FTF | FREESCALE TECHNOLOGY FORUM POWERING INNOVATION

Power Conversion (Part 1) Trends and Roadmap Overview

FTF-SEG-F0176

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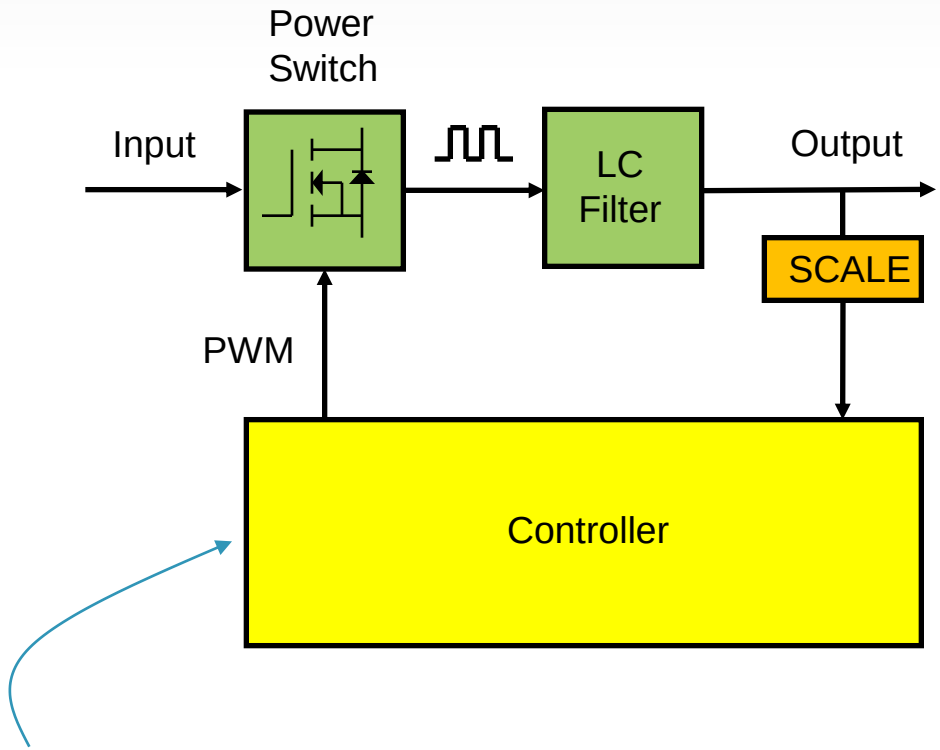
Agenda

- **What is Digital Power Conversion**
- **Why Digital Controlled Power Conversion**
- **Freescale Portfolio**
- **Freescale Development Support**

- *On completion of this course, attendees should:*
  - Understand the Key Advantages and Trends in Digital Power Conversion
  - Understand the Freescale future roadmap addressing digital power conversion
  - Find key resources to help develop next generation

Generic SMPS Block Diagram



The controller block is the key difference between a digital switching-mode power supply and analog one

What is Digital Power Supply?

- "Digital Power Supply" is a power system that is controlled by digital circuits, in much the same way as would be with analog circuits, to monitor, supervise, communicate and control looping.
- A fully digital controlled power system includes both "Digital Control" and "Digital Power Management"

Digital Control

Power switch control feedback or feed forward loop, which is controlled by the digital circuit or programmable controller regulates the output of the power system by driving the power switch duty cycle using pulse width modulation techniques

Advanced adaptive control system, the control circuits combine A/D conversion, pulse width modulation, communication interfaces, operating entirely or mostly in digital mode to gain excellent system performance

Digital Power Management

A digital circuit or programmable controller provides the functions of configuration, diagnosis, monitoring , protection, supply sequencing, and communication with the environment.

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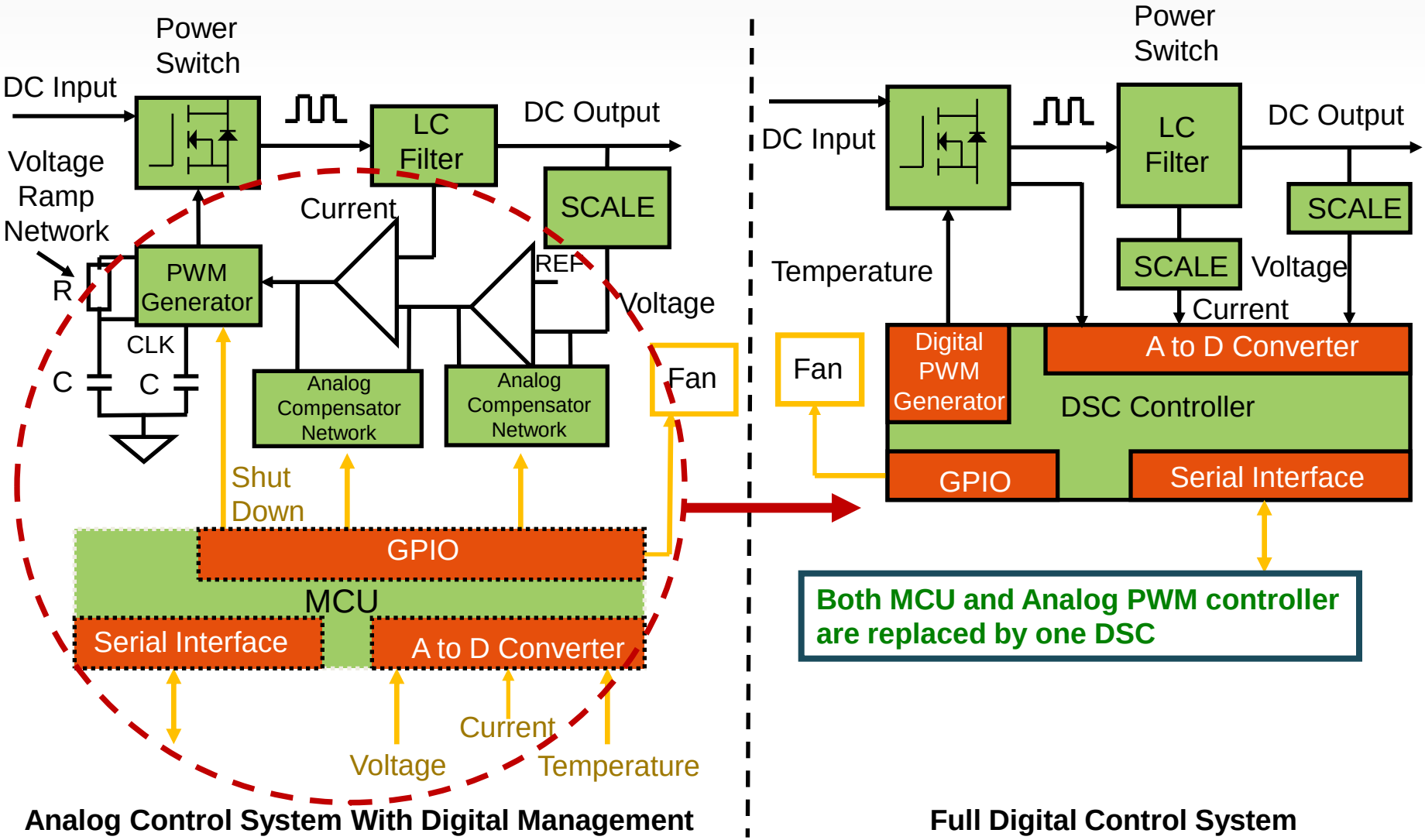
Analog vs. Digital Power Control System



The Trends of Power Supply Technology

- **High Efficiency**
  - Meet Energy Star, 80 plus specifications (www.plugloadsolutions.com/**80Plus**PowerSupplies.aspx)
  - High efficient from light load to full rated load range
  - Cost effective soft-switching techniques
- **High Power Density**
  - Compact size: high watt per cubic inch
- **High Intelligent Control**
  - Digital controlled multi-mode power conversion
  - Adaptive control algorithms – nonlinear loads and components drift
  - Fast transient response
  - Intelligent power management and communication
- **High Reliability**
  - Less components usage
  - System monitoring and protection
  - Redundancy – load sharing
- **Quiet Operation**
  - Low harmonics, radiated and conducted EMI
- **Innovative Power Distribution**
  - New intermediate bus architecture – eliminate isolated DC/DC converter
- **Low Cost**

Energy

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The Challenges of Power Supply Design

Increased performance and cost pressures
Pressure to increase performance while reducing cost to meet customer demands

System complexity
On the rise with the need for more features and Functionality in smaller form factors

Time to market constraints
Increasingly complex development environments and design cycle time-frames that are constantly shrinking

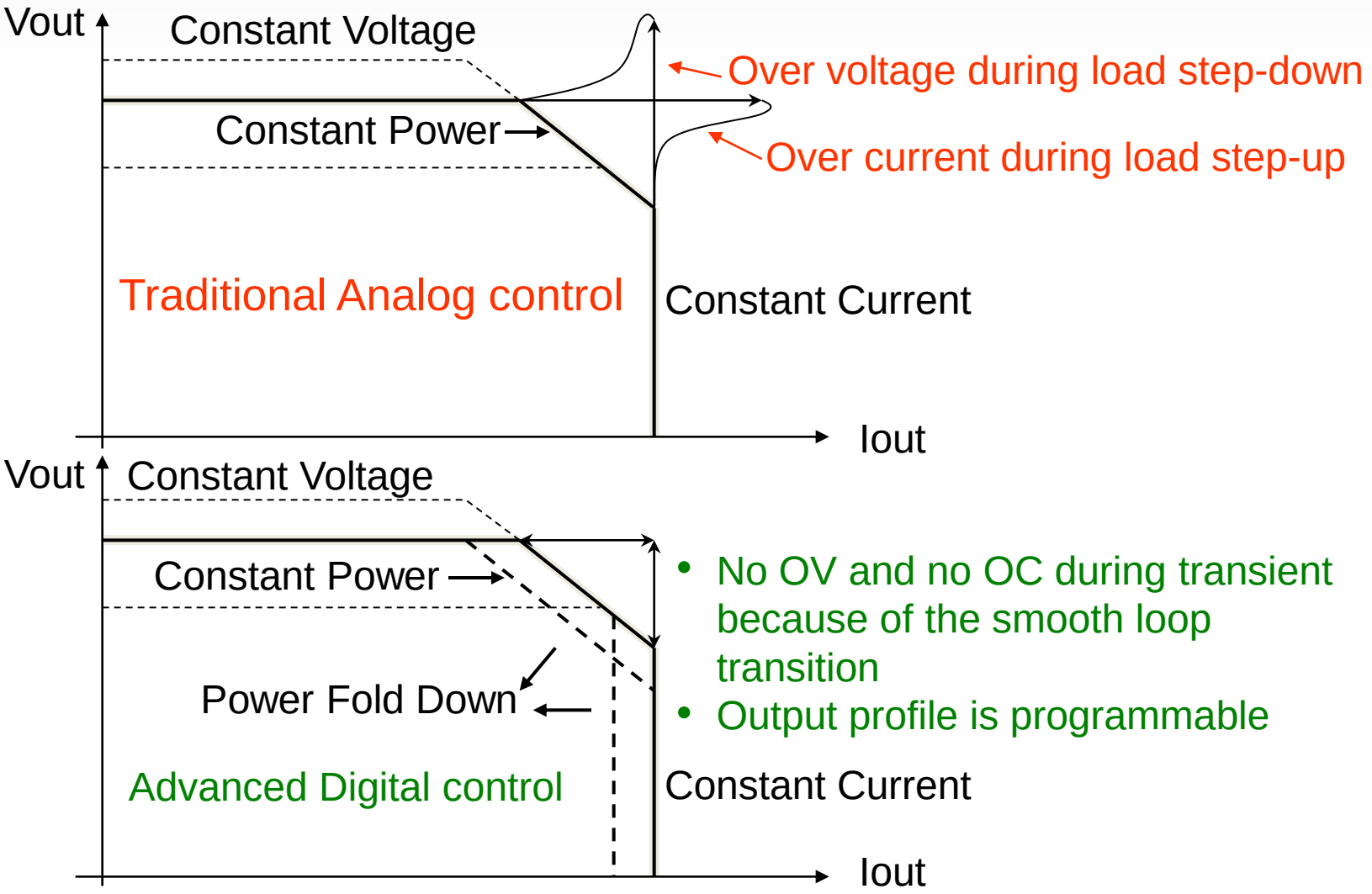
Scalable & Compatible
Easy migration from existing S08 product with common core, IP and tools

