



Introduction to Motor Control with Freescale

AMF-IND-T0487

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Applications Engineer

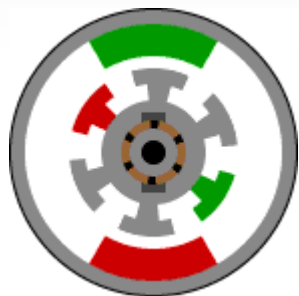


September 2013

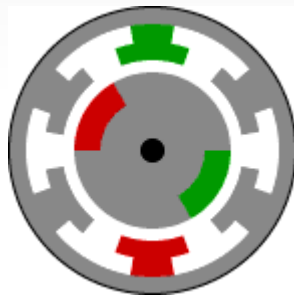
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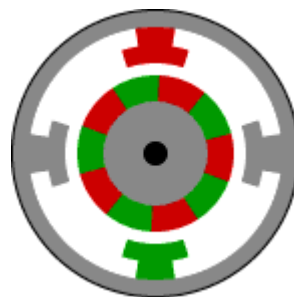
Many Different Motor Types ...



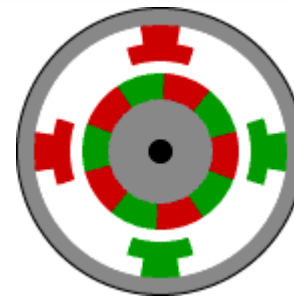
DC Motor



**Brushless DC Motor
(BLDC)**



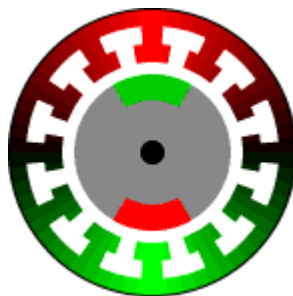
Stepper Motor (full step)



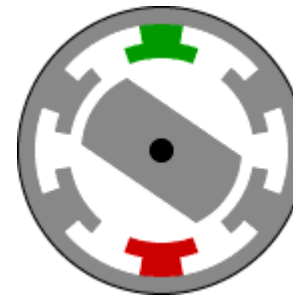
Stepper Motor (half step)



AC Induction Motor (ACIM)



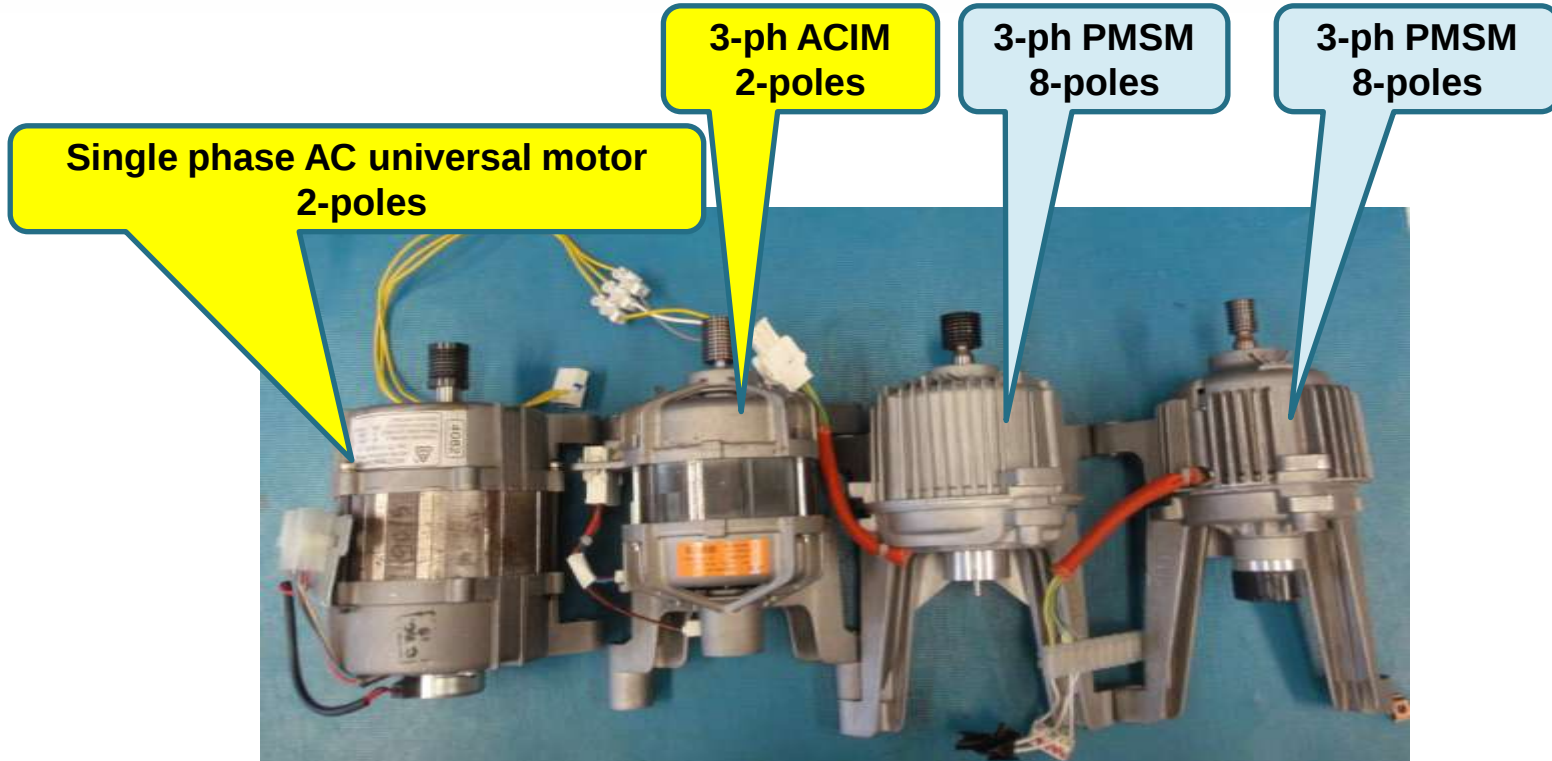
**Permanent Magnet
Synchronous Motor (PMSM)**



Switched Reluctance Motor

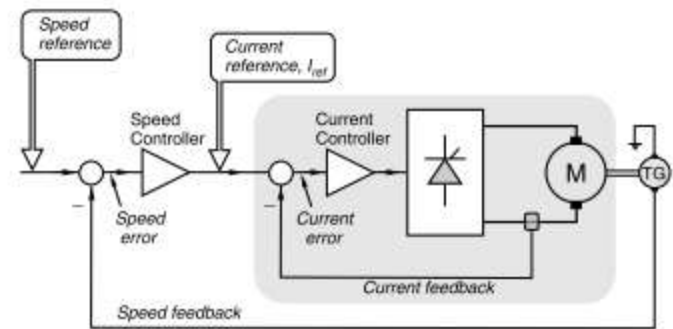
Washer Components

Washer motors – about 750W



Basic Motor Control Structures

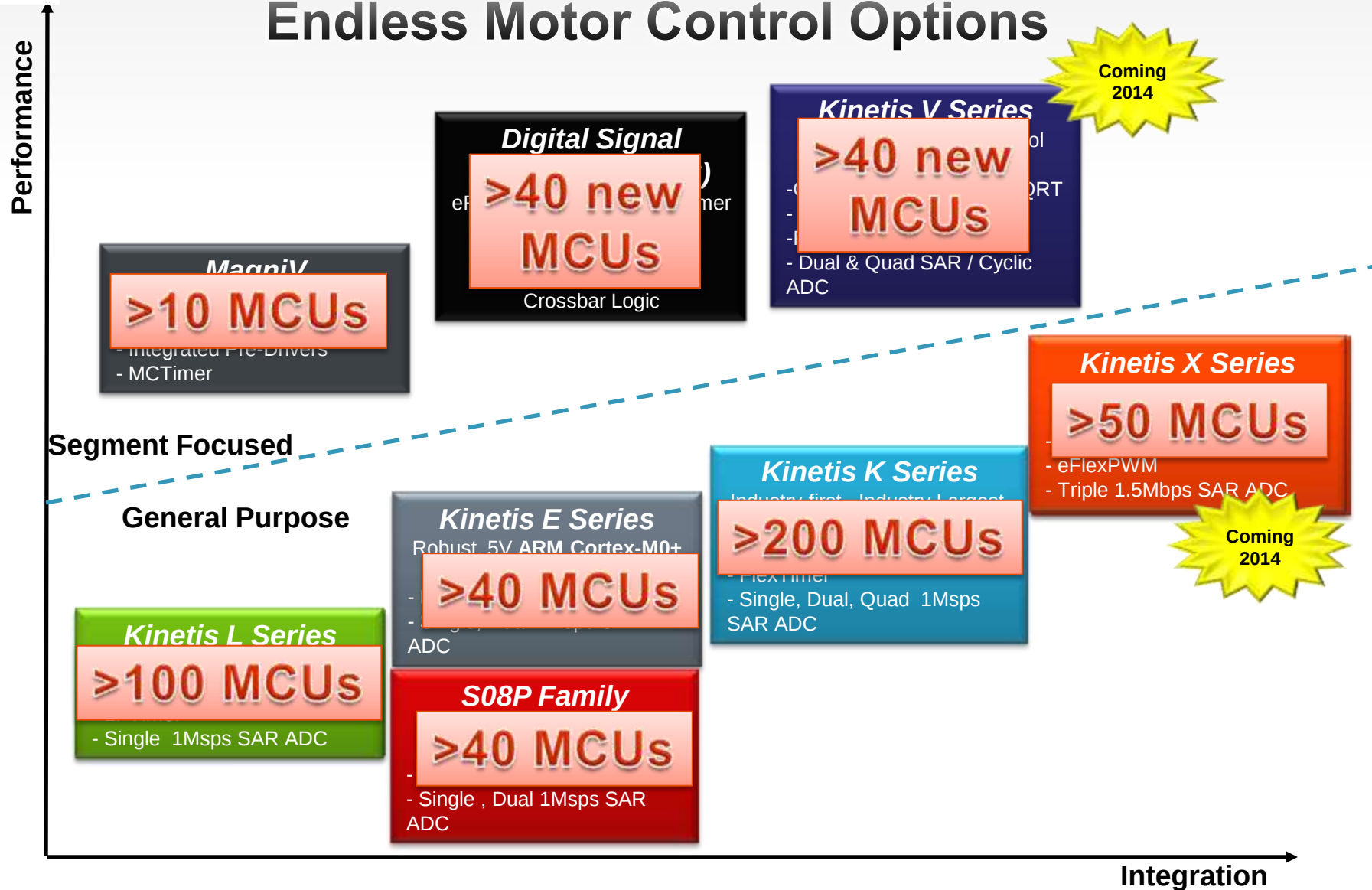
- **Speed Control**
 - Applications requiring the motor to operate with a specified speed (pumps, fans, compressors, etc.)
 - Low dynamic performance
 - The actual motor speed is kept by speed controller to follow reference speed command
- **Speed Control with Inner Current Loop**
 - Majority of variable speed drives
 - High dynamic performance
- **Position Control**
 - Applications with additional position control loop to keep desired position (servos, industrial robots, linear motors)
 - Most complex drives
- **Torque Control**
 - Applications requiring the motor to operate with a specified torque regardless of speed (vehicles, electric power steering, winding machines, etc.)



