

UCC28060EVM 300-W Interleaved PFC Pre-Regulator

The UCC28060 is a dual-phase, transition-mode Power Factor Correction (PFC) pre-regulator. The UCC28060EVM is an evaluation module (EVM) with a 390-V, 300-W, dc output that operates from a universal input of 85 V_{RMS} to 265 V_{RMS} and provides power-factor correction.

Throughout this document, the acronym *EVM* and the phrases *evaluation board* and *evaluation module* are synonymous with the UCC28060EVM.

1 Description

The pre-regulator uses the [UCC28060 PFC interleaved controller](#) to shape the input current wave to provide power-factor correction. This device uses TI's *Natural Interleaving*[™] technology to interleave boost phases.

This user's guide provides the schematic, List of Materials list, assembly drawing for a single-sided printed circuit board application, and test set-up information necessary to evaluate the UCC28060 in a typical PFC application.

2 Thermal Requirements

This evaluation module will operate up to 300 W without external cooling in ambient temperatures of 25°C.

3 Electrical Characteristics

[Table 1](#) summarizes the electrical specifications of the UCC28060EVM.

Table 1. UCC28060EVM Electrical Specifications

| PARAMETER | CONDITIONS | UCC28060EVM | | | UNITS |
|-----------------------------------|-----------------|-------------|-----|-----|------------------|
| | | MIN | TYP | MAX | |
| RMS input voltage (ac line) | | 85 | | 265 | V _{RMS} |
| Output voltage, V _{OUT} | | | 390 | | V |
| Line frequency | | 47 | | 63 | Hz |
| Power factor (PF) at maximum load | | 0.9 | | | |
| Output power | | | | 300 | W |
| Full load efficiency | AC line = 115 V | | 94% | | |
| | AC line = 230 V | | 97% | | |

Natural Interleaving is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

4 Schematics

Figure 1 and Figure 2 show the schematics for this EVM. See the [List of Materials](#) for specific values. To evaluate inductor ripple currents, Jumpers JP8 and JP9 can be removed and replaced with current loops.

