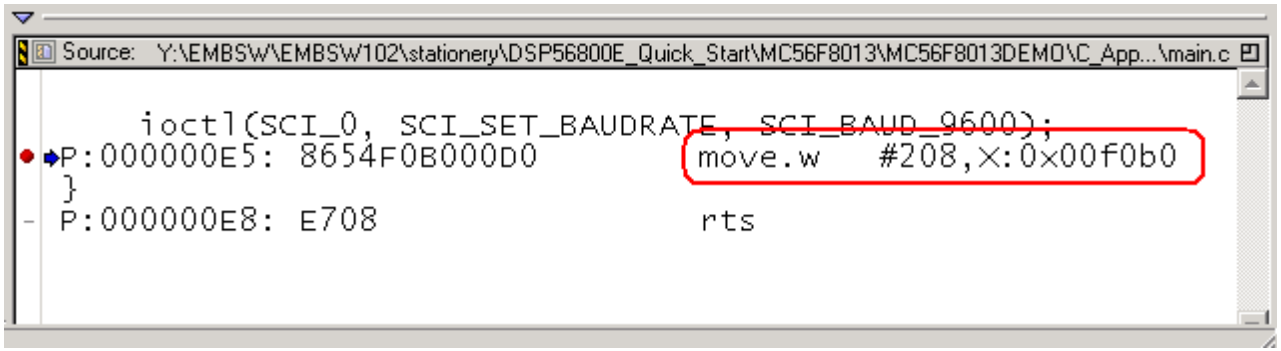
- **Quick Start Low-level Drivers**
  - Full control over and full access to all processor resources
  - Unifies access to peripheral memory space (**`ioctl`** call)
  - Registers are not accessed directly, although this is still possible
  - **`ioctl`** calls are optimally compiled macros or functions

```
ioctl(SCI_0, SCI_SET_BAUDRATE, SCI_BAUD_9600)
```

**Module identifier**

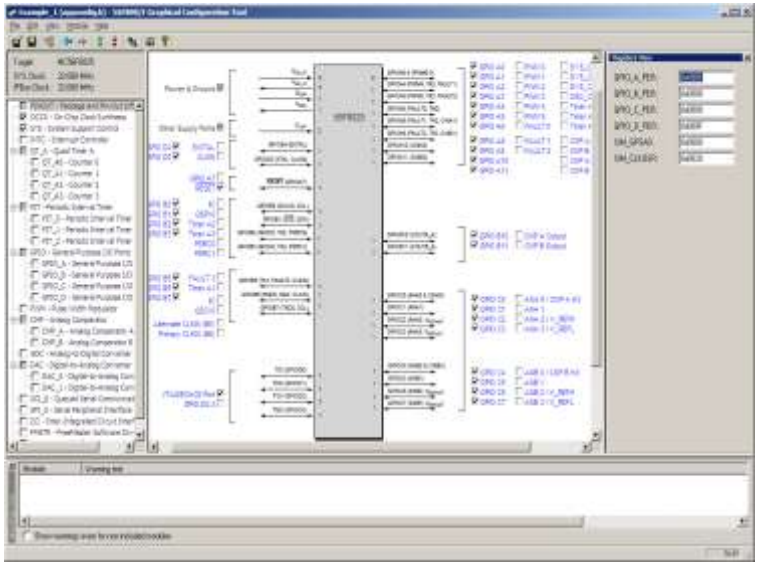
**Command to perform**

**Command Parameter**



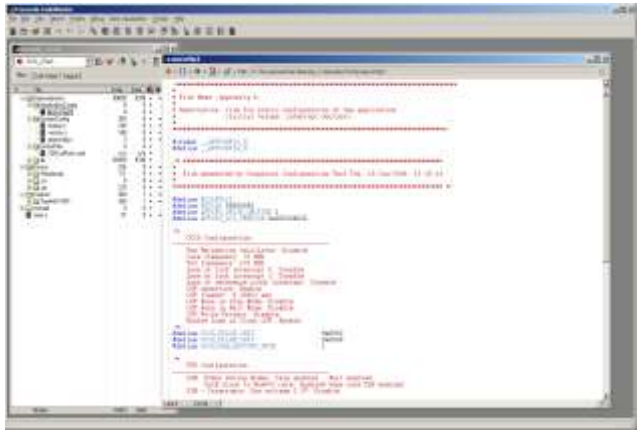
# Graphical Configuration Tool

- **Features:**
  - Edits post-reset processor configuration graphically
  - Configuration saved/**read** from a single ANSI C header file
  - GUI to configuration bits of all peripheral module registers
  - Possible conflict warnings
  - Pin-out view of processor I/O pins



# Graphical Configuration Tool

- Used to edit the ANSI C-compatible application configuration header file (**`appconfig.h`**)
- **`appconfig.h`** contains a single macro constant per peripheral register

