EVM User's Guide: PFC23338EVM-107

PFC23338EVM-107 Evaluation Motherboard

Description

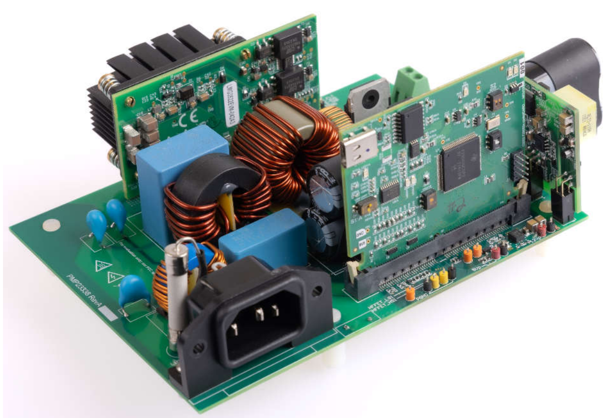
This reference design is a Gallium nitride (GaN) based, 3.6kW, single-phase, continuous conduction mode (CCM) totem-pole bridgeless power factor correction (PFC) converter targeting M-CRPS server power supply. This design includes E-meter functionality with 0.5% accuracy using AMCx306 as current sensing device, eliminating the need for external power metering ICs. An alternative low cost current sensing option using TMCS1133 is also provided in this design. The supply is designed to support a maximum input current of 16-ARMS and peak power of 3.6kW. The power stage is followed by a baby boost converter, which helps to greatly reduce the size of the bulk capacitor. This design works with TI GaN half bridge daughter cards (E.g. LMG3522EVM-042, LMG3422EVM-043, LMG3650EVM-113). LMG3522R030, LMG3422R030, LMG3650R025 are TI 25-30mΩ high-voltage GaN FET with integrated driver and protections, enable high efficiency and high power density. The F28003x C2000™ real-time microcontroller is used for all the advanced controls including re-rush current limit, baby boost operation during AC drop out event, e-metering, and communication between PFC and house-keeping controller. In addition, the F28003x microcontroller has built-in Sigma-Delta filter module to interface with AMC1306 precision current sensing reinforced isolated modulator to achieve industry leading low total harmonic distortion (iTHD) and high measurement accuracy. The PFC operates at a switching frequency of 65kHz and achieves peak efficiency of 98.93%.

Features

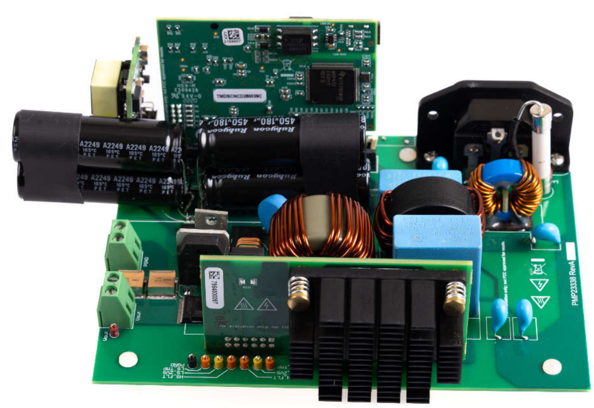
- Integrated e-metering function with 0.5% accuracy
- <10% iTHD at 0–10% load, <5% iTHD at 10%–20% load, <3% iTHD at 20%–50% load, <2% iTHD at 50%–100% load
- Peak efficiency of 98.93% at 230Vac
- Smart re-rush current control when AC comes back from dropout, meet M-CRPS re-rush current specification
- Include baby boost converter to extend holdup time and allow only 720µF bulk cap
- Two current sense options: Isolated Delta-Sigma Modulator (default) or Hall Sensor
- GaN optimized with driver integration
- 3.6kW rated power targeting 73.5mm M-CRPS PSU

Applications

- Rack and server PSU with 48V output
- Server PSU with 12V output
- Merchant telecom rectifiers
- Industrial AC-DC
- Single phase online UPS



Board Side View



Board Top View

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1 System Description

1.1 System Block Diagram

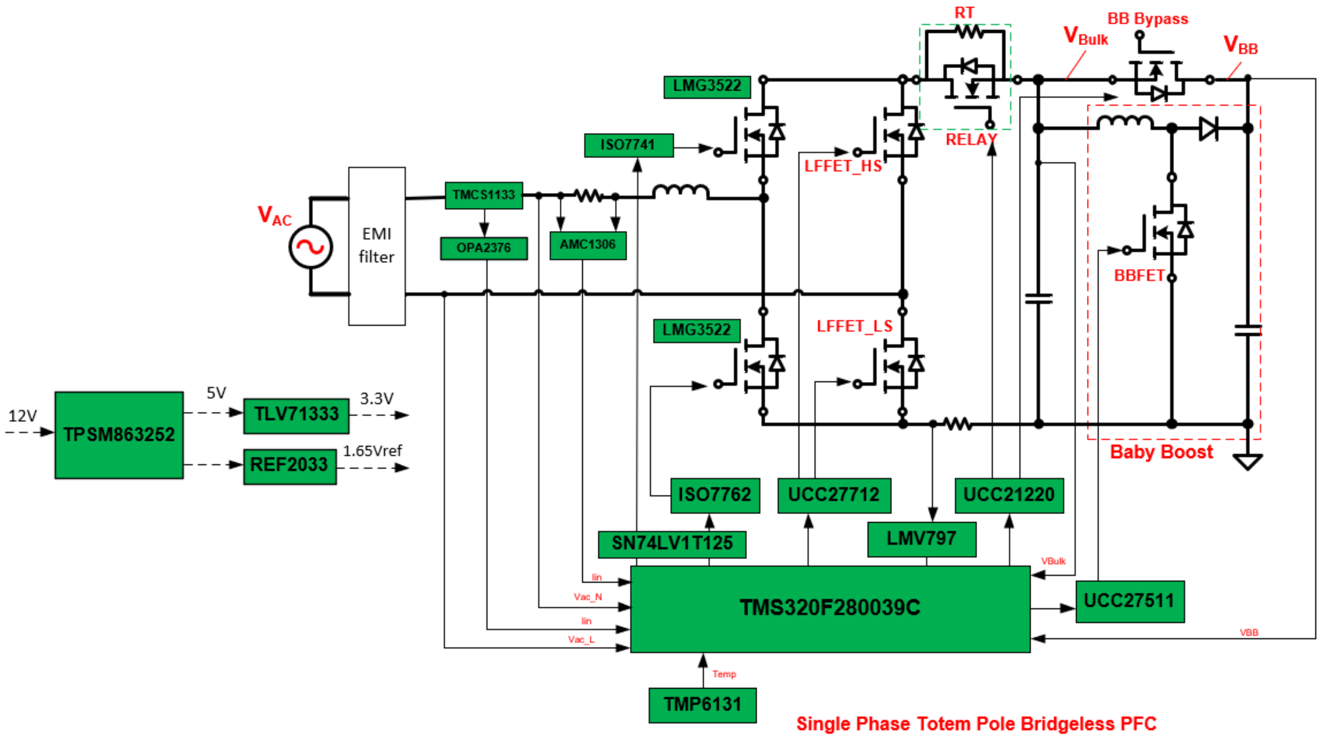

Figure 1-1. PMP23338 Block Diagram

1.2 Kit Contents

This EVM includes one totem-pole PFC motherboard and one PMP20306 bias supply daughter card. The GaN half-bridge daughtercard and C2000 control card will need to be ordered separately.

The EVM requires a C2000 control card. Please order and use the TMDSCNCD280039C.

The PFC23338EVM-107 uses the standard TI GaN daughter card pin interface. Any of the TI GaN daughtercards following this pin out work with the PFC23338EVM-107 (E.g. LMG3522EVM-042, LMG3422EVM-043, LMG3650EVM-113).

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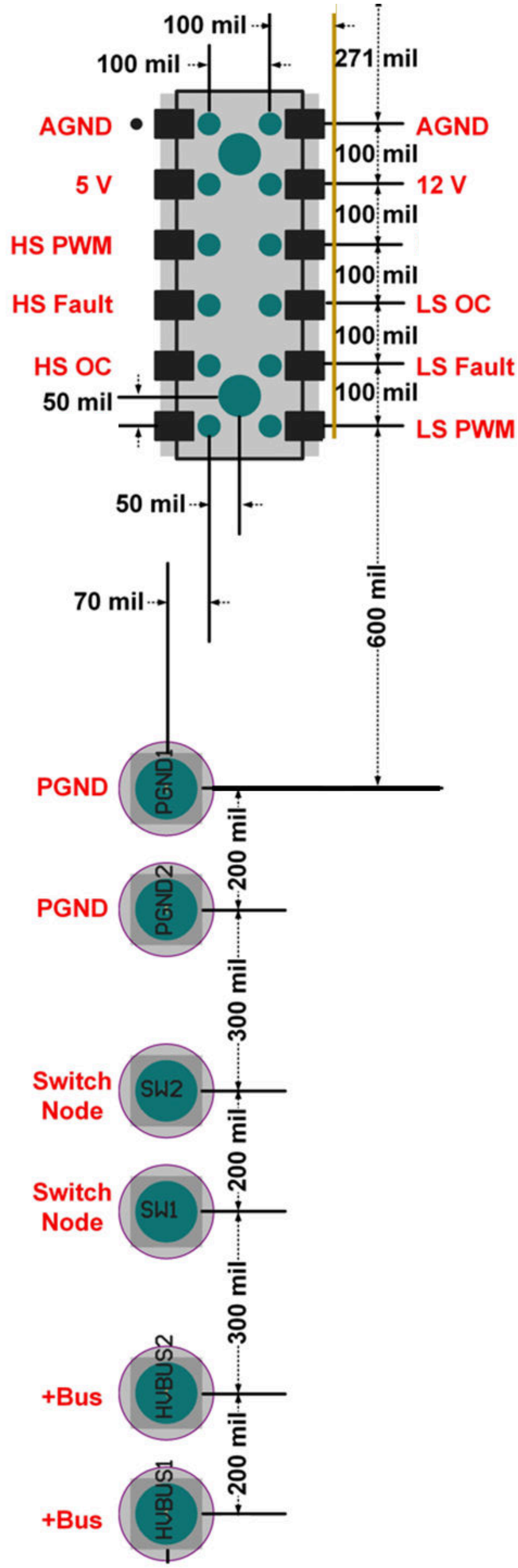

Figure 1-2. TI GaN Daughter Card Pinout

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1.3 Voltage and Current Requirements

Table 1-1. Voltage and Current Spec

Parameter	Specifications	Unit
Input Voltage	90–265	VAC
Line Frequency	47–63	Hz
Input Current (Max)	16	A
Output Voltage	385	V
High Line Output Power	3	kW
Low Line Output Power	1.5	kW

1.4 Design Consideration

1.4.1 Boost Inductor Design

Single phase continuous conduction mode (CCM) totem pole bridgeless PFC is selected in this design. As the design is targeting to achieve high power density with inductor height lower than 32mm, the switching frequency is selected at 65kHz so the EMI filter doesn't need to deal with the 1st and 2nd harmonic of the noise generated by PFC switching frequency (the targeted CISPR 32 conduction EMI limitation starts from 150kHz). In order to minimize the inductor dimension, low inductance is selected to allow low inductor winding turns applied. Powder iron core materials have a soft saturation characteristic which is suitable for high power CCM converters with high DC bias current. As the inductor inductance drops when the inductor current increases, core material has to be carefully chosen so the inductor doesn't saturate at heavy or peak loads.

The design target is to have less than 40% inductor current ripple at 3600W full load at 230Vrms input.

Use Equation 1 below:

$$L_{PFC} = \frac{1}{I_{L,ripple}\%} \cdot \frac{V_{IN,RMS}^2}{P_{IN}} \cdot \left(1 - \frac{\sqrt{2} \cdot V_{IN,RMS}}{V_o}\right) \cdot \frac{1}{F_{SW}} \tag{1}$$

The PFC inductor inductance can be calculated to be 92.21μH. That is, inductor inductance needs to be higher than 92.21μH at maximum inductor current. Use Equation 2 below.

$$I_{L,max} = \frac{\sqrt{2} \cdot P_{IN}}{V_{IN,RMS}} \cdot \left(1 + \frac{I_{L,ripple}\%}{2}\right) \tag{2}$$

Maximum inductor current can be calculated to be 26.64A.

Toroid inductors with Kool Mμ Max (Mag-inc P/N: 0079894A7HT19) and high flux cores (Mag-inc P/N: C058894A2HT19) were selected and wounded with the same 44 turns to get around 240μH inductance at 0A current also meet the 33mm height requirement. The two inductors were then applied to the PFC boost stage one by one to test their inductance with current applied. Figure 1-3 shows that the inductor inductance using High Flux core is able to achieve our inductance target with less number of turns over the inductor using Kool Mμ Max core. Therefore, inductor with high flux core is selected in this design.