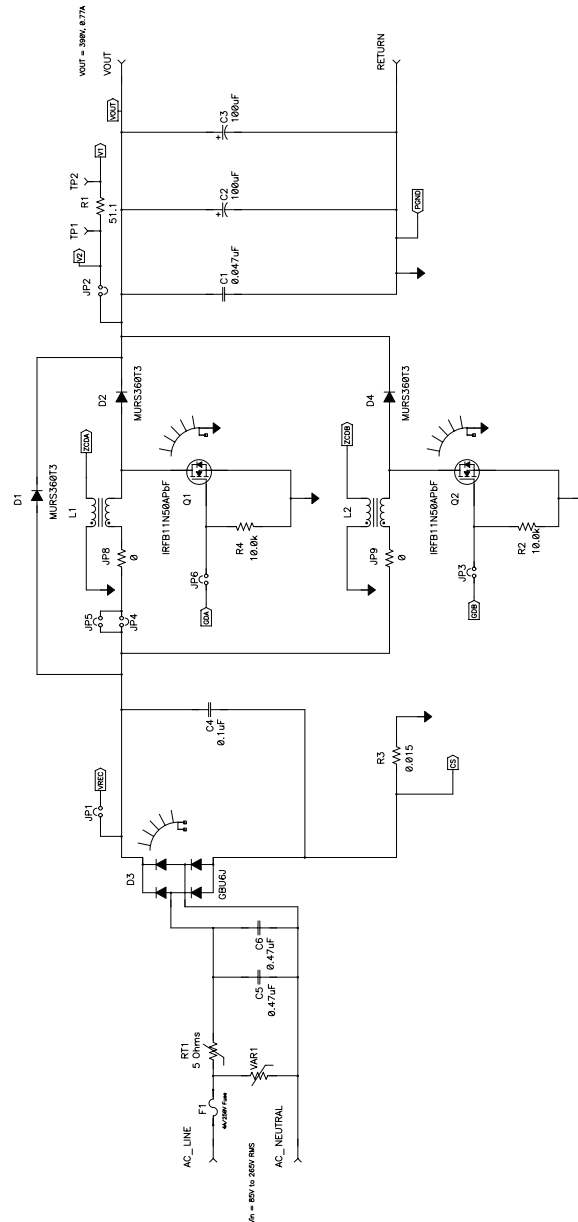


Figure 1. Interleaved PFC Power Stage

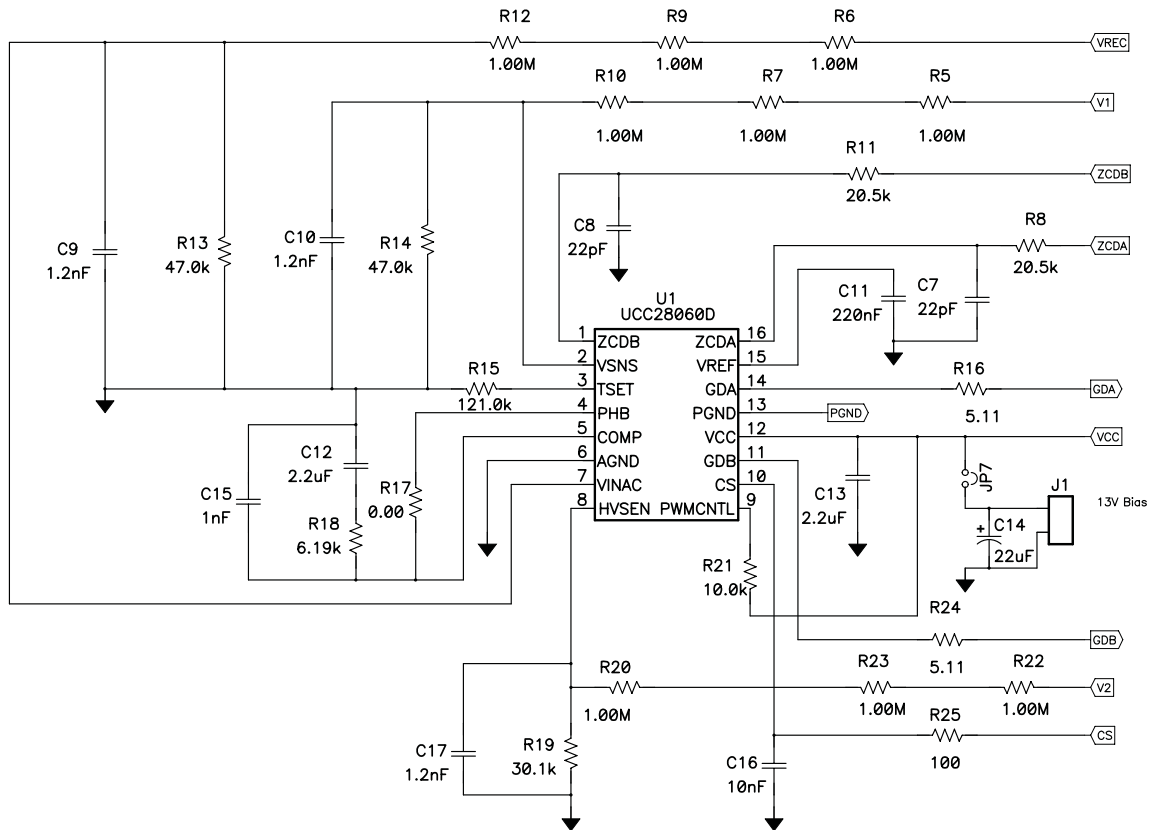


Figure 2. Controller Circuitry

5 Test Setup and Power-Up/Power-Down Instructions

WARNING

There are high voltages present on the pre-regulator. It should only be handled by experienced power supply professionals. To evaluate this board as safely as possible, the following test configuration should be used:

- Connect an isolation transformer between the source and unit
- Attach a voltmeter and a resistive or electronic load to the unit output **before** supplying power to the EVM.

A separate 13-V bias supply is required to power the UCC28060 control circuitry. The unit will start up under no-load conditions. However, for safety, a load should be connected to the output of the device before it is powered up. The unit should also never be handled while power is applied to it or when the output voltage is above 50-V dc. Refer to [Figure 3](#) for a recommended test setup diagram.

CAUTION

There are very high voltages on the board. Components can and will reach temperatures greater than 100°C. Use caution when handling the EVM.

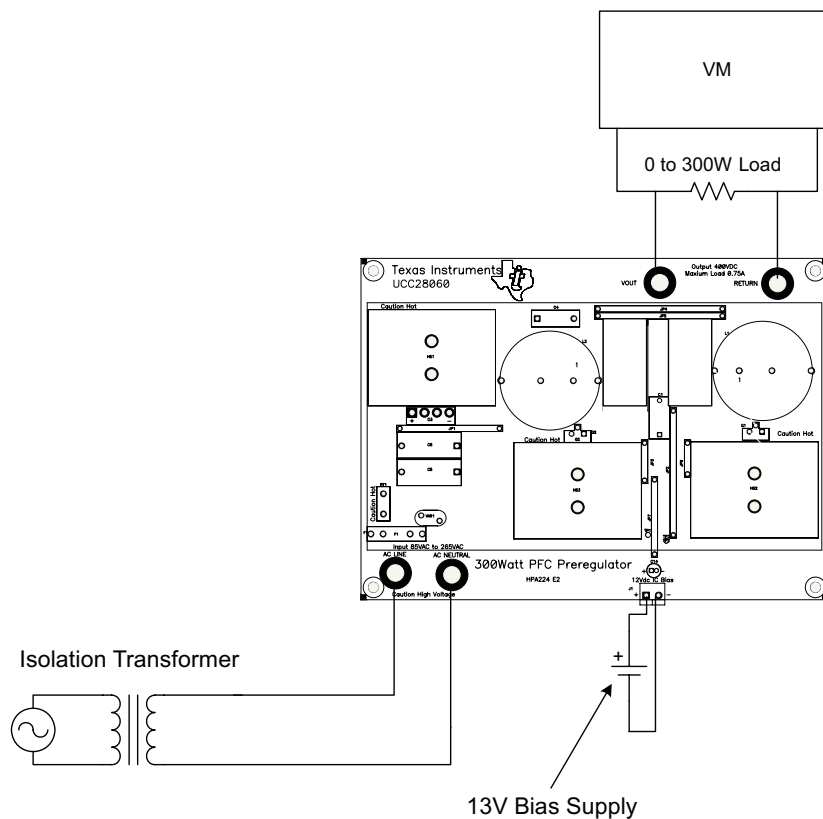


Figure 3. Test Setup

6 Typical Performance Data

Figure 4 through Figure 7 present characteristic performance data for the UCC28060EVM.

