Low-Voltage Power Factor Correction Development Kit User's Guide

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Preface

NOTICE TO CUSTOMERS

All documentation becomes dated, and this manual is no exception. Microchip tools and documentation are constantly evolving to meet customer needs, so some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our website (www.microchip.com) to obtain the latest documentation available.

Documents are identified with a "DS" number. This number is located on the bottom of each page, in front of the page number. The numbering convention for the DS number is "DSXXXXXXXXA", where "XXXXXXXX" is the document number and "A" is the revision level of the document.

For the most up-to-date information on development tools, see the MPLAB® IDE online help. Select the Help menu, and then Topics to open a list of available online help files.

INTRODUCTION

This chapter contains general information that will be useful to know before using the Low-Voltage Power Factor Correction (LVPFC) Development Kit. Items discussed in this chapter include:

- Document Layout
- Conventions Used in this Guide
- Recommended Reading
- The Microchip Website
- Product Change Notification Service
- Customer Support
- Document Revision History

DOCUMENT LAYOUT

This document describes how to use the LVPFC Development Kit to ensure safe voltage levels at moderate power. The document is organized as follows:

- **Chapter 1. "Overview"** — This chapter introduces the LVPFC Development Kit and provides a brief overview of its various features.
- **Appendix A. "Board Layout and Schematics"** — This appendix presents the schematics and board layouts for the LVPFC Development Kit and the Auxiliary Power Supply module.
- **Appendix B. "Bill of Materials (BOM)"** — This appendix presents the Bill of Materials for the LVPFC Development Kit and the Auxiliary Power Supply module.
- **Appendix C. "Example Algorithm"** — This appendix provides algorithm examples for the LVPFC Development Board.
- **Appendix D. "Optional Supporting Equipment"** — This appendix presents the recommended supporting equipment to be used with the LVPFC Development Board.

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

<table>
<tr><th>Description</th><th>Represents</th><th>Examples</th></tr>
<tr><td colspan="3">Arial font:</td></tr>
<tr><td rowspan="2">Italic characters</td><td>Referenced books</td><td>MPLAB® IDE User's Guide</td></tr>
<tr><td>Emphasized text</td><td>...is the only compiler...</td></tr>
<tr><td rowspan="3">Initial caps</td><td>A window</td><td>the Output window</td></tr>
<tr><td>A dialog</td><td>the Settings dialog</td></tr>
<tr><td>A menu selection</td><td>select Enable Programmer</td></tr>
<tr><td>Quotes</td><td>A field name in a window or dialog</td><td>"Save project before build"</td></tr>
<tr><td>Underlined, italic text with right angle bracket</td><td>A menu path</td><td><u>File>Save</u></td></tr>
<tr><td rowspan="2">Bold characters</td><td>A dialog button</td><td>Click OK</td></tr>
<tr><td>A tab</td><td>Click the Power tab</td></tr>
<tr><td>N'Rnnnn</td><td>A number in verilog format, where N is the total number of digits, R is the radix and n is a digit.</td><td>4'b0010, 2'hF1</td></tr>
<tr><td>Text in angle brackets < ></td><td>A key on the keyboard</td><td>Press <Enter>, <F1></td></tr>
<tr><td colspan="3">Courier New font:</td></tr>
<tr><td rowspan="7">Plain Courier New</td><td>Sample source code</td><td><code>#define START</code></td></tr>
<tr><td>Filenames</td><td><code>autoexec.bat</code></td></tr>
<tr><td>File paths</td><td><code>c:\mcc18\h</code></td></tr>
<tr><td>Keywords</td><td><code>_asm, _endasm, static</code></td></tr>
<tr><td>Command-line options</td><td><code>-Opa+, -Opa-</code></td></tr>
<tr><td>Bit values</td><td><code>0, 1</code></td></tr>
<tr><td>Constants</td><td><code>0xFF, 'A'</code></td></tr>
<tr><td>Italic Courier New</td><td>A variable argument</td><td><code>file.o</code>, where <code>file</code> can be any valid filename</td></tr>
<tr><td>Square brackets [ ]</td><td>Optional arguments</td><td><code>mcc18 [options] file [options]</code></td></tr>
<tr><td>Curly brackets and pipe character: { | }</td><td>Choice of mutually exclusive arguments; an OR selection</td><td><code>errorlevel {0|1}</code></td></tr>
<tr><td rowspan="2">Ellipses...</td><td>Replaces repeated text</td><td><code>var_name [, var_name...]</code></td></tr>
<tr><td>Represents code supplied by user</td><td><code>void main (void)
{ ...
}</code></td></tr>
</table>

RECOMMENDED READING

This user's guide describes how to use LVPFC Development Kit. Other useful document(s) are listed below. The following Microchip document(s) are recommended as supplemental reference resources.

- ***"Digital Power Development Board User's Guide"*** (www.microchip.com/DS50002814); available for download from the Microchip website.

THE MICROCHIP WEBSITE

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- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip consultant program member listing
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- Local Sales Office
- Corporate Application Engineer (CAE)
- Embedded Solutions Engineer (ESE)

Customers should contact their distributor, representative or Embedded Solutions Engineer (ESE) for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document.

Technical support is available through the website at:

http://www.microchip.com/support.

DOCUMENT REVISION HISTORY

Revision A (April 2019)

This is the initial version of this document.

NOTES:

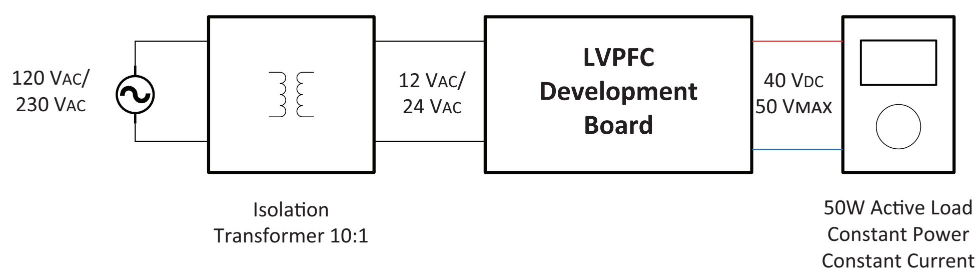
Chapter 1. Overview

1.1 INTRODUCTION

When developing high-voltage applications, especially offline Power Factor Correction (PFC) applications, engineers face safety concerns with high-voltage and high-energy electronic devices. The purpose of the Low-Voltage Power Factor Correction (LVPFC) Development Kit is to offer safe voltage levels at moderate power, while designing algorithms for a boost Power Factor Correction topology. These algorithms can be applied on real systems under development with minimal effort. The LVPFC Development Kit utilizes Microchip's latest Digital Power Plug-In Module (DP PIM) with the dsPIC33EP128GS806 device, supporting fully digital and advanced power control algorithm schemes. However, the pinout is standardized and the kit supports all currently available DP PIMs, thus allowing users to evaluate different devices under the same conditions. For more information on the available DP PIMs, visit: https://www.microchip.com.

Figure 1-1 shows the high-level block diagram.

FIGURE 1-1: HIGH-LEVEL BLOCK DIAGRAM



Note: Please note that the Isolation Transformer has 10:1 turns ratio. Therefore, every voltage at the primary side will be scaled down by a factor of 10.
For documentation simplicity, further on we will talk about 24 VAC input voltage.

The topics covered in this chapter include:

- Low-Voltage Power Factor Correction Development Kit
- System Setup
- Test Points
- Electrical Characteristics
- Mating Socket Pinout
- Measurement Results

1.2 LOW-VOLTAGE POWER FACTOR CORRECTION DEVELOPMENT KIT

The LVPFC Development Kit consists of:

1. LVPFC Development Board.
2. Digital Power Plug-In Module (DP PIM) Board.

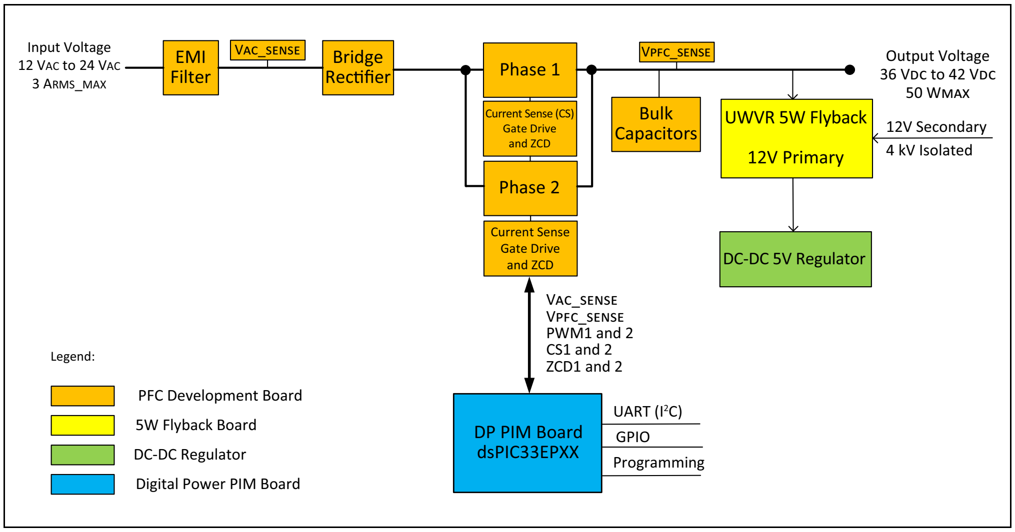
Optional supporting equipment:

3. Isolation Transformer.
4. Active Load 50W.

1.2.1 LVPFC Development Board

The LVPFC Development Board is based on conventional Interleaved Boost Power Factor Correction (PFC) topology. The converter supports a 24 VAC input, but the PCB is designed following high-voltage design rules. With some modifications, the board can support a universal offline voltage range of 80 VAC to 260 VAC, and up to 200W output power at 400 VDC output voltage. Figure 1-2 shows the high-level overview.

FIGURE 1-2: LVPFC DEVELOPMENT BOARD



The main blocks of the LVPFC Development Board are:

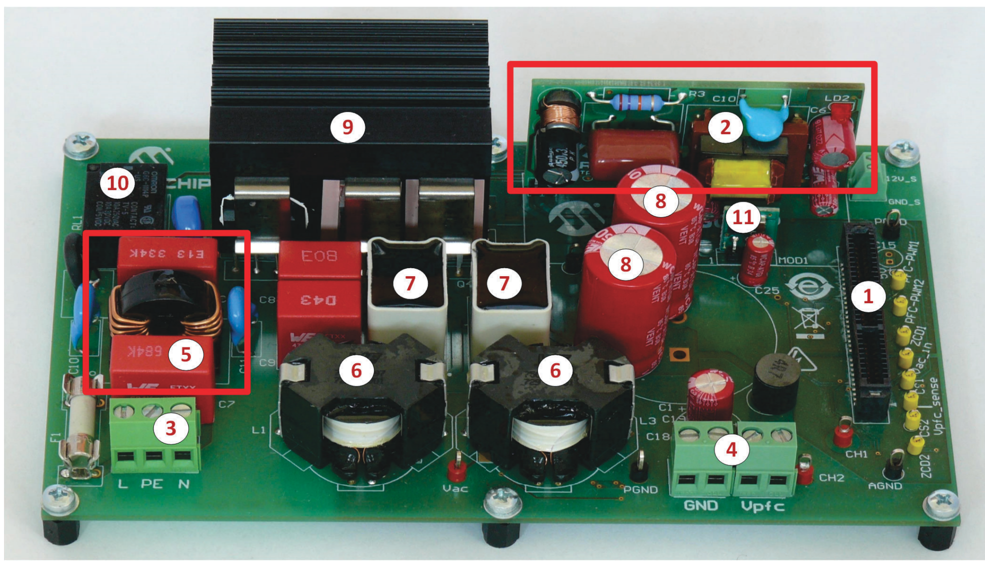
- EMI/EMC Filter at the Input (capable of high voltage)
- Bridge Rectifier (3 A_{MAX}, capable of high voltage)
- Phase 1 (MOSFET, Current Transformer, diode rectifier)
- Phase 2 (MOSFET, Current Transformer, diode rectifier)
- Ultra-Wide Voltage Range (UWVR) 5W Flyback (capable of low and high voltage); provides a 12V primary, non-galvanic isolated and 12V secondary, 4 kV galvanic isolated voltage
- Switch Mode Step-Down Regulator, 5V/400 mA, Pin-to-Pin Compatible with the LAN780X Family of Linear Regulators

