

# Digital Power Supply Design Overview

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SECURE CONNECTIONS  
FOR A SMARTER WORLD

# Agenda

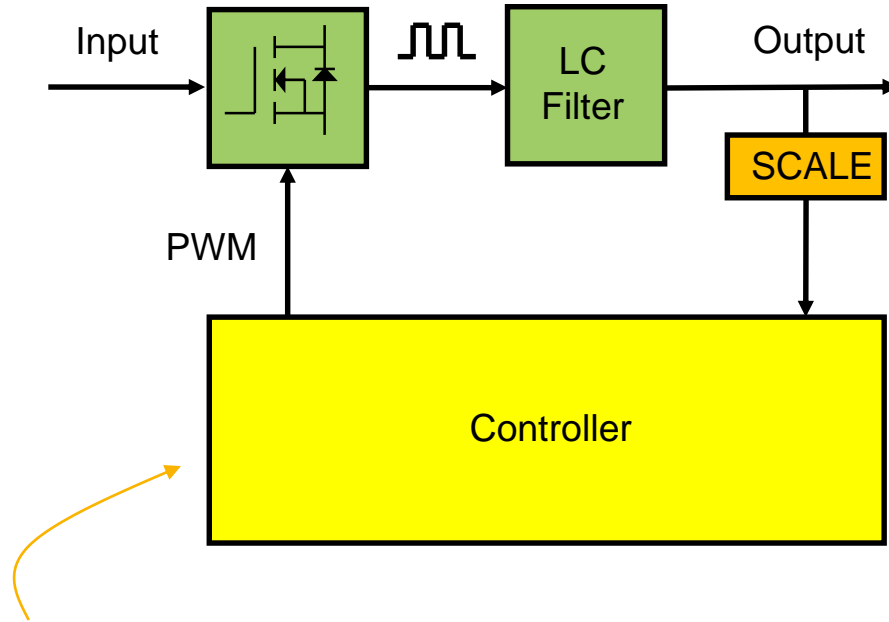
- ▶ What is Digital Power Supply
- ▶ Why Digital Control Techniques
- ▶ CPU and Peripherals Used for Digital Power Supply
- ▶ Design a Digitally Controlled Server Power Supply
- ▶ Reference Design
- ▶ Digital Signal Controller & Kinetis V