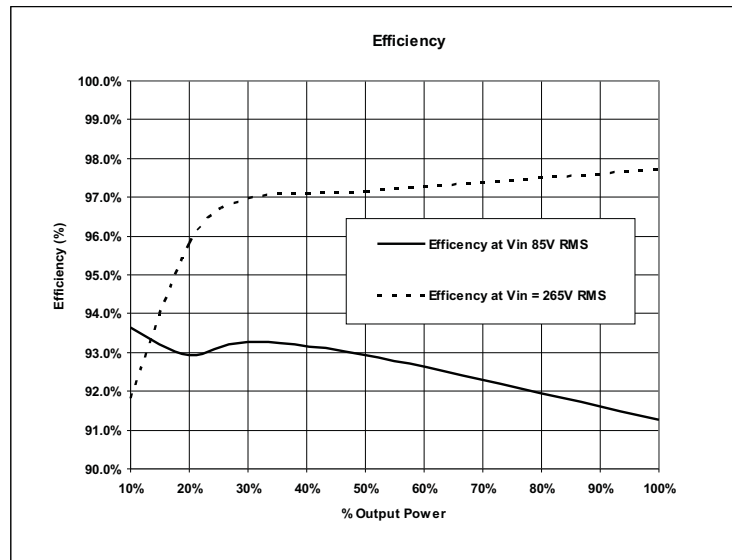


Figure 4. Efficiency at 85V_{RMS} and 265V_{RMS}

The UCC28060 control device has phase management capability to improve light load efficiency. To demonstrate the light load efficiency, the unit efficiency was measured with phase management enabled and disabled at 115 V_{RMS} and 230 V_{RMS} input voltages. Phase management improved the light load efficiency up to 3%. Refer to the [UCC28060 data sheet](#) for details on how to use the phase management function of this device.

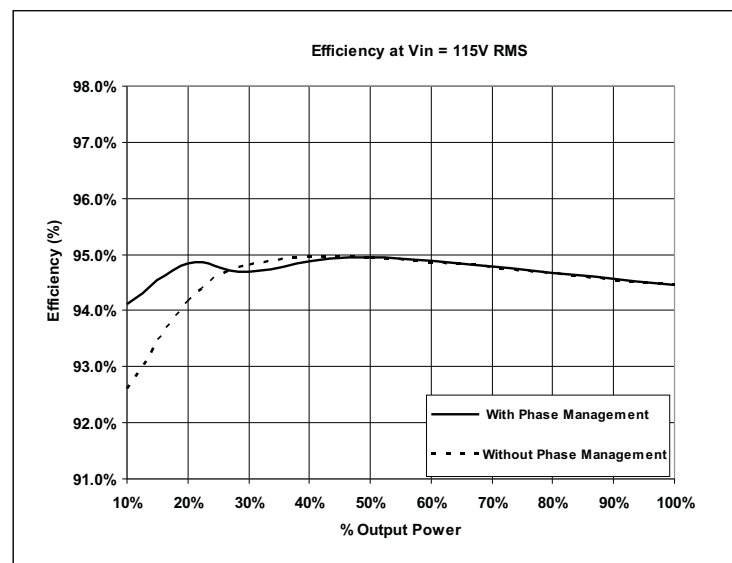


Figure 5. Efficiency at 115 V_{RMS}, With and Without Phase Management

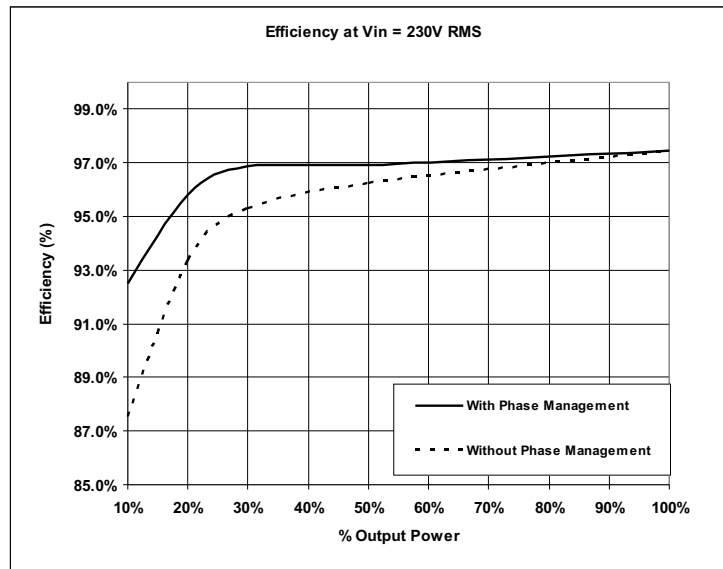


Figure 6. Efficiency at 230 V_{RMS}, With and Without Phase Management

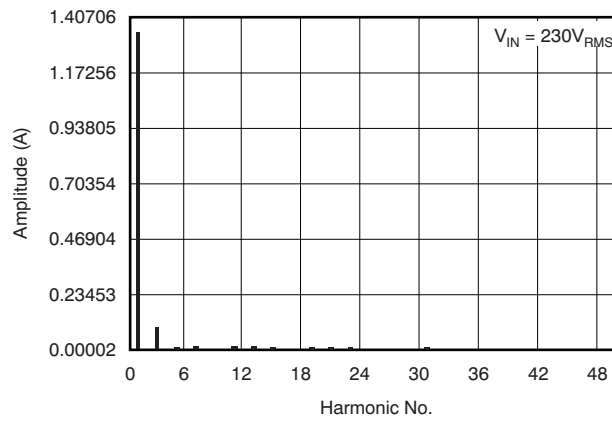


Figure 7. Current Harmonics

6.1 Output Ripple Voltage at Full Load

Figure 8 illustrates the output ripple voltage.