The LVPFC Development Board supports:

- Single-Phase or Dual Phase Operation Mode
- Discontinuous, Transition, Continuous Current Mode of Operation
- Input AC Voltage, Output DC Voltage: Resistive Voltage Divider Sense
- Current Sense in Each Power Switch Leg: Current Transformers
- Zero-Cross Detection (ZCD): Auxiliary Winding Placed at Storage Chokes
- Inrush Current Limiter: Negative Temperature Coefficient (NTC) Resistor and Relay
- Output Overvoltage Protection (OVP): Analog Comparator with Hysteresis and Disabling Gate Drivers; power Reset (unplug the power) is needed to reset the comparator
- Mating Socket for DP PIM Board

The LVPFC Development Board has the following features, as shown in Figure 1-3:

FIGURE 1-3: LVPFC DEVELOPMENT BOARD



1. Socket for Digital Power Plug-In Module (DP PIM) boards. Socket type is Samtec, Inc. (Part #: MECF-30-01-L-DV-WT).
2. Auxiliary Power Supply module.
3. Input power connector.
4. Output power connector.
5. Input EMI filter.
6. PFC storage chokes.
7. Current Transformers.
8. Output bulk capacitors.
9. Input rectifier, power MOSFETs with their heat sink.
10. Inrush current limiter (NTC resistor and relay).
11. DC-DC 5V regulator.

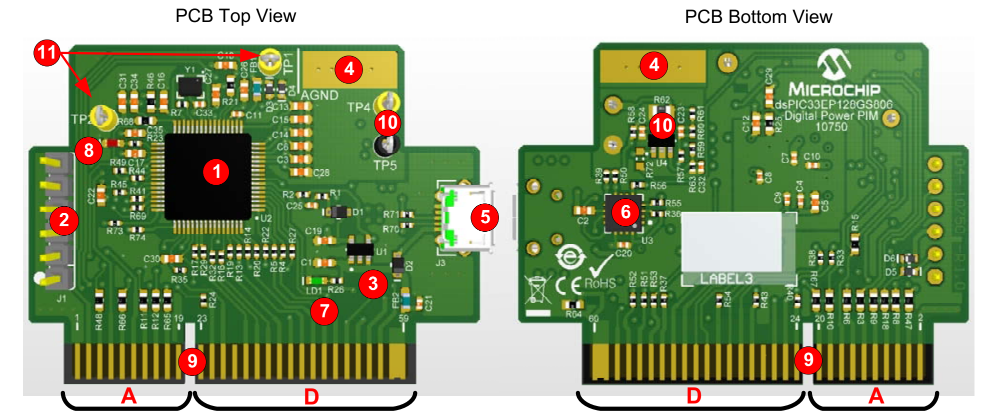
Board dimensions are: 160 mm (length) x 100 mm (height).

1.2.2 Digital Power Plug-In Module (DP PIM) Board

The dsPIC33EP128GS806 Digital Power Plug-In Module (DP PIM) is a demonstration board that showcases the Microchip dsPIC33EP128GS806 16-Bit Digital Signal Controller (DSC) features. The DP PIM provides access to the dsPIC33EP128GS806 analog inputs, the Digital-to-Analog Converter (DAC) outputs, the Pulse-Width Modulation (PWM) outputs and the General Purpose Input and Output (GPIO) ports. The Microchip series of DP PIMs for digital power share the same pinout at the mating socket. However, these DP PIMs show slightly different performing characteristics.

Figure 1-4 shows the features of the dsPIC33EP128GS806 DP PIM Board.

FIGURE 1-4: dsPIC33EP128GS806 DP PIM BOARD



1. Microchip dsPIC33EP128GS806 16-bit Digital Signal Controller (64-pin TQFP package).
2. ICSP™ programming header (6-pin, 2.54 mm header).
3. On-board LDO (3.6 VDC to 6.3 VDC) with Power Good (PG) function.
4. Solder pad for ground connection.
5. Micro-USB connector. (Please note that there is no galvanic isolation provided at this point.)
6. MCP2221A USB to UART/I^{2}C serial converter.
7. Power indicator LED (green).
8. User LED (red).
9. Board edge connection interface for analog inputs/outputs, PWM outputs and GPIO ports.
10. Analog input with op amp buffer via test point loop connector; can be used for Bode plot measurements.
11. Test point loops for DAC outputs.

Board dimensions are: 51 mm (length) x 38.5 mm (width).

For more information on the DP PIM Board, refer to the *"dsPIC33EP128GS806 Digital Power Plug-In Module (PIM) User's Guide"* (www.microchip.com/DS50002761).

1.2.2.1 SOCKET FOR DP PIM BOARDS

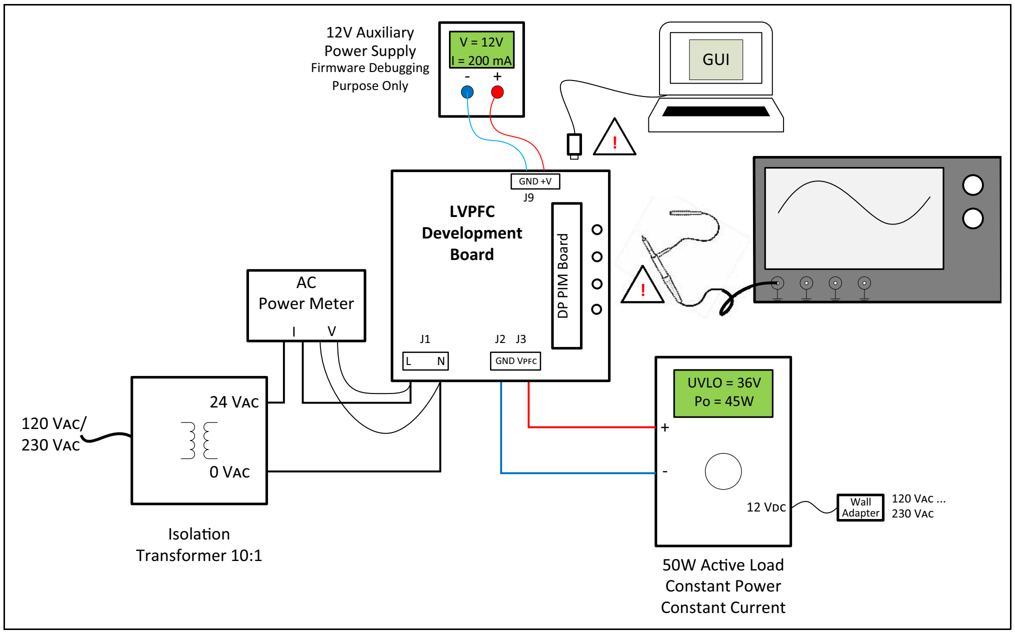
Insert the DP PIM Board under test into the socket located at the end of the board. This socket has a slot that defines the DP PIM Board direction. Be careful not to break the slot when inserting the DP PIM Board into the socket.

The DP PIM Board has a micro-USB connector that can be used for communication with the dsPIC® device. The UART protocol and Graphical User Interface (GUI) are used to establish communication. For more information, please visit: www.microchip.com.

1.3 SYSTEM SETUP

Figure 1-5 shows the standard test setup. For more information on the isolation transformer and the active load, refer to **Appendix D. "Optional Supporting Equipment"**.

FIGURE 1-5: STANDARD SYSTEM SETUP



Isolation Transformer: Be careful to position the input voltage selector into the proper place (120V or 230V) before plugging into mains. The Protective Earthing (PE) connection between the transformer and the LVPFC Development Board is not mandatory. Use the switch at the front panel to provide or cut off the power to the LVPFC Development Board.

The isolation transformer can be coupled with an adjustable AC source to support a wider AC input voltage range. Output impedance of the transformer should be very close to the Line Insertion Stabilization Network (LISN), which is used for EMI measurements. It allows a certain grade of impedance matching and interference to bring the LVPFC Development Board closer to real-world applications. If using a different type of transformer, please take care that the leakage inductance is in the range of 50 µH (±20%). Also, if using an active AC source only, the usage of differential voltage probes is mandatory.

Active Load: Please read the user manual of the device before operating. Incorrect setup can damage the LVPFC Development Board. The purpose of the PFC stage is to source loads, such as a DC/DC downstream converter, which is acting as a constant power system. Therefore, all measurements must be done under this condition. The active load, prepared for this development kit, can act as a downstream converter with the following features: constant power, constant current, Undervoltage Lockout (UVLO), load step of 100 Hz and 50% duty cycle (pulse). If different equipment is used, please note that some functions on the supplementary equipment may not be available and special care must be taken during start-up, light or no load conditions.

DP PIM Board USB Connection: Use the micro-USB cable to connect the DP PIM Board with the host PC and run the dSMPS GUI to communicate with the dsPIC device; it is allowed *only* if the board is galvanically isolated (isolation transformer is used). For more information, refer to the user's guide of the specific DP PIM Board that is used.

12V Auxiliary Power Supply: Connecting this voltage source to the board provides a permanent 12V. It is useful for debugging purposes, where powering a main power train is not needed.

Test Points: Use an oscilloscope to access the test points at the edge of the board. For reference potential, use GND_P or GND_A; this is allowed *only* if the board is galvanically isolated (isolation transformer is used).

AC Power Meter: Use the AC power meter for algorithm optimizations at the AC line (power factor, THD, efficiency, etc.); it is not mandatory for basic algorithm development.

1.4 TEST POINTS

Test loop points are placed mostly on the LVPFC Development Board. They can be used to access analog and PWM signals coming from or to the DP PIM Board. Table 1-1 lists the test points on the LVPFC Development Board.

TABLE 1-1: TEST POINTS

Test Point Name	Function/Description
TP1, TP2	GND_P (power reference GND)
TP3	Switching Node, Phase 1
TP4	Power GND Reference Potential
AGND	Analog GND Reference Potential
TP6	Switching Node, Phase 2
CH2	Output PFC Voltage, Spectrum Analyzer Injection Point
CH1	Spectrum Analyzer Injection Point
VAC	Rectified Input AC Voltage
ZCD1	Zero-Cross Detection, Phase 1
ZCD2	Zero-Cross Detection, Phase 2
PFC-PWM1	dsPIC® DSC PWM Output, Phase 1
PFC-PWM2	dsPIC DSC PWM Output, Phase 2
CS1	Current Transformer – Current Sense, Phase 1
CS1	Current Transformer – Current Sense, Phase 2
Relay	dsPIC DSC Output Control – Relay On/Off
VAC_SENSE	Input AC Voltage Sense Line
VPFC_SENSE	PFC Voltage Sense Line
5V	System VDD Rail

1.5 ELECTRICAL CHARACTERISTICS

Table 1-2 shows the electrical characteristics of the LVPFC Development Board.

TABLE 1-2: ELECTRICAL CHARACTERISTICS

Parameter	Low-Voltage Solution	High-Voltage Solution
Input Voltage Range (V_{AC})	8 to 26	80 to 260
Output Power (W_{MAX})	50	200
Output Load Current (A_{MAX})	1.28	0.51
Input Current (A_{MAX})	3	
Efficiency (%)	~90	~96
Operating Temperature Range	0°C to +40°C	

1.6 MATING SOCKET PINOUT

The pinout is shown in Table 1-3.

