50W Interleaved LLC Converter Development Board 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 on-line help. Select the Help menu, and then Topics to open a list of available on-line help files.

INTRODUCTION

This preface contains general information that will be useful to know before using the 50W Interleaved LLC Converter Development Board User's Guide. Topics discussed in this preface 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 user's guide provides an overview of the 50W Interleaved LLC Converter Development Board. The document is organized as follows:

- **Chapter 1. "Overview"** – This chapter introduces the 50W Interleaved LLC Converter Development Board User's Guide and provides a brief overview of its features.
- **Appendix A. "Schematics and Custom Parts Specifications"** – This appendix provides schematic diagrams for the 50W Interleaved LLC Converter Development Board.
- **Appendix B. "Test Results"** – This appendix provides the 50W Interleaved LLC Converter Development Board test results.
- **Appendix C. "Bill of Materials (BOM)"** – This appendix provides the component list used in assembling the 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 braces 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 the 50W Interleaved LLC Converter Development Board. The device-specific data sheets contain current information on programming the specific microcontroller or digital signal controller devices. Other useful document(s) are listed below. The following Microchip document(s) are recommended as supplemental reference resources.

- **Microchip Power Board Visualizer – Windows Graphical User Interface Software** (www.microchip.com/en-us/software-library/power_board_visualizer)
- **Digital Power Development Board** (Part Number: DM330029)
- ***"dsPIC33CK256MP506 Digital Power Plug-In Module (PIM) User's Guide"*** (DS50002819)
- ***"Power Board Visualizer User's Guide"*** (DS50003115)

These documents are available for download from the Microchip website (www.microchip.com).

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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, listings of Microchip sales offices, distributors and factory representatives

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- Local Sales Office
- Field Application Engineer (FAE)
- Technical Support

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Technical support is available through the website at: https://support.microchip.com

DOCUMENT REVISION HISTORY

Revision A (January 2022)

This is the initial released version of this document.

Chapter 1. Overview

1.1 INTRODUCTION

The 50W Interleaved LLC Converter Development Board is a generic development board for this topology that supports rapid prototyping and code development based on dsPIC33 devices. The board provides two identical half-bridge stages with LLC tank circuitry at the primary and voltage doubler rectification at the secondary. The board offers well organized building blocks that include an input filter, power stage, AUX supply, mating socket for Microchip's newest Digital Power Plug-In Modules (DP PIMs), Human Machine Interface (HMI) and test points.

The electrical characteristics are prepared to allow safe voltage levels of up to 50 VDC in and up to 12 VDC out. Topology and design are scalable and can be easily turned into real industrial demands targeting 400 VDC or 800 VDC bus operating voltage. A mating socket for dsPIC33 plug-in modules allows the system to be evaluated with different controllers. The pinout is compatible for EP, CK and CH dsPIC® DSC DP PIMs.

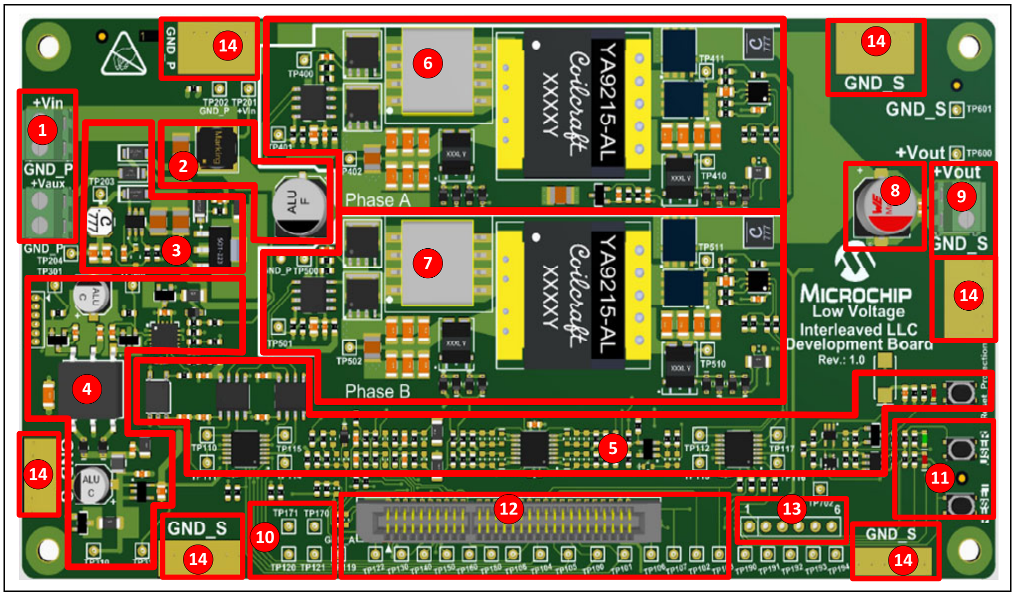
The topics covered in this chapter include:

- Features
- Electrical Characteristics
- Power Stage
- Signal Conditioning
- Powering Up the Demo Board
- Testing the Board in Open Loop
- Testing the Board in Closed Loop
- Firmware Components
- Firmware Structure
- Miscellaneous

1.2 FEATURES

The 50W Interleaved LLC Converter Development Board features are shown in Figure 1-1.

FIGURE 1-1: 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD



1. DC Input Connectors

> **Note:** J200 supplies power to the AUX and power converters, while J201 can supply the AUX converter only. Both voltages are tied together over ORing diodes, D200, D201. However, as soon as the V_{IN} goes above V_{AUX}, it will override it.

2. Input Filter
3. Input and Start-up Circuitry
4. Auxiliary Power Supply
5. Protection Circuitry
6. LLC Converter, Phase A Power Converter
7. LLC Converter, Phase B Power Converter
8. Output Filter
9. Output Connector
10. Test Points for Inner and Outer Loop Measurements
11. HMI Interface (push buttons and two LEDs)
12. dsPIC33-DSC DP-PIM Socket with Test Points at the Edge of the Board
13. AUX Connector

> **Note:** Supports UART communication, GPIO, Analog input, DAC signal output and 3.3V analog AUX supply.

14. GND Surface for Ground Clips Connection

1.3 ELECTRICAL CHARACTERISTICS

Table 1-1 shows the electrical characteristics of the 50W Interleaved LLC Converter Development Board.

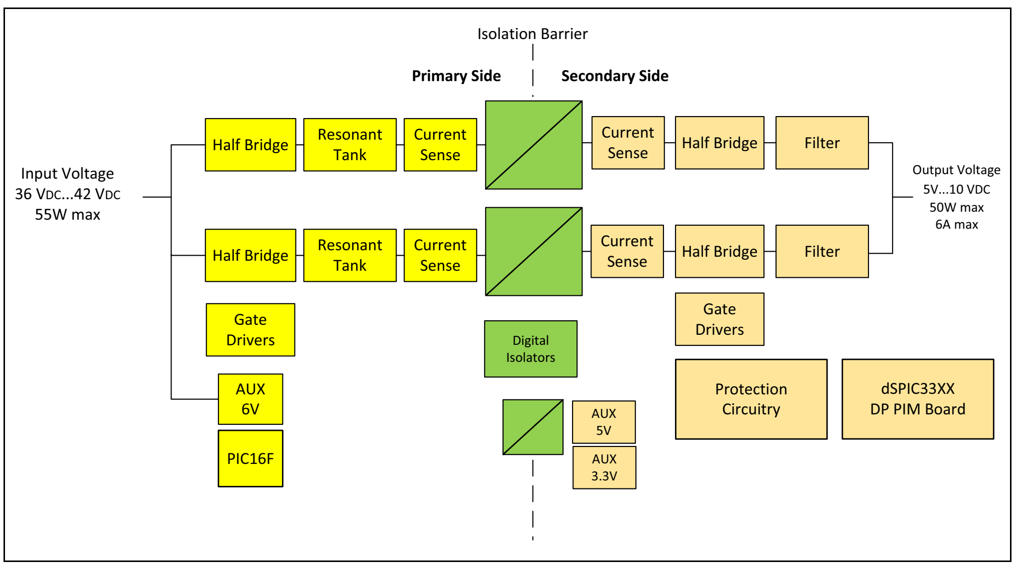
TABLE 1-1: 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD ELECTRICAL CHARACTERISTICS

Parameter	Value
Input Working Voltage Range	36 to 42 VDC
AUX Supply Input Working Voltage Range	16V to 55 VDC
Max. Output Power	30W per phase
Max. Output Voltage	15V
Max. Output Current	3A per phase
Minimum Switching Frequency	800 kHz
Maximum Switching Frequency	1000 kHz
Steady-State Output Ripple Voltage	<2%
Spikes (50 Ohm, 20 MHz bandwidth)	<2%
Primary-Secondary Isolation Voltage	500 VDC
Bidirectional Capability	Yes
Operating Ambient Temperature	-40°C to 65°C
Board Size	150 mm x 80 mm

1.4 POWER STAGE

Figure 1-2 shows a simplified schematic diagram.

FIGURE 1-2: SIMPLIFIED SCHEMATIC BLOCK DIAGRAM



The main building blocks responsible for power transfer are:

Input Filter – A Pi filter at the input provides impedance matching for proper power conversion and good EMI/EMC performance.The frequency corner of this filter sits at 18 kHz (-3 dB).

Half-Bridge Primary – A generic half-bridge inverter stage must always be running in Alternating mode (switch on/off time at high and low side must be equal). This stage converts DC voltage into a high-frequency square wave of pulses and applies to the resonant tank circuitry including an isolation transformer. A small dead time is needed between the consecutive transitions, both to prevent the possibility of cross-conduction and allow time for Zero Voltage Switching (ZVS) to be achieved. This time can be hardware-dependent; demowise is 50 ns.This stage is, by default, bidirectional (synchronous rectification). To control the amount of power transfered from the source to load; the primary to the secondary side, the frequency modulation must be applied to the half-bridge stage in such a way that lower switching frequency results in high-power transfer and higher switching frequency results in low-power transfer.

Resonant Circuit and Galvanic Isolation – Also called a resonant network, consists of the series resonant inductance (L401) and capacitance (C404...C409), and the transformer's Magnetizing Inductance, Lm. The transformer turn ratio is n (4:1). The resonant network circulates the electric current, and as a result, the energy is circulated and delivered to the load through the transformer. The transformer's primary winding receives a bipolar square wave voltage from the half-bridge inverter. This voltage is transferred to the secondary side, providing both electrical isolation and scaling ratio to deliver the required voltage level to the output.

Voltage Doubler Rectification at Secondary – A generic voltage doubler rectification circuitry is placed at the secondary side. This stage turns high-frequency AC current into DC current and enables the output capacitor to build up output DC voltage. Synchronous MOSFETs are always running in Alternating mode. A small dead time is needed between the consecutive transitions, both to prevent the possibility of cross-conduction and to allow time for Zero Voltage Switching (ZVS) to be achieved. Body diodes are switching in Zero Current Switching (ZCS). This time can be hardware-dependent; demo vise is adaptive and can go down to 50 ns. Synchronous rectification enables higher efficiency and bidirectional power flow. Depending on the algorithm, the synchronous rectification can be enabled or disabled. Attention must be paid on Disabled mode; hence, the body diodes are conducting only and power loss on the board cannot be handled without forced cooling. For up to 1A DC output current per phase, a temperature increase is still acceptable.