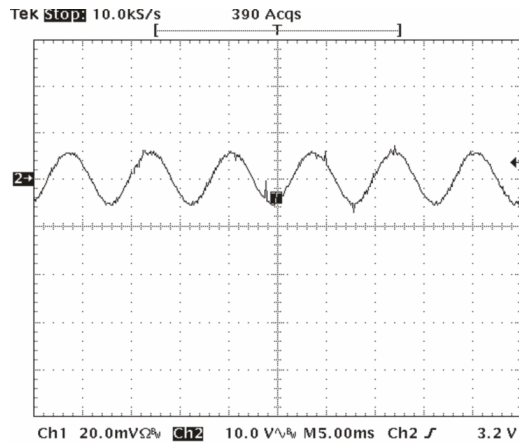


Figure 8. V_{OUT} Ripple, $P_{OUT} = 300\text{ W}$

6.2 Input Ripple Current Cancellation

Figure 9 through Figure 14 show the input current ($M_1 = I_{L1} + I_{L2}$), Inductor Ripple Current (I_{L1} , I_{L2}) versus rectified line voltage. From these graphs, it can be observed that interleaving reduces the magnitude of input ripple current caused by the inductor ripple current.

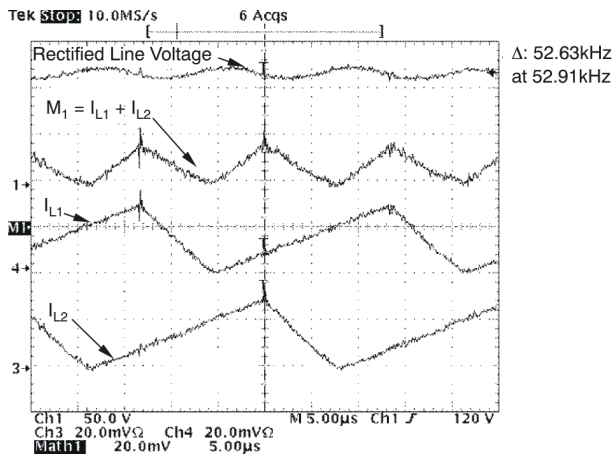


Figure 9. Inductor and Input Ripple Current at 85 V_{RMS} at Peak of Line Voltage

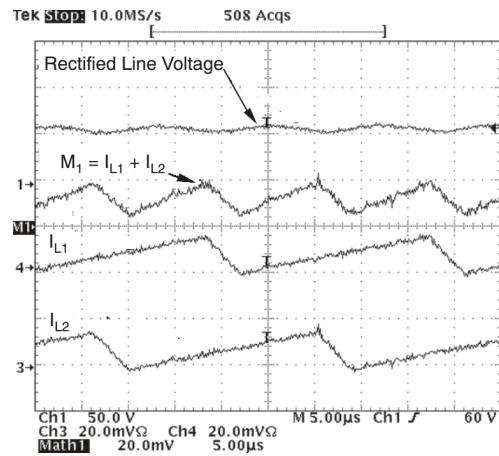


Figure 10. Inductor and Input Ripple Current at 85 V_{RMS} Input at Half the Line Voltage

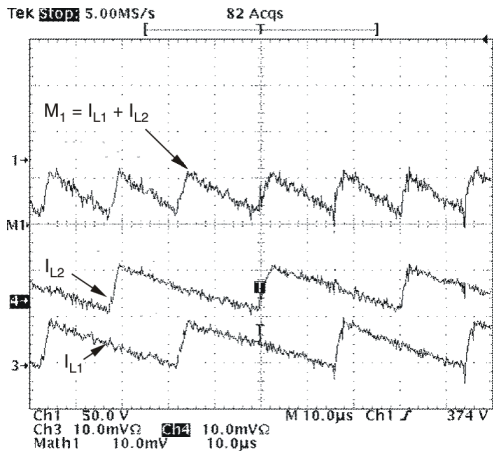


Figure 11. Inductor and Input Ripple Current at 265 V_{RMS} Input at Peak Line Voltage

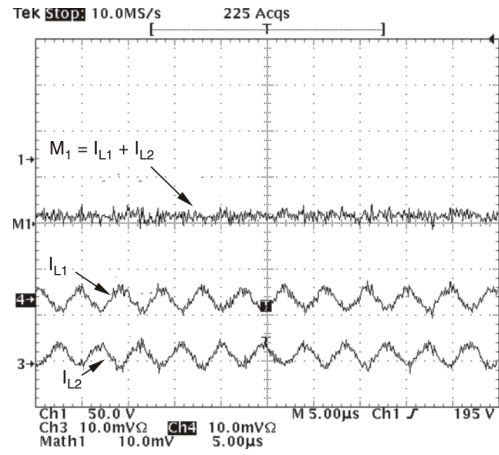


Figure 12. Inductor and Input Ripple Current at 265 V_{RMS} Input at Half Peak Line Voltage