## What is Digital Power Supply

# 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



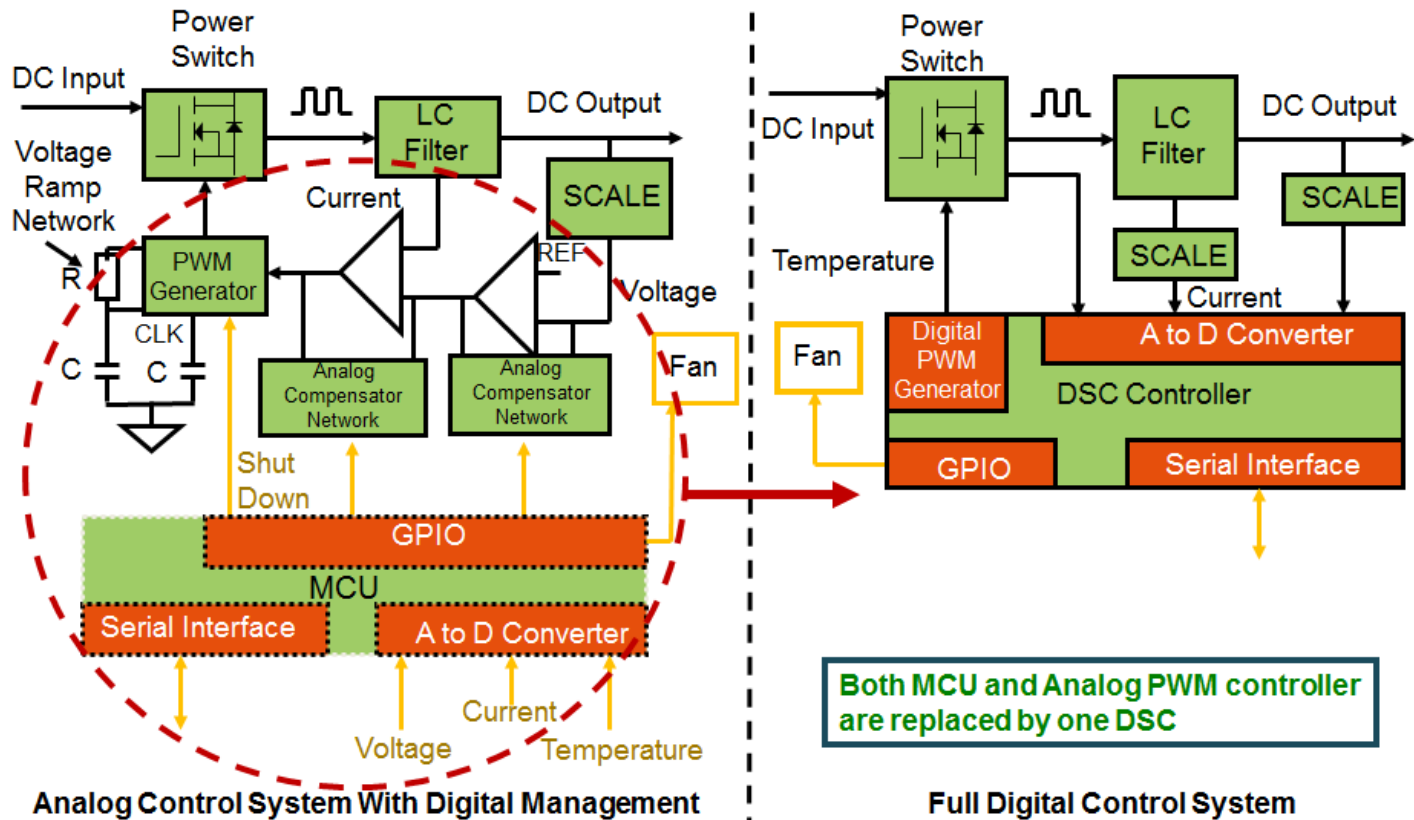
## Digital Power Management

A digital circuit or programmable controller provides the functions of

- configuration,
- diagnosis,
- monitoring ,
- protection,
- supply sequencing, and
- communication

with the environment.

# Analog vs. Digital Power Control System





# Why Digital Control Techniques

# The Trends of Power Supply Technology

## ▶ High Efficiency

- Meet Energy Star, 80 plus specifications ([www.plugloadsolutions.com/80PlusPowerSupplies.aspx](http://www.plugloadsolutions.com/80PlusPowerSupplies.aspx))
- High efficient from light load to full rated load range

## ▶ 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
- Power management and communication

## ▶ High Reliability

- Less components usage
- System monitoring and protection

## ▶ Quiet Operation

- Low harmonics, radiated and conducted EMI

## ▶ Innovative Power Distribution

## ▶ Low Cost





# The Challenges of Power Supply Design



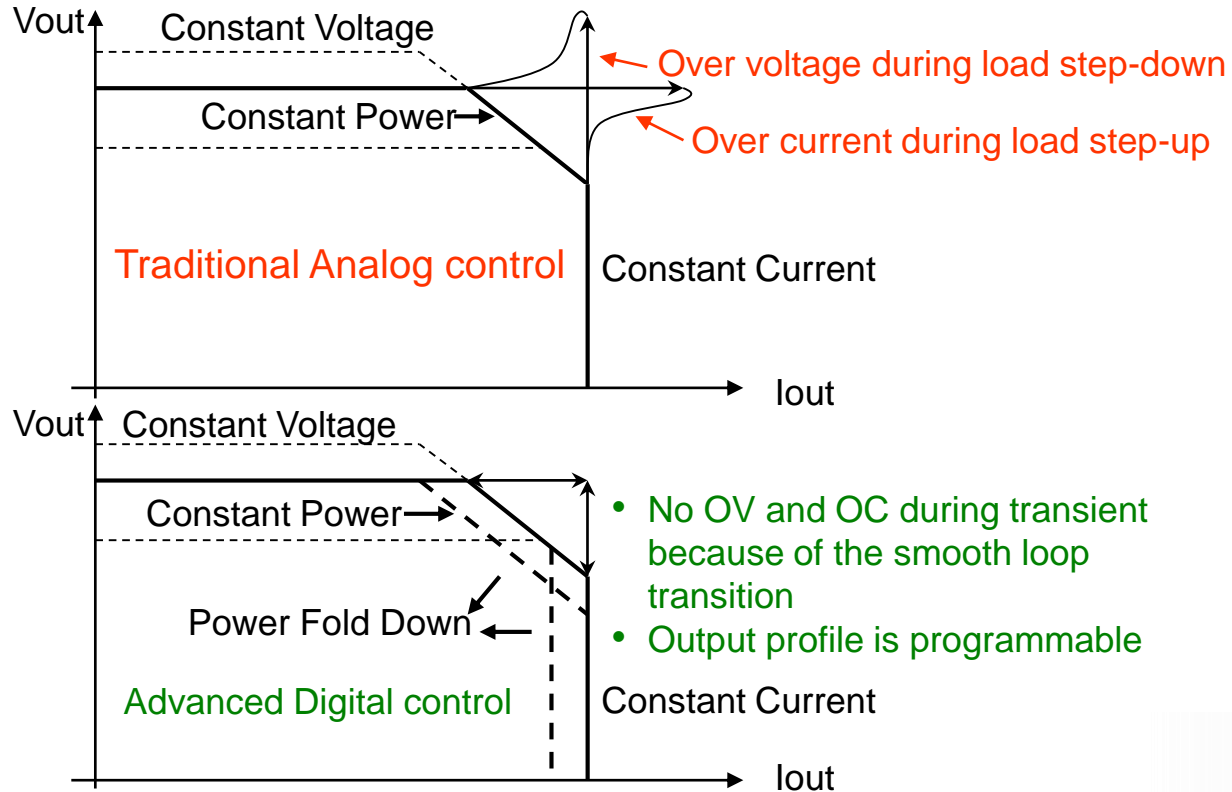
# Benefits of Digital Controlled Power Supply

- ▶ Eliminate the effects of component tolerance, parametric drift, aging, etc
- ▶ Configurable feedback loop structure for specific application requirements
- ▶ 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
- ▶ IP protection and technology differentiation