Benefits of Digital Controlled Power Supply

- Eliminate the effects of component tolerance, parametric drift, aging, etc
- Configurable feedback loop structure for specific application requirements
- Adaptive control to meet changes in the operating conditions
- Much greater product flexibility by adding new features without hardware changes
- Store operational data for diagnostic and record keeping
- Flexible communication capabilities
- Reduced component count and cost due to the over all integration
- Shorter R&D cycle, fewer turns of board prototyping
- Project portability
- Improved end system performance
  - Energy savings
  - Quieter operation
  - Improved EMI performance
  - System Cost savings
  - Enhanced Reliability
- IP protection and technology differentiation

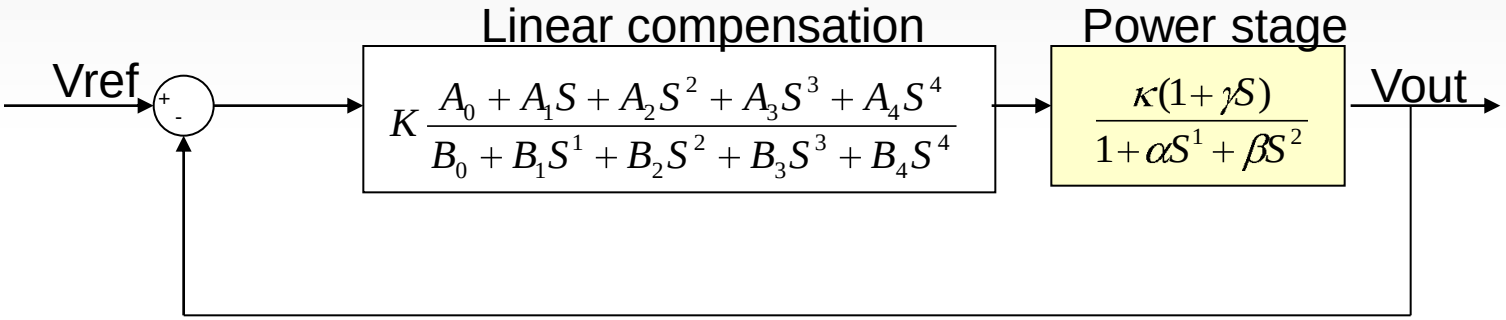
Analog Control vs. Digital Control

- Transient Response Comparison

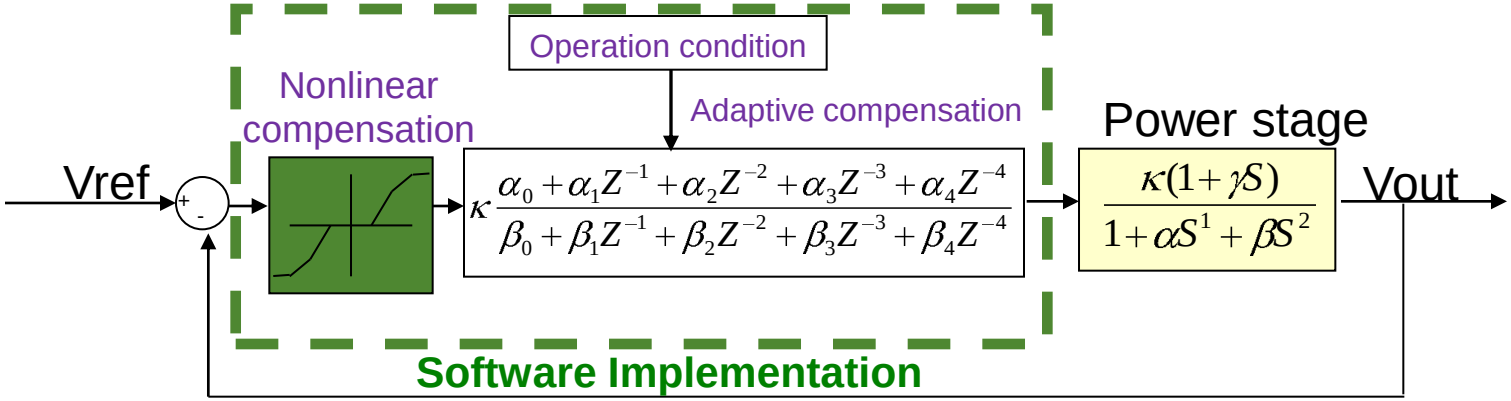


- No OV and no OC during transient because of the smooth loop transition
- Output profile is programmable

Analog vs. Digital Control Algorithm



A typical control loop implemented by an analog circuit



A digital control loop implemented by Digtal Signal Controller

Benefit of digital control:
1) Advanced control algorithm implemented to control complex topologies
2) Optimize feedback loop to meet application requirements
3) Runtime changes to compensation parameters according to operating conditions

Digital Power Supply Lifecycle

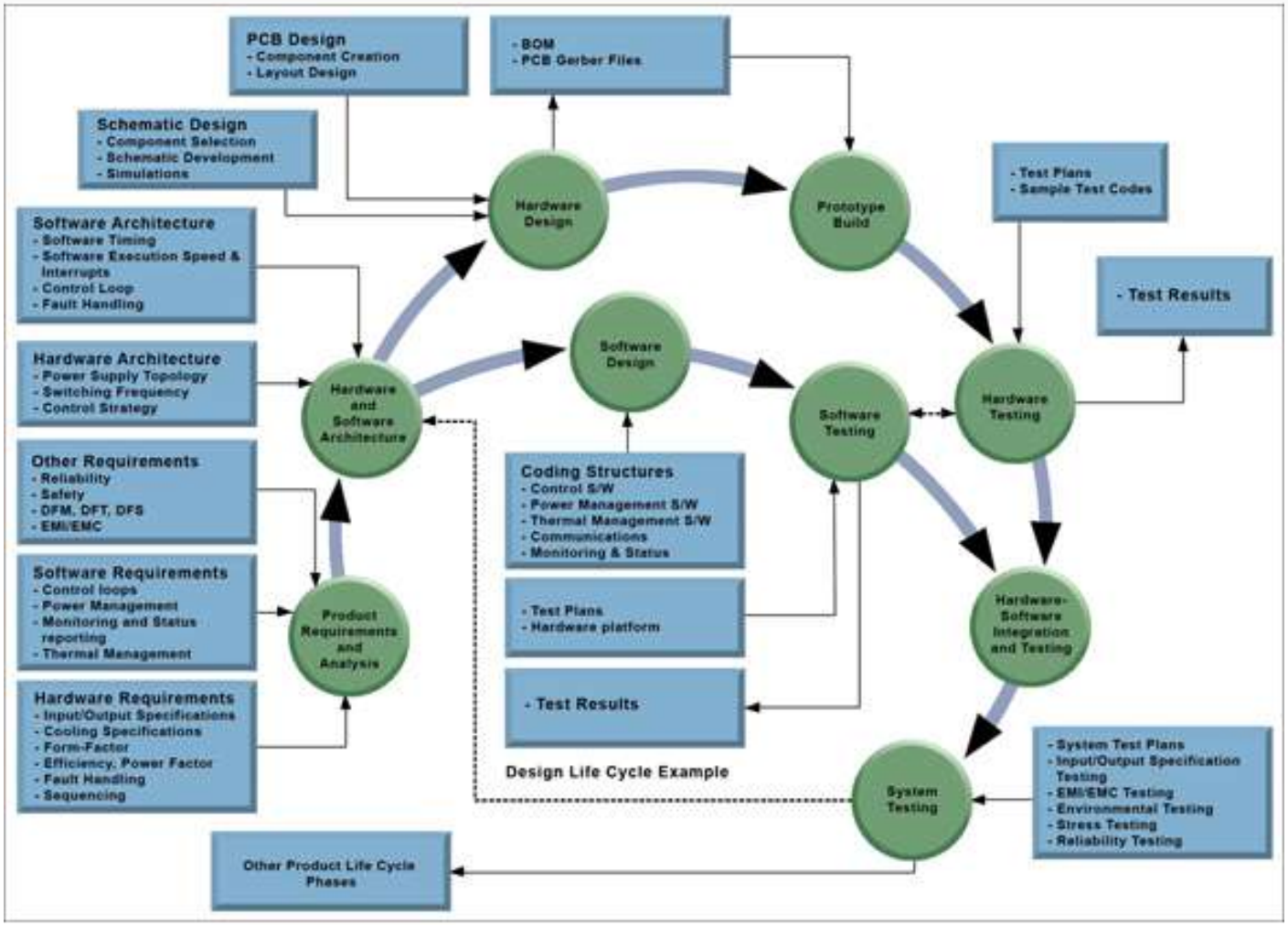
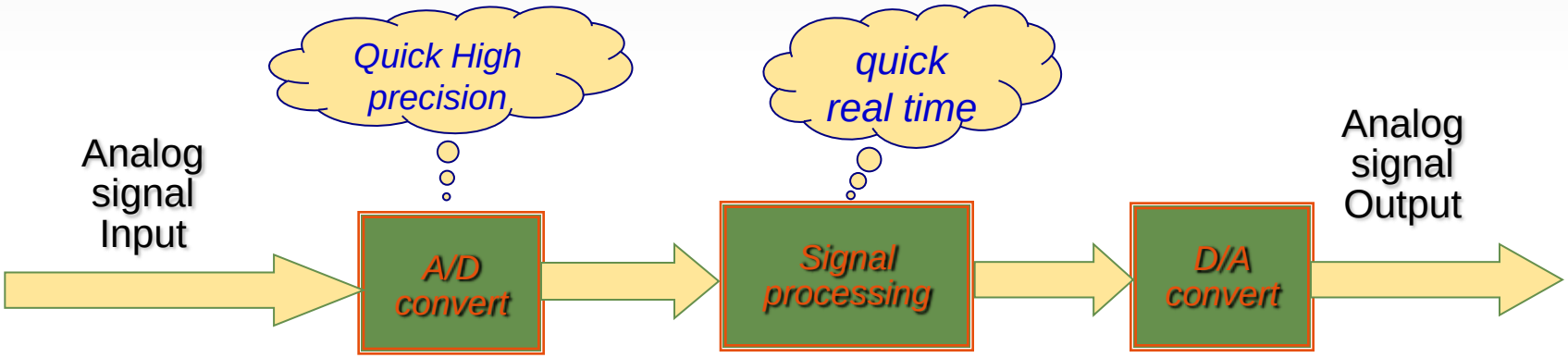
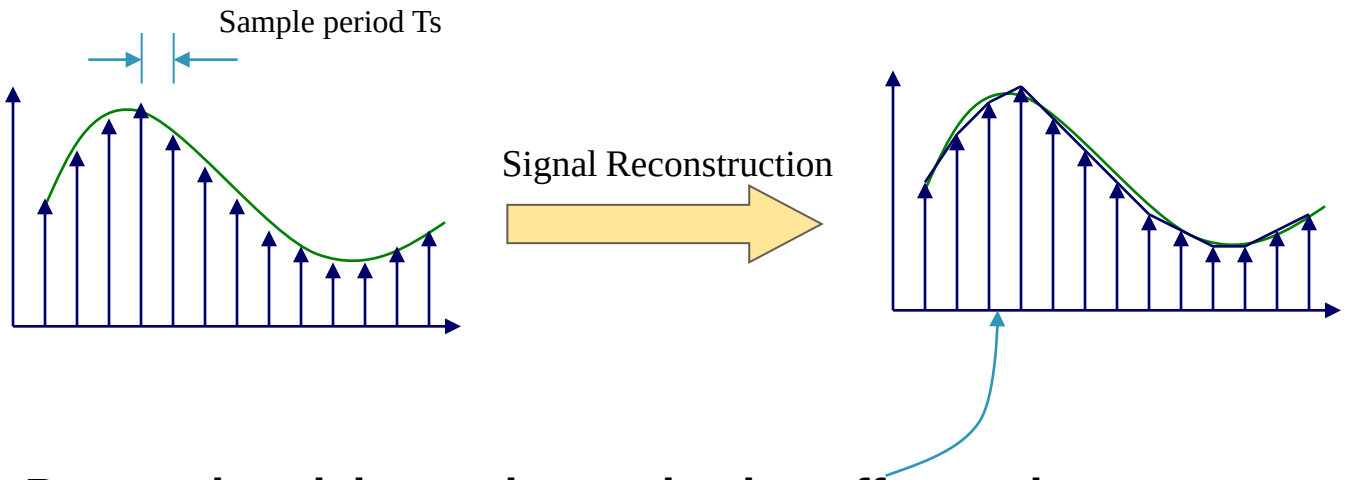