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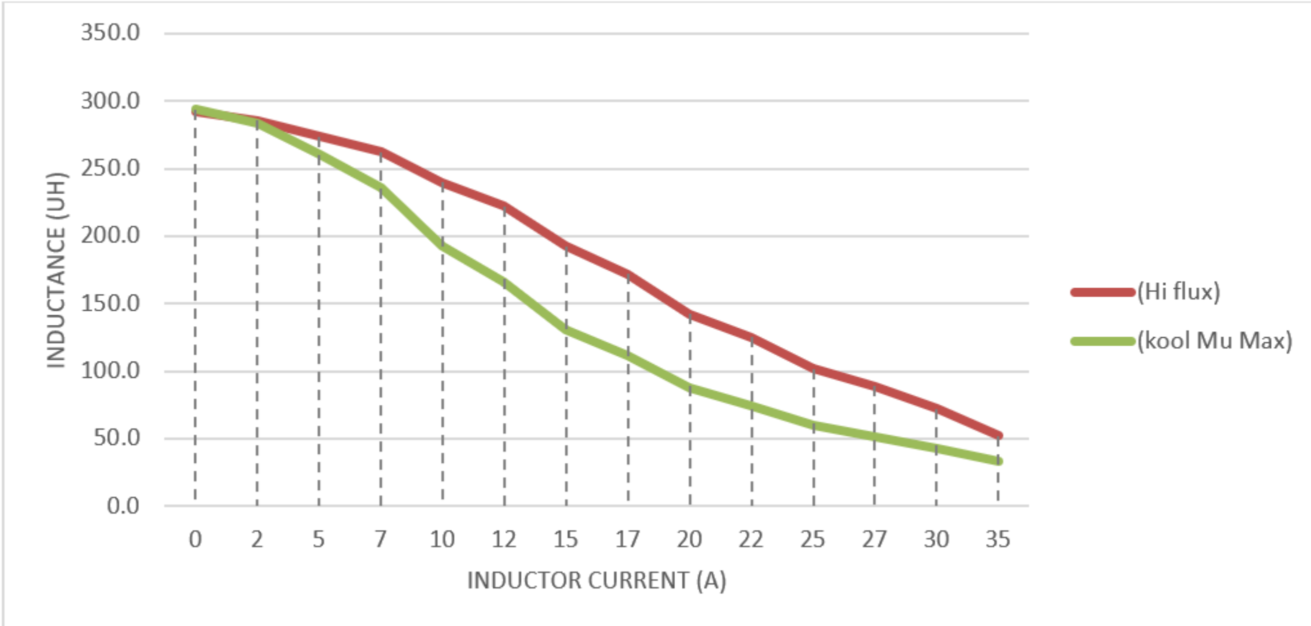

Figure 1-3. Inductance Versus Current

1.4.2 High Frequency Power Switch Selection

As wide-bandgap devices are the necessary high frequency power switches for a CCM totem-pole bridgeless PFC Boost rectifier, TI "GaN CCM Totem Pole PFC Power Loss Calculation Excel Sheet" is used to estimate the loss on the power switches and select which GaN device is applicable. A screen shot of the calculation results is shown in Figure 1-4. 30mΩ GaN devices (LMG3522R030 or LMG3422R030) are eventually selected for this design.

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TEXAS INSTRUMENTS

Constant
Input
Output

	Configuration 1	Configuration 2	
Configuration	CCM Totem Pole	CCM Totem Pole	
Select FET	LMG3422R030	LMG3522R030	
Select # of phase legs	1	1	
$R_{DS,ON}$	35	35	mΩ
$R_{th,\ junction\ to\ case}$	0.33	0.13	C/W
E_{on}	69	73	uJ
E_{off}	0.05	0.00	uJ
AC $V_{IN,\ RMS}$	230	230	V
DC V_{OUT}	390	390	V
Switching Frequency	65	65	kHz
Deadtime	100	100	ns
Ambient Temperature	50	50	C
Junction Temperature (T_j)	125	125	C
Slew Rate	100	100	V/ns
Max Output Power	3600	3600	W
$R_{th,\ case\ to\ ambient}$	6.474	6.588	C/W
$R_{th,\ junction\ to\ ambient}$	**6.804**	**6.718**	C/W
R_{DS,ON_temp}	0.063	0.063	Ω
Device Conduction Power Loss	8.035	8.035	W
Device Coss Power Loss	2.335	2.367	W
Overlap Power Loss	0.311	0.421	W
Deadtime Loss	0.277	0.277	W
Driver Loss	0.065	0.065	W
Total Loss per Device	**11.023**	**11.165**	W
Input RMS Current	15.972	15.972	A
Device Average Current	7.190	7.190	A

Figure 1-4. GaN FET Loss Calculation for CCM Totem Pole Bridgeless PFC

1.4.3 Input AC Voltage Sensing

The line and the neutral voltages are sensed by resistor divider to the ground of the board as shown in Figure 1-5. The two readings are subtracted on the controller to get the Vac sensing.

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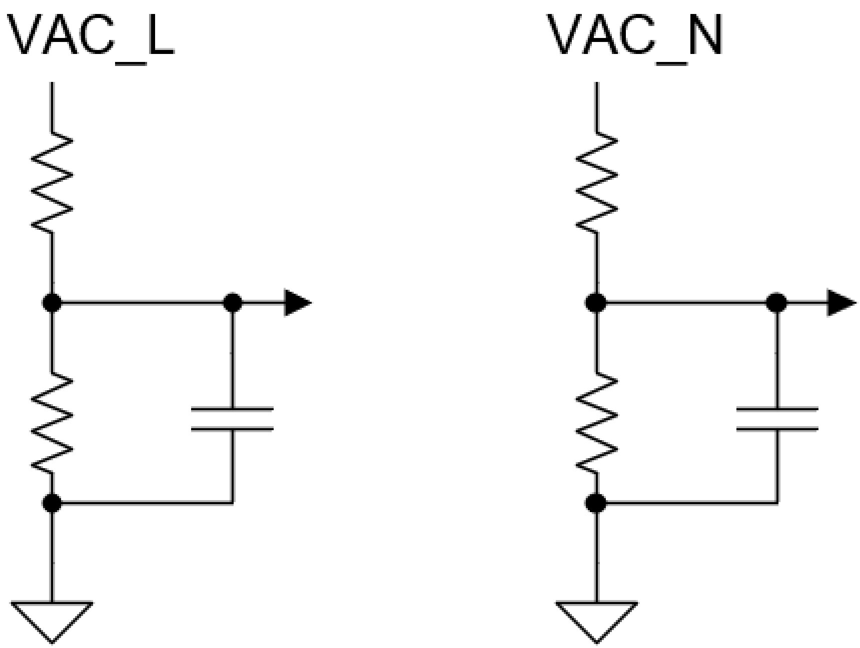

Figure 1-5. Input AC Voltage Sensing

1.4.4 Bulk Voltage Sensing

Similarly the bulk voltage is sensed by a resistor divider network as shown in Figure 1-6.

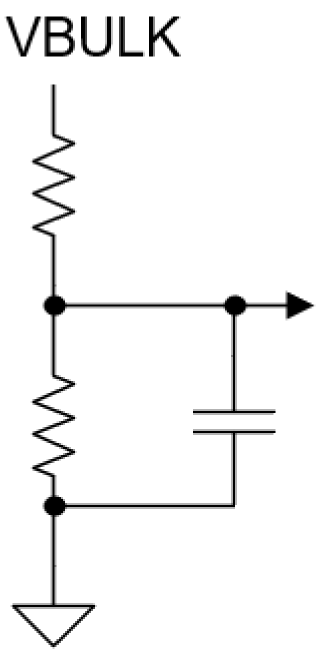

Figure 1-6. Bulk Voltage Sensing

1.4.5 Input Current Sensing

Ther are two current sensors in this design, but only 1 sensor is needed for PFC operation. The code supports both current sensors, seperated by a compiling flag, user can choose which sensor to use by changing the compiling flag and then re-download the code.

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Option 1: Use an isolated Delta-Sigma modulator AMC1306 to sense input current (Figure 1-7). This is the deafult configuration in the code. The output of AMC1306 is a 1-bit stream, as shown in Figure 1-8. This 1-bit stream is sent to C2000 and decoded by a built-in delta-sigma digital filter. Two delta-sigma digital filters are used, one is configured with high speed but relatively low resolution for PFC current loop control, the other is configured with high resolution but relatively low speed for e-metering (Figure 1-9). For details of AMC1306 and E-meter, please refer to [2].

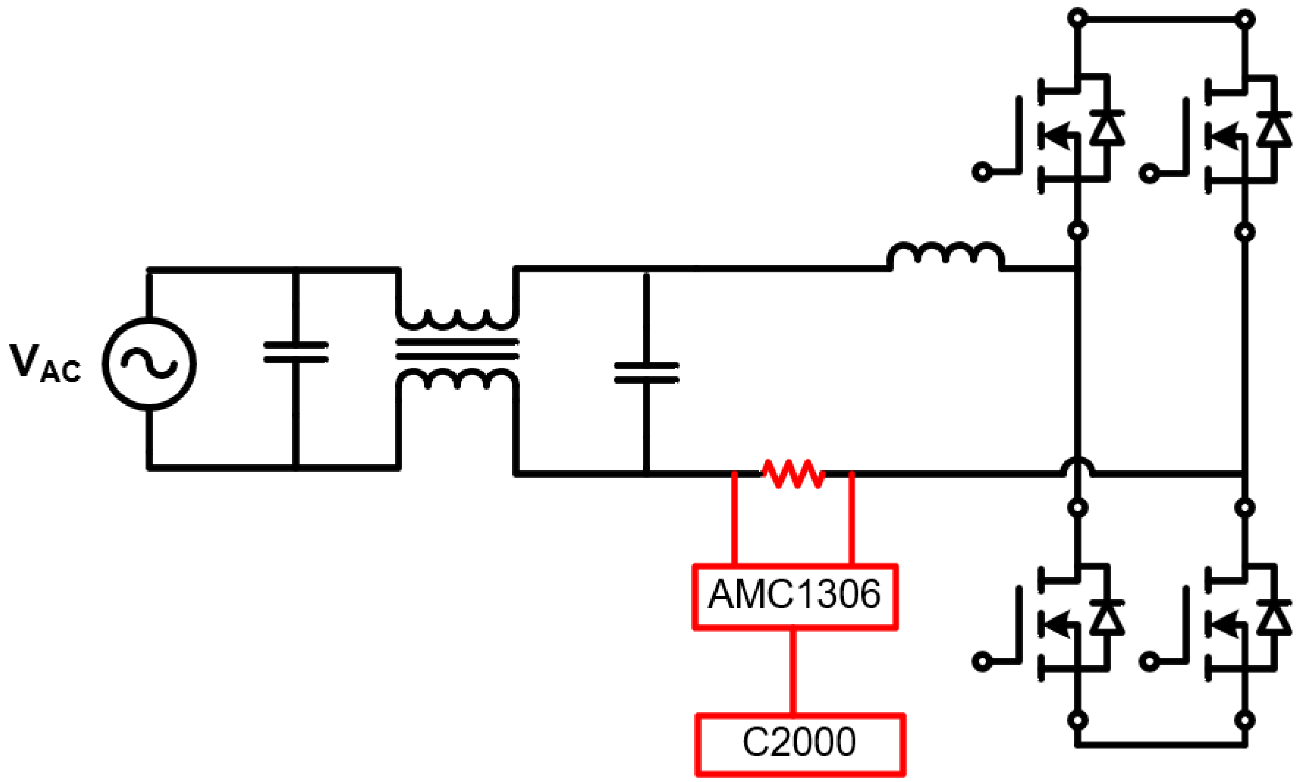

Figure 1-7. Use AMC1306 for Current Sensing

Figure 1-8. AMC1306 Output

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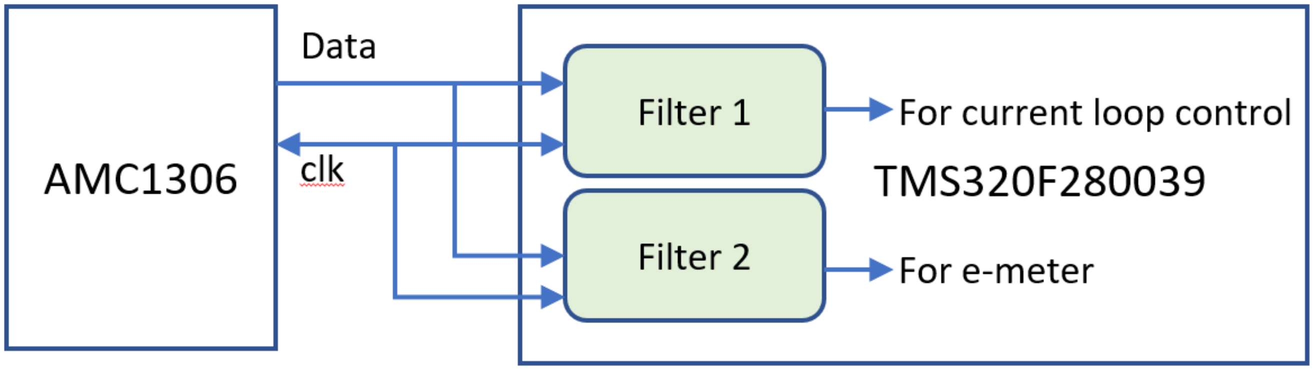

Figure 1-9. Delta-Sigma Filter Configuration

Option 2: Use a hall effect sensor TMCS1133 to sense input current. This is a conventional current sense method. The output of the hall sensor is amplified by a op-amp circuit (Figure 1-10). With sine wave AC input, the output of hall sensor is a sine wave with a DC offset. This signal is measured by C2000, then substract the DC offset to get the real AC input current signal.