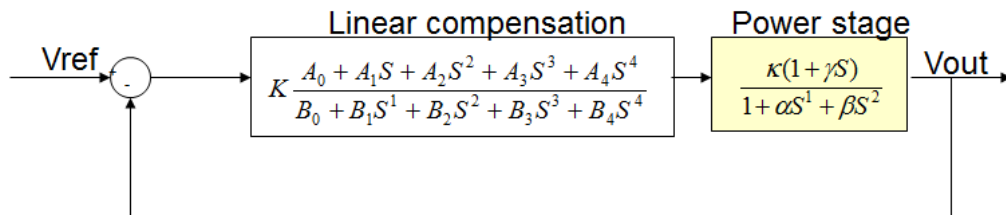


# Analog Control vs. Digital Control

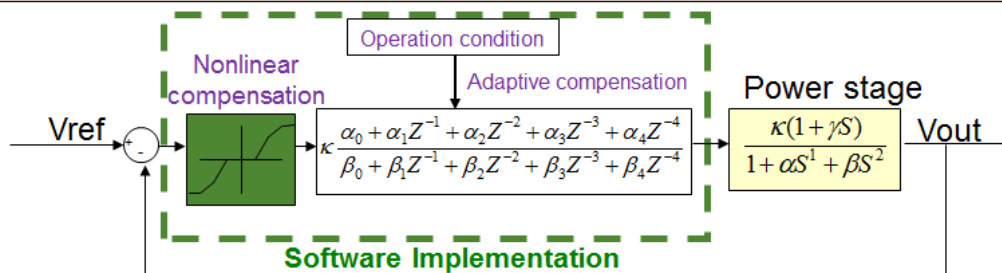
## - Transient Response Comparison



# Analog vs. Digital Control Algorithm



A typical control loop implemented by an analog circuit

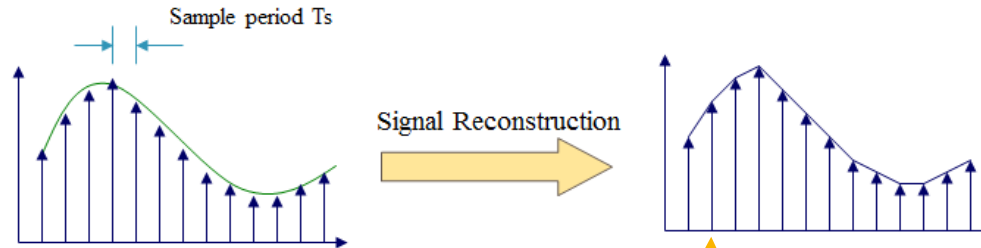
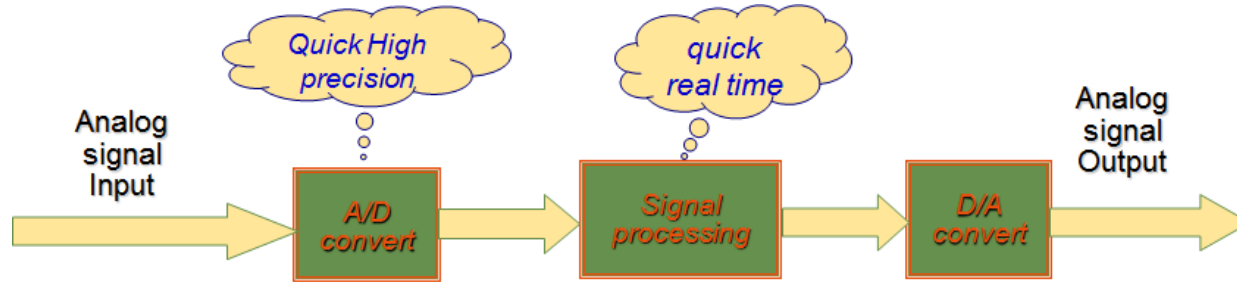


A digital control loop implemented by Digital Signal Controller

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 Control System



**Processing delay and quantization effect reduce system precision and performance**

# Analog vs. Digital Power Control System Checklist

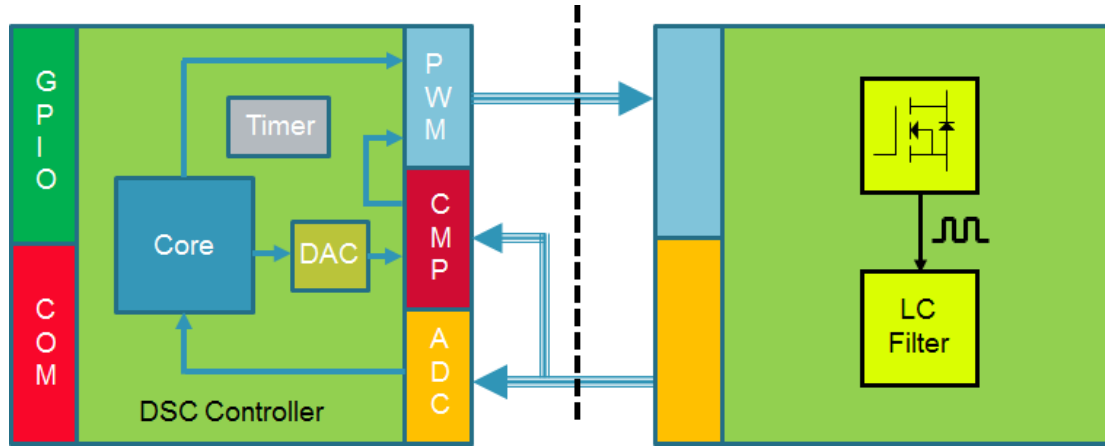
|                          | Analog Control | Digital Control                  |
|--------------------------|----------------|----------------------------------|
| <b>Control Circuit</b>   | Complex, Bulky | Simple, Programmable, Integrated |
| <b>IP Protection</b>     | Bad            | Good                             |
| <b>System Record</b>     | Bad            | Good                             |
| <b>Flexibility</b>       | Bad            | Good                             |
| <b>Reliability</b>       | Bad            | Good                             |
| <b>Design Continuity</b> | Bad            | Good                             |
| <b>Update</b>            | No             | Yes                              |
| <b>Sample Mode</b>       | Continuous     | Discrete                         |
| <b>Processing</b>        | Continuous     | Control Delay                    |