Processor Requirements for Motor Control Applications

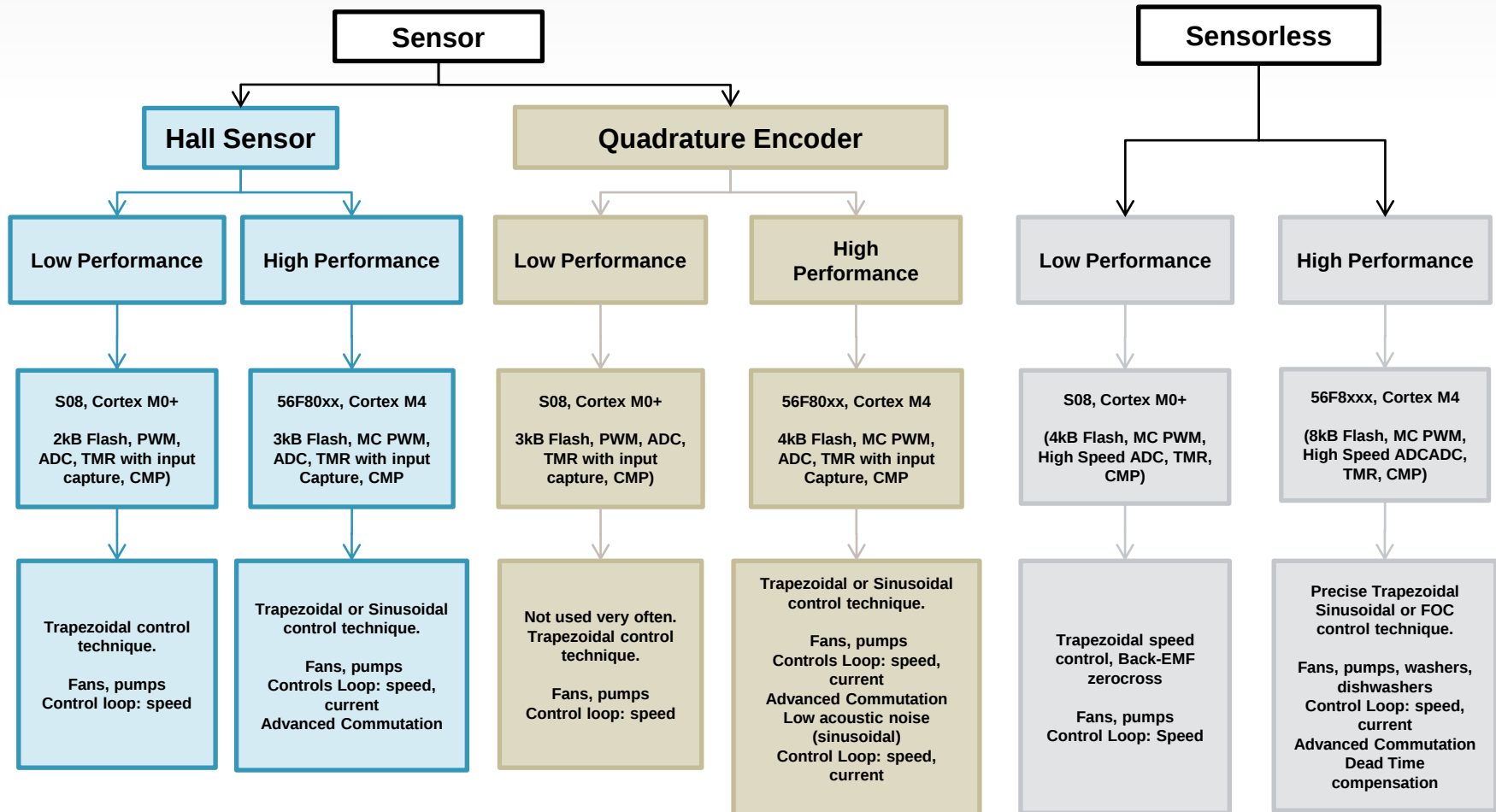
- **ADC module**
 - We need to measure DC Bus voltage, Back-EM voltage, phase currents, DC Bus current, heating temperature
- **PWM module**
 - We need to generate 1 up 8 PWM according to motor type
- **Timer/Quadrature decoder**
 - We need to measure speed and rotor position from different sensors (hall sensors, quadrature encoder, tacho generator, sin/cos interface, etc.)
- **User interface**
 - Communication interfaces, if required (SCI, SPI, CAN, I2C)
 - GPIO pins
- **Build-in analog devices**
 - We need to detect fault conditions (over-current, over-voltage)
 - Allows to eliminate external comparators
 - Build in DAC allows SW control of fault level

Endless Motor Control Options

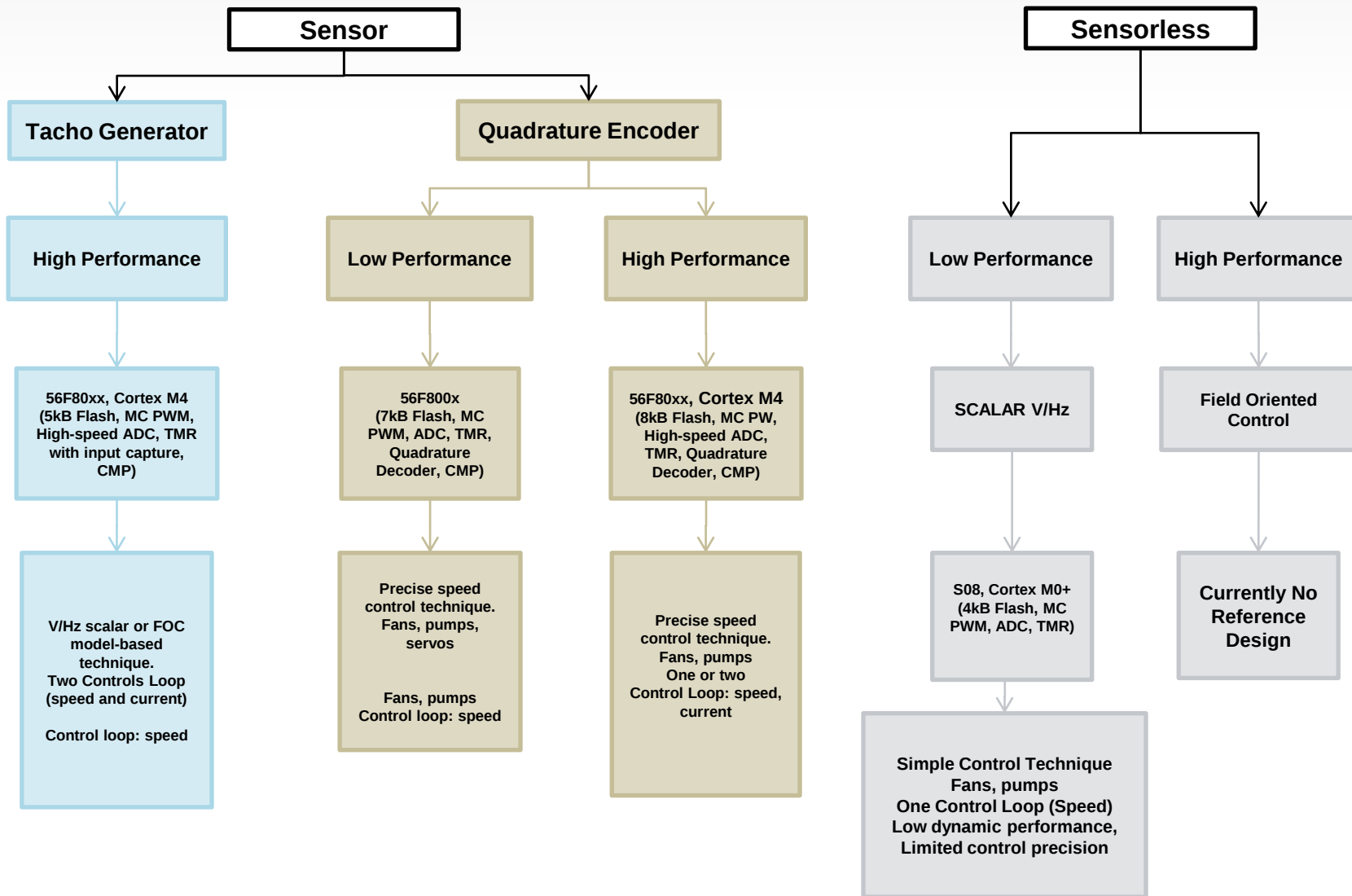


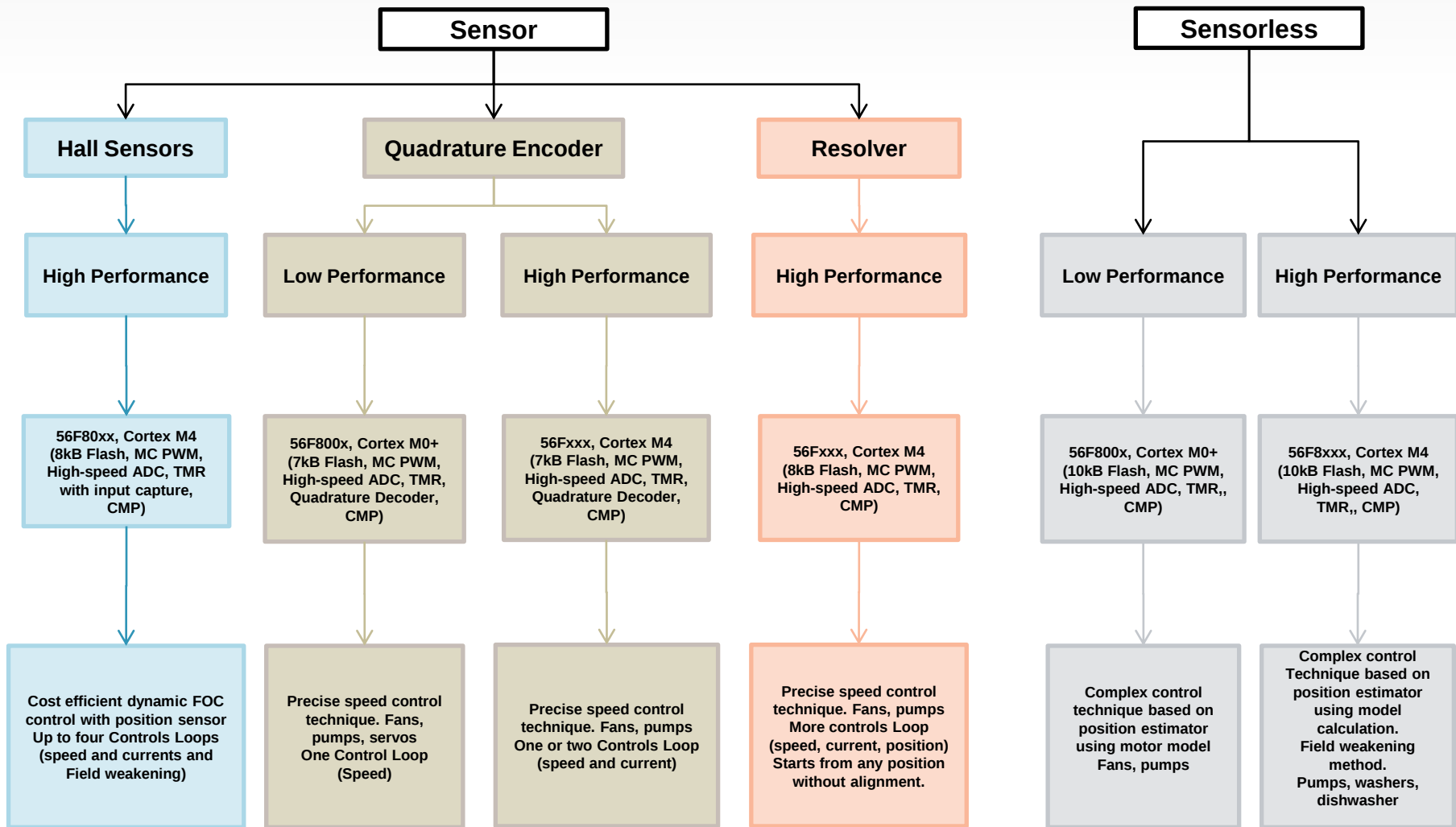
Freescale Motor Control Module Overview

Freescale Module	PWM Modules	ADC speeds for Motor Control	Other Key Modules
Vybrid	FlexTimer	2x 12-bit SAR @ 1us	Programmable Delay Block
Freescale DSC	eFlexPWM	2x 12-bit Cyclic @ 300ns	4 Accumulators QuadTimer
Kinetis V Series CortexM4 100-120Mhz	FlexTimer	2x 12-bit SAR @ 1us	Floating Point Unit Programmable Delay Block
Kinetis K Series 120MHz-150Mhz	FlexTimer LPTimer	Up to 4x 12-bit SAR @ 1us	Floating Point Unit Programmable Delay Block
Kinetis K Series 72MHz-100MHz	FlexTimer LPTimer	2x 12-bit SAR @ 1us	Programmable Delay Block
Kinetis V Series CortexM0+ @ 75MHz	FlexTimer	2x 12-bit SAR @ 1us	Programmable Delay Block
Kinetis K Series 50MHz	FlexTimer LPTimer	1x 12-bit SAR @ 1us	Programmable Delay Block
Kinetis E Series 20MHz / 50MHz	FlexTimer	2x 12-bit SAR @ 1us	Programmable Delay Block
S08P Family 20MHz	FlexTimer	2x 12-bit SAR @ 1us	Programmable Delay Block
Kinetis L Series 50MHz	LPTimer	1x 12-bit SAR @ 1us	

