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Microchip received ISO/TS-16949:2009 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company’s quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip’s quality system for the design and manufacture of development systems is ISO 9001:2000 certified.

QUALITY MANAGEMENT SYSTEM CERTIFIED BY DNV

ISO/TS 16949

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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:

<table>
<thead>
<tr>
<th>DOCUMENTATION CONVENTIONS</th>
<th>Description</th>
<th>Represents</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arial font:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italic characters</td>
<td>Referenced books</td>
<td><em>MPLAB® IDE User’s Guide</em></td>
<td>...is the only compiler...</td>
</tr>
<tr>
<td>Emphasized text</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial caps</td>
<td>A window</td>
<td>the Output window</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A dialog</td>
<td>the Settings dialog</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A menu selection</td>
<td>select Enable Programmer</td>
<td></td>
</tr>
<tr>
<td>Quotes</td>
<td>A field name in a window or dialog</td>
<td>“Save project before build”</td>
<td></td>
</tr>
<tr>
<td>Underlined, italic text with right angle bracket</td>
<td>A menu path</td>
<td>*File&gt;*Save</td>
<td></td>
</tr>
<tr>
<td>Bold characters</td>
<td>A dialog button</td>
<td>Click <strong>OK</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A tab</td>
<td>Click the <strong>Power</strong> tab</td>
<td></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>
<td></td>
</tr>
<tr>
<td>Text in angle brackets &lt; &gt;</td>
<td>A key on the keyboard</td>
<td>Press <em>&lt;Enter&gt;</em>, <em>&lt;F1&gt;</em></td>
<td></td>
</tr>
<tr>
<td>Courier New font:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plain Courier New</td>
<td>Sample source code</td>
<td>ndefine START</td>
<td></td>
</tr>
<tr>
<td>Filenames</td>
<td></td>
<td><em>autoexec.bat</em></td>
<td></td>
</tr>
<tr>
<td>File paths</td>
<td></td>
<td><em>c:\mcc18\h</em></td>
<td></td>
</tr>
<tr>
<td>Keywords</td>
<td></td>
<td>_asm, _endasm, static</td>
<td></td>
</tr>
<tr>
<td>Command-line options</td>
<td></td>
<td>-Opa+, -Opa-</td>
<td></td>
</tr>
<tr>
<td>Bit values</td>
<td></td>
<td>0, 1</td>
<td></td>
</tr>
<tr>
<td>Constants</td>
<td></td>
<td>OxFF, ‘A’</td>
<td></td>
</tr>
<tr>
<td>Italic Courier New</td>
<td>A variable argument</td>
<td><em>file.o</em>, where <em>file</em> can be any valid filename</td>
<td></td>
</tr>
<tr>
<td>Square brackets [ ]</td>
<td>Optional arguments</td>
<td>mcc18 [options] file [options]</td>
<td></td>
</tr>
<tr>
<td>Curly brackets and pipe character: {</td>
<td>Choice of mutually exclusive arguments; an OR selection</td>
<td>errorlevel {0</td>
<td>1}</td>
</tr>
<tr>
<td>Ellipses...</td>
<td>Replaces repeated text</td>
<td>var_name [, ]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Represents code supplied by user</td>
<td>void main (void) { ... }</td>
<td></td>
</tr>
</tbody>
</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.

  (www.microchip.com/DS50002814); available for download from the Microchip website.

THE MICROCHIP WEBSITE

Microchip provides online support via our website at www.microchip.com. This website is used as a means to make files and information easily available to customers. Accessible by using your favorite Internet browser, the website contains the following information:

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- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip consultant program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events; and listings of Microchip sales offices, distributors and factory representatives

PRODUCT CHANGE NOTIFICATION SERVICE

Microchip’s customer notification service helps keep customers current on Microchip products. Subscribers will receive e-mail notification whenever there are changes, updates, revisions or errata related to a specified product family or development tool of interest.

To register, access the Microchip website at www.microchip.com, click on **Product Change Notification** and follow the registration instructions.

CUSTOMER SUPPORT

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- 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.
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**

![Block Diagram](image)

---

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

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.
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\textsubscript{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

3. Input power connector.
4. Output power connector.
5. Input EMI filter.
6. PFC storage chokes.
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

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/I2C 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).