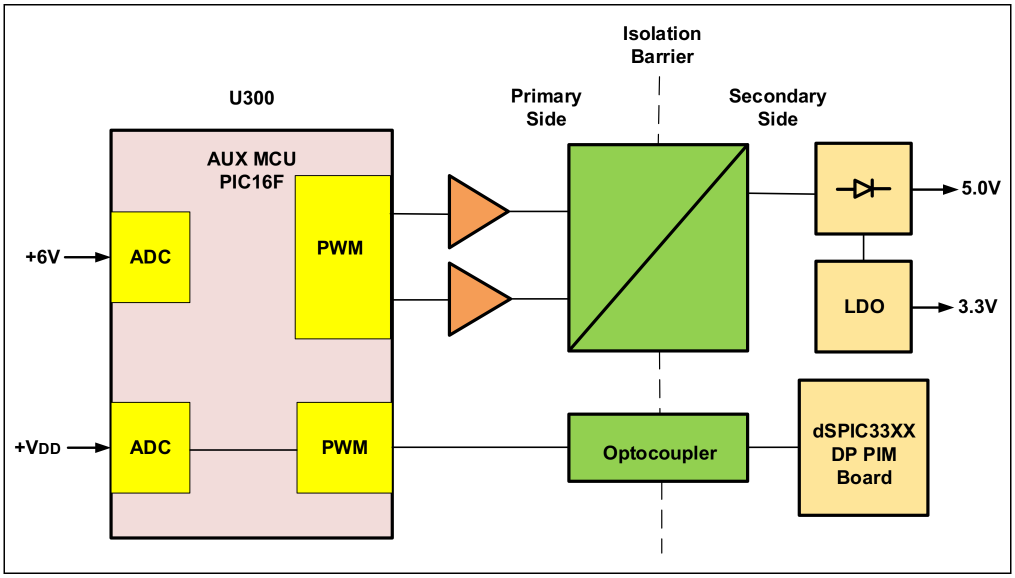
Output Filter – An additional LC filter at the output provides impedance matching, proper power conversion and meets the converter specification (requirements for output voltage ripple and spikes). The frequency corner of this filter sits at 30 kHz (-3 dB).

Auxiliary Supply Primary Side – An independent AUX supply, driven by U210 (MCP16331), is placed at the primary side of the board. This can be supplied from an external AUX connector (J201) or main power connector, J200. Using J201 will enable the main voltage supply to start from zero, which is good practice for code development purposes. This stage provides a stable 6 VDC rail that supplies the following building blocks:

- Primary half-bridge drivers (U400, U500)
- U300 (PIC16 device) and high-frequency push-pull stage

A high-level block diagram with functions and features is presented in Figure 1-3.

FIGURE 1-3: AUX-PS BLOCK DIAGRAM



Auxiliary Supply Secondary Side – A PIC16 device generates a 500 kHz push-pull PWM signal. These two complementary PWM signals with ~50% duty cycle are fed into a push-pull switching stage that is feeding the power into the HF transformer. At the secondary side, this signal is rectified and filtered. That way, there is a decoupled, galvanic isolated 5V auxiliary supply at the secondary side. Out of this 5 V_S, with the help of an LDO, a 3.3 V_S rail is generated. 5 V_S can be generated through the AUX supply or from the DP PIM if the same is connected to the USB port. Therefore:

- 5V rail supplies half-bridge drivers (U410, U510) and DP PIM
- 3.3V rail supplies digital isolators and protection circuitry

Note:	When using only a USB cable, the primary AUX supply will NOT be available.

Protection Circuitry – This building block is pure analog/digital circuitry and its purpose is to cut PWM signals coming out of DP PIM as soon as currents or voltage reach the maximum allowed level. Once the maximum level is reached, the error will be latched. To reset the protection circuitry, please disable all PWMs first (or keep dsPIC in reset mode) and press short button “Reset protection.”

Digital Isolators – This building block provides an isolation channel for PWM signals crossing the isolation barrier from secondary to primary (U100, U101), or primary to secondary (U102). PWM signals are transferred from the DP PIM toward the primary half-bridges. Also, the information about VDD voltage from the primary side is transferred using PWM modulation.

1.5 SIGNAL CONDITIONING

The following techniques are used to provide information about current and voltages in the power stage and make the information visible to the dsPIC device.

1.5.1 Current Sensing

1.5.1.1 CURRENT TRANSFORMER PRIMARY (TR401, TR501, R420, R520)

A high-frequency current transformer with full wave rectifier is used to detect current at the primary side. This information is bidirectional, which means it will show the current flow from the source to load and backward. The current must stay alternative all the time. At switching frequencies (demo-wise: 800-1000 kHz), the signal level error coming from the transformer magnetizing inductance is ~10%. This error is current sense level and frequency-dependent. However, this accuracy is acceptable for inner current loops. The same error will be compensated by the outer loop.

1.5.1.2 CURRENT TRANSFORMER SECONDARY (TR402, TR502, R422, R522)

A high-frequency current transformer with full wave rectifier is used to detect current at the secondary side. This information is bidirectional, which means it will show the current flow from the source to load and backward. The current must stay alternative all the time. At switching frequencies (demo-wise: 800-1000 kHz), the signal level error coming from the transformer magnetizing inductance is ~1%. This error is current sense level and frequency-dependent. However, this accuracy is acceptable for inner current loops. The same error will be compensated by the outer loop. Taking an average value, the output load current can be precisely detected. This can be used for precise load measurement if some sensitive loads are used (such as LEDs or batteries). This information is also used in Backward mode to monitor source current (usually battery).

Signal sensitivity information is shown in Table 1-2.

TABLE 1-2: SECONDARY CURRENT SENSE

IOUT/DC [A]	IOUT_SENSE [V]
0.00	0.5348
0.25	0.6085
0.50	0.6971
0.75	0.7889
1.00	0.8802
1.25	0.972
1.50	1.0635
1.75	1.1552
2.00	1.2468
2.25	1.3387
2.50	1.4304
2.75	1.5222
3.00	1.6142

FIGURE 1-4: IOUT CURRENT SENSE

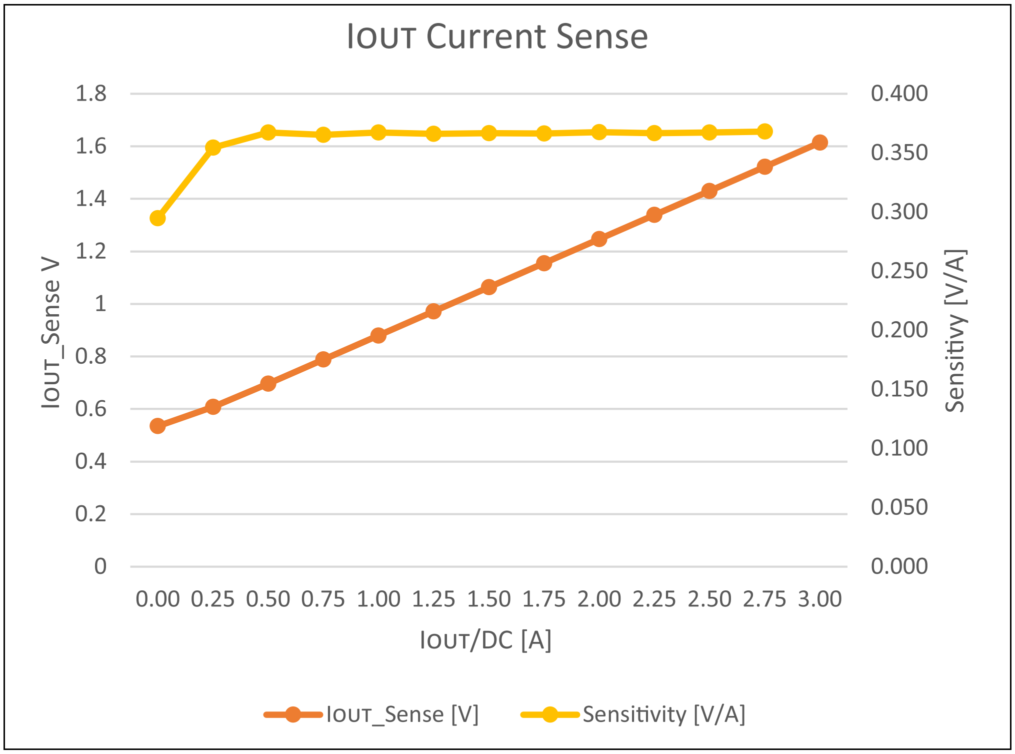
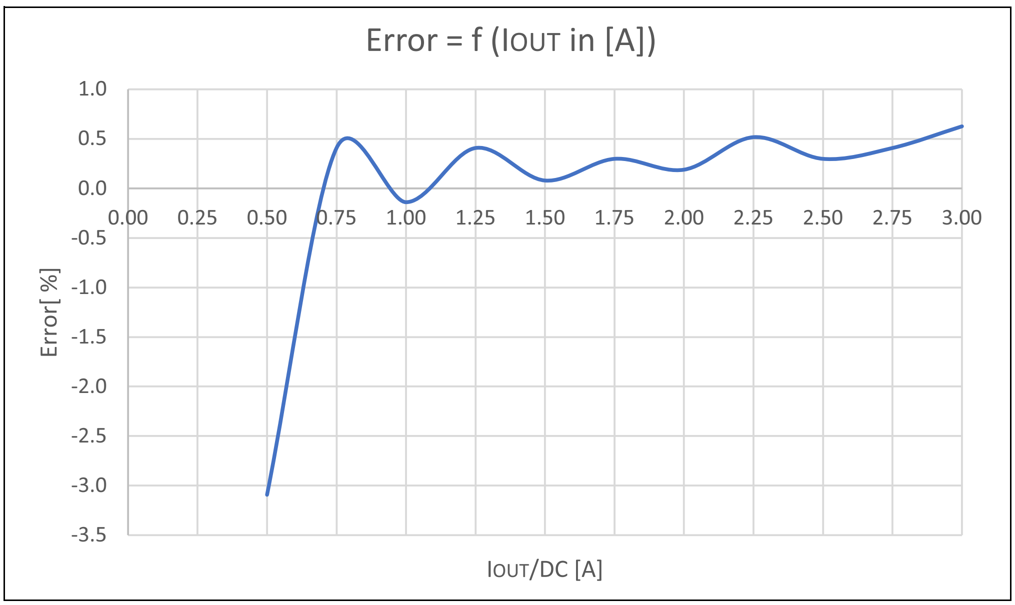


FIGURE 1-5: ERROR PERCENTAGE



1.5.2 Voltage Sensing

1.5.2.1 VDD SENSING (PRIMARY VOLTAGE SENSING)

The PIC16 device measures the supply voltage, +VDD, at the primary side and converts it to a 10 kHz PWM signal that can be submitted to the secondary side through a galvanic isolation with a high-speed optocoupler. This PWM is limited to a duty cycle minimum of 5%, and a maximum of 95%, to allow a permanent low or high used for Fault detection. At the secondary side, this PWM signal can then be picked up by the main microcontroller and can be used for UVLO/OVLO functions or power regulation purposes (such as feed-forward). A simple voltage divider with a 32.7:1 scaling factor is used to feed VDD sense to the ADC input. Voltage sensing information is shown in Table 1-3.

