

# **Evaluating UCD3138 in Interleave PFC or Bridgeless PFC Configurations using UCD3138PFCEVM-026**

## **Application Note**

---

## Table of Contents

1	Introduction.....	3
2	UCD3138PFCEVM-026 Hardware Modification .....	3
2.1	2-Phase Interleaved PFC.....	3
2.2	Bridgeless PFC .....	3
3	UCD3138 Firmware Re-configuration in UCD3138PFCEVM-026 .....	4
3.1	Interleaved PFC .....	4
3.2	Bridgeless PFC .....	4
4	Experimental Results .....	5
4.1	Interleave PFC .....	5
4.2	Bridgeless PFC .....	7
5	Theory of Operation.....	8
5.1	2-Phase Interleave PFC Implementation using UCD3138 .....	8
5.2	Bridgeless PFC Implementation using UCD3138 .....	9
6	References.....	10

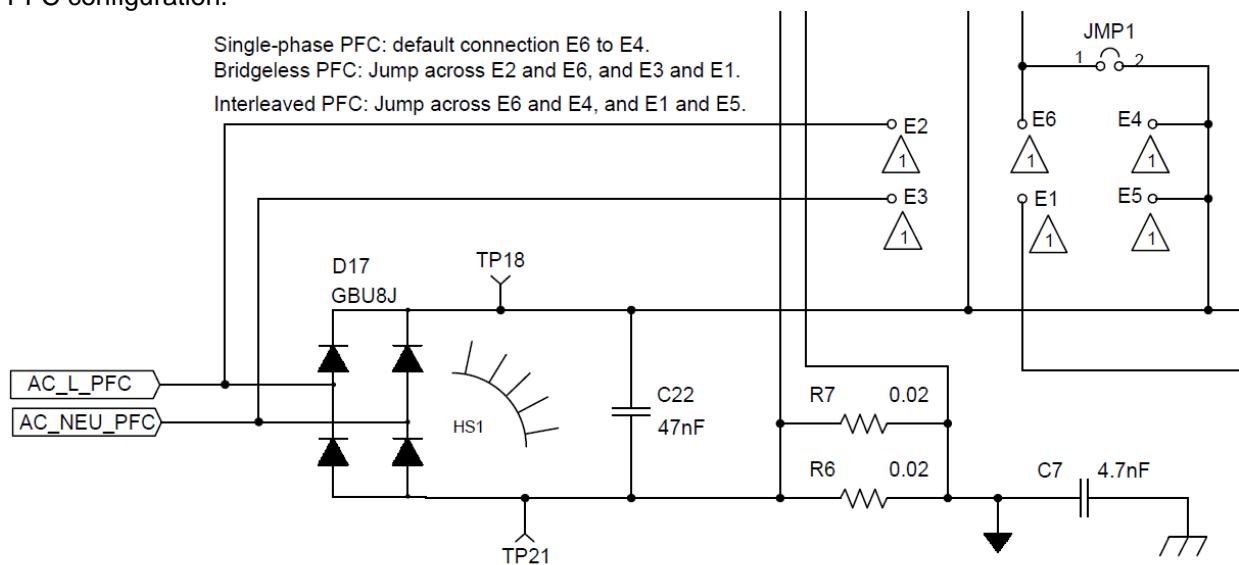
# 1 Introduction

The default configuration of UCD3138PFCEVM-026 is single phase PFC. It can re-configured to interleave 2-phase PFC or bridgeless PFC by hardware modification and re-configuration of the firmware in the UCD3138 controller.

**Warning: the PFC EVM could be damaged if a wrong firmware is downloaded or if the hardware modifications are implemented incorrectly.**

## 2 UCD3138PFCEVM-026 Hardware Modification

Follow the instructions in the schematic below to implement the hardware modification for the desired PFC configuration.



**Figure 1: UCD3138PFCEVM-026 Schematic**

### 2.1 2-Phase Interleaved PFC

As shown in the schematic above, simply install a jumper across E6 and E4, and E1 and E5. This is the only hardware modification to implement 2-phase interleave PFC.

