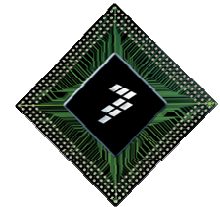




# Emerging Challenges in Designing Power Converters with Digital Signal Controllers (DSCs)

Charlie Wu  
Senior System & Application Engineer  
Microcontroller Division  
Freescale Semiconductor

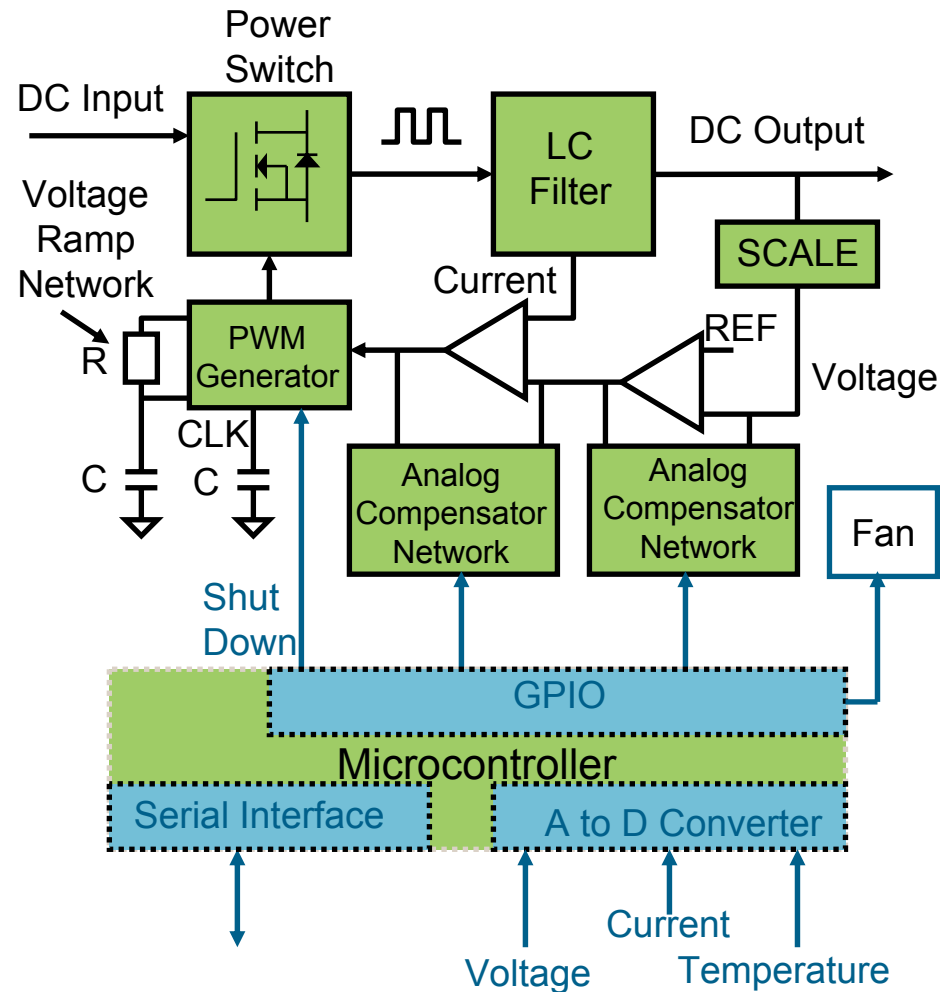


Besides exploring some key benefits of using the latest digital signal controllers (DSC) with advanced peripherals in digital power conversion, this paper will also investigate current and emerging challenges confronting designers of digital power supplies, and also what DSC developers are doing to meet the demands of emerging digital power supplies.

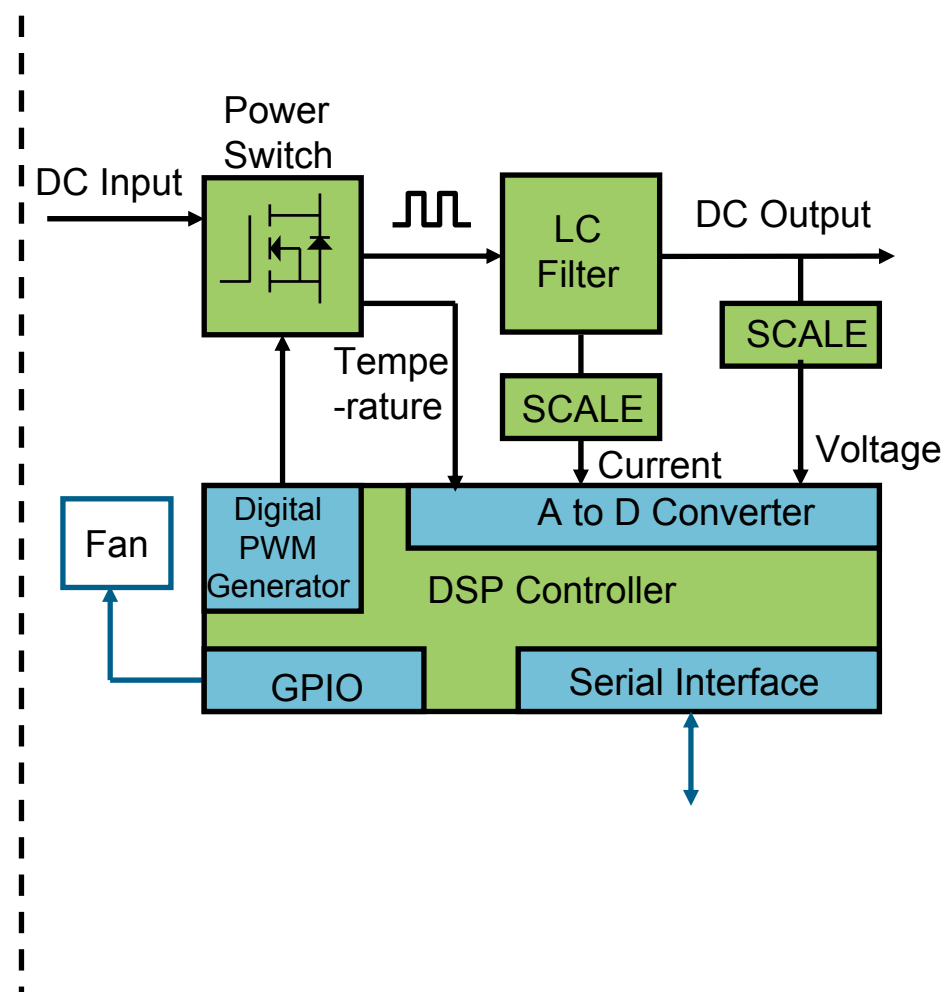
# What is Digital Signal Controller

- Specialized microprocessor whose architecture contains a core engine capable of competitively performing both microcontroller and digital signal processor functionalities
- Core processing capability applicable to many types of system solutions
- Common basic features:
  - > MAC, single instruction cycle allowing several memory accesses, address generation units, algorithms for efficient looping
- Specialized cost effective, high performance on-board interfaces utilized in implementing embedded control applications :
  - > PWM; multifunction timer; high speed ADCs; DACs; Comparators; SCIs (UART); SPIs; CANs and I2Cs, etc.
- Embedded nonvolatile memory:
  - > Flash memory, ROM or EEPROM
- Easy to use development tools

# Comparison of Analog and Digital Power Control System

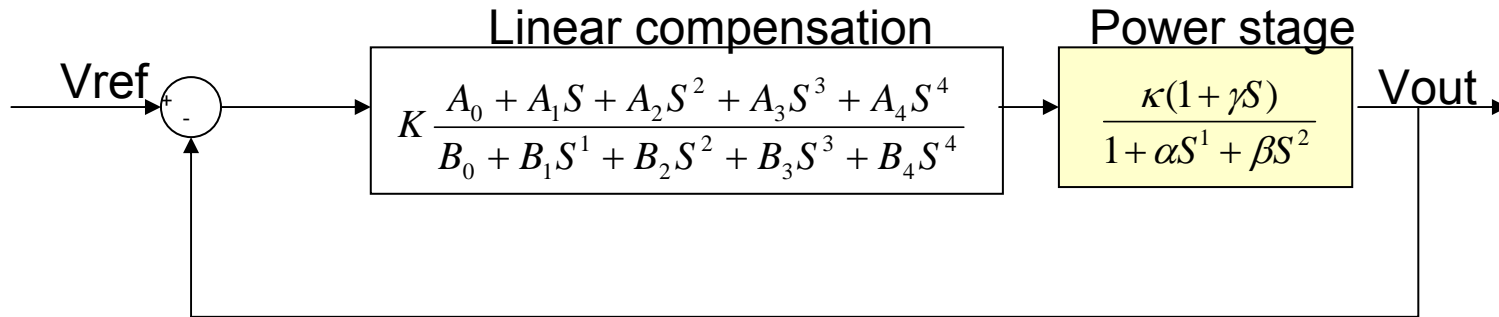


**Analog Control System With Digital Management**

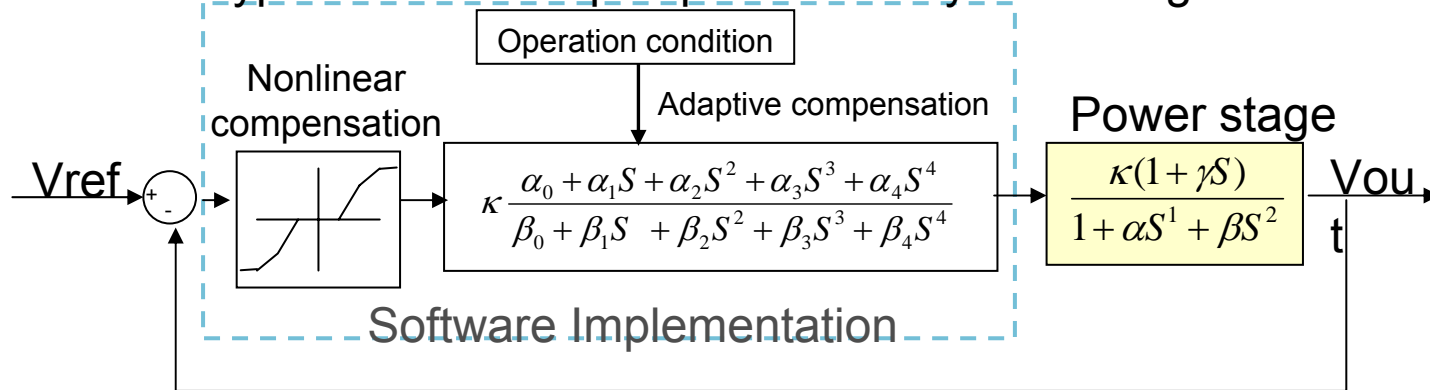


**Full Digital Control System**

# ► Digital vs. Analog Control Loop



A typical control loop implemented by an analog circuit



A digital control loop implemented by Digital Signal Controller (DSC)