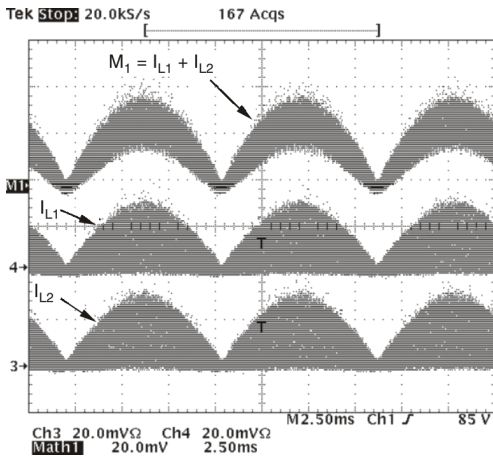


Figure 13. Inductor and Input Ripple Current at $V_{IN} = 85 V_{RMS}$, $P_{OUT} = 300 W$

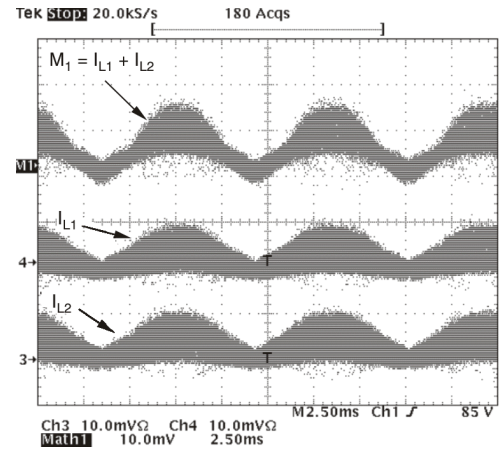


Figure 14. Inductor and Input Ripple Current at $V_{IN} = 265 V_{RMS}$, $P_{OUT} = 350 W$

6.3 Startup Characteristics

Figure 15 and Figure 16 illustrate the UCC28060EVM startup characteristics.

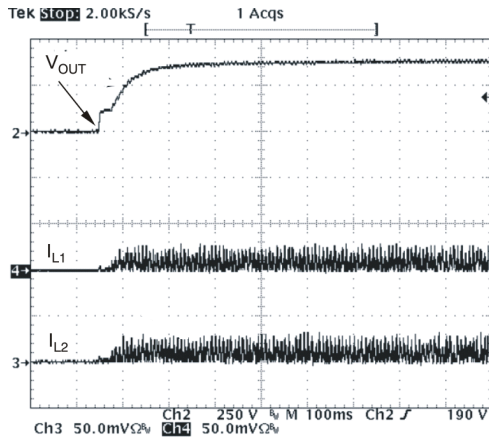


Figure 15. Start-Up at $V_{IN} = 85 V_{RMS}$, $P_{OUT} = 350 W$

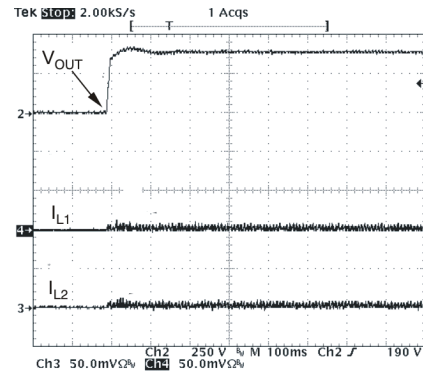


Figure 16. Start-Up at $V_{IN} = 265 V_{RMS}$, $P_{OUT} = 0 W$

6.4 Brownout Protection

The UCC28060 has a brownout protection that shuts down both gate drives (GDA and GDB) when the VINAC pin detects that the RMS input voltage is too low. This EVM was designed to go into a brownout state when the line drops below $64 V_{RMS}$. Once the UCC28060 control device has determined that the input is in a brownout condition, a 400-ms timer starts to allow the line to recover before shutting down the gate drivers. After 400 ms of brownout, both gate drivers turn off, as shown in Figure 17 and Figure 18.

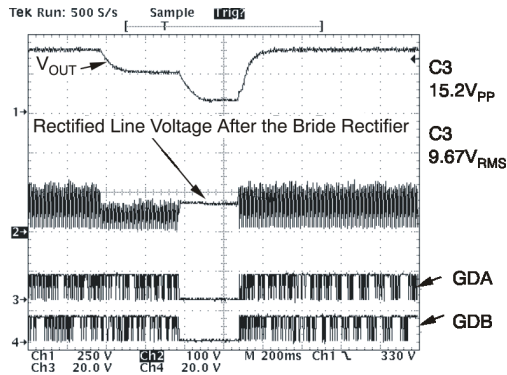


Figure 17. Brownout at $85 V_{RMS}$

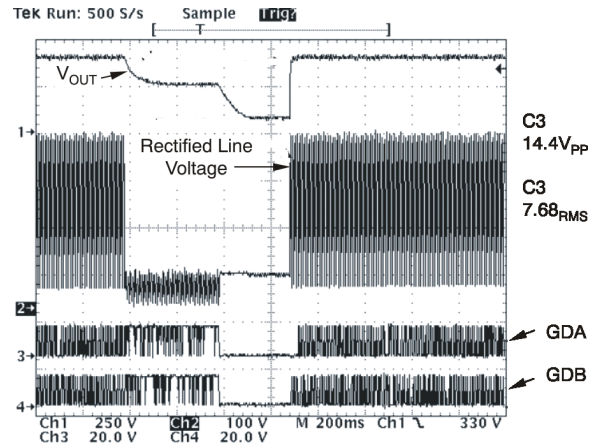


Figure 18. Brownout at $265 V_{RMS}$

6.5 Line Transient

A line transient test was conducted with an ac source on the reference design. The line was varied from 230 V_{RMS} to 115 V_{RMS} to 230 V_{RMS} and the transient response was evaluated in each case. From the oscilloscope image in Figure 19, it can be observed that the output recovered from line transients within 300ms at full load.