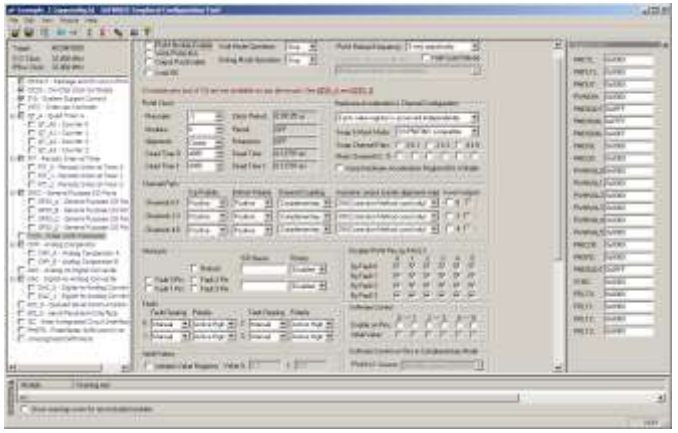


**Metrowerks CodeWarrior IDE**

#include "appconfig.h"
#defines used to initialize peripherals

**Ctrl+F10 invoked GCT opens the appconfig.h for a current project**

**appconfig.h file**

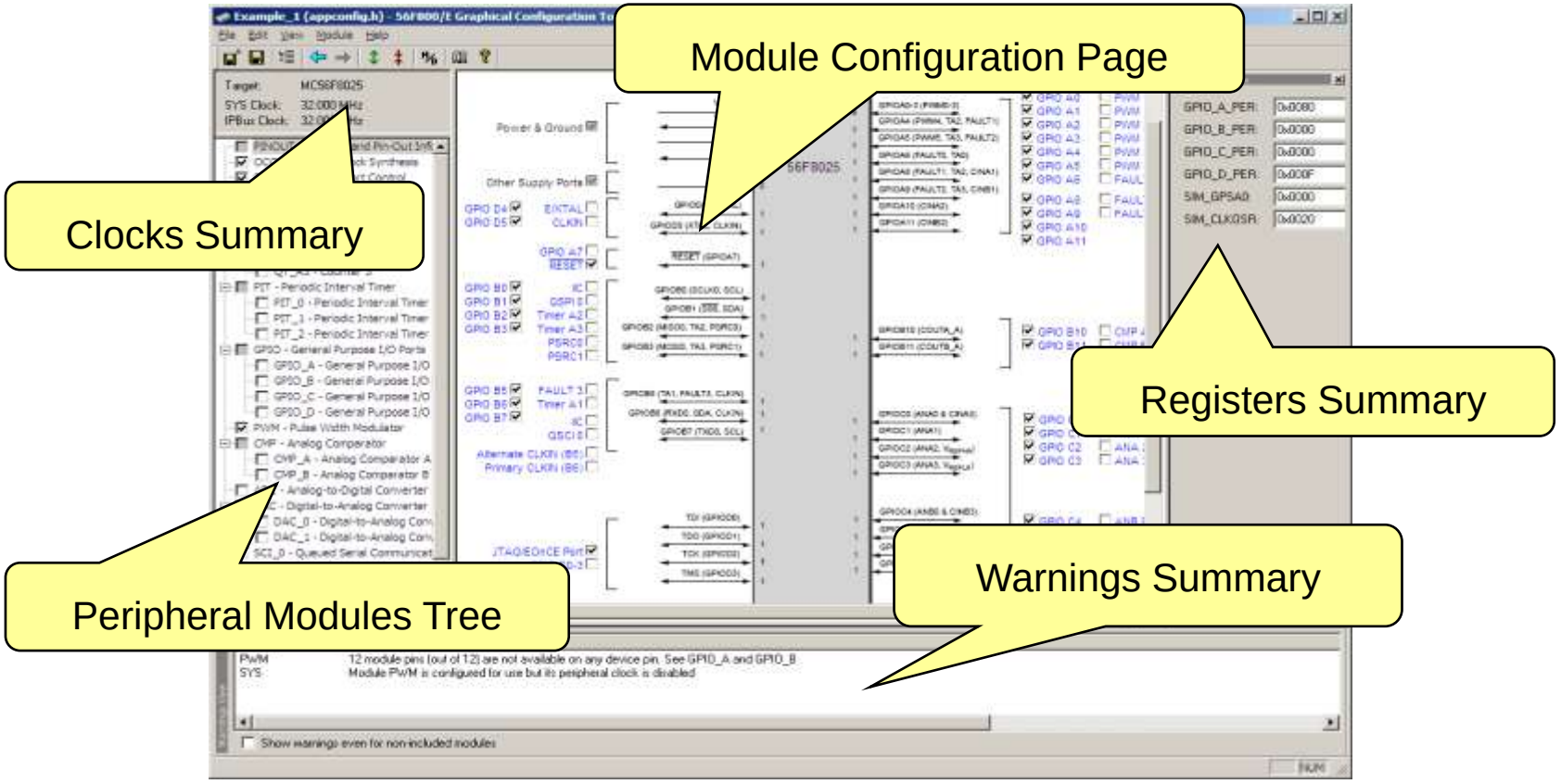


**Graphical Configuration Tool**

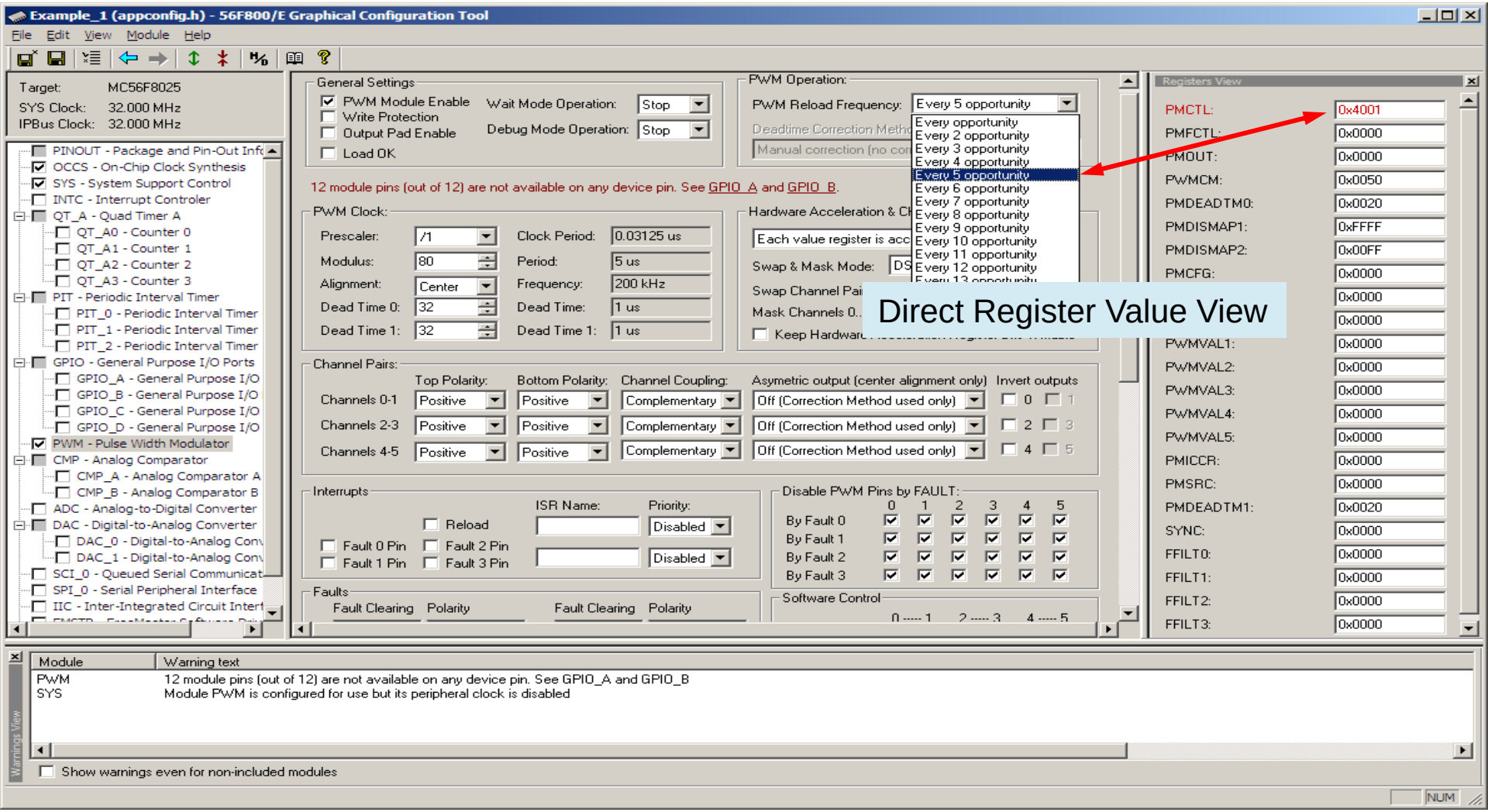
Read & Write access to appconfig.h

# Graphical Configuration Tool

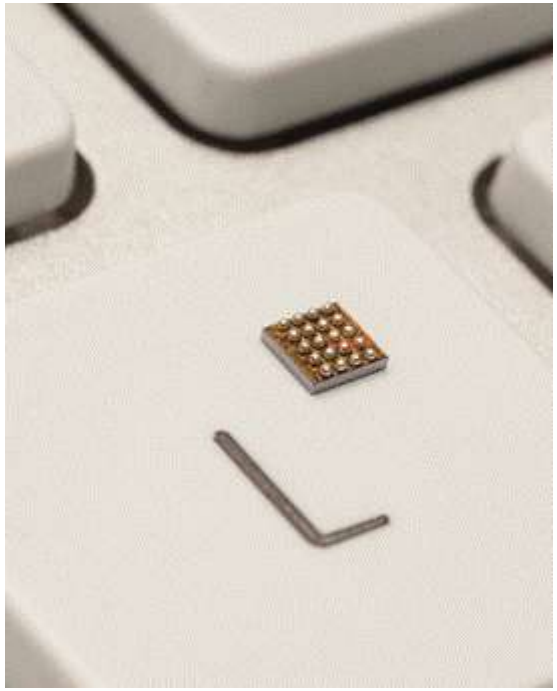
Different Control Page for each Peripheral Module



# Graphical Configuration Tool



# Motor Control Enablement



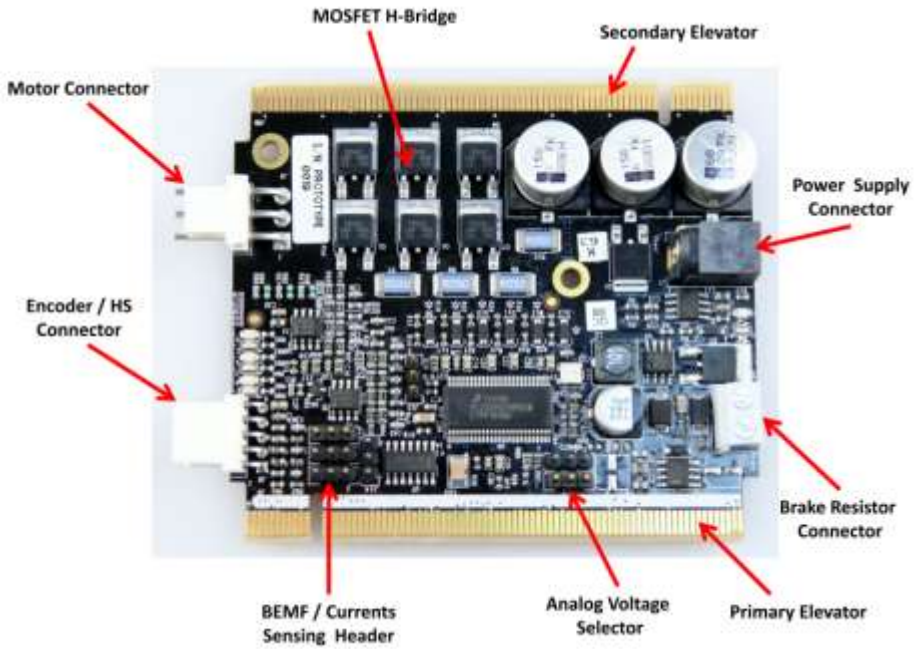
- Hardware Kits
- Algorithm Software Libraries
- IEC60730 Safety Libraries
- MC Reference Designs
- MC Application Tuning (MCAT)

# Motor Control Hardware Kits

# Tower Low Voltage Power Control Board

- Tower system module for BLDC / PMSM control
- Support most of current and new TWR MCU modules
- Launched kit includes power supply and BLDC motor with application examples using K40 and MC56F825x devices

- Features:
  - Power supply voltage input  24VDC
  - Output current up to 8 Amps
  - Power supply reverse polarity protection circuitry
  - 3-phase bridge inverter (6-MOSFET's)  with over-current  and under-voltage protection
  - 3-phase and d.c. bus-current-sensing shunts
  - DC bus-voltage and 3-phase back-EMF voltage sensing
  - Low-voltage on-board power supplies
  - Encoder/Hall sensor sensing circuitry




Product Page at Freescale.com:

TWR-MC-LV3PH

# 3-ph BLDC/PMSM High Voltage MC Drive

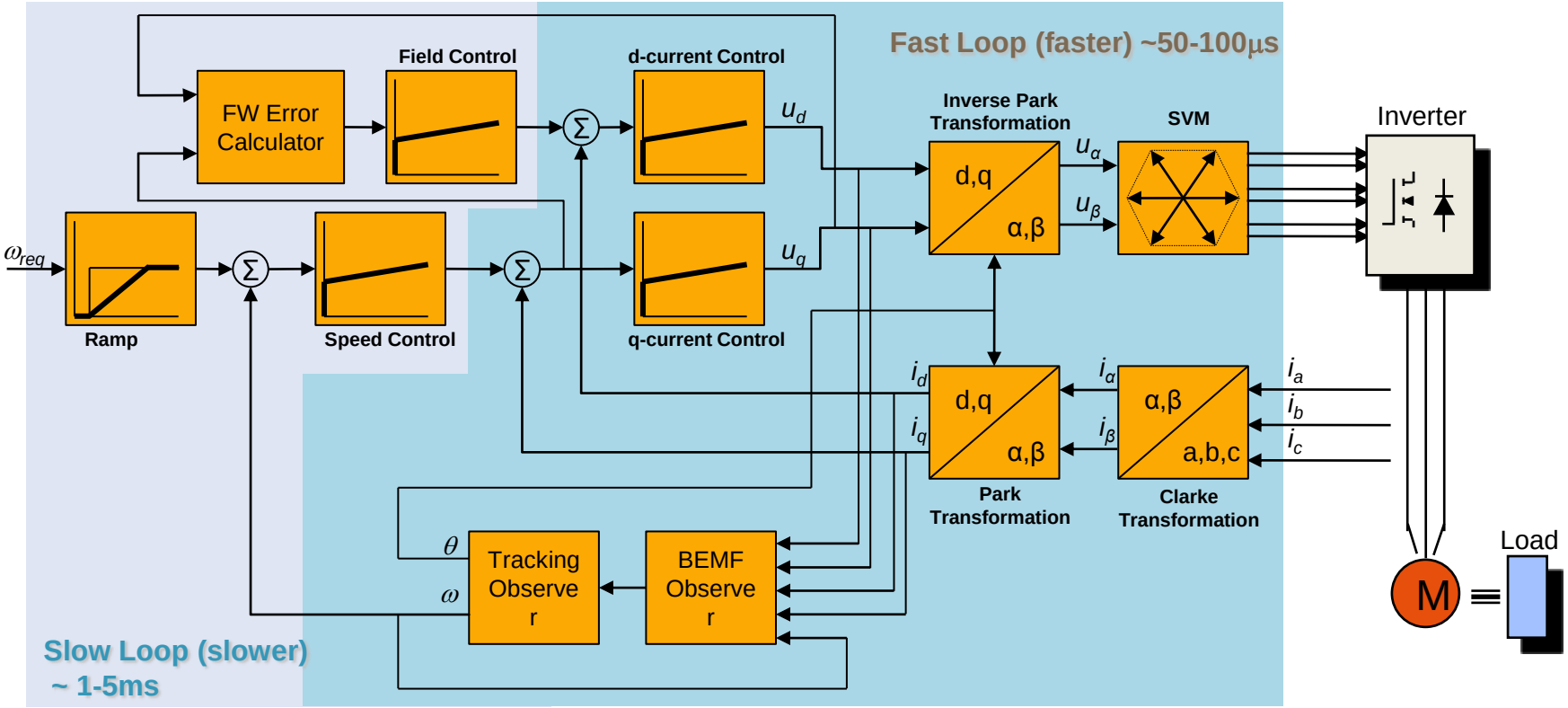
- **Main board + MCU daughter cards**
- **Available MCU cards:**
  - MC9S08MP16
  - MC56F8006 / MC56F8013 / MC56F8023
  - MC56F8257
  - MC56F82xxx
  - K40X256

- **Board Features:**
  - Input Voltage 115-230Vac, 50/60Hz / Output Power 1kW
  - 3-phase IGBT inverter bridge with over-current protection
  - Interleave PFC (coming in Rev2)
  - 3-phase motor current and BEMF sensing
  - DC-Bus current and voltage sensing
  - Isolated SCI / USB interface
  - User LED's
  - Encoder / Hall Sensor and tacho interface
  - DC-Brake
  - Isolated JTAG (in Rev 2)