Figure 2: The Design Lifecycle of a Digital Power Supply

Digital Control System





Processing delay and quantization effect reduce system precision and performance

Analog vs. Digital Power System Checklist

	Analog Control	Digital Control
Control Circuit	Complex, Bulky	Simple, Programmable, Integrated
IP Protection	Bad	Good
PFA Record	Bad	Good
Flexibility	Bad	Good
Reliability	Bad	Good
Design Continuity	Bad	Good
On-the-fly Update	No	Yes
Sample Mode	Continuous	Discrete
Processing	Continuous	Control Delay

Note: Digital Logic Shrinking Much Faster Than Analog Circuitry

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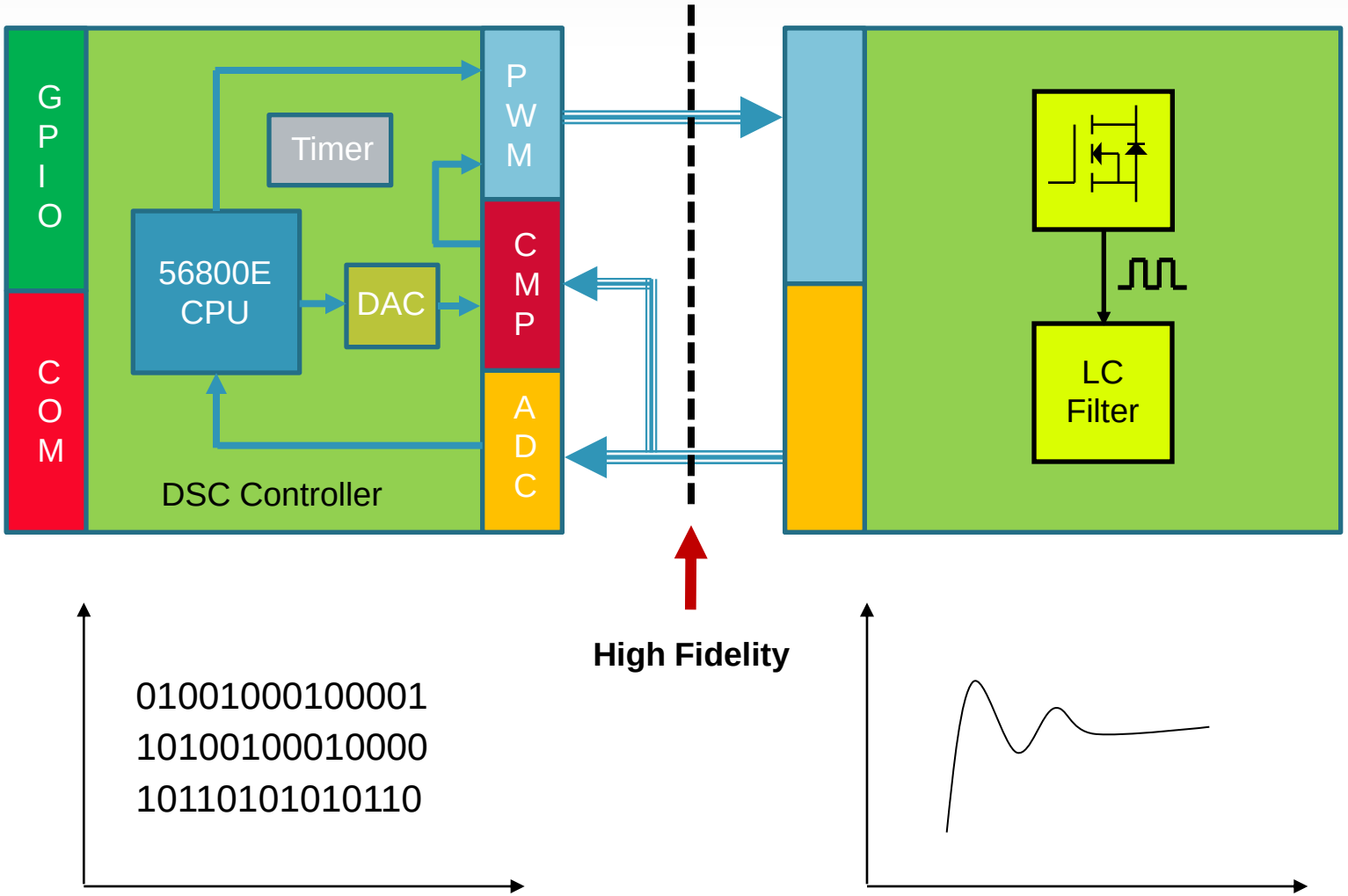
Digital Controlled Power Supply System Mapping



Digital Power Control, Market Drivers #1

General requirements:

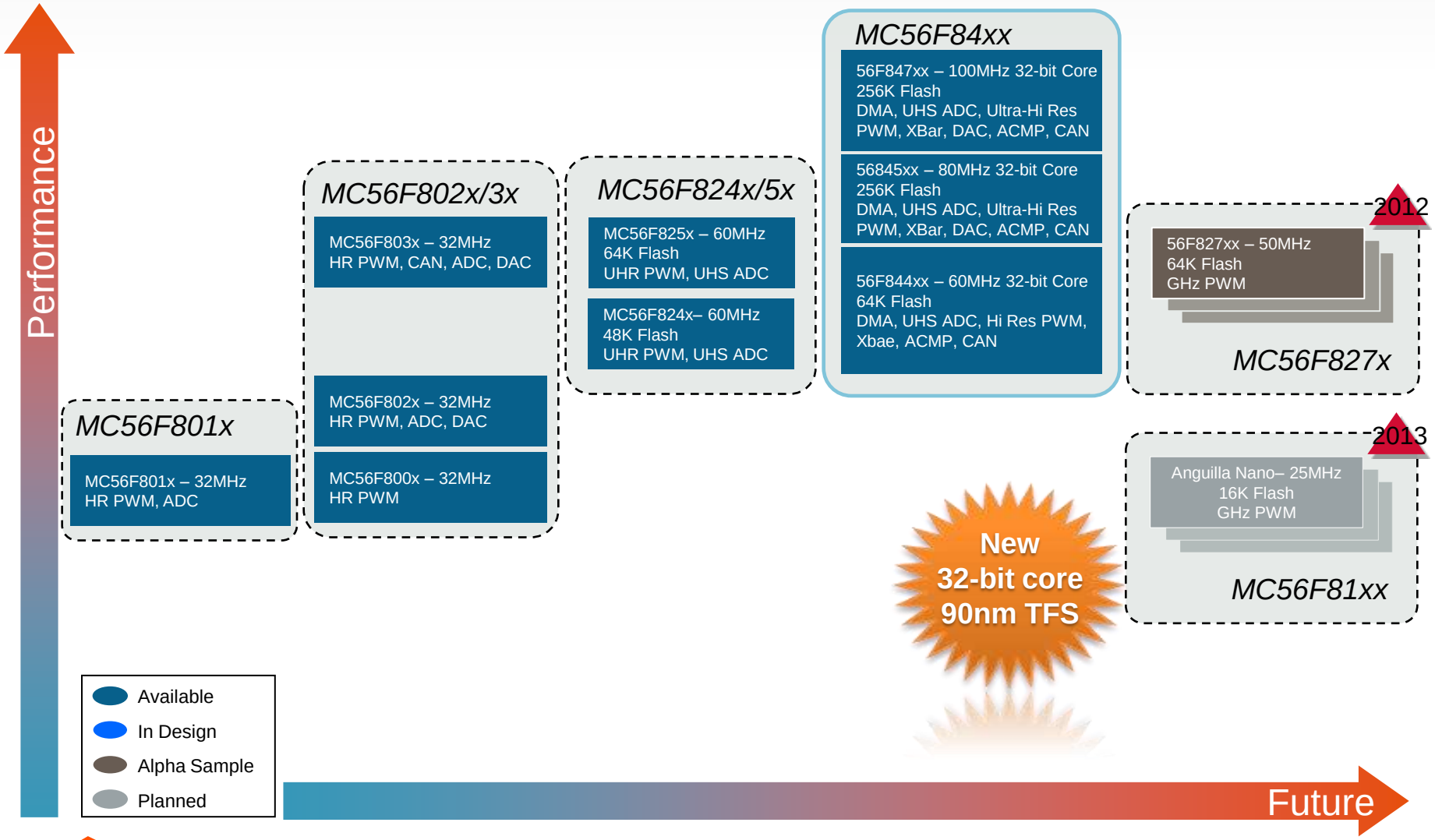
- **Powerful Core**
  - The control loop is calculated every 5-20 μs
- **Very fast A/D Converter** (less than 1μs conversion, capable of parallel conversion)
  - At least 12-bit resolution, high dynamical conversion precision
  - Hardware synchronization with PWM
- **PWM module** capable of **high resolution frequency** and **duty cycle** generation
  - The resolution should be comparable to resolution of ADC measurement
  - It means more than 10 bits for frequencies 100 – 400 kHz
  - Flexibility to drive many stages and all available topologies in market
- **Build in analog devices**
  - Low propagation delay, anti-jamming features
  - Automatic waveform generation for slope compensation control