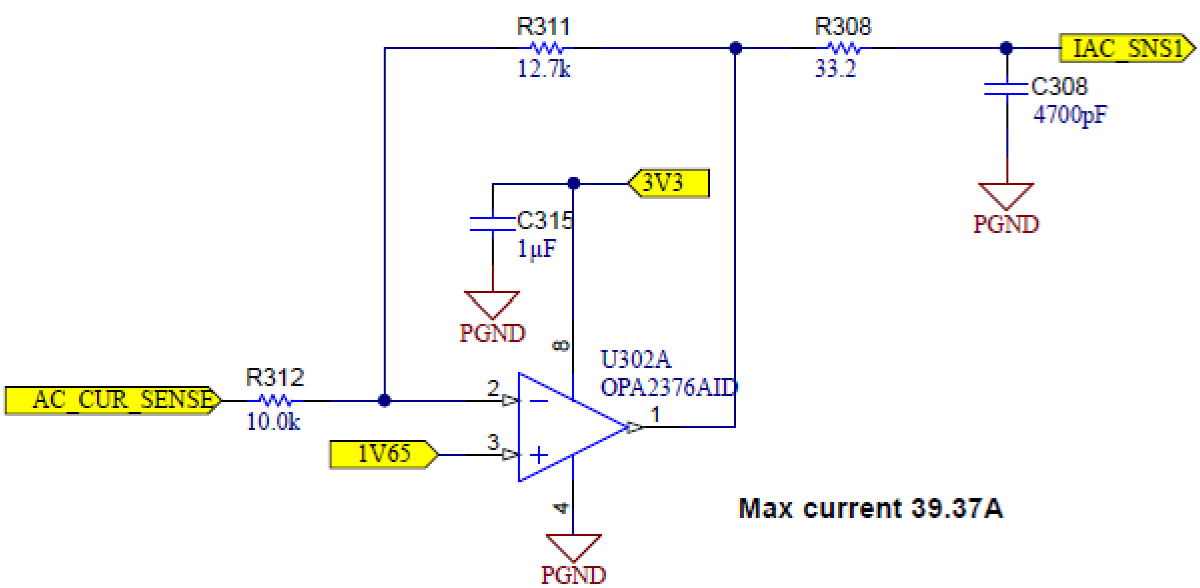

Figure 1-10. Current sense amplifier

1.4.6 Baby Boost Design

To maintain holdup time and reduce bulk capacitance, a baby boost converter is added between the PFC and DC/DC as shown in the Figure 2-1. The baby boost converter is a compact boost converter that only operates during AC dropout events. During normal operation, the baby boost converter is off and bypassed by a MOSFET. When AC line dropout occurs, the Bypass FET turns off, baby boost converter turns on to ensure VBB maintains above the UVLO level for the isolated DC/DC converter. In order to minimize the magnetic dimension, the switching frequency of baby boost is set at 500KHz.

1.4.7 Relay

A MOSFET, as shown in Figure 2-1, is used as a solid-state relay (SSR) in this design. The SSR provides faster response time, wider operational temperature range, higher reliability than the traditional mechanical relay. Moreover, M-CRPS requires input current (re-rush current) must be limited when the input voltage returns after an input brown out / black out event for a few ms. Due to the fast response time, the SSR is controlled to do a rapid on/off operation to limit the re-rush currrent. Details of re-rush control can be found in [1][2].

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1.4.8 Protection

1.4.8.1 Over Voltage Protection

Vbus voltage is measured by ADC, firmware turns off PFC if Vbus exceeds 450V.

1.4.8.2 Over Current Protection

Over current protection is achieved through on-chip comparator. It can be configured as shut down and latch (default), or cycle-by-cycle current limit. User can choose which protection to be used by changing the compiling flag and then re-download the code.

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2 Software

2.1 Quickstart guide

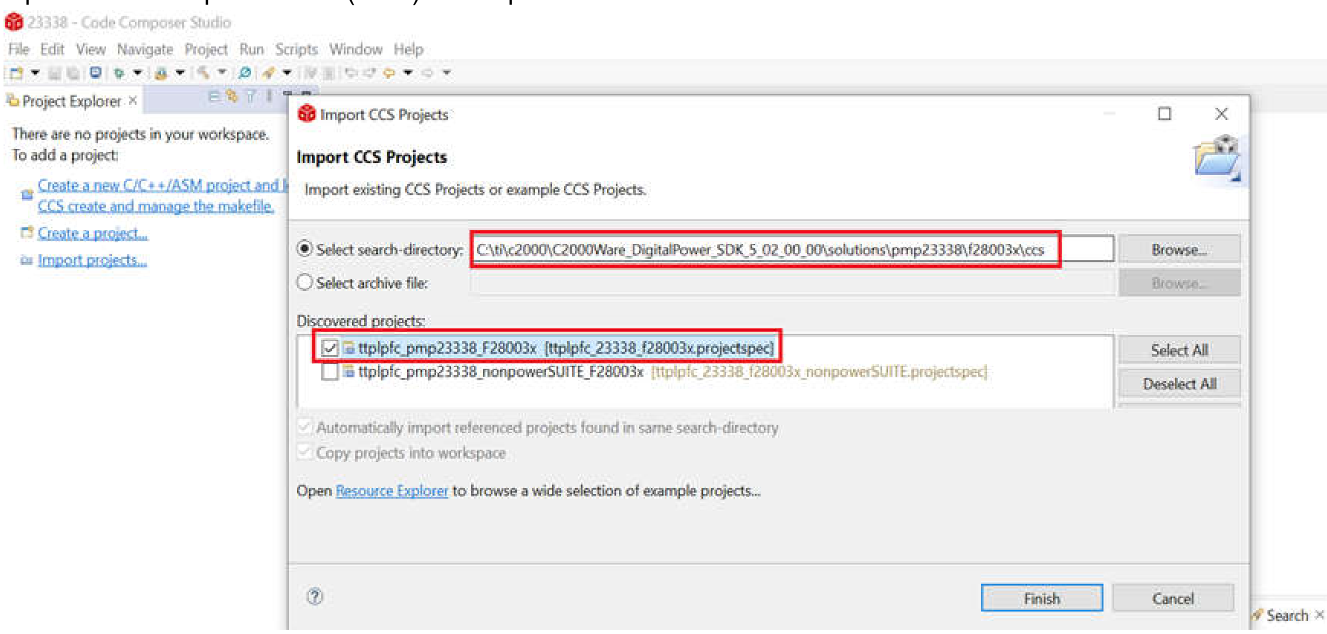
For quickstart, to begin testing with AC input closed voltage and current control loop, begin reading below in *Download Firmware* and follow this guide.

To explore full options and labs for this board review the software guide for the code. The software guide is located in the folder downloaded for the DigitalPower_SDK. To find the software guide, locate the DigitalPower_SDK folder then follow: C2000Ware_DigitalPower_SDK_x_xx_xx_xx → solutions → pmp23338 → docs → pmp23338_software_guide.pdf. This guide goes through the steps for testing with the PFC23338EVM-107 and the different labs included in the software for this EVM. The guide also includes helpful information on the design of the control for the system.

2.2 Download Firmware

PFC23338EVM-107 needs to works with C2000 control card TMDSCNCD280039C. In the case your control card has not been downloaded PFC23338EVM-107 code yet, follow these steps to download the code:

1. Download the latest digital power SDK from: https://www.ti.com/tool/C2000WARE-DIGITALPOWER-SDK#downloads
2. Install the digital power SDK and locate the pmp23338 firmware in the solution folder.
3. Open Code Compser Studio (CCS) and import the code as shown below:



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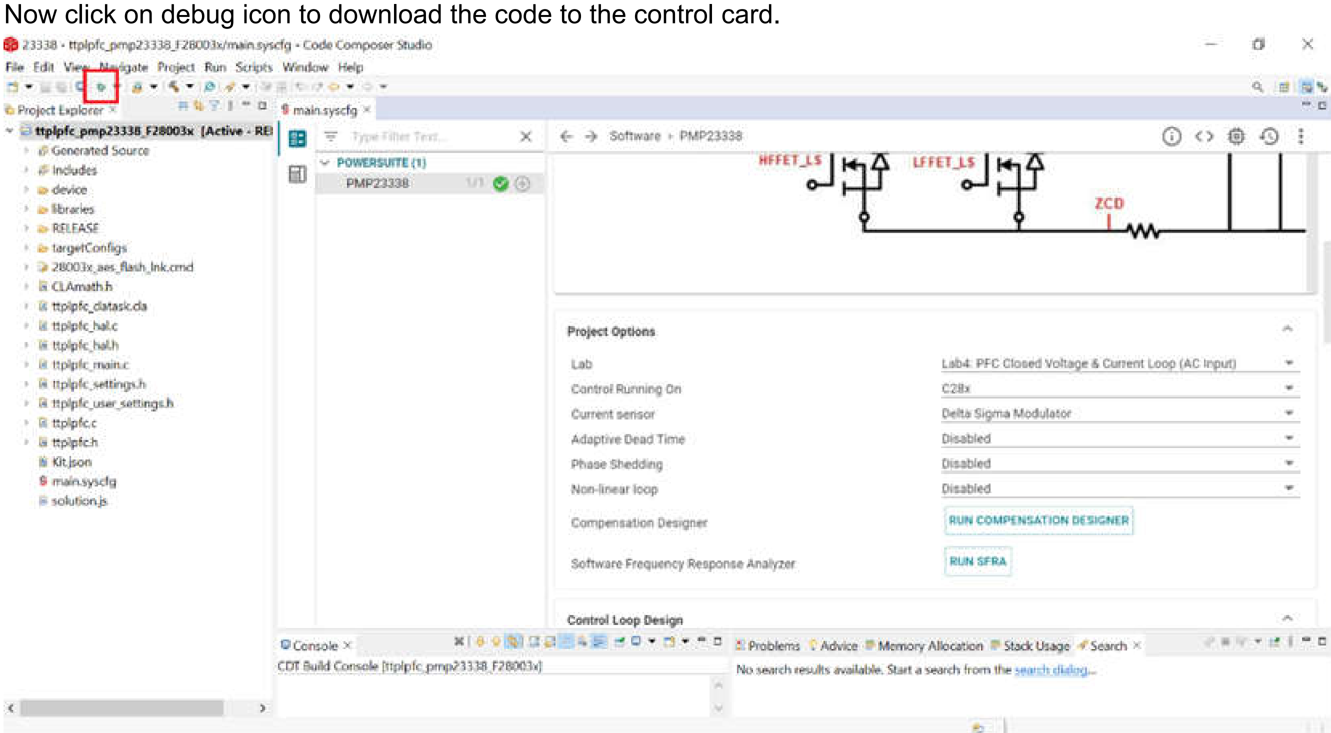
4. Move the Boot pin switches to position 1 of the TMDSCNCD280039C control card:

5. For downloading and flashing the code, connect the control card with PC using the USB cable.
6. Now click on debug icon to download the code to the control card.



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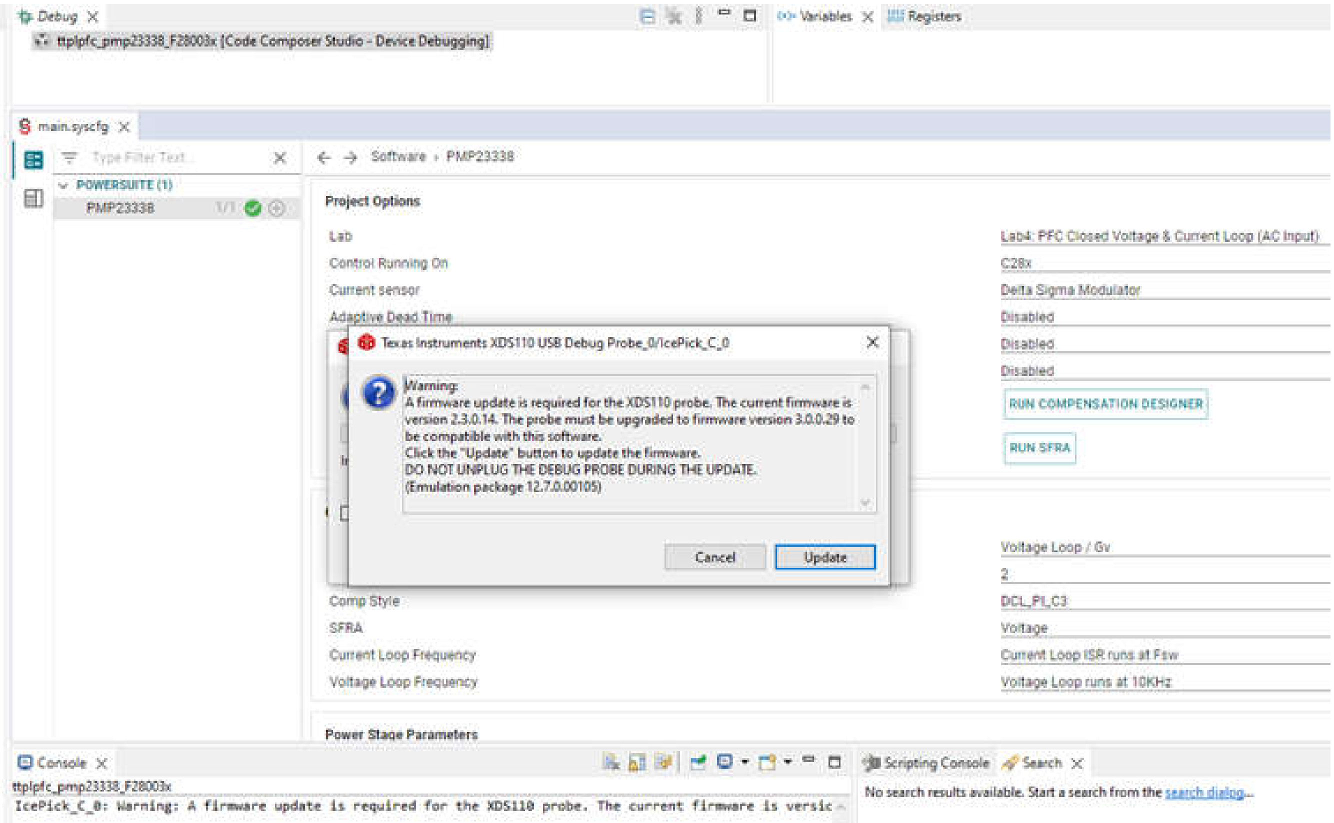
7. Click on update if prompted.