- Rev.1 – prototypes - Available per specific business opportunities
- Rev.2 – productization – in progress, to be available in Q1 2014

# Embedded Software Libraries

# S/W Algorithms for Sensorless Vector Control



# Embedded Software Libraries

- **Set of** basic **trigonometric, general math, filter & motor control algorithms** as the building blocks for the motor control applications

- Provided in highly optimized layered architecture, support of **16/32-bit fixed-point** and **single precision floating point**

- Matlab/Simulink models included in the package

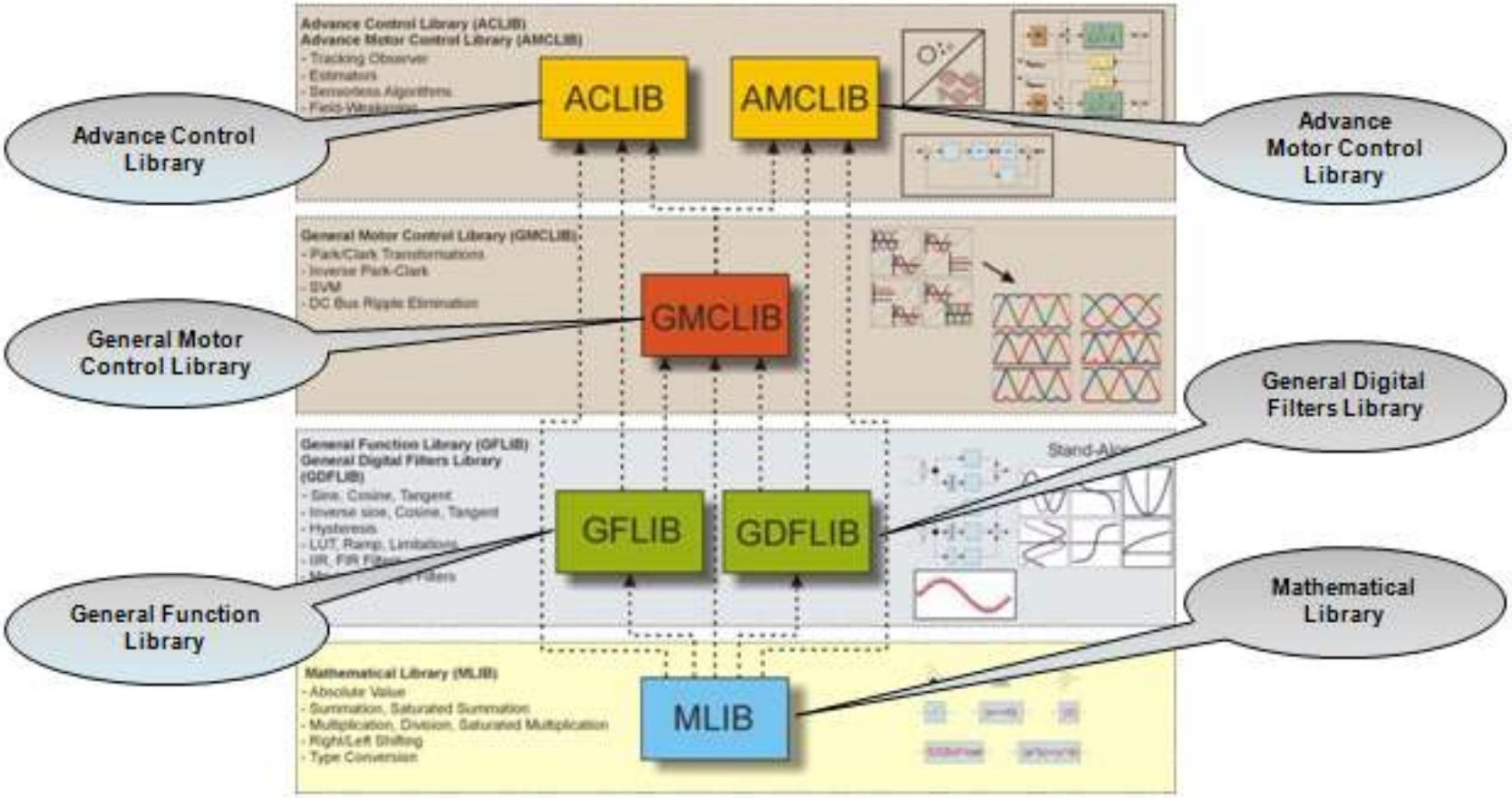
- Delivered as object file for the **evaluation purposes for free**, source code under specific business conditions

# Freescale Embedded Software and Motor Control Libraries

## Algorithms divided into five sub-libraries:

- **Mathematical Library (MLIB)** contains basic math functions.
- **General Function Library (GFLIB)** contains trigonometric, look-up table and control functions. These software modules are basic building blocks.
- **Motor Control Library (MCLIB)** contains vector modulation, transformation and specific motor related functions to build digitally controlled motor drives.
- **General Digital Filter Library (GDFLIB)** contains filter functions for signal conditioning.
- **Advanced Control Library (ACLIB)** contain functions to enable building the variable speed AC motor drive systems with field oriented control techniques without position or speed transducer

# Math and Motor Control Library Set




Note:

- MC Lib for 56800E – Math functions included into the individual algorithms
- MC Lib for Kinetis and 56800EX - Math functions separated into MLIB

# Math and Motor Control Library Set – Contents

## MLIB

- **Absolute Value, Negative Value**
  - MLIB_Abs, MLIB_AbsSat
  - MLIB_Neg, MLIB_NegSat
- **Add/Subtract Functions**
  - MLIB_Add, MLIB_AddSat
  - MLIB_Sub, MLIB_SubSat
- **Multiply/Divide/Add-multiply Functions**
  - MLIB_Mul, MLIB_MulSat
  - MLIB_Div, MLIB_DivSat
  - MLIB_Mac, MLIB_MacSat
  - MLIB_VMac
- **Shifting**
  - MLIB_ShL, MLIB_ShLSat
  - MLIB_ShR
  - MLIB_ShBi, MLIB_ShBiSat
- **Normalisation, Round Functions**
  - MLIB_Norm, MLIB_Round
- **Conversion Functions**
  - MLIB_ConvertPU, MLIB_Convert

## GFLIB

- **Trigonometric Functions**
  - GFLIB_Sin, GFLIB_Cos, GFLIB_Tan
  - GFLIB_Asin, GFLIB_Acos, GFLIB_Atan, GFLIB_AtanYX
  - GFLIB_AtanYXShifted
- **Limitation Functions**
  - GFLIB_Limit, GFLIB_VectorLimit
  - GFLIB_LowerLimit, GFLIB_UpperLimit
- **PI Controller Functions**
  - GFLIB_ControllerPIr, GFLIB_ControllerPIrAW
  - GFLIB_ControllerPIp, GFLIB_ControllerPIpAW
- **Interpolation**
  - GFLIB_Lut1D, GFLIB_Lut2D
- **Hysteresis Function**
  - GFLIB_Hyst
- **Signal Integration Function**
  - GFLIB_IntegratorTR
- **Sign Function**
  - GFLIB_Sign
- **Signal Ramp Function**
  - GFLIB_Ramp
- **Square Root Function**
  - GFLIB_Sqrt

## GDFLIB

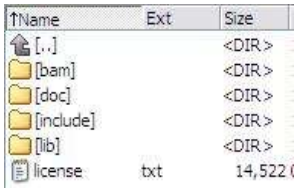
- **Finite Impulse Filter**
  - GDFLIB_FilterFIR
- **Moving Average Filter**
  - GDFLIB_FilterMA
- **1st Order Infinite Impulse Filter**
  - GDFLIB_FilterIIR1init
  - GDFLIB_FilterIIR1
- **2nd Order Infinite Impulse Filter**
  - GDFLIB_FilterIIR2init
  - GDFLIB_FilterIIR2

## GMCLIB

- **Clark Transformation**
  - GMCLIB_Clark
  - GMCLIB_ClarkInv
- **Park Transformation**
  - GMCLIB_Park
  - GMCLIB_ParkInv
- **Duty Cycle Calculation**
  - GMCLIB_SvmStd
- **Elimination of DC Ripples**
  - GMCLIB_ElimDcBusRip
- **Decoupling of PMSM Motors**
  - GMCLIB_DecouplingPMSM

## ACLIB/AMCLIB

- **Angle Tracking Observer**
- **Tracking Observer**
- **PMSM BEMF Observer in Alpha/Beta**
- **PMSM BEMF Observer in D/Q**




**Delivery Content**

→ Matlab/Simulink Bit Accurate Models
→ User Manuals
→ Header files
→ Compiled Library File
→ License File (to be accepted at install time)

# Develop an Application Using Libraries

- The coding of the fast control loop of the PMSM vector control using libraries is then limited to peripherals handling and calling of the libraries functions, while passing the addresses of the application structures

```
....
  // Iq current PI controllers
  uDQReq.s32Arg2 = GFLIB_ControllerPIpAW(iDQErr.s32Arg2,&qAxisPI);
  // inverse Park trf for voltages
  GMCLIB_ParkInv(&uAlBeReq,&thRotElSyst,&uDQReq);
 // Elimination of DC bus ripple
 elimDcbRip.s32ArgDcBusMsr  = uDCBus;
 GMCLIB_ElimDcBusRip(&uAlBeReqDCB,&uAlBeReq,&elimDcbRip);
  // Calculation of Standard space vector modulation
  svmSector = GMCLIB_SvmStd(&pwm32,&uAlBeReqDCB);
....
```

# Automotive Math and Motor Control Library Set

| Target Platform | Latest Release Number | GreenHills Multi | CodeWarrior | | WindRiver Diab | Cosmic |
|---|---|---|---|---|---|---|
| | | Version 6.x | Version 2.10 | Version 10.3/10.4 | Version 5.9.1 | Version 4.2.3/4.2.4 |
| **MPC5604P** | **1.0.0** | Available | Available | Available | Available | Not supported |
| **MPC564xL** | **1.0.0** | Available | Available | Available | Available | Not supported |
| **MPC567xK** | **1.0.0** | Available | Available | Available | Available | Not supported |
| **MPC567xF** | **1.0.0** | Available | Available | Available | Available | Not supported |
| **S12ZVM** | **1.0.0 Release Candidate** | N/A | N/A | In Development | N/A | In Development |
| **MPC574xP** | **1.0.0** | Available | Not supported | Not supported | Available | Not supported |
| **MPC577xK** | **1.0.0 Release Candidate** | In Development | Not supported | Not supported | In Development | Not supported |

Product releated web pages:

**www.freescale.com/AutoMCLib**

*Note: AutoMCU Lib does not support advanced (sensorless) algorithms yet*

# MCU Math and Motor Control Library

| Target Platform | CodeWarrior | | Keil | IAR |
|---|---|---|---|---|
| | CW8.3 | CW10.5 | | |
| 56800E | Available | N/A | N/A | N/A |
| 56800E/EX | N/A | Available | N/A | N/A |
| ColdFireV1 | Available | N/A | N/A | N/A |
| CortexM4 FixPoint (K, KV) | N/A | Available | Available | Available |
| CortexM0+ (KL, KV, KE) | N/A | Oct 2013 | Oct 2013 | Oct 2013 |
| CortexM4 Float (K, KV) | N/A | 2014 | 2014 | 2014 |

Product releated web pages:

**www.freescale.com/FSLESL**

# IEC60730 Safety

# Application Safety – Home Appliance

- **From Oct 2007, home appliances to be sold in Europe have to comply with IEC60730 standard**
- The IEC60730 standard defines the test and diagnostic methods that ensure the safe operation of embedded control hardware and software for household appliances
- Intention of the regulation is to implement features that will avoid failure or at least ensure that any failure in the appliance does not present a safety hazard to the user.
- **Semiconductor suppliers must consider the impact of these standards on home appliance manufacturers when developing microelectronics for these devices**
- The standard is applied to overall solution
  - Hardware
  - Software
- The standard classifies applicable equipment into three categories:
  - Class A
  - Class B
  - Class C
- Implemented safety features (software and hardware features) have to pass the certification process at the certification authority

# IEC 60730 Classification of Appliances

- **Class A** are products with no feature/function that can harm a human being.
  - room thermostats, humidity controls, lighting controls, timers and switches.