TABLE 1-3: VOLTAGE SENSING

Parameter	Value	Comment
Rhigh [Ohm]	78400	
Rlow [Ohm]	2481	
C_low [pF]	100000	
Divider Gain	0.0306	
Bias Current [mA]	0.825	At full scale, 2.049V
R_thevenin [Ohm]	3481	
Fc [Hz]	457	Frequency corner (-3 dB)

This VDD sense voltage is converted into a PWM signal according to following formula:

$DF(V_{DD}) = \{ 5\% \text{ if } V_{DD} \leq 10V$

$5\% + k * V_{DD} \text{ if } 10V < V_{DD} < 50V$

$95\% \text{ if } V_{DD} > 50V$

Where DF- duty factor, k = 0.444

1.5.2.2 VOUT SENSING (R120, R121, R122, R123)

A simple voltage divider with a 4.3:1 scaling factor is used to provide information about the output voltage. R120, including TP119, TP120 and TP121, are for open-loop measurement purposes only. Connect a signal injector across R120 for Bode plot measurements.

TABLE 1-4: VOUT SENSING

Parameter	Value	Comment
Rhigh [Ohm]	3300	
Rlow [Ohm]	1000	
C_low [pF]	5600	Capacitance on DP_PIM, at ADC input
Divider Gain	0.233	
Bias Current [mA]	3.3	At full scale, 3.3V
R_thevenin [Ohm]	917	Including 150R on DP_PIM
Fc [Hz]	31008	Frequency corner (-3 dB)

1.5.2.3 VAUX SENSING (R110, R109, C111)

A simple voltage divider with a 2:1 scaling factor is used to provide AUX voltage information. VAUX sensing information can be found in Table 1-5.

TABLE 1-5: VAUX SENSING

Parameter	Value	Comment
Rhigh [Ohm]	3300	
Rlow [Ohm]	3300	
C_low [pF]	5600	Capacitance on DP_PIM, at ADC input
Divider Gain	0.500	
Bias Current [mA]	1.0	At full scale, 3.3V
R_thevenin [Ohm]	1800	Including 150R on DP_PIM
Fc [Hz]	15797	Frequency corner (-3 dB)

1.5.2.4 V6V_P SENSING (R314, R315, C314)

A simple voltage divider with a 4:1 scaling factor is used to provide information about 6V_P voltage. V6V_P sensing information can be found in Table 1-6.

TABLE 1-6: V6V_P SENSING

Parameter	Value	Comment
Rhigh [Ohm]	10000	
Rlow [Ohm]	3300	
C_low [pF]	100000	
Divider Gain	0.248	
Bias Current [mA]	0.62	At Full Scale 2.049V
R_thevenin [Ohm]	2481	
Fc [Hz]	159	Frequency Corner (-3 dB)

TABLE 1-7: MATING SOCKET PINOUT

Name	Pin Number	Description
AGND	1	Analog Ground
AGND	2	Analog Ground
DACOUT	3	DAC Output
AN15	4	General Purpose Analog Input
FB_S_CT2_FILT	6, 14 (optional)	Current Sense Input – Filtered – Current Transformer – Secondary Side – Power Stage 2
FB_S_CT2	8	Current Sense Input – Current Transformer – Secondary Side – Power Stage 2
FB_P_CT2_FILT	9	Current Sense Input – Filtered – Current Transformer – Primary Side – Power Stage 2
FB_VOUT	10, 16 (optional)	Output Voltage Sense
FB_S_CT1_FILT	12	Current Sense Input – Filtered – Current Transformer – Secondary Side – Power Stage 1
FB_P_CT1_FILT	13	Current Sense Input – Filtered – Current Transformer – Primary Side – Power Stage 1
FB_TEMP	17	Temperature Sense Input
FB_S_CT1	18	Current Sense Input – Current Transformer – Secondary Side – Power Stage 1
FB_VAUX	20	AUX Voltage Sense
GPIO_3	24	General Purpose I/O
GPIO_1	25	General Purpose I/O
GPIO_4	26	General Purpose I/O
GPIO_2	27	General Purpose I/O
GPIO_5	28	General Purpose I/O
RX	34	UART RX
FB_VDD-PWM	35	Input Voltage Sense
TX	36	UART TX
PWM_C_H2	37	PWM Driving Signal for Switching Elements
PWM_C_SR_L1	40	PWM Driving Signal for Switching Elements
PWM_C_L2	41	PWM Driving Signal for Switching Elements
PWM_C_SR_H1	42	PWM Driving Signal for Switching Elements
PWM_C_SR_H2	43	PWM Driving Signal for Switching Elements
PWM_C_SR_L2	44	PWM Driving Signal for Switching Elements
PWM_C_H1	45	PWM Driving Signal for Switching Elements
PWM_C_L1	47	PWM Driving Signal for Switching Elements
SW2	48	Switch Input
LED0	53	LED (Green)
LED1	55	LED (Red)
+5V5	57, 59	Power Supply for Control Card
GND_P	58, 60	Power (Digital) Ground
N/C	5, 7, 11, 15, 19, 23, 29, 30, 31, 32, 33, 38, 39, 46, 50, 52, 54	Pins are not used

TABLE 1-8: TEST POINTS

Signal Group	Designator	Signal Description
Loop Measurement	TP120	Test Point Pair for Loop Measurement (Voltage Loop)
	TP121	
	TP170	Test Point Pair for Loop Measurement (Current Loop)
	TP171	
	TP119	Analog Ground
Controller – PWM – Power Stage 1	TP100	PWM_HIGH_PRIMARY
	TP101	PWM_LOW_PRIMARY
Controller – PWM – Power Stage 2	TP104	PWM_HIGH_PRIMARY
	TP105	PWM_LOW_PRIMARY
Controller – PWM – Power Stage 1	TP102	PWM_HIGH_SYNCHRON
	TP103	PWM_LOW_SYNCHRON
Controller – PWM – Power Stage 2	TP106	PWM_HIGH_SYNCHRON
	TP107	PWM_LOW_SYNCHRON
Transformer Primary – Power Stage 1	TP110	PWM_HIGH_PRIMARY
	TP111	PWM_LOW_PRIMARY
	TP400	Switching Node
Transformer Primary – Power Stage 2	TP114	PWM_HIGH_PRIMARY
	TP115	PWM_LOW_PRIMARY
	TP500	Switching Node
Synchronous Rectifier – Power Stage 1	TP112	PWM_HIGH_SYNCHRON
	TP113	PWM_LOW_SYNCHRON
	TP410	Switching Node
Synchronous Rectifier – Power Stage 2	TP116	PWM_HIGH_SYNCHRON
	TP117	PWM_LOW_SYNCHRON
	TP510	Switching Node
Feedback Lines	TP122	+VOUT Feedback Signal
	TP112	+VDD Feedback PWM Signal
	TP160	Current Transformer Primary – Power Stage 1 – Current Sense Feedback Signal
	TP130	Current Transformer Primary – Power Stage 2 Current Sense Feedback Signal
	TP180	Current Transformer Secondary – Power Stage 1 – Current Sense Feedback Signal
	TP150	Current Transformer Secondary – Power Stage 2 – Current Sense Feedback Signal
	TP170	Current Transformer Secondary – Power Stage 1 – Current Sense Feedback Signal
	TP140	Current Transformer Secondary – Power Stage 2 – Current Sense Feedback Signal
Efficiency Measurement Lines	TP201	+VIN (Sense Line for Efficiency Measurements)
	TP202	GND_P (Sense Line for Efficiency Measurements)
	TP600	+VOUT (Sense Line for Efficiency Measurements)
	TP601	GND_P (Sense Line for Efficiency Measurements)

TABLE 1-8: TEST POINTS (CONTINUED)

Signal Group	Designator	Signal Description
AUX Supply	TP203	Switching Node AUX Supply (~500 kHz, -16% duty cycle at 40V_V_{IN})
	TP204	+6V_P
	TP310	+5.5 V_S (DC AUX rail voltage)
	TP311	+3.3 V_S (DC AUX rail voltage)
	TP119	Analog Ground
Protection	TP702	Fault Signal
	TP190	General Purpose Input/Output
	TP191	General Purpose Input/Output
	TP192	General Purpose Input/Output
	TP193	General Purpose Input/Output
	TP194	General Purpose Input/Output
	TP300	500 kHz, 50% Duty Cycle PWM Output
	TP301	500 kHz, 50% Duty Cycle PWM Output
	TP400	Half-Bridge Switching Node
	TP401	V_{GS} Voltage at Low-Side HB Switch
	TP402	Voltage across Resonant Capacitor
	TP500	Half-Bridge Switching Node
	TP501	V_{GS} Voltage at Low-Side HB Switch
	TP502	Voltage across Resonant Capacitor

1.6 EXTENSION CONNECTOR J101

There is an additional header connector on the board, J101. The header provides additional pinout and connections to the DP PIM board. This header can be used to connect the development board to external boards and establish analog, digital or mixed signal interaction. The pinouts are provided in Table 1-9.

TABLE 1-9: PINOUT CONNECTIONS

Name	Pin Number	Description
DAC OUT	1	DAC Output
AN15	2	General Purpose Analog Input
AGND	3	Analog/Digital Ground
RX	4	UART Line Connection
TX	5	UART Line Connection
3V3	6	V_{AUX} 3V3 Rail (max. consumption at this pin: 100 mA allowed)

For more information about pinout capabilities, please review the ***“dsPIC33CK256MP506 Digital Power Plug-In Module (PIM) User’s Guide”*** (DS50002819), which is available at: www.microchip.com.