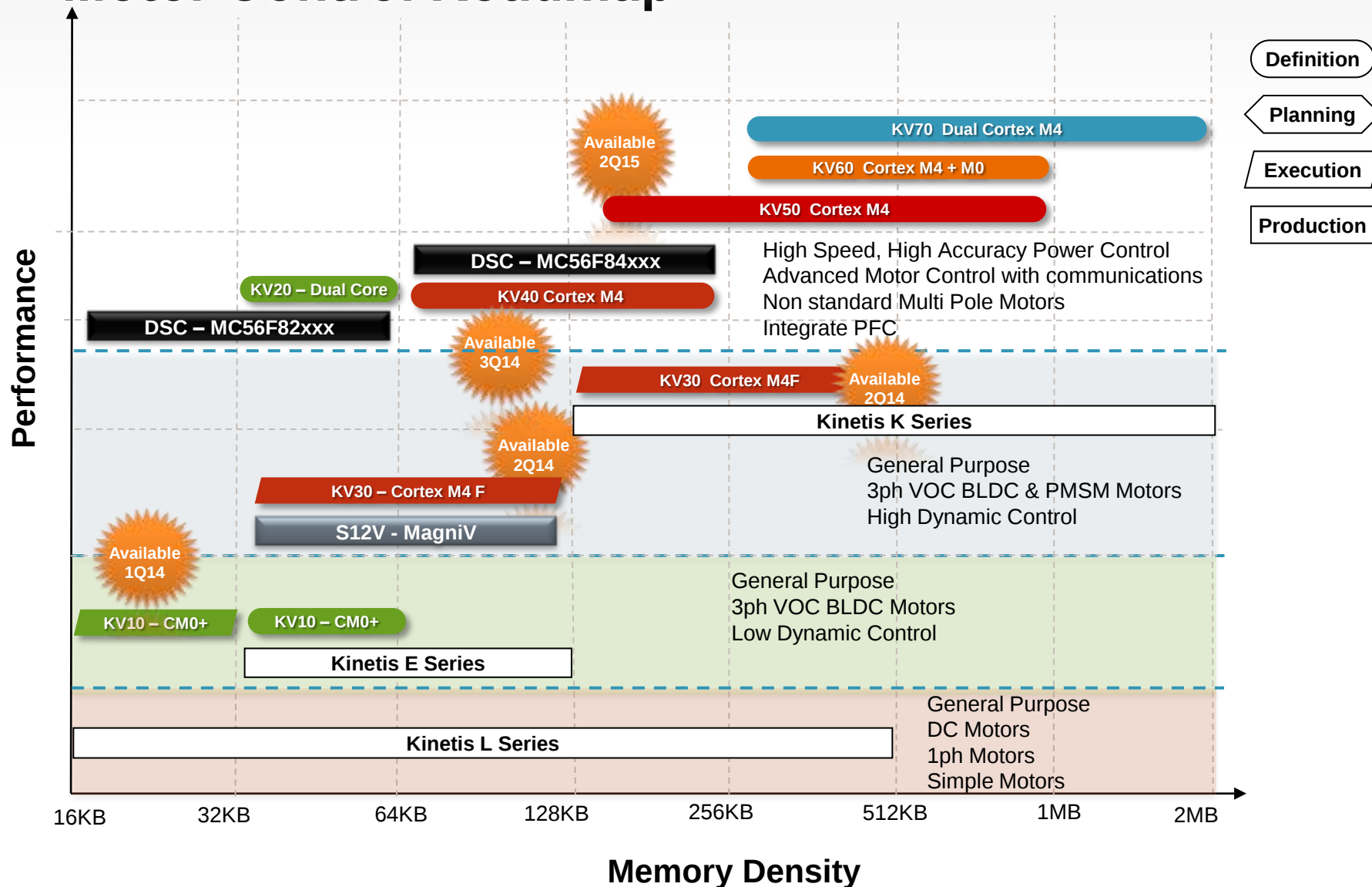


ACIM





Motor Control Roadmap



MC56F827xx (64kB Flash, 50/100MHz)

Key Features:

Core

- 56800EX @ 50/100MHz supporting fractional arithmetic with 4 accumulators, 8 cycle pipeline, separate program and data memory maps for parallel moves, single cycle math instructions, nested looping, and superfast interrupts that far outpace any competitive core on the market.

System

- Inter-module crossbar directly connecting any input and/or output with flexibility for additional logic functions (AND/OR/XOR/NOR)
- DMA controller for reduced core intervention when shifting data from peripherals
- Memory resource protection unit to ease safety certification

Timers

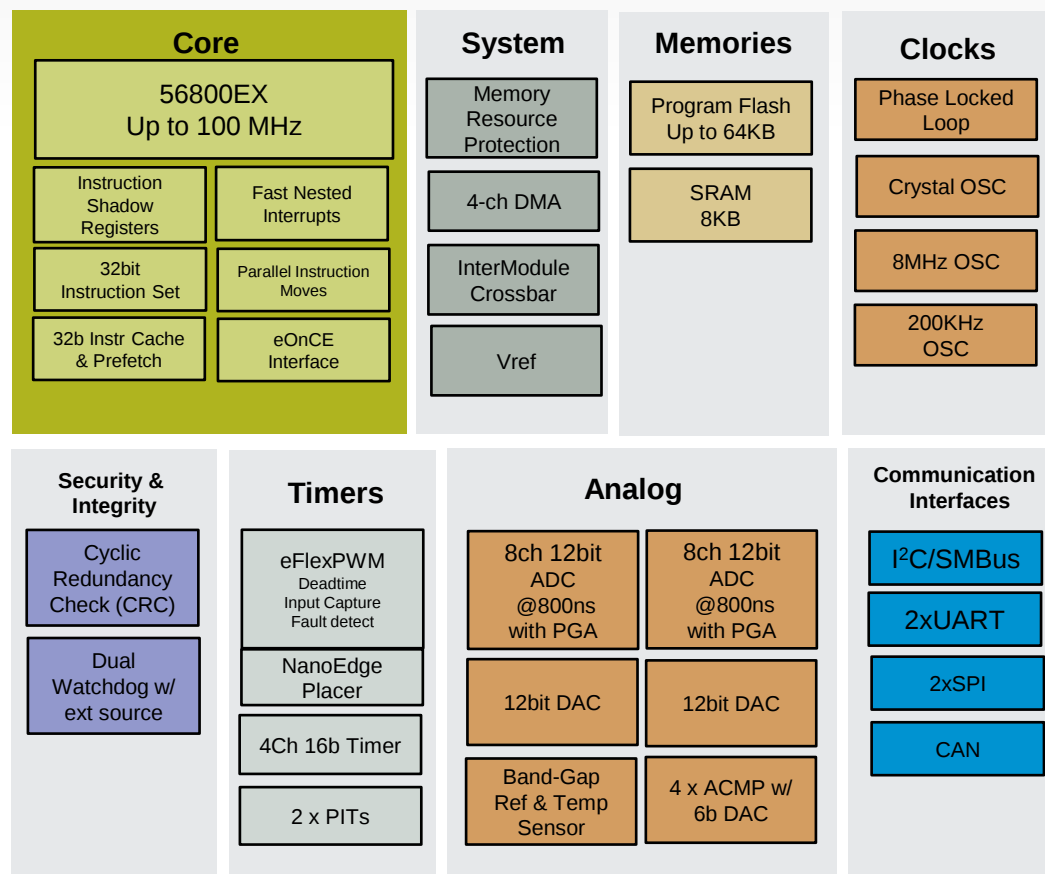
- eFlexPWM – Freescale’s most advance timer for Digital Power Conversion, up to 8ch and 312 pico-sec resolution, 4 independent time bases, with half cycle reloads for increased flexibility, automatic complimentary mode for ease of use and best in class performance

Analog

- 2x12-bit high-speed ADCs each with 800ns conversion rates
- 4 analog comparators with integrated 6-bit DACs that can enable emergency shutdown of the PWMs
- Integrated PGAs to increase the accuracy of ADC conversions on small voltages and currents

Power Consumption:

- Best in class Power Consumption – 50% better than nearest competitor



Others: 5-volt tolerant I/O for cost-effective board design

Packages: 32QFN (5x5), 32LQFP, 48LQFP, 64LQFP

Temperature: -40 to +105C across all packages, with -40 to +125C option on 64LQFP

MC56F823xx (32kB Flash, 50MHz)

Key Features:

Core

- 56800EX @ 50MHz supporting fractional arithmetic with 4 accumulators, 8 cycle pipeline, separate program and data memory maps for parallel moves, single cycle math instructions, nested looping, and superfast interrupts that far outpace any competitive core on the market.

System

- Inter-module crossbar directly connecting any input and/or output with flexibility for additional logic functions (AND/OR/XOR/NOR)
- DMA controller for reduced core intervention when shifting data from peripherals
- Memory resource protection unit to ease safety certification

Timers

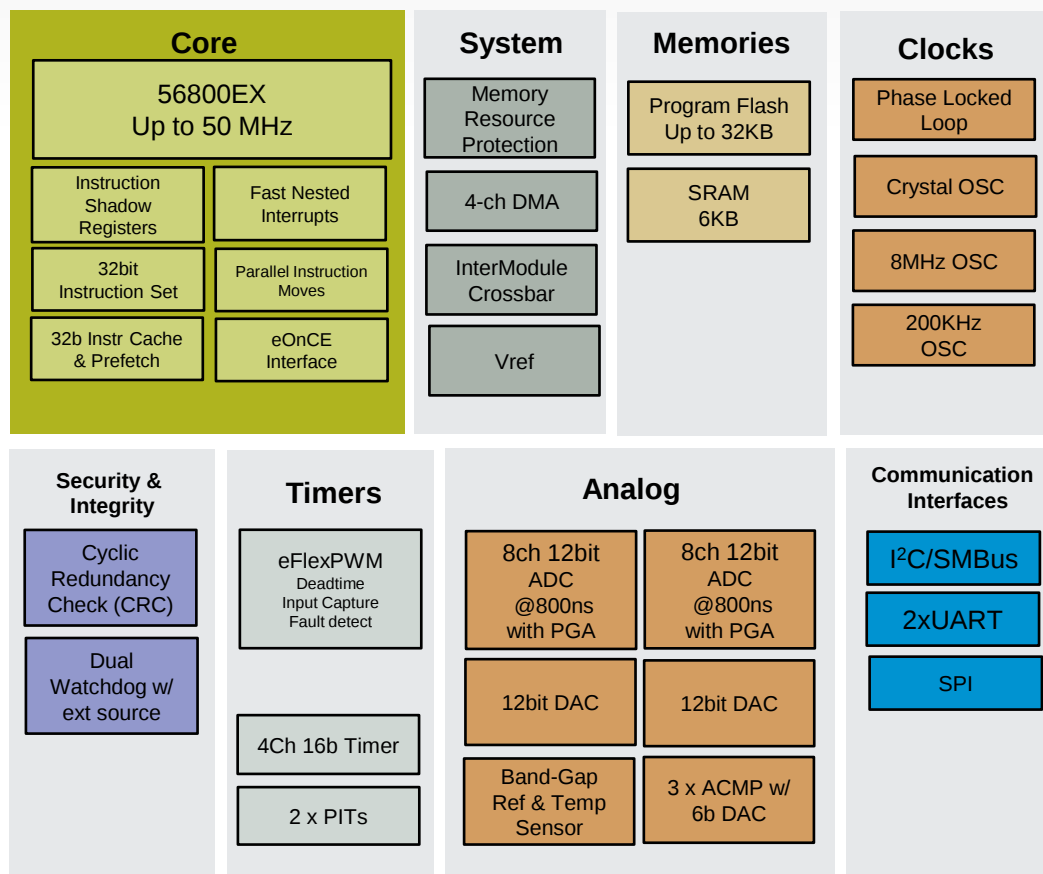
- eFlexPWM – Freescale's most advance timer for Digital Power Conversion, up to 8ch and 312 pico-sec resolution, 4 independent time bases, with half cycle reloads for increased flexibility, automatic complimentary mode for ease of use and best in class performance