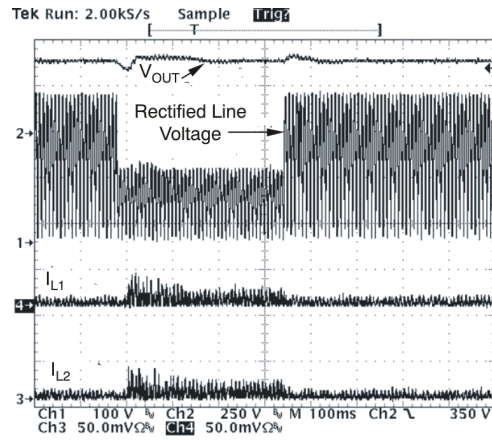


Figure 19. Line Transient, P_{OUT} = 300W

7 Reference Design Assembly Drawing

Figure 20 and Figure 22 show the top and bottom layers (respectively) of the UCC28060EVM.

Note: Board layouts are not to scale. These figures are intended to show how the board is laid out; they are not intended to be used for manufacturing UCC28060EVM PCBs.

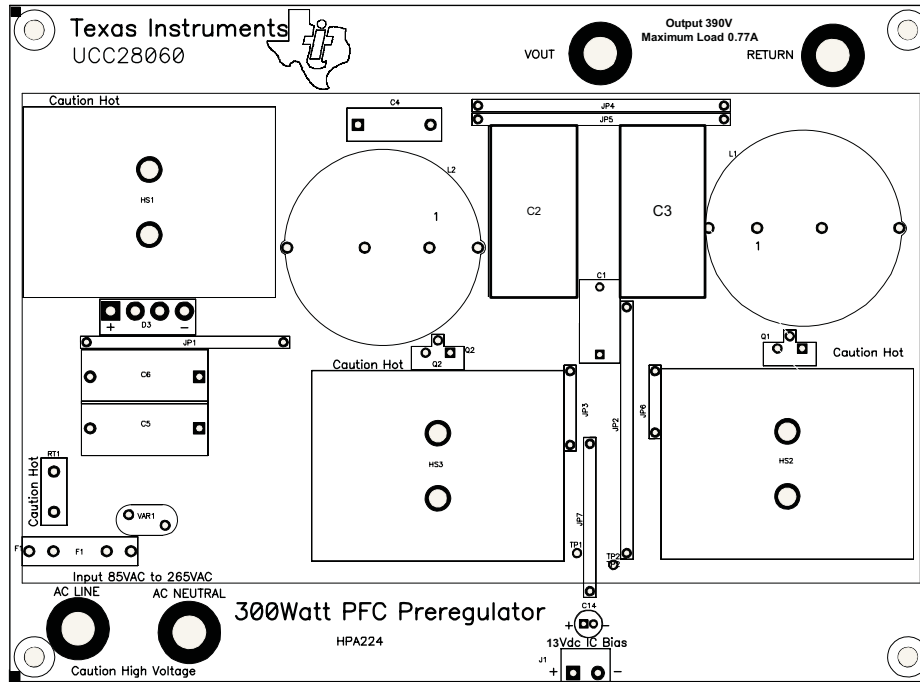


Figure 20. Top Layer Assembly

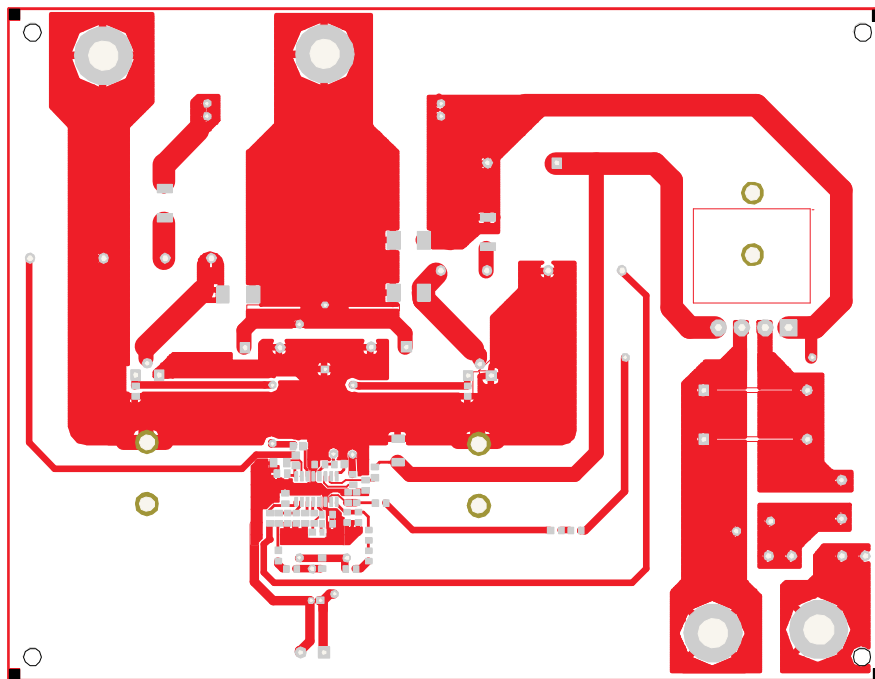


Figure 21. Bottom Layer Copper

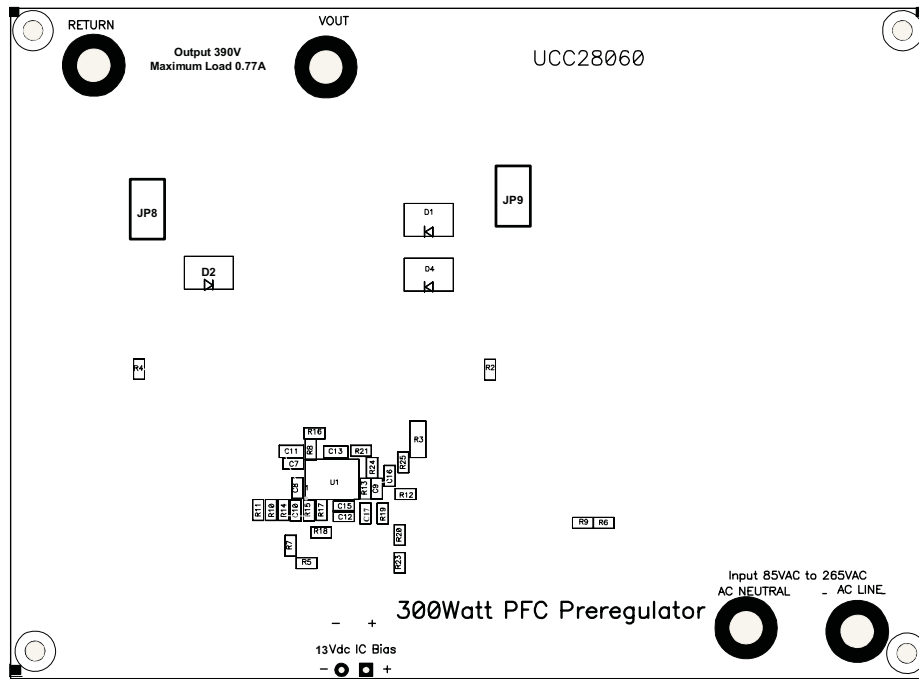


Figure 22. Bottom Layer Assembly

8 List of Materials

Table 2 lists the EVM components as configured according to the schematics (see Section 4).

Table 2. List of Materials

| Qty | RefDes | Value | Description | Size | Part Number | MFR |
|-----|--|---------------|--|--------------------------------|------------------------|---------------------|
| 4 | AC_LINE, AC_NEUTRAL, VOUT, RETURN | 3267 | Connector, Banana Jack, Uninsulated | 0.500 dia. inch | 3267 | Pomona |
| 1 | C1 | 0.047 μ F | Capacitor, Polyester, 630V, 10% | 0.256in \times 0.650in | ECQ-E6473KZ | Panasonic |
| 1 | C11 | 220nF | Capacitor, Ceramic, 16V, X7R, 10% | 1206 | Std | Std |
| 2 | C12, C13 | 2.2 μ F | Capacitor, Ceramic, 16V, X7R, 10% | 0805 | Std | Std |
