Application Note
Introduction to UCD3138x Devices

TEXAS INSTRUMENTS

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ABSTRACT

UCD3138x devices are digital power controllers that are specifically designed for power applications. This application note is a valuable reference that answers the following questions:

1. What are the UCD3138x devices?
2. Why use the UCD3138x devices?
3. What resources does TI provide for the UCD3138x devices?
4. How do I learn more about the UCD3138x devices?

This guide covers all aspects of development with UCD3138x devices, including hardware, software, applications and additional support. In addition to key reference documents, each section provides relevant links and resources to further expand on the information covered.

Table of Contents

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1 Quick Start

1. Navigate to ti.com/digitalpower for UCD3138x product selection.
2. Watch tutorials from *Basics and tools* section of Introduction to digital power controllers video series.
3. Download and install Code Composer Studio™ + Fusion Digital Power Studio™.
   a. Configure CCS for Arm® compiler v5.2.4.
4. Buy UCD3138x hardware.
   a. To follow UCD Training Labs, buy an open-loop evaluation module (EVM) and USB-to-GPIO2 adapter.
   b. Next, buy a closed-loop application EVM according to your topology (PFC, LLC, HSFB, PSFB)
      i. Application EVMs come with a populated PCB, a pre-programmed UCD3138x digital controller, a control card, and an adapter.
   c. Or, build a reference design and purchase both a UCD3138x controller and an adapter.
5. Watch remaining video tutorials and start developing!
   a. Leverage TI E2E™ design support forums, *UCD31xx Technical Reference Manual*, and UCD3138 FW_SDK.

2 Ecosystem

The UCD3138x devices' ecosystem contains numerous hardware, development tools, and software to support a variety of applications. For more information about each section of the ecosystem, see the respective section within this document.
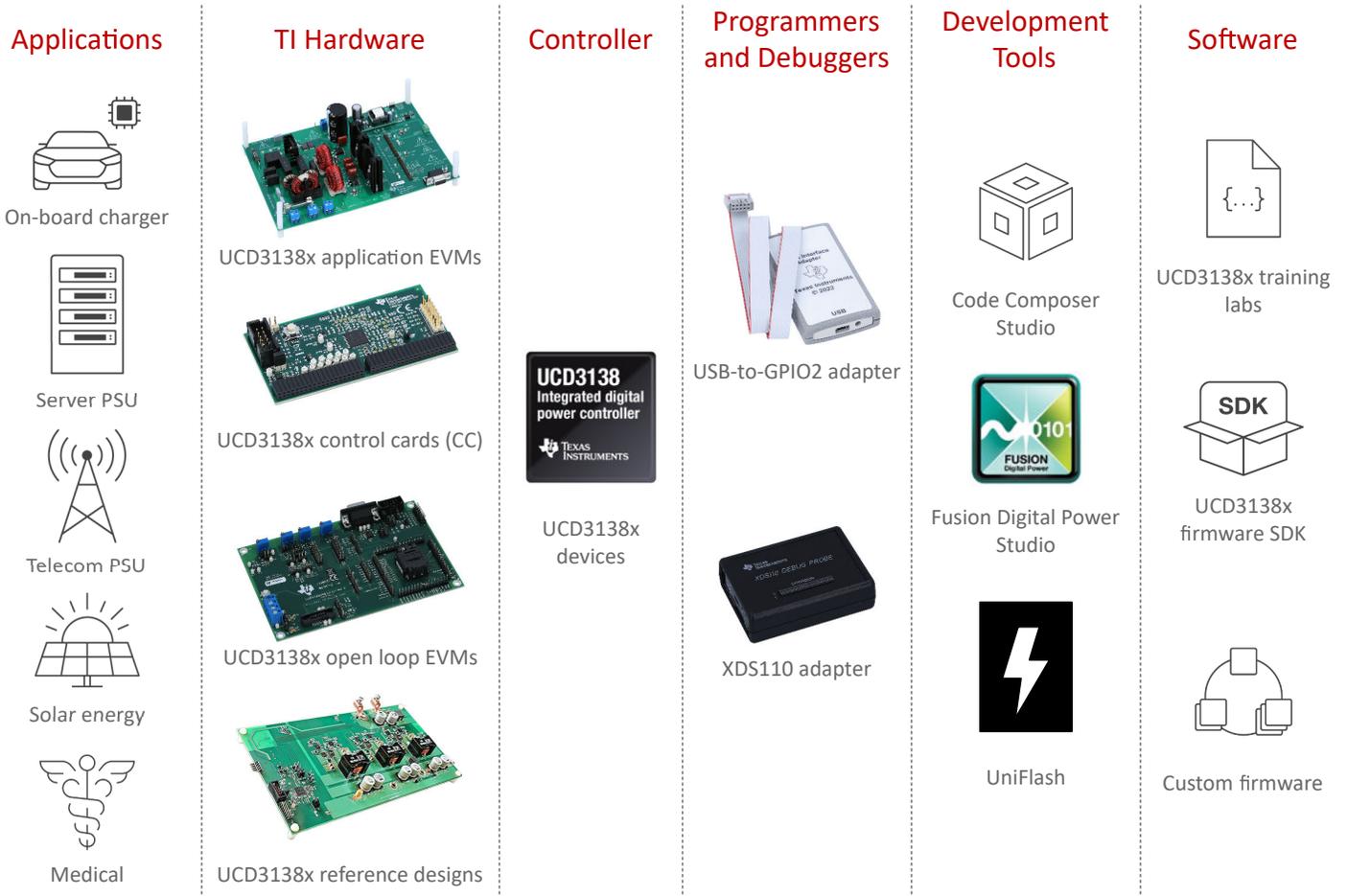
Figure 2-1. UCD3138x Ecosystem Diagram

Note
The UCD3138x Devices can be used in a variety of applications, including the shown end-equipment.

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3 Introduction

The UCD3138x family of digital power controllers offer superior levels of integration and performance in a single-chip solution. The UCD3138x devices are flexible and are designed for a wide variety of power conversion applications. In addition, multiple peripherals inside the device have been specifically optimized to enhance the performance of AC-DC and DC-DC applications, and to reduce the total component count.

The UCD3138x devices are a fully programmable power controller offering customers complete design control and autonomy. With high levels of configuration, complex firmware is not needed. TI simplifies our customers' development with integrated and easy-to-use tools. The UCD3138x devices can be programmed using TI's Code Composer Studio™ (CCS) Integrated Development Environment (IDE) or our powerful Fusion Digital Power Studio Graphical User Interface (GUI) Suite. Thus, customers receive the power and flexibility of digital control without the challenge of complex firmware.