### 2.2 Bridgeless PFC

As shown in the schematic above, simply install a jump across E2 and E6, and E3 and E1. This is the only hardware modification to implement bridgeless PFC.

**NOTE: Make sure to only have the jumpers installed for a single option at one time. The PFC EVM could be damaged if more jumpers are installed than are necessary for the required topology.**

## 3 UCD3138 Firmware Re-configuration in UCD3138PFCEVM-026

**Note:** Please contact your local TI representative to obtain the firmware source code for reconfiguring UCD3138PFCEVM-026 into interleaved PFC or Bridgeless PFC.

A compilation flag is used to compile the source code into the different PFC topologies.

### 3.1 Interleaved PFC

To compile the source code as a 2-phase interleaved PFC:

- Open “system\_defines.h”
- Define the PFC\_TYPE as **0**, as shown below:

```
//PFC type defines: choose the right type, DO NOT CHNAGE THE VALUES!  
#define PFC_TYPE 0 //for interleave PFC with shunt sensing  
//#define PFC_TYPE 1 //for single phase PFC with shunt sensing  
//#define PFC_TYPE 2 //for bridgeless PFC with CT sensing
```

- Compile the code in Code Composer Studio v3.3

### 3.2 Bridgeless PFC

To compile the source code as a bridgeless PFC:

- Open “system\_defines.h”
- Define the PFC\_TYPE as **2**, as shown below:

```
//PFC type defines: choose the right type, DO NOT CHNAGE THE VALUES!  
//#define PFC_TYPE 0 //for interleave PFC with shunt sensing  
//#define PFC_TYPE 1 //for single phase PFC with shunt sensing  
#define PFC_TYPE 2 //for bridgeless PFC with CT sensing
```

- Compile the code in Code Composer Studio v3.3

For detailed information regarding how to compile the project and download the executable file (.xo) into the UCD3138 device, please refer to the document “Using the UCD3138CC64EVM-030” (Texas Instruments Literature #: SLU886, User guide for the UCD3138CC64EVM-030 EVM).

<http://www.ti.com/tool/ucd3138cc64evm-030>

## 4 Experimental Results

For the Figures below, **CH1: V<sub>AC</sub>**; **CH2: I<sub>AC</sub>**; **CH3: I<sub>L1</sub>**; **CH4: I<sub>L2</sub>**