TABLE 1-3: MATING SOCKET PINOUT

Name	Mating Socket Pin	Function/Description
GND_A	1, 2	Analog Ground
CS2	6	Current Sense, Phase 2
ZCD2	8	Zero-Cross Detection, Phase 2
Temp	9	Temperature Sense
VPFC_SENSE	10	Output PFC Voltage Sense
CS1	12	Current Sense, Phase 1
VAC_SENSE	14	Input AC Voltage Sense
ZCD1	18	Zero-Cross Detection, Phase 1
PFC-PWM2	42	PWM Output, Phase 2
PFC-PWM1	45	PWM Output, Phase 1
Relay	46	Inrush Control – Relay On/Off
+5V	57, 59	V_{DD} Rail
GND_D	58, 60	Digital Ground

1.7 MEASUREMENT RESULTS

If not otherwise stated, all measurements were done at 24 VAC input voltage and 50W output load, using the setup shown in Figure 1-5. The algorithm used was supporting the interleaved Transition Mode (TM) regulation technique. The regulated output voltage was 40 VDC. Distortion in the input AC signal is coming from the mains voltage. The input current distortion close to zero cross is due to the fact that the voltage below 1.2V cannot cross the bridge rectifier at the input. This 1.2V is approximately 4% of the input voltage. In case of full voltage scale at the mains, this error would be one decade below, that is, 0.4%.

Figure 1-6 through Figure 1-12 show the oscilloscope measurements.

FIGURE 1-6: SWITCHING NODES

Legend:

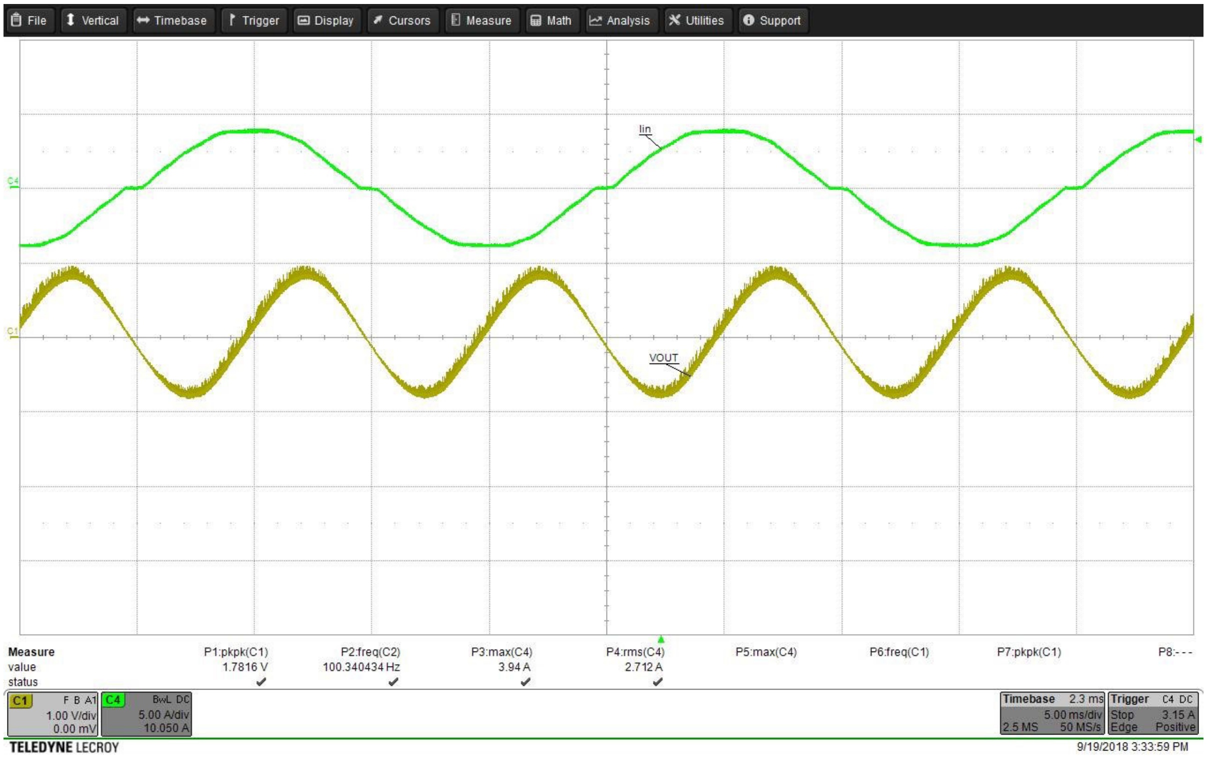
C1 (yellow): Gate Voltage

C2 (red): Drain Voltage

C4 (green): Input Current

Time Base: 10 µs/div

FIGURE 1-7: 100 Hz OUTPUT RIPPLE VOLTAGE



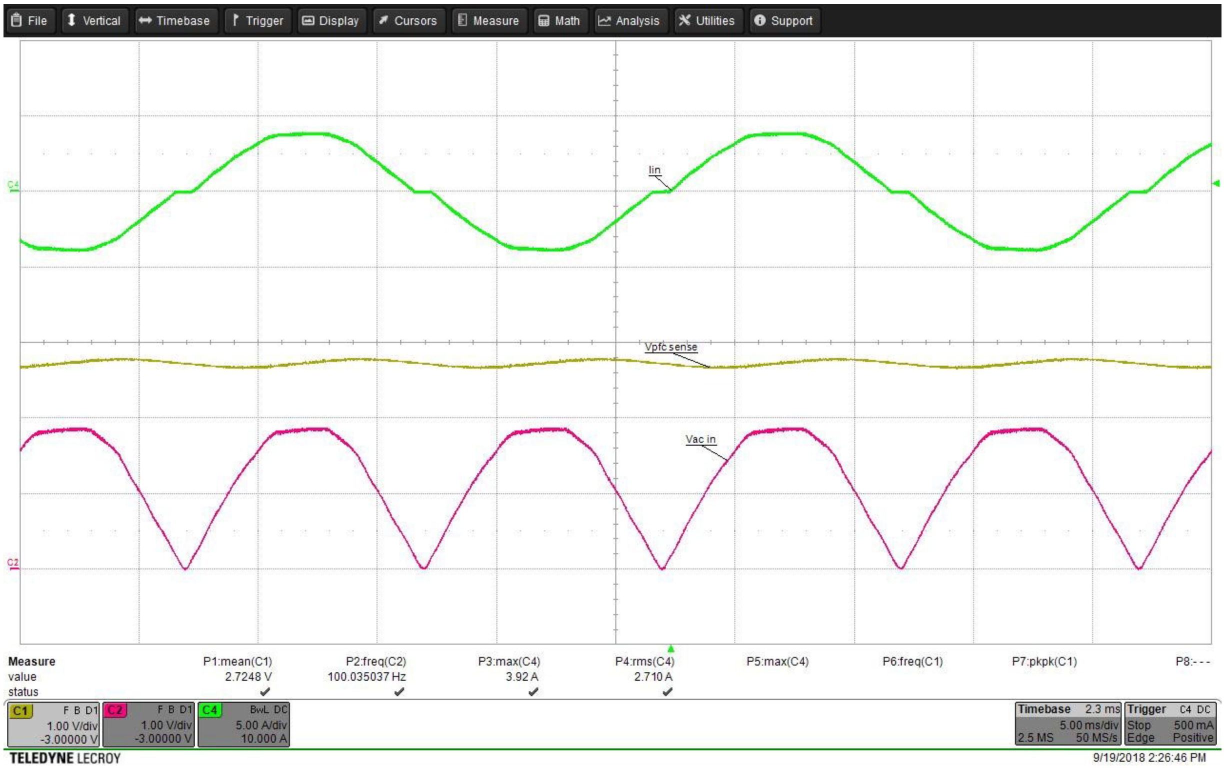
Legend:

C1 (yellow): VOUT (AC coupled)

C4 (green): Input Current

Time Base: 5 ms/div

FIGURE 1-8: VPFC_SENSE, VAC_IN TEST POINTS



Legend:

C1 (yellow): VPFC_SENSE

C2 (red): VAC_IN

C4 (green): Input Current

Time Base: 5 ms/div

FIGURE 1-9: ZERO-CROSS DETECTION (ZCD), PWM TEST POINTS

Condition: Input current close to minimum.

Legend:

C1 (yellow): ZCD Test Point

C2 (red): PWM Test Point

C4 (green): Input Current

Time Base: 5 µs/div

FIGURE 1-10: ZERO-CROSS DETECTION (ZCD), PWM TEST POINTS

Condition: Input current at the peak.

Legend:

C1 (yellow): ZCD Test Point
C2 (red): PWM Test Point
C4 (green): Input Current

Time Base: 10 µs/div

FIGURE 1-11: CURRENT TRANSFORMER (CT), PWM TEST POINTS

Condition: Input current close/around zero cross.

Legend:

C1 (yellow): CT Test Point

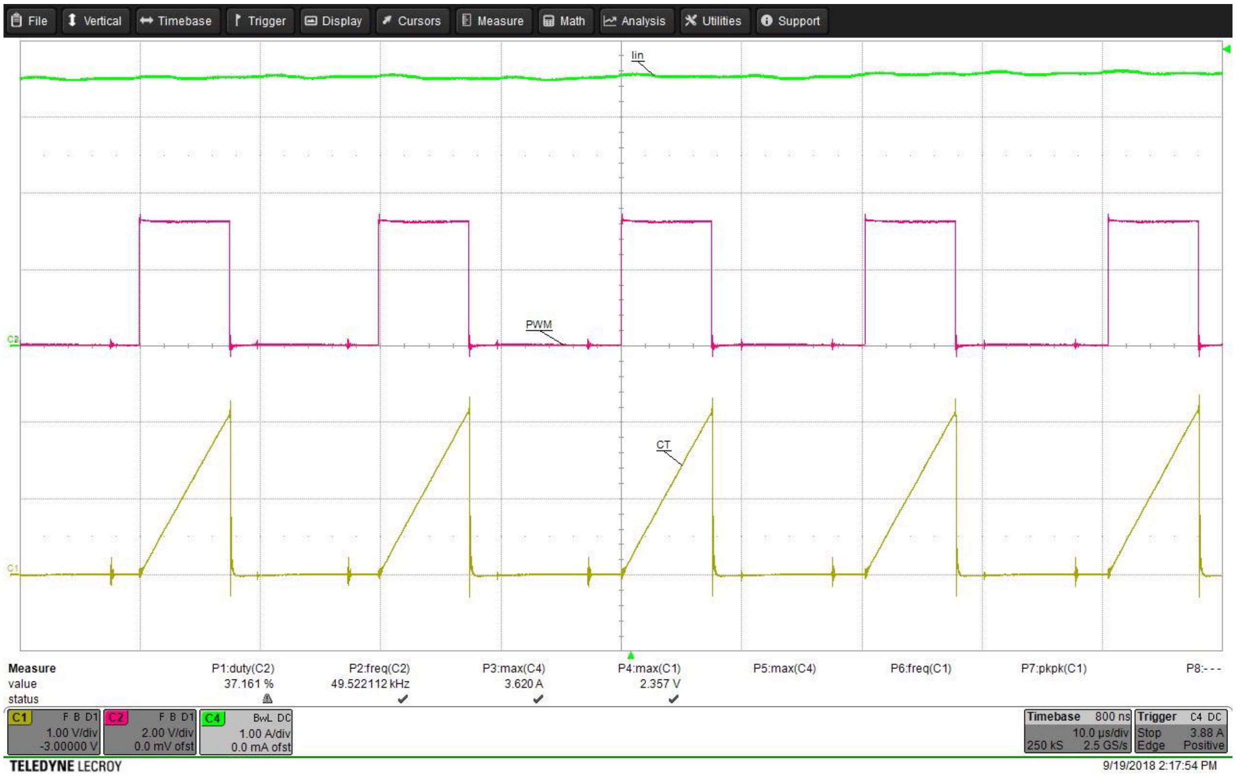
C2 (red): PWM Test Point

C4 (green): Input Current

Time Base: 10 µs/div

FIGURE 1-12: CURRENT TRANSFORMER (CT), PWM TEST POINTS

Condition: Input current at the peak.



