Introduction to Digital Power

Presenter: Dennis Barrett
Marketing Manager
High Performance Controllers

Additional Material Authors: Hrishikesh Nene
Vaibhav Desai
Digital Power Benefits

System-Level Integration
Integrated control hardware allows for fewer, smaller devices that perform more complex functions.

Higher System Efficiency
Sense line and load changes and intelligently varies the power stage operation to optimize efficiency in real time.

Greater Power Density / Faster Control Loops
Achieve faster operating frequencies and smaller components with dedicated power peripherals, feedback, and high resolution PWM control.

Broad Selection
From ASSPs to Programmable uC to DSPs for high-performance PFC, AC/DC, and isolated DC/DC power supplies.

Power Topology Flexibility
Precise waveform control no matter the topology with high resolution phase control, period control, and duty cycle control.

System-Level Reliability, Monitoring, and Safety
Optimize designs by collecting field power consumption data.
Digital Power Today: Mainstream Applications

**Telecom Infrastructure**
- Application Examples:
  - Isolated and Non-Isolated DC/DC Converters
  - Power Modules
  - Telecom Rectifiers
  - Wireless Basestation Power
  - Uninterruptable Power Supplies (UPS)
- Driving Requirements:
  - Power Density
  - Efficiency
  - High Frequency Operation
  - Advanced Housekeeping

**Server Power**
- Application Examples:
  - High End Computing
  - High End Storage
  - High End Networking
  - PC Power/Gaming
- Driving Requirements:
  - Regulatory standards
  - Power Quality (PF and THD)
  - Redundancy
  - Advanced Housekeeping

**Solar**
- Application Examples:
  - Solar Microinverters
  - String Inverters
  - Power Optimizers
  - PV Inverters
- Driving Requirements:
  - Efficiency
  - Complex MPPT
  - Extended Lifetime

**Automotive**
- Application Examples:
  - Bi-Directional DC/DC
  - Battery Chargers
  - Hybrid and EV Charging Stations
- Driving Requirements:
  - Communication
  - Reliability
  - Fault Reporting
“Like switch-mode regulation, digital control is not a limited technology. It has applications in embedded and external ac-dc power supplies, isolated and non-isolated dc-dc converters, telecom rectifiers, and lighting ballasts. Most importantly, digital has penetrated nearly all application segments, from high-performance computing to high-volume consumer products”

What is Digital Power?
Generic Power System Block Diagram

The controller block is what differentiates between a digital power system and a conventional analog power system.
An Example Switch-Mode Power Converter

- It’s a Discrete Control System
- It uses an Analog Controller
- The Controller Is a PWM Generator and Compensator
Analog Control System

\[ C(s) = \frac{R_2}{R_1} \left( \frac{1 + R_1 C_1 s}{1 + R_2 C_2 s} \right) \]

Need to find: \( R_1, R_2, C_1, C_2 \)

"Analog Computation" Differential equations

\[ \frac{d^3 y(t)}{dt^3} + k_2 \frac{d^2 y(t)}{dt^2} + k_1 \frac{dy(t)}{dt} + k_0 y(t) = f(t) \]

Differential equations 1\(^{st}\), 2\(^{nd}\), 3\(^{rd}\),...order

Laplace Transform
Digitally Controlled Switch-Mode Power Converter – “Digital Power”

Analog Controller is replaced with:
• A Digital Controller/MCU and
• Drivers and OpAmps (considered extra only in low-power, low-performance applications)

- Still a **discrete** control system
- PWM generator is now a peripheral module
- Compensator is now implemented via CPU executing S/W code
Digital Control System

Difference equation

\[ U(n) = a_2 \cdot U(n-2) + a_1 \cdot U(n-1) + b_2 \cdot E(n-2) + b_1 \cdot E(n-1) + b_0 \cdot E(n) \]

where \( E(n) = R(n) - Y(n) \)

Need to find: \( a_1, a_2, b_0, b_1, b_2 \)

Differential equations

\[ \frac{d^3 y(t)}{dt^3} + k_2 \frac{d^2 y(t)}{dt^2} + k_1 \frac{dy(t)}{dt} + k_0 y(t) = f(t) \]

Need to find: \( a_1, a_2, b_0, b_1, b_2 \)

Laplace Transform

Z Transform
Why Digital Control Techniques?

Controller
Analog or Digital ??

PWM

Sensor(s)

Power Elec.

<table>
<thead>
<tr>
<th>Analog Controller</th>
<th>Digital Controller</th>
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<tbody>
<tr>
<td>• High bandwidth</td>
<td>• Insensitive to environment (temp, drift,…)</td>
</tr>
<tr>
<td>• High resolution</td>
<td>• S/w programmable / flexible solution</td>
</tr>
<tr>
<td>• Well understood</td>
<td>• Precise / predictable behavior</td>
</tr>
<tr>
<td>• Historically lower cost</td>
<td>• Advanced control possible (non-linear, adaptive,…)</td>
</tr>
<tr>
<td>+</td>
<td>• Can perform multiple loops and “other” functions</td>
</tr>
<tr>
<td>• Component drift and aging / unstable</td>
<td>• Bandwidth limitations (sampling loop)</td>
</tr>
<tr>
<td>• Component tolerances</td>
<td>• PWM frequency and resolution limits</td>
</tr>
<tr>
<td>• Hardwired / not flexible</td>
<td>• Numerical problems (quantization, rounding,…)</td>
</tr>
<tr>
<td>• Limited to classical control theory only</td>
<td>• AD / DA boundary (resolution, speed, cost)</td>
</tr>
<tr>
<td>• Large parts count for complex systems</td>
<td>• CPU performance limitations</td>
</tr>
<tr>
<td>-</td>
<td>• Bias supplies, interface requirements</td>
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Benefits of Digital Control