At the core of the UCD3138x devices are the digital control loop peripherals, also known as Digital Power Peripherals (DPPs). These DPPs are high-speed digital control loops independent of the internal microcontroller (MCU). Each DPP consists of an Error Analog-to-Digital Converters (EADC), a PID-based compensator, and DPWM outputs. The UCD3138x devices also have general-purpose ADCs for real-time sensing. Lastly, the UCD3138x devices can communicate to external peripherals via Universal Asynchronous Receiver/Transmitter (UART), Inter-Integrated Circuit (I2C) or Power Management Bus (PMBus). All the processes are managed by the internal 32-bit Arm®7 MCU using programmable flash memory or on-chip RAM/ROM.
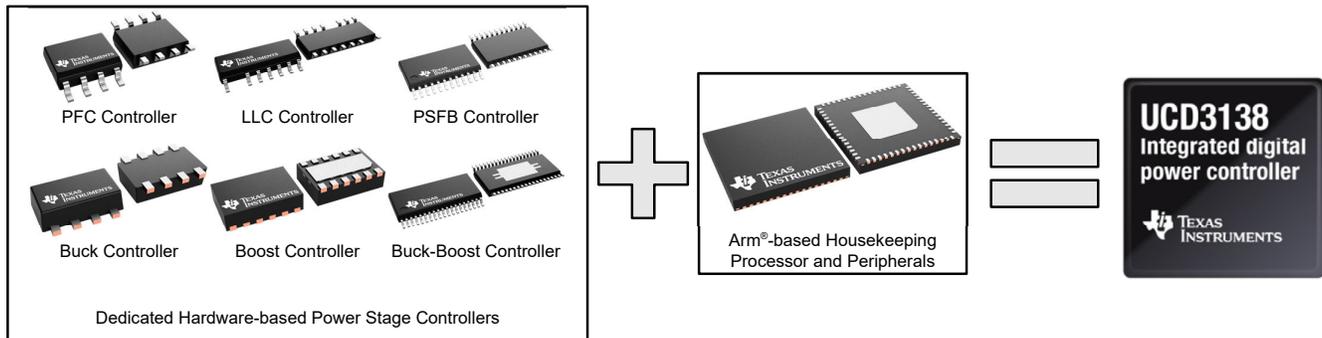
The UCD3138x Devices enhance your design by combining a Dedicated Hardware-based Power Stage Controller with an Arm-based Housekeeping Processor and Peripherals

Figure 3-1. Abstraction of UCD3138x Devices

4 TI Controller Options for Power Supplies

This section discusses the motivation for using the UCD3138x devices and the different packages available on ti.com.

4.1 Power Controller Landscape

Common power converters typically use an analog controller, such as the TI UCCx products, since analog controllers are simple and low cost. In higher power and complex power converters, a more flexible product is needed. The typical option engineers look to are DSP-based microcontrollers, such as the TI C2x products. However, DSP-based microncontrollers have high firmware skill and component cost that deter engineers. DSP-based controllers also have slower response times and are limited by the MCU's bandwidth. Thus, engineers possibly need a power controller that has more features than analog, but is not strictly driven by software.

The UCD3138x devices seek to bridge this gap by combining the benefits of both analog and DSP-based microcontrollers. The UCD3138x devices are fully programmable, giving flexibility in design. In addition, TI's Fusion Digital Power Studio GUI Suite allows our customers to easily customize designs without intensive programming. The UCD3138x devices are also specifically designed for power converters. The dedicated power loops are not limited by the MCU bandwidth and the firmware is designed to be easily configured for power applications. Thus, power engineers can design fast yet flexible power converters.

Figure 4-1. Power Controller Landscape
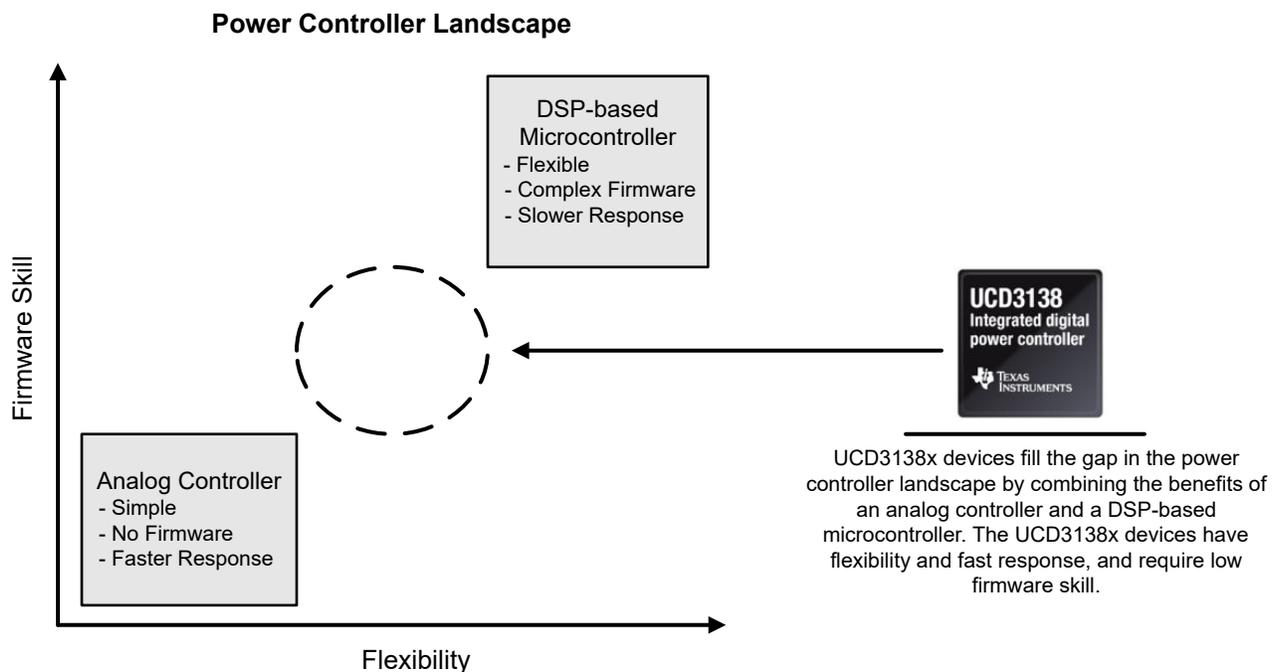
4.2 UCD3138x Product Selection

The UCD3138x family have multiple devices to choose from. The main differences are the flash memory size and the number of pins. The UCD3138xA devices also provide enhanced parametrics such as Dead Time Control (DTC) by enabling Synchronous Rectification (SR). The flash memory and number of pins are shown for each available UCD3138x device in Table 4-1.