1.7 POWERING UP THE DEMO BOARD

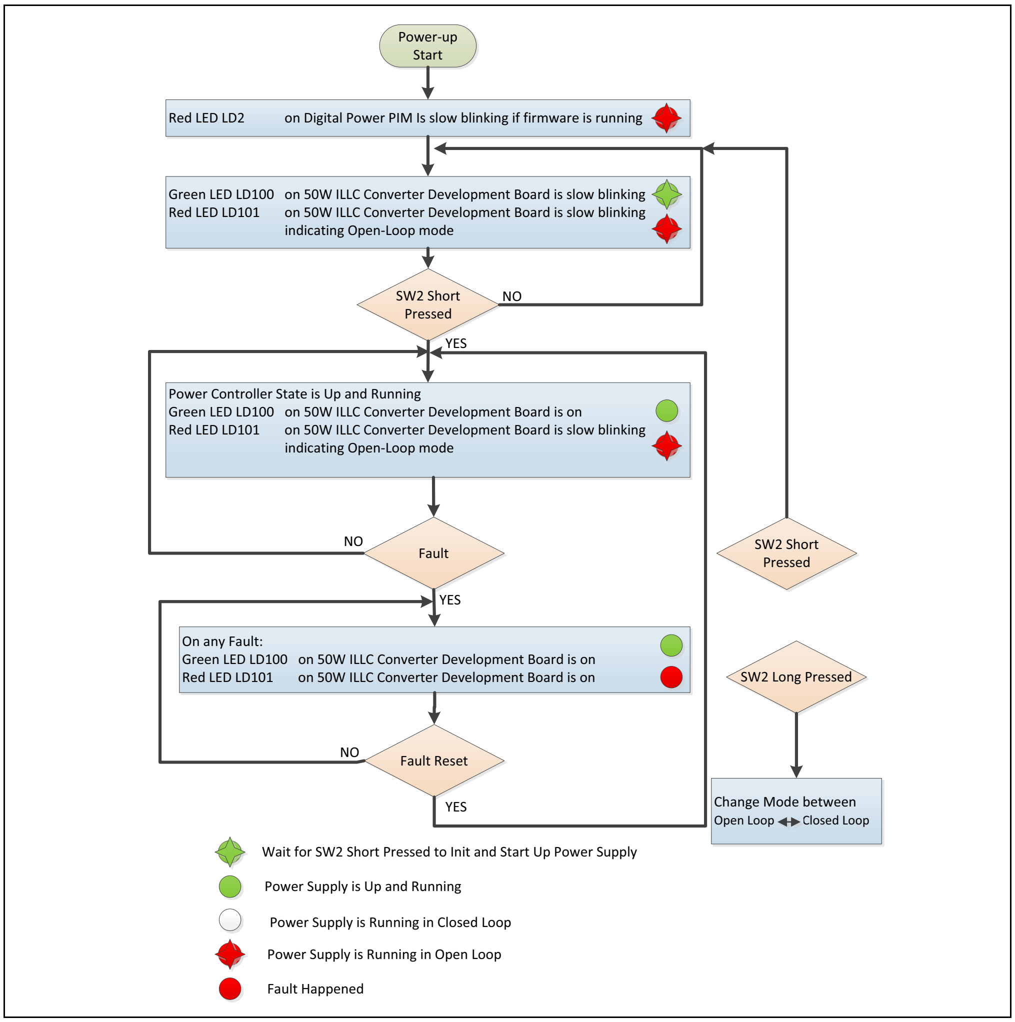
Before powering up the ILLC power board, make sure a DP PIM is added. Either preprogram the DP PIM or run in Debug mode with any type of Microchip In-Circuit Debugger. First, power the board using the USB connection on the DP PIM or AUX connector J201 only. This method allows all PWM signals to be checked without powering the power stage. When the DP PIM is powered on, the green LED on the PIM will light up.

Using the provided demo code after power-up, and if the software is running, the red LED on the DP PIM will slowly blink. On the power board, the green LED (LD100) and the red LED (LD101) are blinking. PWM signals are disabled.

The USER button (SW102) is programed to have two functions:

- PWM ENABLE/DISABLE function: **A short press (<1s)** disables or enables the PWM. When ENABLE is selected, the green LED (LD100) will stop blinking and change to solid green. A slow blinking red LED (LD101) indicates that the converter is running in open loop.
- Power controller (control loops) ENABLE/DISABLE function: **A long press (>2s)** disables or enables the power controller (control loop). Either currents or voltage are under control in this case. However, the Fault handler is still running, which means UVLO and OVLO are still active and the PWMs will be disabled if some of the parameters are out of range. This function is very useful while optimizing control loops. Figure 1-6 shows the state machine.

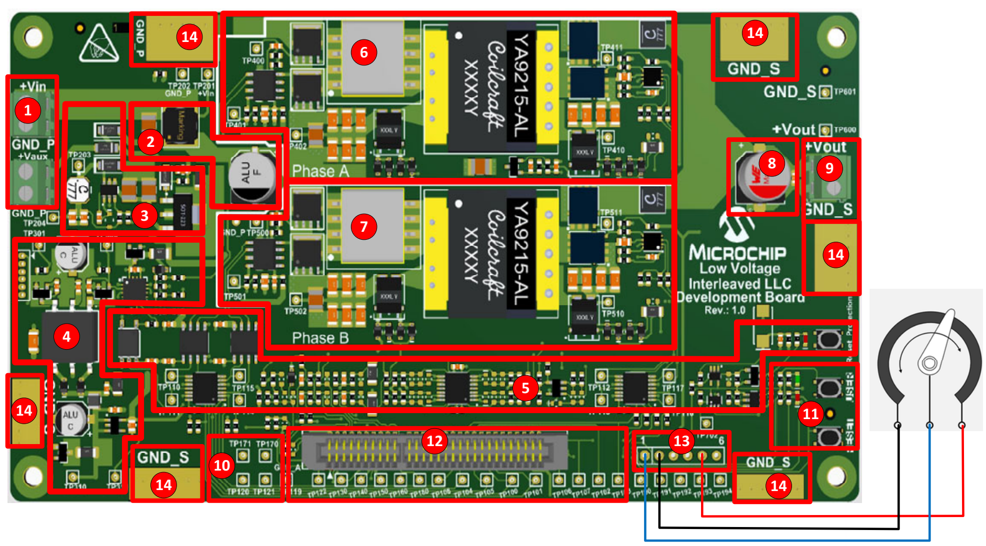
FIGURE 1-6: STATE MACHINE FLOWCHART



1.8 TESTING THE BOARD IN OPEN LOOP

1. Connect a DC source to either input, VIN Connector or VAUX Connector (Number 1 in Figure 1-7) and a load (Number 9 in Figure 1-7). Make sure to use correct polarities. Use a Micro-USB cable to connect a PC and DP PIM (Number 12 in Figure 1-7), and run the SMPS GUI. This allows voltage and current reading/plotting and sets parameters.
2. Without using the GUI, connect a Potentiometer (e.g., 10 kΩ) as shown in Figure 1-7.
3. After power-up, the software checks if a potentiometer is connected. If a potentiometer is NOT connected, the reference for the output voltage is set to 12V (closed loop). In open loop, the fixed output voltage is close to the input voltage. The GUI can use an alternative method, as mentioned in Step 1.
   The red LED (LD101) should slowly blink, indicating that the board is running in Open-Loop mode.

FIGURE 1-7: BOARD SETUP FOR OPEN-LOOP TEST



   The connected potentiometer sets the internal reference and will define the duty cycle of the PWM signals coming out.
4. Turn the potentiometer to minimum and then power up the board. The LED user interface works as described in Figure 1-8.

FIGURE 1-8: USER INTERFACE

LD100 On = Converter is running

LD100 Slowly Blinking = Wait for SW2 short press to initialize and start up converter

LD101 On = A Fault has occurred

LD101 Off = Converter is running in Closed-Loop mode

LD101 Slowly Blinking = Converter is running in Open-Loop mode

5. Press the USER button to enable the converter. To control the output voltage, turn the potentiometer to change the value. With no control loop active, the output voltage will be a function of the input voltage, load and potentiometer reference (PWM duty cycle will be directly proportional to this value).
   An oscilloscope can be used to observe the duty cycle change on test points. All PWMs are switching all the time. This enables seamless transition between Buck and Boost mode, while keeping input/output ripple voltage/currents continuous. This also works well if $V_{IN} = V_{OUT}$.

1.8.1 UART/USB Interface with Power Board Visualizer GUI

A graphic users interface displays analog values of the converter as well as the status flags. The reference for output voltage can be set by digital slider instead of analog potentiometer.

1.9 TESTING THE BOARD IN CLOSED LOOP

Press and hold the USER button for at least two seconds to change the working mode. The red LED (LD101) will turn off, indicating that the board is in Closed-Loop mode. If a potentiometer is used, it will receive a reference for setting up an output voltage.

Note: Output voltage can be adjusted from 5V to 10V.

Using the board in Closed-Loop mode creates a controlled stable output voltage. It must be independent from input voltage or load changes. The reference for the output voltage can be set with a potentiometer and/or with the GUI. See **Appendix B. "Test Results"** for stability measurements results.

1.10 FIRMWARE COMPONENTS

Figure 1-9 shows a high-level overview of the firmware blocks.

FIGURE 1-9: FIRMWARE BLOCK DIAGRAM

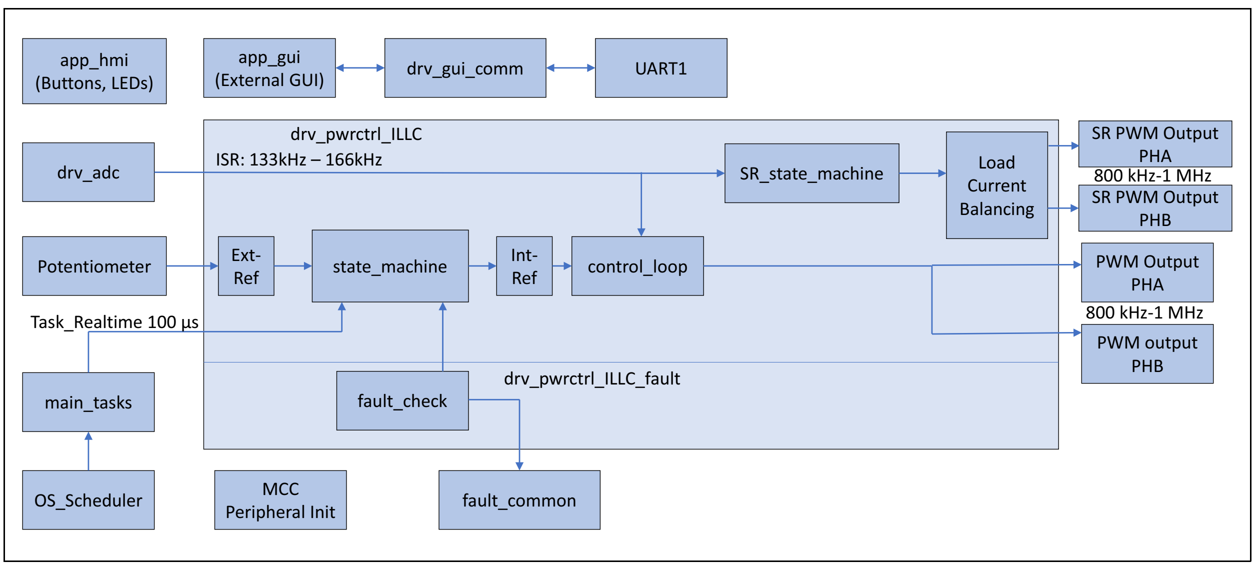


Table 1-10 explains the firmware blocks with basic functionality. A detailed firmware specification and how the blocks are used in power supplies will be described in an Application Note.