Digital Power Control, Market Drivers #2

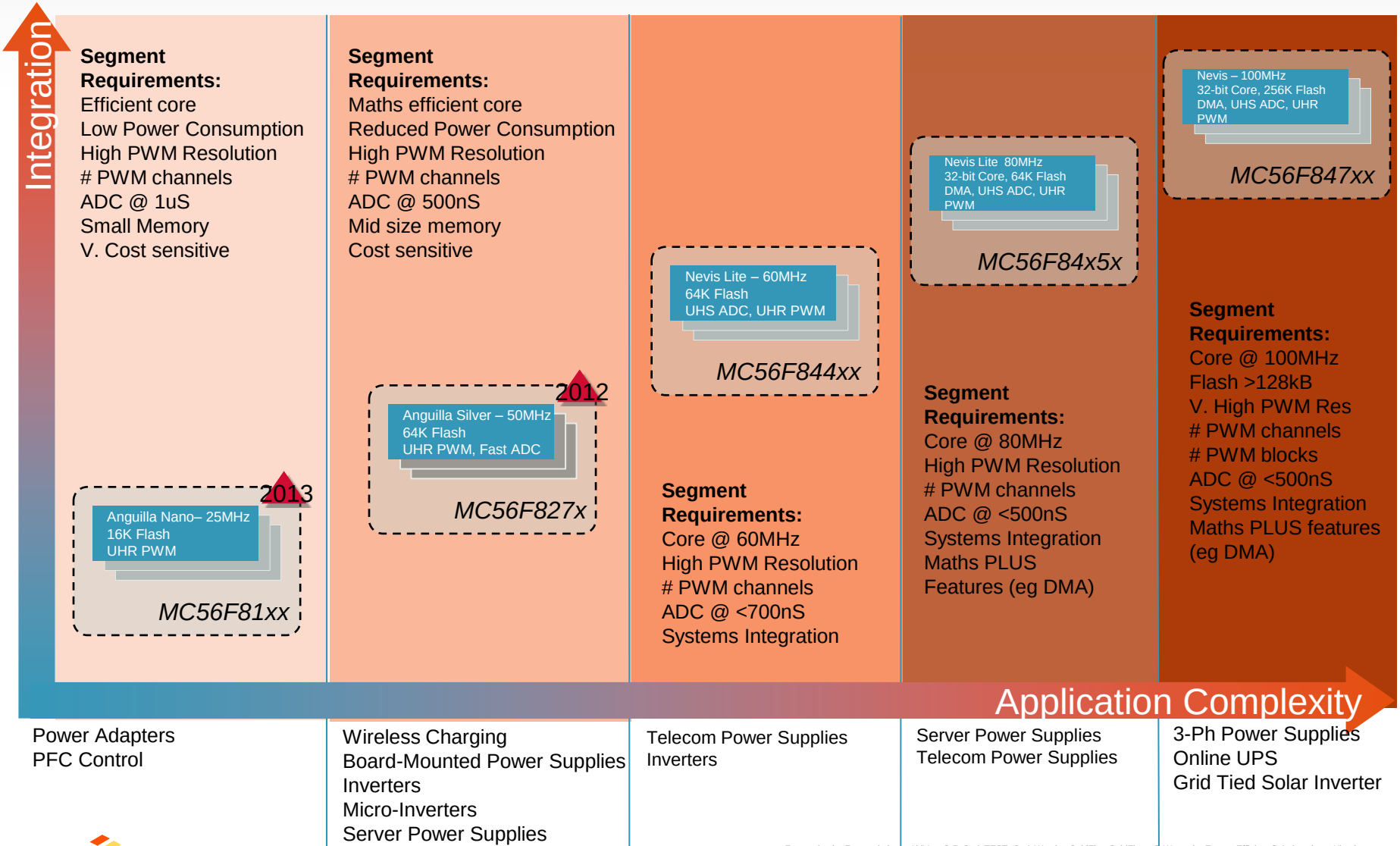
General requirements:

- **Timer**
  - Enough channels for system timing management
  - Capacity to work as capture functionality
  - High resolution
- **User interface**
  - Communication interfaces, if required (SCI, SPI, CAN, I2C with SMBus/PMBus compliant)
  - 5V tolerance GPIO, low status after reset, high drive strength
- **On-Chip Memory**
  - Rich memory configuration
  - Fast access speed, high data retention

Freescale DSC - Roadmap



Next Generation: Digital Control Landscape



Power Adapters
PFC Control

Wireless Charging
Board-Mounted Power Supplies
Inverters
Micro-Inverters
Server Power Supplies

Telecom Power Supplies
Inverters

Server Power Supplies
Telecom Power Supplies

3-Ph Power Supplies
Online UPS
Grid Tied Solar Inverter

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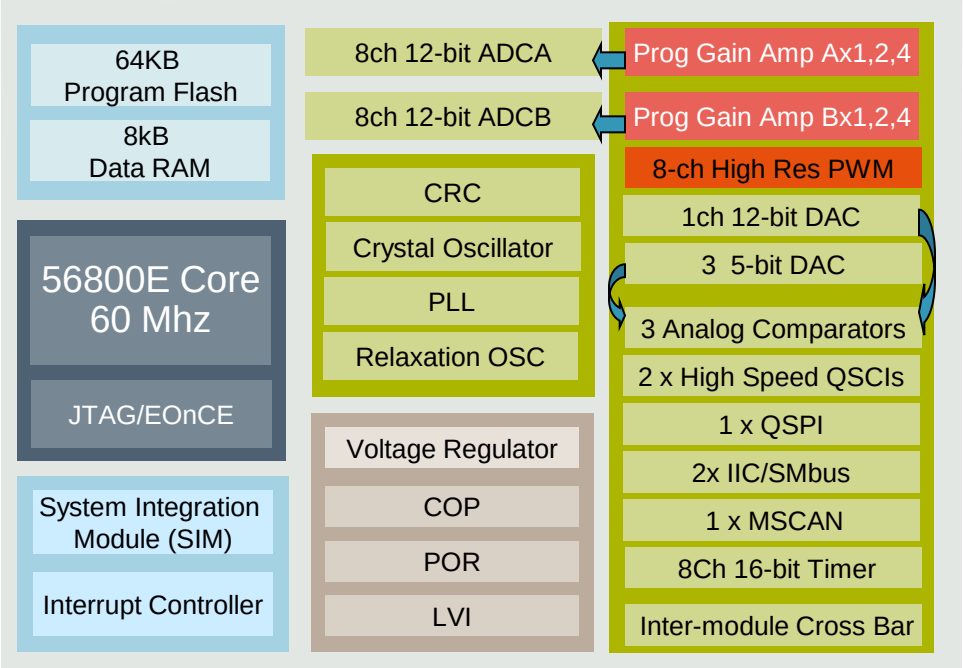
Innovative MC56F82xx Family

- 60 MHz/60 MIPS from 56800E core
- 2.7-3.6V operation
- 64K Bytes program FLASH
- 8K Bytes program/data RAM
- Flash security
- 8Mhz/400Khz tunable internal relaxation oscillator
- Software programmable phase locked loop
- Up to 120 MHz peripherals – timers and QSCI
- Hi-resolution flexible PWM
  - 8 output PWMs module
  - 520ps PWM and PFM resolution
- 2 12-bit ADCs with total 16 inputs
  - 600ns conversion rate
  - built-in PGA with 1x, 2x, 4x gains
- 1 12-bit digital to analog converter
- 3 5-bit digital to analog converters
- 3 analog comparators
- 8 16-bit enhanced GP multifunction programmable timers
- Cyclic redundancy check generator (CRC)
- Computer operating properly timer
- 2 high speed queued serial communication interfaces (QSCI)
- 1 queued serial peripheral interface (QSPI)
- 1 MS-CAN bus interface
- 2 I^2C/SMbus communication interfaces
- Up to 54 GPIOs
- Inter module cross-bar
- JTAG/EOnCE™ debug port
- Temperature range: -40°C to 125°C with 60 Mhz



Package: 44LQFP, 48LQFP, 64 LQFP

Breakthrough Features:

- New generation high speed PWM module
  - 520 ps duty cycle and frequency resolution
  - Flexible edge placement
- High speed ADC with programmable gain amplifiers
  - 600ns conversion rate
  - Supports multi trigger source in one ADC scan
- Inter-module cross bar
  - Programmable inter module connection

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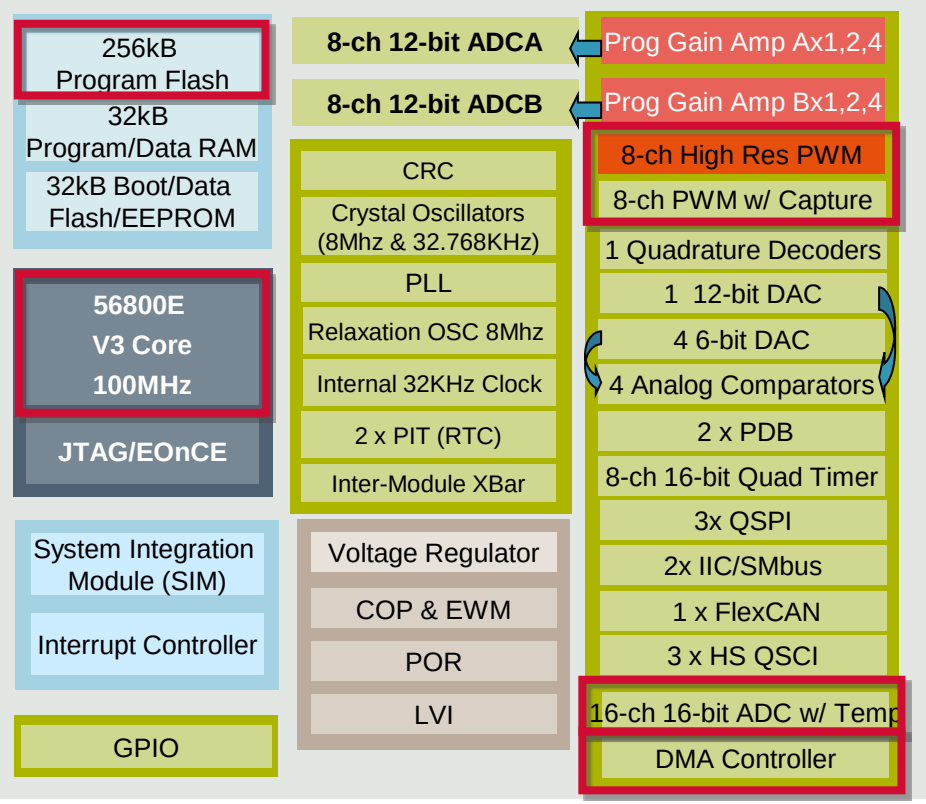
Next-Generation MC56F84xxx Family



Package: 48 LQFP, 64 LQFP, 80LQFP, 100LQFP

Break Through Features

- 32-bit compatible DSC core
- 100MHz flash based device
- DMA controller
- High Speed ADCs with 300ns conversion time
- High-resolution PWM with 312ps resolution

Core

- 100 MHz/100MIPS 56800E V3 Core
  - 32bit dual Harvard architecture
  - 32 x 32bit MAC and 32bit arithmetic operation and set-clear bit manipulation instructions
- 2.7-3.6V operation

Memory

- 256kB program Flash & 32kB boot/data Flash
- 32kB data/program RAM or 16kB RAM + 2kB EEPROM