Table 4-1. UCD3138x Devices and Packages Available on ti.com

Product	40-Pin QFN	64-Pin QFN	80-Pin QFP
UCD3138128A (128kB flash with enhanced parametrics)	N/A	N/A	
UCD3138128 (128kB flash)			
UCD3138A64 (64kB flash)			
UCD3138064A (64kB flash with enhanced parameterics)			N/A
UCD3138064 (64kB flash)			
UCD3138A (32kB flash with enhanced parametrics)			
UCD3138 (32kB flash)			
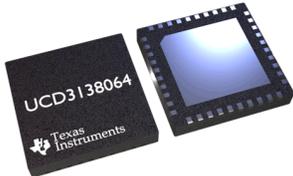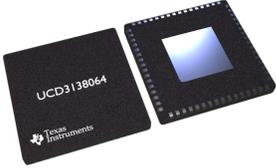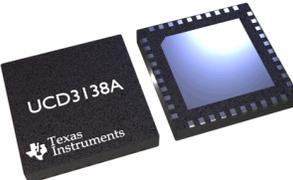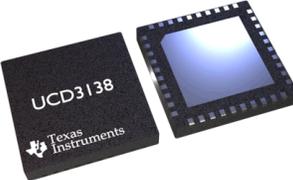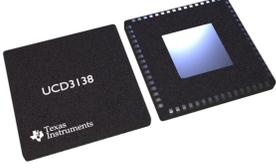
5 TI Hardware

This section showcases TI's entire portfolio of UCD3138x hardware to help you quickly start development with the UCD3138x devices.

5.1 Open Loop EVMs

The UCD3138x Open Loop Evaluation Modules (EVMs) offer an easy to use test platform for stand-alone evaluation of the UCD3138x digital controllers. The EVMs are intended for hardware and firmware engineers to manipulate signals on individual pins and study the open loop operation. There are also numerous ports and peripherals to test individual signals and communication, such as UART, I2C and PMBus. TI offers training labs with the open loop EVM to learn about the UCD3138x devices.

TI offers three Open Loop EVMs for each UCD3138x device pinout option.

Table 5-1. UCD3138x Device Open Loop (OL) Hardware Available on ti.com.

UCD3138x Open Loop (OL) EVMs		
40-Pin QFN	**64-Pin QFN**	**80-Pin QFP**
UCD3138OL40EVM-032	UCD3138OL64EVM-031	UCD3138A64OEVM-662

5.2 Application EVMs

The UCD3138x Application EVMs showcase the UCD3138x device in a variety of power converters. Four application EVMs are available on ti.com with three requiring an included UCD3138x Control Card (CC).

Table 5-2. UCD3138x Application Hardware Available on ti.com

UCD3138x Application Kits			
Evaluation Mode (EVM)	**Description**	**Special Features**	**Control Card?**
	• Single-phase PFC, dual-phase interleaved PFC or bridgeless PFC • 360W, 400 VDC rated power • Universal AC input: 95-265VAC	• High PF and low iTHD (<5% @ 20% load, <2% @ 100% load) • Can achieve <1 and power metering accuracy	Y
UCD3138x PFC EVM: UCD3138PFCEVM-026			
	• Hard-switched full-bridge DC/DC • Constant current and constant power • Secondary side control • 360W full-load power • 30 A full-load current • DC input: 36-72VDC	• Supports input voltage feed-forward control with constant start time • Supports voltage-mode control • Supports peak current-mode control	N
UCD3138x HSFB EVM: UCD3138HSFBEVM-029			

Table 5-2. UCD3138x Application Hardware Available on ti.com (continued)

UCD3138x Application Kits			
Evaluation Mode (EVM)	**Description**	**Special Features**	**Control Card?**
	• High efficient, digitally controlled, and standalone phase-shifted full-bridge DC/DC power conversion • 360W full-load power • 30 A full-load current • DC input: 350 - 400VDC	• Constant current and constant power • Secondary side control • Constant start time	Y
UCD3138x PSFB EVM: UCD3138PSFBEVM-027			
	• Resonant half-bridge LLC for DC/DC power conversion • Supports synchronous rectification • 340W full-load power • 29 A full-load current • DC input: 350 - 400VDC	• Burst-mode cycle-by-cycle current limiting with duty cycle matching protection • Over-voltage, over-current and brownout features	Y
UCD3138x LLC EVM: UCD3138ALLCEVM150			

A.   Some EVMs require a Control Card (CC).

5.3 Control Cards

The UCD3138x Control Cards (CC) are daughter cards intended for operation with an external power converter or stand-alone study. By placing the UCD3138x device on a separate PCB, the digital controller can be abstracted away and the power converter can be evaluated independently. The Control Cards also contain PMBus and JTAG headers for external communication and debug. Each Control Card supports different UCD3138x devices.

Table 5-3. UCD3138x Device Control Card (CC) Hardware Available on ti.com

UCD3138x Control Card (CC) EVMs		
64-Pin QFN		**80-Pin QFP**
 UCD3138CC64EVM-030 64-pin CC EVM Includes: UCD3138 (32kB flash)	 UCD3138064EVM-166 64-pin CC EVM Includes: UCD3138064 (64kB flash)	 UCD3138A64CEVM-660 80-pin CC EVM Includes: UCD3138A64 (64kB flash) Supports: UCD3138128 (128kB flash) UCD3138128A (128kB flash with enhanced parametrics)
 UCD3138ACCEVM149 64-pin CC EVM Includes: UCD3138A (32kB flash with enhanced parametrics)	 UCD3138064AEVM149 64-pin CC EVM Includes: UCD3138064A (64kB flash with enhanced parametrics)	
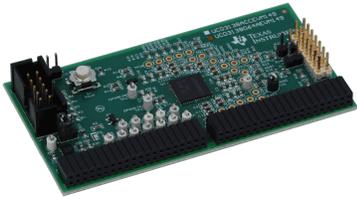
The UCD3138PFCEVM-026 Power Factor Correction EVM shows how the UCD3138x device Control Card inserts into a power converter PCB. The power converter PCB has an I/O header that the Control Card can attach to. The Control Card power is typically supplied from the power converter PCB.
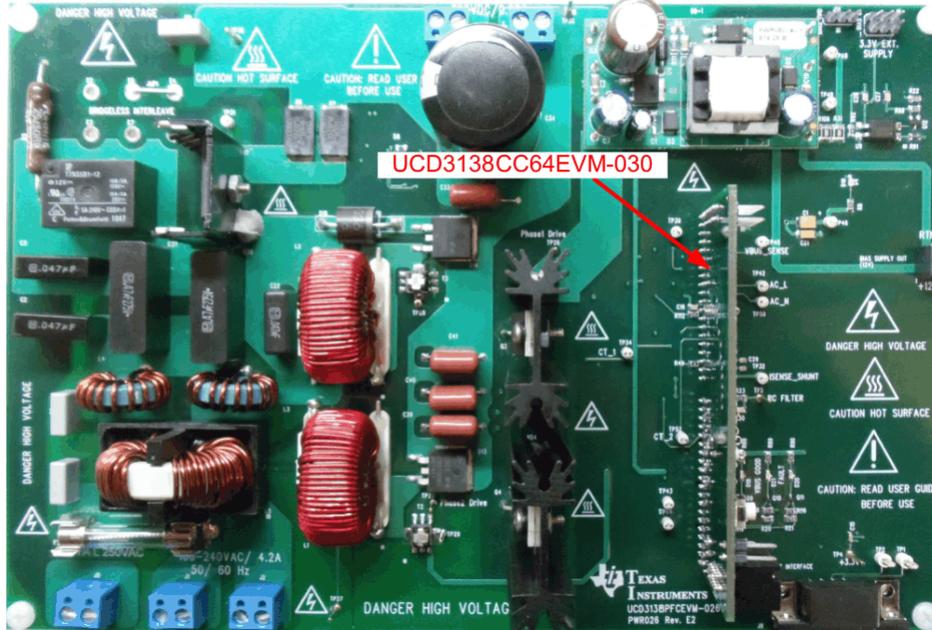
Figure 5-1. UCD3138PFCEVM-026