- **Class B**
  - IEC 60730-1: Control functions intended to prevent unsafe operation of the controlled equipment.
    - washing machines, dishwashers, dryers, refrigerators, freezers and cookers/stoves
  - ***IEC 60335-1: Software that includes code intended to prevent hazards if a fault, other than a software fault occurs in the appliance***

- **Class C**
  - IEC 60730-1: Control functions which are intended to prevent special hazards (e.g. Explosion of the controlled equipment).
    - automatic burner controls and thermal cut-outs for closed water heater systems (unvented).
  - ***IEC 60335-1: Software that includes code intended to prevent hazards without the use of other protective devices.***

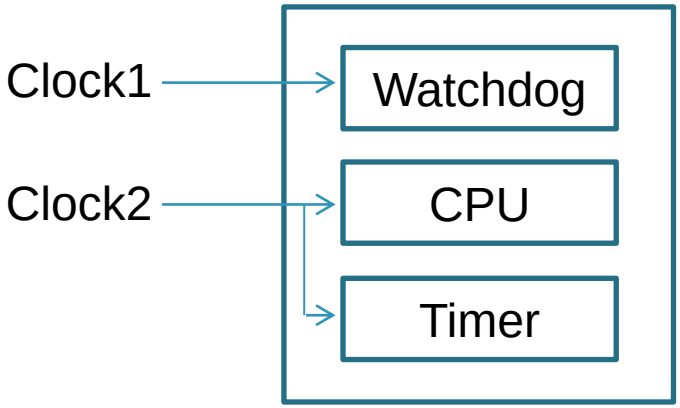
# IEC 60730 – Class B

- Recommended self-diagnostic tests for microcontrollers in Class B
  - Diagnostic of CPU registers
  - Diagnostic of PC (program counter)
  - Diagnostic of watchdog
  - Memory testing – Flash
  - Memory testing – RAM

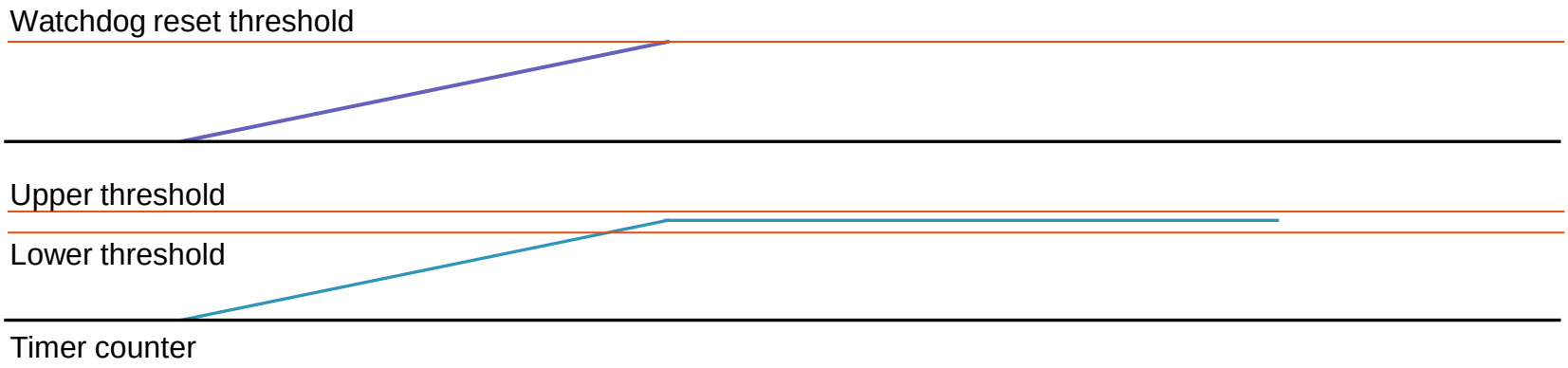
Provided by Freescale as a certified library

  - Runtime diagnostic of stack failure
  - Diagnostic of interrupt handling and execution
  - Diagnostic of clock frequency (accuracy)
  - Diagnosis of abnormalities in external interface (communications)
  - Runtime diagnostic of critical variables of control algorithm
  - Etc. (depends on the application)

# Watchdog Test







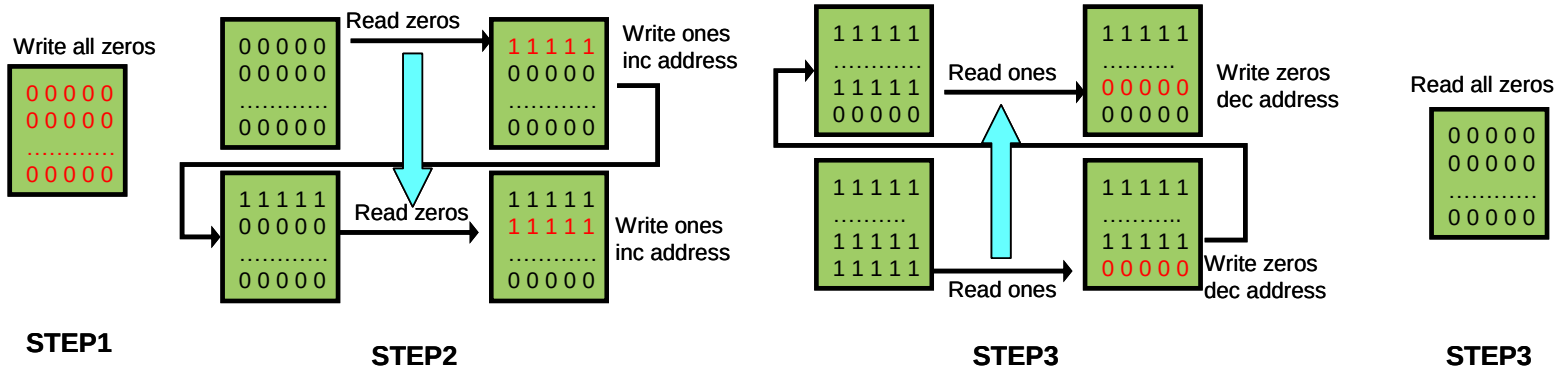
# Register Tests

1. Write 01010101… value into the register (0x55)
2. Compare if the written value is really in the register
3. Write its complement 10101010… (0xAA)
4. Compare if the write value is really in the register

- All registers are tested using this technique
- Certain registers do not have direct access
  - Example: PC (program counter) – workaround required

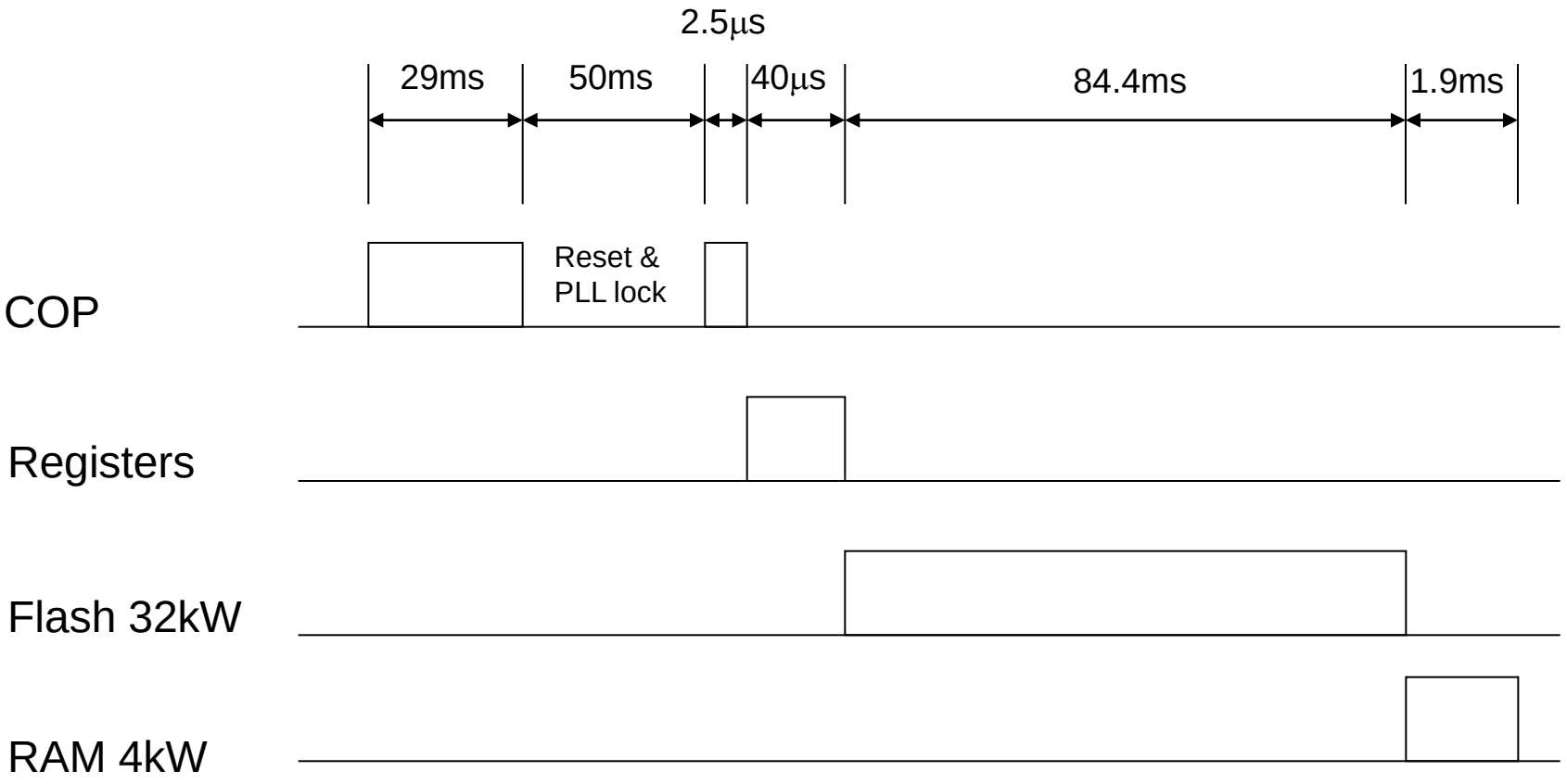
# Memory – March X

1. Write all zeros to array
2. Starting at lowest address, read zeros, write ones, increment up array.
3. Starting at highest address, read ones, write zeros, decrement down array.
4. Read all zeros from array.