Legend:

C1 (yellow): CT Test Point

C2 (red): PWM Test Point

C4 (green): Input Current

Time Base: 10 µs/div

Appendix A. Board Layout and Schematics

This appendix contains the schematics and board layouts for the LVPFC Development Board. The topics covered in this appendix include:

- LVPFC Development Board Schematics
- LVPFC Development Board PCB Layout
- Auxiliary Power Supply Module Schematics
- Auxiliary Power Supply Module PCB Layout

A.1 LVPFC DEVELOPMENT BOARD SCHEMATICS

Figure A-1 and Figure A-2 show the board schematics.

FIGURE A-1: LOW-VOLTAGE POWER FACTOR CORRECTION DEVELOPMENT BOARD SCHEMATICS (PAGE 1 OF 2)

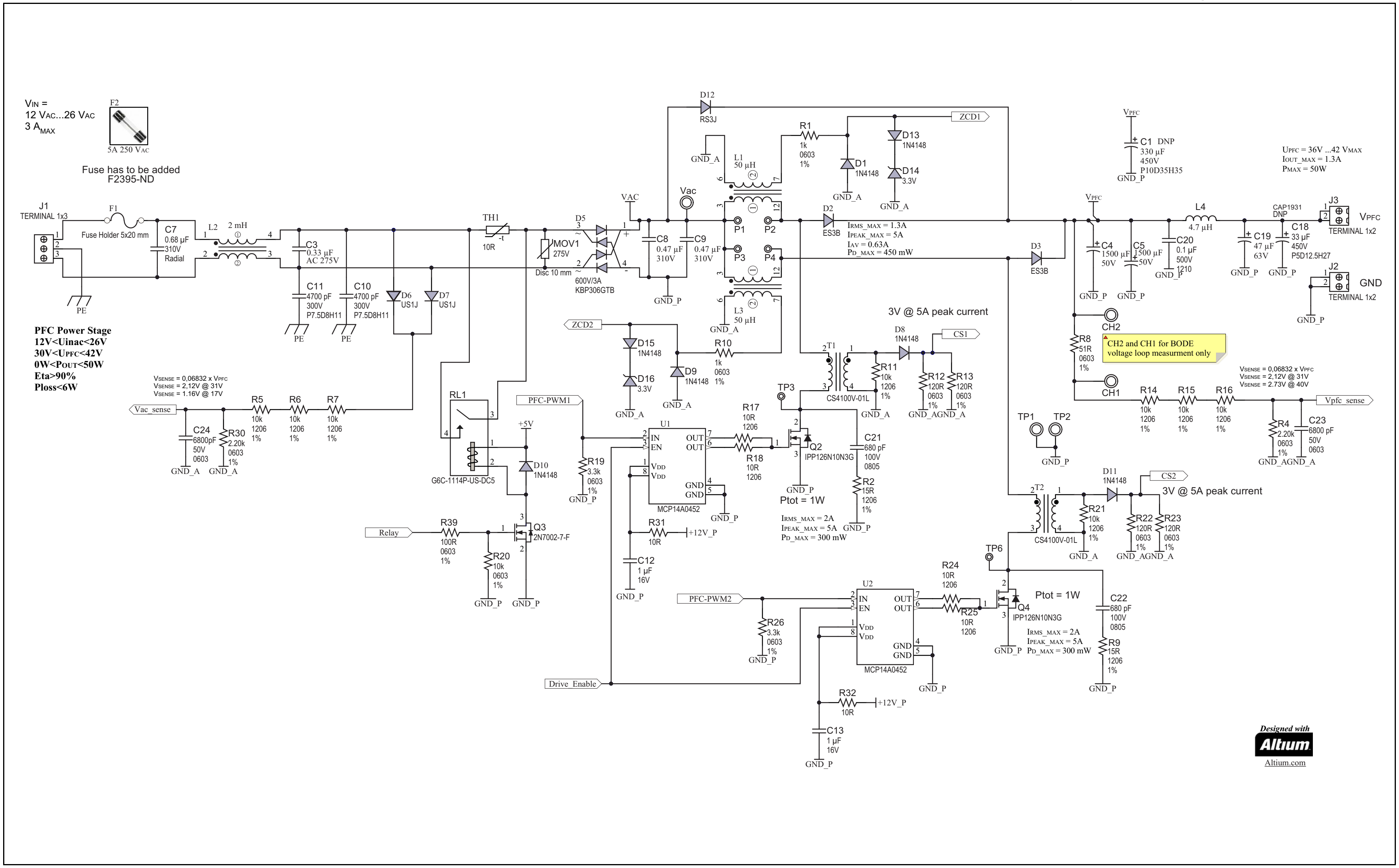
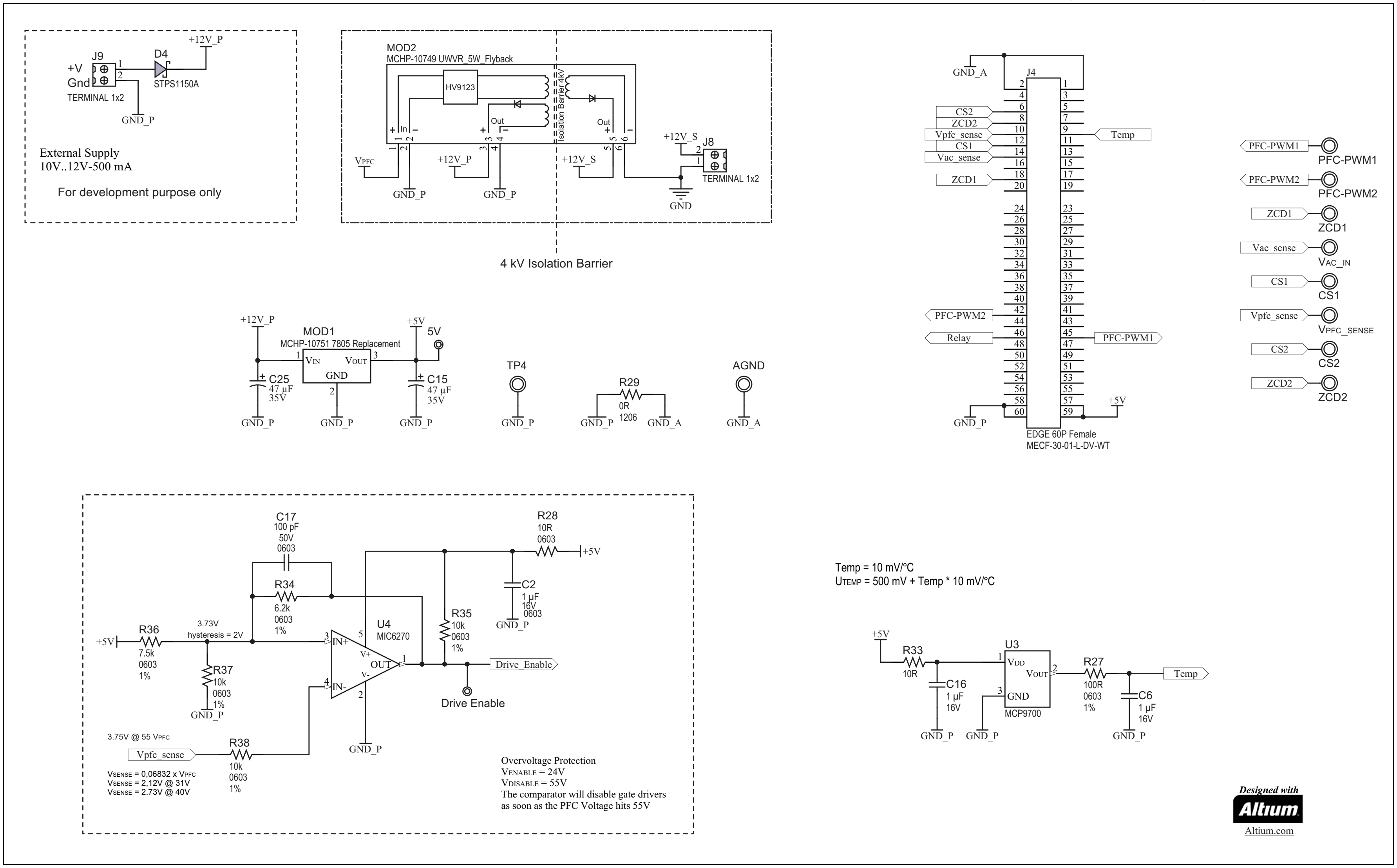


FIGURE A-2: LOW-VOLTAGE POWER FACTOR CORRECTION DEVELOPMENT BOARD SCHEMATICS (PAGE 2 OF 2)



A.2 LVPFC DEVELOPMENT BOARD PCB LAYOUT

The LVPFC Development Board is a two-layer FR4, 1.55 mm, Plated-Through-Hole (PTH) PCB construction with a copper thickness of 70 µm. Figure A-3 and Figure A-4 show the top and bottom assembly of the LVPFC Development Board.