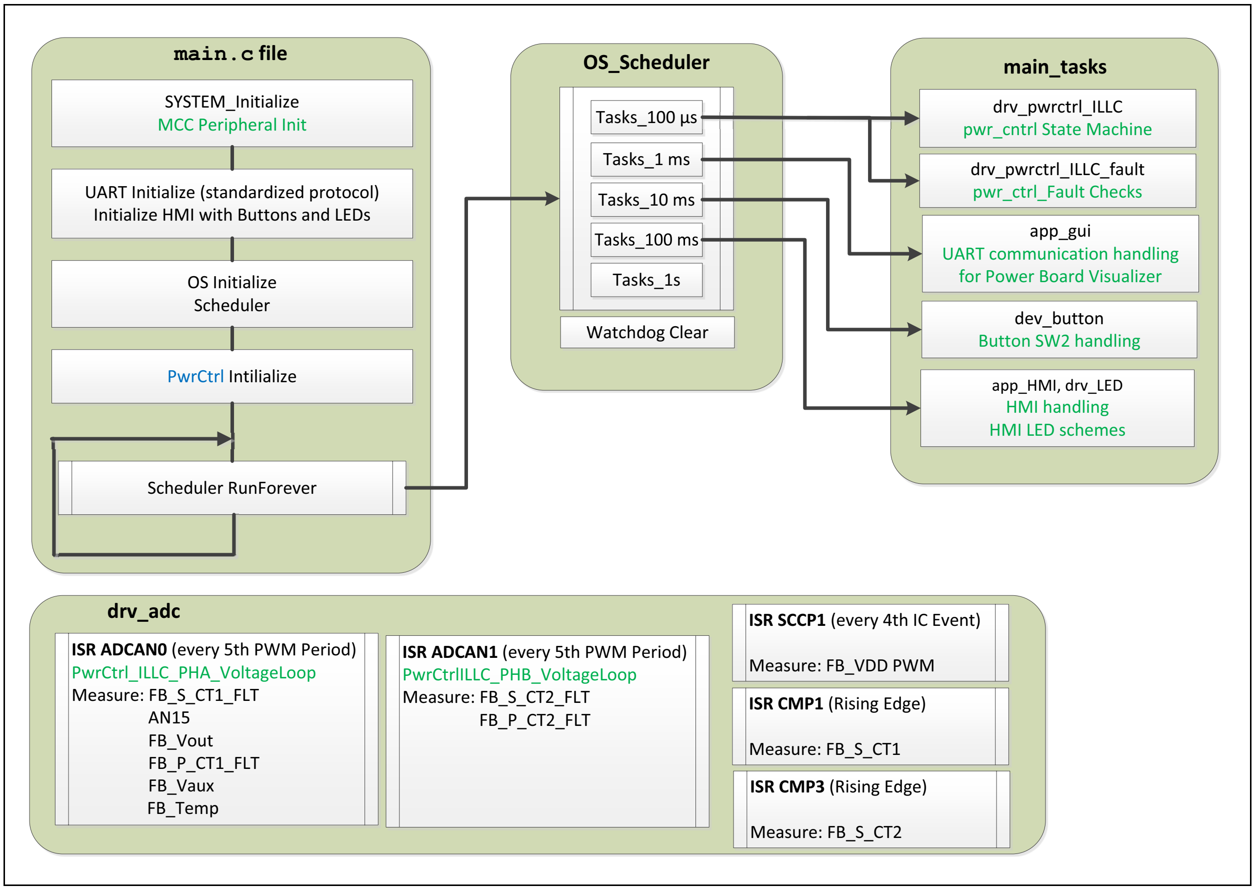
TABLE 1-10: FIRMWARE BLOCKS

Component	Description
OS_Scheduler	Core of the Cooperative Operation System; calls real-time and non real-time functions.
MCC Peripheral Init	Contains initialization and APIs for the peripherals.
fault_common	Contains common functions to do Fault checks. In this project, they are used from the fault_check handler of the ILLC.
main_tasks	Contains all functions that are called by the scheduler. Main point where other important functions are being called.
drv_pwrctrl_ILLC_fault	Contains all Fault check functions to check if voltages and currents are in the right range. This Fault check function is called from the ILLC state machine.
drv_pwrctrl_ILLC	Main component of the ILLC. Contains the state machine and the control loop.
Potentiometer	The potentiometer position is being used as a reference voltage for the ILLC.
drv_adc	Handles the analog/digital conversion synchronous to the PWM and calls the control loop of the ILLC.
app_gui, drv_gui_comm, uart1	Control of the synchronous rectifier switches. Adaptive settings of switch on delay compared to primary switching.
Load Current Balancing	The duty cycle of the synchronous rectifier switches is individually controlled for each interleaved phase to get the same load current in every interleaved phase.

1.11 FIRMWARE STRUCTURE

Figure 1-10 shows an overview of the firmware structure.

FIGURE 1-10: FIRMWARE STRUCTURE



The firmware uses the MPLAB® Code Configurator (MCC) to set up the peripherals.

The firmware runs two main tasks: a scheduler with different time slots, as well as interrupt-driven measurements and control loop handling. In this case, the interrupt is triggered-based on the actual switching frequency divided by 6.

A state machine (see Figure 1-6) runs a high-priority scheduler task and the Fault checks are also running.

In addition to the Fault check based on ADC values, there are Faults based on a hardware comparator that switches off the PWM immediately when the comparator trips. Other tasks, such as communication and user interface, run at slower scheduler tasks.

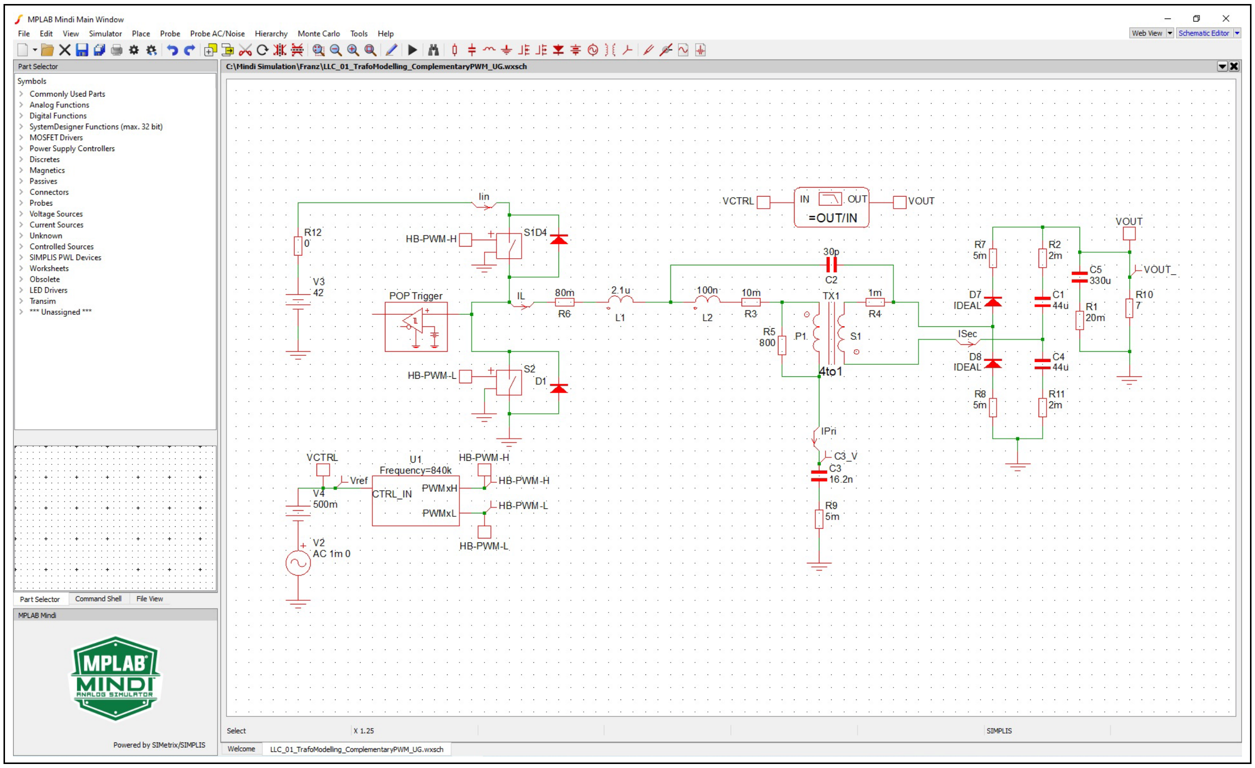
The UART protocol used for communication with a Graphical User Interface (GUI) is described within the PC GUI software.

1.12 MISCELLANEOUS

1.12.1 MPLAB Mindi™ Analog Simulation

Figure 1-11 is a screen shot of the MPLAB Mindi Analog Simulation, which enables the simulation of the power stage in Open-Loop mode and the option to measure the plant transfer function.

FIGURE 1-11: MINDI™ ANALOG SIMULATION



Additional MPLAB Mindi Analog Simulator files for dedicated usage of the 50W Interleaved LLC Converter Development Board are available at the Microchip website (https://www.microchip.com/mplab/mplab-mindi).

Appendix A. Schematics and Custom Parts Specifications

This appendix contains the schematics and board layouts for the 50W Interleaved LLC Converter Development Board. The schematics in this appendix include:

A.1 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD SCHEMATICS

FIGURE A-1: 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD SCHEMATIC (SHEET ONE)

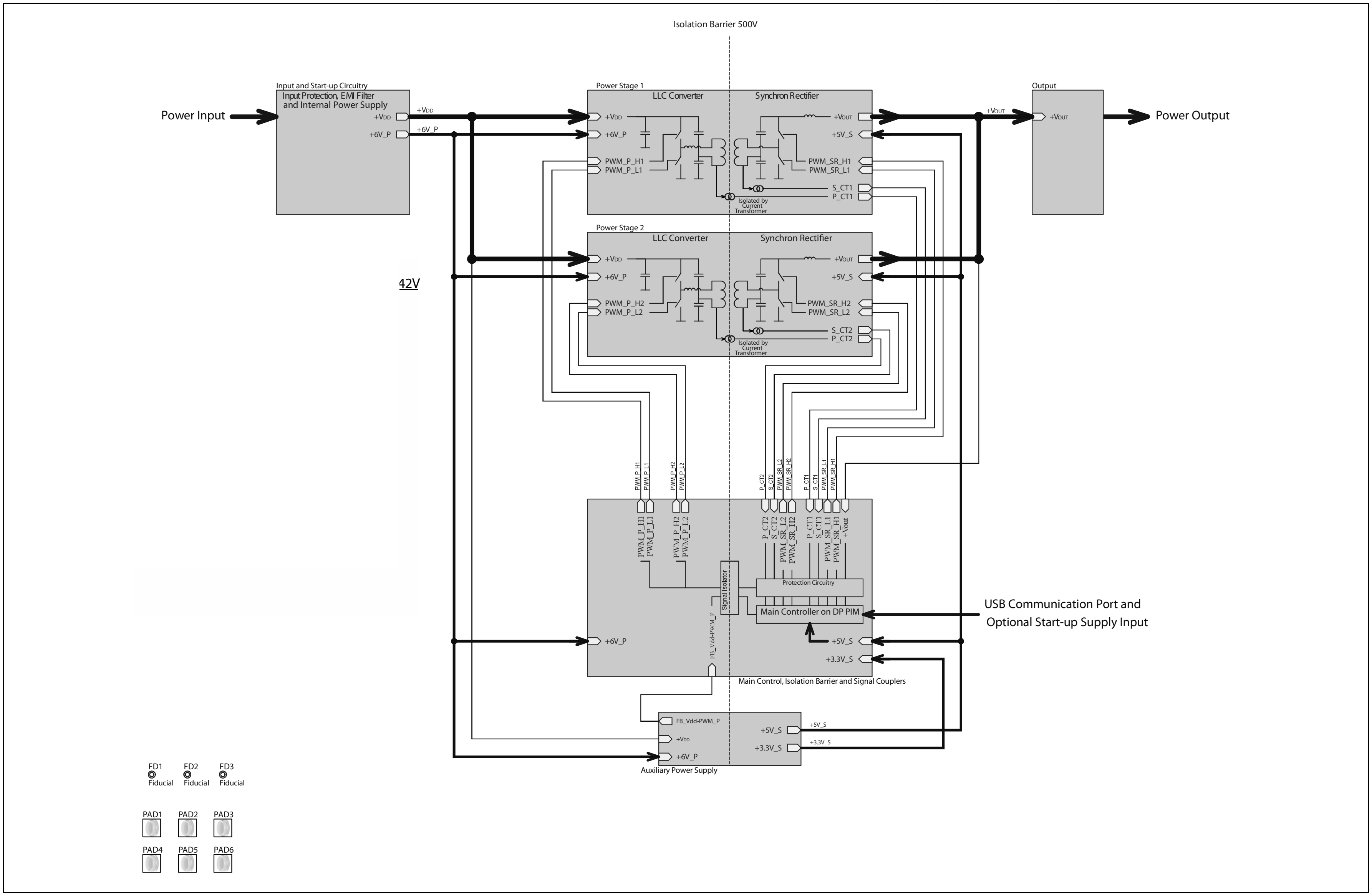


FIGURE A-2: 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD SCHEMATIC (SHEET TWO)