5.4 Reference Designs

The TI Reference Design Library is a robust reference design library spanning analog, embedded processor, and connectivity. Created by TI experts to help you jump start your system design, all reference designs include schematic or block diagrams, BOMs, and design files to speed your time to market.

Search and download UCD3138 Reference Designs.

6 Programmers and Debuggers

TI and third parties provide several hardware and software tools for programming and debugging the UCD3138x devices. This section highlights the two main hardware tools. However, other tools are also compatible.

6.1 USB-to-GPIO2 Interface Adapter

The USB-to-GPIO2 Interface Adapter is the primary communication bridge between the UCD3138x devices and your host PC. The adapter communicates with the UCD3138x via PMBus and communicates with the host PC via USB.

Product Page: USB-to-GPIO2

6.2 JTAG Debuggers

The UCD3138x devices can be programmed and debugged via JTAG. The XDS110 JTAG Debug Probe is the recommended tool to program your CCS software onto your UCD3138x device.

Product Page: TMDSEMU110-U.

7 Software

TI provides comprehensive training and software libraries for UCD3138x devices to support our customer's development.

7.1 UCD3138x Training Labs

TI provides UCD3138x Training Labs to quickly start software development. The Training Labs include a 5-part video series with accompanying training lab firmware.

To get started with the UCD3138x Training Labs:

1. Buy a UCD3138x Open Loop EVM (40-pin, 64-pin or 80-pin).
2. Buy a USB-to-GPIO2 Interface Adapter.
3. Download Code Composer Studio (CCS) and Fusion Digital Power Studio.
4. Configure CCS for Arm v5.2.4.
5. Download the UCD-TRAINING-LABS;
6. Watch the Introduction to Digital Power Controllers video series.

The UCD3138x Training Labs are divided into the following sections:

- General UCD3138x introduction and overview
- Lab 1: UCD3138x basics and tools
- Lab 2: Digital PWM (DPWM) module
- Lab 3: Digital filter (EADC) module
- Lab 4: Analog front end
- Lab 5: JTAG interface

Downloads:

Standalone version: UCD-TRAINING-LABS

7.2 UCD3138 Application Development Firmware Kit

The UCD3138 Application Development Firmware Kit is a free software development kit (SDK) for 6 different power topologies:

- Power Factor Correction (PFC)
- Resonant Half-bridge LLC
- Phase-shift Full-bridge LLC (PS-LLC)
- Hard-switch Full-bridge (HSFB)
- Phase-shift Full-bridge (PSFB)
- Non-isolated Bi-directional Converter

The development kit assists in the evaluation and development phase. The development kit encompasses firmware development tools along with supporting collateral for each topology. More topologies are going to be available in the future.

Downloads

Standalone version: UCD3138_FW_SDK

7.3 Custom Firmware

Experienced users can develop custom firmware to include features such as multiple power stage control, e-metering, diagnostics, automatic shutdown, and more! Technical details can be found in the *UCD31xx Technical Reference Manual*.

8 Development Tools

TI provides numerous development tools to support our customer's design.

Figure 8-1. UCD3138x Firmware Development Flow

8.1 Code Composer Studio (CCS)

Code Composer Studio is an integrated development environment (IDE) that supports TI's Microcontroller and Embedded Processors portfolio. Code Composer Studio comprises a suite of simple tools used to develop and debug embedded applications. Code Composer Studio includes an optimizing C/C++ compiler, source code editor, project build environment, debugger, profiler, and many other features. The IDE provides a single interface, taking the user through each step of the application development flow. Familiar tools and interfaces allow users to get started faster than ever before.

Firmware development for the UCD3138x devices on Code Composer Studio **requires Arm Compiler v5.2.4**. To set up Arm Compiler v5.2.4, complete the following steps:

1. Install and open the latest version of Code Composer Studio.
2. Go to **Help → Install New Software…**.
3. Click on **What is already installed?** and uninstall any Arm compiler version higher than v5.2.4. Once all other Arm version have been removed, restart Code Composer Studio.
4. Go to **Help → Install New Software…**.
5. Select **– All Available Sites—** in the dropdown and check **Arm Compiler Tools** version **5.2.4**. Click **Next**, accept the agreements, and finish. Then, restart Code Composer Studio.
6. Once Arm compiler v5.2.4 has been installed, change the compiler version by going to **Project → Properties → General → Compiler version** and select **TI v5.2.4** in the dropdown.
7. Build the UCD project.

For more details, see E2E FAQ on Code Composer Studio setup.

Downloads

• Standalone version: CCSTUDIO
• Online version: CCS Cloud

Resources

Code Composer Studio User's Guide explains the features and capabilities of the Code Composer Studio IDE.

8.2 Fusion Digital Power Studio

Fusion Digital Power Studio incorporates software tools for Texas Instruments' UCD3138x Integrated Digital Controller family. The software helps power supply engineers gain benefits of digital power without learning complex programming skills by using a graphical user interface (GUI). The GUI is an intuitive tool that helps assist in the evaluation phase, the development phase, and the testing phase of the design.

Fusion Digital Power Studio consists of various tools designed to help engineers through the evaluation, design, and production stage.