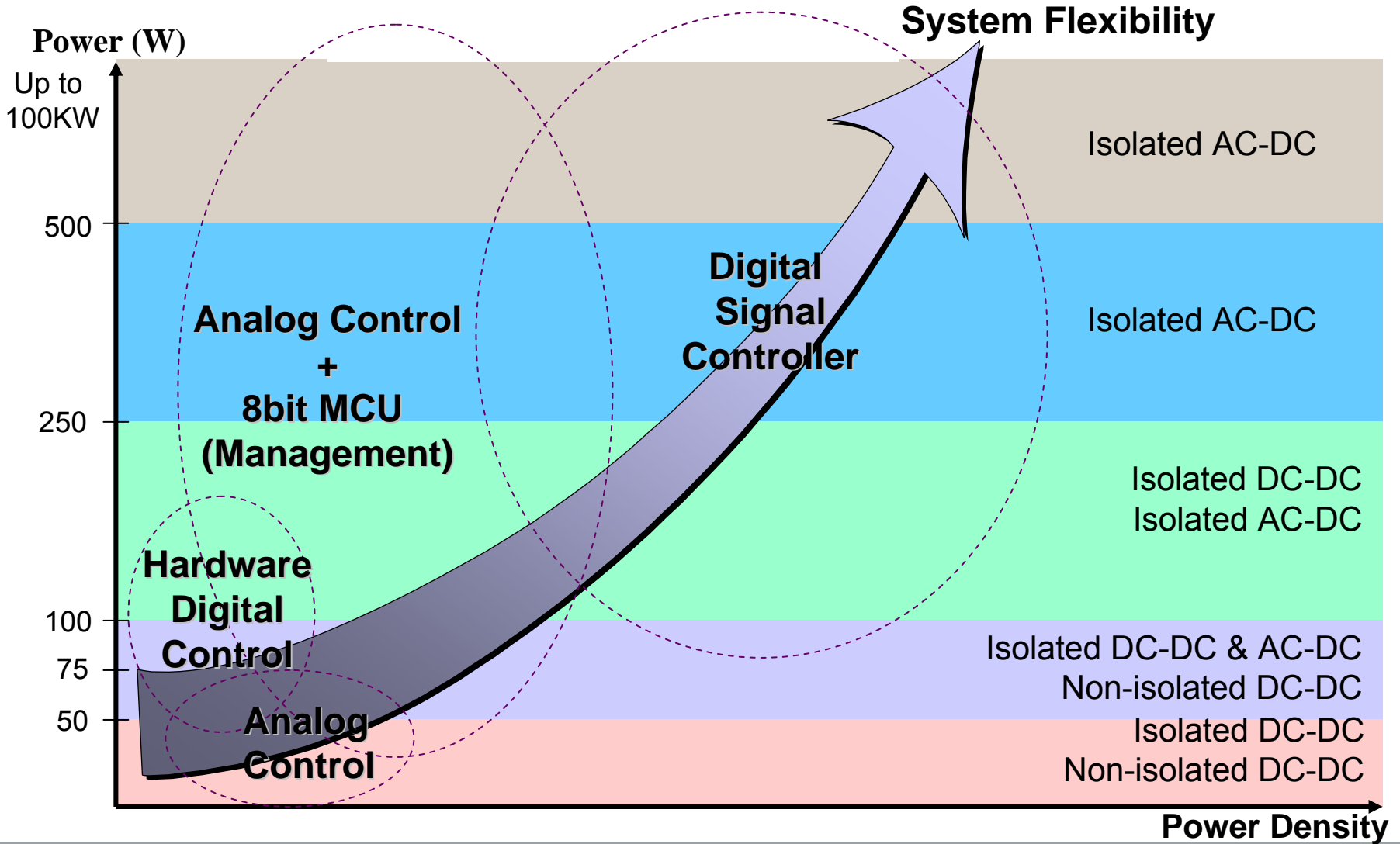
Benefit of digital control:

- 1) Optimize feedback loop to meet application requirements
- 2) Runtime changes to compensation parameters according to operating conditions

# Benefits of Digital Power

- **Free from** the effects of **component tolerance**, parametric drift, aging, etc
- **Configurable** feedback loop **structure** for specific application requirements
- **Adaptive control** to meet changing operating conditions
- **Flexible** Pulse Width **Waveform-generation** module
- **Programmable relationships** among **PWM** outputs
- **Upgradeable** with new features **without hardware** changes
- **Retainable** operational **data** for diagnostic and record keeping
- **Diverse communications** capabilities
- **Reduced** component count - and **cost**
- **Higher** power density due to over all **integration**
- **Shorter R&D cycle**, fewer turns of board prototyping
- **Portable Projects** for faster reuse
- **Defendable firmware** - protects IP and differentiating technology

# Current Power Supply Landscape



# Challenge for Power Converter Design Engineers

## ➤ Control Algorithms Selection

- Full digital control
- Analog control + digital power management
- Average current mode control
- Peak current mode control
- Average current mode control during step load and average current mode control during steady load

## ➤ Converter Topology Selection

- Hard switching or soft switching
- Full bridge converter or half bridge converter
- Phase shifting converter or resonant converter
- Interleave multi phase or single phase

## ➤ Innovation and IP protection

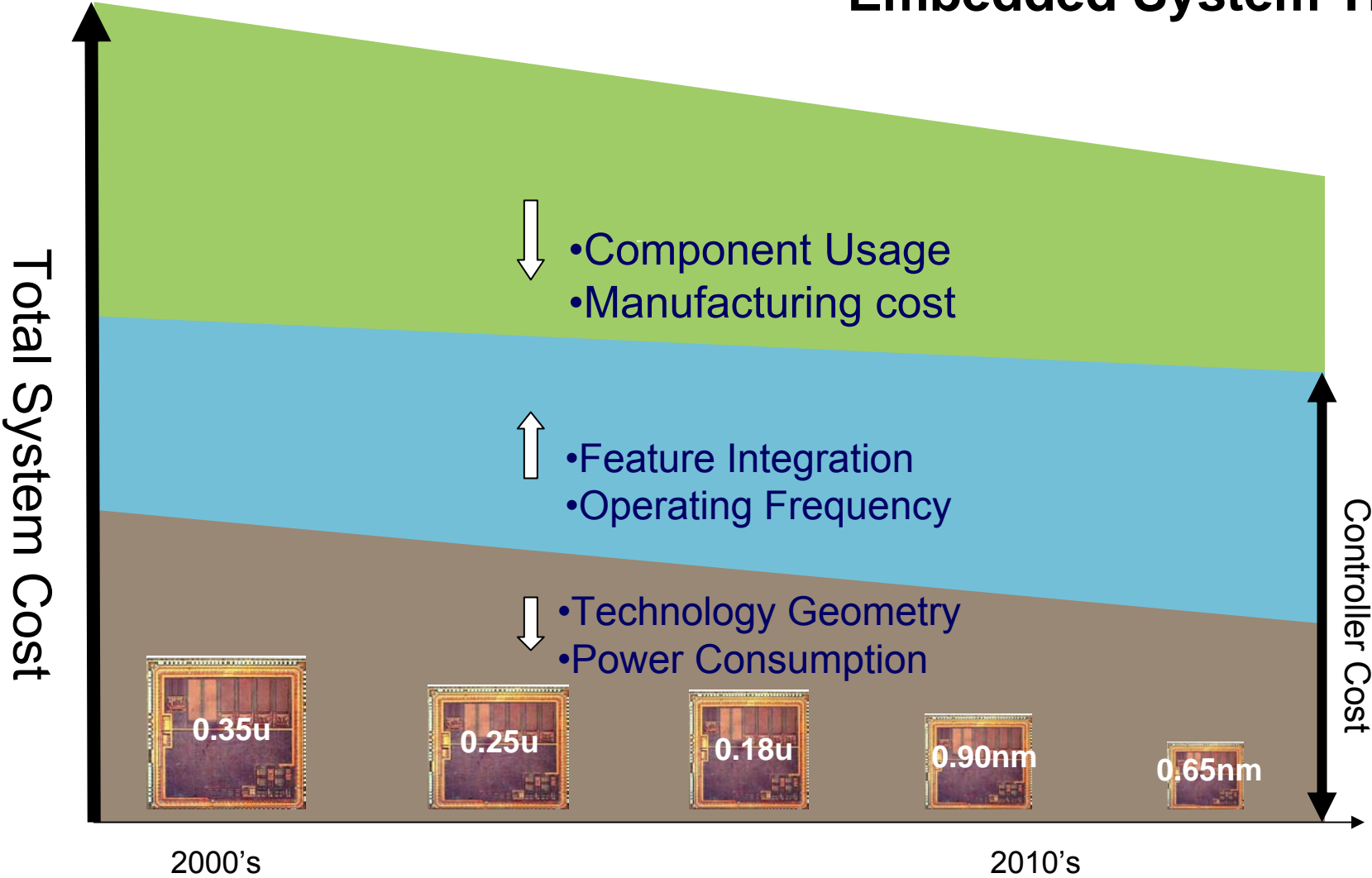
- Do whatever silicon provider provided
- Implement advanced proprietary topology & Algorithms using general controller

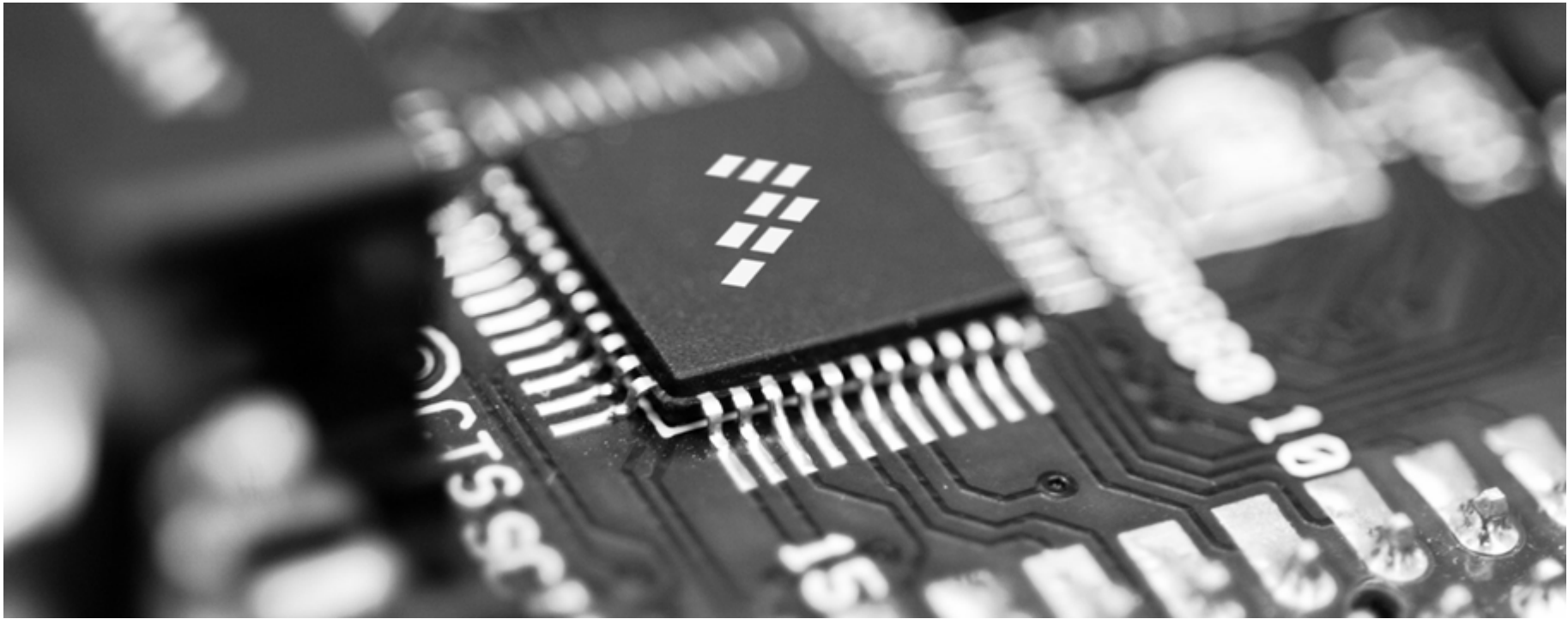
## ➤ Cost and Performance

- Inventory and Manufacturing and maintenance cost
- Trade off between material cost and system performance
- Trade off between product competence and time-to-market

