WARNING

Always follow the TI set-up and application instructions, including use of all interface components within their recommended electrical rated voltage and power limits. Always use electrical safety precautions to help ensure your personal safety and the safety of those working around you. Contact the TI Product Information Center http://support.ti.com for further information.

Save all warnings and instructions for future reference.

Failure to follow warnings and instructions may result in personal injury, property damage, or death due to electrical shock and/or burn hazards.

The term TI HV EVM refers to an electronic device typically provided as an open framed, unenclosed printed circuit board assembly. It is intended strictly for use in development laboratory environments, solely for qualified professional users having training, expertise, and knowledge of electrical safety risks in development and application of high-voltage electrical circuits. Any other use and/or application are strictly prohibited by Texas Instruments. If you are not suitably qualified, you should immediately stop from further use of the HV EVM.

1. Work Area Safety:
   (a) Keep work area clean and orderly.
   (b) Qualified observer(s) must be present anytime circuits are energized.
   (c) Effective barriers and signage must be present in the area where the TI HV EVM and its interface electronics are energized, indicating operation of accessible high voltages may be present, for the purpose of protecting inadvertent access.
   (d) All interface circuits, power supplies, evaluation modules, instruments, meters, scopes and other related apparatus used in a development environment exceeding 50 V<sub>RMS</sub>/75 V<sub>DC</sub> must be electrically located within a protected Emergency Power Off (EPO) protected power strip.
   (e) Use a stable and non-conductive work surface.
   (f) Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.

2. Electrical Safety:
   (a) De-energize the TI HV EVM and all its inputs, outputs, and electrical loads before performing any electrical or other diagnostic measurements. Revalidate that TI HV EVM power has been safely de-energized.
   (b) With the EVM confirmed de-energized, proceed with required electrical circuit configurations, wiring, measurement equipment hook-ups and other application needs, while still assuming the EVM circuit and measuring instruments are electrically live.
   (c) Once EVM readiness is complete, energize the EVM as intended.

   WARNING: while the EVM is energized, never touch the EVM or its electrical circuits as they could be at high voltages Capacitorable of causing electrical shock hazard.

3. Personal Safety:
   (a) Wear personal protective equipment (for example, latex gloves and/or safety glasses with side shields) or protect EVM in an adequate lucent plastic box with interlocks from accidental touch.

4. Limitation for Safe Use:
   (a) Do not use EVMs as all or part of a production unit.
LM3447-PAR-230VEVM is a Phase-Dimmable, Primary-Side Regulated LED Driver

1 Introduction
The LM3447-PAR-230VEVM is a 16-W, 230-V<sub>AC</sub> isolated dimmable LED driver with form-factors intended for BR and PAR applications.

2 Description
The LM3447-PAR-230VEVM is a primary-side power regulated PFC controller used for commercial and residential phase-cut dimmer compatible LED lamp drivers. The LM3447-PAR-230VEVM uses fixed frequency valley switching operation resulting in discontinuous current operation.

2.1 Typical Applications
• BR Bulb Form Factor
• PAR Bulb Form Factor

2.2 Features
• Primary-Side Control
• Power Factor Correction
• Leading and Trailing Edge Compatible
• 50:1 Dimming Range
• Valley Switching with Fixed Frequency Discontinuous Operation
• Thermal Foldback
• Efficient Triac Hold Current Operation
• LED Short and Open Circuit Protection
### Electrical Performance Specifications

Table 1. LM3447-PAR-230VEVM Electrical Performance Specifications

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage range</td>
<td></td>
<td>180</td>
<td>230</td>
<td>265</td>
<td>V</td>
</tr>
<tr>
<td><strong>Output Characteristics</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Output voltage, $V_{OUT}$</td>
<td>9 to 11 LED’s</td>
<td>30</td>
<td>32</td>
<td>34</td>
<td>V</td>
</tr>
<tr>
<td>Output load current, $I_{OUT}$</td>
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<td>500</td>
<td></td>
<td></td>
<td>mA</td>
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<tr>
<td>Output over voltage</td>
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<td>38</td>
<td></td>
<td></td>
<td>V</td>
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<tr>
<td><strong>Systems Characteristics</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switching frequency</td>
<td></td>
<td>69</td>
<td></td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td>Full-load efficiency</td>
<td>$V_{IN} = 230 V_{AC}$</td>
<td></td>
<td></td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>Power factor, PF</td>
<td></td>
<td></td>
<td></td>
<td>0.96</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. LM3447-PAR-230VEVM Schematic
5 Test Setup