Fusion Digital Power Studio GUI (1)
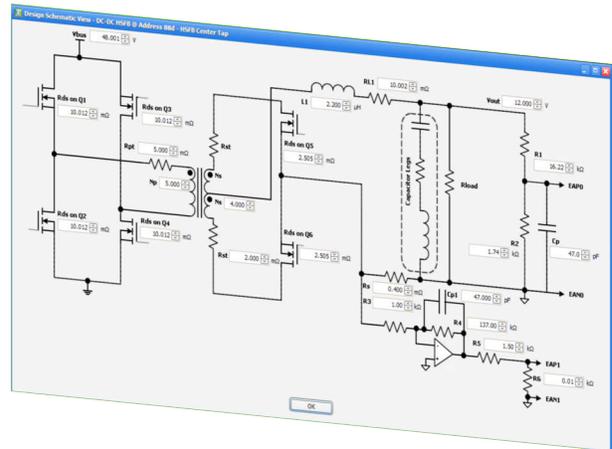
Fusion Digital Power Studio GUI (2)

Downloads

• Standalone version: FUSION-DIGITAL-POWER-STUDIO

References

Fusion Digital Power Studio GUI for Isolated Power Applications is an in-depth user's guide of the software.

8.3 UniFlash

UniFlash is a programming GUI tool developed by TI, which supports JTAG. Customers can debug and program the on-chip flash of the UCD3138x devices. UniFlash provides both graphical and command-line interfaces.

Downloads

• Standalone version: UNIFLASH
• Online version: UniFlash Cloud

Resources

UniFlash Quick Start Guide explains the features and capabilities of UniFlash.

9 Application

This section discusses how to use the UCD3138x devices in various power converters and how these devices can improve your design.

The UCD3138x devices excel in a wide variety of applications. Five of the main categories are highlighted below:

- Multiple Series Power Stages
- Multiple Parallel Power Stages
- High Performance
- External Communication
- High Power Density

The UCD3138x devices achieve high performance and high flexibility with a dedicated hardware-based power stage controller. This is a configurable control loop that is etched into the silicon and is independent from the MCU. Thus, the control loop is easy to configure and is not limited by the MCU bandwidth.
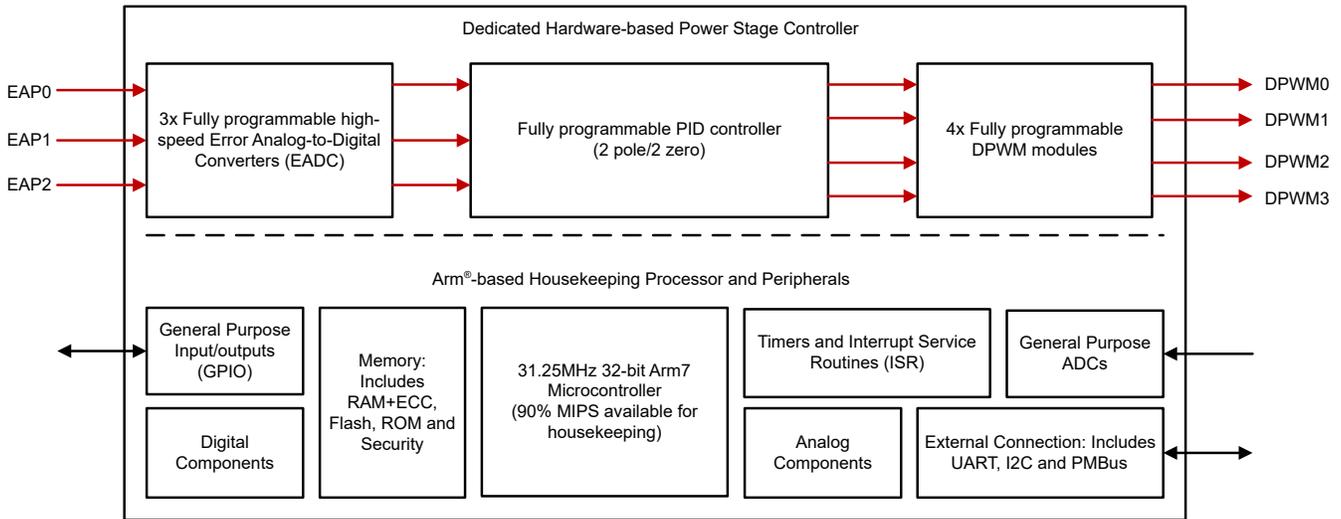
Figure 9-1. Functional Block Diagram of the UCD3138x Devices

9.1 Multiple Series Power Stages

Typical power applications require multiple power stages in series to achieve system requirements. For example, an offline AC/DC circuit typically consists of a single-phase boost PFC followed by a resonant LLC converter and synchronous buck converter. Each of these three topologies can require separate analog controllers. Performance can also be improved with the addition of Synchronous Rectification (SR). The figures below show a simplified application and do not include additional devices, such as gate drivers.
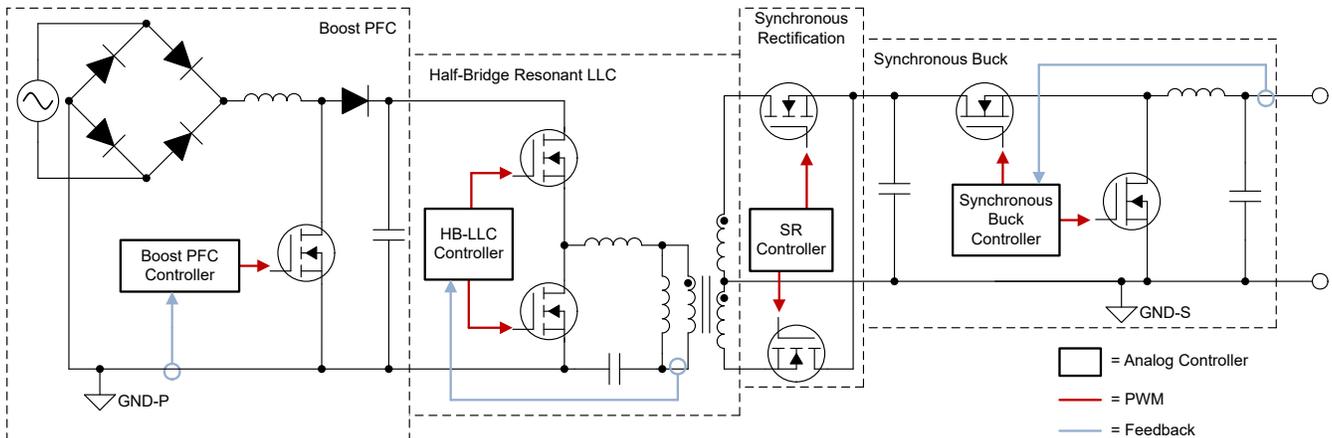
Figure 9-2. Typical 3-Stage power converter system with SR requires four separate analog controllers