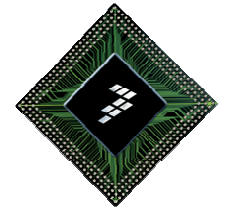
- **High performance Nonvolatile Memory – Flash memory**
  - Fast access speed, small page size enables user to designate a flash page as EEPROM
  - Longer Data retention and higher program erase cycles
  - Wide operating temperature range ( -40C to 125C ambient operating temperature)
- **High speed/flexible PWM module**
  - Improved PWM resolution on both duty cycle and frequency – Resonant converter applications
  - Arbitrary PWM pulse generation which can be used for any power stage topology
- **High speed, 12-14 bits Analog-to-Digital Converter**
  - High input impedance
  - Various power operating modes
- **High performance On-chip Analog Modules - DACs, Comparators, Programmable Gain Amplifiers – Allowing analog designer to work in digital control world**
  - Low offset, lifetime drift and gain error
  - Programmable comparator hysteresis
  - Adaptive slope compensation for peak current mode control
- **On-Chip Power-on reset and Low voltage detection**
  - Eliminate external Reset and Power supply monitoring devices.
- **On-Chip regulator improves device EMI acceptability**
  - On-Chip linear regulator powers the CPU and peripheral logic circuits
- **Multiple clock sources – multiple On-Chip clocks and external clock source**
  - Clock redundancy
  - Greatly improve EMI acceptability
- **Enhanced On-Chip Emulator**
  - Enables debugging of target system using low cost, isolated debug tool.
- **5V I/O**
  - Directly Interface to drive circuit
- **Low Cost**
  - System cost lower than the existing analog plus MCU system

# Embedded System Trend

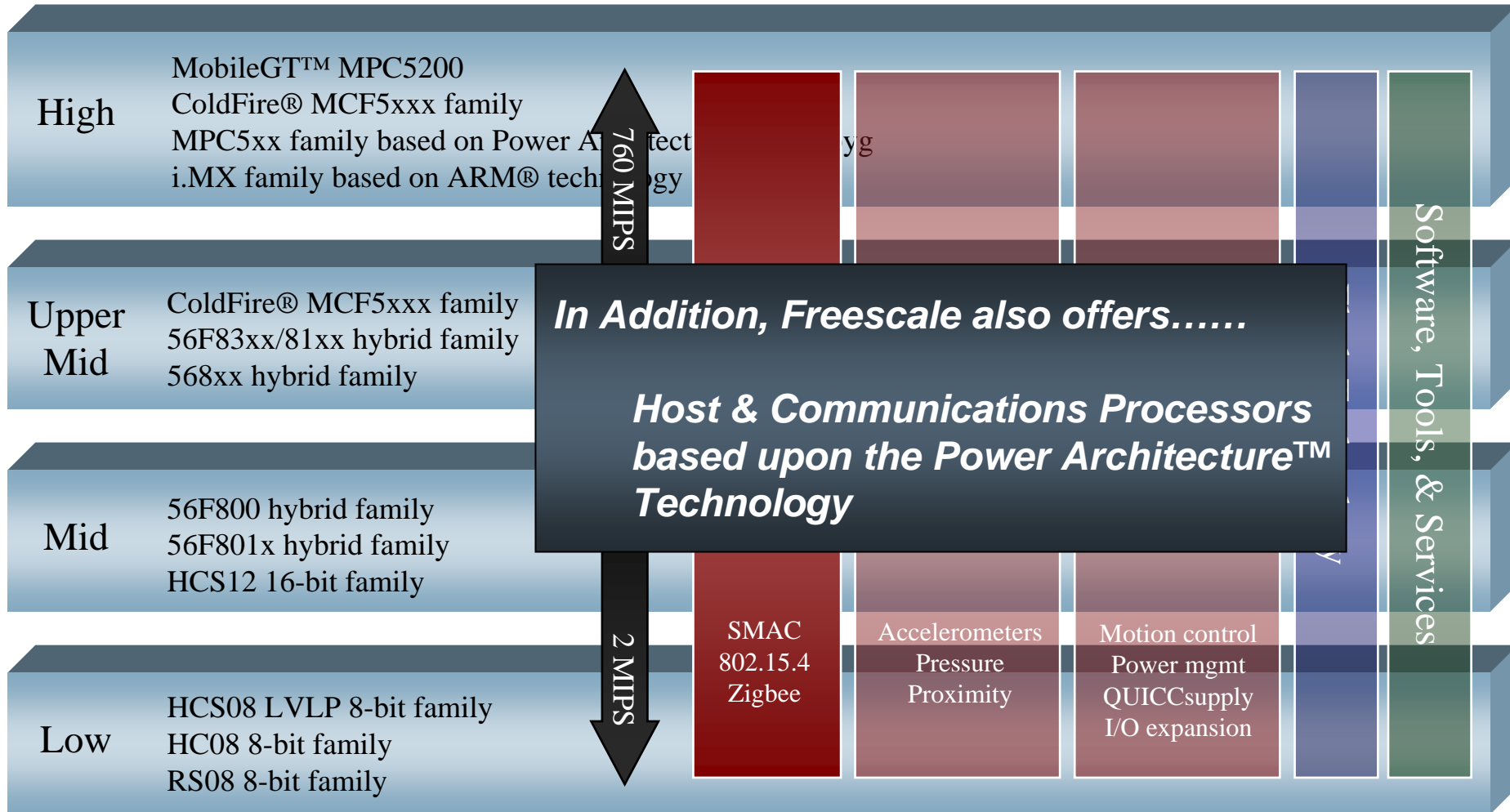




# Production Overview



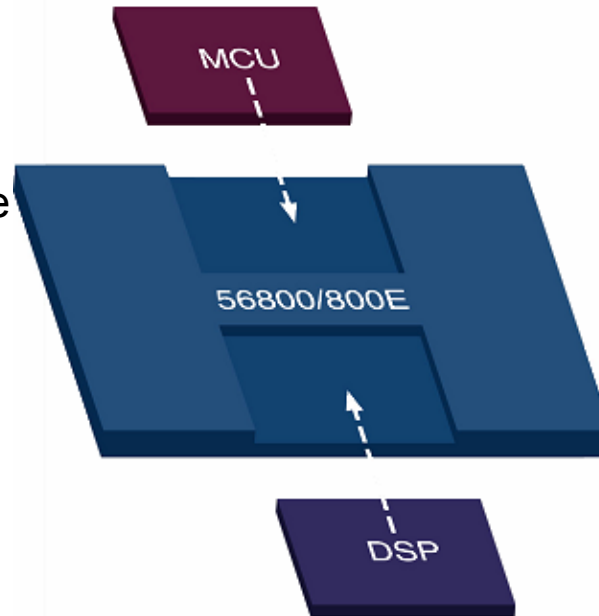
# Controller Continuum



# 56800/E Family Combining Signal Processing and Controller Functionality

## Traditional Microcontroller

- Designed for Controller Code
- Compact Code Size
- Easy to Program
- **Inefficient Signal Processing**



## Traditional DSP Engine

- Designed for DSP Processing
- Designed for Matrix Operations
- **Complex Programming**
- **Less Suitable for Control**

- Instructions Optimized for Controller Code, DSP, Matrix Operations
- Compact Assembly and “C” Compiled Code Size
- Easy to Program
- Additional MIPS Headroom and extended addressing space

# DSP56800E Core Features

CPU	MIPS	# Interrupt Priorities	Registers	Data Types	Program Memory Adr Space	Data Memory Adr Space	Technology
DSP56800E	120 from RAM 60 from Flash	5	7 Data 8 Address	8-bit, 16-bit 32-bit	4 MB	32 MB	Fully Synthesizable and Scanable

## 56800/E MCU Functionality

True Software  
Stack and Pointer

16-bit Program Word

20 Addressing Modes and Atomic  
Read-Modify-Write Instructions

General Purpose Register Files and Orthogonal  
Instructions to Data and Address Register Files

Full Set of Bit and Bitfield Manipulation  
Instructions and 16- and 32-bit Shifting

Superfast Interrupt

## 56800/E DSP Functionality

Multiplier - Accumulator (MAC)  
Single And Dual Parallel Move  
Instructions

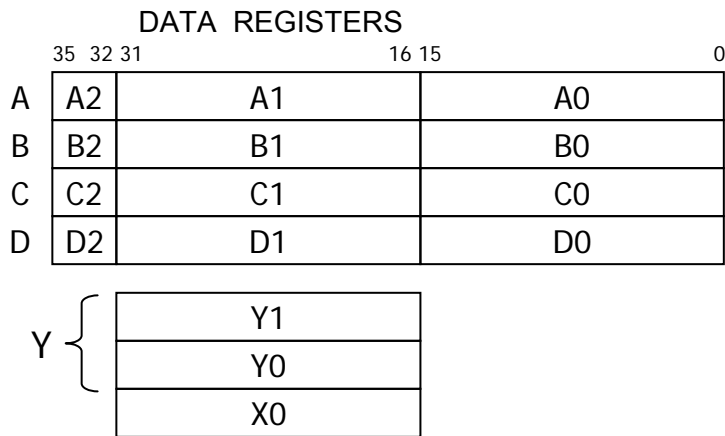
No Overhead Hardware Looping  
Nested Looping Capability

Modulo arithmetic (For Circular Buffers)  
Integer and Fractional Arithmetic Support

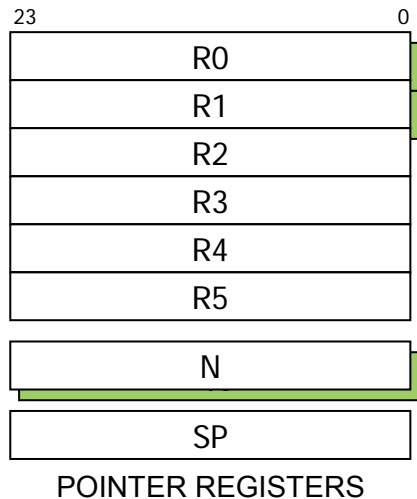
Nested Interrupt with HW priority  
Fast Interrupt Support