### 4.1 Interleave PFC

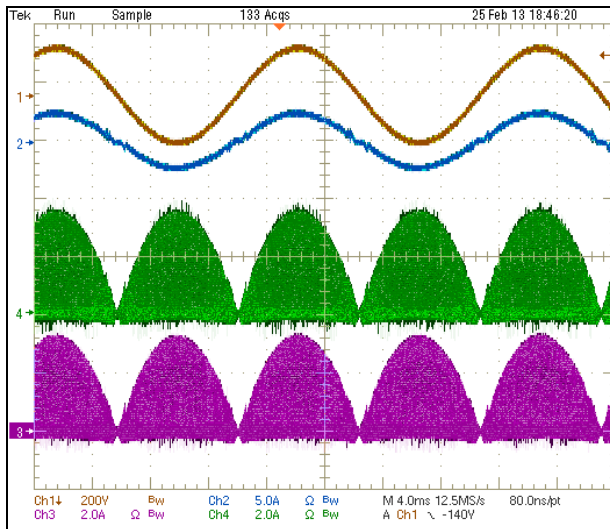


Figure 2: 115VAC, 190W Inductor Currents

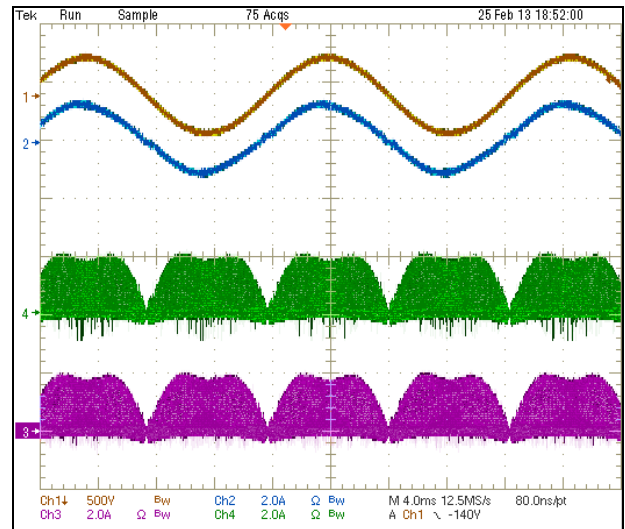


Figure 3: 230VAC, 190W Inductor Currents

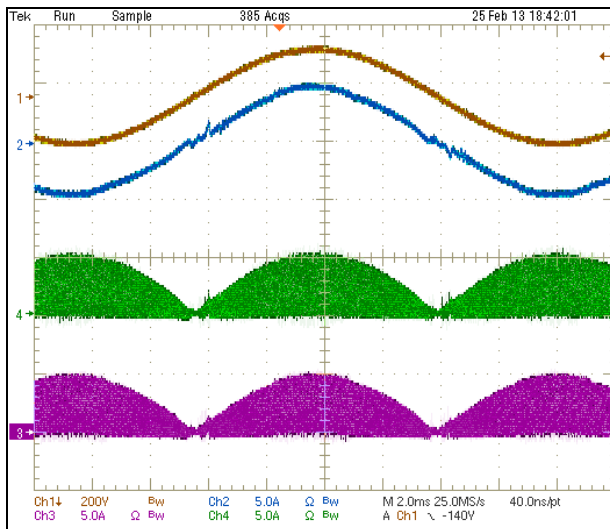


Figure 4: 115VAC, 360W Inductor Currents

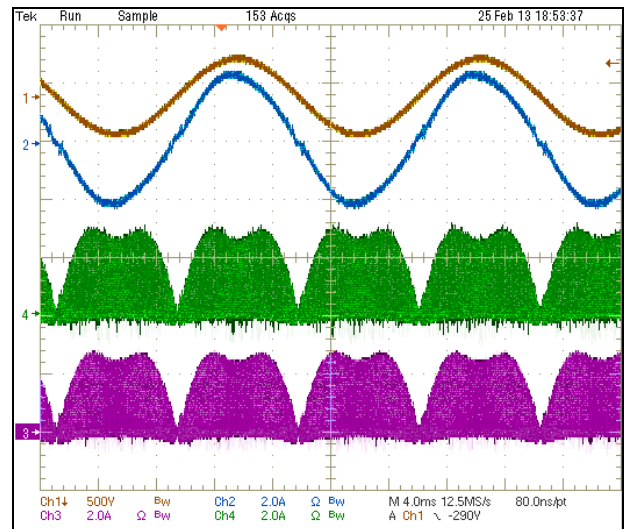
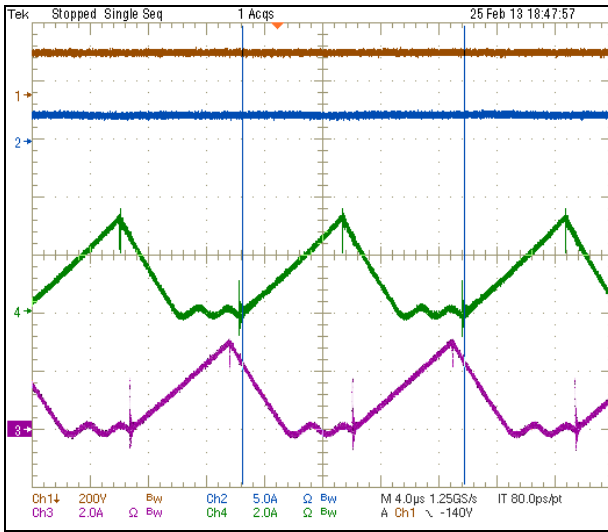
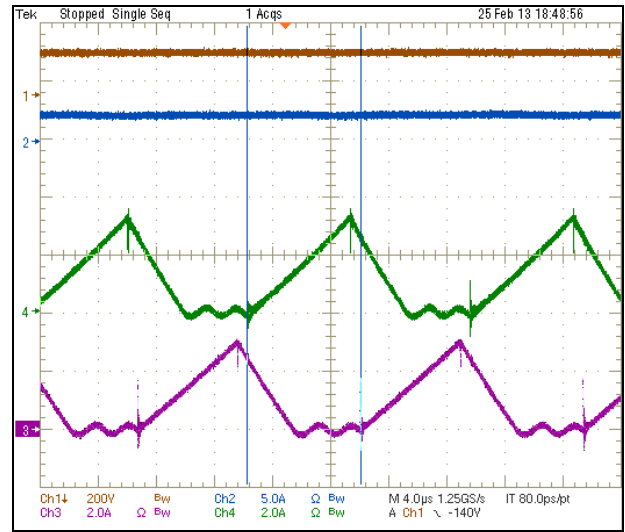