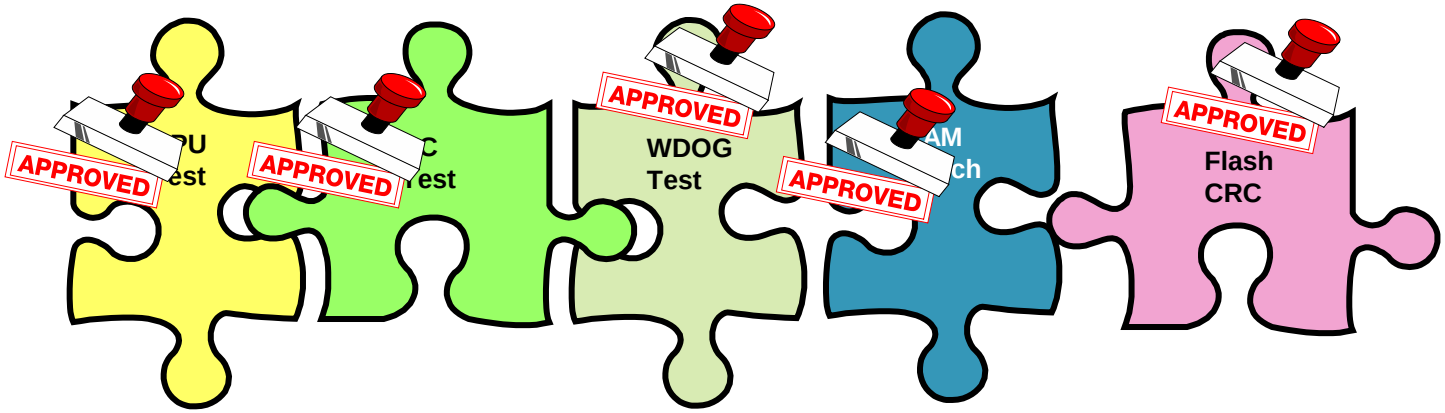

Fault coverage – AFs, SAFs

# Test Routines Timing 56F8037




Standard clock source 32MHz

# V.D.E. Approved IEC60730 Safety s/w Routines




| Microcontroller | IEC60730 Class B | IEC60730 Class C |
|---|---|---|
| MC9S08ACxx | Available | Available |
| MCF51xx | Available | not planned |
| MC56F8xx/80xx | Available | not planned |
| MC56F82xx/84xx | Certified in June 2013 | not planned |
| Kinetis K, KE, KL, KV, KM (CM0, CM4, CM4 Float) | Certified in June 2013 | not planned |

***"All pieces have been certified by VDE to help accelerate manufacturer development "***

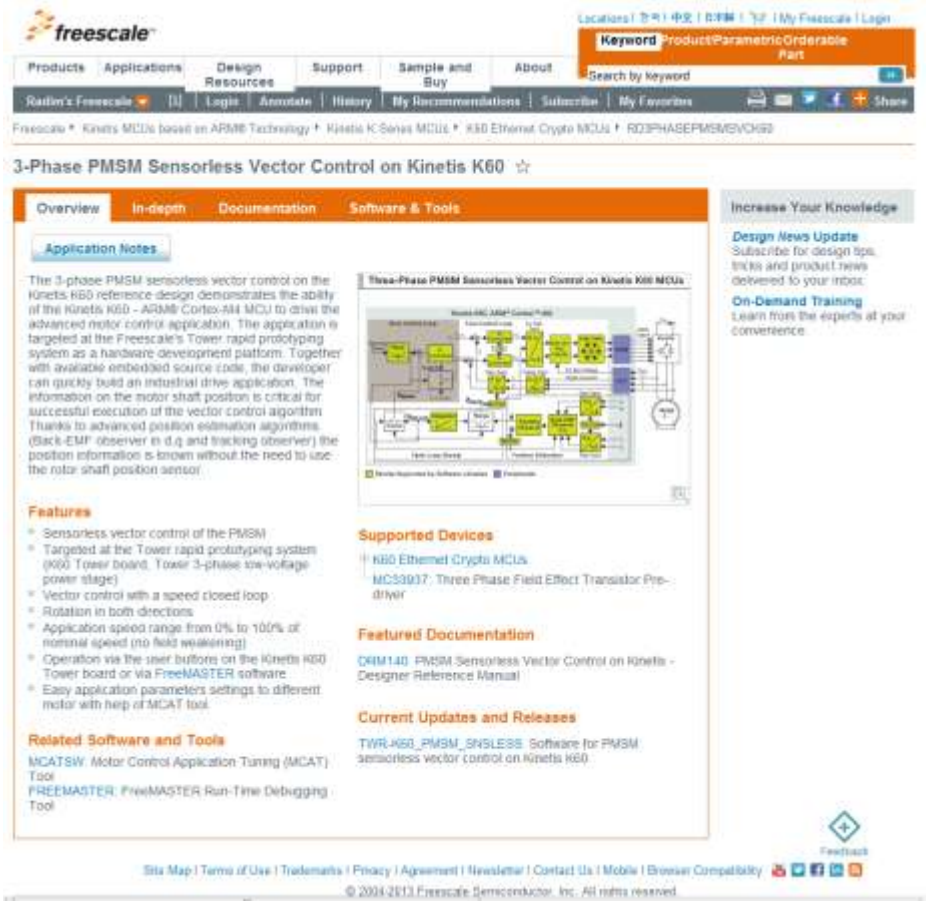
FSL Web page: **IEC 60730 Safety Standard for Household Appliances**

# Motor Control Reference Designs

# www.freescale.com/motorcontrol

- Rich set of reference designs
- RD's cover:
  - All motor types
  - Majority of algorithms
  - MC microcontrollers

The most popular Freescale application web page!



# DSC Ref. Designs

| Applications | Device | Status / Timeline | Notes |
|---|---|---|---|
| ACIM VC single shunt with Encoder | MC56F802x/3x | RD on freescale.com | DRM092 |
| BLDC sensorless Zero Crossing | MC56F802x/3x | RD on freescale.com | DRM070 |
| BLDC variable DC-link 6-step inverter | MC56F802x/3x | RD on freescale.com | DRM078 |
| BLDC with Hall Sensors | 56F805 | RD on freescale.com | DRM025 |
| PMSM Vector Control with Encoder | MC56F802x/3x | RD on freescale.com | DRM102 |
| PMSM Sensorless for Compressors | MC56F802x/3x | RD on freescale.com | DRM099 |
| PMSM Sensorless VC for H-axis Belt washer | MC56F802x/3x | RD on freescale.com | DRM110 |
| SRM with encoder | DSC56F805 | RD on freescale.com | DRM030 |
| SRM sensorless | DSC56F805 | RD on freescale.com | DRM031 |
| BLDC Sensorless ADC Back-EMF Sensing | 56F8006 | RD on freescale.com | DRM108 |
| 2-phase SR High Speed for Vacuum Cleaner | 56F8013 | RD on freescale.com | DRM100 |
| PMSM Sensorless Dish Washer, Pump, Fan | 56F8006 | Tradeshow demo available | Demo |
| BLDC Motor Control with Hall Sensors | 56F82xx | AN on freescale.com | AN4413 |
| PMSM Sensorless for compressor | 56F82xx | Tradeshow demo available | Demo |
| BLDC with Hall Sensors | 56F84xxx | Nevis Out-Of-Box-Experience | released |
| PMSM FOC with Encoder for Industrial Drives | 56F84xxx | Available at freescale.com | AN4656 |
| 3-in-1 (dual sensorless PMSM + PFC) for AirCon | 56F84xxx | RD on freescale.com | DRM139 |
| PMSM FOC sensorless with PFC | 56F82xxx | In progress, Q4 2013 | DRM |

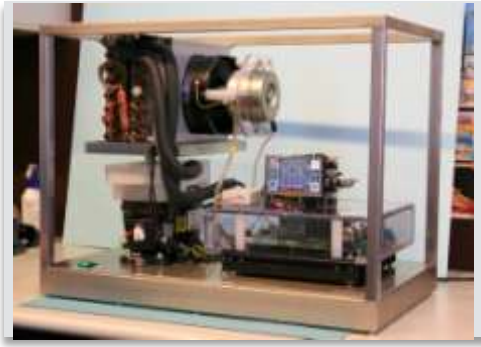
# Kinetis

| Cortex Applications | Device | Status / Timeline | Notes |
|---|---|---|---|
| BLDC with Hall Sensors (MQX & Bare metal) | K60 | **Available on freescale.com** | AN4376, sw |
| BLDC Sensorless (MQX & Bare metal) | K60 | **Available on freescale.com** | DRM135 |
| PMSM FOC with Encoder | K40 | **Available on freescale.com** | DRM128 |
| Dual PMSM FOC with Encoder | K70 | **Available on freescale.com** | AN4407 |
| PMSM FOC Sensorless with MCAT | K60 | **Available on freescale.com** | DRM140 |
| | | | |
| BLDC Sensorless with MCAT | TorqCopper | **In Progress, release – Oct/Nov 2013** | |
| PMSM Sensorless with MCAT | TorqCopper | **In plan, release - Q1 2014** | |
| ACIM V/Hz and Sensorless | TorqCopper | **In plan** | |

# DSC Based Motor Control

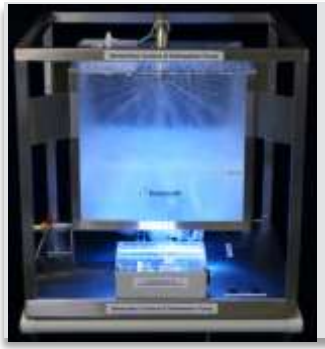
**PMSM FOC with Encoder for Industrial Drives**

- Sinusoidal FOC for industrial
- MCAT support
- Based on Tower
- demo and s/w available



**VF 3 in 1 Motor Control for AirCon with MC56F84xxx**

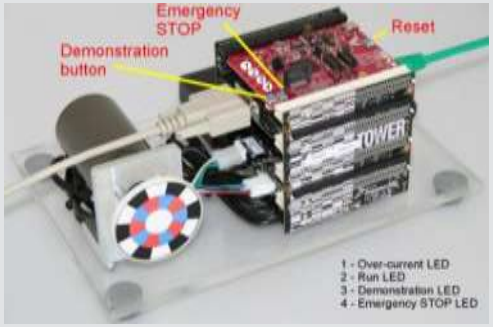
- 1.5 KW output power, support sensor-less PMSM motor control for both outdoor fan and compressor with FOC algorithm
- Support digital PFC (average current control)
- Demo, h/w and s/w available