# DSP56800E Programming Model

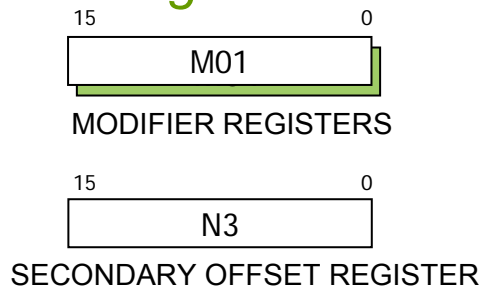
## DATA ARITHMETIC LOGIC UNIT



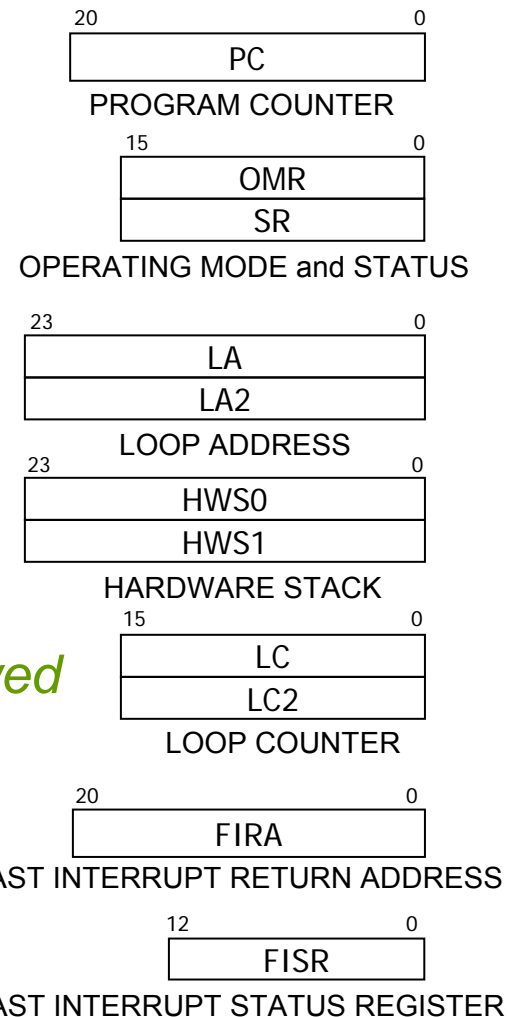
## ADDRESS GENERATION UNIT



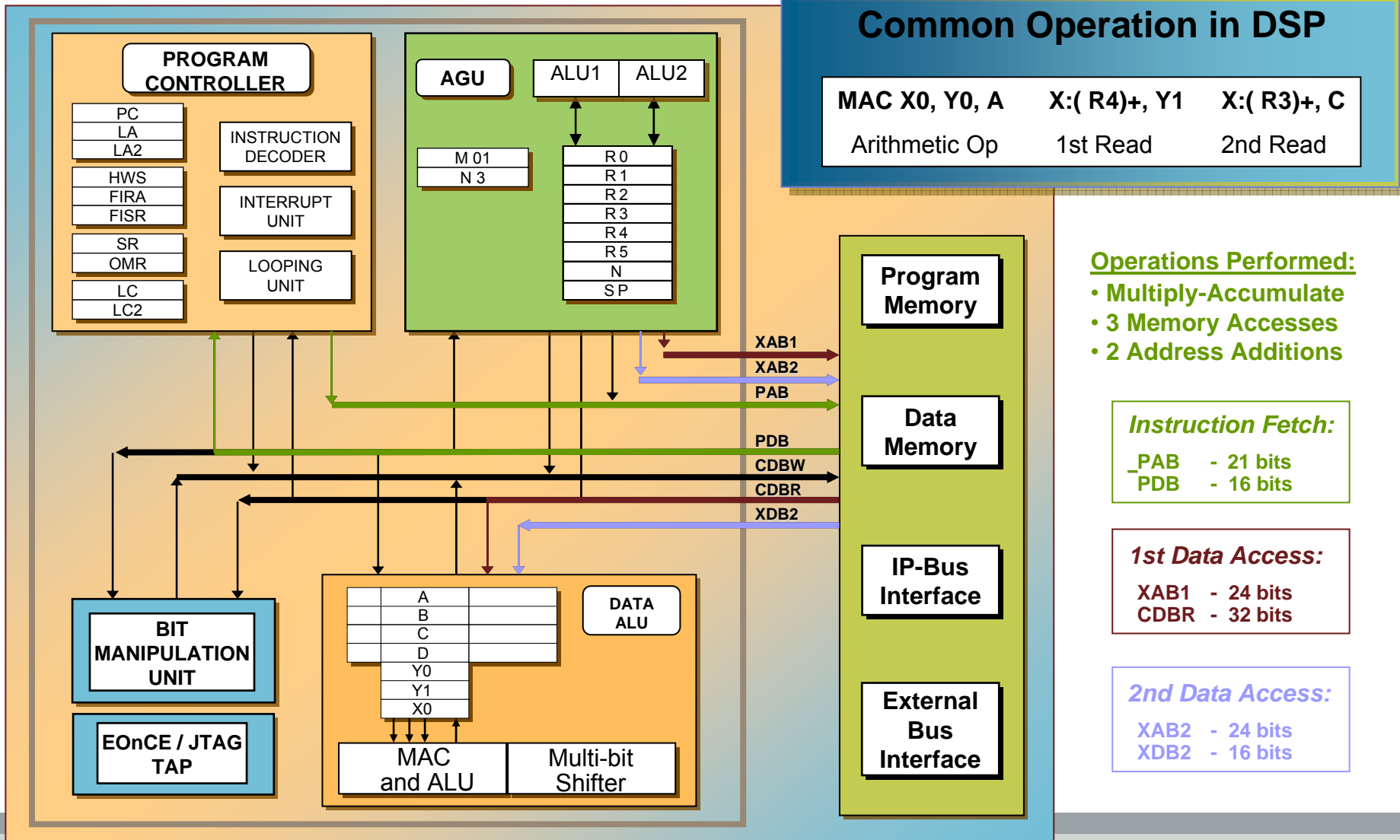
*==> R0, R1, N, and M01 registers are shadowed*



## PROGRAM CONTROL UNIT

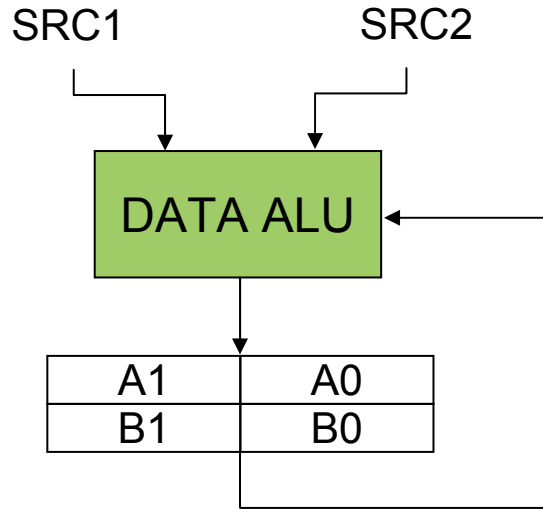


# Mapping the Architecture to DSP Algorithms



# Data ALU - General Purpose Register File

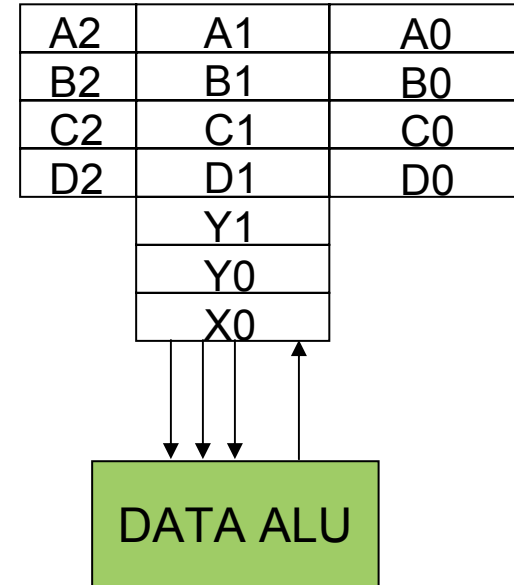
## Conventional DSP



INC,DEC [A or B]  
 ASL,ASR [A or B]  
 ADD, etc. [SRC1], [A or B]

**“Accumulator Based”**

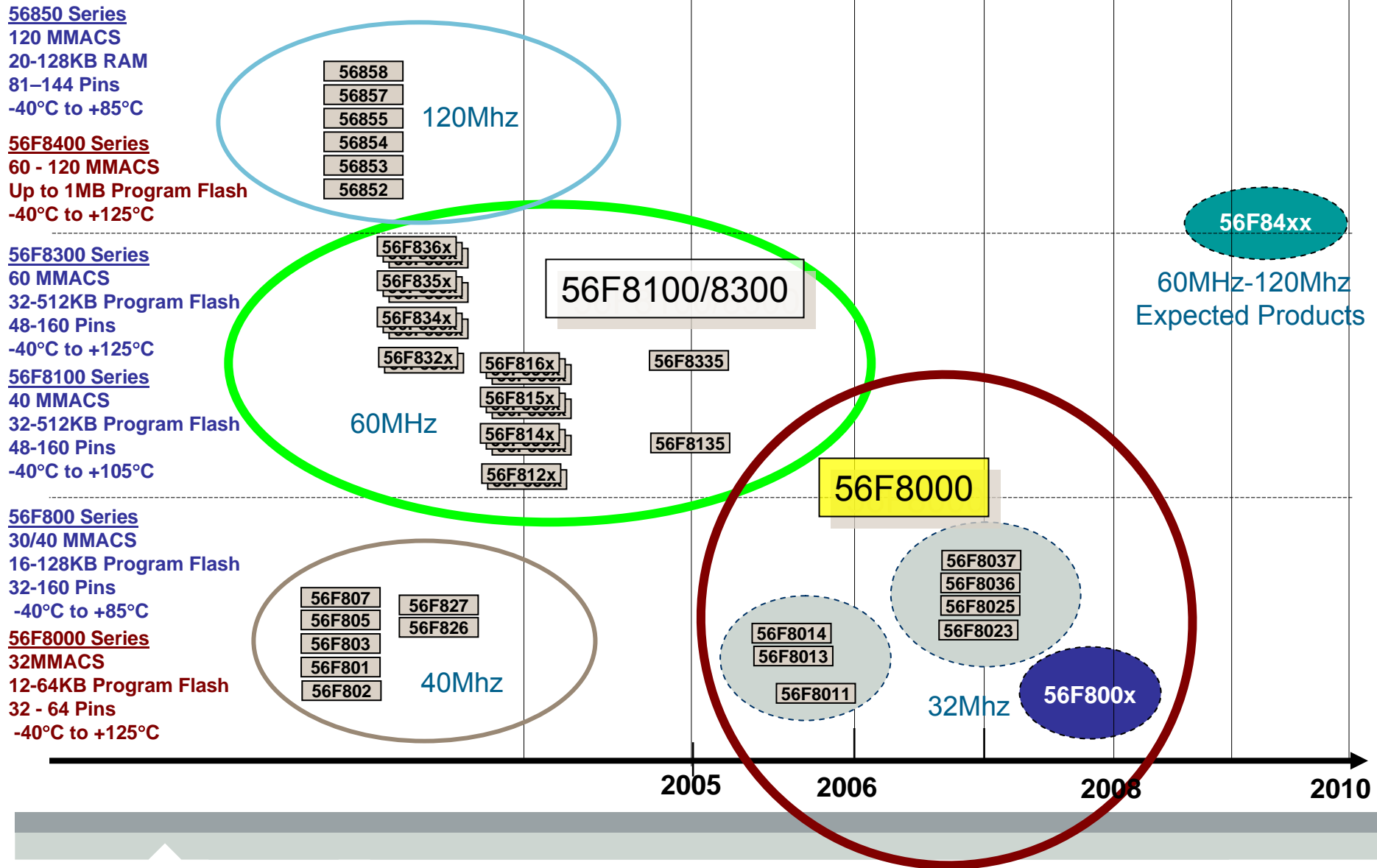
## DSP56800E



INC.W, DEC.W [FFF]  
 ASL, ASR [FFF]  
 ADD, etc. [FFF], [FFF]