Analog

- 2x12-bit high-speed ADCs each with 800ns conversion rates
- 4 analog comparators with integrated 6-bit DACs that can enable emergency shutdown of the PWMs
- Integrated PGAs to increase the accuracy of ADC conversions on small voltages and currents

Power Consumption:

- Best in class Power Consumption – 50% better than nearest competitor



Others: 5-volt tolerant I/O for cost-effective board design

Packages: 32QFN (5x5), 32LQFP, 48LQFP

Temperature: -40 to +105C across all packages

MC56F84xxx (256kB Flash, 100MHz)

Key Features:

Core

- 56800EX @ 100MHz supporting fractional arithmetic with 4 accumulators, 8 cycle pipeline, separate program and data memory maps for parallel moves, single cycle math instructions, nested looping, and superfast interrupts that far outpace any competitive core on the market.

System

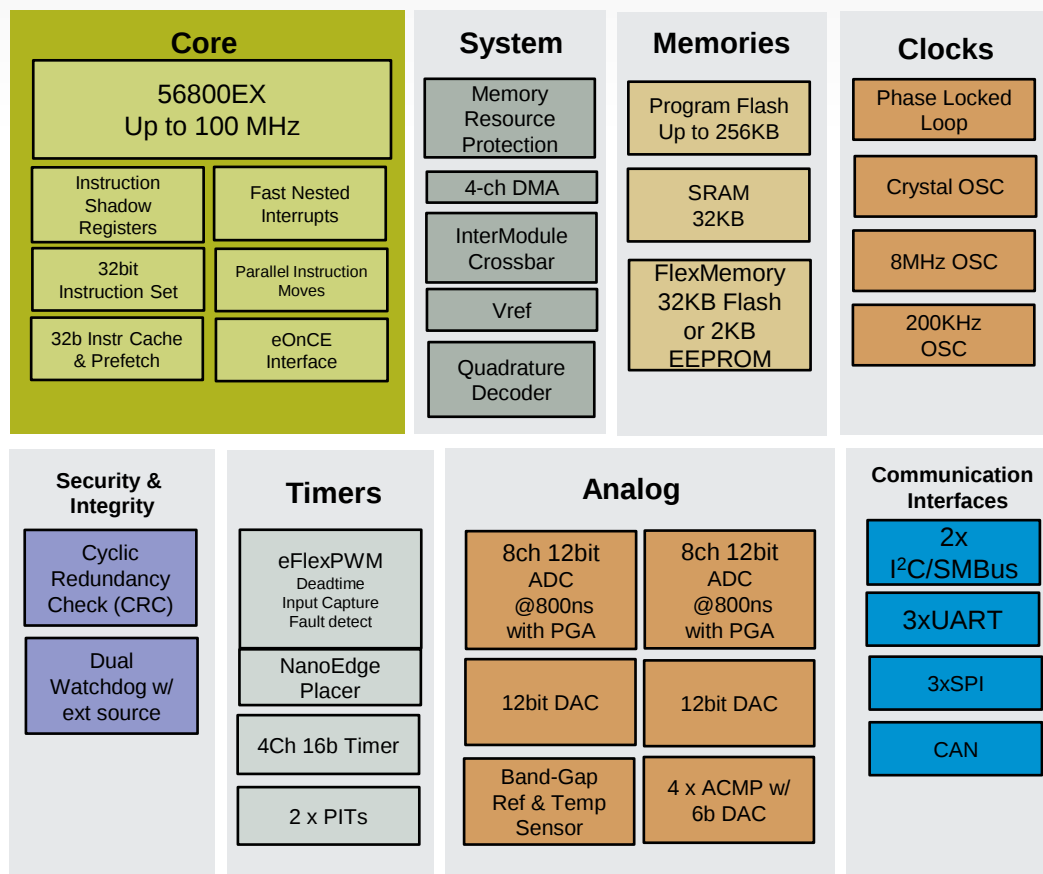
- Inter-module crossbar directly connecting any input and/or output with flexibility for additional logic functions (AND/OR/XOR/NOR)
- DMA controller for reduced core intervention when shifting data from peripherals
- Memory resource protection unit to ease safety certification

Timers

- eFlexPWM – Freescale's most advance timer for Digital Power Conversion, up to 8ch and 312 pico-sec resolution, 4 independent time bases, with half cycle reloads for increased flexibility, automatic complimentary mode for ease of use and best in class performance

Analog

- 2x12-bit high-speed ADCs each with 800ns conversion rates
- 16 ch 16b SAR ADC that enables external sensors inputs and accurate system measurements
- 4 analog comparators with integrated 6-bit DACs that can enable emergency shutdown of the PWMs
- Integrated PGAs to increase the accuracy of ADC conversions on small voltages and currents



Others: 5-volt tolerant I/O for cost-effective board design
Freescale FlexMemory for simplified data storage

Packages: 48LQFP, 64LQFP, 80LQFP, 100LQFP

Temperature: -40 to +105C across all packages

Key Features:

- **Cortex-M4** @ 100MHz

- 64KB Flash,
- 16KB SRAM

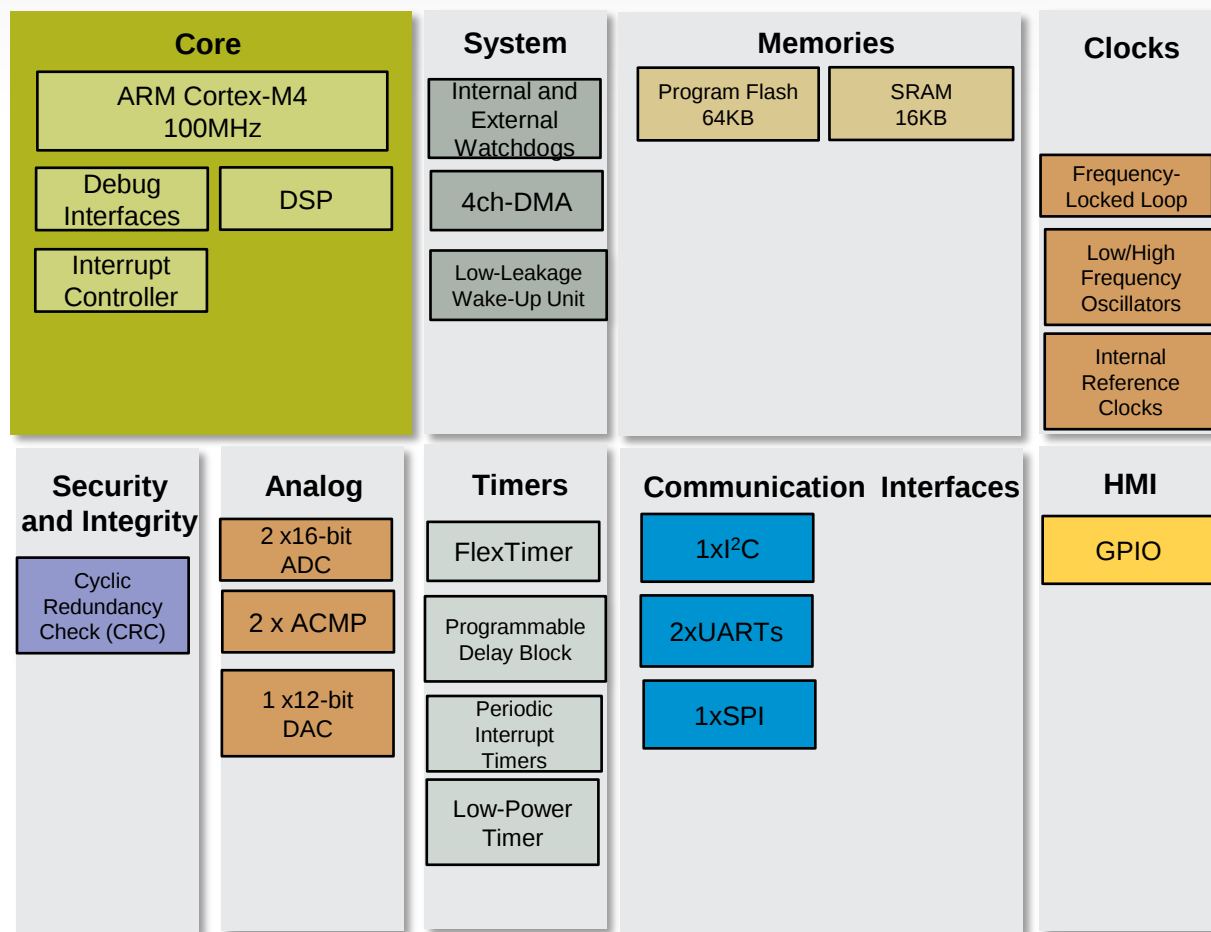
- Multiple serial ports

- 2 x 16-bit ADC
- 1 x 12-bit DAC
- 2 x ACMP

- 1x6ch FTM (PWM)
- 2x2ch FTM (PWM/Quad Dec.)
- Low Power Timer

- Up to TBD I/Os
- 6 high-drive I/Os (20mA) – SPI/I2C
- 1.71V-3.6V; -40 to 105oC

32QFN, 48LQFP, 64LQFP



KV10s: 100MHz Cortex M4 128K Flash

Key Features:

Core/System

- **Cortex-M4** @ 100MHz

Memory

- 128KB Flash,
- 16KB SRAM

Communications

- Multiple serial ports

Analog

- 2 x 16-bit ADC
- 1 x 12-bit DAC
- 2 x ACMP

Timers

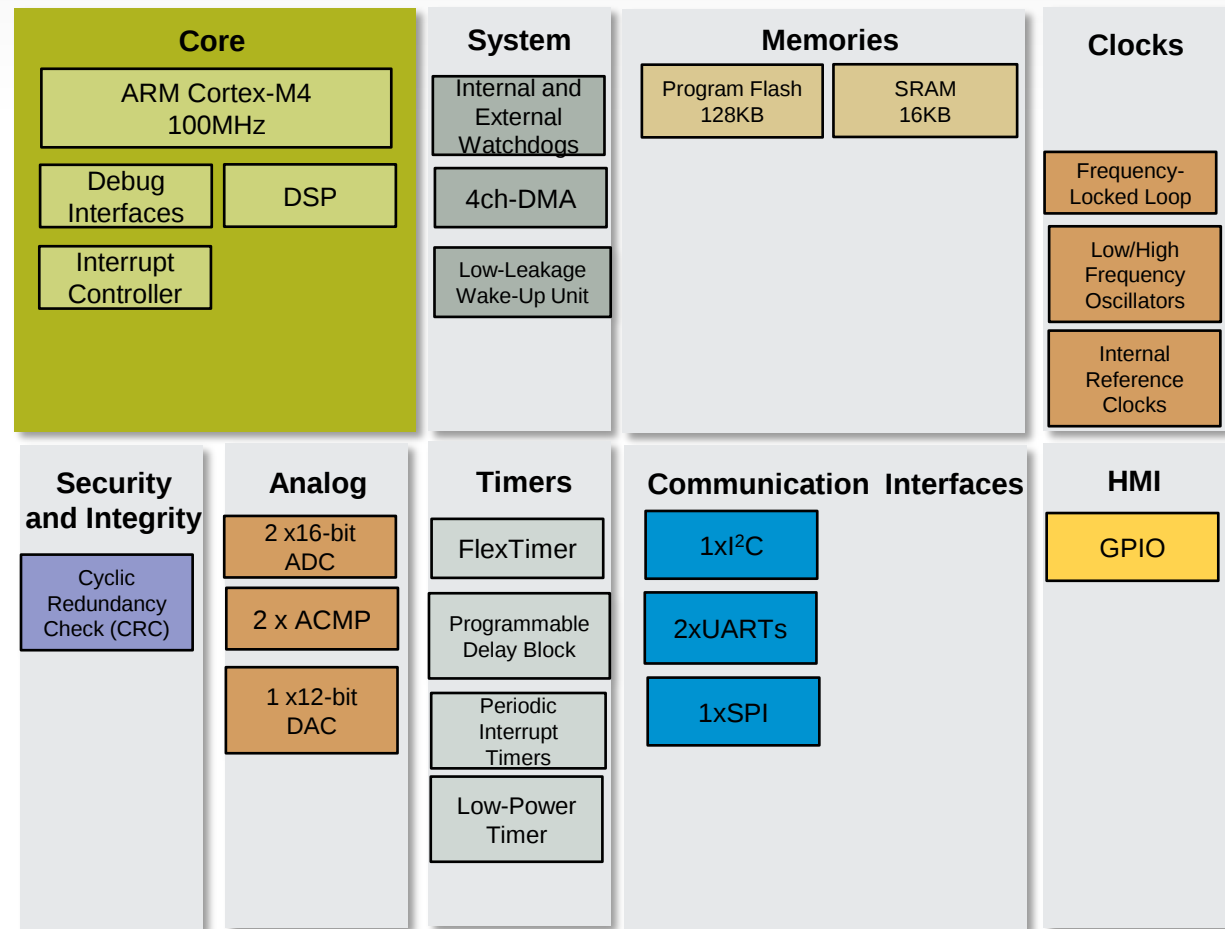
- 1x6ch FTM (PWM)
- 2x2ch FTM (PWM/Quad Dec.)
- Low Power Timer

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



KV10s: 100MHz Cortex M4 FPU 128K Flash

Key Features:

Core/System

- **Cortex-M4** @ 100MHz / FPU

Memory

- 128KB Flash,
- 24KB SRAM

Communications

- Multiple serial ports

Analog

- 2 x 16-bit ADC
- 1 x 12-bit DAC
- 2 x ACMP

Timers

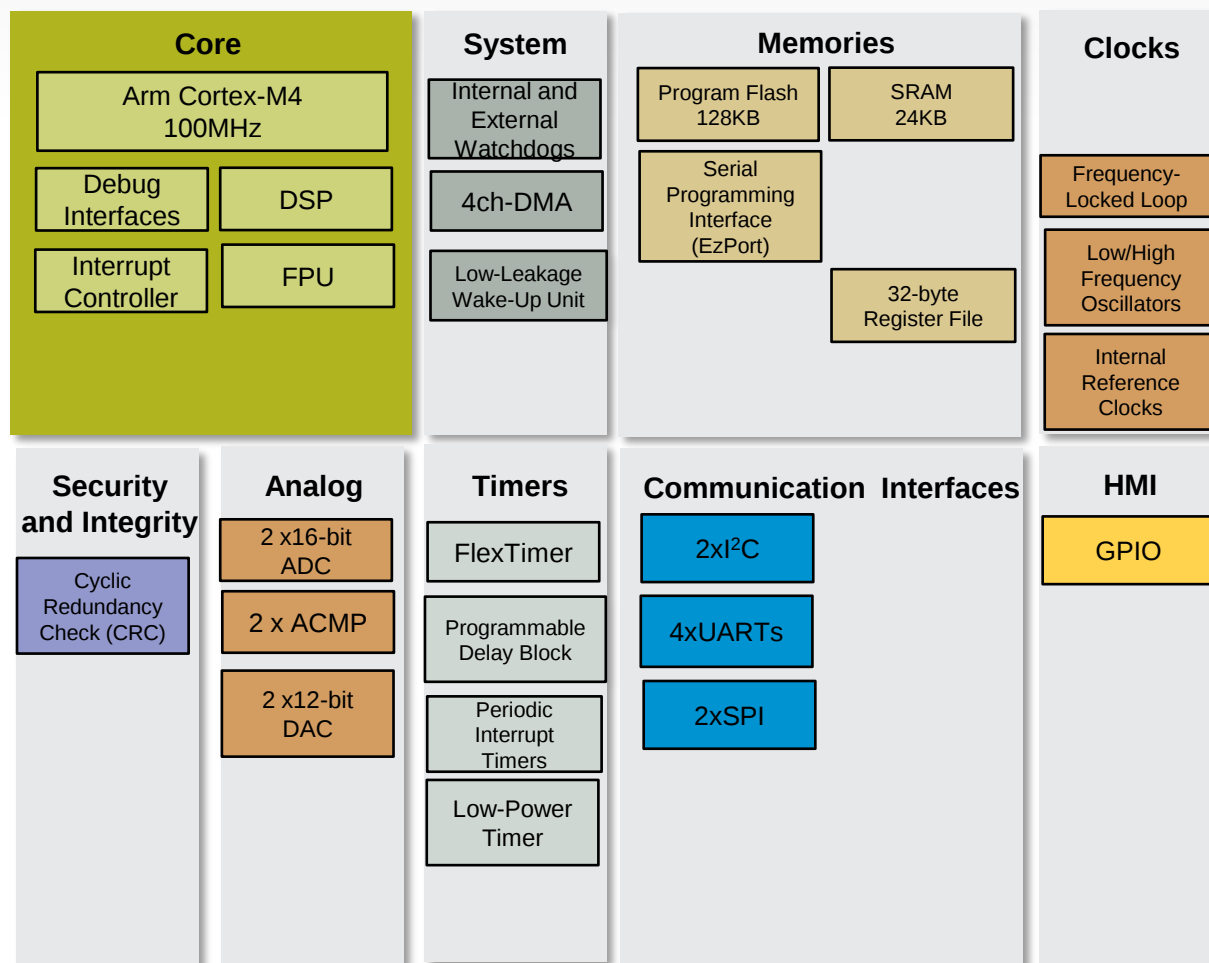
- 1x8ch FTM (PWM)
- 2x2ch FTM (PWM/Quad Dec.)
- Low Power Timer

Others

- Up to TBD I/Os
- 6 high-drive I/Os (20mA) – SPI/I2C
- 1.71V-3.6V; -40 to 105oC

Packages

64LQFP, 100LQFP



10s –120MHz Cortex M4 FPU 512KB/256KB Flash

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 x 16-bit ADC
- Up to 2 x 12-bit DAC
- 2 x ACMP

Timers

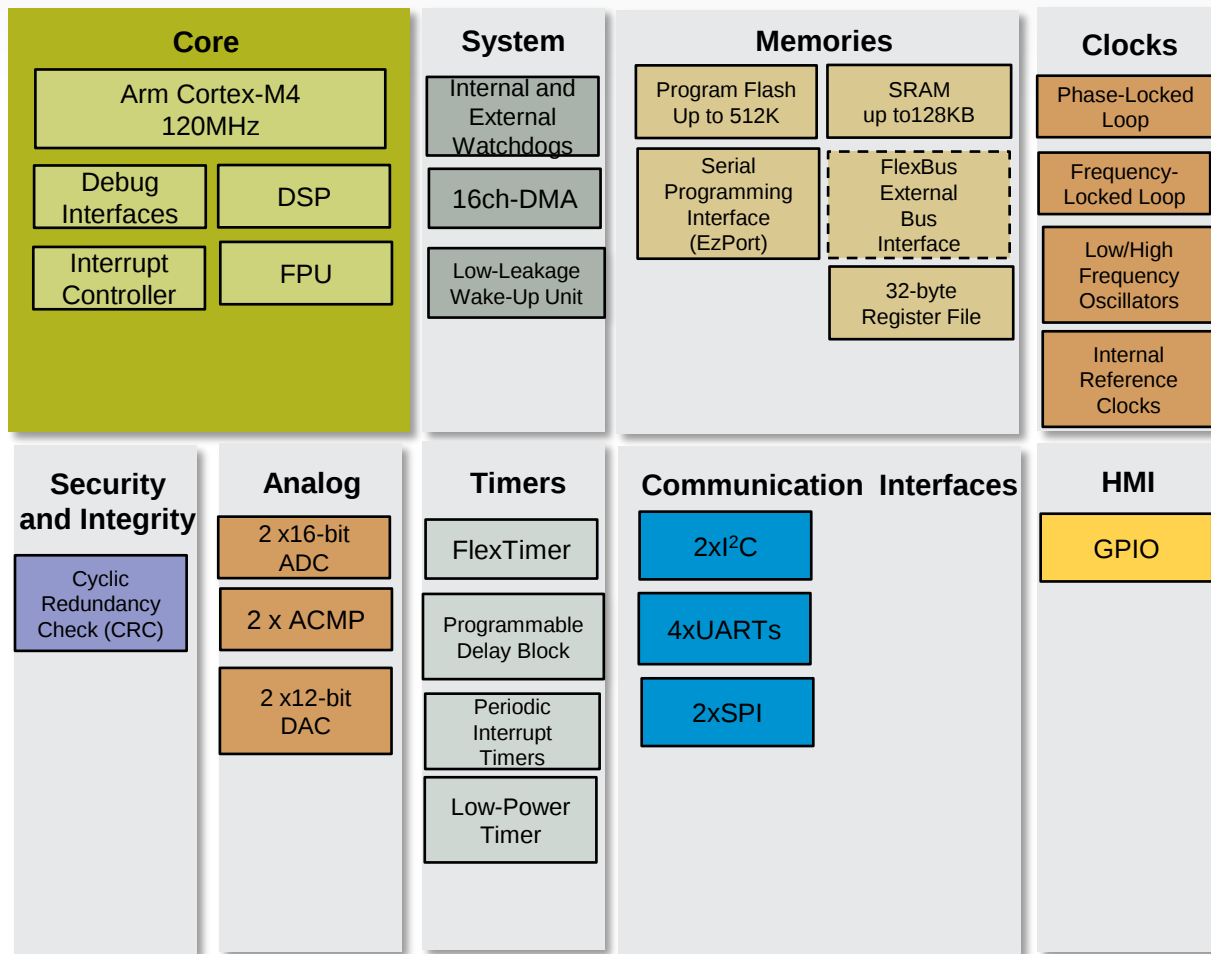
- up to 2x8ch FTM (PWM)
- 2x2ch FTM (PWM/Quad Dec.)
- Low Power Timer