FIGURE A-3: LOW-VOLTAGE POWER FACTOR CORRECTION DEVELOPMENT BOARD TOP ASSEMBLY

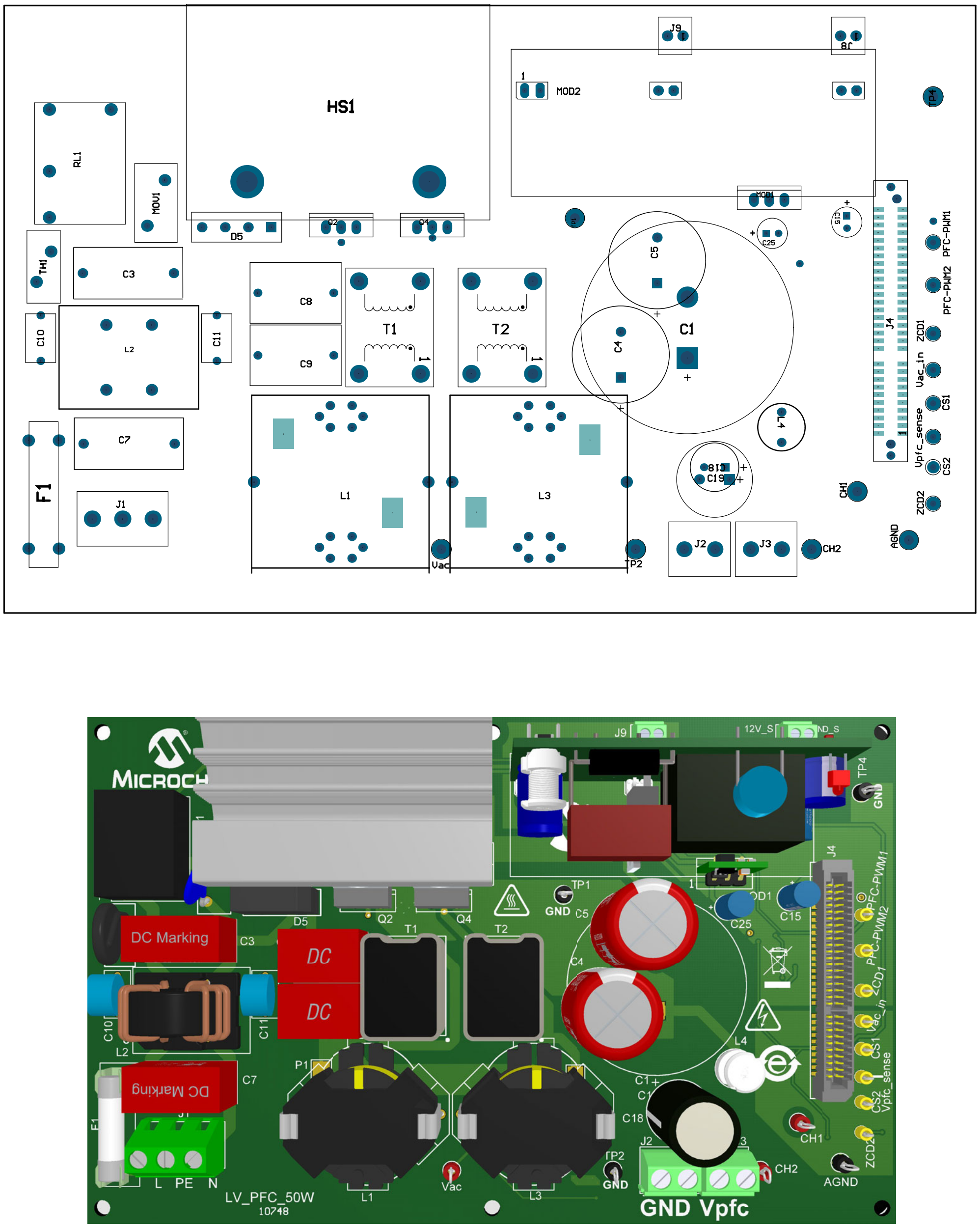
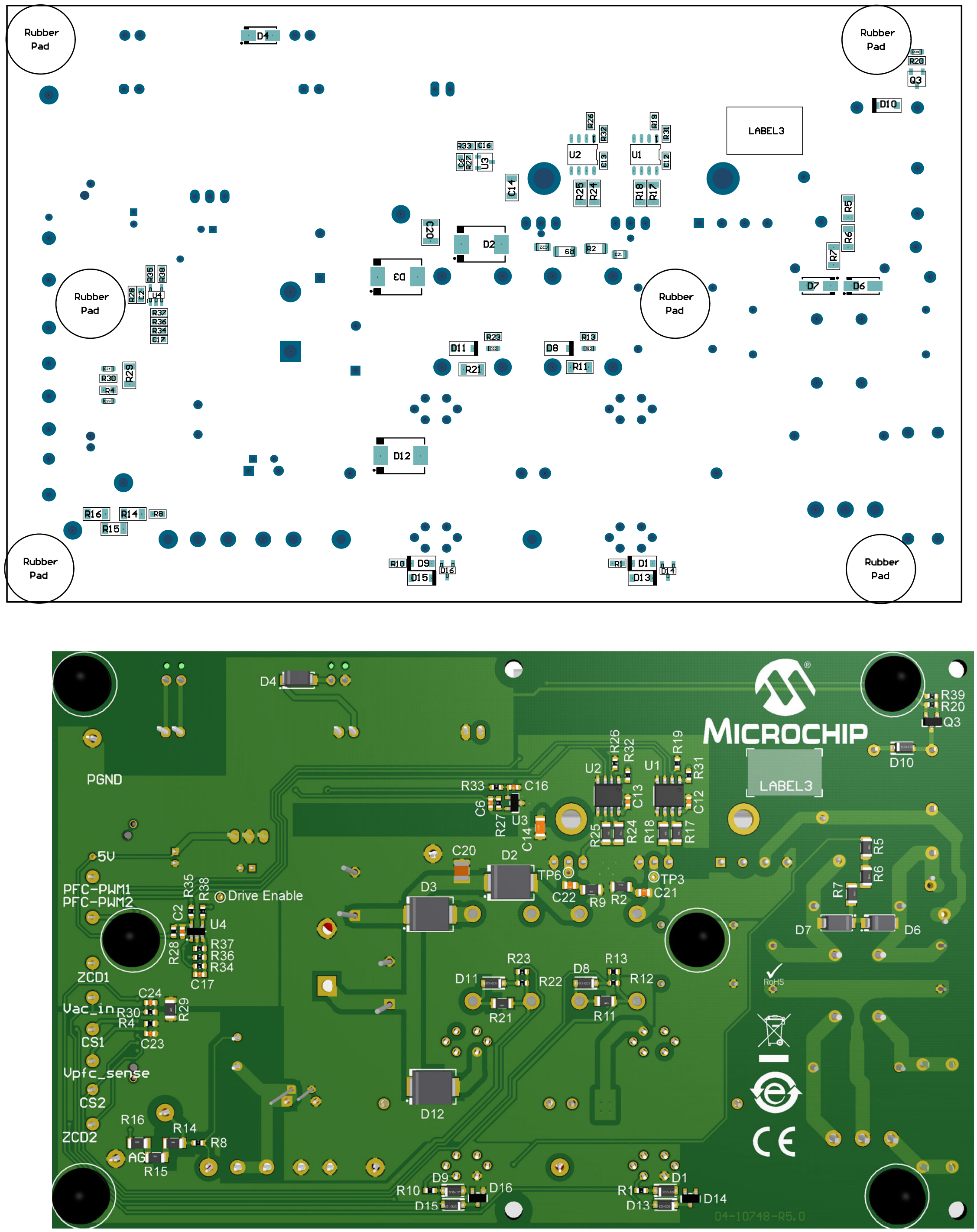


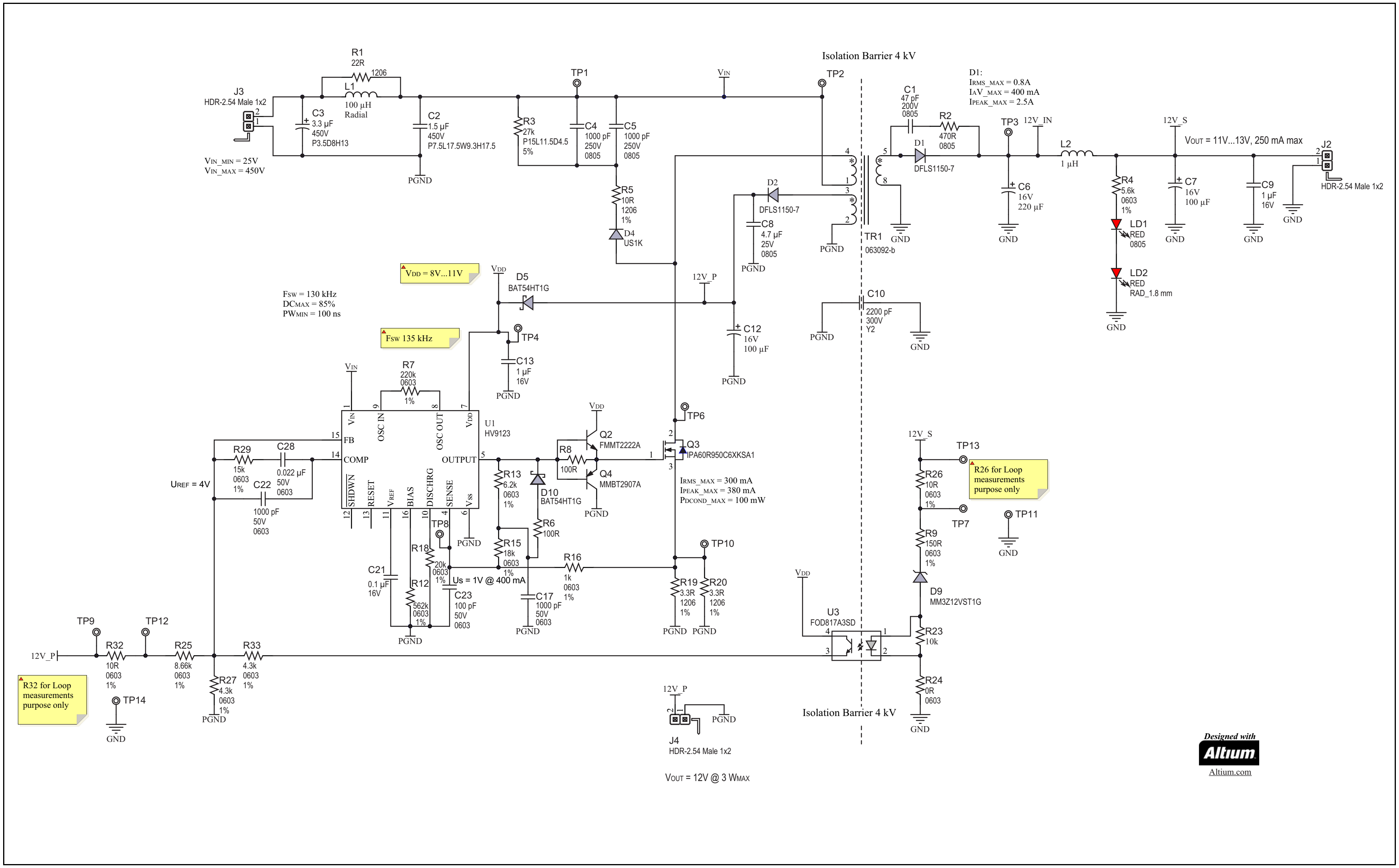
FIGURE A-4: LOW-VOLTAGE POWER FACTOR CORRECTION DEVELOPMENT BOARD BOTTOM ASSEMBLY



A.3 AUXILIARY POWER SUPPLY MODULE SCHEMATICS

Figure A-5 shows the Auxiliary Power Supply module schematics (refer to Figure 1-3).

FIGURE A-5: AUXILIARY POWER SUPPLY MODULE SCHEMATIC



A.4 AUXILIARY POWER SUPPLY MODULE PCB LAYOUT

The Auxiliary Power Supply module is a two-layer FR4, 1.55 mm, Plated-Through-Hole PCB construction. Figure A-6 and Figure A-7 show the top and bottom assembly of the Auxiliary Power Supply module.