## CPU and Peripherals Used for Digital Power Supply Design

# Digital Controlled Power Supply System Mapping



01001000100001  
10100100010000  
10110101010110





# 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

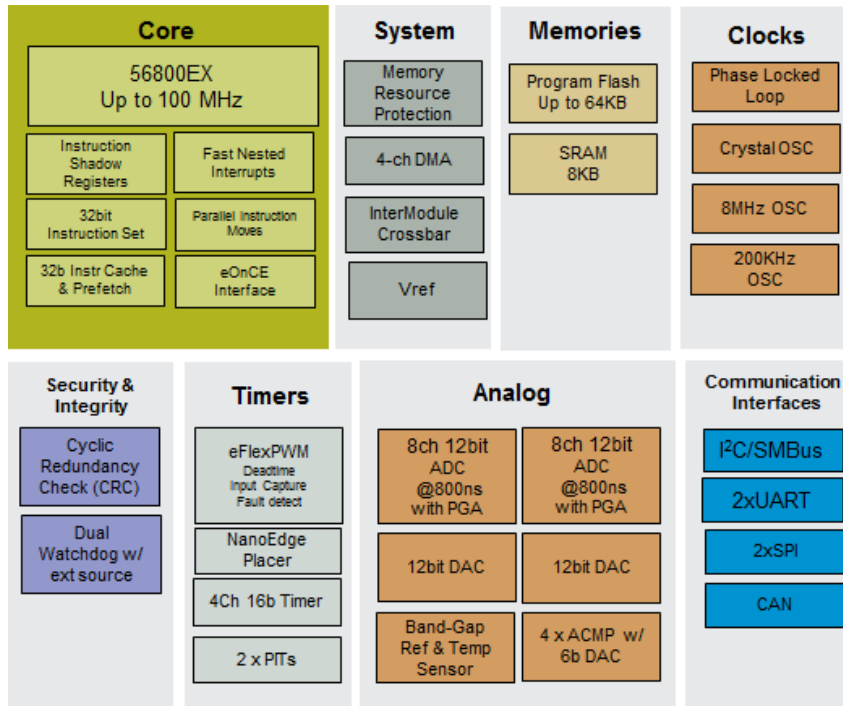
- eFlexPWM – Freescale's most advance timer for Digital Power Conversion, up to 8ch and 312 pico-sec resolution, 4 independent time bases, with half cycle reloads for increased flexibility, automatic complimentary mode for ease of use and best in class performance

### 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



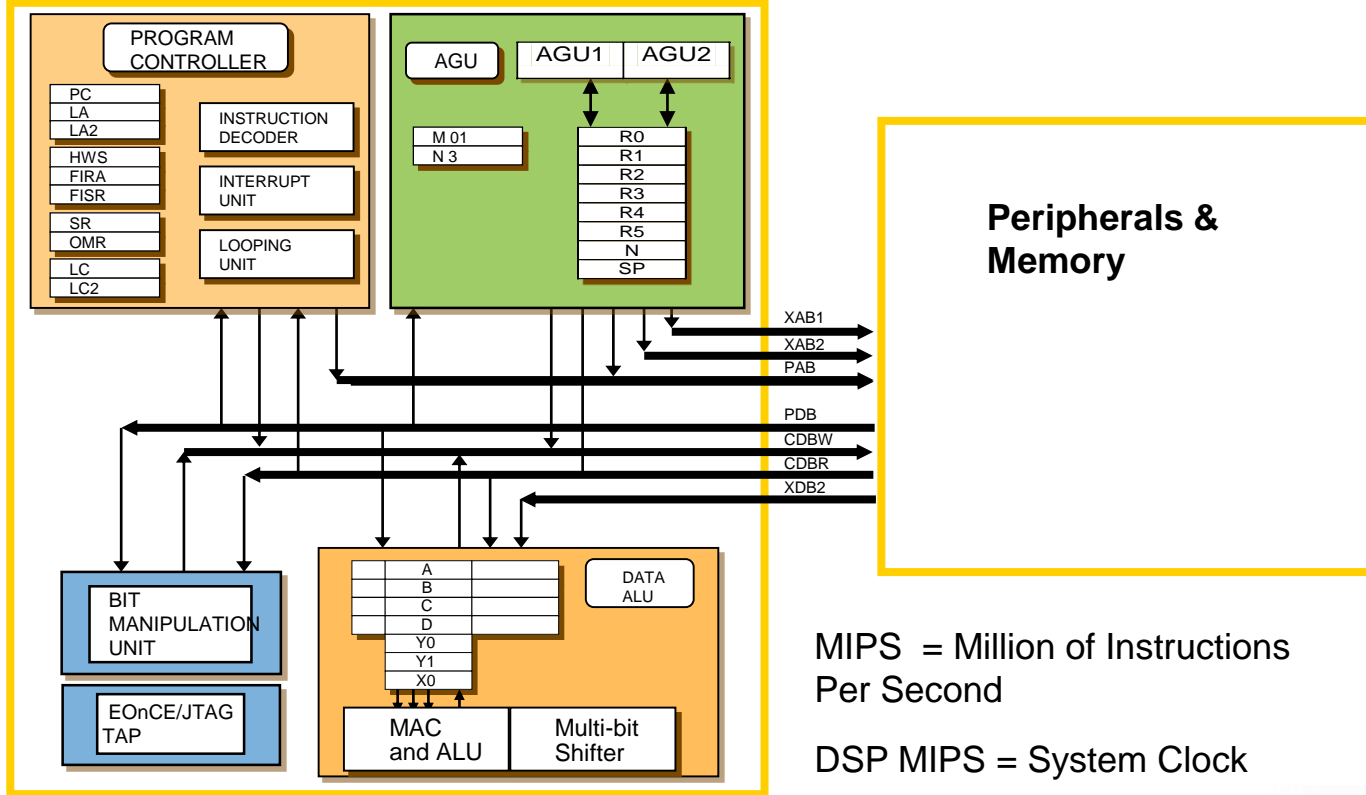
**Others:** 5-volt tolerant I/O for cost-effective board design