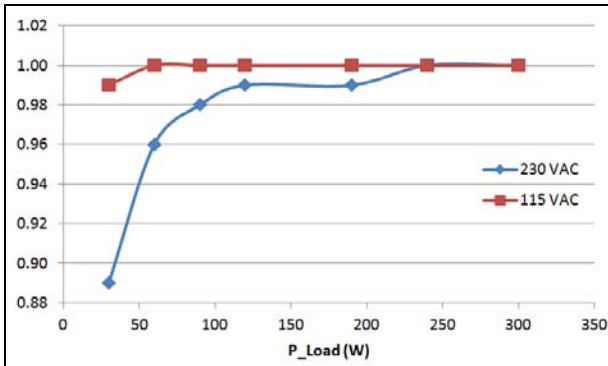
Figure 5: 230VAC, 360W Inductor Currents



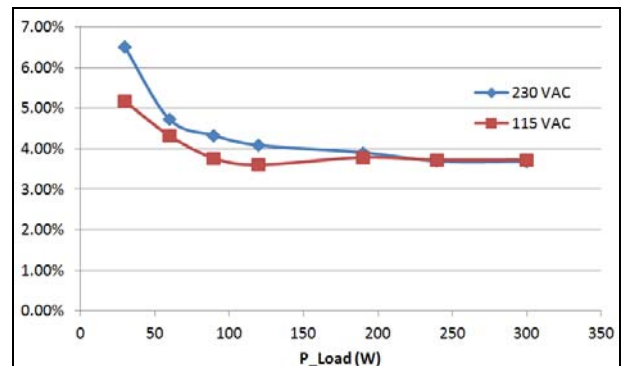
**Figure 6: Inductor Currents Switching Frequency**