5.1 Test Equipment
Voltage Source: 180 V\textsubscript{RMS} to 270 V\textsubscript{RMS} isolated AC source Agilent 6812B
Multimeters: Agilent 34410A
Power Meter: WT210 Digital Power Meter (Voltech)
Output Load: 10 LEDs in series (VF = 3.2 V at 350 mA per LED)
Oscilloscope: DPO4054 (TEKTRONIX)
Operating Temperature: 25°C
Recommended Wire Gauge: 18 AWG not more than two feet long

5.2 Recommended Test Setup

5.3 List of Test Points

<table>
<thead>
<tr>
<th>TEST POINTS</th>
<th>NAME</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>J3-1</td>
<td>Line</td>
<td>230 V\textsubscript{AC} neutral connection</td>
</tr>
<tr>
<td>J3-2</td>
<td>Neutral</td>
<td>230 V\textsubscript{AC} line voltage</td>
</tr>
<tr>
<td></td>
<td>LED+</td>
<td>LED anode connection</td>
</tr>
<tr>
<td></td>
<td>LED-</td>
<td>LED cathode connection</td>
</tr>
</tbody>
</table>
6 Test Procedure

6.1 Line/Load Regulation and Efficiency Measurement Procedure
1. Connect EVM per Figure 2. An external LED load must be used to start up the EVM.
2. Prior to turning on the AC source, set the voltage to 180 $V_{RMS}$.
3. Turn on the AC source.
4. Record the output voltage from Voltmeter 2 and output current reading from Ammeter 2 and input current from Ammeter 1.
5. Increase output voltage by 5 $V_{RMS}$.
6. Repeat steps 4 and 5 until 265 $V_{AC}$ is reached.
7. Refer to Section 6.2 for shutdown procedure.

6.2 Equipment Shutdown
1. Turn off equipment.
2. Make sure Capacitoracitors are discharged.

6.3 EVM Phase Angle Decode vs LED Current
1. Connect EVM per Figure 2. An external LED load must be used to start up the EVM.
2. Prior to turning on the AC source, set the voltage to 230 VRMS.
3. Connect scope probe to EVM per Figure 2 to bridge rectifier output.
4. Turn on the AC source.
5. Record the output voltage from Voltmeter 2 and output current reading from Ammeter 2 and input current from Ammeter 1.
6. Set dimmer to maximum setting and note the LED current.
7. Vary the dimmer from maximum to minimum setting and evaluate the dimming performance.
8. Refer to Section 6.2 for shutdown procedure.

NOTE: The scope must be isolated.
The following figures (Figure 3 through Figure 6) show the design of the LM3447-PAR-230VEVM printed circuit board.

Figure 3. LM3447-PAR-230VEVM Top Layer Copper (top view)

Figure 4. LM3447-PAR-230VEVM Bottom Layer Copper (bottom view)

Figure 5. LM3447-PAR-230VEVM Top Assembly Drawing (top view)
Figure 6. LM3447-PAR-230VEVM Bottom Assembly Drawing (bottom view)
8 Performance Data and Typical Characteristic Curves

Figure 7 through Figure 30 present typical performance curves for LM3447-PAR-230VEVM.

8.1 Efficiency

![Efficiency Graph]

Figure 7. LM3447-PAR-230VEVM Efficiency

8.2 Power Factor

![Power Factor Graph]

Figure 8. LM3447-PAR-230VEVM Power Factor vs Line Voltage

8.3 Line Regulation

![Line Regulation Graph]

Figure 9. LM3447-PAR-230VEVM Input Power Regulation
8.4 **Input Current THD**

![Graph showing Input Current THD vs Line Voltage]

Figure 11. LM3447-PAR-230VEVM- Current THD % vs Line Voltage

8.5 **Output Ripple**

![Graph showing Output Ripple]

Figure 12. Output Ripple

(Ch1 - rectified line voltage (100V/div); Ch3 - line current (100mA/div); Ch4- LED current (100 mA/div))
8.6 Switch Node Voltage Valley Switching

Figure 13. Switch Node Waveform
(Ch1 - switch node (100V/div); Ch2 - rectified line voltage (100V/div))