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

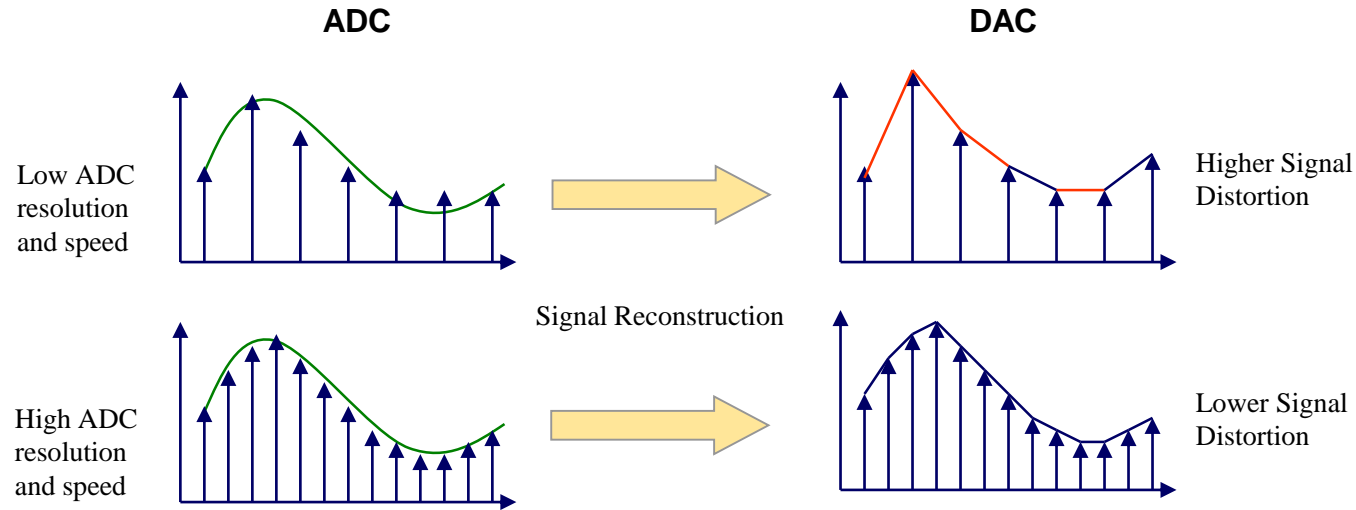
**Temperature:** -40 to +105C across all packages, with -40 to +125C option on 64LQFP



# Efficient and Powerful 56800EX Core

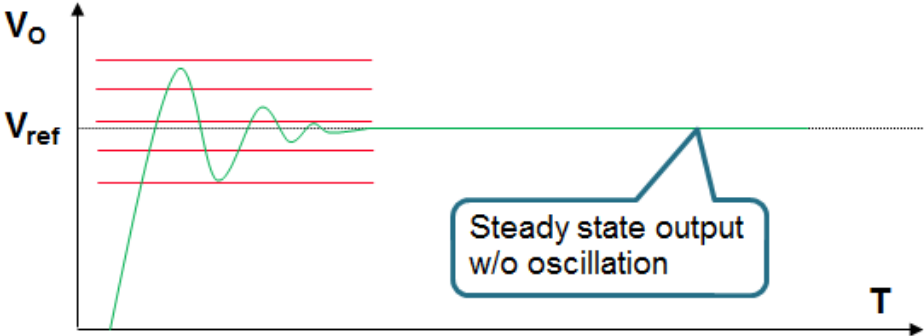
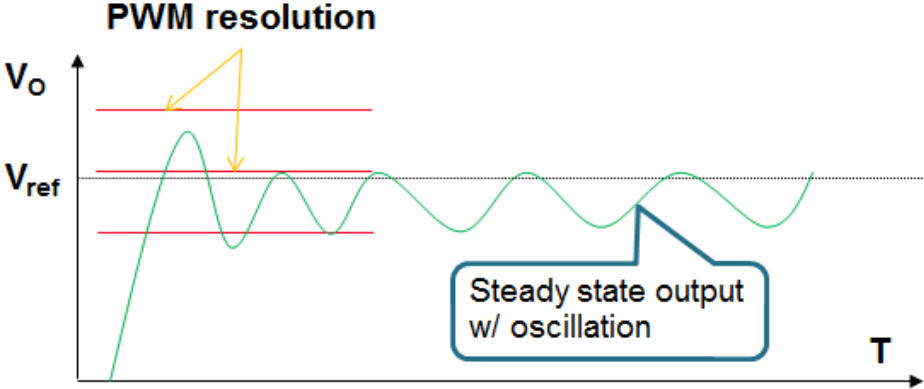


# ADC Requirements



Real-time loop control requires high speed ADC to improve loop performance, high output precision requires high resolution ADC conversion. It's recommended that total ADC conversion time is less than 10% control loop execution time.