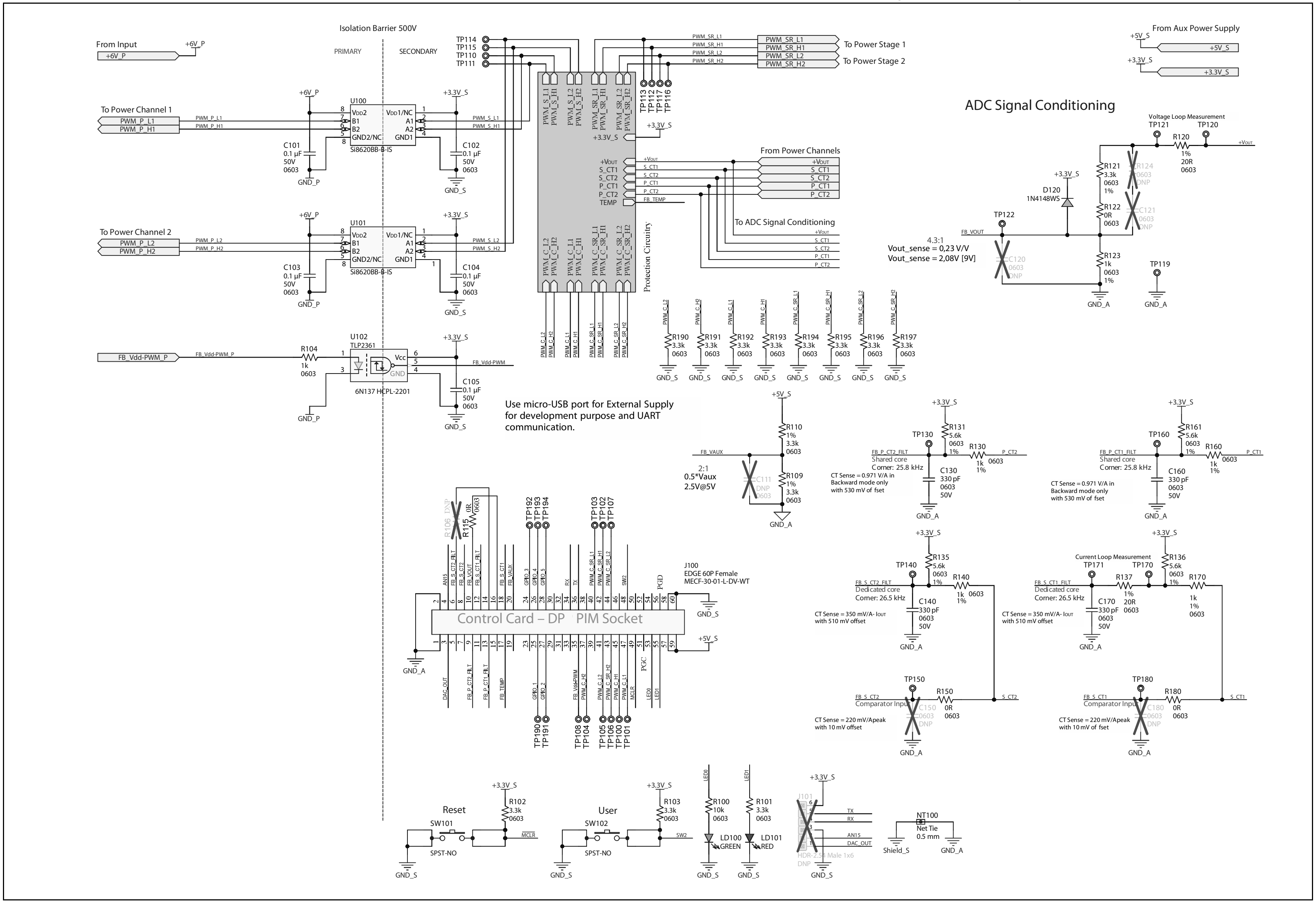


FIGURE A-3: 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD SCHEMATIC (SHEET THREE)

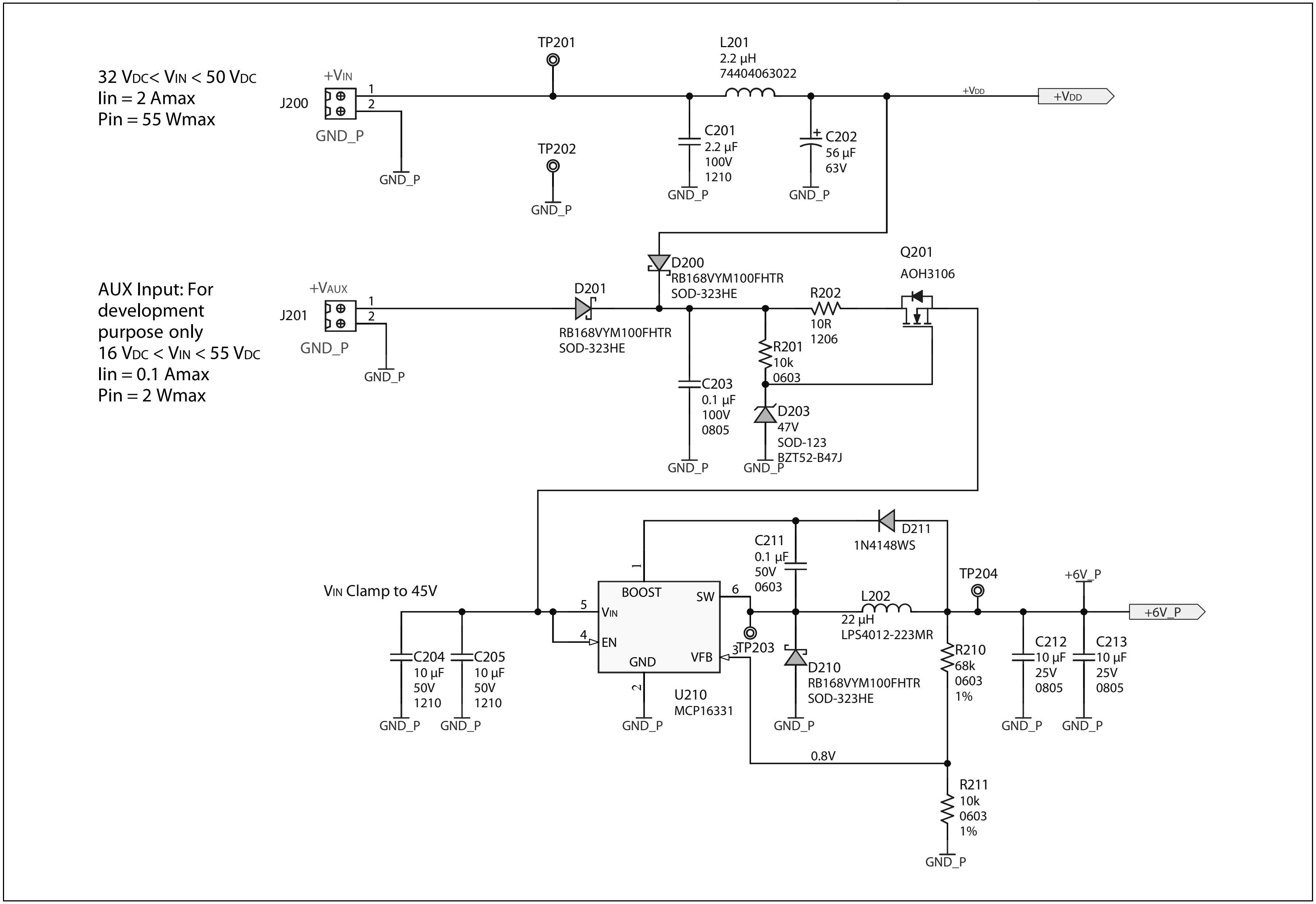


FIGURE A-4: 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD SCHEMATIC (SHEET FOUR)

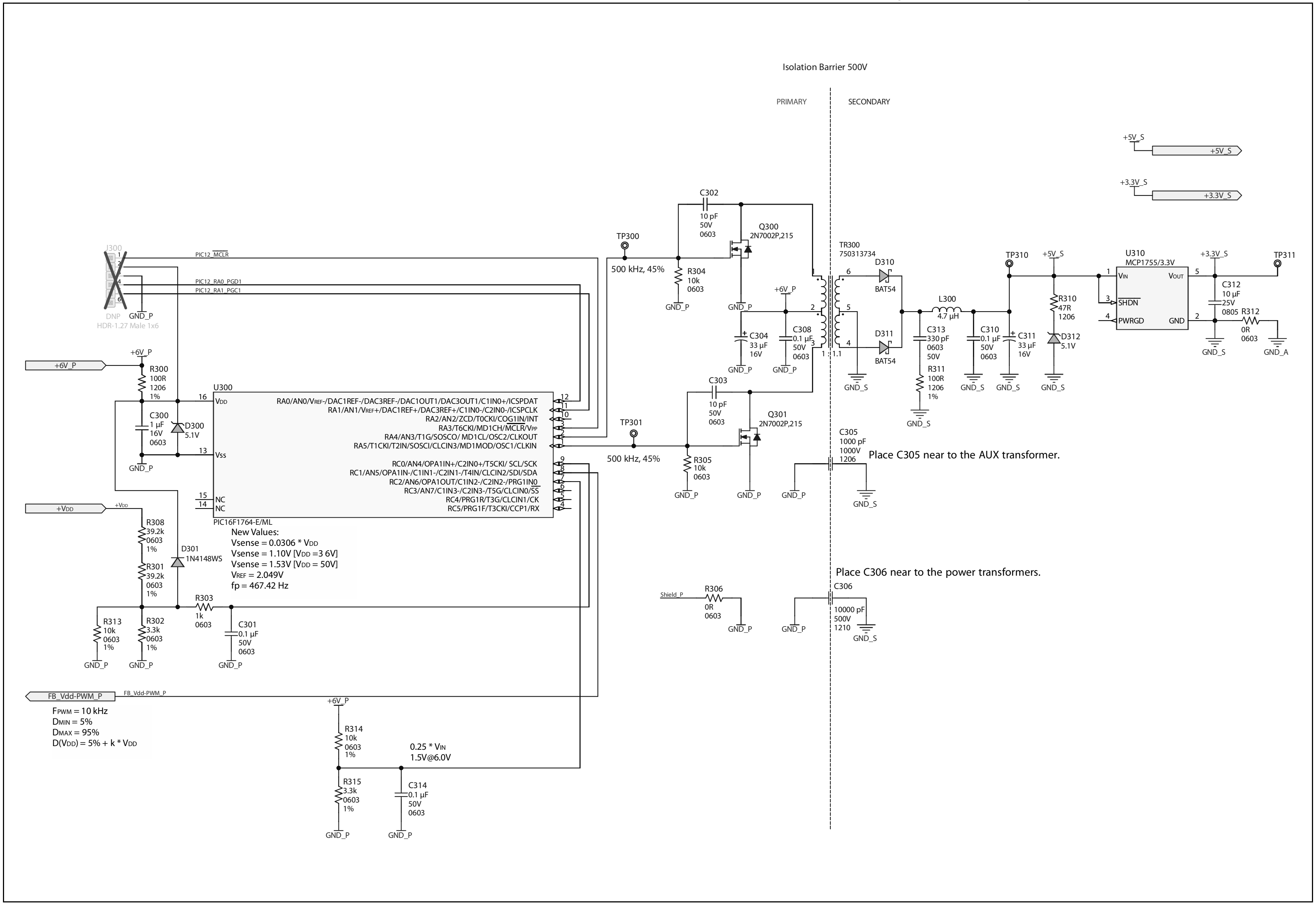


FIGURE A-5: 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD SCHEMATIC (SHEET FIVE)