Integration

- 3xHS-QSCI, 3xQSPI, 2xIIC/SMBus,1xFlexCAN
- Multi-purpose Timers
  - 2 periodic interval timers with real time interrupt generation
  - 2 programmable delay blocks
  - 8-channel multi-function timers
- 8-ch high-resolution PWM module
  - 100MHz clock, 5-bit (MEP) rising and falling edge positioning
  - 312ps PWM and PFM resolution
- 8-ch PWM module with enhanced input capture
- 2 8-ch 12-bit A/D converters with built-in PGA
  - 300ns/3.33MHz conversion time with 12-bit resolution
  - Build-in PGA with 1x, 2x, 4x gain amplification
- 16-ch 16-bit SAR ADC with built-in temperature sensor
  - 2us conversion time
  - Build-in temperature sensor
- 4 analog comparators w/ 6-bit DAC
- 1 quadrature decoder
- 1 12bit DAC with external output
- DMA controller
- Inter-module crossbar
- CRC
- On-chip voltage regulator (single 3.3V power supply)
- System integration: internal relaxation oscillator, PLL, COP, 32kHz auxiliary internal clock
- 5V tolerant I/O
- Temperature range: -40°C to +105°C

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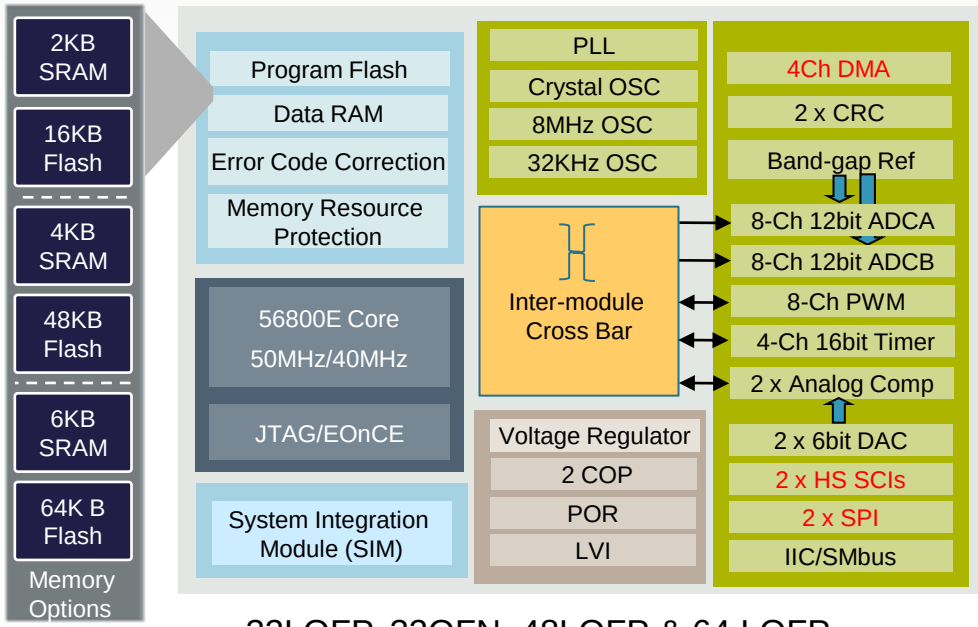
Cost-Effective MC56F827xx

- 56800E V3 Core @ 100MHz from cache (50MHz from flash)
- 2.7-3.6V Operation
- Up to 64KB Program FLASH ,with Flash Security
- Up to 6KB Program/Data RAM
- Memory Resource Protection Unit
- Error code correction
- Up to 100 MHz Peripherals – Timers, PWMs and SCIs
- Eight Channel Enhanced PWM (100MHz)
- (Inclusion of Nano Edge PWM under investigation)
  - Up to four programmable fault protection input
  - Dead-time insertion
  - Input Capture function
- 2 x12-bit ADCs with total 16 Inputs
  - 800ns conversion rate
  - Band-gap reference
- 2 x Comparators with 6-bit voltage reference
- 2 x CRC Generator
- 2 x COP with Multiple clock sources (Watchdog)
- 4 x 16-bit Enhanced Multifunction Programmable Timers
- 2 x High Speed SCI
- 2 x SPI
- 1x I^2C/SMbus Communications Interface
- Four channel DMA controller
- Inter Module cross-bar
- Software Programmable Phase Locked Loop
- Multiple Clock sources
  - External Crystal/Resonator Oscillator
  - 8MHz/400KHz Tunable Internal Relaxation Oscillator
  - 32KHz Internal RC relaxation Oscillator
- 5V Tolerant IO
- Industrial temperature:-40C to 105C @ 50MHz
- AEC – Q100 Level 2



32LQFP, 32QFN, 48LQFP & 64 LQFP

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

Run Current < 30mA (using control loop example code)

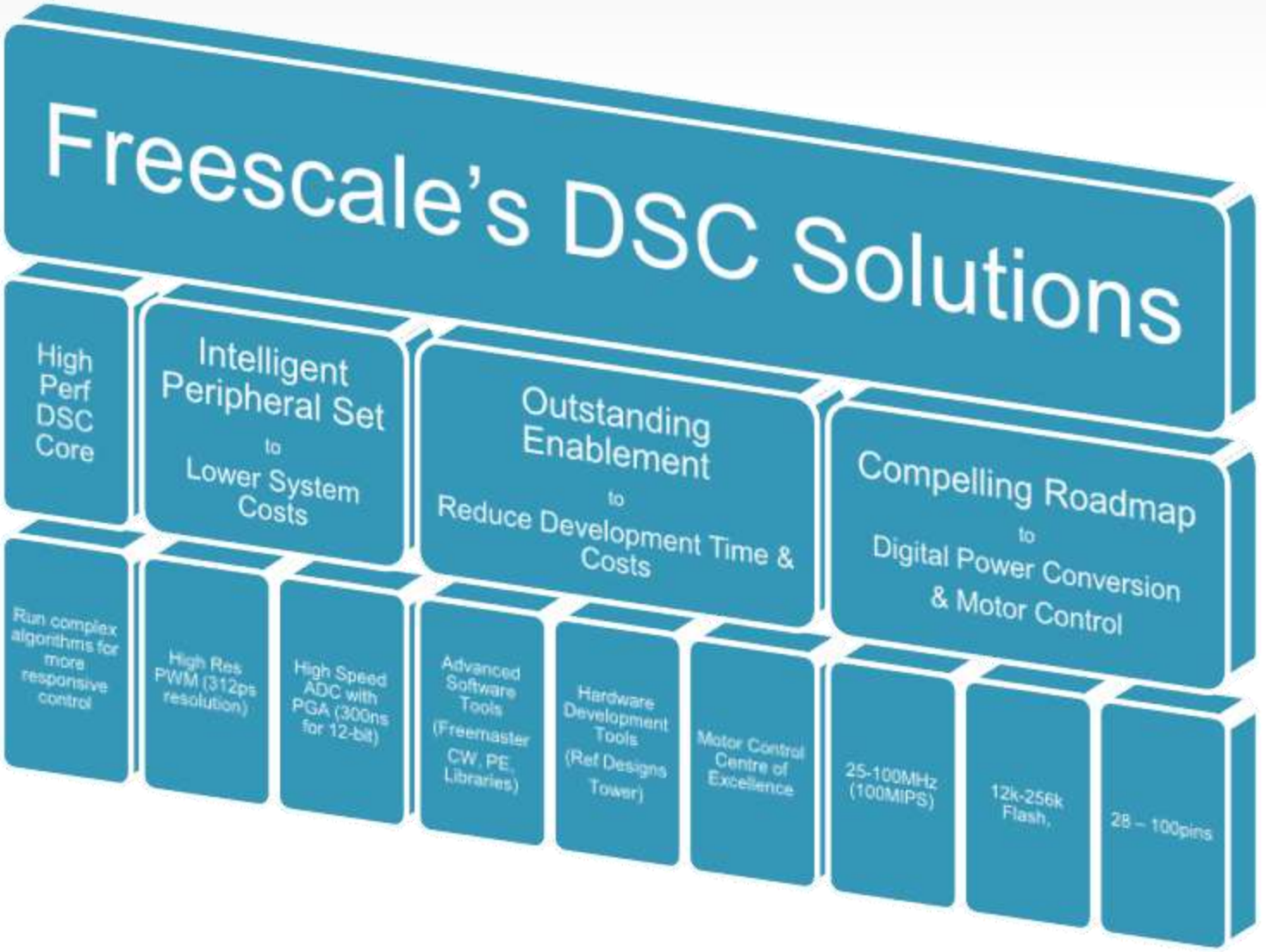
Breakthrough Features:

- High speed ADC @ 800ns conversion time
- Inter-module Cross bar
- DMA

Freescale Solution – Highly Integrated Controllers

- **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 susceptibility**
  - On-Chip linear regulator powers the CPU and peripheral logic circuits
- **Multiple clock sources – multiple On-Chip clocks and external clock source**
  - Clock redundancy
- **Low Cost**
  - System cost lower than the existing analog plus MCU system

Winning in Digital Power with DSCs



Tools & Software

Modular, expandable and cost-effective development platform

FreeMASTER

Allows control of an application remotely from a graphical environment running on a PC

Complete IDE that provides a highly-visual, automated framework to accelerate development of the most complex embedded applications

Control Loop & Math Libraries

Market-focused software components increasing ease of use and decreasing time to market

QEDesign

Complimentary filtering tool ideal for designing FIR and IIR filters

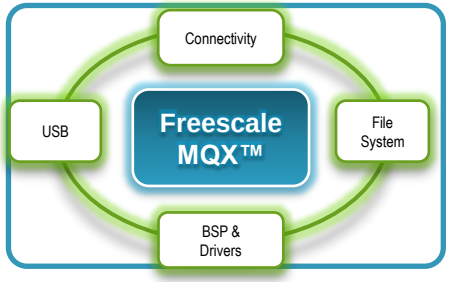
Processor Expert

Rapid application design tool that combines easy-to-use component-based application creation with an expert knowledge system

Reference Designs

Complimentary Gerbers, code and schematics for:

- PMSM/BLDC Motor Control
- LLC Resonant Converter
- Solar Power Conversion
- And more



Accelerate design success with complimentary RTOS that is simple to fine tune custom applications and scalable to fit requirements