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**

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

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low-Voltage Solution</th>
<th>High-Voltage Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage Range (VAC)</td>
<td>8 to 26</td>
<td>80 to 260</td>
</tr>
<tr>
<td>Output Power (WMAX)</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>Output Load Current (A_MAX)</td>
<td>1.28</td>
<td>0.51</td>
</tr>
<tr>
<td>Input Current (A_MAX)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>~90</td>
<td>~96</td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>0°C to +40°C</td>
<td></td>
</tr>
</tbody>
</table>

1.6 MATING SOCKET PINOUT

The pinout is shown in Table 1-3.

<table>
<thead>
<tr>
<th>Name</th>
<th>Mating Socket Pin</th>
<th>Function/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GND_A</td>
<td>1, 2</td>
<td>Analog Ground</td>
</tr>
<tr>
<td>CS2</td>
<td>6</td>
<td>Current Sense, Phase 2</td>
</tr>
<tr>
<td>ZCD2</td>
<td>8</td>
<td>Zero-Cross Detection, Phase 2</td>
</tr>
<tr>
<td>Temp</td>
<td>9</td>
<td>Temperature Sense</td>
</tr>
<tr>
<td>VPFC_SENSE</td>
<td>10</td>
<td>Output PFC Voltage Sense</td>
</tr>
<tr>
<td>CS1</td>
<td>12</td>
<td>Current Sense, Phase 1</td>
</tr>
<tr>
<td>VAC_SENSE</td>
<td>14</td>
<td>Input AC Voltage Sense</td>
</tr>
<tr>
<td>ZCD1</td>
<td>18</td>
<td>Zero-Cross Detection, Phase 1</td>
</tr>
<tr>
<td>PFC-PWM2</td>
<td>42</td>
<td>PWM Output, Phase 2</td>
</tr>
<tr>
<td>PFC-PWM1</td>
<td>45</td>
<td>PWM Output, Phase 1</td>
</tr>
<tr>
<td>Relay</td>
<td>46</td>
<td>Inrush Control – Relay On/Off</td>
</tr>
<tr>
<td>+5V</td>
<td>57, 59</td>
<td>VDD Rail</td>
</tr>
<tr>
<td>GND_D</td>
<td>58, 60</td>
<td>Digital Ground</td>
</tr>
</tbody>
</table>
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: V_PFC_SENSE, V_AC_IN TEST POINTS

Legend:
C1 (yellow): V_PFC_SENSE
C2 (red): V_AC_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)