FIGURE A-6: AUXILIARY POWER SUPPLY MODULE TOP ASSEMBLY

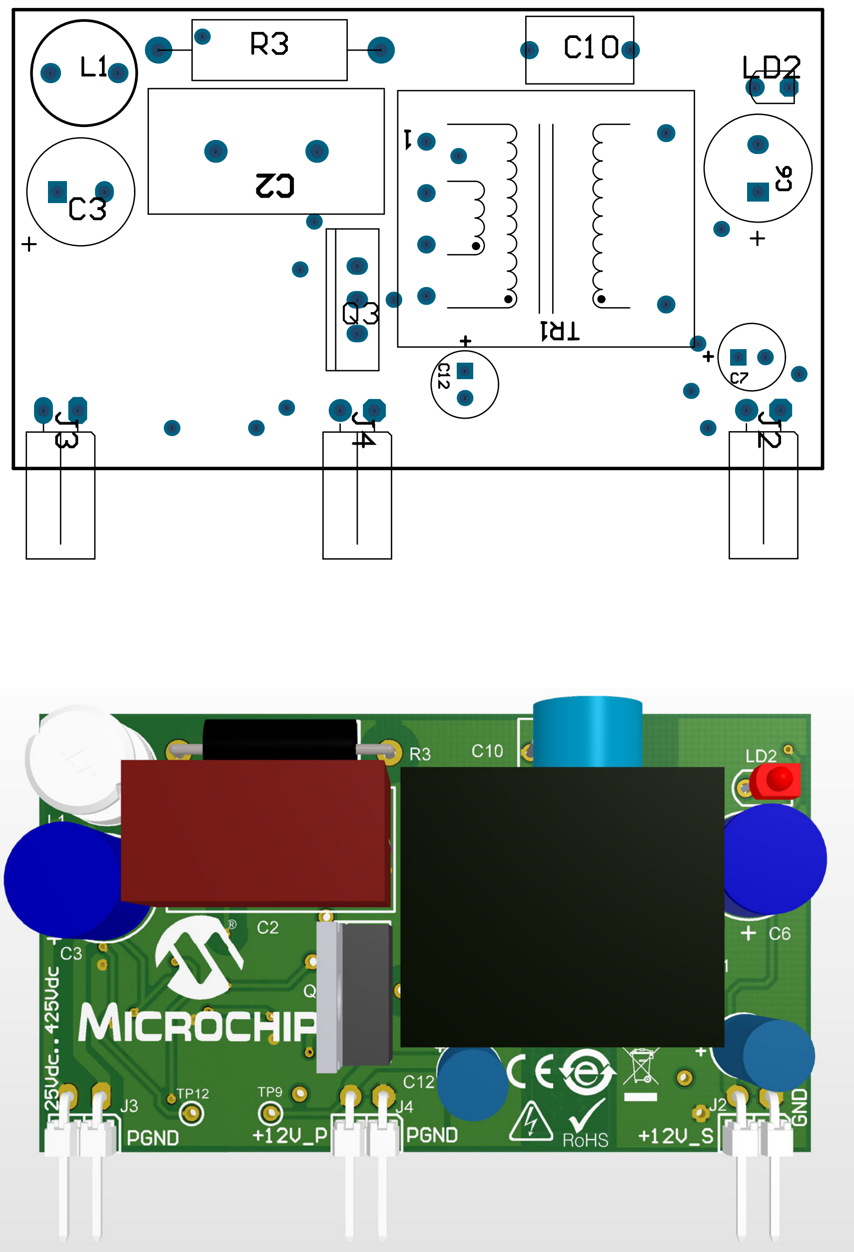
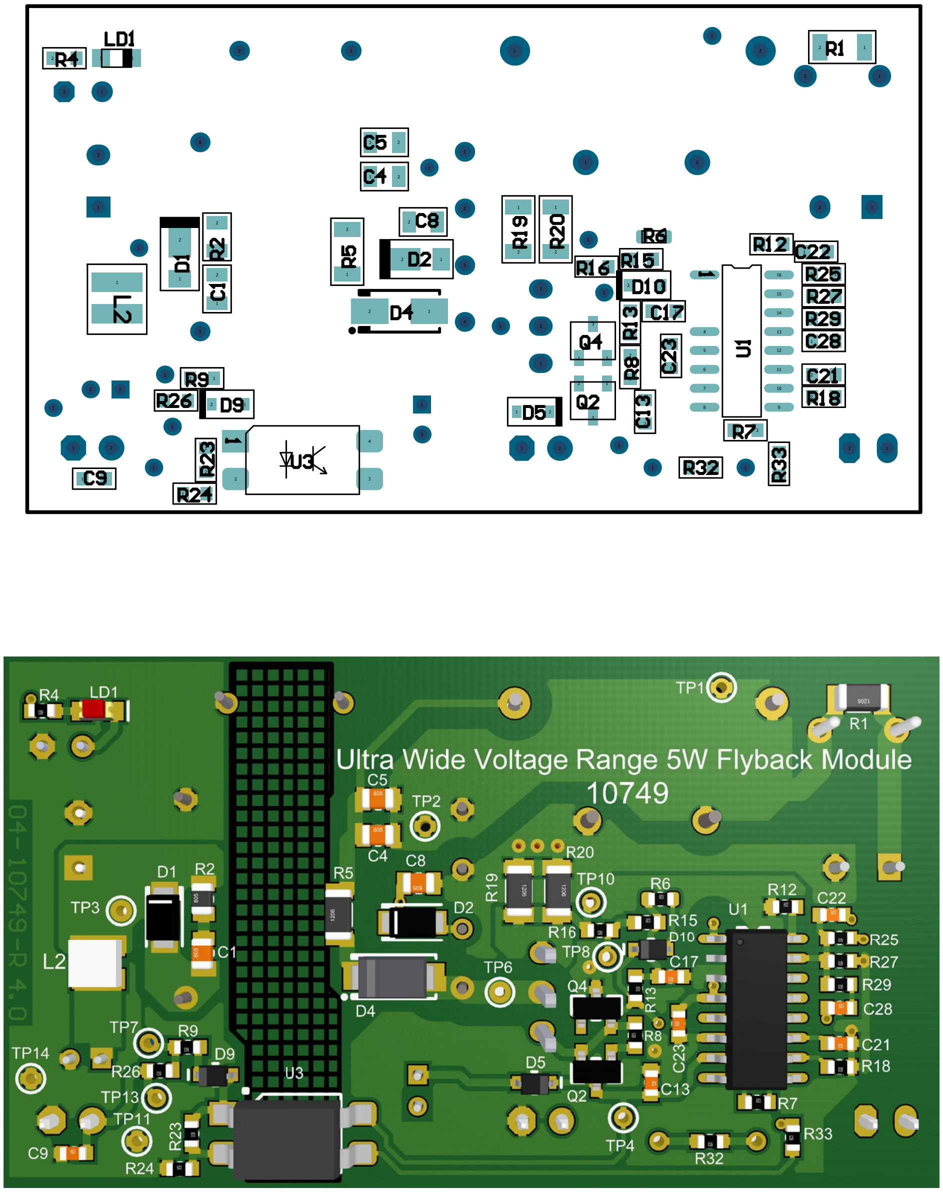


FIGURE A-7: AUXILIARY POWER SUPPLY MODULE BOTTOM ASSEMBLY



Appendix B. Bill of Materials (BOM)

This appendix contains the Bill of Materials (BOMs) for the LVPFC Development Board and for the Auxiliary Power Supply module.

- Bill of Materials – LVPFC Development Board
- Bill of Materials – Auxiliary Power Supply Module

B.1 BILL OF MATERIALS – LVPFC DEVELOPMENT BOARD

Table B-1 shows the Bill of Materials for the LVPFC Development Board.

TABLE B-1: BILL OF MATERIALS (BOM) – LVPFC DEVELOPMENT BOARD

Qty	Designator	Description	Manufacturer	Manufacturer Part Number
4	AGND, TP1, TP2, TP4	Connector Test Point, Loop, Black, Through-Hole (TH)	Keystone Electronics Corp.	5011
5	C2, C6, C12, C13, C16	Capacitor, Ceramic, 0.1 µF, 16V, 10%, X7R, SMD, 0603	Taiyo Yuden Co., Ltd.	EMK107B7105KA-T
1	C3	Capacitor, Film, 0.33 µF, 10%, 275 VAC, Radial	Wurth Elecktronic	890324025034CS
2	C4, C5	Capacitor, 1500 µF, 20%, 50V	Wurth Elecktronic	860010680026
1	C7	Capacitor, Film, 0.68 µF, 10%, 310 VAC, Radial	Wurth Elecktronic	890334025045
2	C8, C9	Capacitor, Film, 0.47 µF, 10%, 310 VAC, Radial	Wurth Elecktronic	890334024005CS
2	C10, C11	Capacitor, Ceramic, 4700 pF, 300V, 20%, Radial, P7.5D8H11	Murata Electronics®	DE2E3KY472MN3AU02F
1	C14	Capacitor, Ceramic, 0.022 µF, 500V, 10%, X7R, SMD, 1206	Johanson Dielectrics	501R18W223KV4E
2	C15, C25	Capacitor, Aluminum, 47 µF, 35V, 20%, Radial, P2D5H12.5	Wurth Elecktronic	860010572005
1	C17	Capacitor, Ceramic, 100 pF, 50V, 10%, X7R, SMD, 0603	Vishay Intertechnology, Inc.	VJ0603Y101KXACW1BC
1	C19	Capacitor, Aluminum, 47 µF, 20%, 63V, Through-Hole	Wurth Elecktronic	860080774008
1	C20	Capacitor, Ceramic, 0.1 µF, 500V, 10%, X7R, SMD, 1210	KEMET	C1210C104KCRACTU
2	C21, C22	Capacitor, Ceramic, 680 pF, 100V, X7R, 0805	Yageo Corporation	CC0805KRX7R0BB681
2	C23, C24	Capacitor, Ceramic, 6800 pF, 50V, 10%, X7R, SMD, 0603	KEMET	C0603C682K5RACTU
3	CH1, CH2, VAC	Connector Test Point, Loop, Red, TH	Keystone Electronics Corp.	5010

TABLE B-1: BILL OF MATERIALS (BOM) – LVPFC DEVELOPMENT BOARD (CONTINUED)

Qty	Designator	Description	Manufacturer	Manufacturer Part Number
8	CS1, CS2, PFC-PWM1, PFC-PWM2, Vac_in, Vpfc_sense, ZCD1, ZCD2	Misc., Test Point PC Mini, 0.040", D, Yellow	Keystone Electronics Corp.	5004
7	D1, D8, D9, D10, D11, D13, D15	Diode, Rectifier, 1N4148, 1.25V, 150 mA, 100V, SOD-123	Micro Commercial Components	1N4148W-TP
2	D2, D3	Diode, Rectifier, ES3B, 900 mV, 3A, 100V, DO-214AB_SMC	Vishay Intertechnology, Inc.	ES3B-E3/57T
1	D4	Diode, Schottky, STPS1150A, 790 mV, 1A, 150V, DO-214AC_SMA	STMicroelectronics	STPS1150A
1	D5	Diode, Rectifier Bridge, 600V, 3A, TH, SIP-4	SMC Diode Solutions Co. LTD	KBP306GTB
2	D6, D7	Diode, Rectifier, US1J 1.7V, 1A, 600V, DO-214AC_SMA	Micro Commercial Components	US1J-TP
1	D12	Diode, Rectifier, RS3J, 1.3V, 3A, 600V, DO-214AB_SMC	Vishay Intertechnology, Inc.	RS3J-E3/57T
2	D14, D16	Diode, Zener, BZX84-C3V3, 3.3V, 250 mW, SOT-23-3	NXP Semiconductors	BZX84-C3V3,215
2	F1	Fuse Holder, 5 mm, TH	Littelfuse®	01110501Z
1	F2	Fuse, Glass, 5A, 250 VAC, 5x20 mm	Littelfuse	0217005.HXP
1	J1	Connector, Terminal, 5 mm, 1x3, Female, 12-28AWG, 16A, TH, R/A	On-Shore Technology, Inc.	OSTVI030152
2	J2, J3	Connector, Terminal, 5.08 mm, 1x2 Female, 12-28AWG, 16A, TH, R/A	On-Shore Technology, Inc.	OSTVI022152
1	J4	Connector, Edge, MECF, 1.27 mm, 60P, Female, SMD, Vertical	Samtec, Inc.	MECF-30-01-L-DV-WT
2	J8, J9	Connector, Terminal, 2.54 mm, 1x2, Female, 20-30AWG, 6A, TH, R/A	PHOENIX CONTACT	1725656
2	L1, L3	Inductor, Customized Part, 11.5A, T/H, PFC	Wurth Elecktronic	750316197
1	L2	Common-mode Choke, 2 mH, 10A, 2 LN, TH	Wurth Elecktronic	7448031002
1	L4	Inductor, Fixed, 4.7 µH, 6.5A, 12.5 mOhm, TH	Wurth Elecktronic	744750230047
1	MOV1	Varistor, MO, 420V, 45J, Disc, 10 mm	TDK Corporation	S10K420
2	Q2, Q4	N-FET, IPP126N10N3G, 100V, 58A, 0.0123R, 94W, TO-220-3	Infineon Technologies AG	IPP126N10N3GXKSA1
1	Q3	N-FET, 2N7002-7-F, 60V, 170 mA, 370 mW, SOT-23-3	Diodes Incorporated®	2N7002-7-F
2	R1, R10	Resistor, TKF, 1k, 1%, 1/10W, SMD, 0603	Panasonic® - ECG	ERJ-3EKF1001V

TABLE B-1: BILL OF MATERIALS (BOM) – LVPFC DEVELOPMENT BOARD (CONTINUED)