# PWM Resolution Requirements

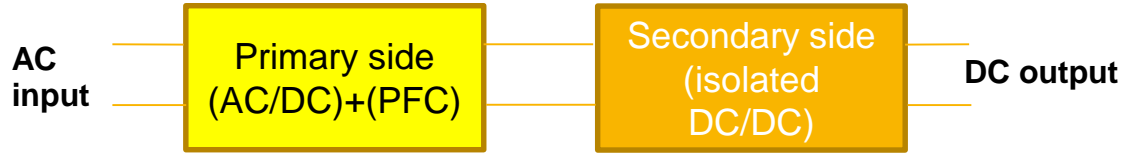




Reference Design



# Popular Server Power Supply Topology



- ❖ Two controllers are required for primary side and secondary side control respectively
- ❖ Two-channel interleaved PFC for primary side
- ❖ Phase-shifted full-bridge or LLC resonant for secondary side

# Totem pole bridgeless PFC Power topology

## Target Devices/Platforms:

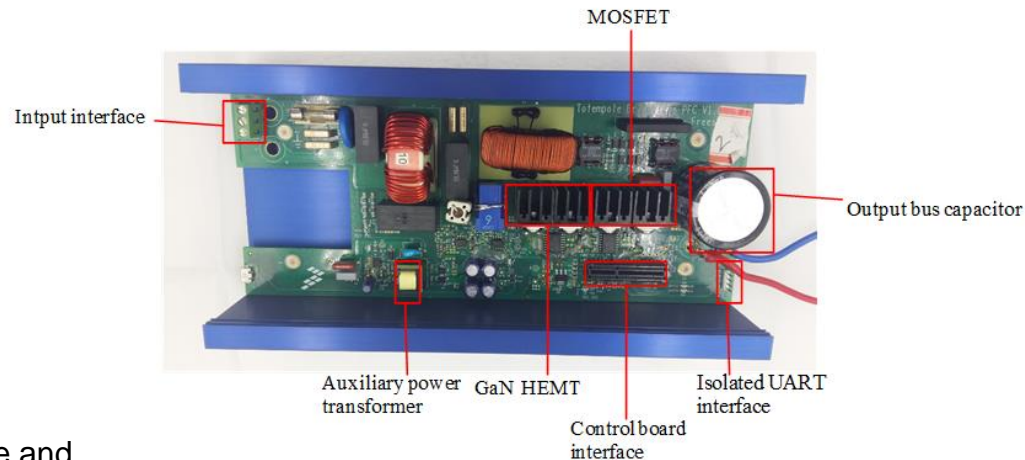
- ❑ MC56F82748

## Applications Usage:

- ❑ Digital AC/DC power supply

## Application Features:

- ❑ 600W output
- ❑ Output DC voltage: 380Vdc.
- ❑ Input AC voltage: 90~265Vac, 45~63Hz
- ❑ PF: full load > 0.99.
- ❑ Isolated SCI communication between primary side and secondary side; Efficiency 96%~98%.
- ❑ iTHD < 5%
- ❑ Isolated USB interface for FreeMASTER connection



## Availability:

- ❑ Less internal boards
- ❑ Demo is ready
- ❑ DRM174 available on web

# LLC Resonant Converter with Sync Rectifier Solution

## Target Devices/Platforms:

- ❑ MC56F82748

## Applications Usage:

- ❑ Digital AC/DC power supply

## Application Features:

- ❑ 12V/240W output with universal mains input
- ❑ Half-bridge LLC with synchronous rectifier
- ❑ Modular software and hardware design for convenient internal reuse and customer evaluation
- ❑ Flash updating
- ❑ Isolated USB interface for FreeMASTER connection
- ❑ Isolated SCI communication between primary side and secondary side; IIC interface is reserved for PMBus communication.
- ❑ 120mVp-p output ripple; Overshoot < 5% @ 0 to 65% load step; Hold up time 20ms @ 50% load, 15ms @ 100% load.
- ❑ Over-current, over-/under-voltage, voltage brown-in, over-temperature, power limit protection functions



## Availability:

- ❑ Less internal boards
- ❑ Demo is ready
- ❑ DRM172 available on web



# HVP-MC3PH: High-Voltage Development Platform

- Main board (power stage) Input voltage 85-240V AC, 110-390VDC
- **Output power 1kW without PFC, 0.8kW with PFC**
- Output current 8A peak
- Analog sensing (input voltage, DCB voltage, DCB current, phase currents, back-EMF voltage, PFC currents, IGBT module temperature monitoring)
- Motor speed/position sensors interface (Encoder, Hall, Tacho generator)
- Over voltage comparator with DC-brake resistor interface
- Current inrush circuit
- Hardware over-current fault protection



| Part number   | Features   |
|---------------|--|
| HVP-MC3PH     | HVP-MC3PH High-Voltage Development Platform which includes the HVP-KV46F150M Controller Card |
| HVP-KV46F150M | KV46 150MHz ARM Cortex-M4 MCU  |
| HVP-KV31F120M | KV31 120MHz ARM Cortex-M4 MCU  |
| HVP-KV10Z32   | KV10 75MHz ARM Cortex-M0+ MCU  |
| HVP-56F82748  | MC56F82748 Digital Signal Controller (DSC) Controller Card, optional                         |