8. After the code is downloaded/flashed, disconnect the control card from the PC.
9. Install the control card to PFC23338EVM-107 board

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3 Power Up

3.1 Required Equipment

- AC Source: 300V, 20A
- Electronic load
- Digital Power Meter
- Isolated voltage probes
- Current probe

3.2 Considerations

1. This PFC needs to be used together with the C2000 control card TMDSCNCD280039C, PMP20306 isolated bias supply reference design and LMG3522EVM-042/LMG3422EVM-043 reference design.
2. Due to the totem-pole topology, the PFC ground (PGND) is floating. This can lead to common-mode current issues with improper test equipment setups. Use differential voltage probes when measuring signals.

3.3 Start-Up Sequence

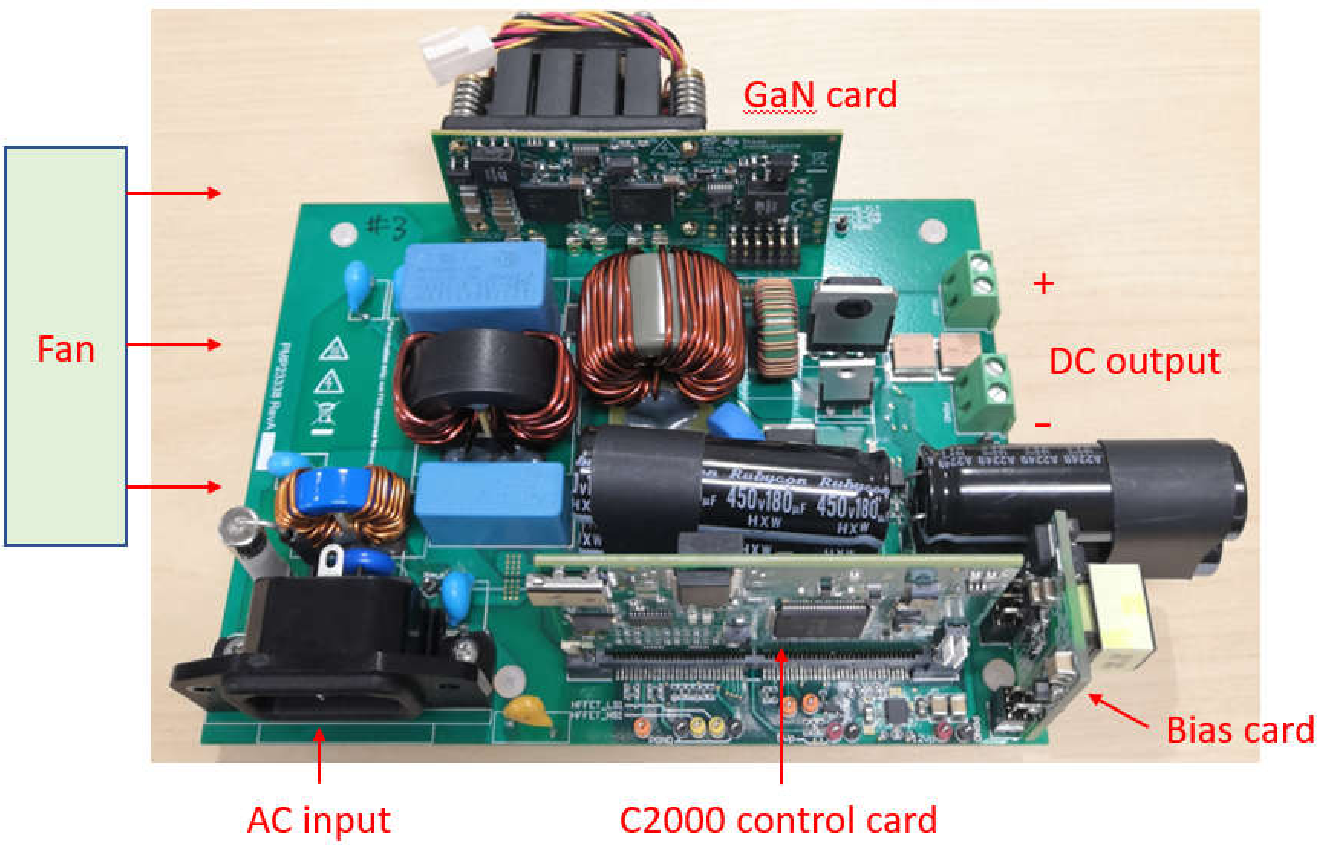

Figure 3-1. Test setup

Start-up sequence:

1. Check GaN card, C2000 control card and Bias card are plugged in correctly and tightly
2. Use a fan for cooling during test
3. Connect a high voltage load to DC output, set load to 0.1A
4. Connect AC source to AC input
5. Use current probe to monitor AC input current, use voltage meter to measure DC output voltage
6. Set AC output at 115V/60Hz, turn on AC, you see DC output voltage is regulated at about 385V
7. Graduate increase load. Full load: 1800W@115VAC, 3600W@230VAC

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4 Implementation Results

4.1 Start-Up Waveform

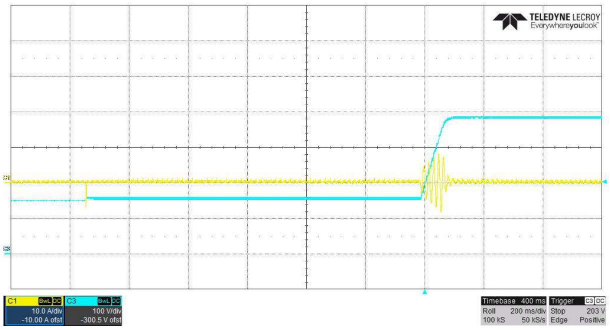

Figure 4-1. PFC starts up at 115 VAC, no load

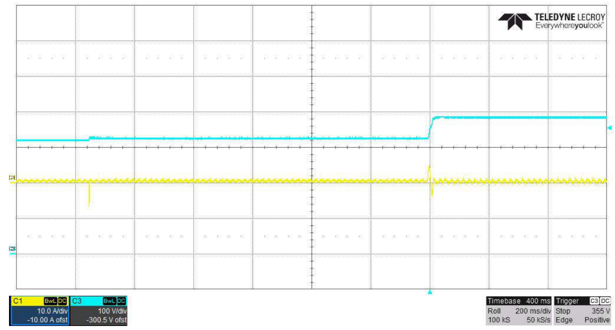

Figure 4-2. PFC starts up at 230 VAC, no load

Note

Blue: Vout, Yellow: Iin

4.2 THD Performance

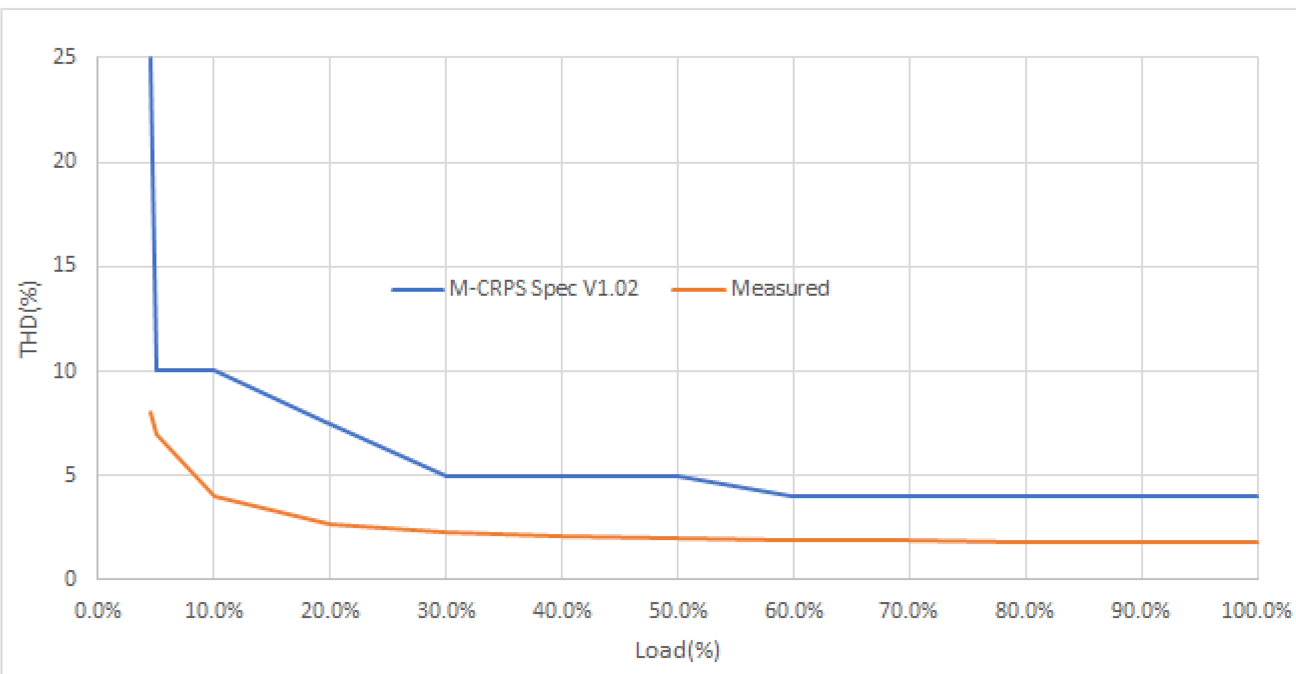

Figure 4-3. THD Graph at 120 VAC Input

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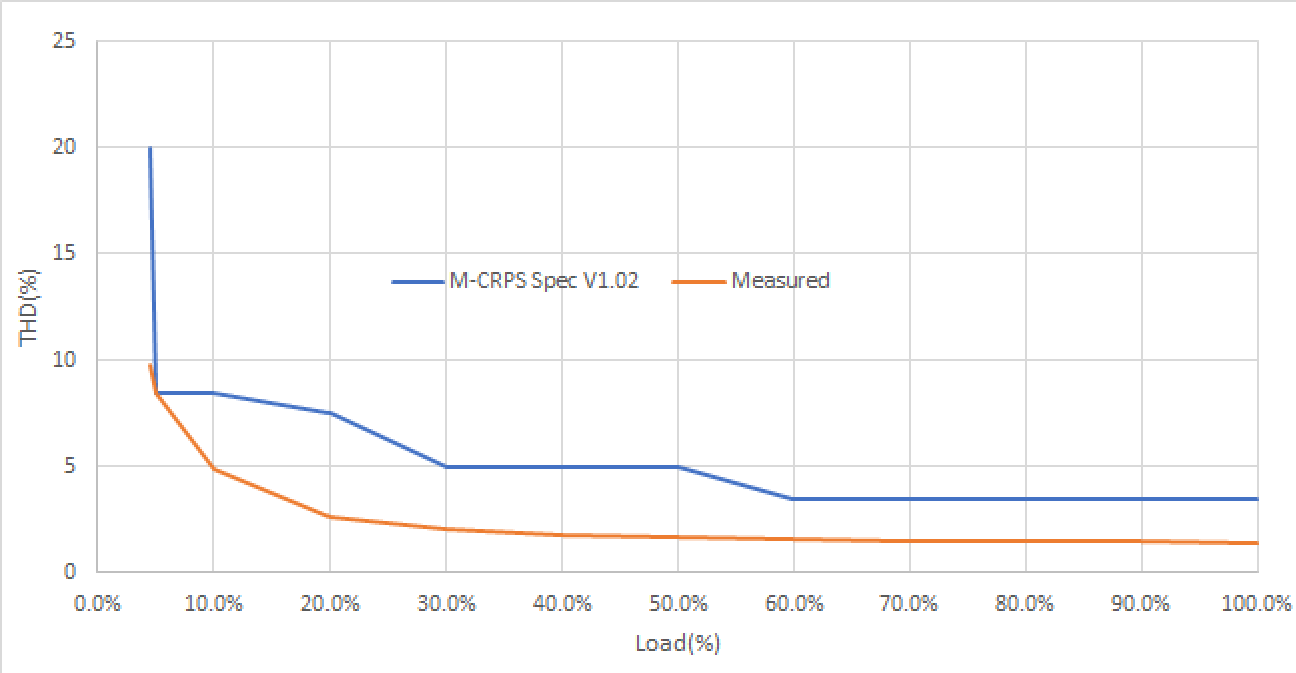