Others

- Up to TBD I/Os
- 6 high-drive I/Os (20mA) – SPI/I2C
- 1.71V-3.6V; -40 to 105oC

Packages

64LQFP, 100LQFP



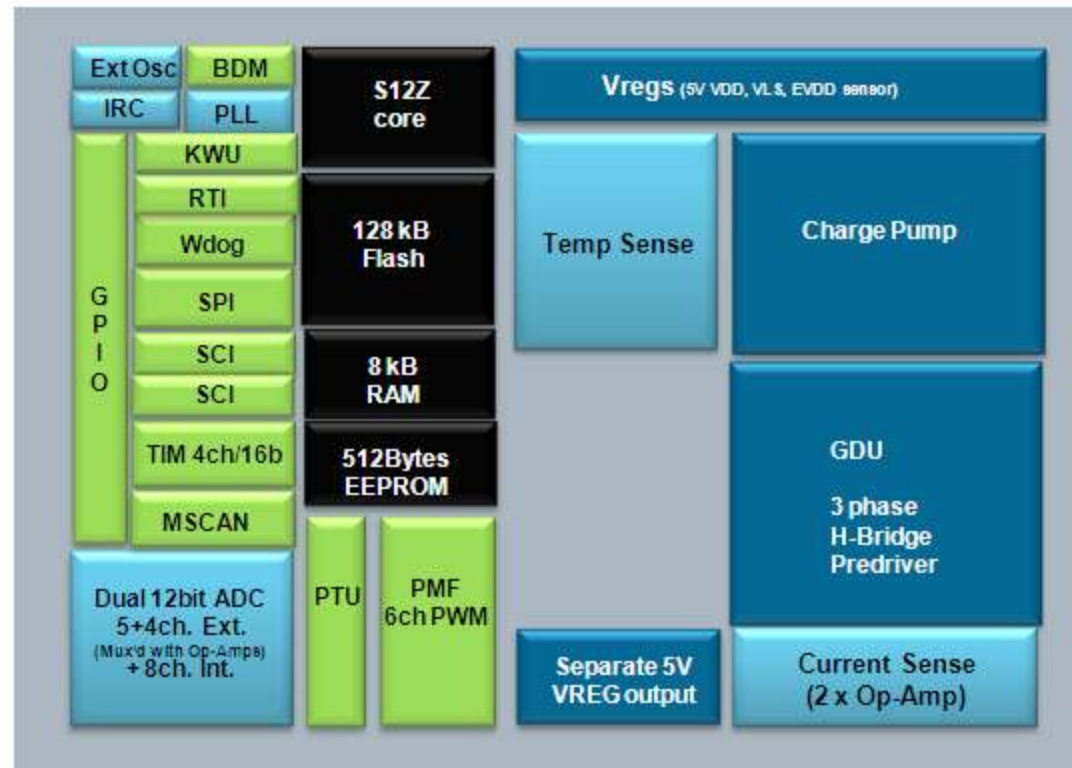
S12ZVMC128

- **Target applications:**

- BLDC motor control
- DC motor control

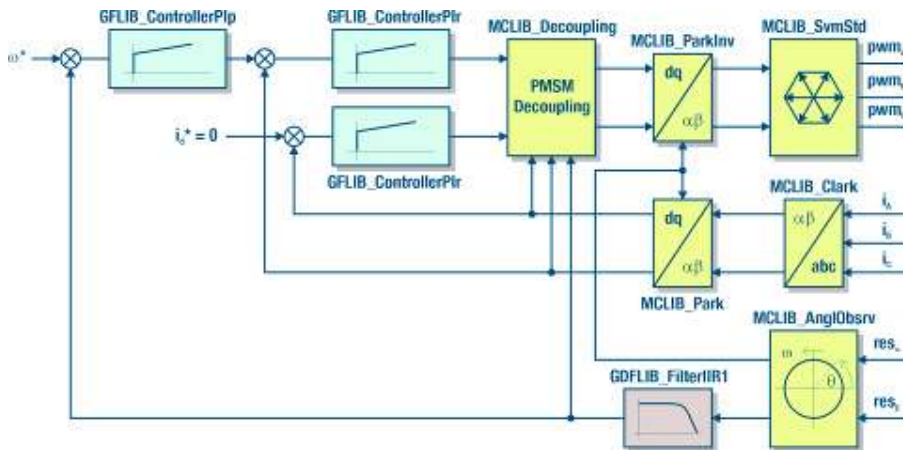
- **Key Features:**

- S12Z CPU @ 50MHz bus speed
- Embedded VREG
- **Separate 2nd VREG**
(to power external CAN phy)
- Embedded GDU for 3ph BLDC
- Embedded EE
- 1x MSCAN controller
- 2xSCI, 1xSPI
- Dual 12bit ADC,
synch with PWM
- 20mA/5V EVDD sensor supply pin
- 2x Op-amp for current sense (each needs 2 pins mux'd with ADC inputs)
- 64LQFP-EP 10x10/0.5mm



FreescalE Embedded Software & Motor Control Libraries

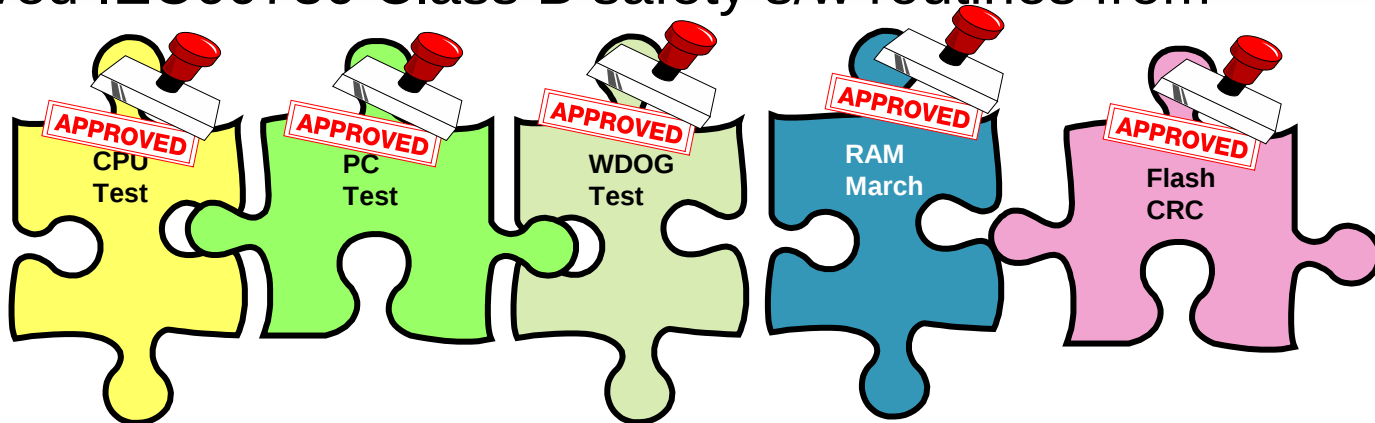
- **Library Provides:**
 - Optimized and tested algorithms
 - Full algorithms documentation
 - S/W library in “.lib” form that can be included into any project
- **Algorithms:**
 - ASM code & C-Code
 - optimized
 - fully tested using Matlab models
- **Algorithm Sets:**
 - General Functions / Math
 - Motor Control
 - Digital Filters
 - Advanced Library (sensorless)
- **Supported devices**
 - Digital Signal Controllers – 568000EX / Hawk V2/V3
 - Kinetis K,V – ARM Cortex-M4
 - Kinetis L,E,V – ARM Cortex-M0



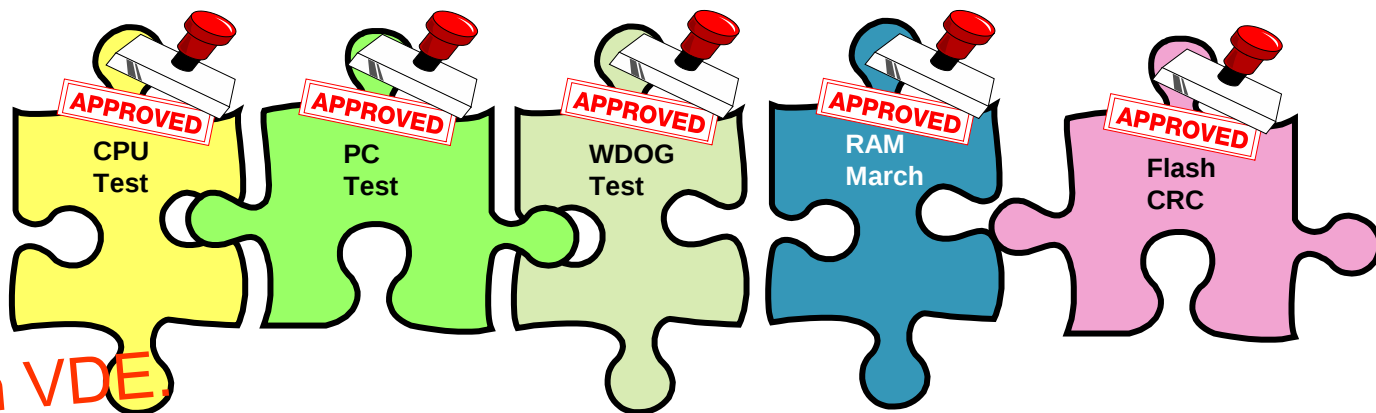
Implemented Algorithms				
Library	Core	DSC 56800E	Cortex M4	Cortex M0+
GFLIB	Sine	3	1	
	Cosine	3	1	
	Tangent	1	1	
	Arcus Sine	1	1	
	Arcus Cosine	1	1	
	Arcus Tangent	1	1	
	Arcus Tangent YX	1	1	
	Sifted Arcus Tangnet YX	1	1	
	Square Root	2	1	
	Ramp	2	1	
	Dynamic Ramp	2	0	
	Limiter	6	3	
	Hysteresis	1	1	
	Signum	2	1	
	Look-up Table	1	1	
	PI Controller	3	2	
	PID Controller	2	0	
MCLIB	Clarke Transformation	1	1	
	Inverse Clarke Transformation	1	1	
	Park Transformation	1	1	
	Inverse Park Transformation	1	1	
	Space Vector Modulation	6	1	
	Vector Limiter	2	1	
	PMSM Decoupling	1	1	
	DC Bus Ripple Elimination	2	1	
GDFLIB	IIR Filter	2	1	
	Moving Avg. Filter	1	1	
ACLIB	Angle Tracking Observer	2	0	
	Tracking Observer	1	1	
	PMSM BEMF Observer in Alpha/Beta	2	0	
	PMSM BEMF Observer in D/Q	1	1	
	Integrator	1	0	

V.D.E. Approved IEC60730 Class B safety s/w routines from Freescale

Kinetis



DSC56F8xxx



Approved from VDE

***“All pieces have been certified by VDE to help accelerate manufacturer development
Of Automatic Control”***

Core Self-Test Routines Certification

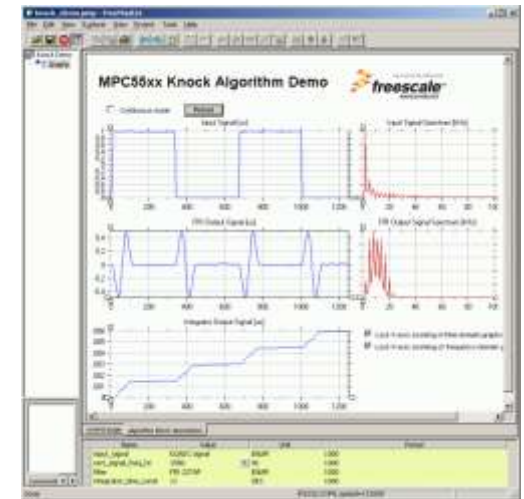
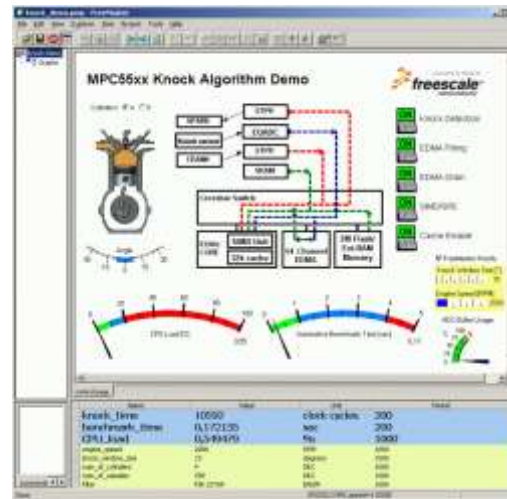
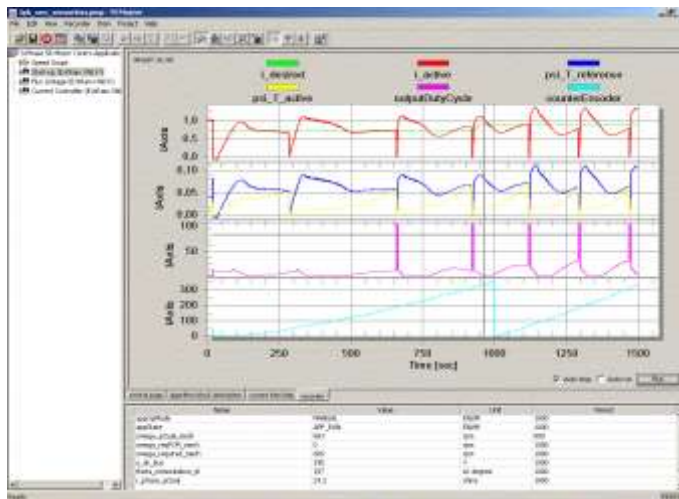
- **DSC** routines
 - Flash
 - RAM
 - MarchX
 - MarchC
 - MarchA5
 - Registers
 - Data registers test
 - Pointer registers test
 - Stack pointer register test
 - Shadow registers test
 - Status register test
 - Loop register test
 - Program counter register test
 - Watchdog
 - Window reset
 - Timeout reset
- **Kinetis** routines (M0+ and M4)
 - Flash
 - RAM
 - MarchX
 - MarchC
 - Runtime test
 - Registers
 - Core registers test fro M0+ and M4
 - FPU registers test on M4 with floating point unit
 - Watchdog
 - Window reset
 - Timeout reset

What is FREEMASTER ?