8.7 Current Sense Waveform

Figure 14. Current Sense Waveform
(Ch1 - switch node voltage (100V/div); Ch2 - R11 current sense (100mV/div))
8.8 LED Open Circuit Protection

**Figure 15. Pre-Open Circuit Waveforms**
(Ch1 - LED voltage (10V/div); Ch3 - line current (100mA/div); Ch4 - LED current(200mA/div))

**Figure 16. Open Circuit Steady State Waveforms**
(Ch1 - LED voltage (10V/div); Ch3 - line current (100mA/div); Ch4 - LED current(200mA/div))

**Figure 17. Open Circuit Transient Waveforms**
(Ch1 - LED voltage (10V/div); Ch3 - line current (100mA/div); Ch4 - LED current(200mA/div))
8.9 LED Short Circuit Protection

Figure 18. Pre-Short Circuit Waveforms
(Ch1 - LED voltage (10V/div); Ch3 - line current (100mA/div); Ch4 - LED current(200mA/div))

Figure 19. Short Circuit Steady State Waveforms
(Ch1 - LED voltage (10V/div); Ch3 - line current (100mA/div); Ch4 - LED current(200mA/div))

Figure 20. Short Circuit Transient Waveforms
(Ch1 - LED voltage (10V/div); Ch3 - line current (100mA/div); Ch4 - LED current(200mA/div))
8.10 Dimming Characteristics with Reverse Phase Dimmer

Figure 21. LED Current vs Conduction Angle

Figure 22. Dimmer at maximum brightness setting
(Ch1 - rectified line voltage (100V/div); Ch3 - line current (100mA/div); Ch4- LED current (100 mA/div))

Figure 23. Dimmer at half brightness setting
(Ch1 - rectified line voltage (100V/div); Ch3 - line current (100mA/div); Ch4- LED current (100 mA/div))
8.11 Dimming Characteristics with Forward Phase Dimmer

Figure 25. LED Current vs Input Voltage

Figure 26. Dimmer at maximum brightness setting
(Ch1 - rectified line voltage (100V/div); Ch3 - line current (100mA/div); Ch4- LED current (100 mA/div))
Figure 27. Dimmer at half brightness setting
(Ch1 - rectified line voltage (100V/div); Ch3 - line current (100mA/div); Ch4- LED current (100 mA/div))

Figure 28. Dimmer at minimum brightness setting
(Ch1 - rectified line voltage (100V/div); Ch3 - line current (100mA/div); Ch4- LED current (100 mA/div))
8.12 EMI Plot

Figure 29. Peak EMI Scan

Figure 30. Average EMI Scan
8.13 Thermal Performance

Figure 31. LM3447-PAR-230VEVM Thermal Image (top view)

Figure 32. LM3447-PAR-230VEVM Thermal Image (bottom view)
Figure 33. Transformer Specification

ELECTRICAL SPECIFICATIONS @ 25°C unless otherwise noted:

D.C. RESISTANCE (at 20°C):
- 3-1, 3.80 Ohms ±10%
- 6-4, 0.385 Ohms ±10%
- 13-14, 0.120 Ohms ±10%

DIELECTRIC RATING:
- 4500VAC, 1 minute tested by applying 4500VAC for 1 second between pins 3-13 (tie 1+6).

INDUCTANCE:
- 1.78mH ±10%, 70kHz, 100mA, 0mA, 3-1, Ls.

LEAKAGE INDUCTANCE:
- 45µH max, 10kHz, 100mA, 3-1 (tie 1+6, 13-14), Ls.

TURNS RATIO:
- (3-1): (6-4), (11.54):(1.00), ±2%
- (3-1): (13-14), (5.17):(1.00), ±2%
- (3-2): (2-1), (1):(1.00), ±2%

OPERATING TEMPERATURE RANGE:
- -40°C to +125°C including temp rise.

Designed to comply with the following requirements as defined by IEC 61558-2-16:
- Reinforced insulation for a primary circuit at a working voltage of 400VDC.

Wire insulation & RoHS status not affected by wire color. Wire insulation color may vary depending on availability.
10 List of Materials

The EVM components list according to the schematic shown in Figure 1.