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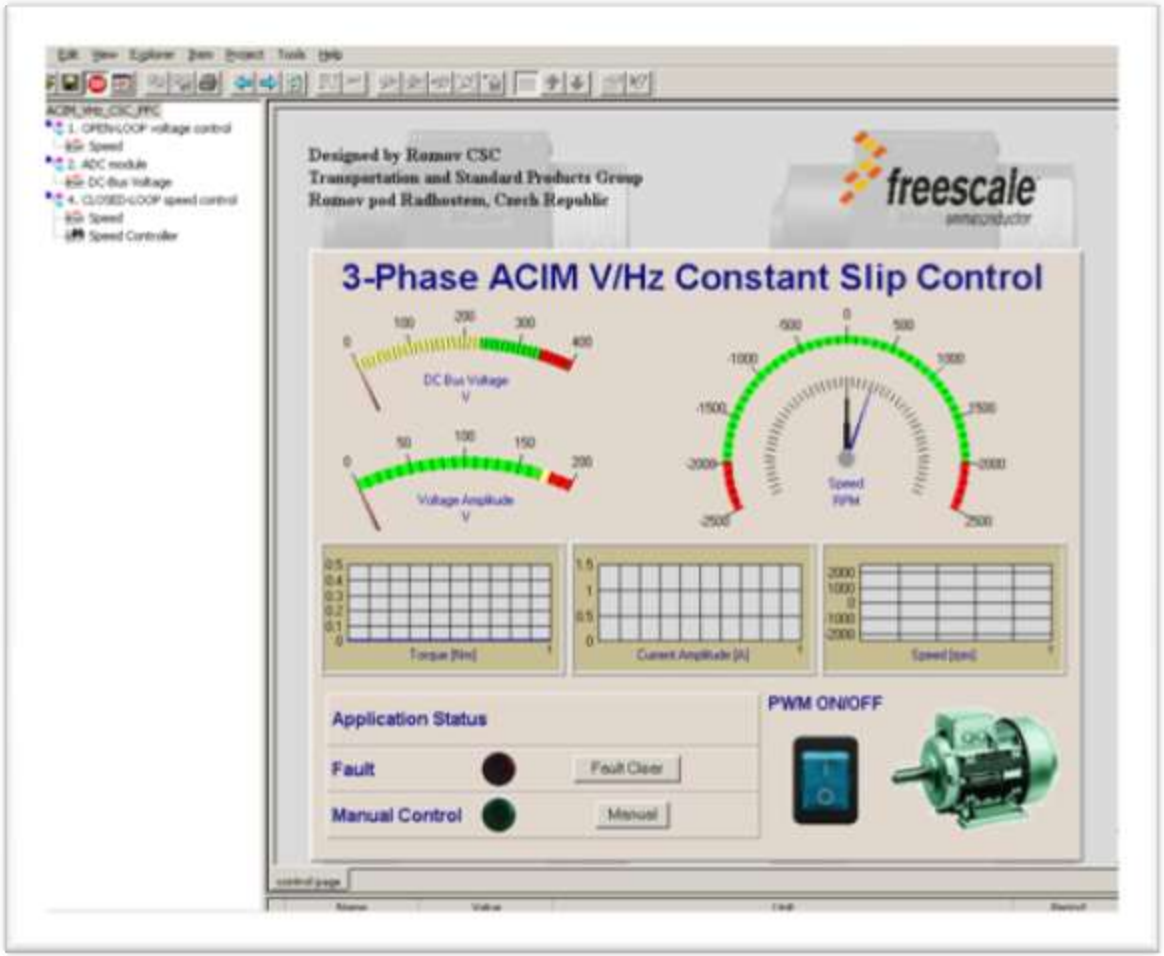
FreeMASTER Monitoring Tool

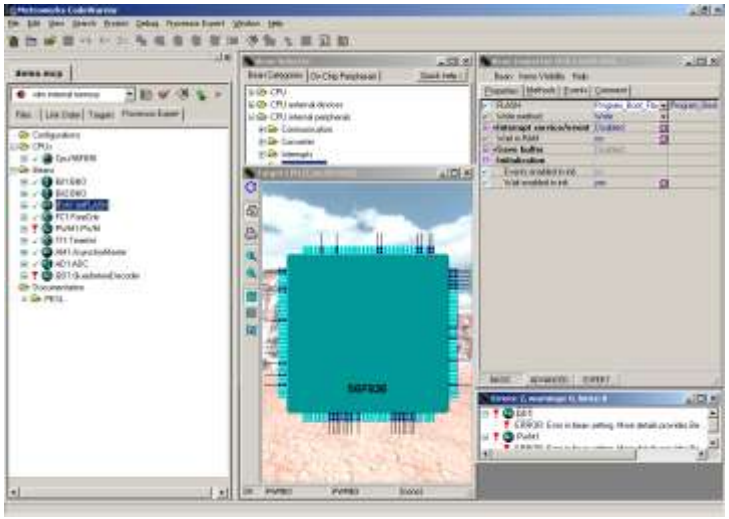
- **Application control and monitor**
- **Live graphs, variable watches, and graphical control page**
- **Real-time operation monitor**
- **Supports:**
  - HCS08, HC12, HCS12 and HCS12X BDM
  - 56F8000, 56F8100 and 56F8300 JTAG
  - SCI driver (FMASTERSCIDRV) for all platforms



www.freescale.com/webapp/sps/site/prod_summary.jsp?code=FREEMASTER

Processor Expert Features

- **Available across DSC product lines**
- **Rapid application development**
- **Expert configuration system**
- **Instant functionality of generated code**
- **Two Peripheral programming levels**
  - Embedded Components
  - PESL
- **Application Specific Algorithm Libraries**
  - All SDK algorithm libraries ported
- **Tested and ready-to-use code**



Development Tools – CodeWarrior™

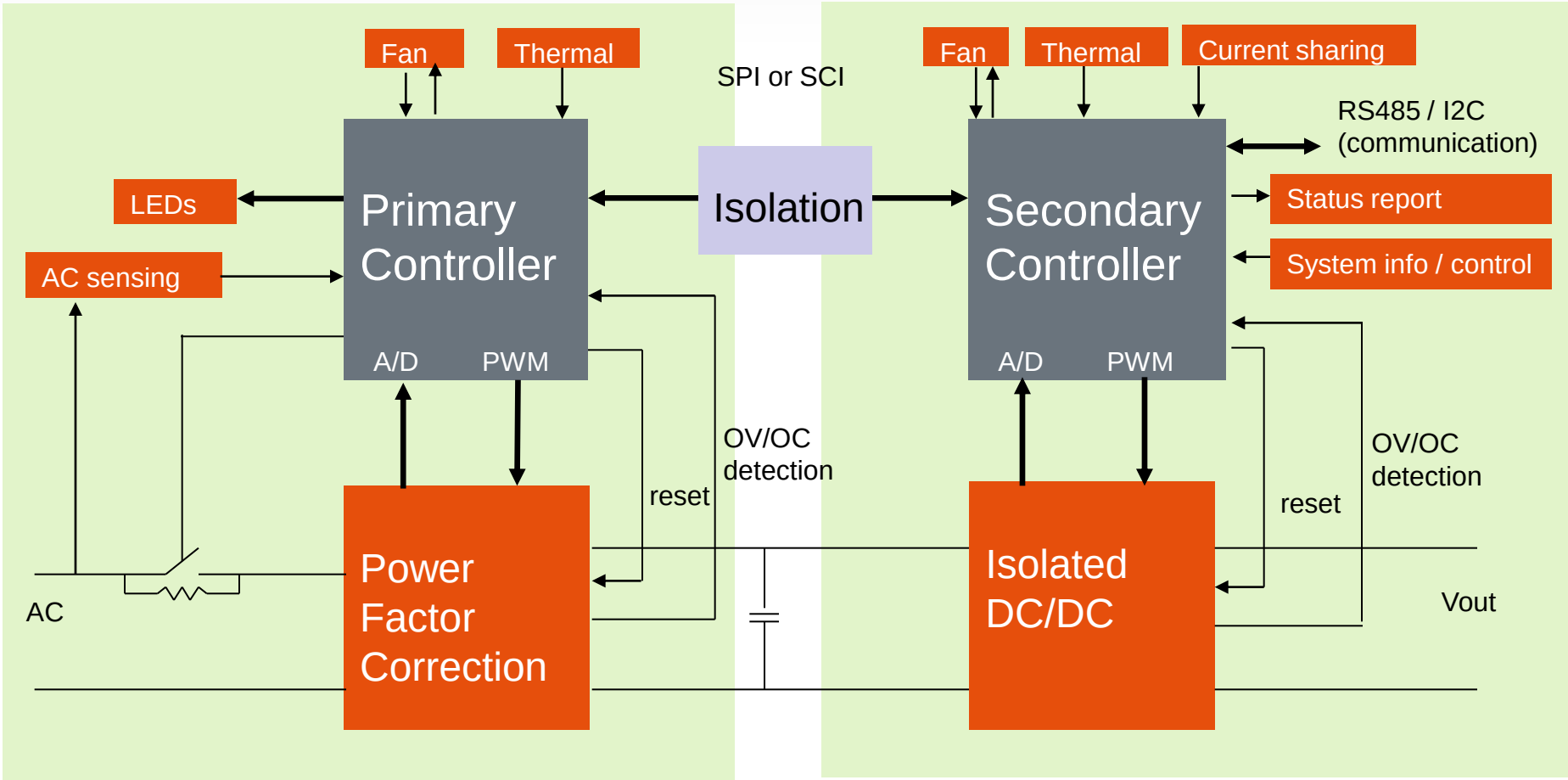
CodeWarrior™ Release 10.2 for 56800/E

- **Comprehensive, scalable application development environment allows concurrent approach to hardware, software and system level engineering to minimize time-to-market.**
  - CodeWarrior™ Development Studio incl. C compiler, assembler, linker, debugger
  - Eclipse-based
  - Stand alone Flash programming software
  - Processor Expert™ rapid application development (RAD) tool

Reference Designs & Application Notes

Implementing a Digital AC/DC Switched-Mode Power Supply using a 56F8300 Digital Signal Controller	AN3115
Design of a Digital AC/DC SMPS using the 56F8323 Device	DRM074
Design of Indirect Power Factor Correction Using DSP56F80X	AN1919
Design of Indirect Power factor Correction Using the 56F800/E	AN1965
Implementing a Digital AC/DC Switched-Mode Power Supply using a 56F8300 Digital Signal Controller	AN3115
Online UPS using the 56F8300	DRM069
Design of a Digital AC/DC SMPS using the 56F8323 Device	DRM074
Direct PFC Using the MC56F8013	DRM098
Solar panel Inverter using MC56F8023	*Coming soon*
LLC Resonant AC/DC Switched-Mode Power Supply using the MC56F8013 and MC56F8257	*DRM119*

Typical Digital Control Topology of SMPS



AC to DC SMPS Demo #1

Target Devices/Platforms:

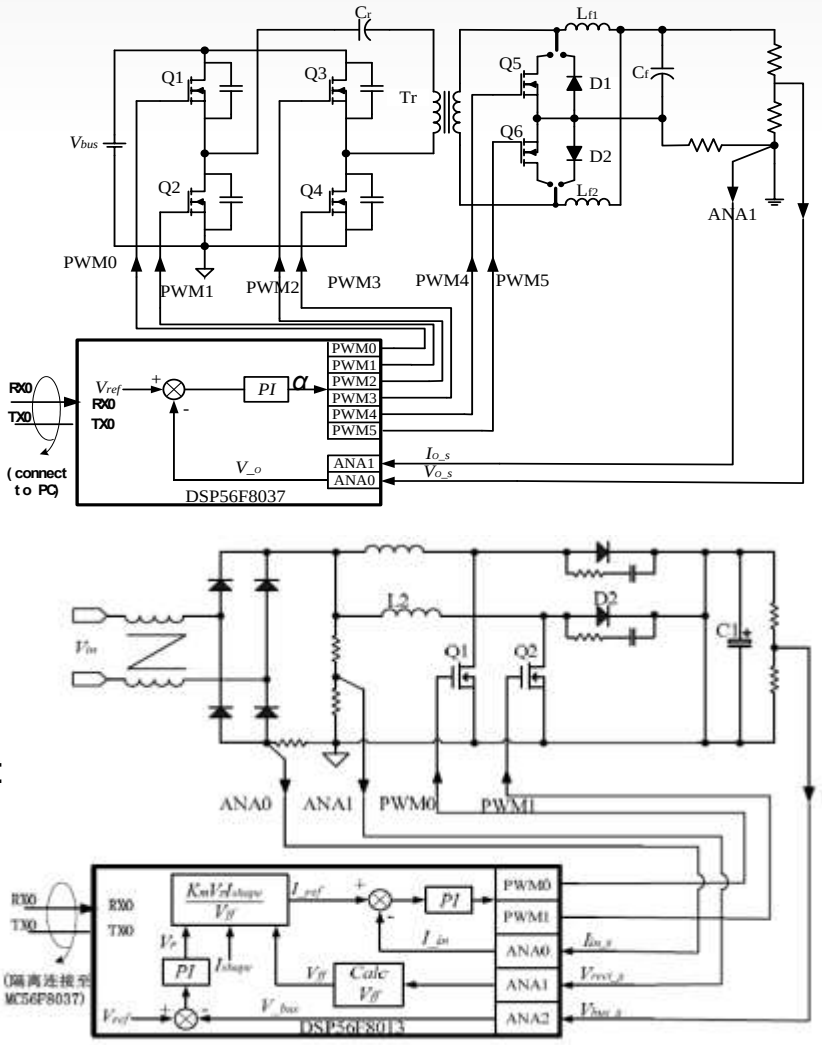
- Switch Mode Power Supply
- DSC:
  - MC56F80xx Family