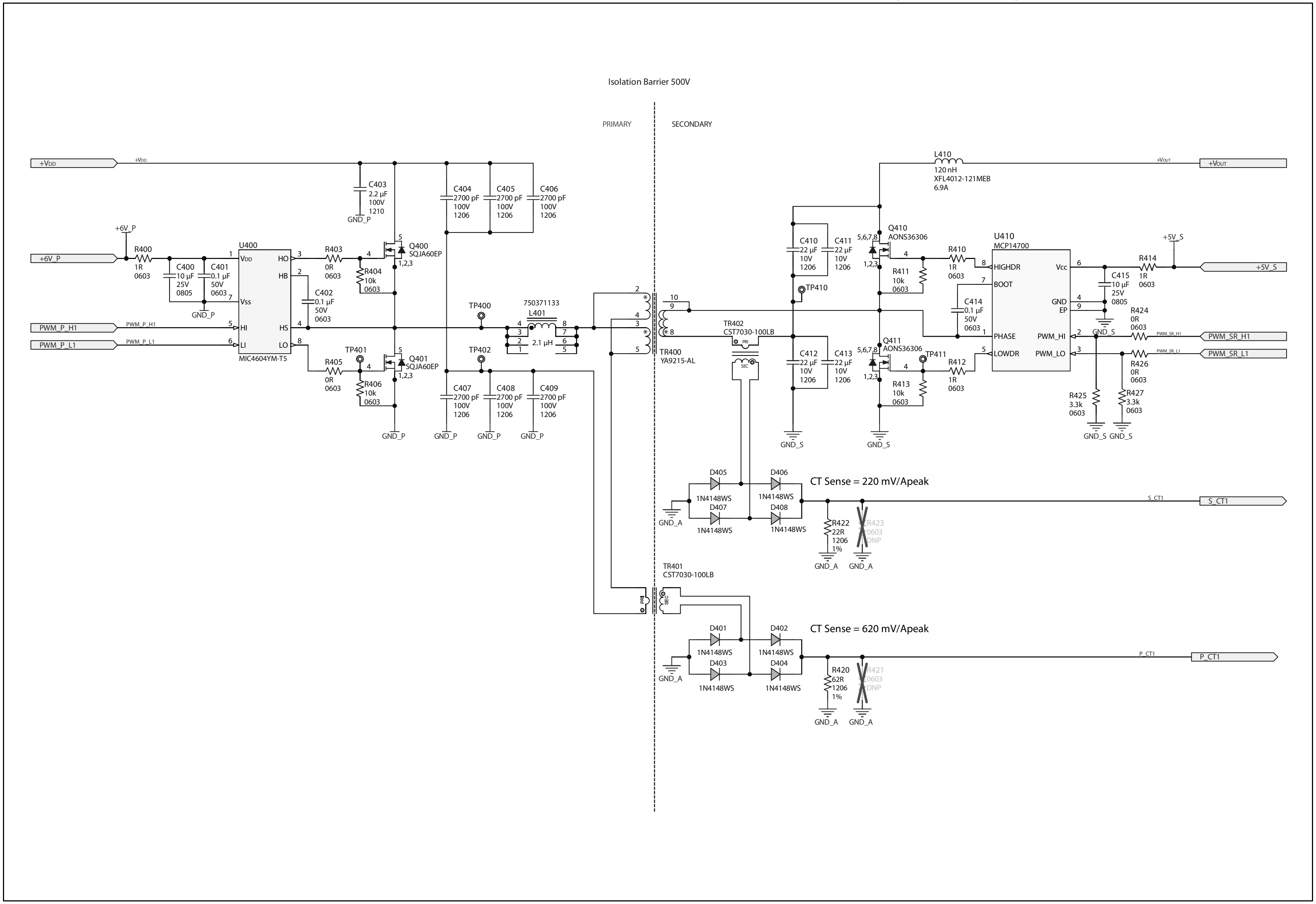


FIGURE A-6: 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD SCHEMATIC (SHEET SIX)

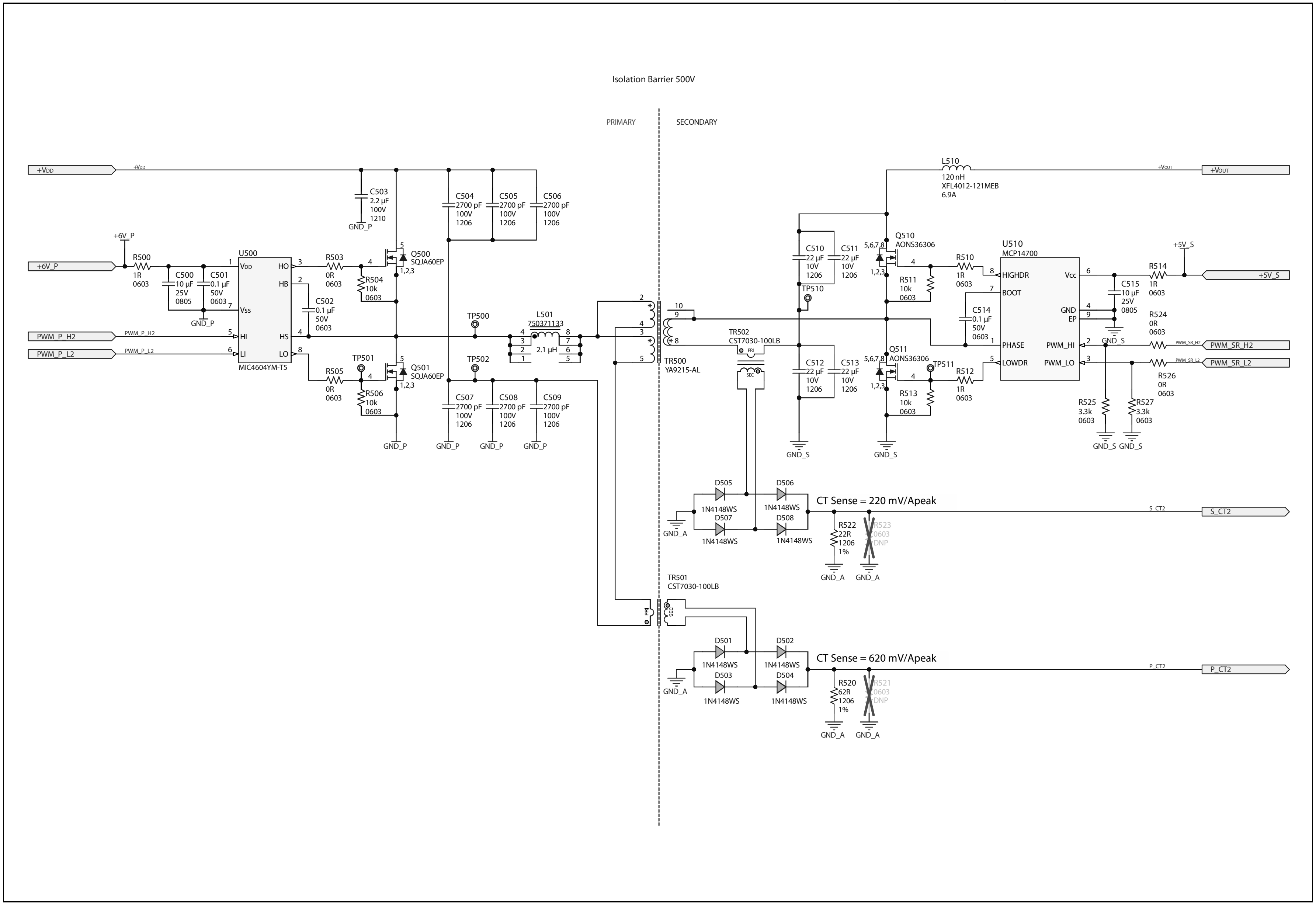


FIGURE A-7: 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD SCHEMATIC (SHEET SEVEN)

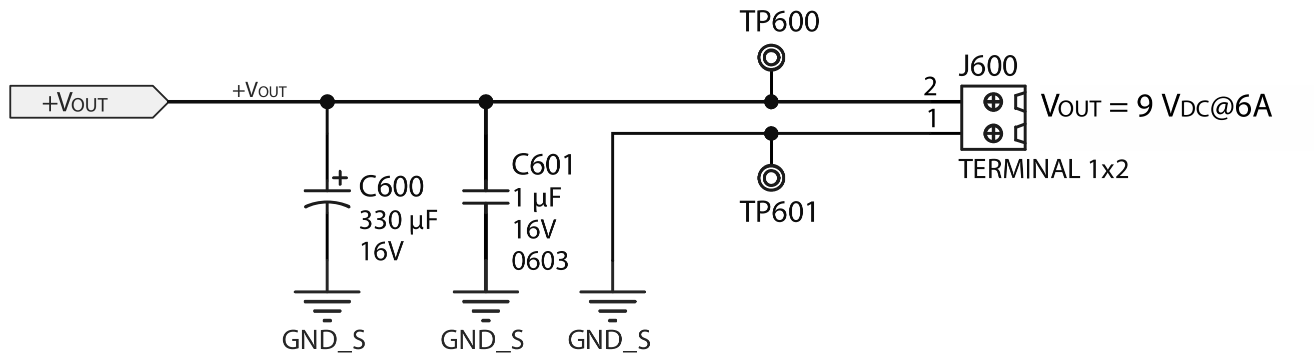


FIGURE A-8: 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD SCHEMATIC (SHEET EIGHT)