Designed with Altium.com
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

<table>
<thead>
<tr>
<th>Qty</th>
<th>Designator</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Manufacturer Part Number</th>
</tr>
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<tbody>
<tr>
<td>4</td>
<td>AGND, TP1, TP2, TP4</td>
<td>Connector Test Point, Loop, Black, Through-Hole (TH)</td>
<td>Keystone Electronics Corp.</td>
<td>5011</td>
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<tr>
<td>5</td>
<td>C2, C6, C12, C13, C16</td>
<td>Capacitor, Ceramic, 0.1 µF, 16V, 10%, X7R, SMD, 0603</td>
<td>Taiyo Yuden Co., Ltd.</td>
<td>EMK107B7105KA-T</td>
</tr>
<tr>
<td>1</td>
<td>C3</td>
<td>Capacitor, Film, 0.33 µF, 10%, 275 VAC, Radial</td>
<td>Wurth Elektronic</td>
<td>890324025034CS</td>
</tr>
<tr>
<td>2</td>
<td>C4, C5</td>
<td>Capacitor, 1500 µF, 20%, 50V</td>
<td>Wurth Elektronic</td>
<td>860010680026</td>
</tr>
<tr>
<td>1</td>
<td>C7</td>
<td>Capacitor, Film, 0.68 µF, 10%, 310 VAC, Radial</td>
<td>Wurth Elektronic</td>
<td>890334025045</td>
</tr>
<tr>
<td>2</td>
<td>C8, C9</td>
<td>Capacitor, Film, 0.47 µF, 10%, 310 VAC, Radial</td>
<td>Wurth Elektronic</td>
<td>890334024005CS</td>
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<tr>
<td>2</td>
<td>C10, C11</td>
<td>Capacitor, Ceramic, 4.700 pF, 300V, 20%, Radial, P7.5D8H11</td>
<td>Murata Electronics®</td>
<td>DE2E3KY472MN3AU02F</td>
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<tr>
<td>1</td>
<td>C14</td>
<td>Capacitor, Ceramic, 0.022 µF, 500V, 10%, X7R, SMD, 1206</td>
<td>Johanson Dielectrics</td>
<td>501R18W223KV4E</td>
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<tr>
<td>2</td>
<td>C15, C25</td>
<td>Capacitor, Aluminum, 47 µF, 35V, 20%, Radial, P2D5H12.5</td>
<td>Wurth Elektronic</td>
<td>860010572005</td>
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<tr>
<td>1</td>
<td>C17</td>
<td>Capacitor, Ceramic, 100 pF, 50V, 10%, X7R, SMD, 0603</td>
<td>Vishay Intertechnology, Inc.</td>
<td>VJ0603Y101XXACW1BC</td>
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<tr>
<td>1</td>
<td>C19</td>
<td>Capacitor, Aluminum, 47 µF, 20%, 63V, Through-Hole</td>
<td>Wurth Elektronic</td>
<td>8600080774008</td>
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<tr>
<td>1</td>
<td>C20</td>
<td>Capacitor, Ceramic, 0.1 µF, 500V, 10%, X7R, SMD, 1210</td>
<td>KEMET</td>
<td>C1210C104KCRACTU</td>
</tr>
<tr>
<td>2</td>
<td>C21, C22</td>
<td>Capacitor, Ceramic, 680 pF, 100V, X7R, 0805</td>
<td>Yageo Corporation</td>
<td>CC0805KRX7R0BB681</td>
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<tr>
<td>2</td>
<td>C23, C24</td>
<td>Capacitor, Ceramic, 6800 pF, 50V, 10%, X7R, SMD, 0603</td>
<td>KEMET</td>
<td>C0603C682K5RACTU</td>
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<tr>
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<td>CH1, CH2, VAC</td>
<td>Connector Test Point, Loop, Red, TH</td>
<td>Keystone Electronics Corp.</td>
<td>5010</td>
</tr>
</tbody>
</table>
### TABLE B-1: BILL OF MATERIALS (BOM) – LVPFC DEVELOPMENT BOARD (CONTINUED)