- Real-time Monitor
- Graphical Control Panel
- Demonstration Platform



FOR YOUR
EMBEDDED
APPLICATION



FREEMASTER as a Real-time Monitor

Highlights:

- FreeMASTER helps developers to debug or tune their applications
- Replaces debugger in situations when the processor core can not be simply stopped (e.g. motor control)
- Recorder may be used to visualize transitions in near 10-us resolution

FREEMASTER as a GUI

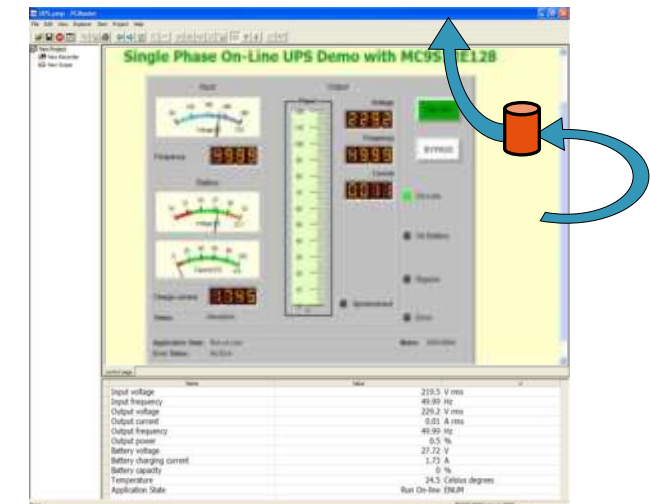
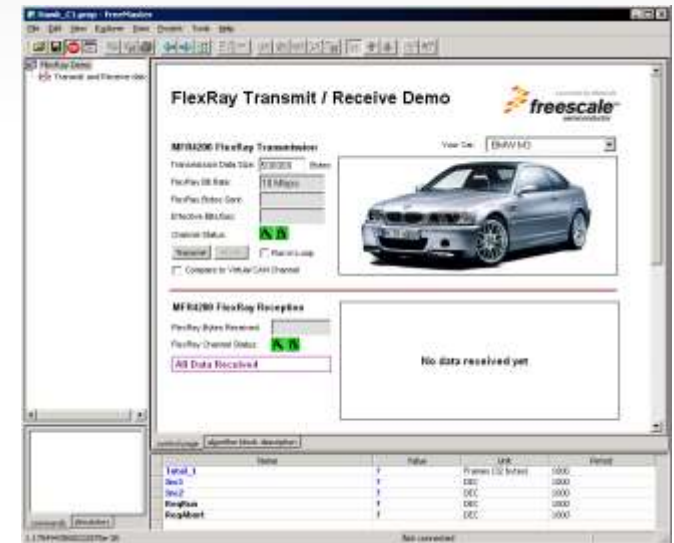
Using FreeMASTER as a Graphical Control Panel

- Variable Watch pane enables direct setting of the variable value
- Sending Application Commands from the application GUI
- Time-table stimulation of the variable value

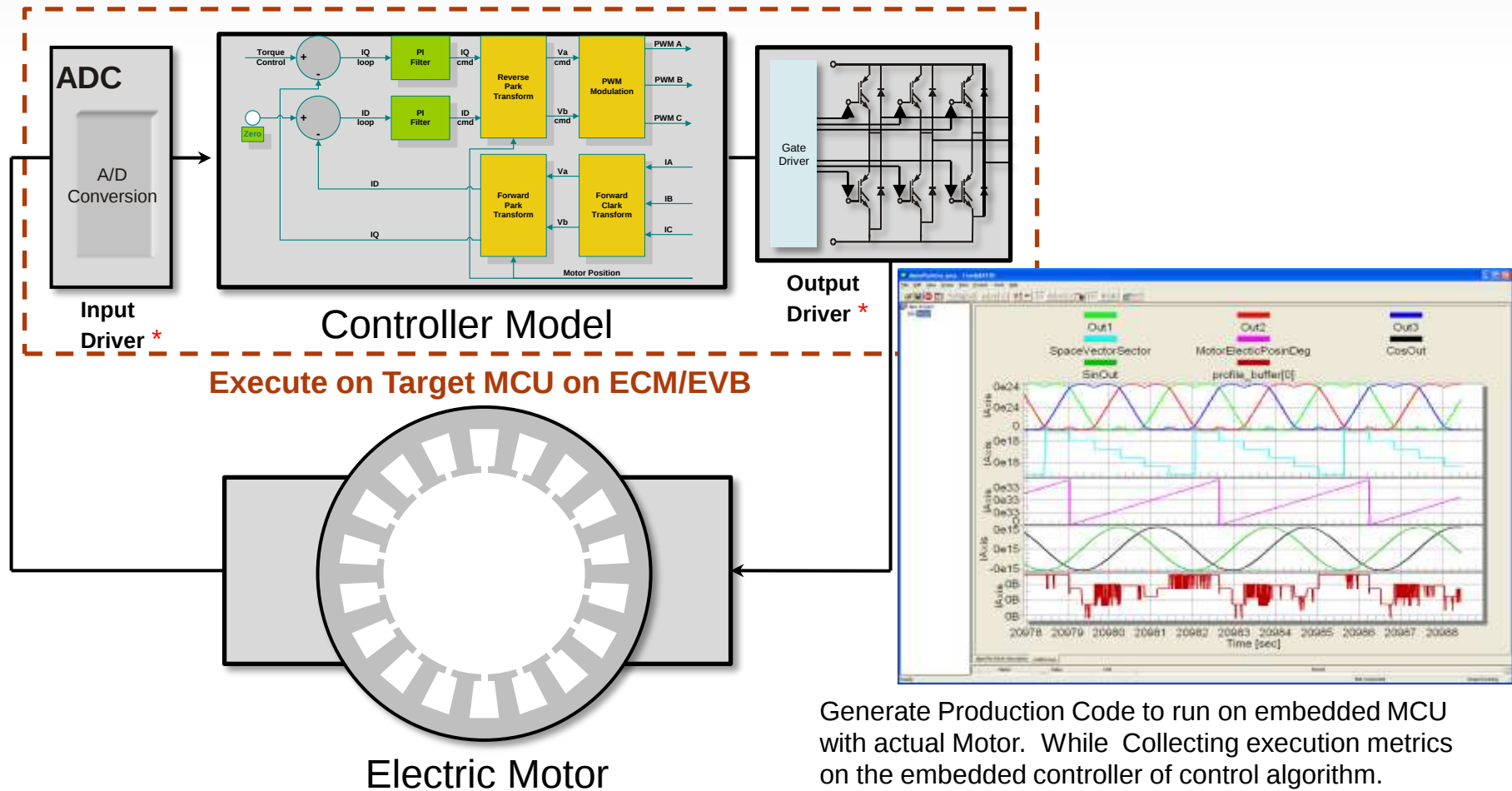
- HTML Pages and Forms
 - JScript or VBScript
 - Push buttons
 - Images, indicators
 - Sounds, videos
 - Sliders, gauges and other
3rd party ActiveX controls

Scripting in FreeMASTER

- HTML pages are displayed directly in the FreeMASTER window
- HTML may contain scripts and ActiveX objects
 - FreeMASTER itself implements an invisible ActiveX object
 - Script accesses the FreeMASTER functionality through this object
 - Variable access
 - Stimulator access
 - Application Commands
 - Recorder Data
- HTML may host whole applications, for example Excel
 - Excel Visual Basic macros may access FreeMASTER as well



Simulink Model and Motor Control Development Toolbox



*I/O Peripheral Driver blocks in Simulink, incorporates Analog device interfaces as well.

Generate Production Code to run on embedded MCU with actual Motor. While Collecting execution metrics on the embedded controller of control algorithm. Validate performance on MCU and use the Freemaster to tune control parameters and data log.

MCAT – Motor Control Application Tuning Tool

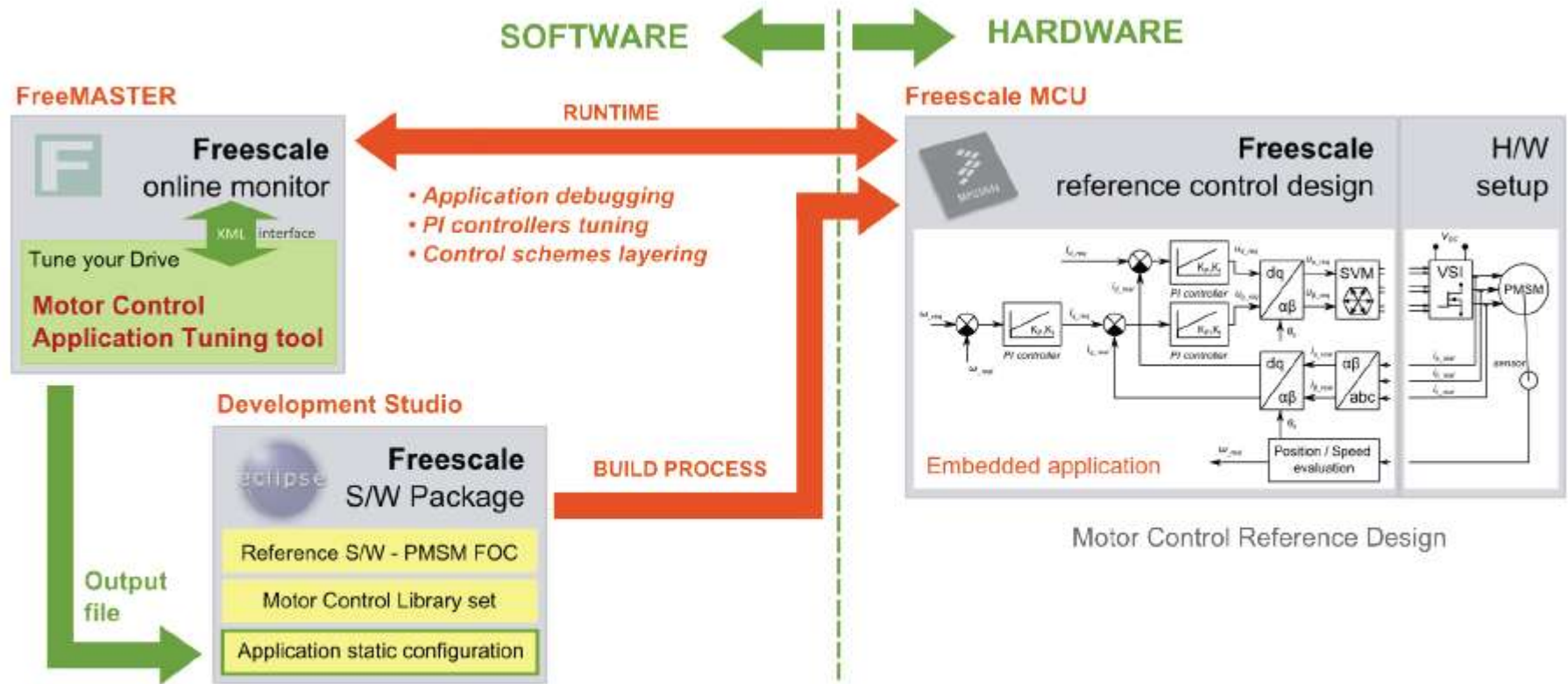


Figure 1. The software concept of MCAT tool utilization

- Supports up to three motor applications, with independent access to each motor.
- Utilizes a Pole Placement method for control parameters estimation
- Real-time tuning and updating of control parameters (Basic & Expert Mode)
- Offers a preview of the static configuration of tuned parameters