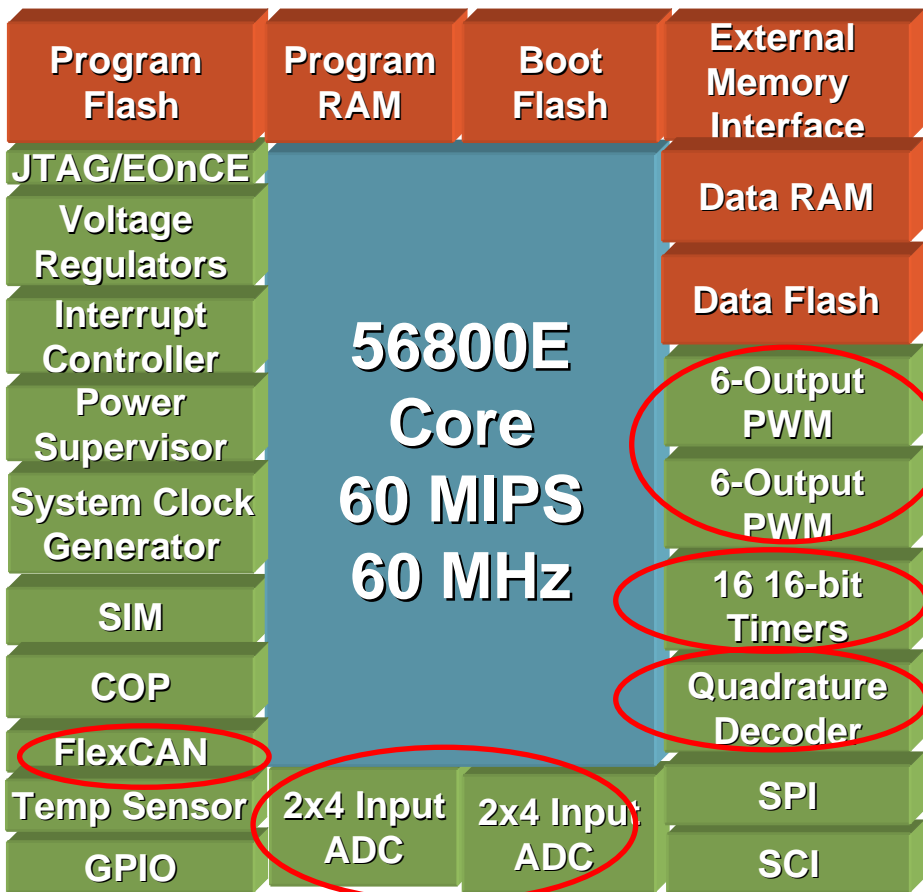
**“GP Register File”**

# Freescale Digital Signal Controller Roadmap



# High Performance 56F8300 Solutions

## 56F836x/56F835x/56F834x/56F832x 60MHz/60MIPS



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

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

► Derivatives: 23 devices

Key Control Peripherals

# 56F8300 Series (1 of 2)

	56F8322	56F8323	56F8335
<b>Performance</b>	60MHz/MIPS	60MHz/MIPS	60MHz/MIPS
<b>Temp. Range</b>	(-40, +125)°C	(-40, +125)°C	(-40, +125)°C
<b>Voltage (Core / I/O)</b>	2.5/3.3V	2.5/3.3V	2.5/3.3V
<b>On-Chip Flash</b>	48KB	48KB	80KB
<b>Program Flash</b>	32KB	32KB	64KB
<b>Data Flash</b>	8KB	8KB	8KB
<b>Boot Flash</b>	8KB	8KB	8KB
<b>On-Chip RAM</b>	12KB	12KB	12KB
<b>Program RAM</b>	4KB	4KB	4KB
<b>Data RAM</b>	8KB	8KB	8KB
<b>Flash Security</b>	Yes	Yes	Yes
<b>Ext. Memory Interface</b>	-	-	-
<b>Internal Voltage Regulator</b>	On-Chip	On/Off-Chip	On/Off-Chip
<b>On-Chip Relaxation Osc.</b>	Yes	Yes	Yes
<b>16-bit Timers</b>	8	8	16
<b>Quadrature Decoder</b>	1 x 4ch	1 x 4ch	2 x 4ch
<b>PWM</b>	1 x 6ch	1 x 6ch	2 x 6ch
<b>PWM Fault Input</b>	1	3	4 + 4
<b>PWM Current Sense Pins</b>	0	3	3 + 3
<b>12-bit ADC</b>	2 x 3ch	2 x 4ch	4 x 4ch
<b>Temperature Sensor</b>	YES	Optional	Optional
<b>CAN</b>	FlexCAN	FlexCAN	FlexCAN
<b>SCI (UART)</b>	2	2	2
<b>SPI (Synchronous)</b>	2	2	2
<b>GPIO (Ded./Shrd/Tot)</b>	0 / 21 / 21	0 / 27 / 27	21 / 28 / 49
<b>JTAG/EOnCE</b>	Yes	Yes	Yes
<b>Package</b>	48LQFP	64LQFP	128LQFP

# 56F8300 Series (2 of 2)

	56F8345	56F8346	56F8347	56F8355	56F8356	56F8357	56F8365	56F8366	56F8367
<b>Performance</b>	60MHz/MIPS	60MHz/MIPS	60MHz/MIPS	60MHz/MIPS	60MHz/MIPS	60MHz/MIPS	60MHz/MIPS	60MHz/MIPS	60MHz/MIPS
<b>Temp. Range</b>	(-40, +125)°C	(-40, +125)°C	(-40, +125)°C	(-40, +125)°C	(-40, +125)°C	(-40, +125)°C	(-40, +125)°C	(-40, +125)°C	(-40, +125)°C
<b>Voltage (Core / I/O)</b>	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V	2.5/3.3V
<b>On-Chip Flash</b>	<b>144KB</b>	<b>144KB</b>	<b>144KB</b>	<b>280KB</b>	<b>280KB</b>	<b>280KB</b>	<b>560KB</b>	<b>560KB</b>	<b>560KB</b>
<b>Program Flash</b>	128KB	128KB	128KB	256KB	256KB	256KB	512KB	512KB	512KB
<b>Data Flash</b>	8KB	8KB	8KB	8KB	8KB	8KB	32KB	32KB	32KB
<b>Boot Flash</b>	8KB	8KB	8KB	16KB	16KB	16KB	16KB	16KB	16KB
<b>On-Chip RAM</b>	<b>12KB</b>	<b>12KB</b>	<b>12KB</b>	<b>20KB</b>	<b>20KB</b>	<b>20KB</b>	<b>36KB</b>	<b>36KB</b>	<b>36KB</b>
<b>Program RAM</b>	4KB	4KB	4KB	4KB	4KB	4KB	4KB	4KB	4KB
<b>Data RAM</b>	8KB	8KB	8KB	16KB	16KB	16KB	32KB	32KB	32KB
<b>Flash Security</b>	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<b>Ext. Memory Interface</b>	-	Yes	Yes	-	Yes	Yes	-	Yes	Yes
<b>Internal Voltage Regulator</b>	On/Off-Chip	On/Off-Chip	On/Off-Chip	On/Off-Chip	On/Off-Chip	On/Off-Chip	On/Off-Chip	On/Off-Chip	On/Off-Chip
<b>On-Chip Relaxation Osc.</b>	No	No	No	No	No	No	No	No	No
<b>16-bit Timers</b>	16	16	16	16	16	16	16	16	16
<b>Quadrature Decoder</b>	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch	2 x 4ch
<b>PWM</b>	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch	2 x 6ch
<b>PWM Fault Input</b>	4 + 4	3 + 4	3 + 4	4 + 4	3 + 4	3 + 4	4 + 4	3 + 4	4 + 4
<b>PWM Current Sense Pins</b>	3 + 3	3 + 3	3 + 3	3 + 3	3 + 3	3 + 3	3 + 3	3 + 3	3 + 3
<b>12-bit ADC</b>	4 x 4 ch	4 x 4 ch	4 x 4 ch	4 x 4ch	4 x 4ch	4 x 4ch	4 x 4 ch	4 x 4ch	4 x 4ch
<b>Temperature Sensor</b>	Optional	Optional	Optional	Optional	Optional	Optional	Optional	Optional	Optional
<b>CAN</b>	FlexCAN	FlexCAN	FlexCAN	FlexCAN	FlexCAN	FlexCAN	FlexCAN (2)	FlexCAN (2)	FlexCAN (2)
<b>SCI (UART)</b>	2	2	2	2	2	2	2	2	2
<b>SPI (Synchronous)</b>	2	2	2	2	2	2	2	2	2
<b>GPIO (Ded./Shrd/Tot)</b>	21 / 28 / 49	0 / 62 / 62	0 / 76 / 76	21 / 28 / 49	0 / 62 / 62	0 / 76 / 76	21 / 28 / 49	0 / 62 / 62	0 / 76 / 76
<b>JTAG/EOnCE</b>	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<b>Package</b>	128LQFP	144LQFP	160LQFP	128LQFP	144LQFP	160LQFP	128LQFP	144LQFP	160LQFP

- ❖ New platform to address the needs of cost sensitive applications requiring a **high performance** 16-bit solution
- ❖ Extended Temperature
  - -40°C to +105°C
  - -40°C to +125°C
- ❖ Low pin count, easy to manufacture with packages
- ❖ **Aggressive** price points

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

## 56F8011/56F8013/56F8014

12K - 16KB  
Program Flash

4kB  
Program/  
Data RAM

56800E Core  
32MHz

JTAG/EOnCE

System Integration  
Module (SIM)

Interrupt Controller

PLL

Relaxation OSC

Voltage Regulator

COP

Power-On-Reset

Power Supervisor

Up to 26 GPIOs

1 x SCI

1 x SPI

1x IIC

3-4ch 12bit ADC

3-4ch 12bit ADC

↑ Synch

4Ch 16bit Timer

↕  
6-ch PWM Output

Package: 32LQFP

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

# 56F8000 Family Expansion

## 56F8023/56F8025/56F8036/56F8037 Features

### 56F8023/56F8025/56F8036/56F8037

32KB - 64KB  
Program Flash

4kB-8KB  
Program/  
Data RAM

56800E Core  
32MHz

JTAG/EOnCE

System Integration  
Module (SIM)