<table>
<thead>
<tr>
<th>Qty</th>
<th>Designator</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Manufacturer Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>CS1, CS2, PFC-PWM1, PFC-PWM2, Vac_in, Vpfc_sense, ZCD1, ZCD2</td>
<td>Misc., Test Point PC Mini, 0.040”, D, Yellow</td>
<td>Keystone Electronics Corp.</td>
<td>5004</td>
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<tr>
<td>7</td>
<td>D1, D8, D9, D10, D11, D13, D15</td>
<td>Diode, Rectifier, 1N4148, 1.25V, 150 mA, 100V, SOD-123</td>
<td>Micro Commercial Components</td>
<td>1N4148W-TP</td>
</tr>
<tr>
<td>2</td>
<td>D2, D3</td>
<td>Diode, Rectifier, ES3B, 900 mV, 3A, 100V, DO-214AB_SMC</td>
<td>Vishay Intertechnology, Inc.</td>
<td>ES3B-E3/57T</td>
</tr>
<tr>
<td>1</td>
<td>D4</td>
<td>Diode, Schottky, STPS1150A, 790 mV, 1A, 150V, DO-214AC_SMA</td>
<td>STMicroelectronics</td>
<td>STPS1150A</td>
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<tr>
<td>1</td>
<td>D5</td>
<td>Diode, Rectifier Bridge, 600V, 3A, TH, SIP-4</td>
<td>SMC Diode Solutions Co. LTD</td>
<td>KBP306GTB</td>
</tr>
<tr>
<td>2</td>
<td>D6, D7</td>
<td>Diode, Rectifier, US1J 1.7V, 1A, 600V, DO-214AC_SMA</td>
<td>Micro Commercial Components</td>
<td>US1J-TP</td>
</tr>
<tr>
<td>1</td>
<td>D12</td>
<td>Diode, Rectifier, RS3J, 1.3V, 3A, 600V, DO-214AB_SMC</td>
<td>Vishay Intertechnology, Inc.</td>
<td>RS3J-E3/57T</td>
</tr>
<tr>
<td>2</td>
<td>D14, D16</td>
<td>Diode, Zener, BZX84-C3V3, 3.3V, 250 mW, SOT-23-3</td>
<td>NXP Semiconductors</td>
<td>BZX84-C3V3,215</td>
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<td>2</td>
<td>F1</td>
<td>Fuse Holder, 5 mm, TH</td>
<td>Littelfuse®</td>
<td>01110501Z</td>
</tr>
<tr>
<td>1</td>
<td>F2</td>
<td>Fuse, Glass, 5A, 250 Vac, 5x20 mm</td>
<td>Littelfuse</td>
<td>0217005.HXP</td>
</tr>
<tr>
<td>1</td>
<td>J1</td>
<td>Connector, Terminal, 5 mm, 1x3, Female, 12-28AWG, 16A, TH, R/A</td>
<td>On-Shore Technology, Inc.</td>
<td>OSTVI030152</td>
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<tr>
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<td>J2, J3</td>
<td>Connector, Terminal, 5.08 mm, 1x2 Female, 12-28AWG, 16A, TH, R/A</td>
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<td>OSTVI022152</td>
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<tr>
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<td>J4</td>
<td>Connector, Edge, MECF, 1.27 mm, 60P, Female, SMD, Vertical</td>
<td>Samtec, Inc.</td>
<td>MECF-30-01-L-DV-WT</td>
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<tr>
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<td>J8, J9</td>
<td>Connector, Terminal, 2.54 mm, 1x2, Female, 20-30AWG, 6A, TH, R/A</td>
<td>PHOENIX CONTACT</td>
<td>1725656</td>
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<td>2</td>
<td>L1, L3</td>
<td>Inductor, Customized Part, 11.5A, T/H, PFC</td>
<td>Wurth Electronick</td>
<td>750316197</td>
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<tr>
<td>1</td>
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<td>Common-mode Choke, 2 mH, 10A, 2 LN, TH</td>
<td>Wurth Electronick</td>
<td>7448031002</td>
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<tr>
<td>1</td>
<td>L4</td>
<td>Inductor, Fixed, 4.7 µH, 6.5A, 12.5 mOhm, TH</td>
<td>Wurth Electronick</td>
<td>744750230047</td>
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<td>MOV1</td>
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<td>TDK Corporation</td>
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<td>N-FET, IPP126N10N3G, 100V, 58A, 0.0123R, 94W, TO-220-3</td>
<td>Infineon Technologies AG</td>
<td>IPP126N10N3GXXA1</td>
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<td>Diodes Incorporated®</td>
<td>2N7002-7-F</td>
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<td>2</td>
<td>R1, R10</td>
<td>Resistor, TKF, 1k, 1%, 1/10W, SMD, 0603</td>
<td>Panasonic® - ECG</td>
<td>ERJ-3EKF1001V</td>
</tr>
</tbody>
</table>
**TABLE B-1: BILL OF MATERIALS (BOM) – LVPFC DEVELOPMENT BOARD (CONTINUED)**