On the other hand, the UCD3138x devices can control multiple power stages in series. The UCD3138x devices can control up to three different control loops using the three EADCs. Each UCD3138x device can also output up to eight unique DPWMs. Each power stage can be configured independently or together to create an efficient and low component count system.
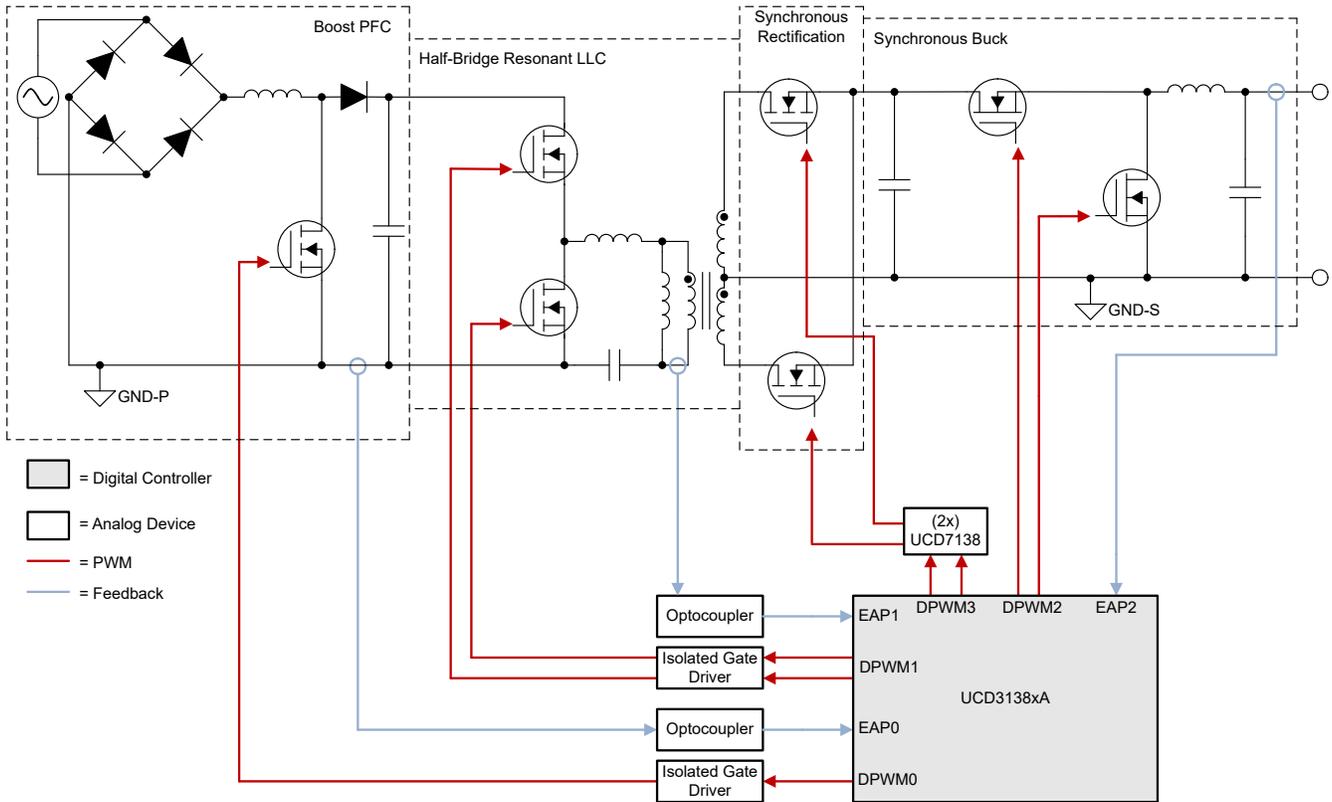
Figure 9-3. The UCD3138x Devices can Control Multiple Stages in Series

A.   The UCD3138xA Devices have enhanced parametrics, such as SR control.

Key Reference Designs:

• PMP40586: 1-kW digital-controlled current mode LLC reference design

9.2 Multiple Parallel Power Stages

Other power conversion applications require multiple power converters in parallel. A system can require multiple outputs from a single source. For example, a 48-V electric vehicle battery can require multiple synchronous buck converters in parallel for bi-directional battery charging applications. A typical design requires separate analog controllers for each power stage.
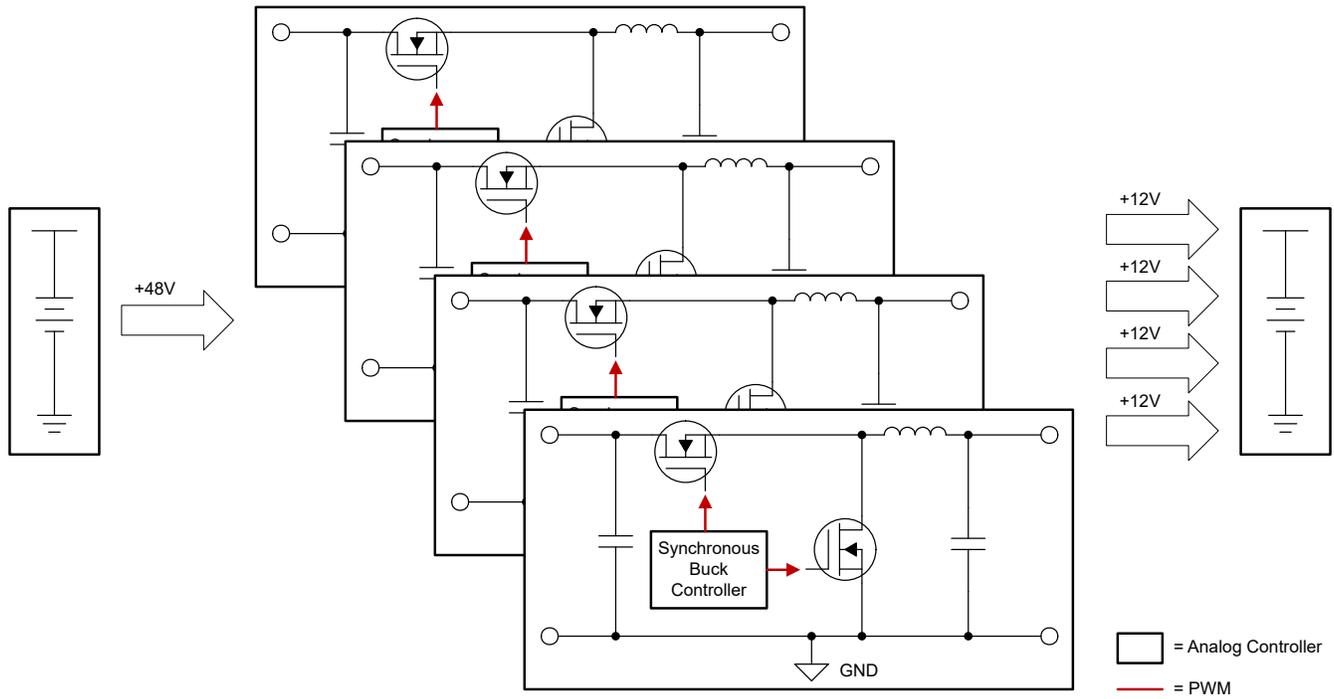
Figure 9-4. Parallel Power Stages Using Analog Controllers