Interrupt Controller

PLL

Relaxation OSC

Crystal OSC

Voltage Regulator

COP

Power-On-Reset

Power Supervisor

Up to 53 GPIOs

2 x QSCI

2 x QSPI

1xIIC

1x MSCAN

3xPIT

8ch 12bit ADC

8ch 12bit ADC

Synch

8Ch 16bit Timer

6-ch PWM Output

2 x 12 bit DAC

2 x Comparators

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

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

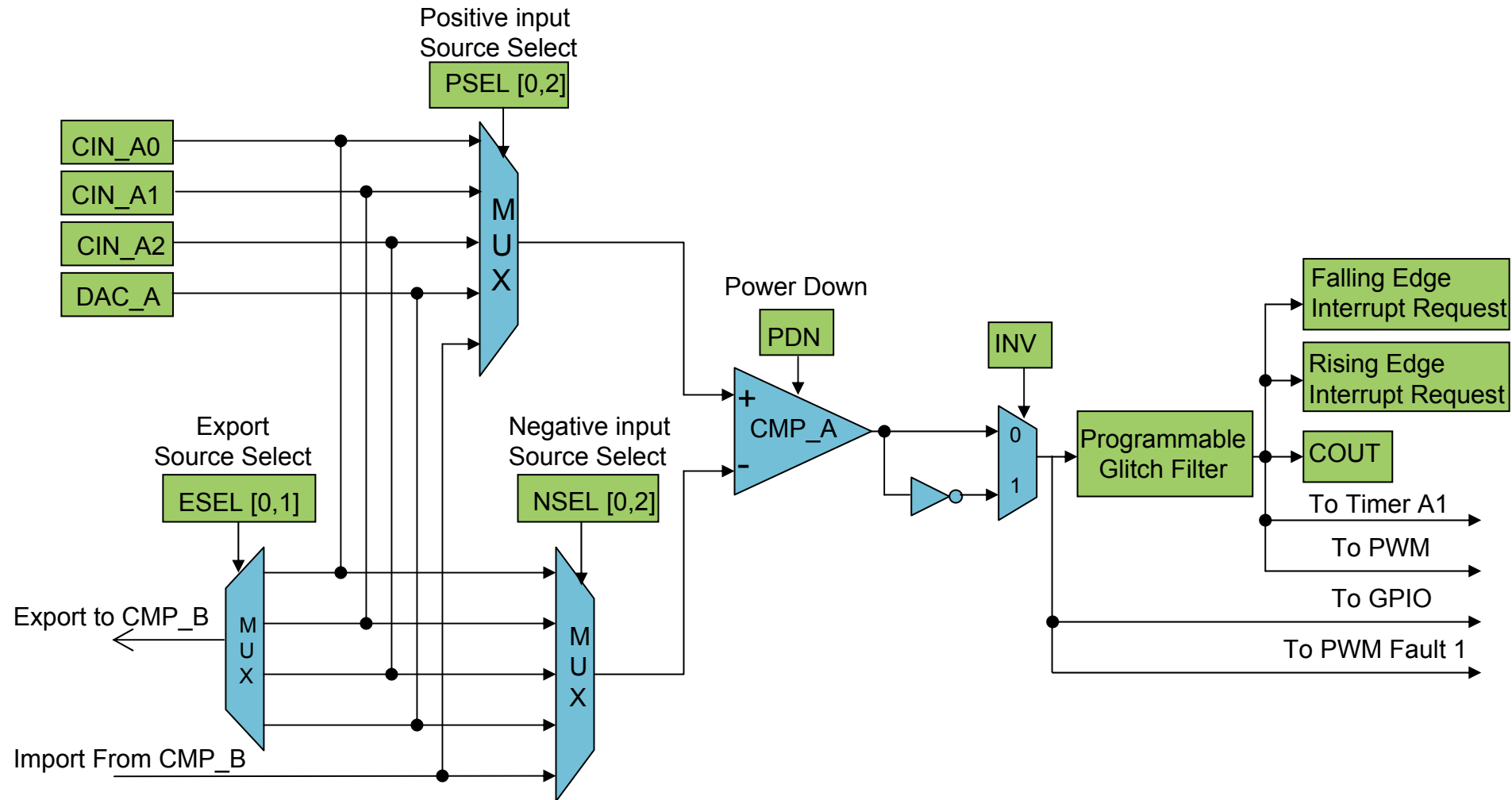
# 56F8000 Series Feature Summary

	56F8011	56F8013	56F8014	56F8023	56F8025	56F8036	56F8037
Performance	32MHz/MIPs	32MHz/MIPs	32MHz/MIPs	32MHz/MIPs	32MHz/MIPs	32MHz/MIPs	32MHz/MIPs
Temperature Range (V)	-40C to 105C	-40C to 105C	-40C to 105C	-40C to 105C	-40C to 105C	-40C to 105C	-40C to 105C
Voltage Range	3.0V - 3.6V	3.0V - 3.6V	3.0V - 3.6V	3.0V - 3.6V	3.0V - 3.6V	3.0V - 3.6V	3.0V - 3.6V
Voltage Regulator	On-Chip	On-Chip	On-Chip	On-Chip	On-Chip	On-Chip	On-Chip
Program/Data Flash	12KB	16KB	16KB	32KB	32KB	64KB	64KB
Program/Data RAM	2KB	4KB	4KB	4KB	4KB	8KB	8KB
Program Security	Yes	Yes	Yes	Yes	Yes	Yes	Yes
On Chip Relaxation Osc.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PLL	Yes	Yes	Yes	Yes	Yes	Yes	Yes
COP	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PWM	1 x 6ch	1 x 6ch	1 x 5ch	1 x 6ch	1 x 6ch	1 x 6ch	1 x 6ch
PWM Fault Inputs	4	4	3	4	4	4	4
12-bit ADCs	2 x 3ch	2 x 3ch	2 x 4ch	2 x 3ch	2 x 4ch	2 x 5ch	2 x 8ch
12-bit DACs	No	No	No	2	2	2	2 (Pinned out)
Analog Comparator	No	No	No	2	2	2	2
16-bit Timers	4	4	4	4	4	4	8
Prog. Interval Timers	No	No	No	1	3	3	3
GPIO (max)	26	26	26	26	35	39	53
IIC	1	1	1	1	1	1	1
SCI (UART) / LIN Slave	1 - SCI	1 - SCI	1 - SCI	1 - QSCI	1 - QSCI	1 - QSCI	2 - QSCI
SPI (Synchronous)	1 - SPI	1 - SPI	1 - SPI	1 - QSPI	1 - QSPI	1 - QSPI	2 - QSPI
CAN						MSCAN	MSCAN
JTAG/EOnCE	JTAG/EOnCE	JTAG/EOnCE	JTAG/EOnCE	JTAG/EOnCE	JTAG/EOnCE	JTAG/EOnCE	JTAG/EOnCE
Package (V) - Industrial	32LQFP (.8p)	32LQFP (.8p)	32LQFP (.8p)	32LQFP (.8p)	44LQFP (.8p)	48LQFP (.5p)	64LQFP (.5p)