**Figure 7: Inductor Currents Phase Delay**



**Figure 8: Interleaved Power Factor**



**Figure 9: Interleaved THD**

### 4.2 Bridgeless PFC

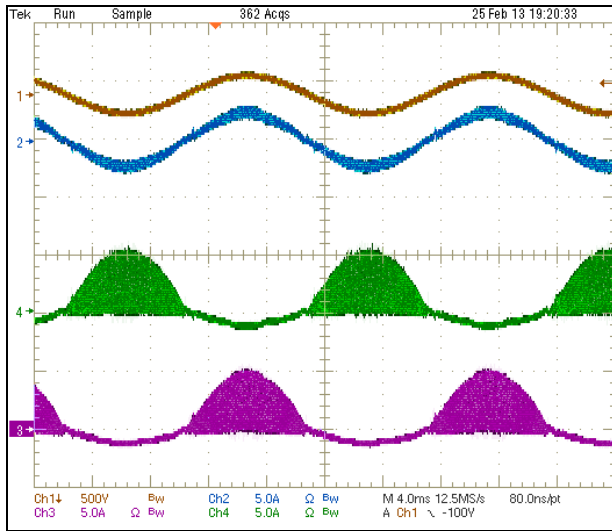


Figure 10: 115VAC, 190W Inductor Currents

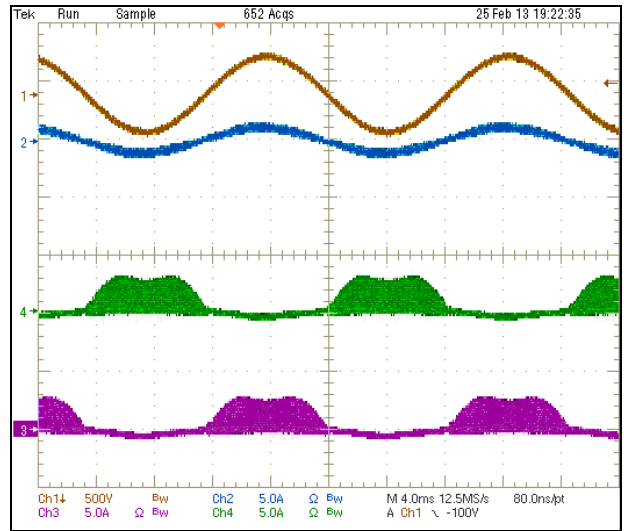


Figure 11: 230VAC, 190W Inductor Currents

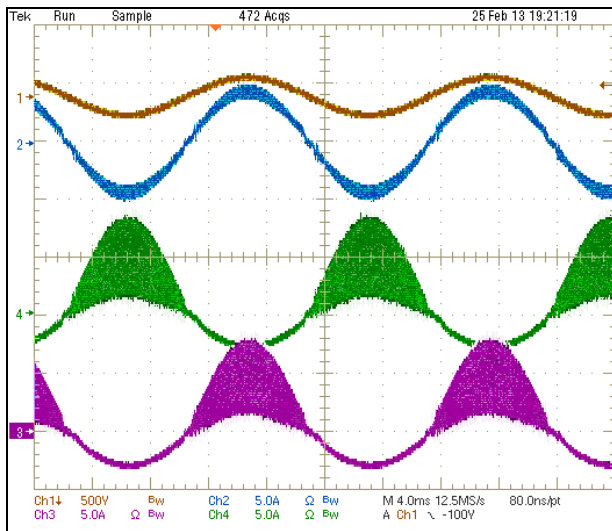


Figure 12: 115VAC, 360W Inductor Currents

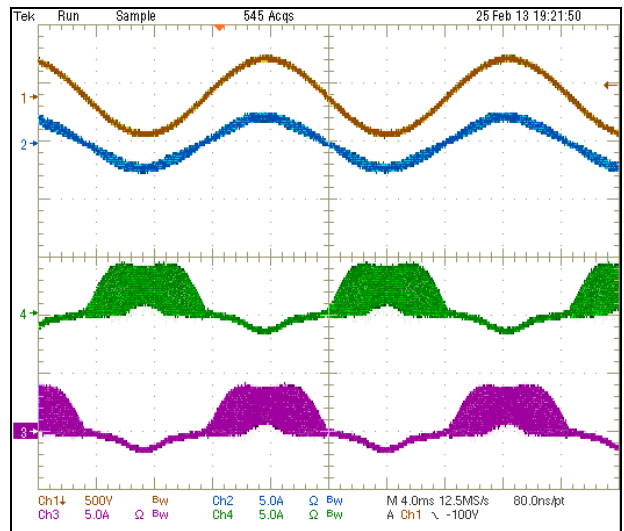


Figure 13: 230VAC, 360W Inductor Currents

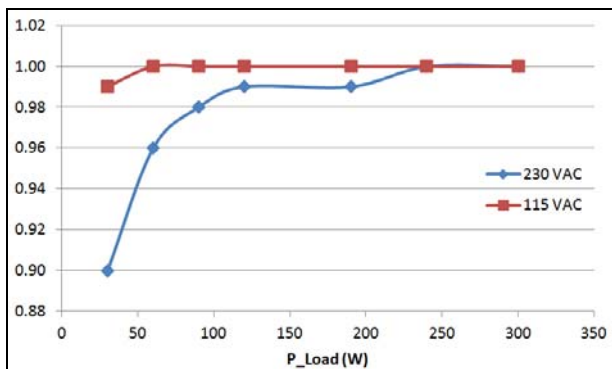


Figure 14: Bridgeless Power Factor

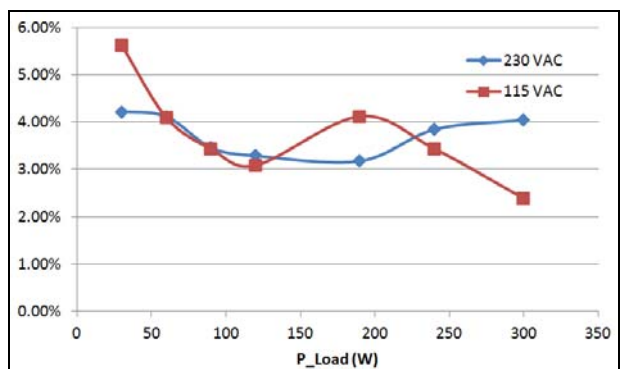


Figure 15: Bridgeless THD

## 5 Theory of Operation

### 5.1 2-Phase Interleave PFC Implementation using UCD3138

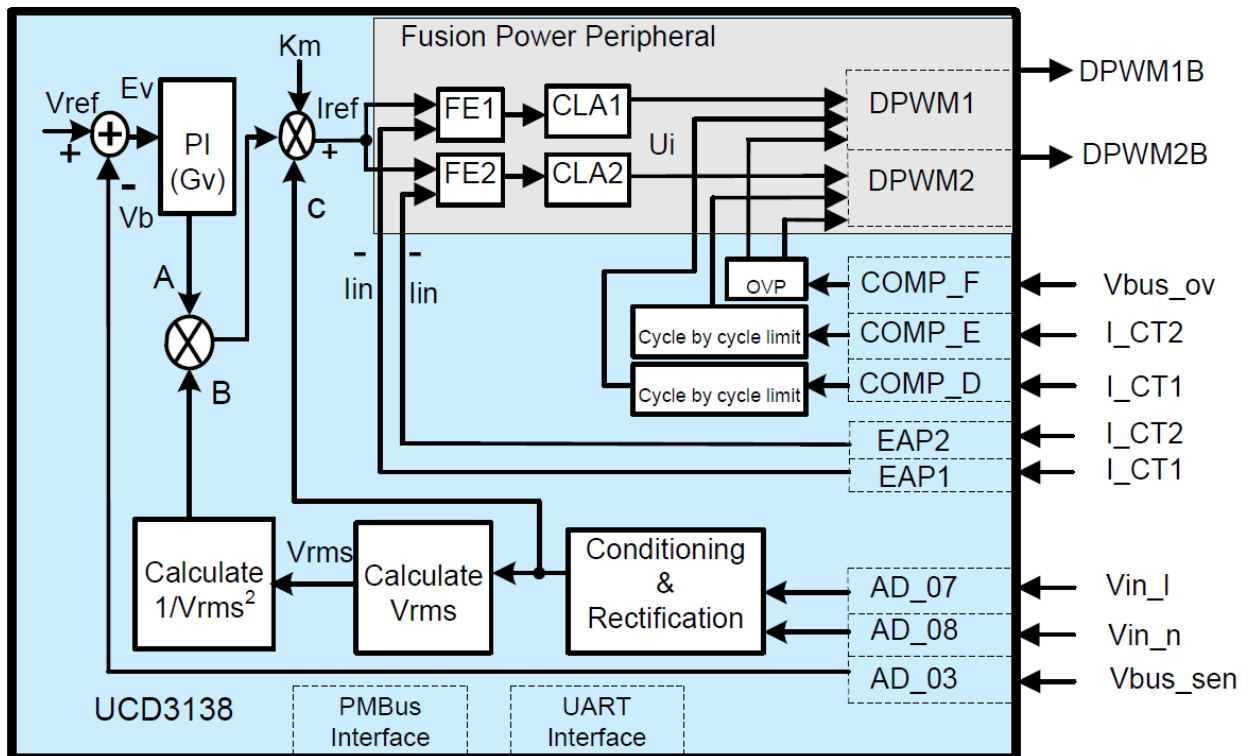


Figure 16: UCD3138 controlled interleaved PFC block diagram