| 1 | C14 | 22 μ F | Capacitor, Aluminum, 35V, \pm 20% | 0.200in \times 0.435in | ECA-1VM220 | Panasonic |
| 1 | C15 | 1nF | Capacitor, Ceramic, 25V, X7R, 10% | 0805 | Std | Std |
| 1 | C16 | 10nF | Capacitor, Ceramic, 25V, X7R, 10% | 0805 | Std | Std |
| 2 | C2, C3 | 100 μ F | Capacitor, Aluminum, 450VDC, \pm 20% | 18mm \times 40 mm | EKXG451ELL101 MM40S | Nippon Chemi-con |
| 1 | C4 | 0.1 μ F | Capacitor, Film, 275VAC, \pm 20% | 0.689in \times 0.236in | ECQU2A104BC1 | Panasonic |
| 2 | C5, C6 | 0.47 μ F | Capacitor, Film, 275VAC, \pm 20% | 0.236 \times 0.591 | ECQ-U2A474MG | Panasonic |
| 2 | C7, C8 | 22pF | Capacitor, Ceramic, 25V, X7R, 10% | 0805 | Std | Std |
| 3 | C9, C10, C17 | 1.2nF | Capacitor, Ceramic, 25V, X7R, 10% | 0805 | Std | Std |
| 3 | D1, D2, D4 | MURS360T3 | Diode, 3000mA, 600V | SMC | MURS360T3 | On Semi |
| 1 | D3 | GBU6J | Diode, Bridge, 6A, 600V | BU6 | GBU6J | Vishay |
| 2 | F1 | 0100056H | Fuse Clip, 5mm \times 20mm | 0.205in \times 0.220in x2 | 0100056H | Wickmann |
| 1 | F1 | BK/GDA-4A | 4A, Fast Acting Fuse | 5mm \times 20mm | BK/S501-4-R | Cooper/ Bussman |
| 3 | HS1, HS2, HS3 | 7-345-2PP | Heatsink, Universal-mount TO-220 | 1.500in \times 2.000in | 7-345-2PP | IERC-CTS |
| 1 | J1 | ED1609-ND | Terminal Block, 2-pin, 15-A, 5.1mm | 0.40in \times 0.35in | ED1609 | OST |