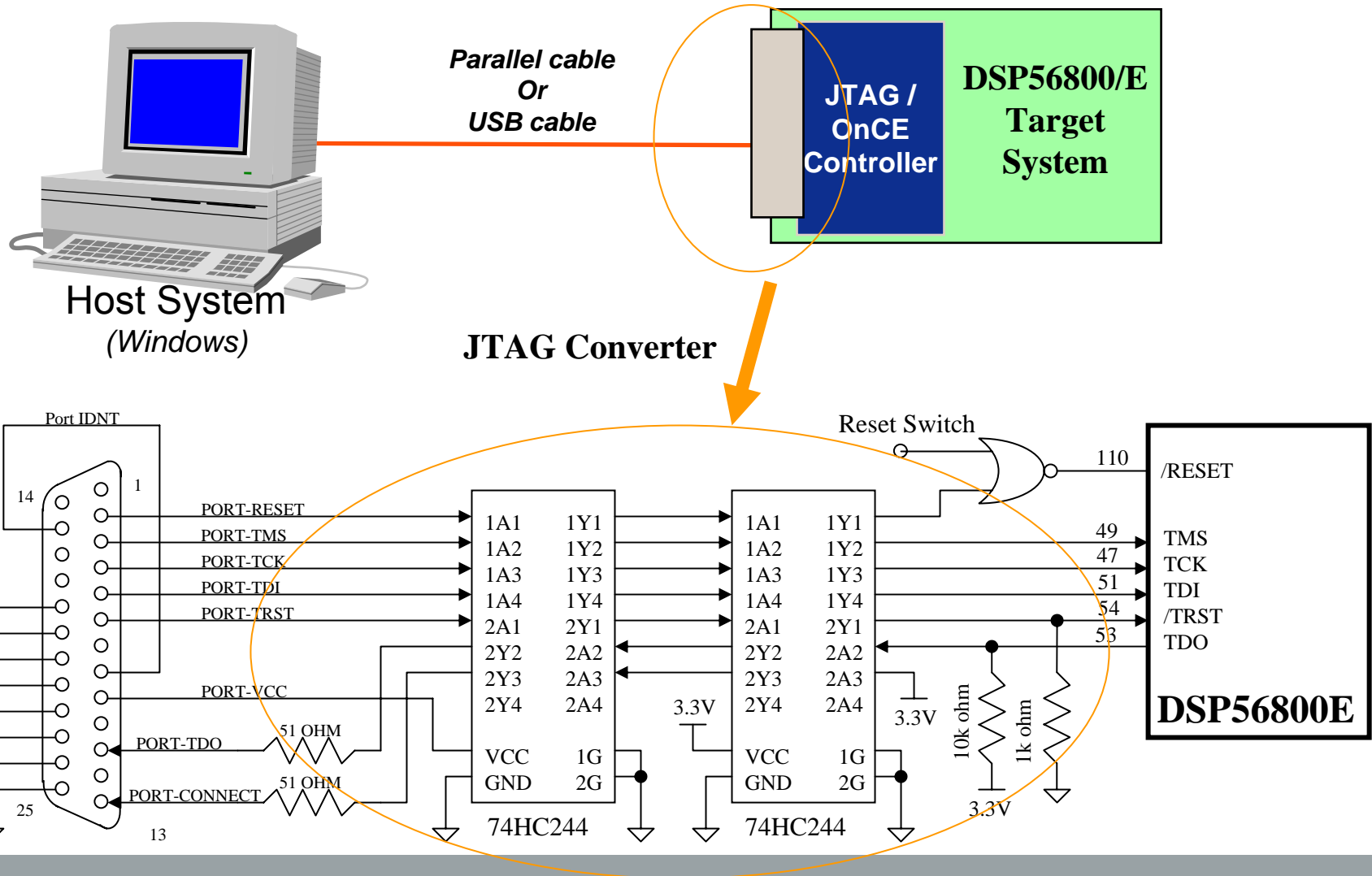
# 56F8000 Cost Saving

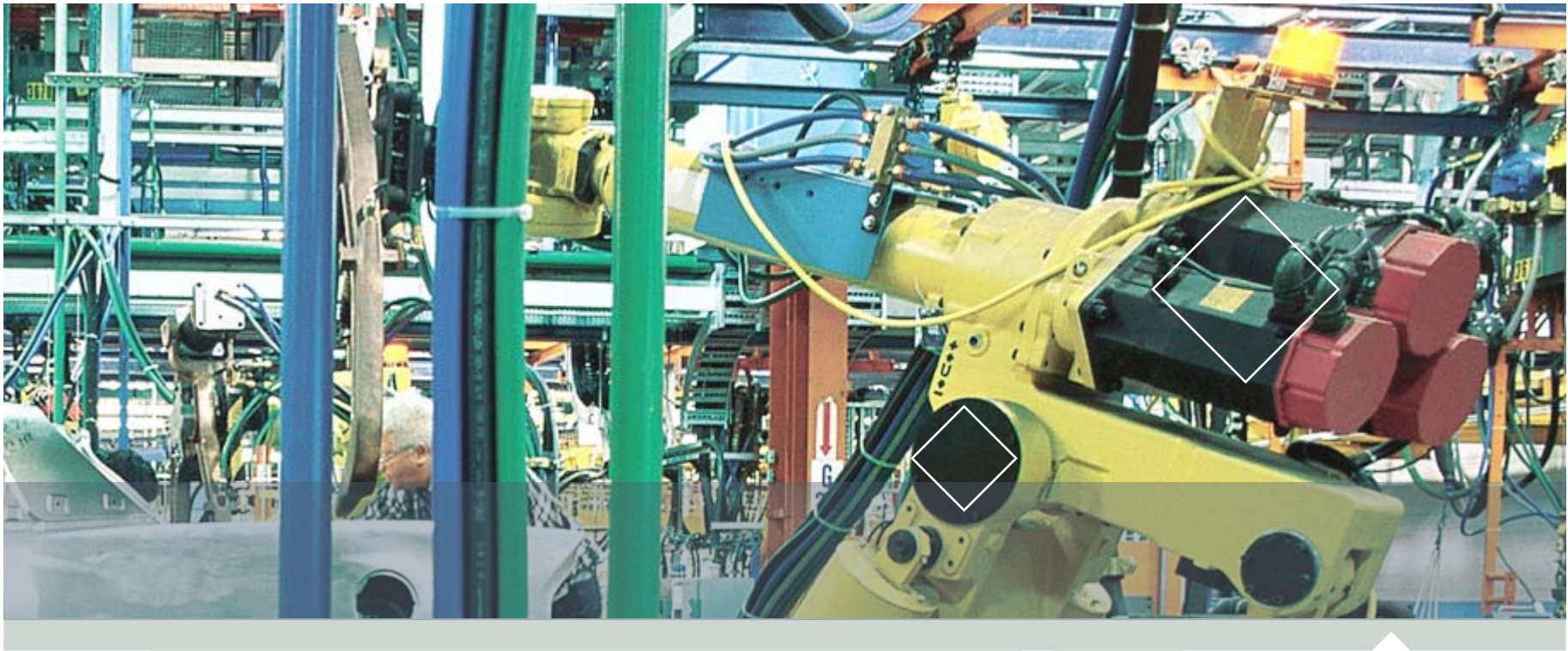
- **56800E architecture optimized for C language**
  - Reduce software development cost
  - Software can be modular and reused
- **On-Chip 12bit Digital-to-Analog Converters (DAC) and Comparators**
  - Dynamic reference settings
  - High speed comparator – Propagation delay: 50ns for internal comparator vs. 1us for external one
- **On-Chip Power-on reset and Low voltage detection**
  - Eliminate external Reset and power supply monitor chip.
- **Single 3.3V supply and 5V I/O port.**
  - Reduce power supply cost
  - Directly interface with 5V system without level shift device
- **On-Chip regulator improves device EMI acceptability**
  - On-Chip 2.5V linear regulator powers the CPU and peripheral logic circuits
- **On-Chip Relaxation oscillator**
  - Eliminate external crystal and reduce PCB size.
  - Greatly improve EMI acceptability
- **Smaller Flash memory page size**
  - Enable User to designate a page flash as EEPROM ( eliminate external EEPROM devices)
- **5 Level interrupt priority**
  - Reduce interrupt overhead
  - improve software efficiency
- **Enhanced On-Chip Emulator**
  - Enable debug of target system using cost effective, isolated debug tool.