Applications Usage:

- As DEMO application for AC/DC conversion
- Communication power supply
- Server power supply
- Digital power supply

Application Features:

- Specification and Performance of PFC converter:
  - Input voltage：**85 ~265*VAC*** ;
  - Input frequency：**45 ~65*HZ*** ;
  - Rating output voltage : **380V** ;
  - Rating output power：**500W** ;
  - Power factor > **99%**
  - Efficiency > **90%**
- Specification and Performance of DC/DC converter:
  - Input voltage：**360~380*VDC*** *(*Output by PFC) ;
  - Output voltage：**48*V*** ,
  - Precision **: 3%**,ripple **: 500mV** ;
  - Output current：**10A** ;
  - Switch frequency：**150K** ;
  - Efficiency > **90%**



AC to DC SMPS Demo #2

Target Devices/Platforms:

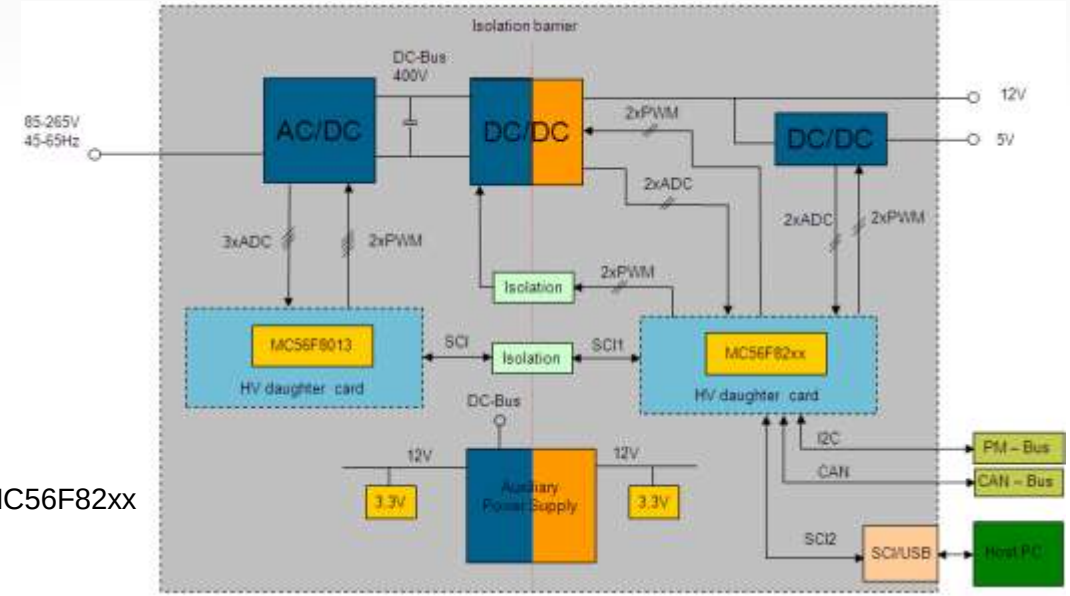
- Switch Mode Power Supply
- DSC:
  - MC56F80xx Family
  - MC56F82xx Family

Applications Usage:

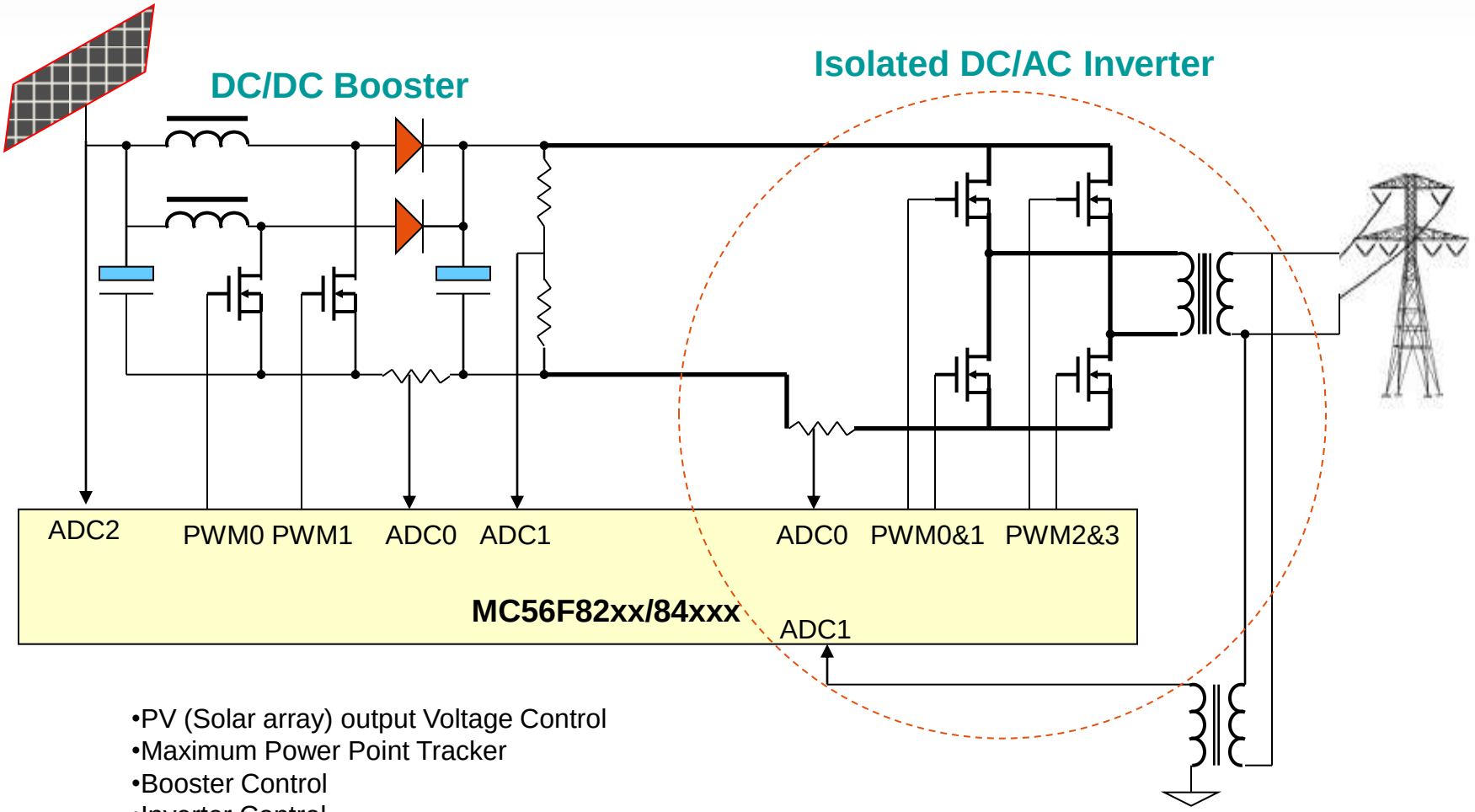
- As DEMO application for AC/DC conversion
- Communication power supply
- Server power supply
- Digital power supply

Application Features:

- General:
  - 1-phase 500W SMPS with MC56F8013 and MC56F82xx
- Input:
  - 45-65 Hz Operating Frequency Range
  - 85V - 265V Operating Voltage Range
  - Power factor at input > 0.9
  - Conversion efficiency > 90%
  - Total Harmonic Distortion < 10%
- Output:
  - Output voltage 12V/41A
  - Output voltage 5V/25A
- Communications:
  - serial communication (SCI) between controllers with opto-isolation
  - serial communication (SCI) of sec. side controller(MC56F82xx) with host PC with opto-isolation
  - serial communication (IIC) of sec. side controller(MC56F82xx) via PM Bus

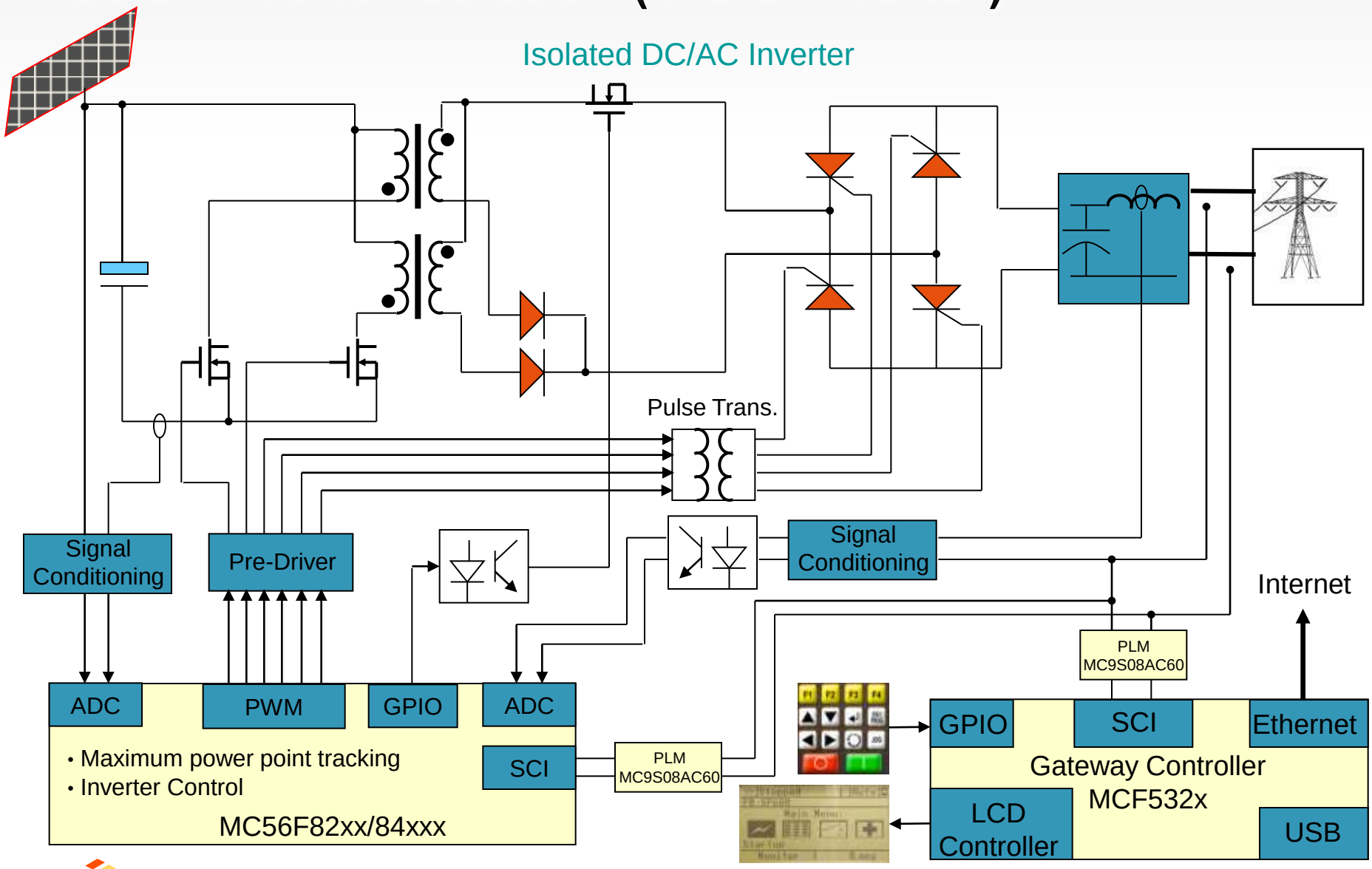


Grid-Tied Solar Generator-Low Power (Less Than 3KW)