Qty	Designator	Description	Manufacturer	Manufacturer Part Number
2	R2, R9	Resistor, TKF, 15R, 1%, 1/4W, SMD, 1206	Panasonic® - ECG	ERJ-8ENF15R0V
2	R4, R30	Resistor, TF, 2.20k, 1%, 1/8W, SMD, 0603	Vishay Intertechnology, Inc.	MCT06030C2201FP500
8	R5, R6, R7, R11, R14, R15, R16, R21	Resistor, TKF, 10k, 1%, 1/4W, SMD, 1206	Vishay Intertechnology, Inc.	CRCW120610K0FKEA
1	R8	Resistor, TKF, 51R, 1%, 1/10W, SMD, 0603	Yageo Corporation	RC0603FR-0751RL
4	R12, R13, R22, R23	Resistor, TKF, 120R, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT120R
4	R17, R18, R24, R25	Resistor, TKF, 10R, 1%, 1/4W, SMD, 1206	Panasonic - ECG	ERJ-8ENF10R0V
2	R19, R26	Resistor, TKF, 3.3k, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF3301V
4	R20, R35, R37, R38	Resistor, TKF, 10k, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF1002V
2	R27, R39	Resistor, TKF, 100R, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF1000V
4	R28, R31, R32, R33	Resistor, TKF, 10R, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT10R0
1	R29	Resistor, TKF, 0R, SMD, 1206	Panasonic - ECG	ERJ-8GEY0R00V
1	R34	Resistor, TKF, 6.2k, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF6201V
1	R36	Resistor, TKF, 7.5k, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF7501V
1	RL1	Relay Power, SPST-NO, 5V, 10A, 250 VAC, TH	Omron Electronics LLC – EMC Division	G6C-1114P-US-DC5
2	SCR1, SCR2	Machine Screw Pan, Phillips, M3	B&F™ Fasteners Supply	MPMS 003 0008 PH
2	T1, T2	Transformer, Current, 1:100, 1 MHz, 24A, TH	Coilcraft	CS4100V-01L
1	TH1	Resistor, Thermistor, NTC, 10R, 3A, Radial	TDK Corporation	B57235S100M54
2	WASHER1, WASHER2	Washer Flat, M3, Nylon	Essentra Components	MFW030A
1	MOD1	Microchip Module, MCHP-10751 7805, Replacement	Microchip Technology Inc.	04-10751
1	MOD2	Microchip Module, MCHP-10749, UWVR, 5W, Flyback	Microchip Technology Inc.	04-10749
2	U1, U2	Microchip Analog FET Driver, MCP14A0452-E/SN, SOIC-8	Microchip Technology Inc.	MCP14A0452-E/SN
1	U3	Microchip Analog Temperature Sensor, -40C to +150°C, MCP9700T-E/TT, SOT-23-3	Microchip Technology Inc.	MCP9700T-E/TT
1	U4	IC Comparator, Precision, 2-36V, SOT23-5	Microchip Technology Inc.	MIC6270YM5-TR

B.2 BILL OF MATERIALS – AUXILIARY POWER SUPPLY MODULE

Table B-2 shows the Bill of Materials for the Auxiliary Power Supply module.

TABLE B-2: BILL OF MATERIALS (BOM) – AUXILIARY POWER SUPPLY MODULE

Qty	Designator	Description	Manufacturer	Manufacturer Part Number
1	C1	Capacitor, Ceramic, 47 pF, 200V, 5%, C0G, NP0, SMD, 0805	KEMET	C0805C470J2GACTU
1	C2	Capacitor, Film 1.5 µF, 450V, 5%, RAD, P7.5L17.5W9.3H17.5	Panasonic® - ECG	ECW-FD2W155JB
1	C3	Capacitor, Aluminum, 3.3 µF, 450V, 20%, RAD_P3.5D8H13	Rubycon Corporation	450PK3R3MEFC8X11.5
2	C4, C5	Capacitor, Ceramic, 1000 pF, 250V, 10%, X7R, SMD, 0805	Murata Electronics®	GRM21AR72E102KW01D
1	C6	Capacitor, Aluminum, 220 µF, 16V, 20%, 0.015R, RAD_P3.5D8H8	Wurth Elecktronic	870025374003
2	C7, C12	Capacitor, 100 µF, 20%, 16V	Wurth Elecktronic	860010372006
1	C8	Capacitor, Ceramic, 4.7 µF, 25V, 20%, X5R, SMD, 0805	TDK Corporation	C2012X5R1E475M125AB
2	C9, C13	Capacitor, Ceramic, 1 µF, 16V, 10%, X7R, SMD, 0603	Taiyo Yuden Co., Ltd.	EMK107B7105KA-T
1	C10	Capacitor, Ceramic, 2200 pF, 300V, 20%, RAD_P7.5D8H11	Murata Electronics	DE2E3KY222MN3AU02F
2	C17, C22	Capacitor, Ceramic, 1000 pF, 50V, 5%, C0G, SMD, 0603	AVX Corporation	06035A102JAT2A
1	C21	Capacitor, Ceramic, 0.1 µF, 16V, 10%, X7R, SMD, 0603	AVX Corporation	0603YC104KAT2A
1	C23	Capacitor, Ceramic, 100 pF, 50V, 5%, NP0, SMD, 0603	Cal-Chip Electronics Inc.	GMC10CG101J50NTLF
1	C28	Capacitor, Ceramic, 0.022 µF, 50V, 5%, X7R, SMD, 0603	AVX Corporation	06035C223JAT2A
2	D1, D2	1.0A High-Voltage Schottky Barrier Rectifier	Diodes Incorporated®	DFLS1150
1	D4	Diode, Rectifier, US1K, 1.7V, 1A, 800V, DO-214AC_SMA	Diodes Incorporated	US1K-13
2	D5, D10	Diode, Schottky, BAT54HT1G, 30V, 200 mA, 40V, SOD-323	ON Semiconductor®	BAT54HT1G
1	D9	Diode, Zener, 12V, 200 mW, SOD-323	ON Semiconductor	MM3Z12VST1G
3	J2, J3, J4	Connector Header, 2.54 Male, 1x2, Gold, 6.75 mm, TH, R/A	Molex®	0901210762
1	L1	Inductor, Fixed, 100 µH, 900 mA, 190 mOhm	Wurth Elecktronic	744772101
1	L2	Inductor, Fixed, 1 µH, 2.7A, 47 mOhm, SMD	Wurth Elecktronic	74438335010
1	LD1	Diode, LED, Red, 2V, 20 mA, 104 mcd, Diffuse, SMD, 0805	OSRAM Opto Semiconductors GmbH.	LS R976-NR-1
1	LD2	Diode, LED, Red, 1.85V, 30 mA, 200 mcd, Diffuse, RAD, 1.8 mm	Kingbright Electronic Co., Ltd.	WP4060SRD
1	Q2	Transistor, BJT, NPN, FMMT2222A, 40V, 600 mA, 330 mW, SOT-23-3	Diodes Incorporated	MMBT2222A-7-F

TABLE B-2: BILL OF MATERIALS (BOM) – AUXILIARY POWER SUPPLY MODULE (CONTINUED)

Qty	Designator	Description	Manufacturer	Manufacturer Part Number
1	Q3	Transistor, FET N-CH, IPA60R950C6XKSA1, 600V, 4.4A, 0.95R, 26W, TO-220-3	Infineon Technologies AG	IPA60R950C6XKSA1
1	Q4	Transistor, BJT, PNP, MMBT2907A, 60V, 800 mA, 350 mW, SOT-23-3	ON Semiconductor®	MMBT2907A
1	R1	Resistor, 22R, 1/4W, 1%, 1206, SMD	Panasonic® - ECG	ERJ-8ENF22R0V
1	R2	Resistor, TKF, 470R, 1%, 1/16W, SMD, 0805	Panasonic - ECG	ERJ-6ENF4700V
1	R3	Resistor, MO, 27k, 5%, 1W, AX, P15L11.5D4.5	Yageo Corporation	RSF100JB-73-27K
1	R4	Resistor, TKF, 5.6k, 1%, 1/10W, SMD, 0603	Yageo Corporation	RC0603FR-075K6L
1	R5	Resistor, TKF, 10R, 1%, 1/4W, SMD, 1206	Panasonic - ECG	ERJ-8ENF10R0V
2	R6, R8	Resistor, TKF, 100R, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF1000V
1	R7	Resistor, TKF, 220k, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF2203V
1	R9	Resistor, TKF, 150R, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT150R
1	R12	Resistor, TKF, 562k, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT562K
1	R13	Resistor, TKF, 6.2k, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF6201V
1	R15	Resistor, TKF, 18k, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF1802V
1	R16	Resistor, TKF, 1k, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF1001V
1	R18	Resistor, TKF, 20k, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF2002V
2	R19, R20	Resistor, TKF, 3.3R, 1%, 1/2W, SMD, 1206	Susumu Co., LTD.	RL1632R-3R30-F
1	R23	Resistor, TKF, 10k, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF1002V
1	R24	Resistor, TKF, 0R, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3GSY0R00V
1	R25	Resistor, TKF, 8.66k, 1%, 1/10W, SMD, 0603	Yageo Corporation	RC0603FR-078K66L
2	R26, R32	Resistor, TKF, 10R, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF10R0V
2	R27, R33	Resistor, TKF, 4.3k, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF4301V
1	R29	Resistor, TKF, 15k, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF1502V
1	TR1	Transformer, SMPS, Flyback 6:1:1, 20V-375V, 5.5W, TH	Kaschke Components GmbH	063092-a
1	U3	Optoisolator, FOD817A3SD, SMD-4	ON Semiconductor	FOD817A3SD
1	U1	Microchip Analog, PWM Controller, 3 MHz, HV9123NG-G, SOIC-16	Microchip Technology Inc.	HV9123NG-G

NOTES:

Appendix C. Example Algorithm

This appendix provides algorithm examples for the LVPFC Development Board.

Examples presented are:

- Interleaved PFC Boost Converter in Transition Mode
- Interleaved PFC Boost Converter in Continuous Conduction Mode

C.1 INTERLEAVED PFC BOOST CONVERTER IN TRANSITION MODE

Figure C-1 shows a standard representation of a high-level block diagram of the implementation of an algorithm example of the interleaved PFC boost converter control system working in Transition mode. The exact implementation is subject to change with alternative control schemes and algorithms, and will be documented in subsequent code examples.

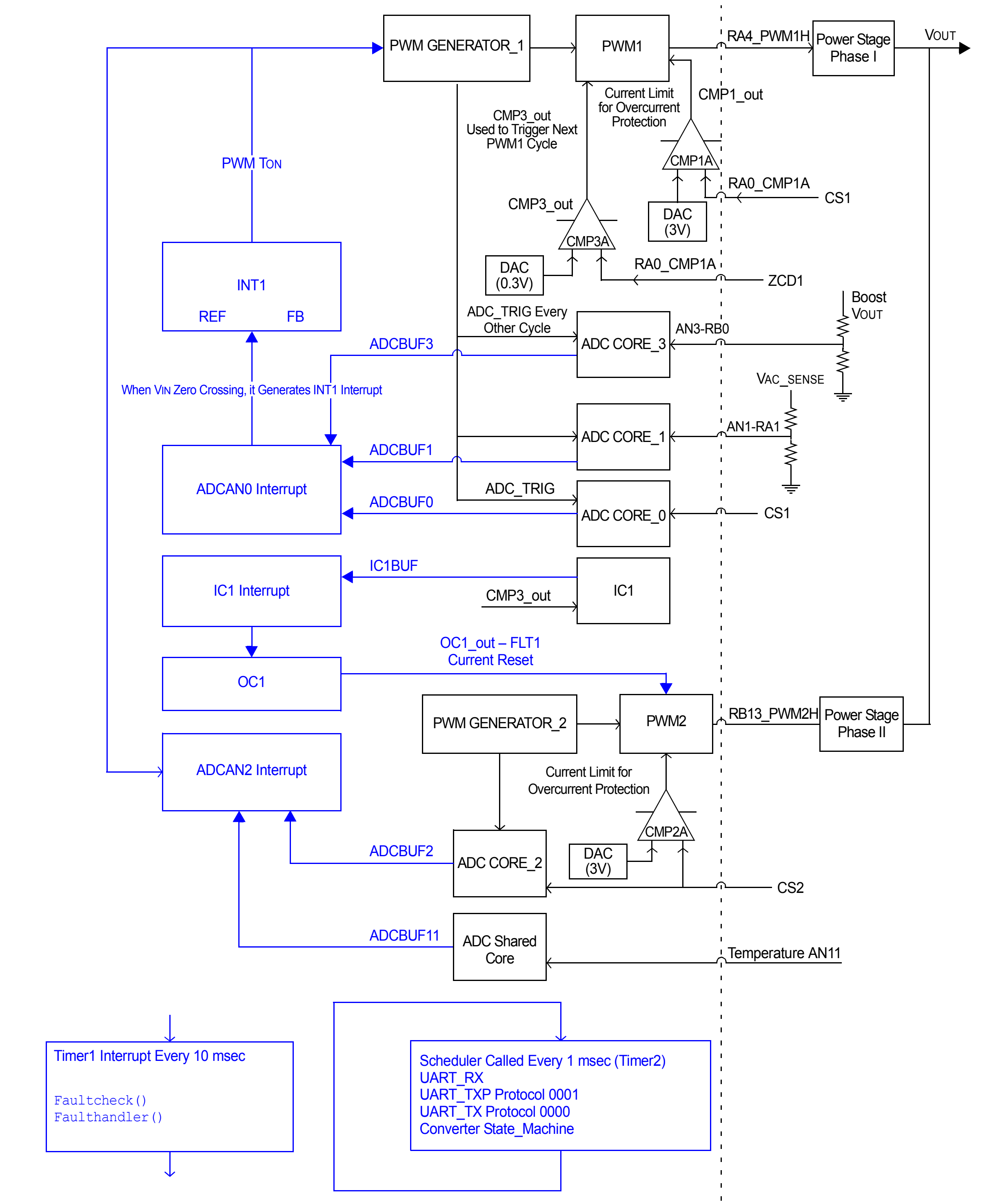
> **Note:** In order to maintain interleaved operation, the Slave phase must have the same switching frequency as the Master phase.