<table>
<thead>
<tr>
<th>QTY</th>
<th>REF DES</th>
<th>DESCRIPTION</th>
<th>MANUFACTURER</th>
<th>PARTNUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>U1</td>
<td>Phase-dimmable, primary-side power regulated, PFC flyback controller for LED Lighting</td>
<td>Texas Instruments</td>
<td>LM3447MTE/NOPB</td>
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<tr>
<td>1</td>
<td>C1</td>
<td>Capacitor, Ceramic, 2200 pF, 250 V, 20%, Radial</td>
<td>TDK Corporation</td>
<td>CD12-E2GA225YNS</td>
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<tr>
<td>2</td>
<td>C3, C5</td>
<td>Capacitor, Film, 0.047 µF, 310 VAC, 20%, Radial</td>
<td>EPCOS</td>
<td>B3292C3473M</td>
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<td>1</td>
<td>C4</td>
<td>Capacitor, Film, 0.01 µF, 630 VDC, 20%, Radial</td>
<td>Vishay BC Components</td>
<td>BFC233820103</td>
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<tr>
<td>2</td>
<td>C6, C9</td>
<td>Capacitor, Ceramic, 0.1 µF, 630 V, ±10%, X7R, Radial</td>
<td>TDK Corporation</td>
<td>FK22X7R210K4</td>
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<td>C7</td>
<td>AP, Aluminum, 680 µF, 50 V, ±20%, Radial</td>
<td>Vishay BC Components</td>
<td>MAL21465181E3</td>
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<td>MuRata</td>
<td>GRM32CR72A105KA35L</td>
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<td>MuRata</td>
<td>GRM21BR71C225KA12L</td>
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<td>MuRata</td>
<td>GRM32ER71E226KE15L</td>
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<tr>
<td>2</td>
<td>C12, C13</td>
<td>Capacitor, Ceramic, 0.1 µF, 16 V, ±10%, X7R, 0603</td>
<td>Murata Electronics North America</td>
<td>GRM21BR71C2475KA35L</td>
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<td>C14</td>
<td>Capacitor, Ceramic, 4.7 µF, 16 V, X7R</td>
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<td>D1</td>
<td>Diode, Switching-Bridge, 600 V, 0.8 A, MiniDIP</td>
<td>Diodes Inc.</td>
<td>HD06-T</td>
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<tr>
<td>1</td>
<td>D2</td>
<td>Diode, GPP Ultrafast, 800 V, 1 A, SMA</td>
<td>Vishay General Semiconductor</td>
<td>US1K-E3/61T</td>
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<td>D3</td>
<td>Diode, Zener, 3.3 V, 200 mW, SOD-323</td>
<td>Diodes Inc.</td>
<td>MMSZ5226BS-7F</td>
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<td>ES2D-13F</td>
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<tr>
<td>2</td>
<td>D5, D6</td>
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<td>BAS316,115</td>
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<td>SMBJ220A</td>
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<td>Fuse, Slow, 500 mA, 250 VAC, Radial</td>
<td>Bel Fuse Inc</td>
<td>RST 500</td>
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<tr>
<td>2</td>
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<td>Inductor, 3300 µH, 290 mA, 9.1 Ω (max), Radial</td>
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<td>STD4NK80ZT4</td>
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<td>4</td>
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<td>Vishay Dale</td>
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<td>Vishay-Dale</td>
<td>CRCW0805100RFKEA</td>
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<td>1</td>
<td>R12</td>
<td>RES, 0.18 Ω, 1%, 0.5W, 1210</td>
<td>Rohm</td>
<td>MCR25JHFLR180</td>
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<td>1</td>
<td>R13</td>
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<td>Vishay-Dale</td>
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<tr>
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<td>Wurth/Midcom</td>
<td>7508115101 Rev 01</td>
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<td>1</td>
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<td>Littelfuse Inc</td>
<td>V275LA4P</td>
</tr>
</tbody>
</table>
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Should this evaluation board/kit not meet the specifications indicated in the User’s Guide, the board/kit may be returned within 30 days from the date of delivery for a full refund. THE FOREGOING WARRANTY IS THE EXCLUSIVE WARRANTY MADE BY SELLER TO BUYER AND IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED, IMPLIED, OR STATUTORY, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE.

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EVM Warnings and Restrictions

It is important to operate this EVM within the input voltage range of 190 V to 265 V and the output voltage range of 26 V to 34 V. 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 90°C. The EVM is designed to operate properly with certain components above 90°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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