<table>
<thead>
<tr>
<th>Qty</th>
<th>Designator</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Manufacturer Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>R2, R9</td>
<td>Resistor, TKF, 15R, 1%, 1/4W, SMD, 1206</td>
<td>Panasonic® - ECG</td>
<td>ERJ-8ENF15R0V</td>
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<tr>
<td>2</td>
<td>R4, R30</td>
<td>Resistor, TF, 2.20k, 1%, 1/8W, SMD, 0603</td>
<td>Vishay Intertechnology, Inc.</td>
<td>MCT06030C2201FP500</td>
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<tr>
<td>8</td>
<td>R5, R6, R7, R11, R14, R15, R16, R21</td>
<td>Resistor, TKF, 10k, 1%, 1/4W, SMD, 1206</td>
<td>Vishay Intertechnology, Inc.</td>
<td>CRCW120610K0FKEA</td>
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<tr>
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<td>R8</td>
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<td>Yageo Corporation</td>
<td>RC0603FR-0751RL</td>
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<td>R12, R13, R22, R23</td>
<td>Resistor, TKF, 120R, 1%, 1/10W, SMD, 0603</td>
<td>Stackpole Electronics, Inc.</td>
<td>RMCF0603FT120R</td>
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<td>R17, R18, R24, R25</td>
<td>Resistor, TKF, 10R, 1%, 1/4W, SMD, 1206</td>
<td>Panasonic - ECG</td>
<td>ERJ-8ENF10R0V</td>
</tr>
<tr>
<td>2</td>
<td>R19, R26</td>
<td>Resistor, TKF, 3.3k, 1%, 1/10W, SMD, 0603</td>
<td>Panasonic - ECG</td>
<td>ERJ-3EKF3301V</td>
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<td>Resistor, TKF, 10k, 1%, 1/10W, SMD, 0603</td>
<td>Panasonic - ECG</td>
<td>ERJ-3EKF1002V</td>
</tr>
<tr>
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<td>R27, R39</td>
<td>Resistor, TKF, 100R, 1%, 1/10W, SMD, 0603</td>
<td>Panasonic - ECG</td>
<td>ERJ-3EKF1000V</td>
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<td>4</td>
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<td>Stackpole Electronics, Inc.</td>
<td>RMCF0603FT10R0</td>
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<td>Panasonic - ECG</td>
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<td>Panasonic - ECG</td>
<td>ERJ-3EKF6201V</td>
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<td>ERJ-3EKF7501V</td>
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<td>G6C-1114P-US-DC5</td>
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<td>B&amp;F™ Fasteners Supply</td>
<td>MPMS 003 0008 PH</td>
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<td>Coilcraft</td>
<td>CS4100V-01L</td>
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<td>TH1</td>
<td>Resistor, Thermistor, NTC, 10R, 3A, Radial</td>
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<td>B57235S100M54</td>
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<td>2</td>
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<td>Washer Flat, M3, Nylon</td>
<td>Essentra Components</td>
<td>MFW030A</td>
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<tr>
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<td>MOD1</td>
<td>Microchip Module, MCHP-10751 7805, Replacement</td>
<td>Microchip Technology Inc.</td>
<td>04-10751</td>
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<tr>
<td>1</td>
<td>MOD2</td>
<td>Microchip Module, MCHP-10749, UWVR, 5W, Flyback</td>
<td>Microchip Technology Inc.</td>
<td>04-10749</td>
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<tr>
<td>2</td>
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<td>Microchip Analog FET Driver, MCP14A0452-E/SN, SOIC-8</td>
<td>Microchip Technology Inc.</td>
<td>MCP14A0452-E/SN</td>
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<tr>
<td>1</td>
<td>U3</td>
<td>Microchip Analog Temperature Sensor, -40C to +150°C, MCP9700T-E/TT, SOT-23-3</td>
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<td>MCP9700T-E/TT</td>
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<td>IC Comparator, Precision, 2-36V, SOT23-5</td>
<td>Microchip Technology Inc.</td>
<td>MIC6270YMS-TR</td>
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### 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