Figure 16 illustrates the block diagram of UCD3138 configured to implement 2-phase interleaved PFC. The input voltage  $V_{in}$  Line and Neutral are sensed separately by two ADC channels AD\_07 and AD\_08. PFC output voltage  $V_{bus\_sen}$  is sensed by another ADC channel AD\_03. In addition, a separate  $V_{out}$  sensing circuit is connect to an on chip analog comparator COMP\_F for over voltage protection (OVP). Two current transformers are used to sense the MOSFETs' instantaneous current and their output I\_CT1 and I\_CT2 are connected to EAP1 and EAP2 respectively for individual current loop control. The two current control loops run independently, each generating a DPWM output to control the respective phase. In addition, I\_CT1 and I\_CT2 are also connected to two on chip analog comparators COMP\_E and COMP\_D for cycle-by-cycle current protection.

An average current mode control is used for input current regulation: current reference is calculated based on  $V_{in}$ , voltage loop output and voltage feed forward. This averaged current reference is then translated to instantaneous signal as if they were sensed at the middle of CT output. The translated reference is then compared to the middle point value of CT output, the error goes through a 2-pole 2-zero digital compensator, a PWM signal is generated based on the compensator output to control the PFC.

It needs to be mentioned here that the above configuration accommodates with TI's PFC evaluation board UCD3138PFCEVM-026. It is not necessary to follow this configuration. For example, I\_CT1/I\_CT2 can be connected to a different EAP channel, different CLAs can be used for current loop compensation, and PFC can be driven by different DPWM outputs also. However, it is recommended using the similar configuration as UCD3138PFCEVM-026, for ease of evaluation.