**Sensorless PMSM for appliance on 56F8006**

- High Voltage Sensorless PMSM FOC
- Applications include washers, dishwashers, pumps, compressors, dryers…
- Migration for latest DSC's

# Kinetis Based Motor Control




## BLDC Sensor-less Drive with MQX on Kinetis K60

- Sensor-less 3-phase trapezoidal BLDC motor control
- Motor Control algorithm running under MQX
- Control over web server or FreeMASTER
- Running on a Tower kit

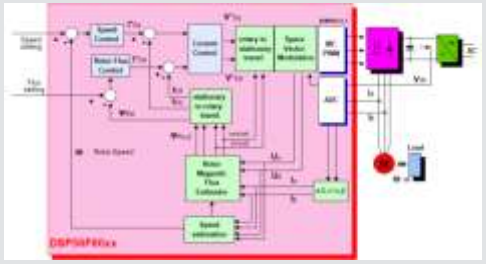
## Dual Sinusoidal PMSM for Industrial drive on K70

- Sensorless Sinusoidal FOC control algorithm with Encoder
- Targets industrial drives
- Running on Tower Kit with added dual motor control support

## Sensorless PMSM on Kinetis K60

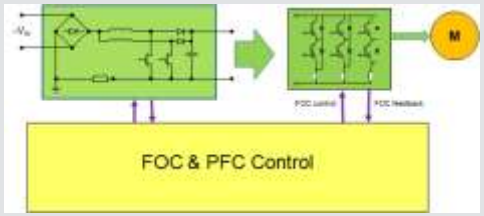
- Sensorless Sinusoidal FOC Drive
- Base for appliance application development
- Includes MCAT
- Running on a Tower kit

# Future Motor Control Solutions



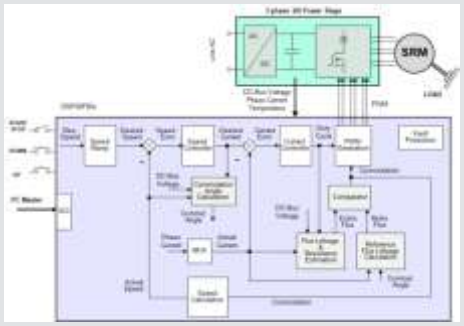
## Sensorless AC Induction Vector Control Drive

- Vector control of three-phase AC induction motor without sensor
- Estimation of motor speed using mathematical models
- Saves Cost




## Sensorless FOC of PMSM with PFC (MC56F827xx)

- Integration of PFC and motor control
- Support of sensorless PMSM motor control with FOC algorithm
- Support  of digital PFC (average current control)




## Sensorless Control of SR Motor Drive (MC56F827xx)

- Medium speed SR motor sensorless control
- Applications targets lawn movers, appliance
- Patented algorithm for On-the-Fly resistance estimation
  (US Patent No. 6,366,865)

# MCAT Tool

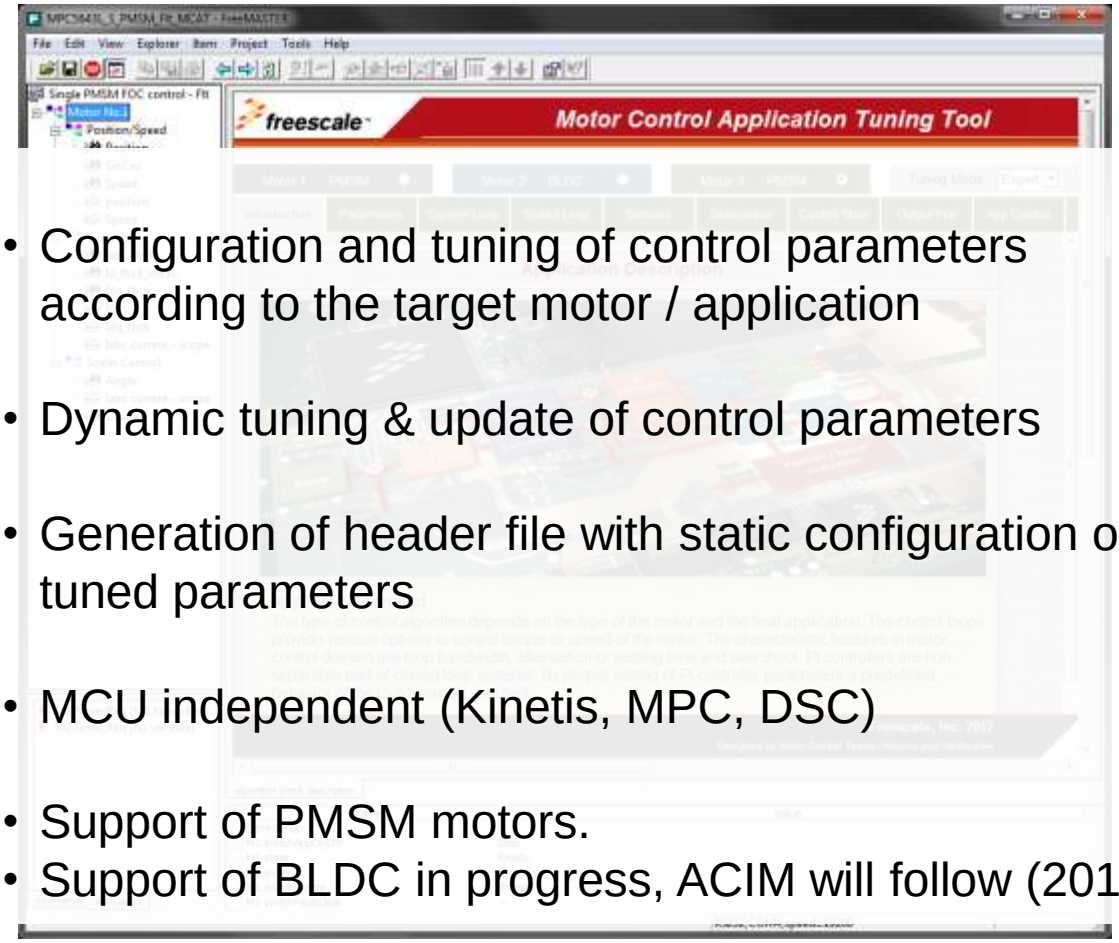
## Motor Control Application Tuning tool

# Motivation

- Existing Freescale motor control solutions are often demos / reference designs that often require expertise know-how to be reused by customers
- More and more un-experienced customers build motor control applications and require turn-key solution
- Our competition offers / claims easy-to-use MC s/w

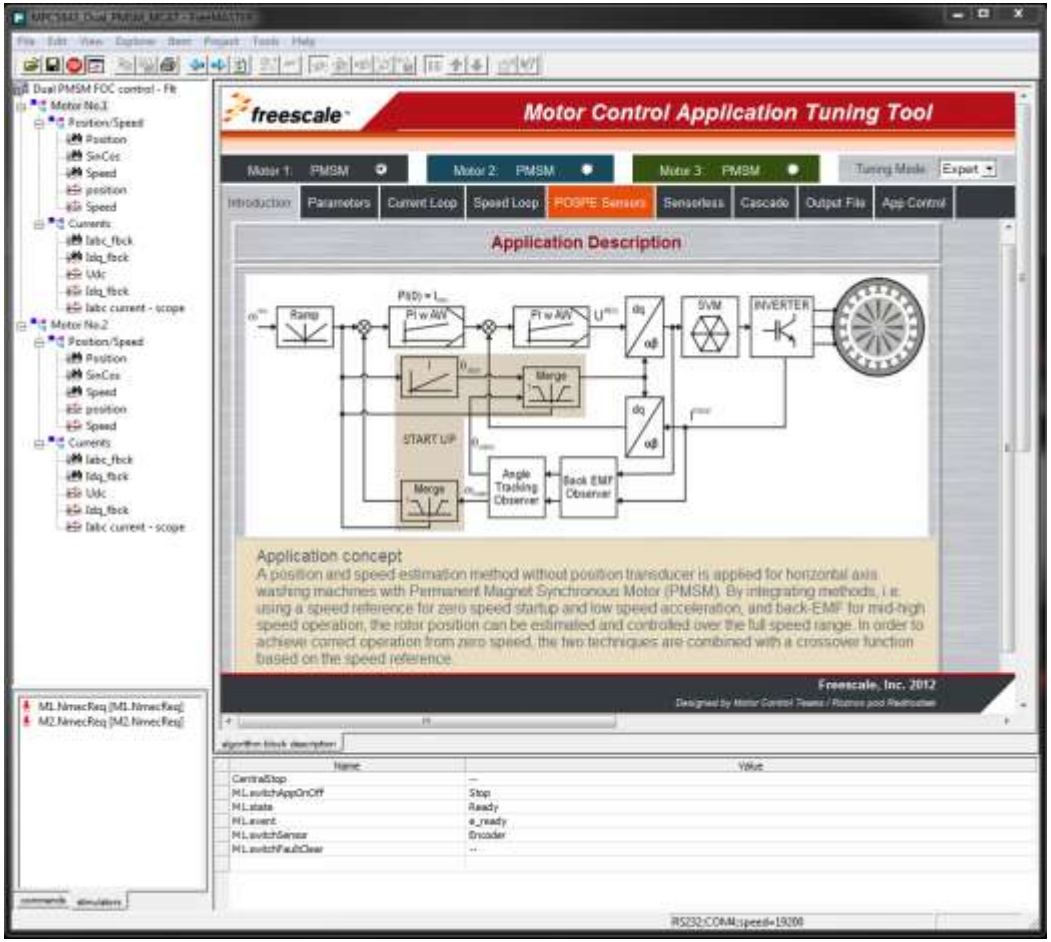
**CUSTOMERS NEED WELL TESTED, EASY-TO-USE & EASY TO CONFIGURE MOTOR CONTROL S/W**