The UCD3138x devices increase efficiency and power density by controlling all power stages at once. By utilizing the 8 DPWM outputs, multiple power stages can be controlled in series. Thus, only one controller is needed to provide a system-level design.
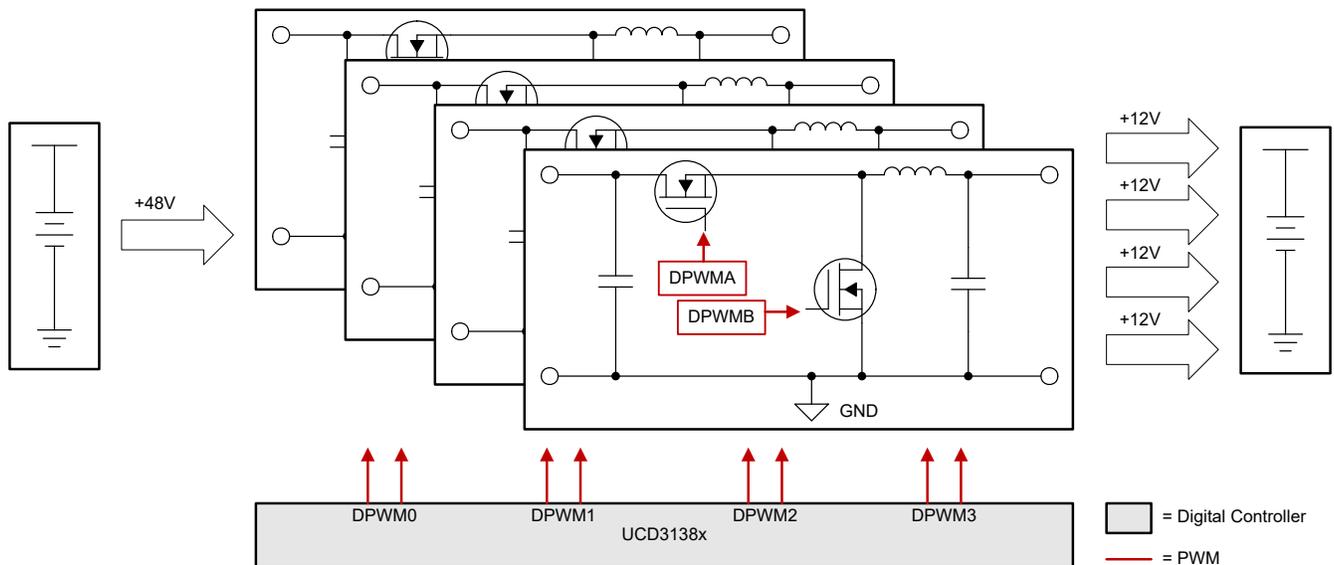
Figure 9-5. Parallel Power Stages Using a UCD3138x Device

The TIDA-00653 reference design provides an example for multiple parallel power stages controlled by one UCD3138x device.

Figure 9-6. TIDA-00653 Demonstrates Multiple Outputs Using One UCD3138128

Key Reference Designs

- TIDA-00653: Non-isolated Bi-directional Converter Reference Design for Battery Charging Applications
- PMP4333: 1-kW Triple-Rail Isolated DC/DC Digital Power Supply for Telecom

9.3 High Performance and External Communication

Efficient high-power topologies, such as Totem-Pole PFC, cannot be easily implemented with analog controllers. Typical analog controllers also do not have external communication features and are thus closed-off from the system.

The UCD3138x devices can upgrade your power converter with efficient high-power topologies and external communication. The UCD3138x devices can control multiple complex topologies that analog controllers cannot control.

UCD3138x devices that control separate power stages can also communicate between each other to further optimize system performance. ALL UCD3138x devices have UART, I2C and PMBus peripherals. External communication delivers special features, such as e-metering, diagnostics, automatic shutdown and more!
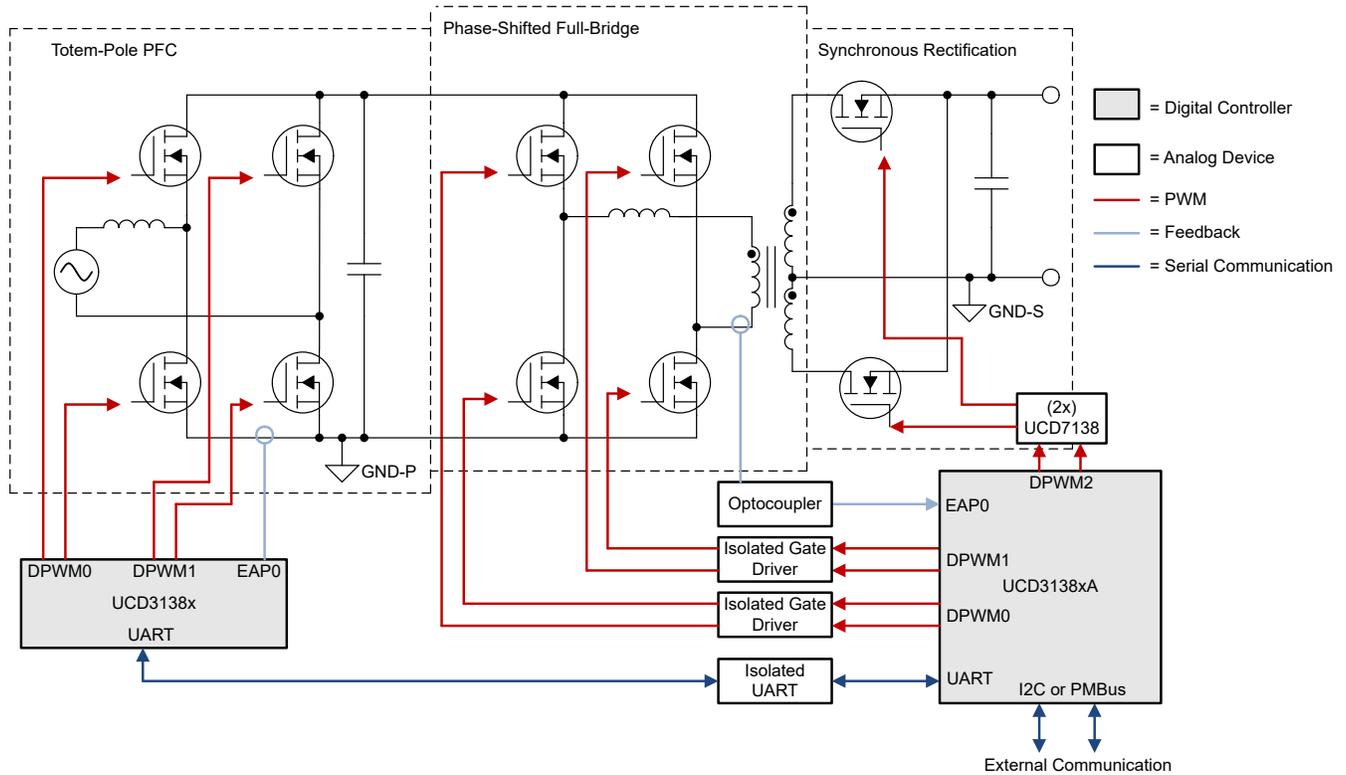
Figure 9-7. **Typical High-Performance Application Using UCD3138x Devices**