- PV (Solar array) output Voltage Control
- Maximum Power Point Tracker
- Booster Control
- Inverter Control

Solar Inverter Solution (Micro inverter)



Solar Panel Inverter Demo

Target Devices/Platforms:

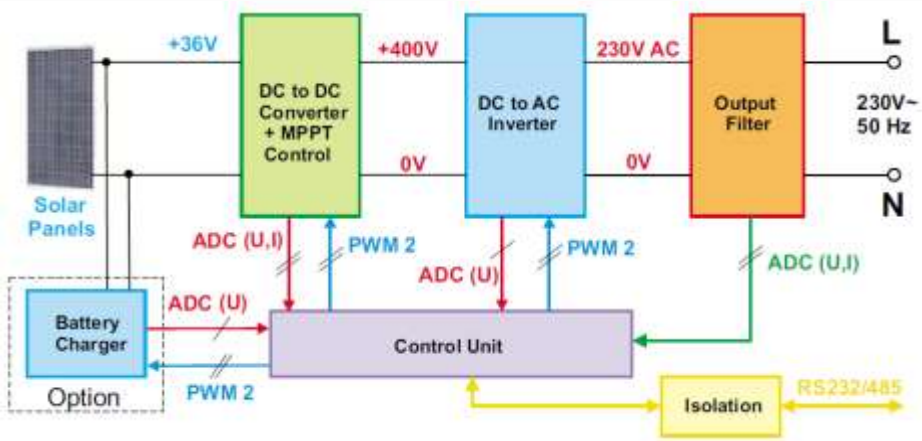
- DSC controlled DC to AC Inverter with MC56F8025

Applications Usage:

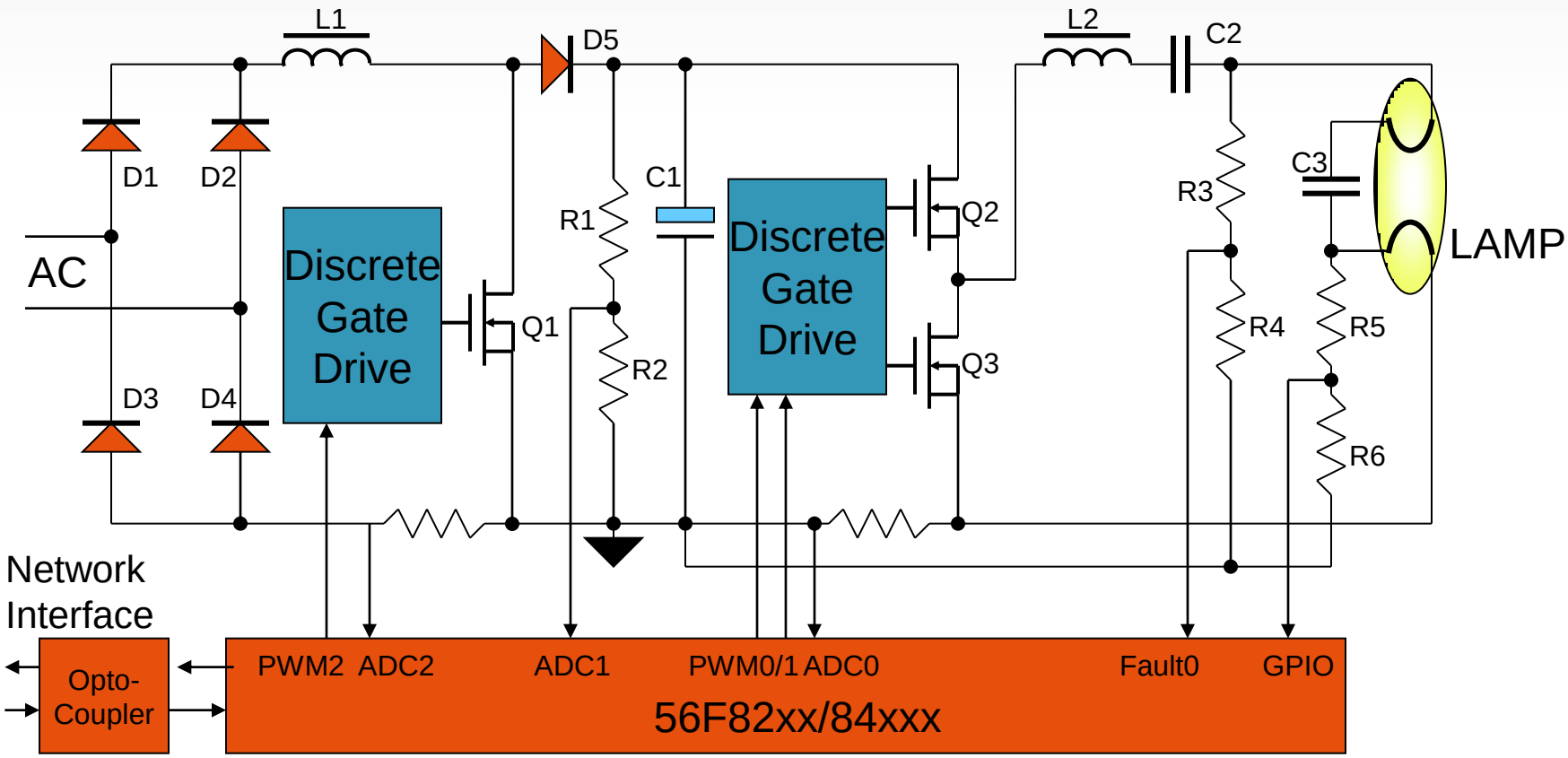
- As DEMO application for the solar energy to power line conversion
- Small power line source for home usage
- Functions as UPS when battery connected

Application Features:

- DC to AC Inverter for solar panel is DSC controlled inverter with battery charger option
- Nominal input voltage is 36V – it represents one 36V panel, or two 18V panels in series, or three lead-acid batteries in series – each of 12V
- Output power is max 400VA / 230V AC / 50Hz
- Can work as grid connected or no
- The MPPT algorithm is implemented to maximize output power from the solar panel
- High frequency power transformer is used to maintain isolation between solar panels and grid connected power line
- The switching frequency is up to 50kHz
- The DC-DC up-converter and full bridge topology is used for the AC voltage generation
- Fault protection implemented – over-current, short-circuit and input under-voltage
- Isolated serial link RS-485 used for connection to whole system



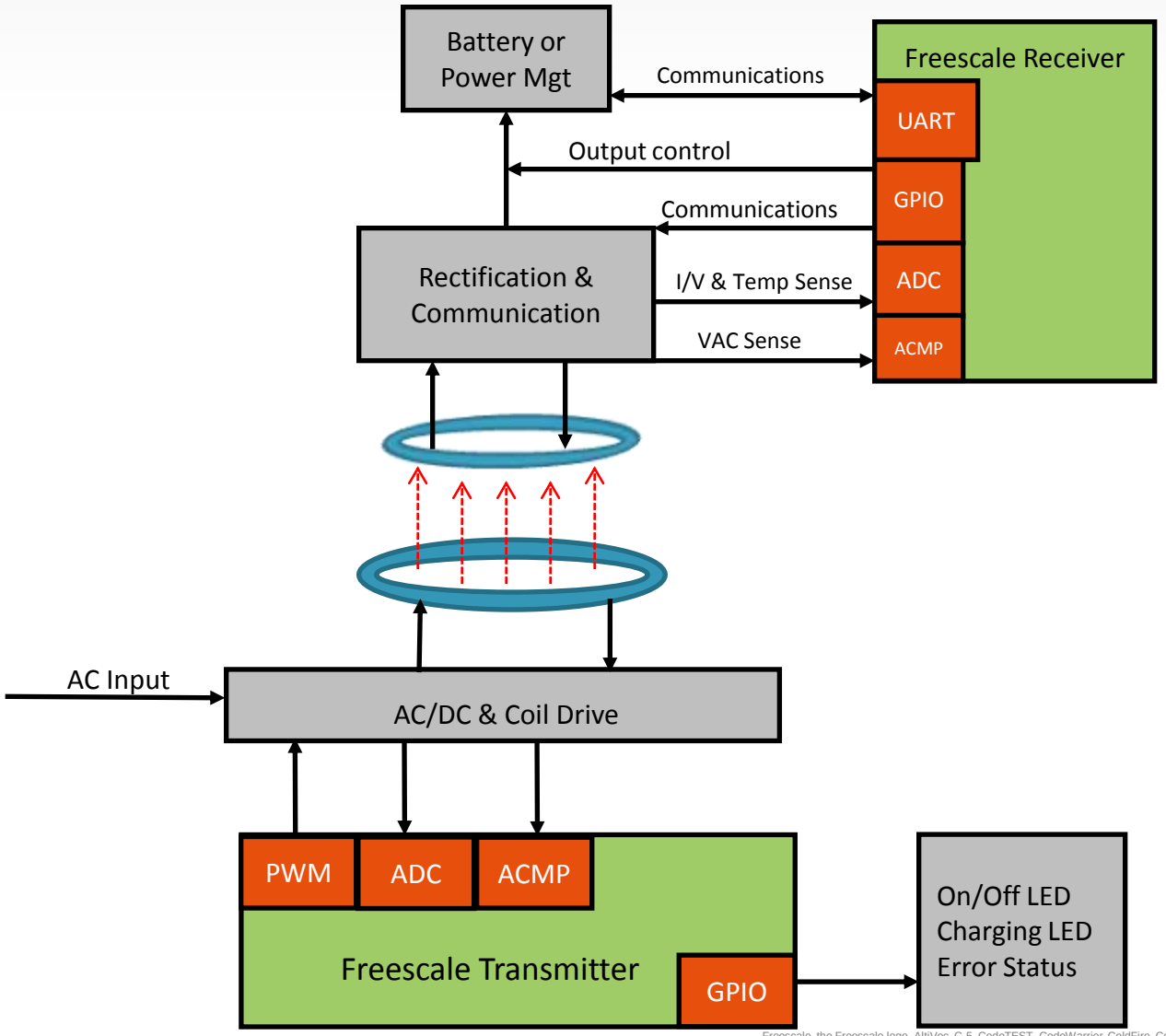
Digital Dimming Ballast Application Example



Feature

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

Wireless Charging Application Example



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