Figure 4-4. THD Graph at 240 VAC Input

4.3 Power Factor

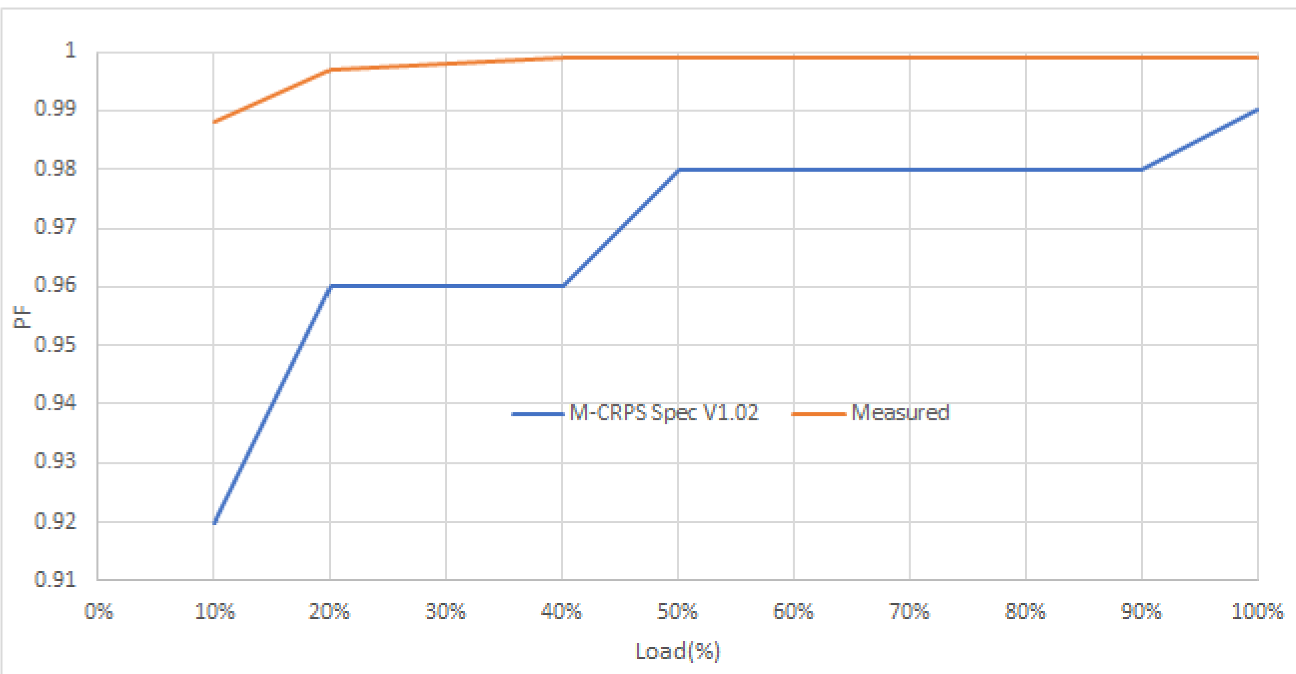

Figure 4-5. Power Factor at 120 VAC input

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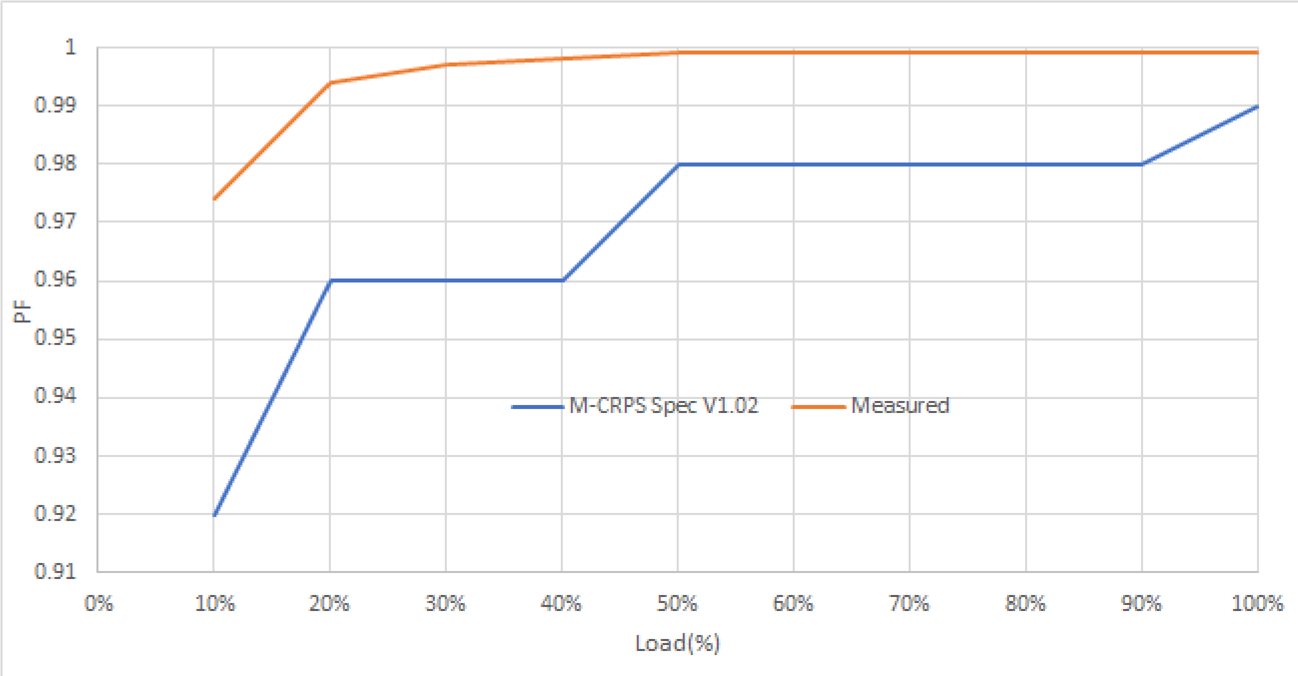

Figure 4-6. Power Factor at 240 VAC Input

4.4 Efficiency Graph

Conditions

- Switching Frequency: 65kHz
- GaN Slew Rate: 100V/ns
- Output: 385V
- Power analyzer: WT5000
- Relay and BB bypass FETs shorted
- Auxiliary supply not included