- **Generates an output file with static configuration of tuned parameters**
- **Supports Kinetis and DSC**
- **Plug-in tool for FreeMASTER, not available as a stand-alone tool**
- **Modular S/W concept, easily configurable**

Accelerate design success with parameter input tool

Recent Application Notes

- [AN4656](#): AN4656, PMSM FOC of Industrial Drives using the 56F84789
- AN4642 - Motor Control Application Tuning (MCAT) Tool
- AN4612 - Sensorless Sinusoidal Vector Control of BLDC Ceiling Fan on MC56F8006
- AN4611 - Freescale Embedded Software and Motor Control Libraries
- AN4583 - MC56F84789 Peripherals Synchronization for Interleaved PFC Control
- AN4586 - How to Add Libraries to project in the CodeWarrior Eclipse Environment
- AN4485 - Using eFlexPWM with MC56F82xx DSC
- AN4413 - BLDC Motor Control with Hall Sensors Driven by DSC using TWR-56F8257 and TWR-MC-LV3PH
- AN4407 - Dual Motor Control for PMSM with Kinetis K70
- AN4381 - Configuring the FlexTimer for Position and Speed Measurement with an Encoder
- AN4376 - BLDC Motor Control with Hall Effect Sensors using MQX on Kinetis
- AN4254 - Motor Control Under MQX

Recent Reference Designs

- [DRM140](#): PMSM Sensorless Vector Control on Kinetis
- DRM139 - Refrigeration System of Dual Sensorless PMSM FOC with PFC and Touch Graphic LCD Remote Control
- DRM110 - Sensorless PMSM Control for an H-Axis Washing Machine Drive
- DRM108 BLDC Sensorless Reference Design Using MC56F8006
- DRM100 - Sensorless High Speed SR Motor Drive for Vacuum Cleaners using an MC56F8013
- DRM099 - Sensorless PMSM Vector Control with Sliding Mode Observer for Compressors



- Target use: Motor Control Techniques Development
- Input voltage 12-24 VDC
- Output Current 5-10 Amps
- Compatible with FSL TWR cards
- Status: on FSL stock

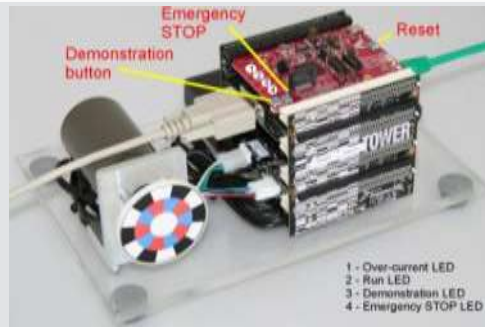


- Target use: appliance and industrial drives
- Input Voltage 115-230Vac, 50/60Hz
- Output Power 1kW
- Supporting: S08MP16, 56F80xx, 56F82xx, 56F84xx, K40
- Status: manufactured in Roznov, productization in 2013



- Target use: AirCon, washers
- Input Voltage 115-230Vac, 50/60Hz
- Output Power: Two Drives up to 1500W and up to 500W
- Using Nevis Daughter Card
- Status: prototype designed, handed over to A/P

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

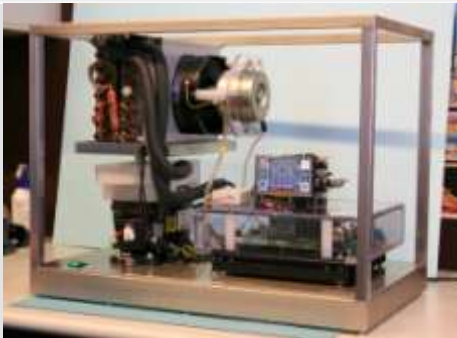
- Sensorless Sinusoidal FOC Drive
- Position and speed detection using dq back-emf observer and tracking observer
- Running on a Tower kit

DSC based Motor Control



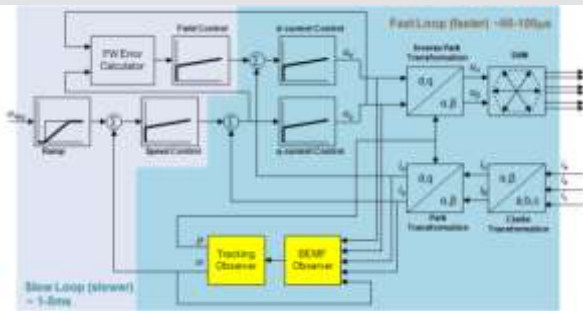
VF PMSM Compressor with MC56F825x

- Sensorless sinusoidal FOC for compressor PMSM motor
- Control using K70 HMI with graphic touch display
- demo and s/w available



VF 3 in 1 Motor Control for AirCon with MC56F84xxx

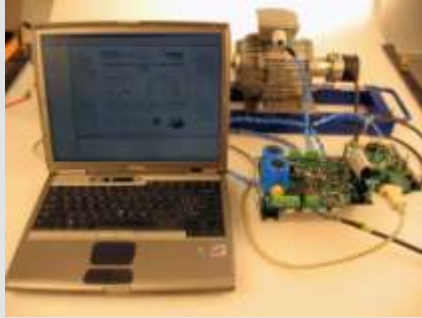
- 1.5 KW output power, support sensor-less PMSM motor control for both outdoor fan and compressor with FOC algorithm
- Support digital PFC (average current control)
- Demo, h/w and s/w available



Sensorless PMSM for fans on MC56F827xx

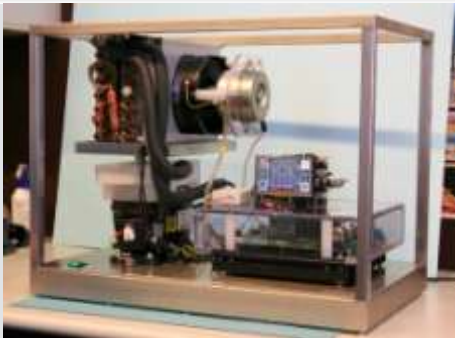
- New application being developed for sensorless sinusoidal PMSM FOC
- Includes Tuning Wizard for easy use
- Prototype for pre-programmed MC device

Innovative Motor Control Solutions



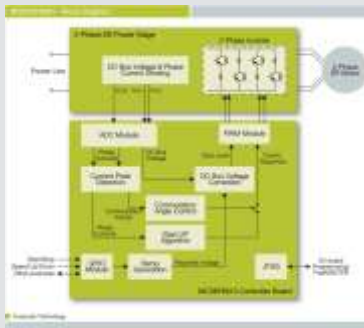
3-Phase AC Induction Vector Control Drive with Single Shunt Current Sensing

- Vector control of three-phase AC induction motor with position encoder
- Reconstruction of three-phase motor currents from DC-Bus shunt resistor
- Saves Costs, Increases Efficiency



Dual VF Motor Control for AirCon with PFC (MC56F84xxx)

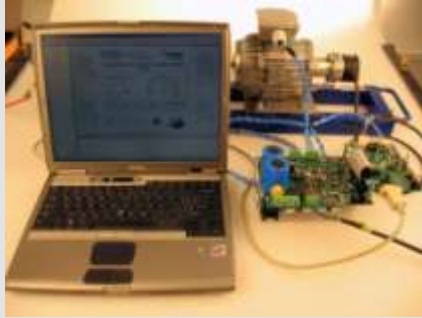
- 1.5 KW output power, support sensorless PMSM motor control for both outdoor fan and compressor with FOC algorithm
- Support digital PFC (average current control)
- Demo, h/w and s/w available



Sensorless High Speed SR Motor Drive

- High-speed 2-phase SR motor sensorless control based on a current peak detection
- Capable of running SR motors at more than 100,000 RPM
- Start-up from any position using alignment and patented algorithm (Patent No. US6448736 B1)

Future Motor Control Solutions

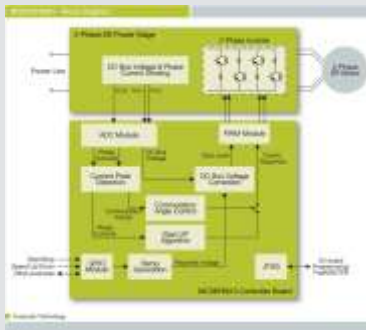


3-Phase AC Induction Vector Control Drive with Single Shunt Current Sensing

- Vector control of three-phase AC induction motor with position encoder
- Reconstruction of three-phase motor currents from DC-Bus shunt resistor
- Saves Costs, Increases Efficiency

Sensorless FOC of PMSM with PFC (MC56F827xx)

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



Sensorless Control of “Silent” SR Motor Drive (MC56F827xx)

- High-speed 2-phase SR motor sensorless control based on a current peak detection
- Capable of running SR motors at more than 100,000 RPM
- Start-up from any position using alignment and patented algorithm (Patent No. US6448736 B1)

Power Conversion & Wireless Charging



200W SMPS with MC56F8013 and MC56F8257

- Primary Side: Two Phase Interleaved PFC
- Secondary Side: Half Bridge LLC Resonant Converter with Synchronous Rectification for 12V output
- Additional Synchronous Buck Converter for 5V output



Solar Micro-Inverter with MC56F8257

- 1-phase 200W non-isolated Micro Solar Inverter
- Includes Interleaved CrCM step-up converter with P&O and RCC MPPT, Sine inverter and output filter
- Project done in cooperation with Future distributor
- Project in finalization



5 W A13 Automotive Wireless Charger

- Request to enhance the AVID/Fulton WC transmitter
- Add digital modulation / demodulation, Touch, CAN
- Project in definition

Tools and Collateral to help you select the right Kinetis MCUs

Online Selector Guide



**Freescale Solutions Advisor @
freescale.com/solutionadvisor**

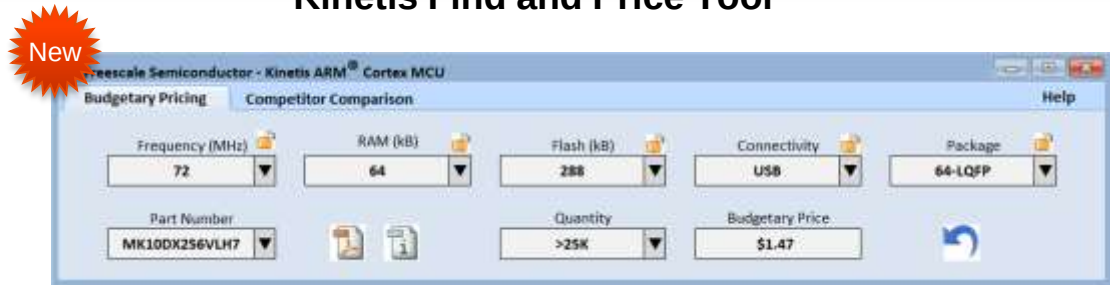
Motor Control Brochure



**Freescale Beyond Bits Motor Control
Edition @ freescale.com/beyondbits**



Kinetis Find and Price Tool



Community site:
<https://community.freescale.com/community/kinetis>

Short Printed Selector Guide



Kinetis Product Summaries @
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