<table>
<thead>
<tr>
<th>Qty</th>
<th>Designator</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Manufacturer Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C1</td>
<td>Capacitor, Ceramic, 47 pF, 200V, 5%, C0G, NP0, SMD, 0805</td>
<td>KEMET</td>
<td>C0805C470J2GACTU</td>
</tr>
<tr>
<td>1</td>
<td>C2</td>
<td>Capacitor, Film 1.5 µF, 450V, 5%, RAD, P7.5L17.5W9.3H17.5</td>
<td>Panasonic® - ECG</td>
<td>ECW-FD2W155JB</td>
</tr>
<tr>
<td>1</td>
<td>C3</td>
<td>Capacitor, Aluminum, 3.3 µF, 450V, 20%, RAD_P3.5D8H113</td>
<td>Rubycon Corporation</td>
<td>450PK3R3MEFC8X11.5</td>
</tr>
<tr>
<td>2</td>
<td>C4, C5</td>
<td>Capacitor, Ceramic, 1000 pF, 250V, 10%, X7R, SMD, 0805</td>
<td>Murata Electronics®</td>
<td>GRM21AR72E102KW01D</td>
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<tr>
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<td>Capacitor, Aluminum, 220 µF, 16V, 20%, 0.015R, RAD_P3.5D8H8</td>
<td>Wurth Elektronic</td>
<td>870025374003</td>
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<tr>
<td>2</td>
<td>C7, C12</td>
<td>Capacitor, 100 µF, 20%, 16V</td>
<td>Wurth Elektronic</td>
<td>860010372006</td>
</tr>
<tr>
<td>1</td>
<td>C8</td>
<td>Capacitor, Ceramic, 4.7 µF, 25V, 20%, X5R, SMD, 0805</td>
<td>TDK Corporation</td>
<td>C2012X5R1E475M125AB</td>
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<td>Taiyo Yuden Co., Ltd.</td>
<td>EMK107B7105KA-T</td>
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<td>Murata Electronics</td>
<td>DE2E3KY222MN3AU02F</td>
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<td>C17, C22</td>
<td>Capacitor, Ceramic, 1000 pF, 50V, 5%, C0G, SMD, 0603</td>
<td>AVX Corporation</td>
<td>06035A102JAT2A</td>
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<td>1</td>
<td>C21</td>
<td>Capacitor, Ceramic, 0.1 µF, 16V, 10%, X7R, SMD, 0603</td>
<td>AVX Corporation</td>
<td>0603YC104KAT2A</td>
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<td>C23</td>
<td>Capacitor, Ceramic, 100 pF, 50V, 5%, NP0, SMD, 0603</td>
<td>Cal-Chip Electronics Inc.</td>
<td>GMC10CG101J50NTLF</td>
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<tr>
<td>1</td>
<td>C28</td>
<td>Capacitor, Ceramic, 0.022 µF, 50V, 5%, X7R, SMD, 0603</td>
<td>AVX Corporation</td>
<td>06035C223JAT2A</td>
</tr>
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<td>D1, D2</td>
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<td>Connector Header, 2.54 Male, 1x2, Gold, 6.75 mm, TH, R/A</td>
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<td>OSRAM Opto Semiconductors GmbH.</td>
<td>LS R976-NR-1</td>
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<td>Kingbright Electronic Co., Ltd.</td>
<td>WP4060SRD</td>
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<td>Panasonic® - ECG</td>
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<td>RSF100JB-73-27K</td>
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<td>Susumu Co., LTD.</td>
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<td>ERJ-3EKF1502V</td>
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<td>Transformer, SMPS, Flyback 6:1:1, 20V-375V, 5.5W, TH</td>
<td>Kaschke Components GmbH</td>
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<td>Optoisolator, FOD817A3SD, SMD-4</td>
<td>ON Semiconductor</td>
<td>FOD817A3SD</td>
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<td>Microchip Analog, PWM Controller, 3 MHz, HV9123NG-G, SOIC-16</td>
<td>Microchip Technology Inc.</td>
<td>HV9123NG-G</td>
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</table>
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 represent 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 I$PH_1$
- **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 I$PH_2$
  - 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

- Timer1 Interrupt Every 10 msec
- Faultcheck()
- Faulthandler()
- Scheduler Called Every 1 msec (Timer2)
  UART_RX
  UART_TXP Protocol 0001
  UART_TX Protocol 0000
  Converter State_Machine
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:
    \[ c2P2Z\_\text{compensator\_out\_V} \times \text{ADCBUF1}/\text{VINAVG}^2 \]
  
  **Note:** ADCBUF1 is proportional to the rectified input AC voltage. VINAVG^2 is proportional to the square of the rectified average value of the input VAC voltage. The "c2P2Z\_compensator\_out" is the output of the voltage loop.

- Samples IPH1 and executes PH1 current loop
- Accumulates VIN and VOUT
- Verifies zero crossing on VIN
- Triggers INT1 if zero crossing is ‘True’

- ADCAN2 Interrupt:
  - Samples IPH2 and executes PH2 current controller

- INT1: Interrupts every 10 msec (VIN zero crossing)
  - Calculates VIN average and squares it (VINAVG²)
  - Calculates VOUT average
  - Runs voltage compensator on VOUT 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**

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

**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.

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