# Analog Comparator Interconnection

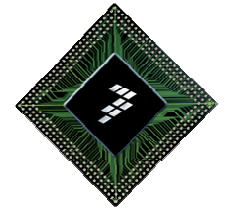


# On-Chip Emulator



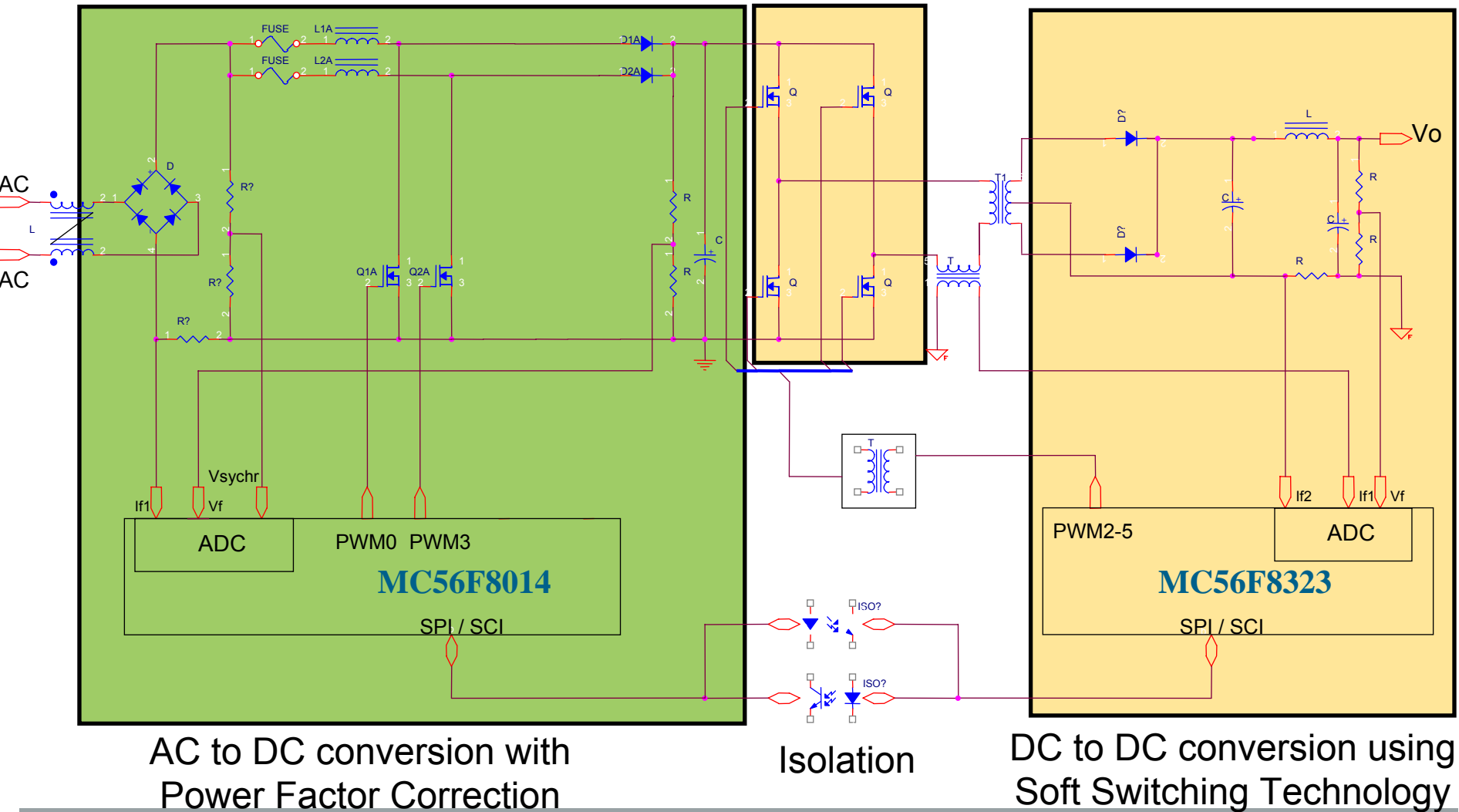


# Applications

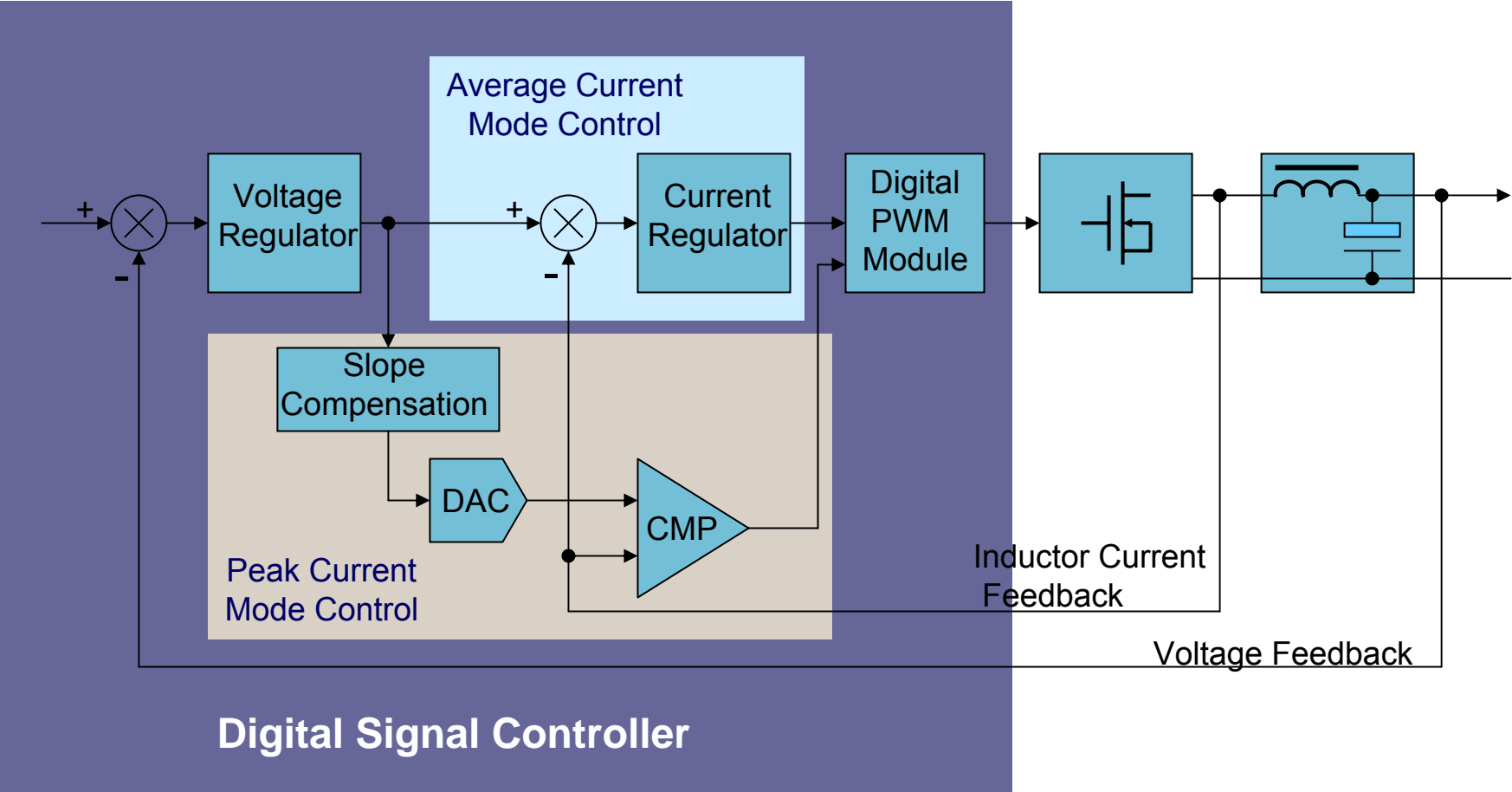


# Power Supply applications

## Digital AC to DC Switch mode Power Supply



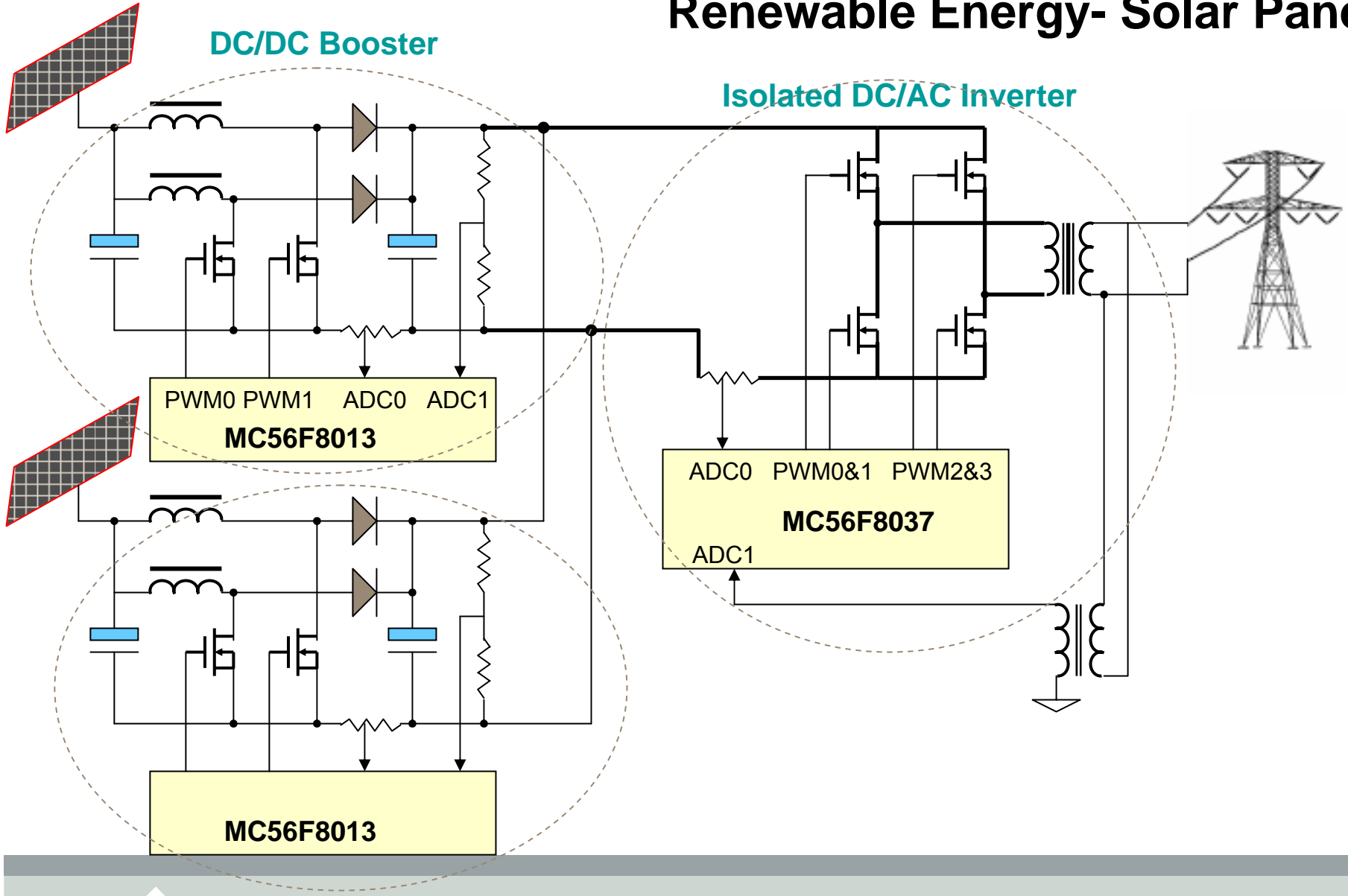
# Hybrid Digital Control



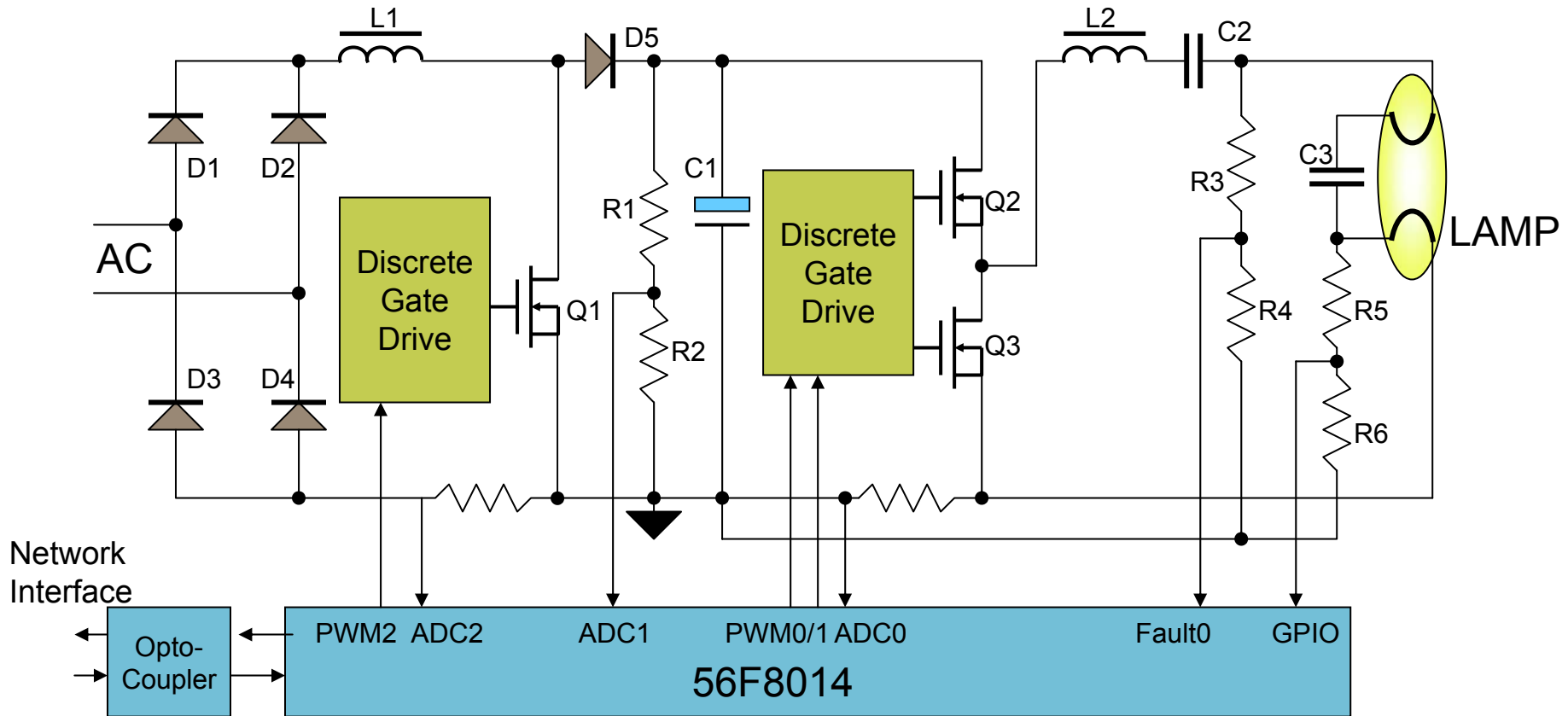
# Renewable Energy- Solar Panel

## DC/DC Booster

## Isolated DC/AC Inverter



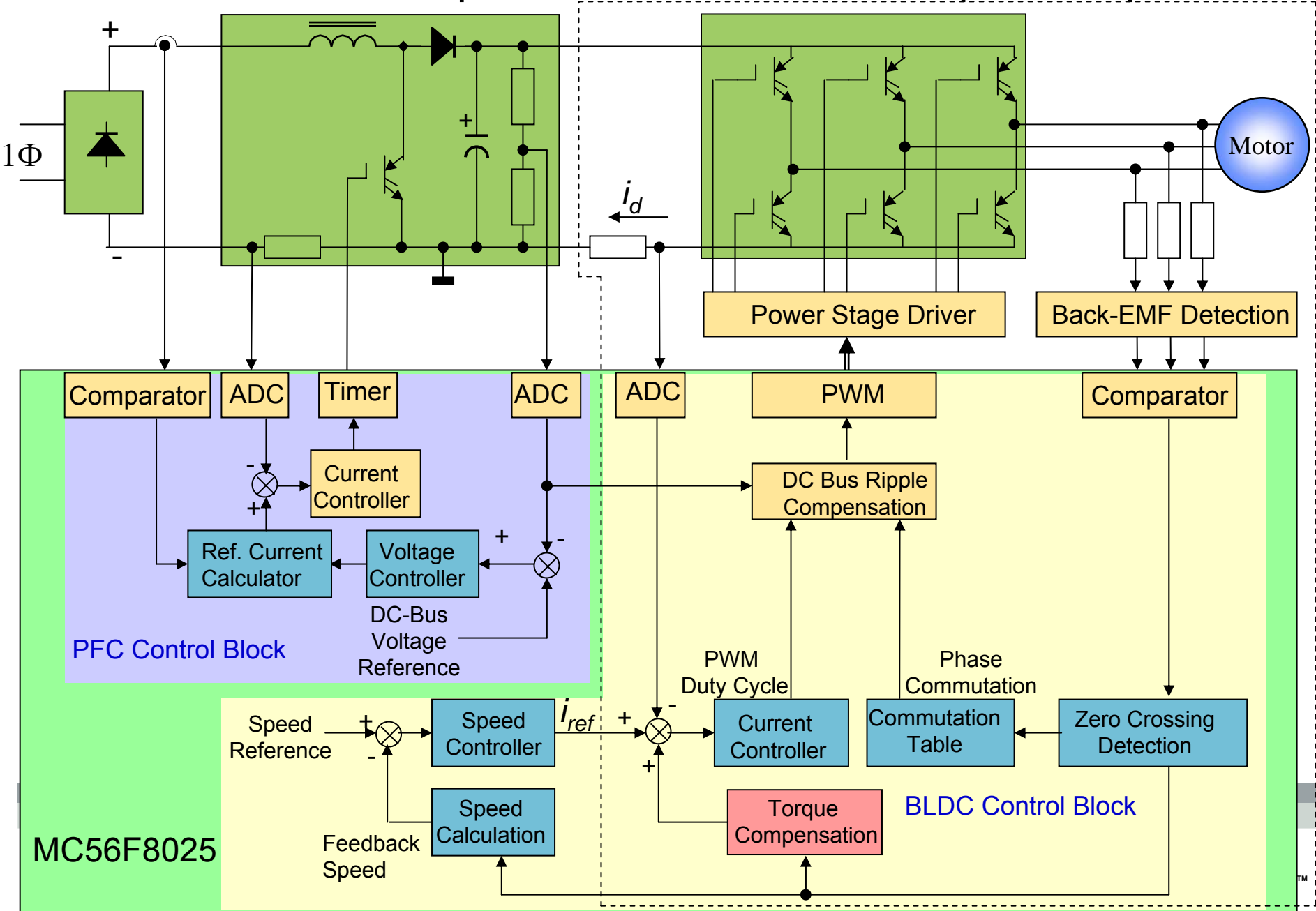
# Digital Dimming Ballast Application Example



## Feature

- One hardware can be used for different tubes
- Control Algorithms and functionalities implemented in software
- Low number of components used which means low manufacturing cost

# BLDC A/C Compressor Control With Torque Compensation



# 56F8000 Demonstration Kit

- Contents:
- Demo Board
- Complimentary permanent license for CodeWarrior® Development Studio with Processor Expert™ tool
- Utilizes on-chip oscillator
- JTAG-to-Parallel Port command converter and parallel cable
- Power supply
- Preprogrammed sample application
- Accelerated Development System CD
- On-board expansion capabilities for development activities
- Ordering Part Number and SRP:
  - DEMO56F8013-EE
  - DEMO56F8014-EE



# 56F8037 Demonstration Kit

- Contents:
- Demo Board
- Complimentary permanent license for CodeWarrior® Development Studio with Processor Expert™ tool
- Utilizes on-chip oscillator (optional off Chip Crystal)
- USBTAP™ Host Target Interface
- Addition USB cable to power board via USB port
- 9V-12V power supply connector
- Preprogrammed sample application
- Development System CD
- On-board 60pin dual row connector expansion capabilities for development activities
- Ordering Part Number and SRP:
  - MC56F8037EVM