Digital Signal Controller & Kinetis V



# 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

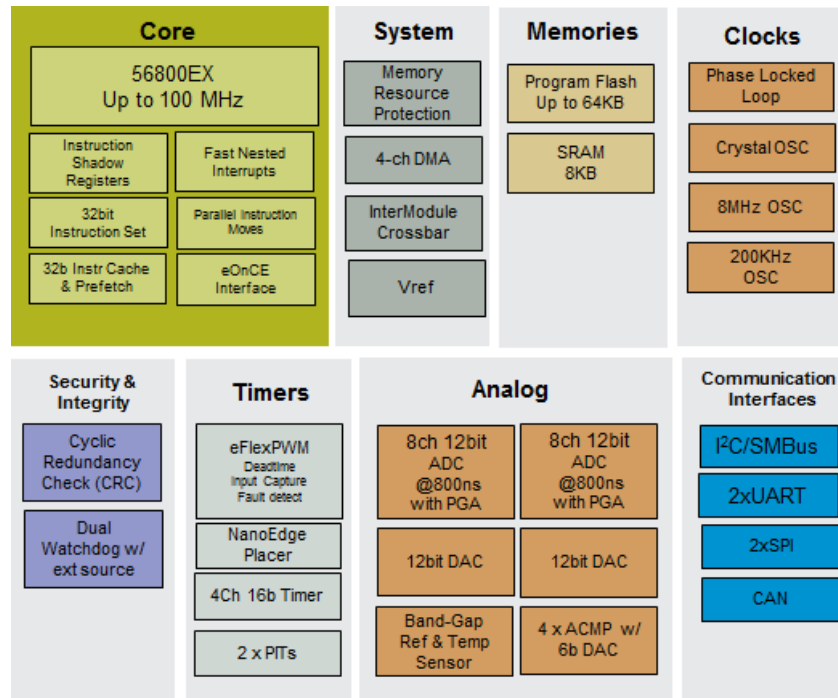
- eFlexPWM – Freescale's most advanced timer for Digital Power Conversion, up to 8ch and 312 pico-sec resolution, 4 independent time bases, with half cycle reloads for increased flexibility, automatic complimentary mode for ease of use and best in class performance

### 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

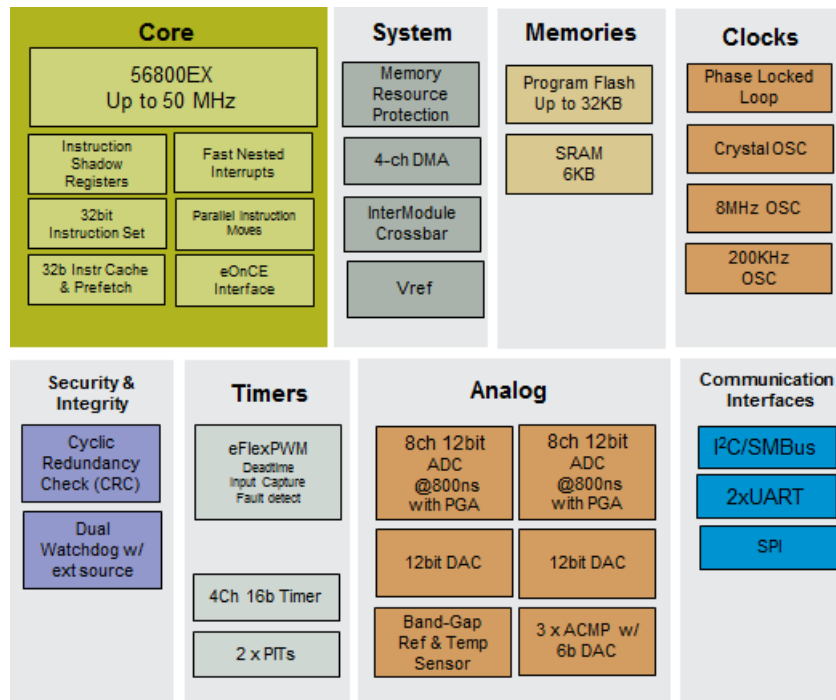
- eFlexPWM – Freescale's most advanced timer for Digital Power Conversion, up to 8ch, 4 independent time bases, with half cycle reloads for increased flexibility, automatic complimentary mode for ease of use and best in class performance

### 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

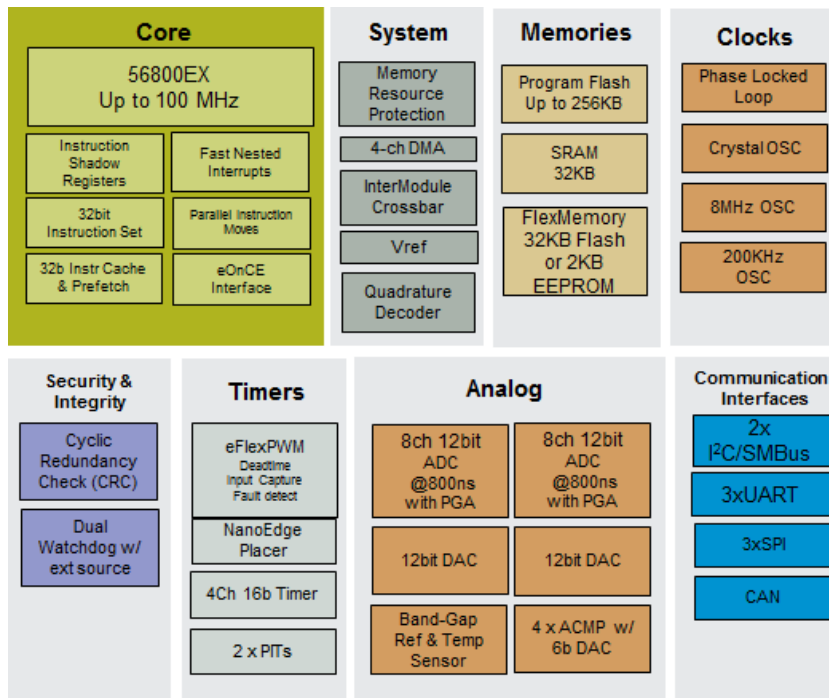
- Inter-module crossbar directly connecting any input and/or output with flexibility for additional logic functions (AND/OR/XOR/NOR)
- DMA controller for reduced core intervention when shifting data from peripherals
- Memory resource protection unit to ease safety certification