Key Reference Designs

- PMP8877: 1/8 Brick Isolated DC/DC Telecom Power Module Digital Control Reference Design
- PMP20873: 99% Efficient 1-kW GaN-based CCM Totem-pole Power Factor Correction (PFC) Converter Reference Design

9.4 High Power Density

The UCD3138x devices offer high-power density due to low controller count and integration with high-power technology, such as GaN and SiC. Thus, compact yet powerful designs can be made. The PMP23340 reference design showcases the UCD3138x in a high-power density, high-power efficiency, and high output power GaN module. The PMP23340 has a power density of >1250W/in^3
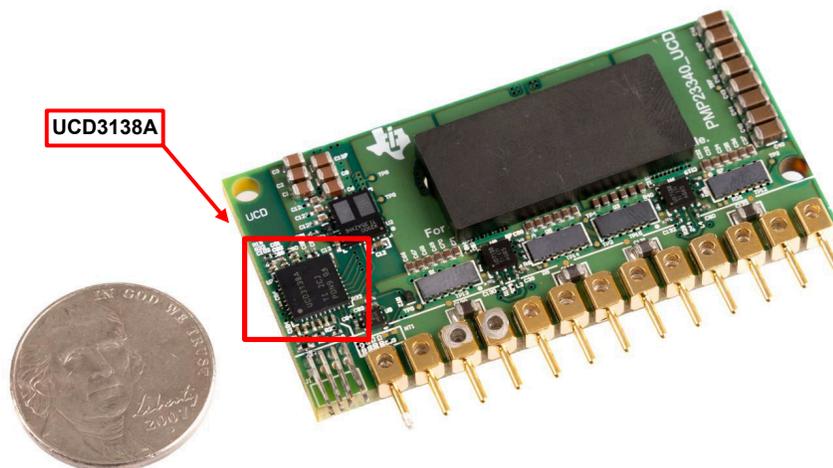
Figure 9-8. The PMP23340 Demonstrates High-Power Density Using the UCD3138A

Key Reference Designs

- PMP23340: 1/8th Brick High Power Density GaN Power Module
- PMP4435: 48Vin, 300W 1/8brick Digital Module with GaN FET Reference Design
- PMP22220: 1500-W AC switch bridgeless PFC reference design

10 Support Resources

This section highlights further references to help with UCD3138x device development.

10.1 Documentation

The UCD3138x devices have an abundance of documentation to help with general overview, product selection, and topology-specific design. For more information, see Section 12.

10.2 TI E2E Support Forum

An engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need. The Getting Started in E2E page has answers to frequently asked questions for specific tasks in the TI E2E forum in chronological order.

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11 Summary

The UCD3138x devices fill the gap in the power controller market by combining the benefits of analog controllers and DSP-based microcontrollers. The UCD3138x devices have high flexibility and fast response times and require low firmware skill. The UCD3138x devices excel in a variety of applications, including multiple power stages, high performance and high-power density. Texas Instruments provides an abundance of resources, including a powerful GUI, hardware EVMs, software development kits and application notes, to help our customers quickly learn and get started with the UCD3138x devices.

12 References

General Design Guides

- Texas Instruments, *How to parallel two DC/DC converters with digital controllers* analog design journal.
- Texas Instruments, *Fast input-voltage transient response with digitally-controlled isolated DC/DC* analog applications journal.
- Texas Instruments, *UCD3138 Family – Practical Design Guideline* application report.
- Texas Instruments, *UCD3138A Migration Guide* application report.
- Texas Instruments, *UCD3138064A Migration Guide* application report.
- Texas Instruments, *UCD3138128A Migration Guide* application report.
- Texas Instrument, *Designing a digital-controlled power supply* technical article.
- Texas Instruments, *UCD3138 Integral Branch of the PID Filter* application report.
- Texas Instruments, *Using UCD7138 and UCD3138A for Advanced Synchronous Rectification Control* application report.
- Texas Instruments, *UCD3138128A Migration Guide* user's guide.

Programming Guides

- Texas Instruments, *UCD31xx Technical Reference Manual*
- Texas Instruments, *UCD3138064 Programmer's Manual*
- Texas Instruments, *Stack Overflow Detection on UCD3138 Devices* application note.
- Texas Instruments, *Lockup Avoidance for UCD3138 Devices* application note.
- Texas Instrument, *Automatic Baud Rate Detection and Configuration in UCD3138* application note.
- Texas Instruments, *Fusion Digital Power Studio for UCD3138 Isolated Power Applications* user's guide.
- Texas Instruments, *UCD3138 – Responding to Multiple PMBus Slave Addresses* application report.
- Texas Instruments, *Designing a Digital Power Supply: How to Write Firmware* technical article.
- Texas Instruments, *Understanding CPU Lock-up Mechanisms in UCD31xx Devices* application report.

PFC Resources

- Texas Instruments, Designing a Digital Power Supply: How to Write Firmware tool.
- Texas Instruments, UCD3138FW-PFC tool.
- Texas Instruments, *Power factor correction using peak current-mode control* analog design journal.
- Texas Instruments, *Digital current balancing for an interleaved boost PFC* analog design journal.
- Texas Instruments, *Increase power factor by digitally compensating for PFC EMI-capacitor reactive current* analog applications journal.
- Texas Instruments, *How to improve PFC light-load efficiency* analog design journal.
- Texas Instruments, *How to reduce current spikes at AC zero-crossing for totem-pole PFC* analog applications journal
- Texas Instruments, *Designing a UCD3138 Controlled Single Phase PFC* application report.
- Texas Instruments, *Designing a UCD3138 Controlled Interleaved PFC* application report.
- Texas Instruments, *Designing a UCD3138 Controlled Bridgeless PFC* application report.
- Texas Instruments, *Evaluating UCD3138 in Interleaved PFC or Bridgeless PFC Configurations* application note.
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