### Traditional Analog Power Supply
- Multiple chips for control
- Micro-controller for supervisory
- Dedicated design

Digital controller enables multi-threaded applications

- Eliminate Components
- Reduce Manufacturing Cost
- Better Performance Across Corners
- One Design, Multiple Supplies
- Failure Prediction
- One Device, Multiple DC Outputs
- Variable DC Output
Different Digital Power Concepts and Controller Architectures

1. Closed Digitally implemented controllers sold same way as Analog controllers
   - Such as UCC28630 and UCC29950 controllers

2. Software managed, h/w implemented digital control
   - Without open MCU (typically a configuration GUI) – e.g. the UCC92xx family of digital POL controllers
   - With open MCU – e.g. TI UCD3xxx digital controllers

3. Fully software executed control
   - Typically requires cycle/cycle speed and parallel execution of DSP for control loops
   - Integrated Hardware for A/D, D/A, analog comparators – e.g. on C2000 MCUs
C2000™ Real-Time Microcontroller

Architecture and technology designed for real-time control applications
UCD Integrated Digital Power Controller

Enhanced EADC (DAC Accuracy) with Hardware Dithering (3x 16 MHz, 1mV resolution offers best in class current sharing accuracy)

Enhanced 2p / 2z Digital Compensator with Simplified PID Structure (for Improved Performance and Simplified Compensation)

DPWM
Hardware mapped shut-down due to faults
Fixed or adaptive sample trigger positioning
Sync FET soft on/off and Ideal Diode Emulation
Mode switching and Light Load Burst mode

Advanced Power Control
• Current Share
• CPCC
• Synchronization
• Primary side Vtg sensing
• Flex and Current Balancing

Protection:
- Highly configurable to initiate CBC w and w/o pulse matching or system shutdown.

ADC:
- 12 bit SAR
- Internal temp sensor
- Dual sample and hold
- Averaging
- Digital comparators
- PMBus addressing current sources

Flexibility:
- Digital Core enabling flexibility and manage housekeeping function.
- Support on-the-Fly firmware update without power supply interruption

Communications:
- Several communication peripherals providing flexibility for host communication.

Programmable Power Peripheral
- HS EADC x 3
- PID based Filter x 3
- HR DPWM x 8
- Advanced Power Control
- Fault Mux
- Analog Comparator x 7
- Digital Comparator x 4
- General Purpose ADC
- OSC
- GPIOx
- PMBus/I2C x2
- UART x2
- SPI
- Timer
- ADDR
- RAM
- Flash
- ARM7TDMI-S

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UCD3138 Power Topologies

UCD3138 family flexible architecture enabling multiple topology support not only limited to above topologies...
Maturity of Digital Power Controller no longer limit to the few...

Support
- E2E support
- Call an expert
- Onsite support
- Application Expertise

Application Kits
- Power Factor Correction
  - 400 Vin Phase Shifted Full-Bridge
  - 400 Vin Resonant LLC
  - 48 Vin Hard-Switching Full-Bridge

Training and Collaterals
- TI Designs
- Web Bench
- Trainings
- Collaterals

SW Development Platforms
- 80 pin Open Loop EVM
- 64 pin Open Loop EVM
- 40 pin Open Loop EVM

Software
- Application Demo Firmware
- Peripherals drivers
- Utilities

Tools
- Fusion Tools
- Simplify development with device agnostic GUI
  - Designer GUI
  - Manufacturing GUI
  - Fusion Designer API

Code Composer Studio
- Unified GUI to support
  - code development
  - Code debugging
  - Flashing

Integrated digital power controller
- UCD3138

Texas Instruments
Example 1: PFC + Power Monitoring Metering with UCD3138

Using existing PFC digital controller device and hardware, server customers are now eliminating traditional dedicated power metering chip and extra sensing circuit.

Results:
- Excellent accuracy (< 1% accuracy for Pin)
- Fast response time ~ 200 ms.
- Simple manufacturing Process: Simple calibration, only needs 2 points, can be AC or DC source
Example 2: On-the-Fly PSU Firmware Upgrade

Capability to Update Firmware <strong>without</strong> Shutting Down power supply

- Hardware Peripherals operate independent of μP and execute critical power supply functions

- 2X Memory Bank architecture supports program execution from one block, while simultaneously programming another block

- Processor bandwidth is freed up for:
  1. programming Block 2 with new firmware
  2. Staging and implementing a “Live Switch” of execution from Block 1 to 2
Example 3: LLC Intelligent Synchronous Rectification Improves Efficiency

- High efficiency: Minimal diode conduction
- Robust operation: Fast negative current protection
- Improved Reliability: Automatically compensate for component variations,
- Easy design: Reduce Development time with new SR Driver
Example 3: LLC Intelligent Synchronous Rectification Improves Efficiency

- **Efficiency Comparison**

  380Vin | 25°C | UCD3138 with SR Driver

  - SR Driver Disabled
  - SR Driver Enabled

  - Peak Efficiency: 94.85% @ 19.92A
  - Efficiency Increase at Peak Efficiency: 0.54%
  - Average Efficiency Increase over Constant Voltage Load Range: 0.63%
  - Peak Efficiency Increase (occurs at no-load): 2.62%

  **SR Driver Enabled**

  Efficiency graph showing improvements with SR Driver Enabled.
Thank You
Questions