## 5.2 Bridgeless PFC Implementation using UCD3138

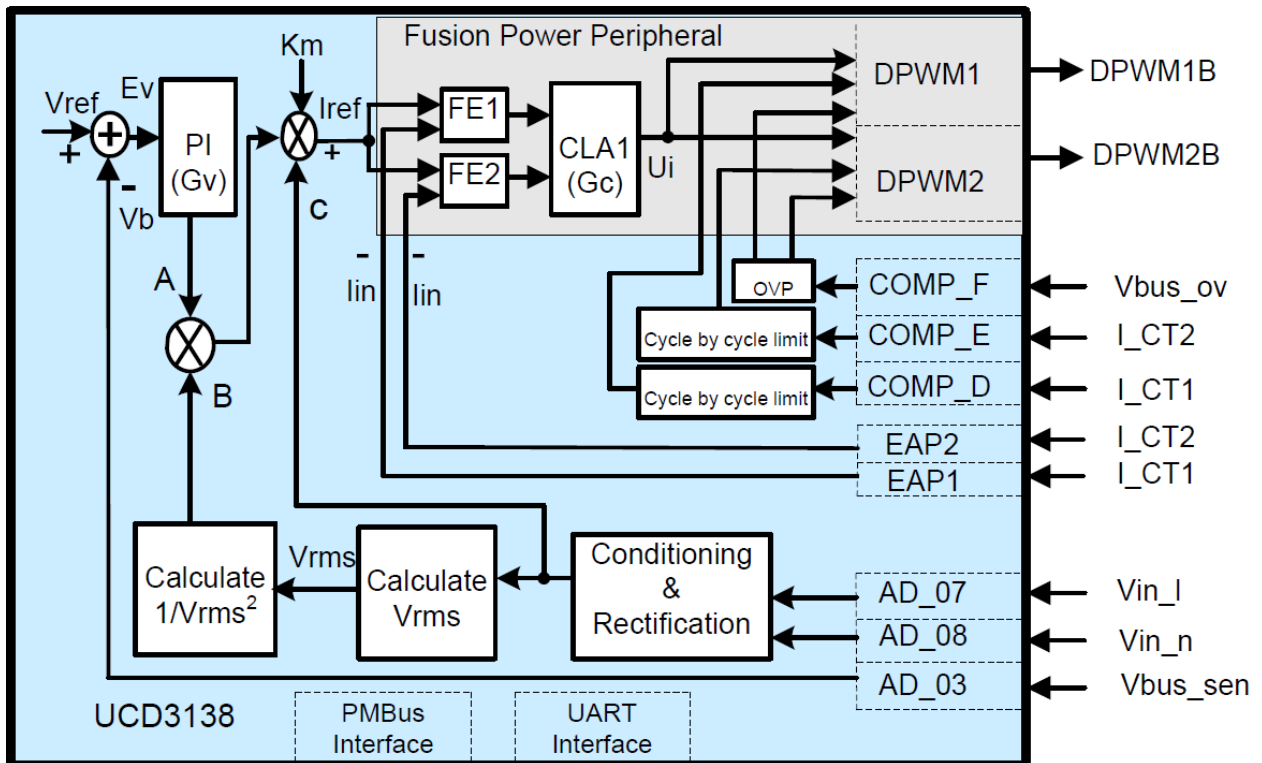


Figure 17: UCD3138 Controlled Bridgeless PFC block diagram

Figure 17 is an example of block diagram of a bridgeless PFC controlled by UCD3138. The input voltage  $V_{in}$  line and neutral are sensed separately by two ADC channels AD\_07 and AD\_08. PFC output voltage  $V_{bus\_sen}$  is sensed by another ADC channel AD\_03. In addition, a separate  $V_{out}$  sensing circuit is connect to an on chip analog comparator COMP\_F for over voltage protection (OVP). Two current transformers are used to sense the MOSFET instantaneous current and their output I\_CT1 and I\_CT2 are connected to EAP1 and EAP2 respectively for current loop control. In addition, I\_CT1 and I\_CT2 are also connected to two on chip analog comparators COMP\_E and COMP\_D for cycle-by-cycle current protection. The control loop generates two PWM outputs DPWM1B and DPWM2B to drive the MOSFETs through gate driver.

An average current mode control is used for input current regulation: current reference is calculated based on  $V_{in}$ , voltage loop output and voltage feed forward. This averaged current reference is then translated to instantaneous signal as if they were sensed at the middle of CT output. The translated reference is then compared to the middle point value of CT output, the error goes through a 2-pole 2-zero digital compensator CLA1, a PWM signal is generated based on the compensator output to control the PFC.

It needs to be mentioned here that the above configuration accommodates with TI's PFC evaluation board UCD3138PFCEVM-026. It is not necessary to follow this configuration. For example, I\_CT1/I\_CT2 can be connected to a different EPA channel, a different CLA can be used for compensation, and PFC can be driven by different DPWM output as well. However, it is recommended using the similar configuration as UCD3138PFCEVM-026, so that most of the UCD3138PFCEVM-026 source code can be reused and the design period can be much shorter.

## 6 References

1. UCD3138 Device Datasheet, Lit # SLUSAP2, <http://www.ti.com/lit/gpn/ucd3138>
2. Using the UCD3138CC64EVM-030, Lit # SLUU886, <http://www.ti.com/lit/pdf/slue886>
3. UCD3138 PFC Application, Contact Texas Instruments

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Applications Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

Automotive and Transportation	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

### TI E2E Community

[e2e.ti.com](http://e2e.ti.com)