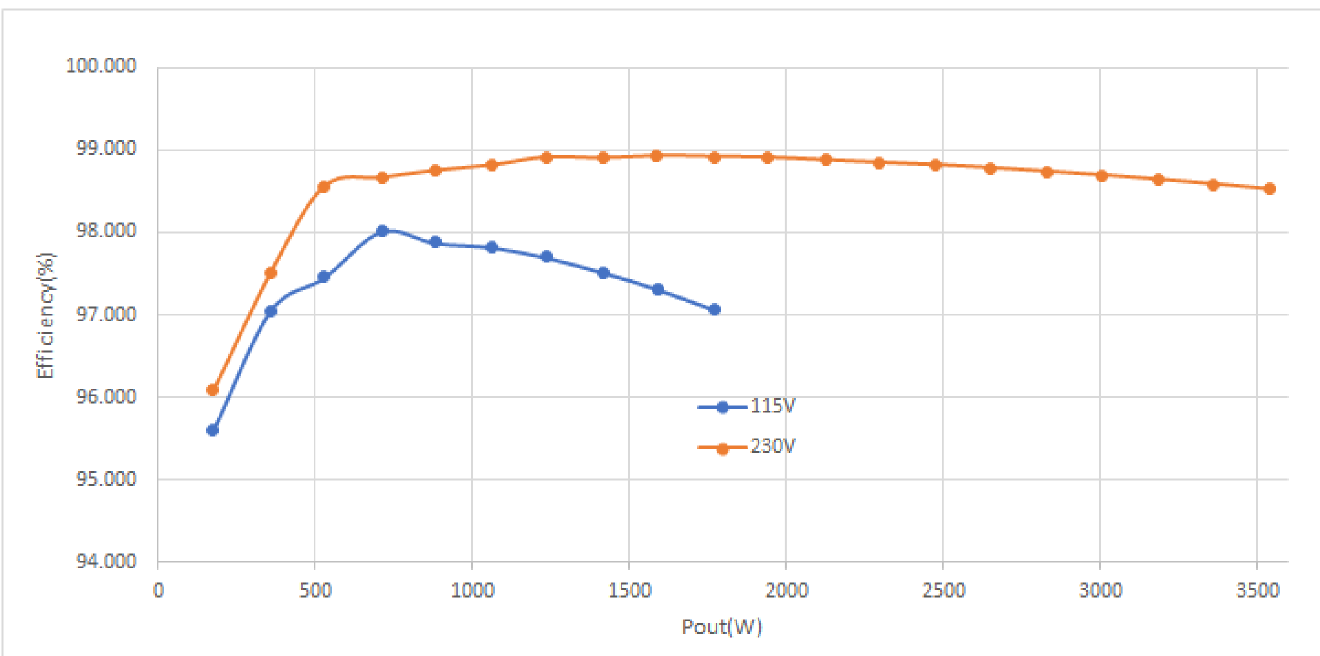

Figure 4-7. Efficiency Graph

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4.5 E-meter Performance

Power analyzer used in the test: WT5000

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4.6 Load Transients

Note

In the follwing figures: Blue: Vout, Pink: Iin, Yellow: Iout

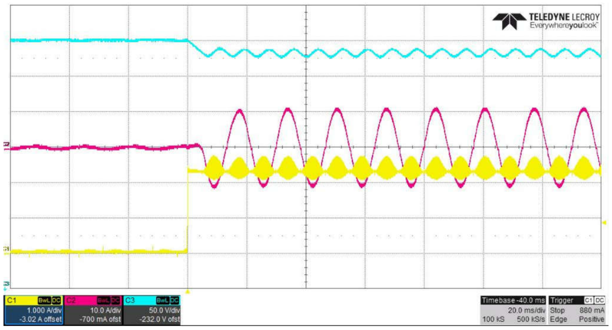

Figure 4-8. 115VAC, 0% -> 50% load

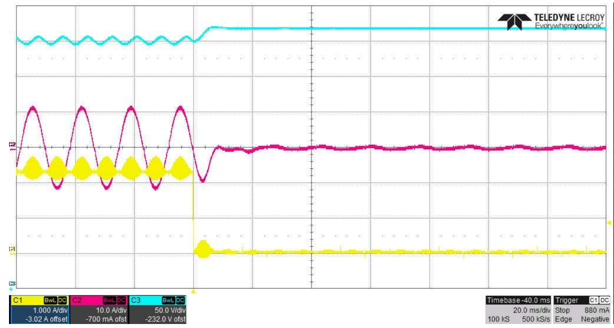

Figure 4-9. 115VAC, 50% -> 0% load

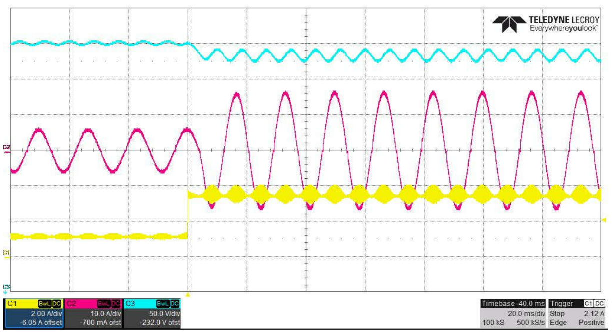

Figure 4-10. 115VAC, 25% -> 75% load

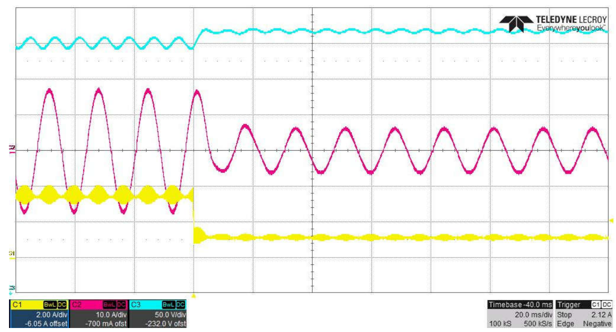

Figure 4-11. 115VAC, 75% -> 25% load

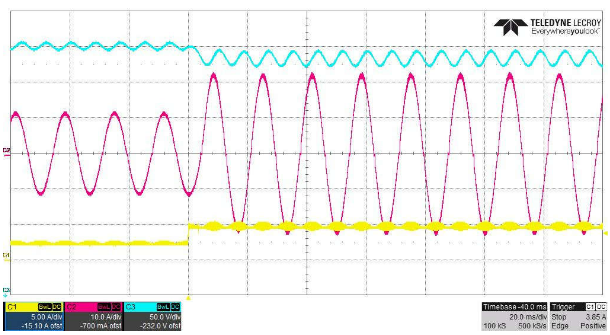

Figure 4-12. 115VAC, 50% -> 100% load

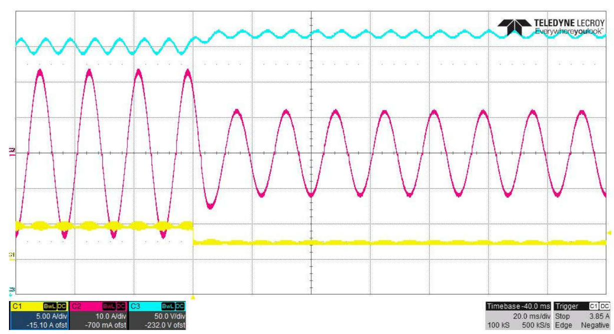

Figure 4-13. 115VAC, 100% -> 50% load

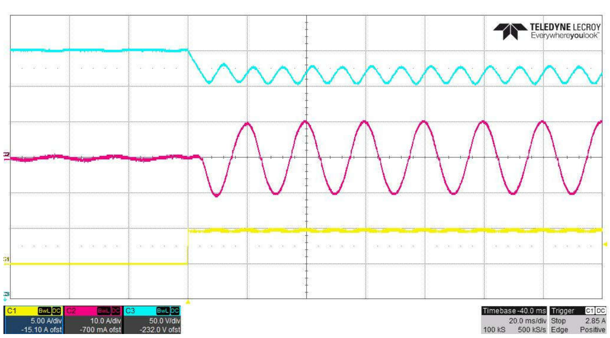

Figure 4-14. 230VAC, 0% -> 50% load

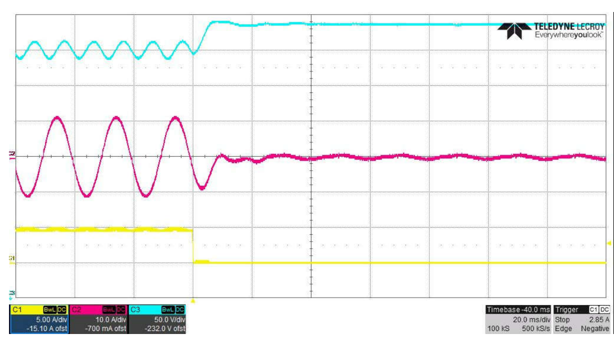

Figure 4-15. 230VAC, 50% -> 0% load

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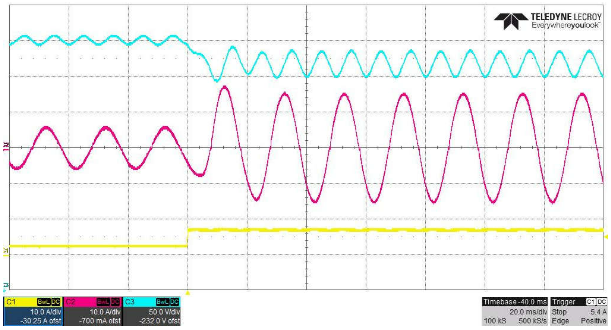

Figure 4-16. 230VAC, 25% -> 75% load

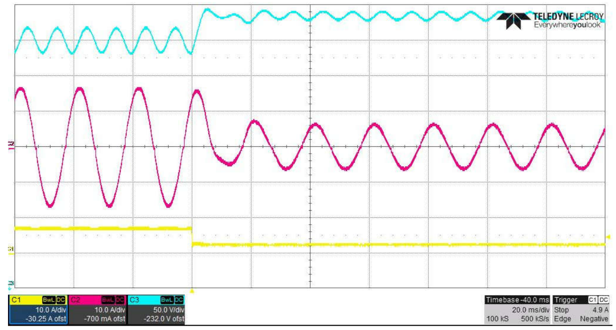

Figure 4-17. 230VAC, 75% -> 25% load

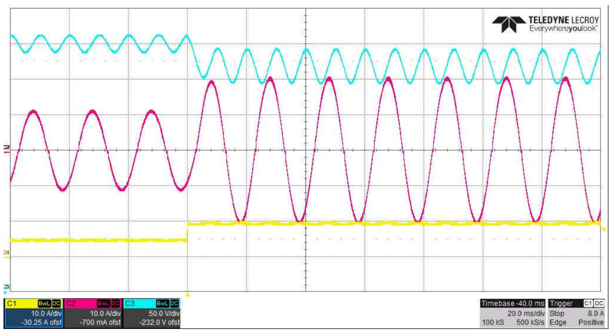

Figure 4-18. 230VAC, 50% -> 100% load

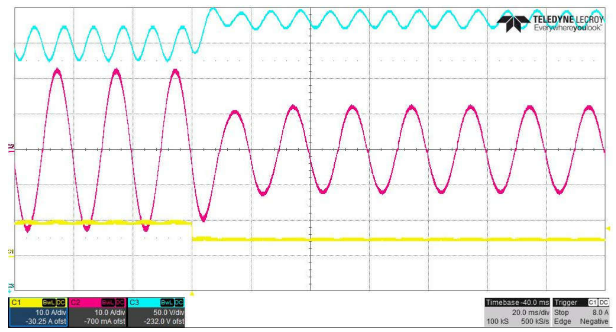

Figure 4-19. 230VAC, 100% -> 50% load

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4.7 Input Current Waveforms

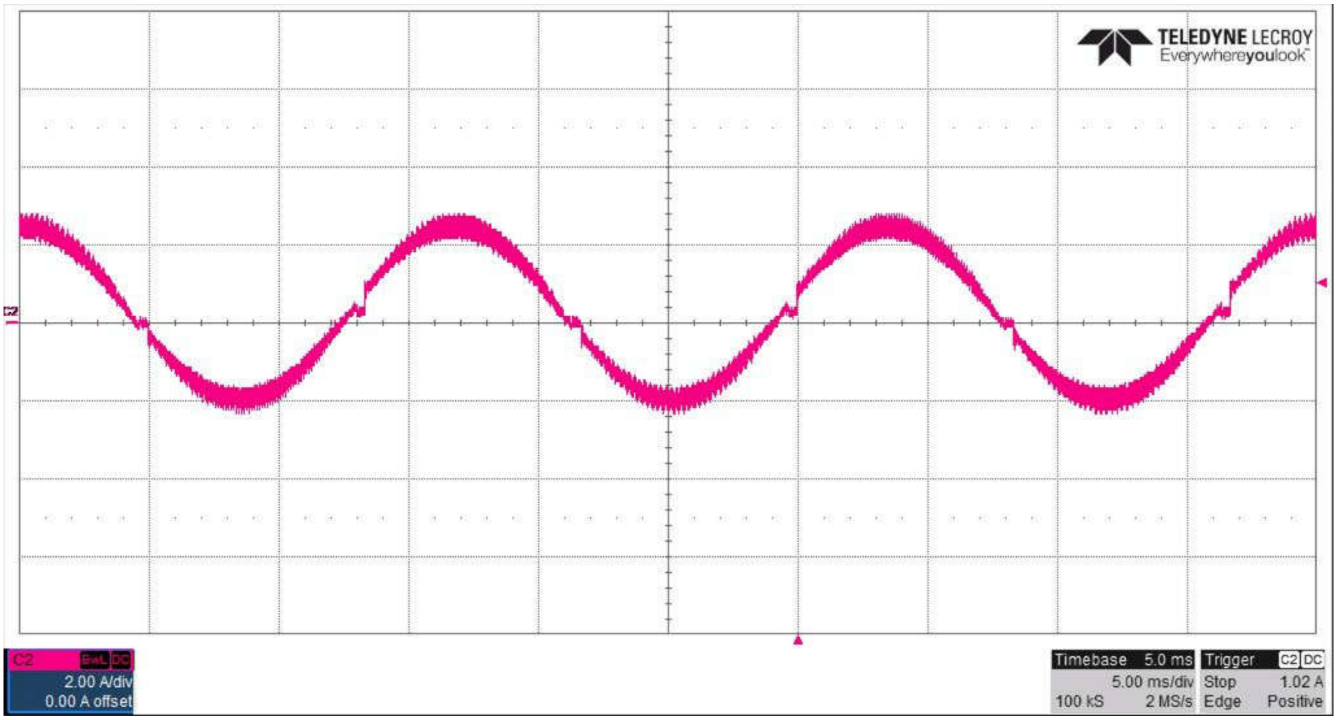

Figure 4-20. 120VAC 10% Load

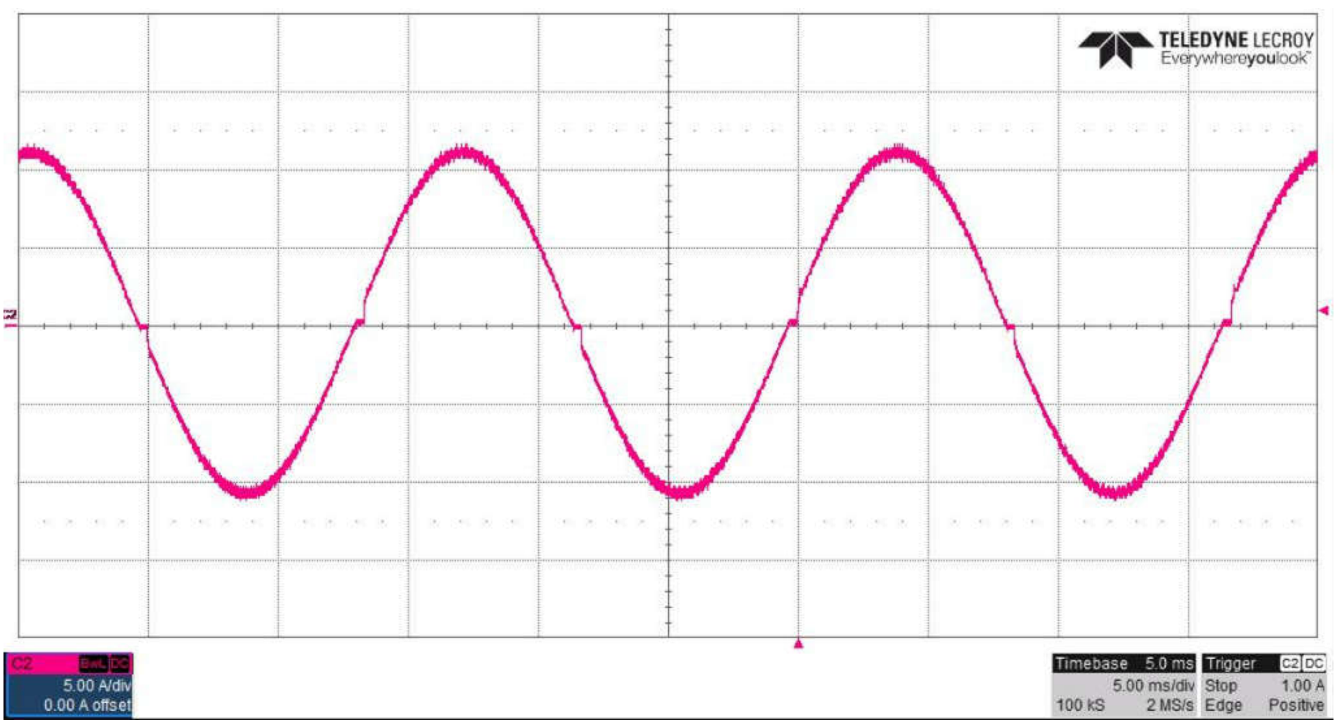

Figure 4-21. 120VAC 50% Load

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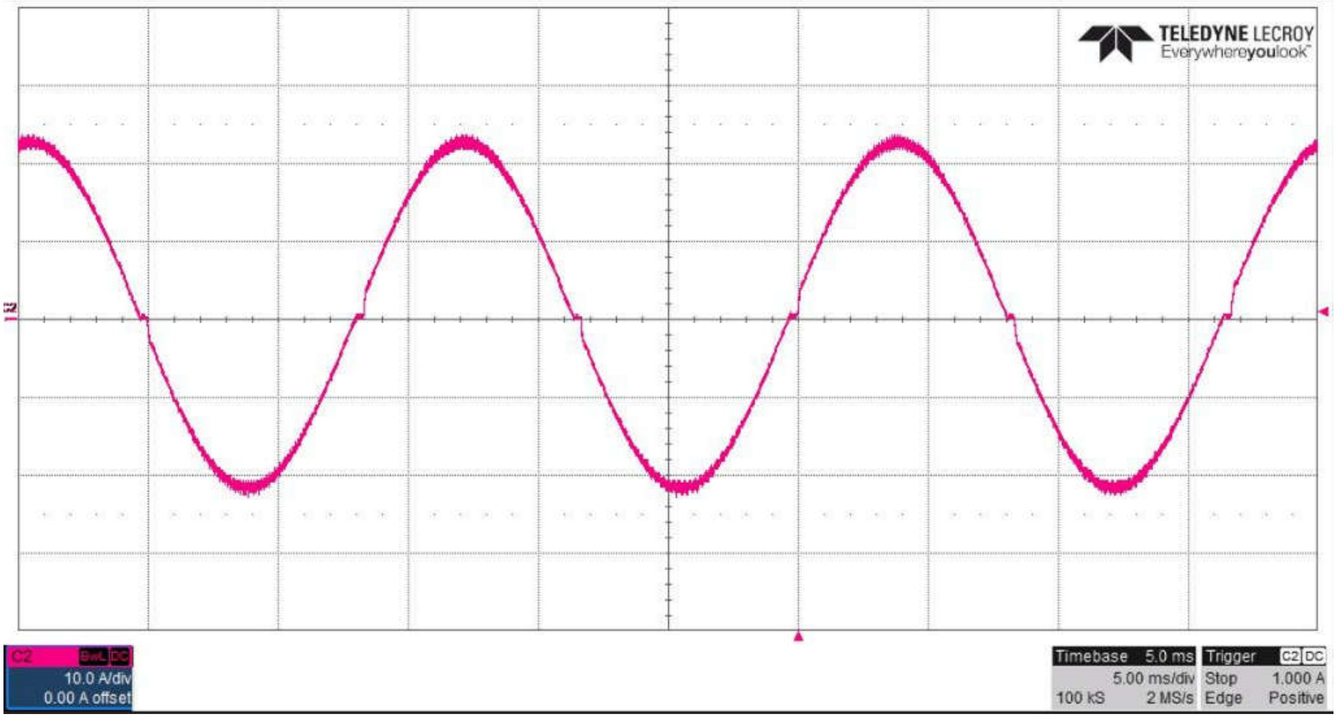