### 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 300ns 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



# Kinetis V Series KV4x

## Core/System

- 150MHz Cortex-M4+ with 16ch DMA
- Floating Point Unit

## Memory

- 64/128/256KB Flash @ 128bits wide w/ 128Byte cache
- 16/24/32KB SRAM
- Bootloader

## Communications

- Multiple serial ports
- Up to 2 x CAN

## Analog

- 2 x 8ch 12-bit ADC
  - Sampling at up to 4.1MS/s (240ns)
  - PGA x1, x2, x4
- 12-bit DAC
- 4 x ACMP with 6-bit DAC

## Timers

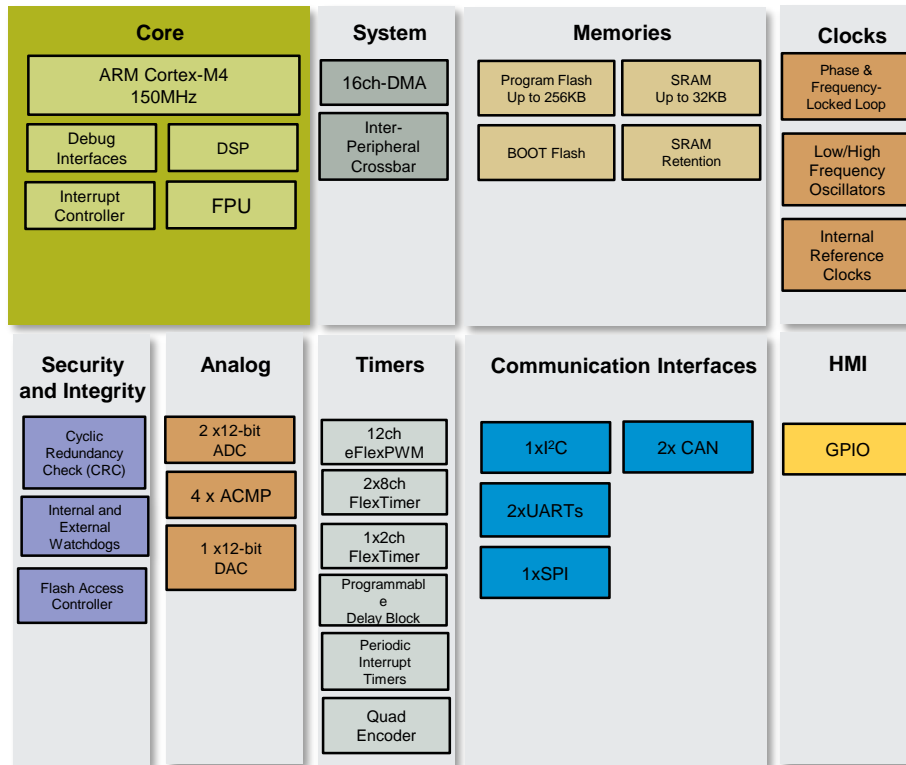
- Up to 12ch eFlexPWM
  - Up to 312ps PWM Resolution (\*)
- 2x8ch + 1x2ch FlexTimer (PWM)
- Quadrature Encoder
- 2 x Programmable Delay Blocks

## Other

- 32-bit CRC
- Inter-Peripheral Crossbar with AND/OR interface
- Up to 56 I/Os
- 1.71V-3.6V; -40 to 105oC

## Packages

- 64 LQFP & 100LQFP



# Kinetis V Series KV5x Family: 1M Flash – 200MHz

## Key Features:

### Core/System

- **200MHz Cortex-M4** with 32ch DMA
  - Floating Point Unit

### Memory

- **1MB Flash**, 128bits wide, 128Byte cache
- **256KB SRAM**
- Boot Flash

### Communications

- Multiple serial ports, **USB**
- 3 x CAN

### Analog

- 2 x 8ch 12-bit ADC
  - Sampling at up to 4.1MS/s (240ns)
  - PGA x1, x2, x4
- 1 x12-bit DAC
- 4 x ACMP w/ 6b DAC

### Timers

- 12ch eFlexPWM
  - 312ps PWM and PFM Resolution
- 2x8ch FlexTimer (PWM)
- 1x2ch FlexTimer (PWM)
- Quadrature Encoder
- 2 x Programmable Delay Blocks

### Others

- 32-bit CRC
- Inter-module Crossbar Switch with AOI
- Memory Protection Unit
- 1.71V-3.6V; -40 to 105oC

### Packages

100LQFP & 144MAPBGA

Pin to Pin compatible with Kinetis K & KV series