Table 2. List of Materials (continued)

| Qty | RefDes | Value | Description | Size | Part Number | MFR |
|-----|--|----------------|---|-------------------|------------------|----------------------|
| 1 | JP1 | 923345-20-C | Jumper, 1.600 inch length, PVC Insulation, AWG 22 | 0.035in dia. | Cut to Dimension | 3M |
| 3 | JP2, JP4, JP5 | 923345-20-C | Jumper, 2.000 inch length, PVC Insulation, AWG 22 | 0.035in dia. | 923345-20-C | 3M |
| 1 | JP3 | 923345-06-C | Jumper, 0.600 inch length, PVC Insulation, AWG 22 | 0.035in dia. | 923345-06-C | 3M |
| 1 | JP6 | 923345-05-C | Jumper, 0.500 inch length, PVC Insulation, AWG 22 | 0.035in dia. | 923345-05-C | 3M |
| 1 | JP7 | 923345-20-C | Jumper, 1.200 inch length, PVC Insulation, AWG 22 | 0.035in dia. | Cut to Dimension | 3M |
| 2 | JP8, JP9 | 0 | Resistor, Chip, 1W, 5% | 2512 | Std | Std |
| 1 | PCB | | HPA224 Printed Circuit Board | | | |
| 2 | L1, L2 | CTX16-17769R | Inductor, Boost PFC With Aux. 330μH at 5.3 A PK | 1.555in dia. | CTX16-17769R | Cooper |
| 2 | Q1, Q2 | IRFB11N50APbF | MOSFET, N-ch, 500V, 11A, 520mΩ | TO-220V | IRFB11N50APbF | IR |
| 1 | R1 | 51.1 | Resistor, Chip, 1/10W, 1% | 0805 | Std | Std |
| 2 | R13, R14 | 47.0k | Resistor, Chip, 1/10W, 1% | 0805 | Std | Std |
| 1 | R15 | 121.0k | Resistor, Chip, 1/10W, 1% | 0805 | Std | Std |
| 2 | R16, R24 | 5.11 | Resistor, Chip, 1/10W, 1% | 0805 | Std | Std |
| 1 | R17 | 0.00 | Resistor, Chip, 1/10W, 1% | 0805 | Std | Std |
| 1 | R18 | 6.19k | Resistor, Chip, 1/10W, 1% | 0805 | Std | Std |
| 1 | R19 | 30.1k | Resistor, Chip, 1/10W, 1% | 0805 | Std | Std |
| 3 | R2, R4, R21 | 10.0k | Resistor, Chip, 1/10W, 1% | 0805 | Std | Std |
| 1 | R25 | 100 | Resistor, Chip, 1/10W, 1% | 0805 | Std | Std |
| 1 | R3 | 0.015 | Resistor, Chip, 1/2W, 1% | 2010 | WSL2010R0150F EA | Vishay |
| 9 | R5–R9, R10, R12, R20, R22, R23 | 1.00M | Resistor, Chip, 1/10W, 1% | 0805 | Std | Std |
| 2 | R8, R11 | 20.5k | Resistor, Chip, 1/10W, 1% | 0805 | Std | Std |
| 1 | RT1 | 5Ω | Thermistor, NTC, 5Ω, 6A | 0.180in × 0.550in | CL-40 | Thermo-metrics |
| 2 | TP1, TP2 | K24A/M | Pin, Thru Hole, Tin Plate, for 0.062 PCBs | 0.039in | K24A/M | Vector |
| 1 | U1 | UCC28060D | IC, Interleave PFC Controller | SO16 | UCC28060D | TI |
| 1 | VAR1 | SIOV-S10K275E2 | VARISTOR 275V RMS | 0.472in × 0.213in | S10K275E2 | Epcos |
| 6 | X1 at HS1 and D3, HS2 and Q1, HS3 and Q2 | | Nut #4-40 (steel) | | Std | Std |
| 6 | X1 at HS1 and D3, HS2 and Q1, HS3 and Q2 | | Pan Head Screw #4-40X3/8 (steel) | | Std | Std |
| 1 | X1 D3 and HS1 | | Thermal Grease | | Std | Std |
| 6 | X1 at HS1 and D3, HS2 and Q1, HS3 and Q2 | | Split Lock Washer #4(steel) | | Std | Std |
| 6 | X1 at HS1 and D3, HS2 and Q1, HS3 and Q2 | | Nylon Shoulder Washer #4 | | 3049 | Keystone Electronics |
| 2 | X1 at HS2 and Q1, HS3 and Q2 | | Thermal Pad Silicon TO220 | | 3223-07FR-51 | BERQUIST |

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EVM WARNINGS AND RESTRICTIONS

It is important to operate this EVM within the input voltage range of 85V_{RMS} to 265V_{RMS} and the output voltage range of 375V to 450V.

Exceeding the specified input range may cause unexpected operation and/or irreversible damage to the EVM. If there are questions concerning the input range, please contact a TI field representative prior to connecting the input power.

Applying loads outside of the specified output range may result in unintended operation and/or possible permanent damage to the EVM. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative.

During normal operation, some circuit components may have case temperatures greater than +100°C. The EVM is designed to operate properly with certain components above +100°C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during operation, please be aware that these devices may be very warm to the touch.

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