Figure 4-22. 120VAC 100% Load

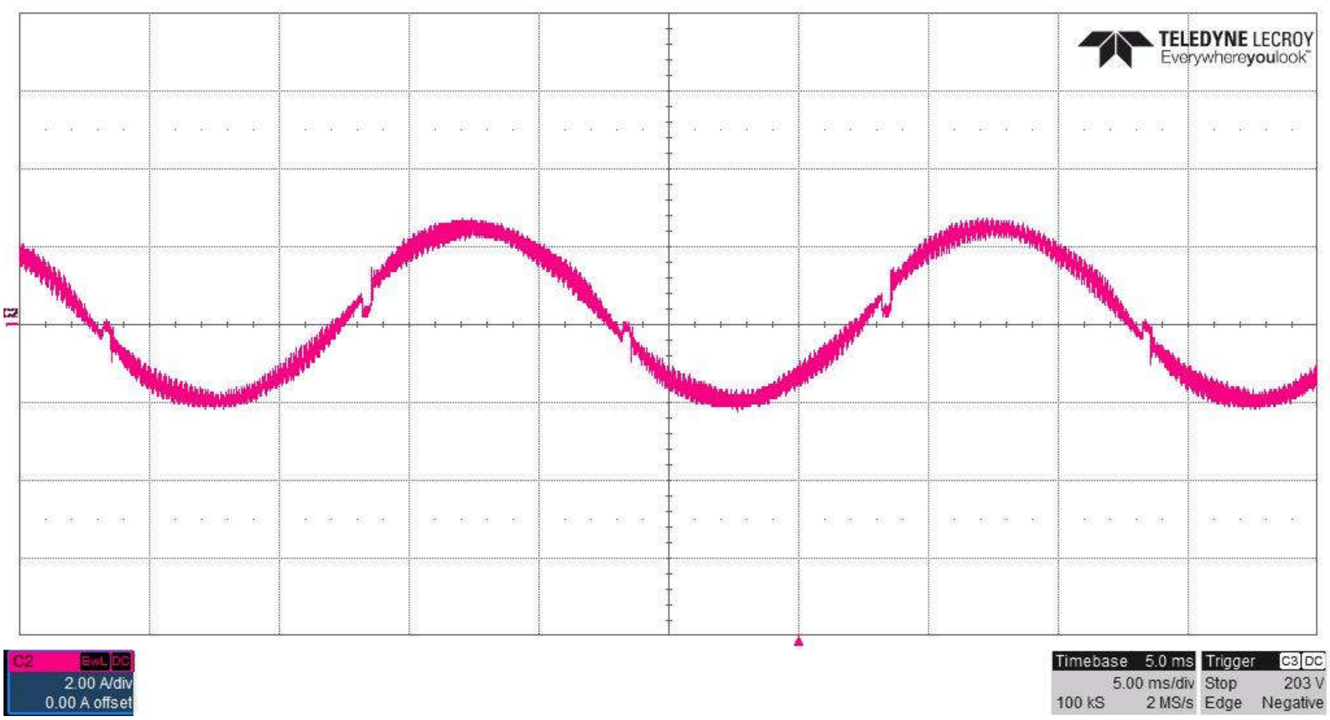

Figure 4-23. 240VAC 10% Load

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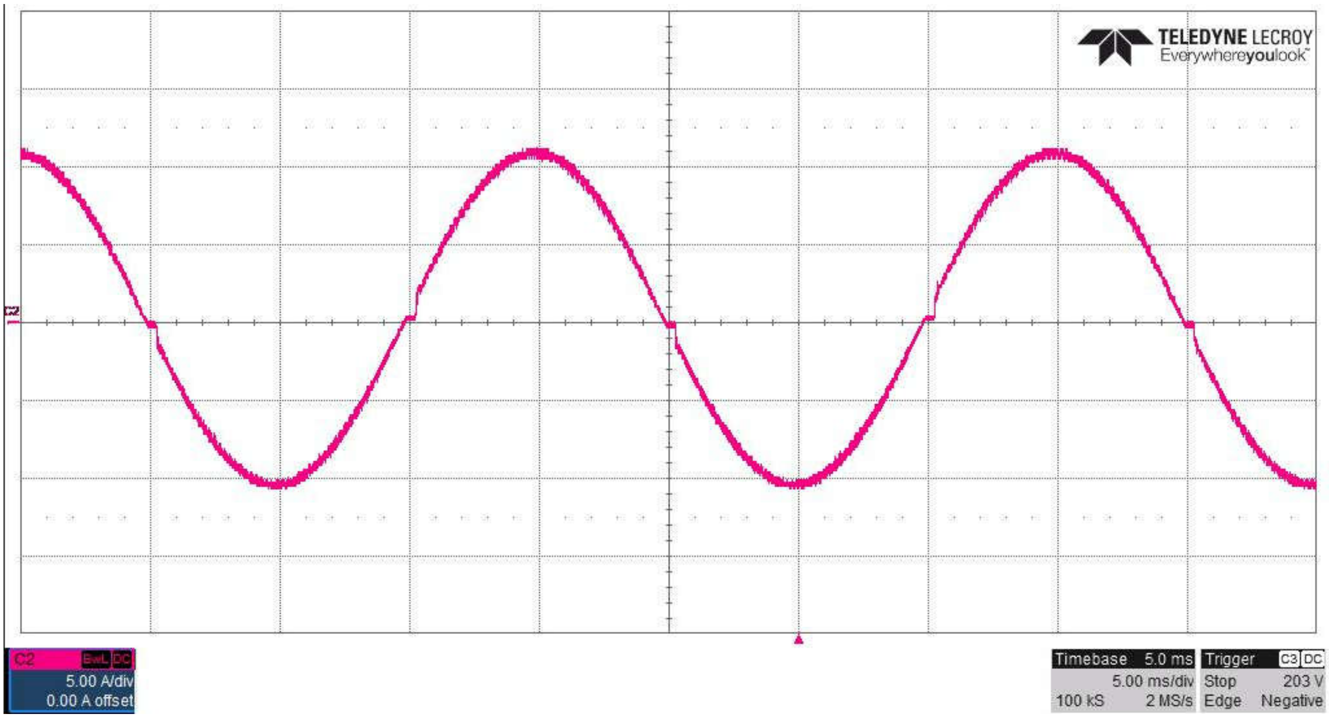

Figure 4-24. 240VAC 50% Load

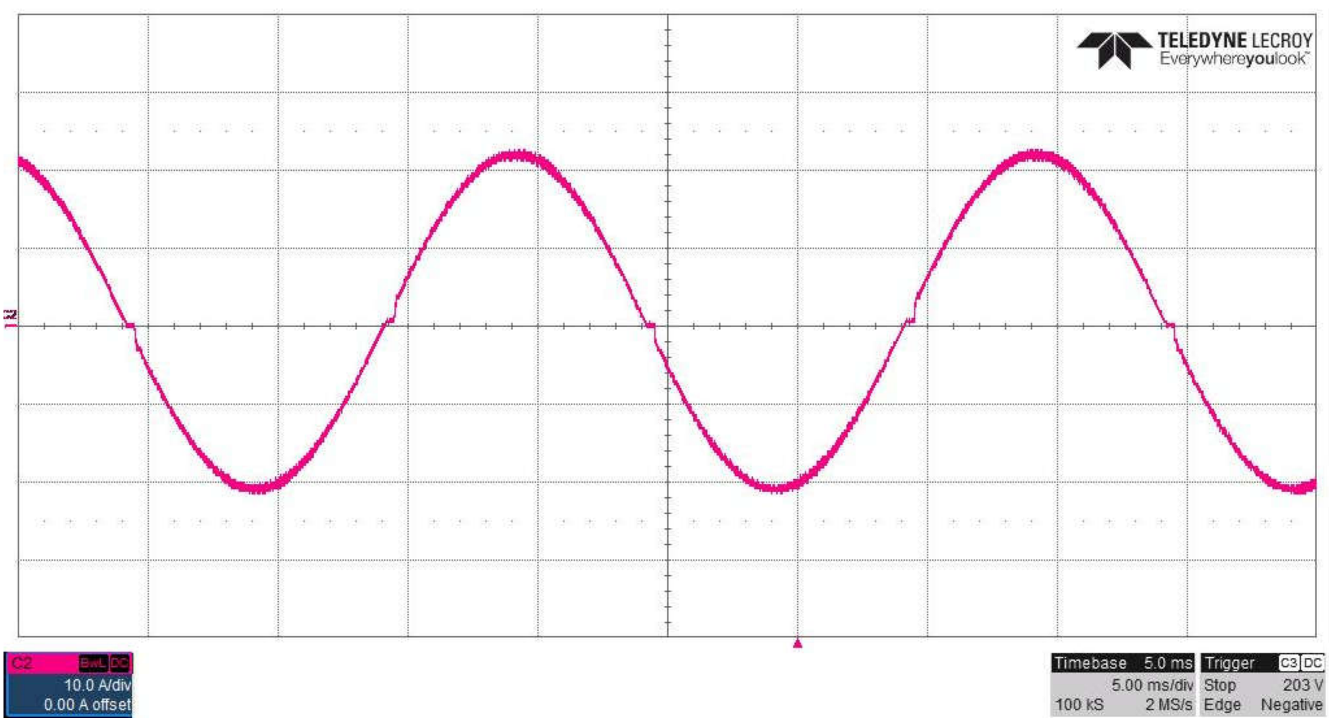

Figure 4-25. 240VAC 100% Load

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4.8 AC Drop Test

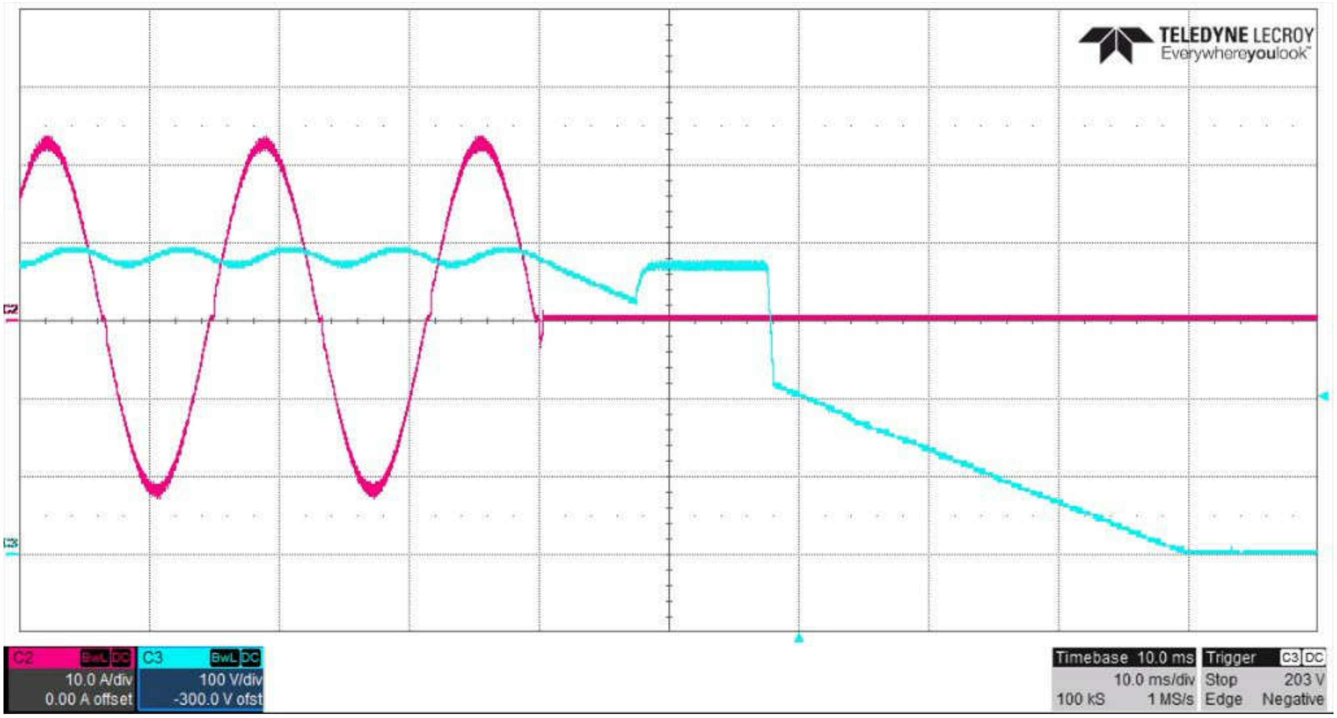

Figure 4-26. AC Drop at 120 VAC, 1800 W Load (Blue: Vout, Pink: Iin)

