Digital Power Supply Design Overview

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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
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

Both MCU and Analog PWM controller are replaced by one DSC
Why Digital Control Techniques
The Trends of Power Supply Technology

- **High Efficiency**
  - 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

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Increased performance and cost pressures</strong></td>
<td>Pressure to increase performance while reducing cost to meet customer demands</td>
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<tr>
<td><strong>System complexity</strong></td>
<td>On the rise with the need for more features and functionality in smaller form factors</td>
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<tr>
<td><strong>Time to market constraints</strong></td>
<td>Increasingly complex development environments and design cycle time-frames that are constantly shrinking</td>
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<tr>
<td><strong>Scalable &amp; Compatible</strong></td>
<td>Easy migration from existing 8Bit product with common core, IP and tools</td>
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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 overall 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

Traditional Analog control
- Over voltage during load step-down
- Over current during load step-up

Advanced Digital control
- No OV and OC during transient because of the smooth loop transition
- Output profile is programmable
Analog vs. Digital Control Algorithm

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

<table>
<thead>
<tr>
<th></th>
<th>Analog Control</th>
<th>Digital Control</th>
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<tbody>
<tr>
<td><strong>Control Circuit</strong></td>
<td>Complex, Bulky</td>
<td>Simple, Programmable, Integrated</td>
</tr>
<tr>
<td><strong>IP Protection</strong></td>
<td>Bad</td>
<td>Good</td>
</tr>
<tr>
<td><strong>System Record</strong></td>
<td>Bad</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Flexibility</strong></td>
<td>Bad</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>Bad</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Design Continuity</strong></td>
<td>Bad</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Update</strong></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Sample Mode</strong></td>
<td>Continuous</td>
<td>Discrete</td>
</tr>
<tr>
<td><strong>Processing</strong></td>
<td>Continuous</td>
<td>Control Delay</td>
</tr>
</tbody>
</table>
CPU and Peripherals Used for Digital Power Supply Design
Digital Controlled Power Supply System Mapping

01001000100001
10100100010000
10110101010110

01001000100001
10100100010000
10110101010110

DSC Controller

Core

DAC

PWM

CMP

ADC

Timer

LC Filter
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

Peripherals & Memory

MIPS = Million of Instructions Per Second
DSP MIPS = System Clock
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

![PWM resolution graph with steady state output with and without oscillation](image.png)
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

<table>
<thead>
<tr>
<th>Part number</th>
<th>Features</th>
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<tbody>
<tr>
<td>HVP-MC3PH</td>
<td>HVP-MC3PH High-Voltage Development Platform which includes the HVP-KV46F150M Controller Card</td>
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<tr>
<td>HVP-KV46F150M</td>
<td>KV46 150MHz ARM Cortex-M4 MCU</td>
</tr>
<tr>
<td>HVP-KV31F120M</td>
<td>KV31 120MHz ARM Cortex-M4 MCU</td>
</tr>
<tr>
<td>HVP-KV10Z32</td>
<td>KV10 75MHz ARM Cortex-M0+ MCU</td>
</tr>
<tr>
<td>HVP-56F82748</td>
<td>MC56F82748 Digital Signal Controller (DSC) Controller Card, optional</td>
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</tbody>
</table>
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 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, 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 +105°C 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 +105°C 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 105°C

Packages
100LQFP & 144MAPBGA
Pin to Pin compatible with Kinetis K & KV series