# MCAT

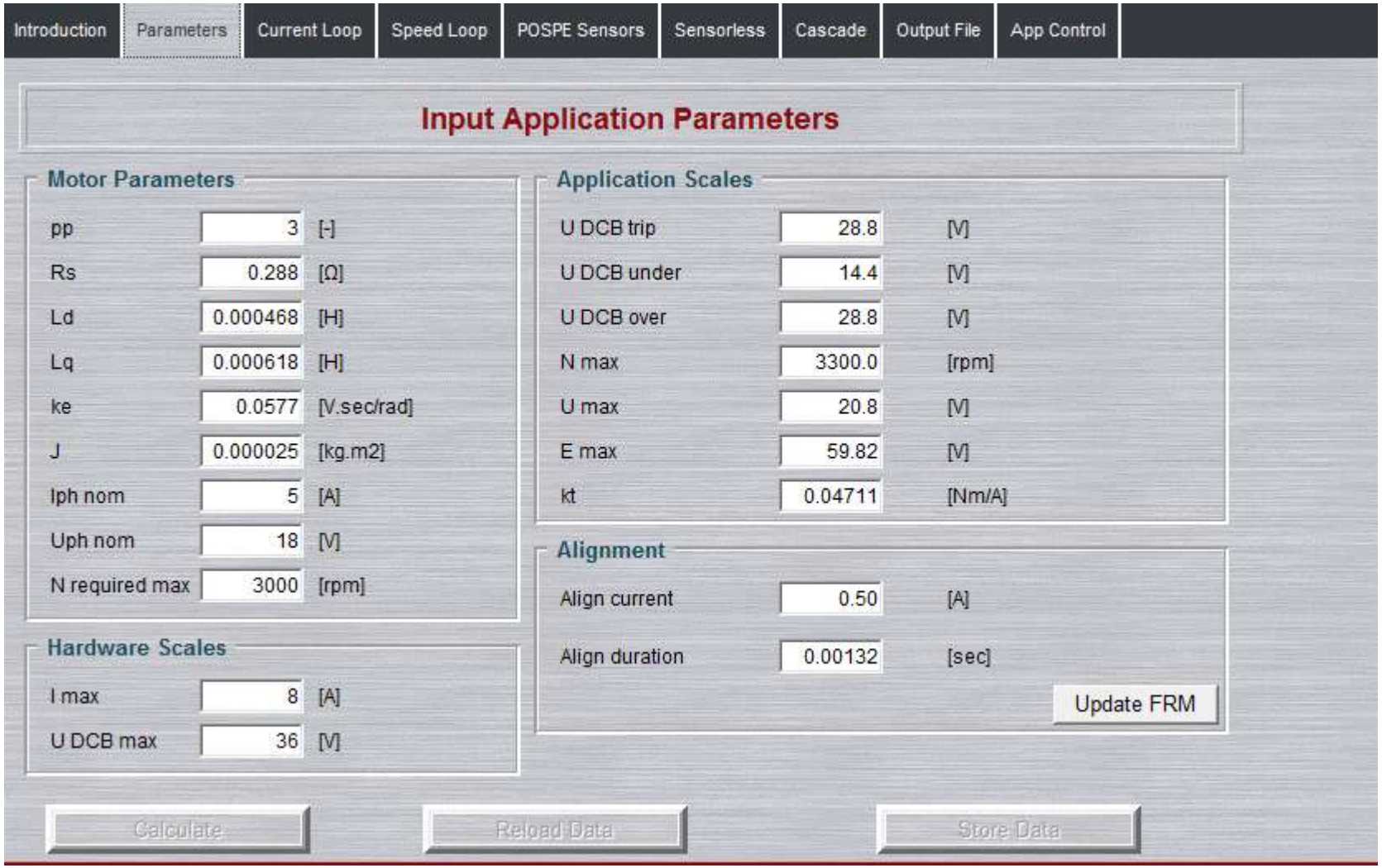



- Configuration and tuning of control parameters according to the target motor / application
- Dynamic tuning & update of control parameters
- Generation of header file with static configuration of the tuned parameters
- MCU independent (Kinetis, MPC, DSC)
- Support of PMSM motors.
- Support of BLDC in progress, ACIM will follow (2013)