Black building blocks represents hardware blocks, while blue building blocks represent software blocks.

Software blocks have the following functions:

- INT1:
  - Calculates V_{IN} average and V_{OUT} average every half of AC cycle (for instance, 10 ms for 50 Hz, 8.33 ms for 60 Hz)
  - Voltage compensator on V_{OUT} average
- ADCAN0 Interrupt:
  - Verifies V_{IN} zero crossing
  - Accumulates V_{IN} and V_{OUT}
  - Stores current in IPH1
- IC1 Interrupt:
  - Measures PWM1 period of time
  - Calculates delay at which to trigger the PWM2 T_{ON} pulse and to set OC1
- OC1:
  - Programmed to generate the trigger for the PWM2 T_{ON} pulse
- ADCAN2 Interrupt:
  - Stores current in IPH2
  - Filters temperature

FIGURE C-1: INTERLEAVED PFC BOOST CONVERTER IN TRANSITION MODE



Legend:
ADC: Analog-to-Digital Converter
CMP: Comparator
IC: Input Capture to measure the PWM period of frequency
PWM: Pulse-Width Modulator
ZCD: Zero-Cross Detection

C.2 INTERLEAVED PFC BOOST CONVERTER IN CONTINUOUS CONDUCTION MODE

Figure C-2 shows a standard representation of a high-level block diagram of the implementation of an algorithm example of the interleaved PFC boost converter control system working in Continuous Conduction mode. The exact implementation is subject to change with alternative control schemes and algorithms, and will be documented in subsequent code examples.

Black building blocks represent hardware blocks, while blue building blocks represent software blocks.

Software blocks have the following functions:

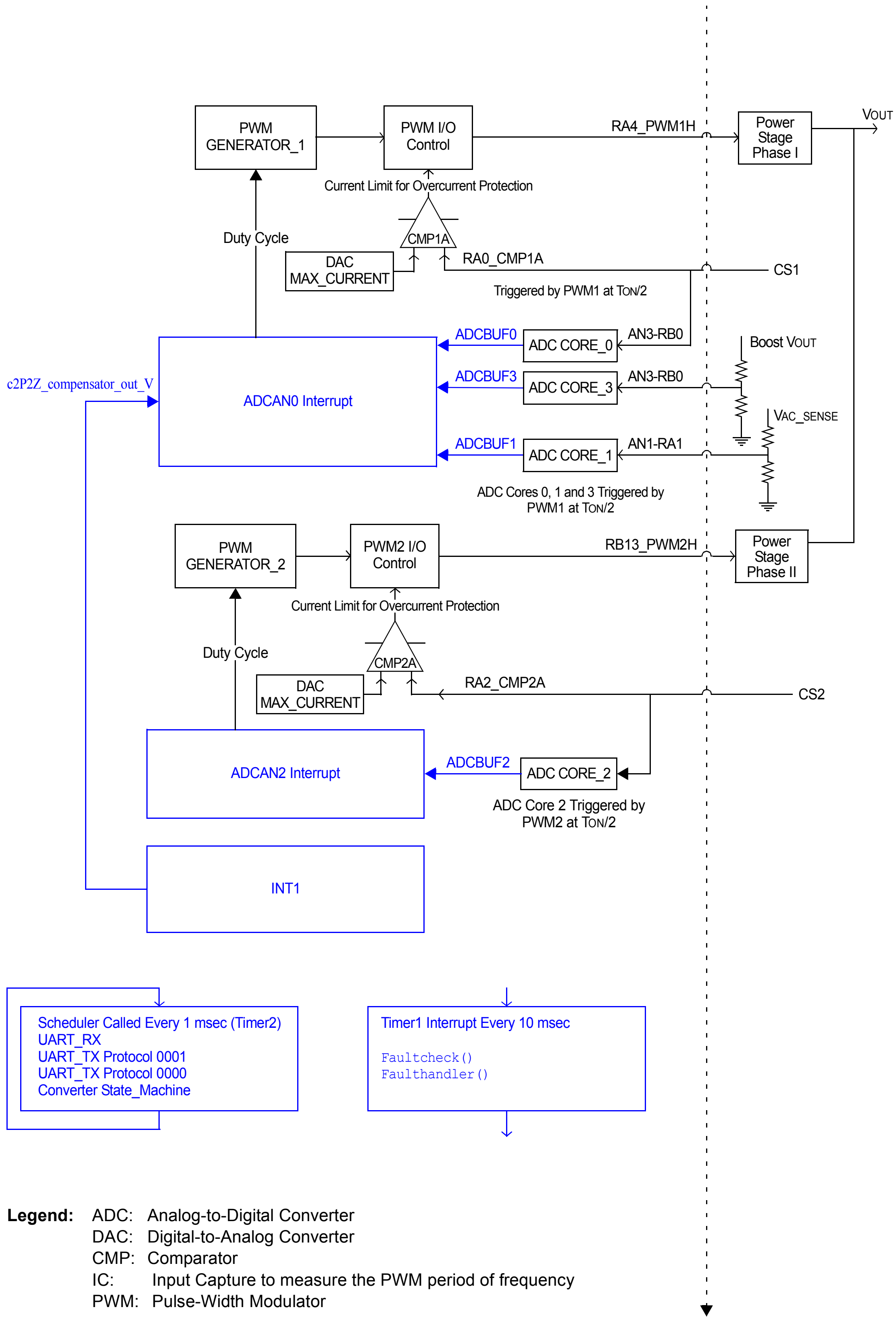
- ADCAN0 Interrupt:
  - Calculates the current reference:

    c2P2Z_compensator_out_V * ADCBUF1/V_{INAVG}^2

> **Note:** ADCBUF1 is proportional to the rectified input AC voltage. V_{INAVG}^2 is proportional to the square of the rectified average value of the input V_{AC} voltage. The "c2P2Z_compensator_out" is the output of the voltage loop.

  - Samples IPH1 and executes PH1 current loop
  - Accumulates V_{IN} and V_{OUT}
  - Verifies zero crossing on V_{IN}
  - Triggers INT1 if zero crossing is 'True'
- ADCAN2 Interrupt:
  - Samples IPH2 and executes PH2 current controller
- INT1: Interrupts every 10 msec (V_{IN} zero crossing)
  - Calculates V_{IN} average and squares it (V_{INAVG}^2)
  - Calculates V_{OUT} average
  - Runs voltage compensator on V_{OUT} average that calculates the DC current reference for the current loops

FIGURE C-2: INTERLEAVED PFC BOOST CONVERTER IN CONTINUOUS CONDUCTION MODE



Legend:
ADC: Analog-to-Digital Converter
DAC: Digital-to-Analog Converter
CMP: Comparator
IC: Input Capture to measure the PWM period of frequency
PWM: Pulse-Width Modulator

Appendix D. Optional Supporting Equipment

D.1 INTRODUCTION

This appendix provides information on the following equipment, which is recommended for use to improve the functionality of the LVPFC Development Kit:

- Isolation Transformer
- Active Load 50W

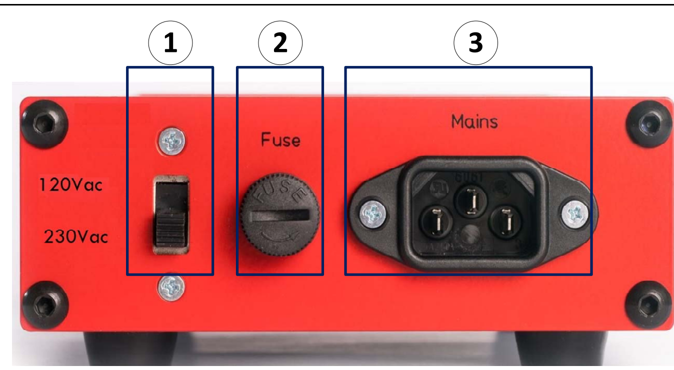
D.2 ISOLATION TRANSFORMER

The Isolation Transformer 10:1 has the following features, as shown in Figure D-1 and Figure D-2.

FIGURE D-1: ISOLATION TRANSFORMER – FRONT PANEL

1. Illuminated mains power switch.
2. Four 4 mm banana plugs (0 VAC, 12 VAC, 24 Vac, PE connections).

FIGURE D-2: ISOLATION TRANSFORMER – BACK PANEL



1. Slide switch for input voltage selection (120 VAC/230 VAC).
2. Fuse socket.
3. IEC plug for mains connection.

Note:	The product number is ASC-70 and the manufacturer is ASCALAB d.o.o. (www.ascalab.com).

D.3 ACTIVE LOAD 50W

The Active Load has the following features, as shown in Figure D-3.

FIGURE D-3: ACTIVE LOAD 50W[1,2]

Front Back

Front Side	Back Side
1. Display 2. On/Off Push Button 3. Pulse Push Button 4. Preset Push Button 5. I/P Push Button 6. Coarse Potentiometer 7. Fine Potentiometer 8. UVLO Potentiometer 9. Pulse Potentiometer 10. Preset LED (green) Pulse LED (yellow) On/Off LED (red)	1. 4 mm Banana Plugs (red for positive and blue for return line) 2. Plug for External 12 VDC Supply

Note 1: The ASC-50W device's standard delivery includes an external AC/DC wall plug adapter. All various AC input plugs are included. Manufacturer: XP Power. Type: VER12US120-JA.

2: The product number is ASC-50W and the manufacturer is ASCALAB d.o.o. (www.ascalab.com).

NOTES:

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China - Xian
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China - Xiamen
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China - Zhuhai
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ASIA/PACIFIC

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India - New Delhi
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India - Pune
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Japan - Osaka
Tel: 81-6-6152-7160

Japan - Tokyo
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Korea - Daegu
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Korea - Seoul
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Malaysia - Kuala Lumpur
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Malaysia - Penang
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Philippines - Manila
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Singapore
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Taiwan - Hsin Chu
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Taiwan - Kaohsiung
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Taiwan - Taipei
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Thailand - Bangkok
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Vietnam - Ho Chi Minh
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EUROPE

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Finland - Espoo
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France - Paris
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Germany - Haan
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Germany - Heilbronn
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Israel - Ra'anana
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Netherlands - Drunen
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Norway - Trondheim
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Poland - Warsaw
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Sweden - Gothenberg
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Sweden - Stockholm
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UK - Wokingham
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