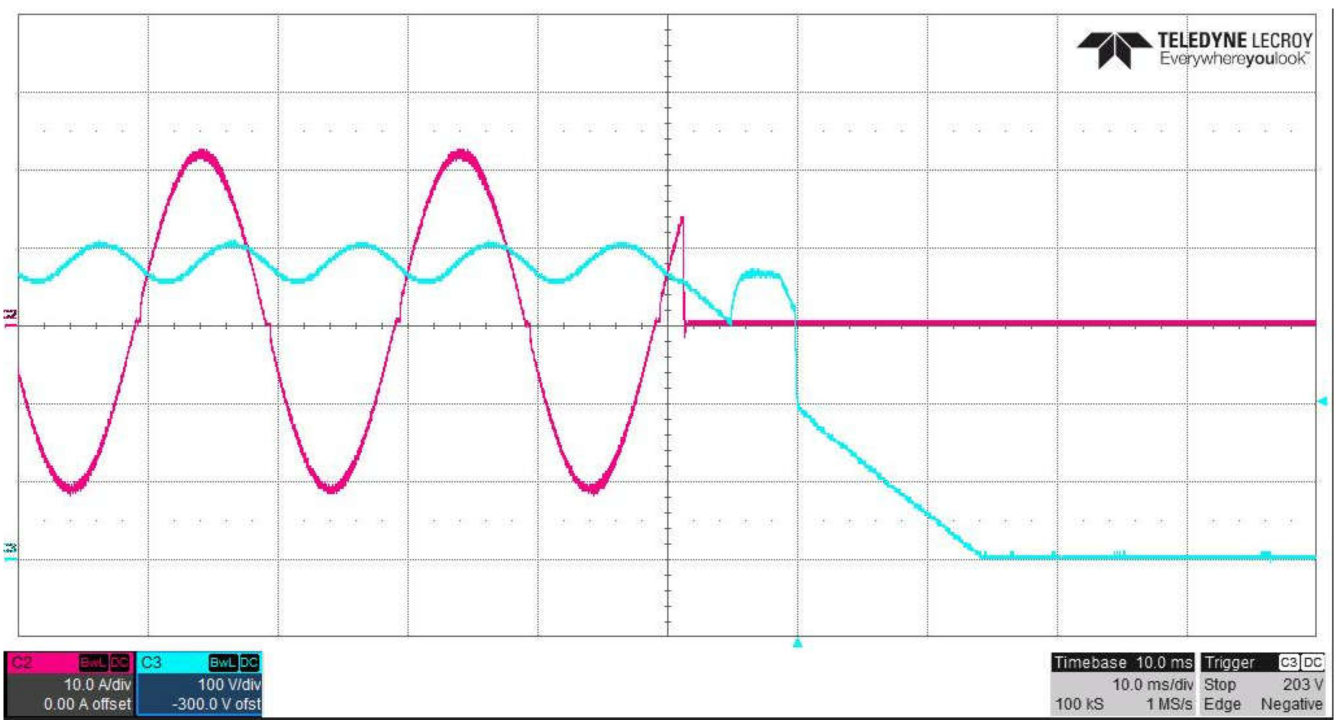

Figure 4-27. AC Drop at 240 VAC, 3600 W Load (Blue: Vout, Pink: Iin)

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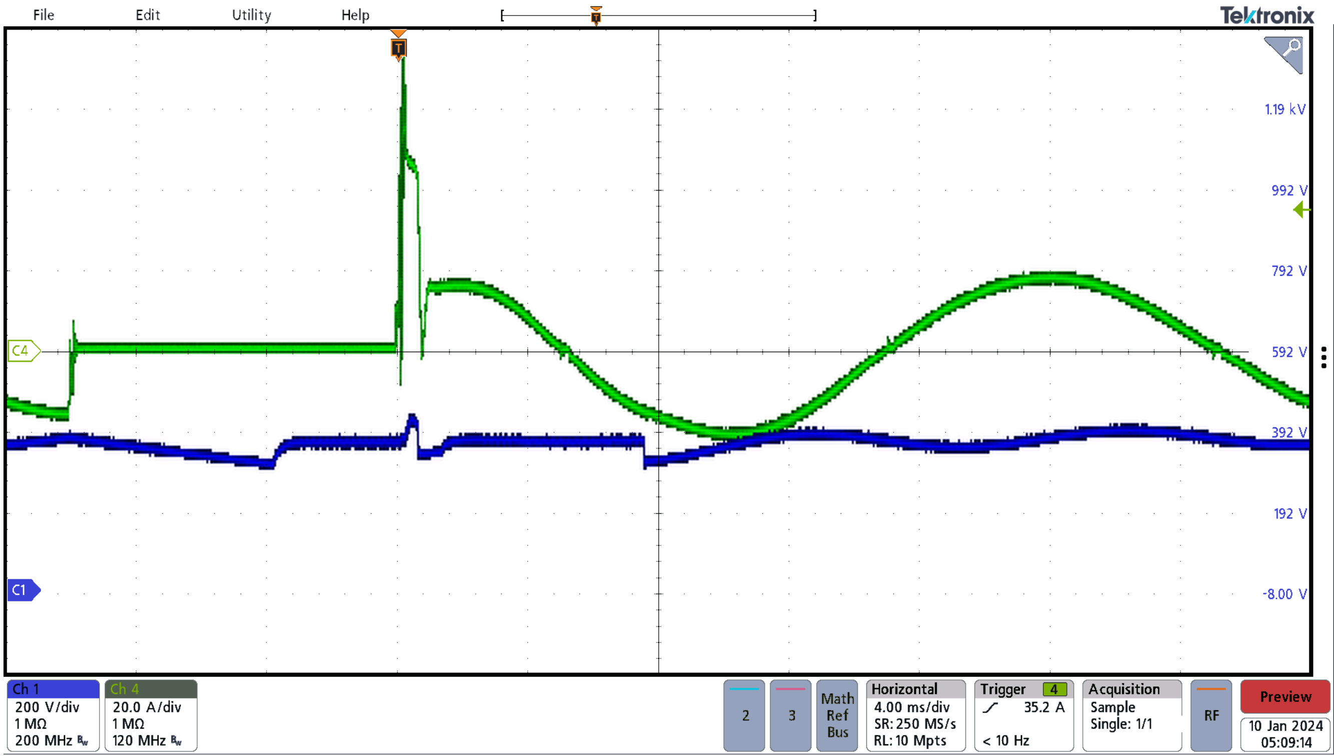

Figure 4-28. Re-rush Current When AC Comes Back From 10ms Drop Out (Green: Iin, Blue: Vout)

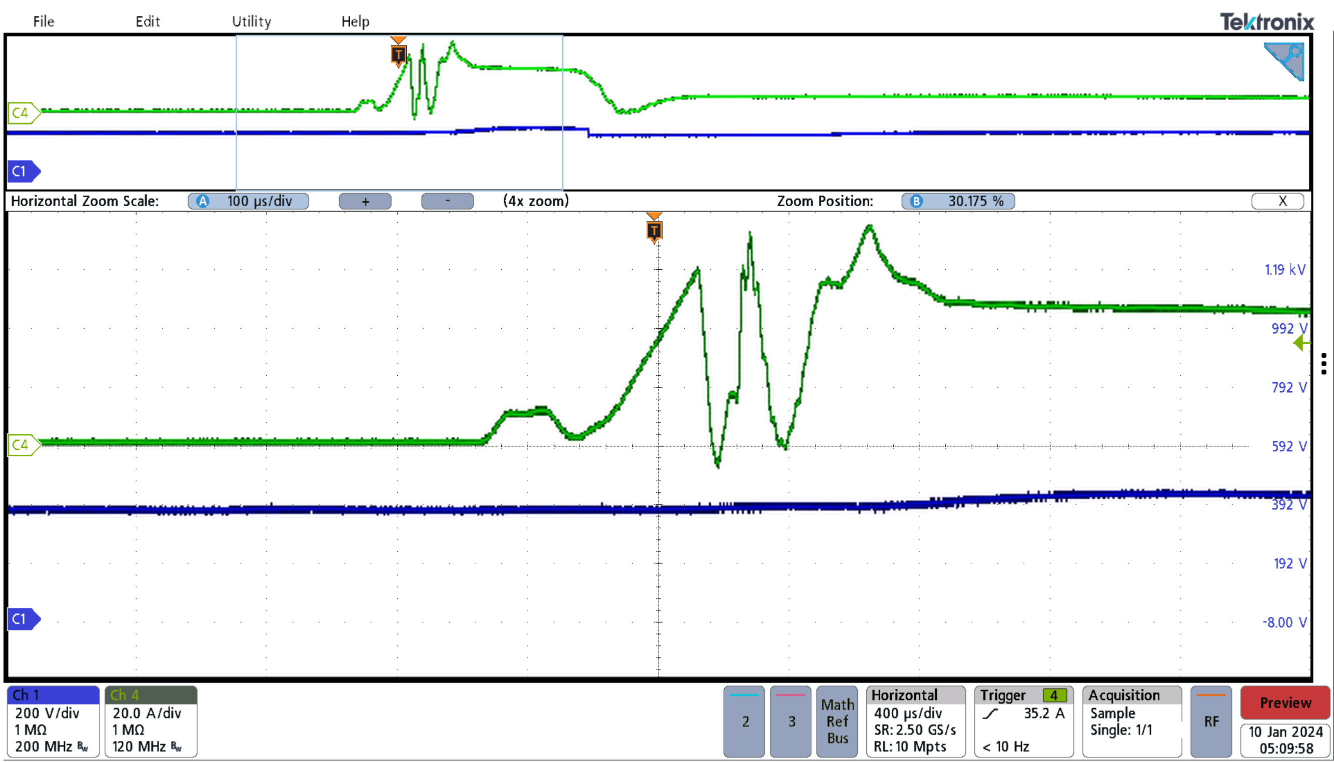

Figure 4-29. Zoom In of Re-rush Current

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4.9 Thermal Images

Test Conditions:

Vin:230 VAC

Vout: 385V

Load: 3.6KW

Air flow: same as "Start-Up Sequence"

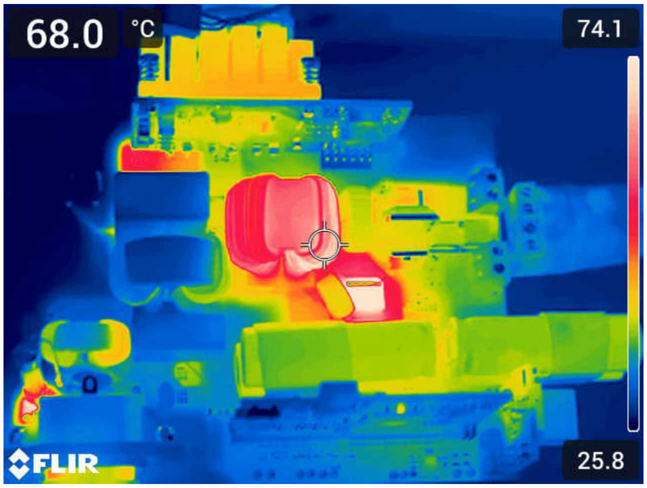

Figure 4-30. Thermal Image

Figure 4-31. Relay Bypass Switch Thermal Image

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5 Hardware Design Files

5.1 Design Files

PFC23338EVM-107 design files are available on product page for this EVM on TI.com.

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6 Related Documentation

6.1 Supplemental Content

Please also refer to:

- PMP23338 Test Report (PFC motherboard)
- PMP23338 Reference design tool page
- PMP20306 Test Report (bias supply daughter card)
- PMP20306 Reference design tool page
- LMG3650R025 GaN Daughtercard
- LMG3522R030 GaN Daughtercard
- LMG3422R030 GaN Daughtercard
- TMDSCNCD280039C Controlcard
- Digital Power Software Development Kit
- PMP23338 Software Guide: In the folder downloaded when installing Digital Power Software Development Kit select: C2000Ware_DigitalPower_SDK_x_xx_xx_xx → solutions → pmp23338 → docs → pmp23338_software_guide.pdf
- Digital Power SDK Getting Started Guide

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7 External Reference

[1] B. Sun, S. Yu, B. Genereaux, L. Yin, "Design and Control Strategy of PFC During AC Dropout in a High Reliability and High-Power Density Server Power Supply", ECCE 2023

[2] B. Sun, S. Yu, T. Hud, "A Totem-pole PFC with Re-rush Current Control, Accurate E-metering, Low iTHD and High Power Density", APEC 2024

[3] Modular Hardware System – Common Redundant Power Supply (MCRPS) Base Specification. Open Compute Project, Version 1.02 RC2, Aug. 23, 2023. [Online].

[4] J. Kim, B. McDonald, S. Yu, "AC Dropout Algorithm for Digitally Controlled Totem-pole Bridgeless PFC", APEC 2023

[5] B. Sun, "How to reduce THD of a PFC", April 2023, EDN

[6] S. Yu, "Current sensing considerations in a bridgeless totem pole PFC", June 2022, EDN

[7] R. Yin, "Five major trends in power supply design for servers", August 2022, EDN

[8] B. Sun, "How to improve the power factor of a PFC", January 2024, EDN

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NOTE:

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3.1.1 *Notice applicable to EVMs not FCC-Approved:*

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

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CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

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https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html

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If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

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