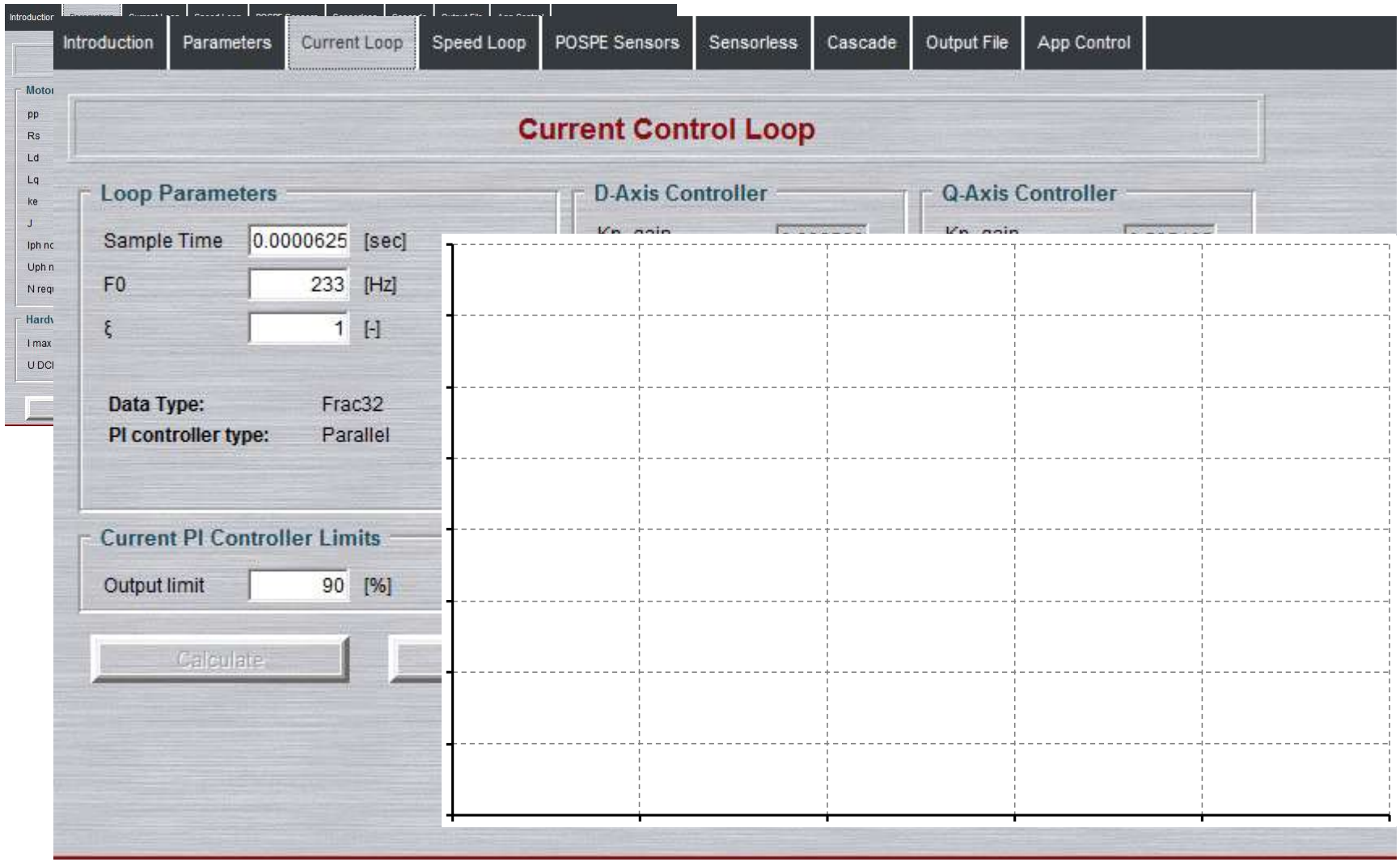
# FreeMASTER with MCAT



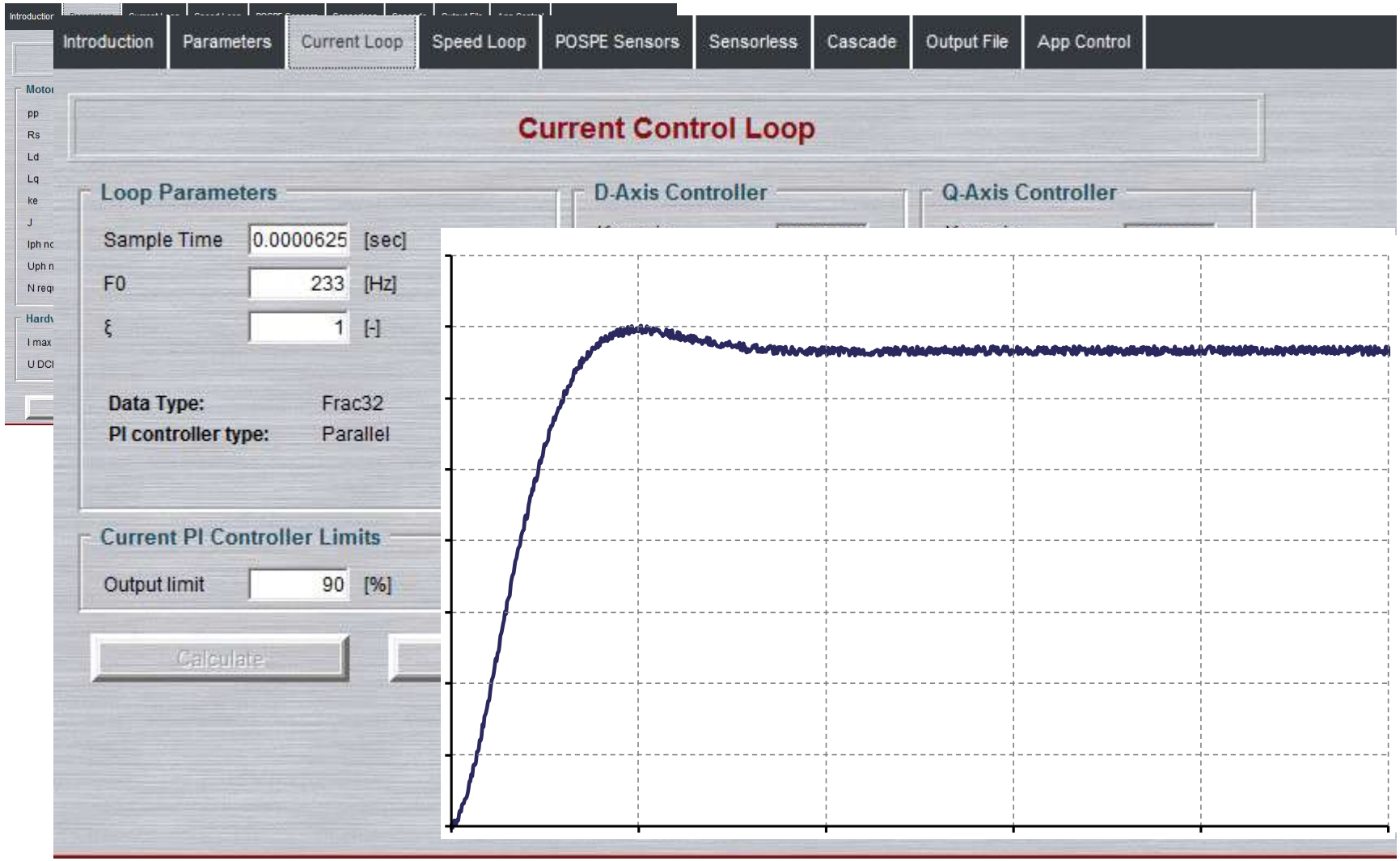
# Steps to Tune Control Loops



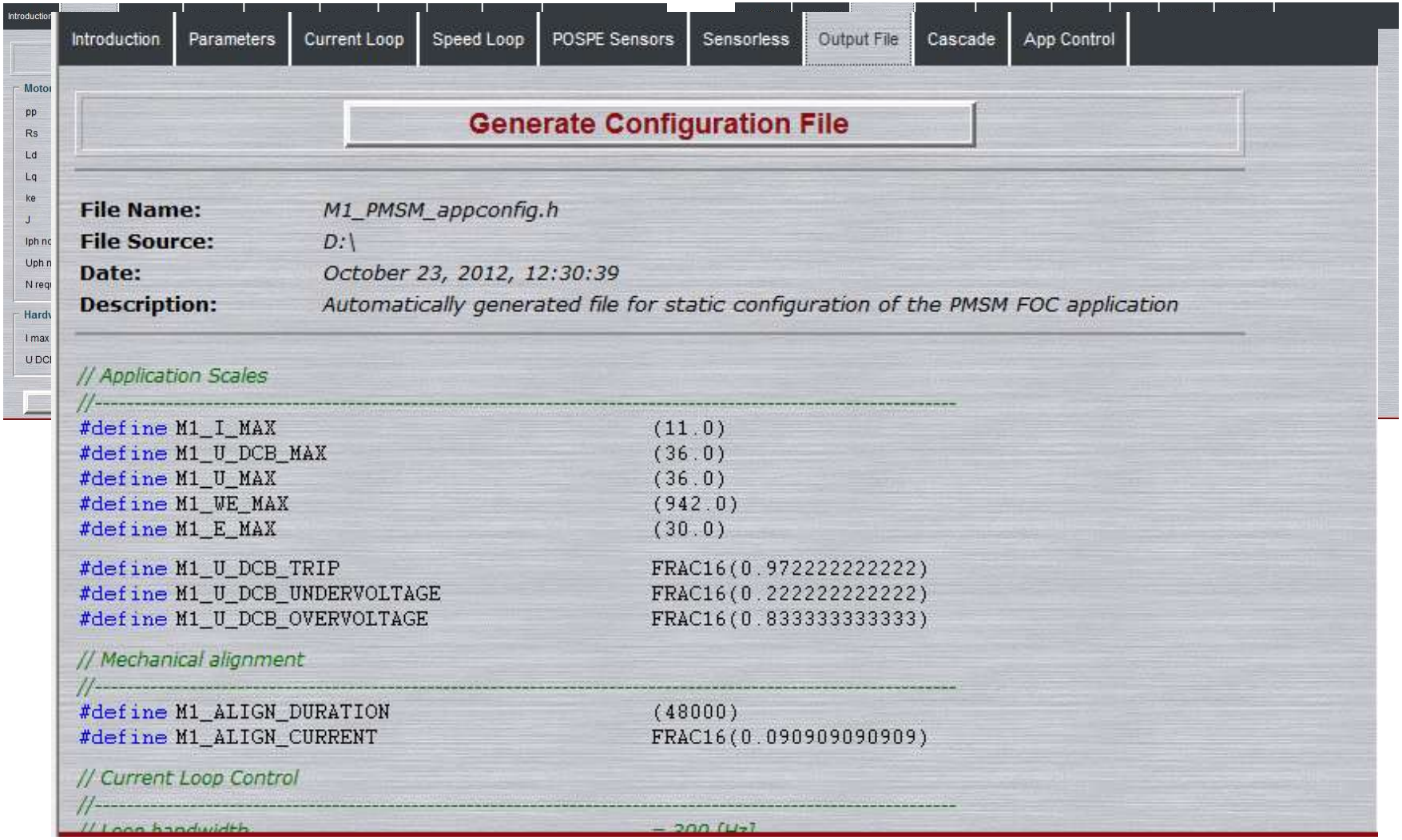
# Steps to Tune Control Loops



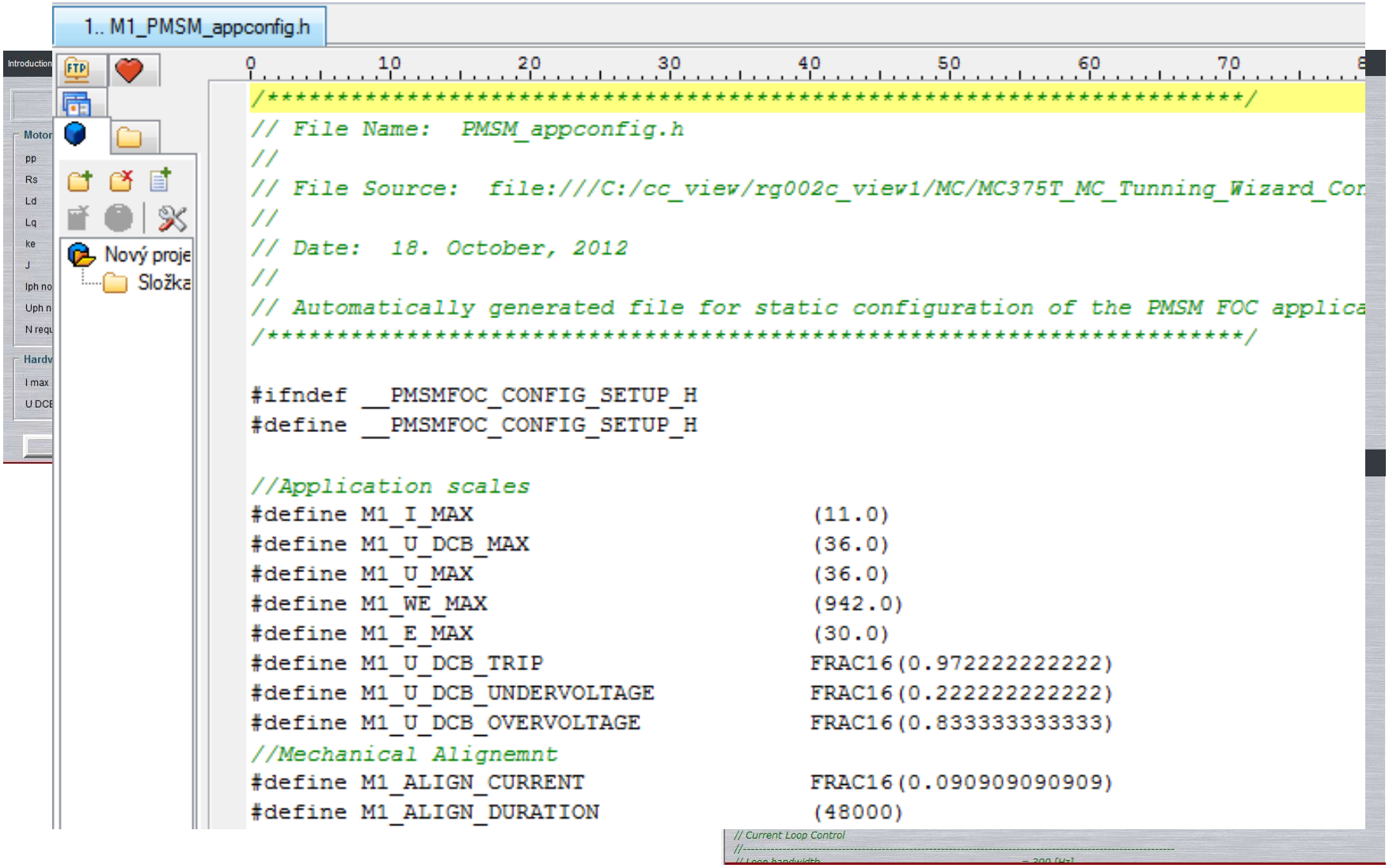
# Steps to Tune Control Loops



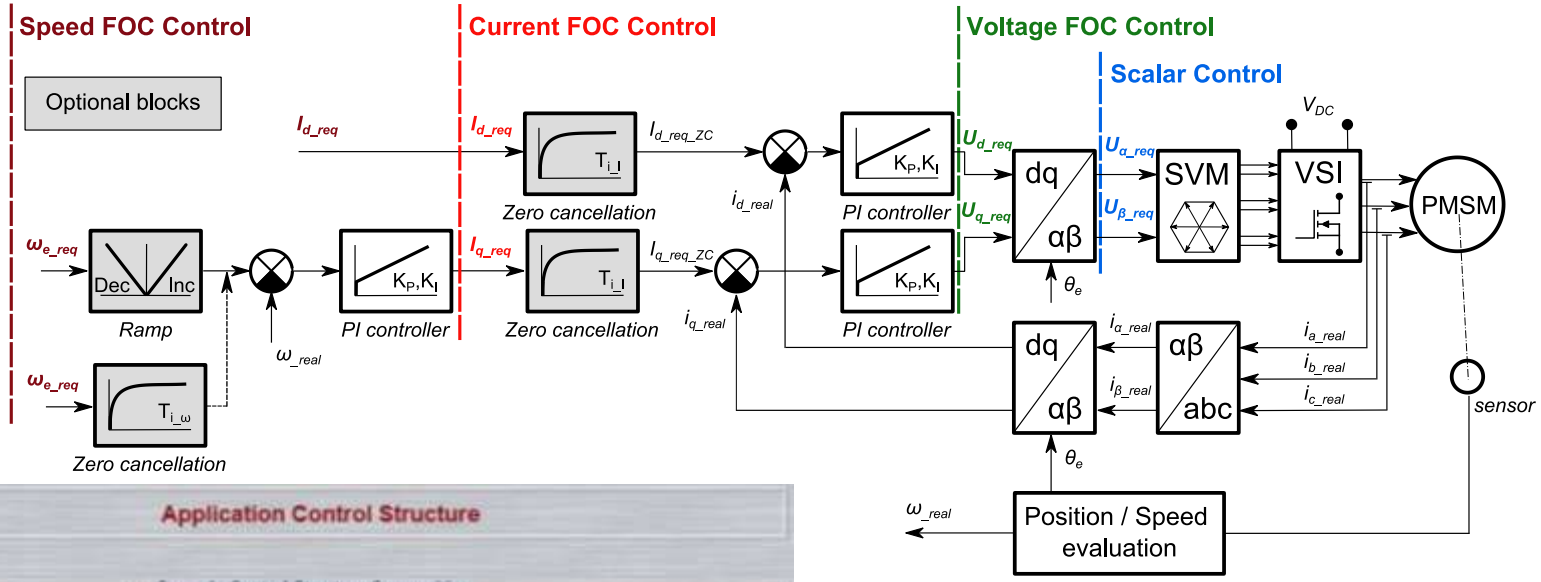
# Steps to Tune Control Loops



# Steps to Tune Control Loops



# MCAT Control Structure Selector





**Open loop control**
no need any current, position or speed feedback

**Voltage control – position required**
no need any current and speed feedback

**Current control – current, position required**
no need any speed feedback

**Speed control - current, position and speed required**

# What will be Coming in Enablement?

- Focus on easy-to-use solutions
  - MCAT for BLDC and ACIM
  - Automated measurement of motor parameters

- Extend offering for Kinetis V portfolio
  - Optimized libraries for CM0+
  - Floating point libraries and applications
  - Sensorless ACIM applications

- Extend range of MC H/W support
  - Offer High Voltage Motor Control Power Stage

# Q & A

# Designing with Freescale

**Tailored live, hands-on training in a city near you**

**2014 seminar topics include**

- QorIQ product family update
- Kinetis K, L, E, V series MCU product training

freescale.com/DwF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