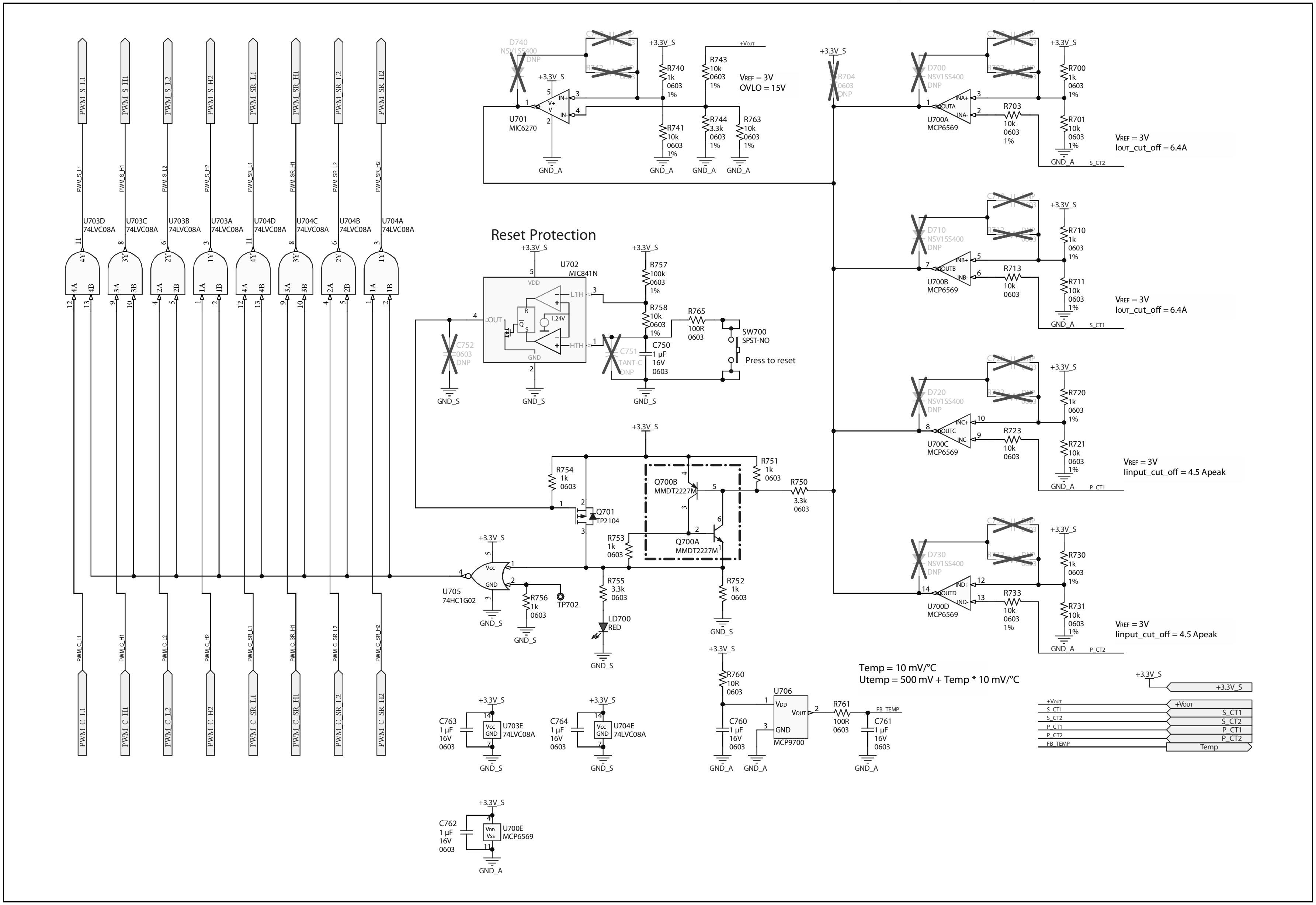


FIGURE A-9: 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD PCB TOP ASSEMBLY

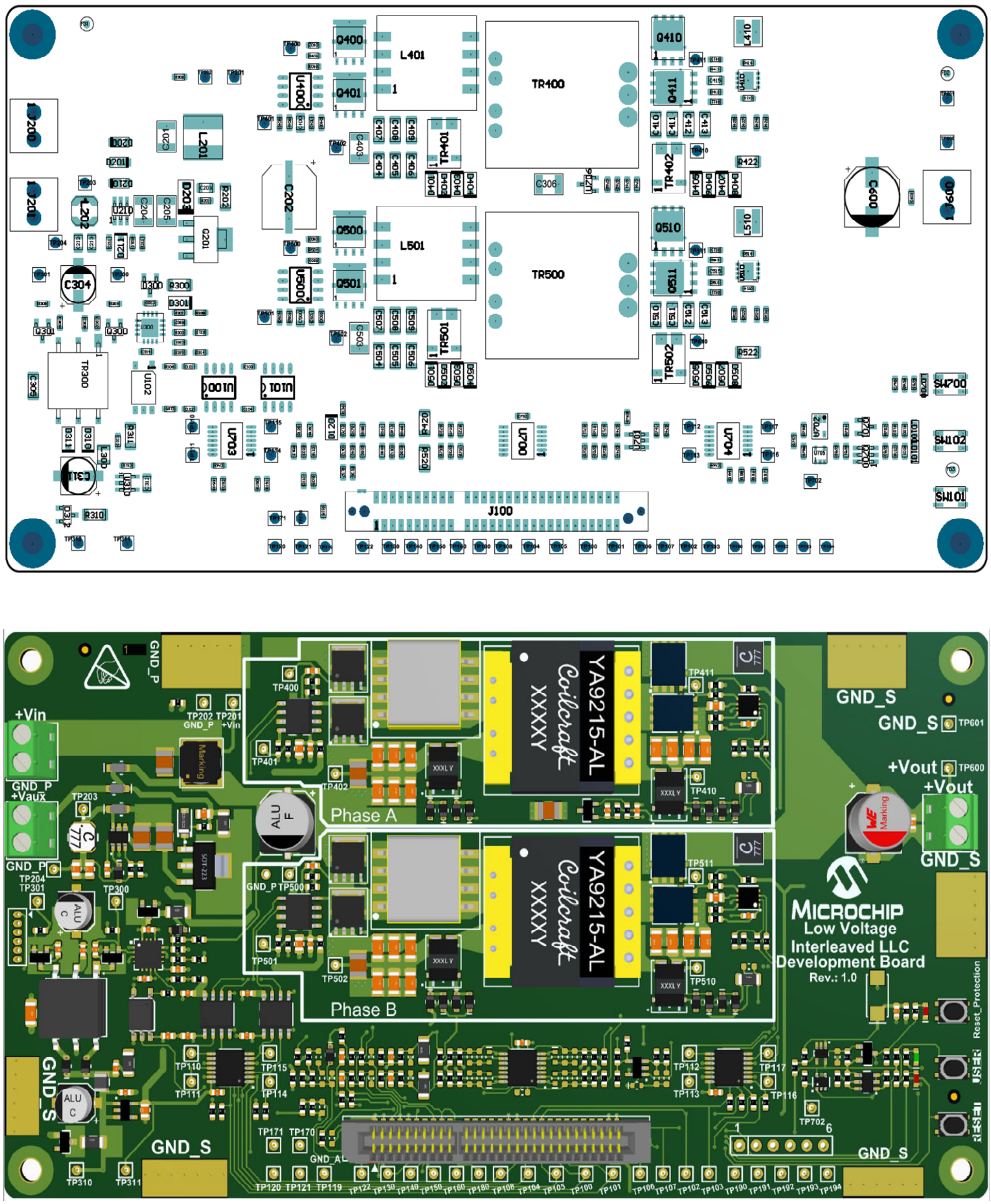
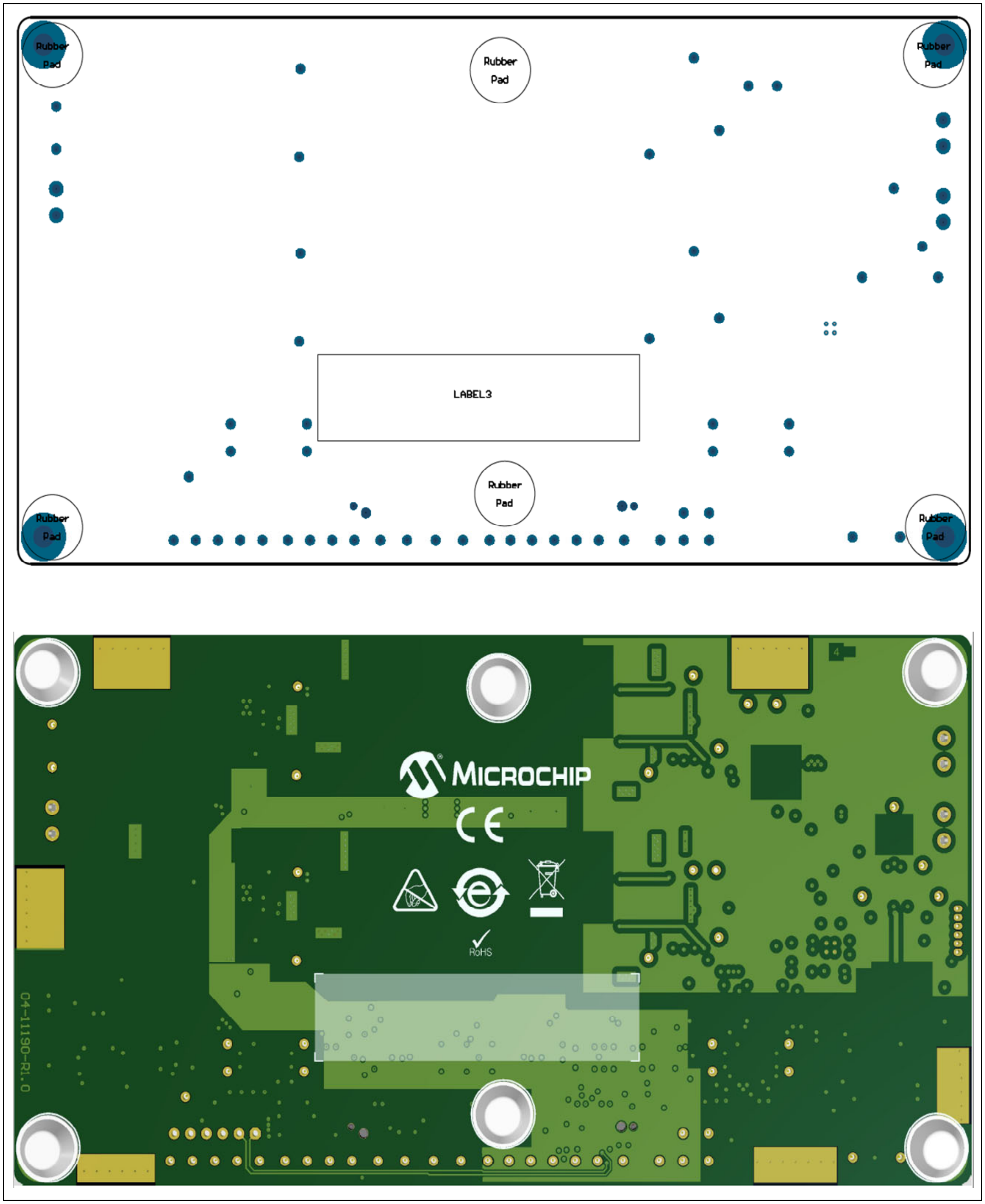


FIGURE A-10: 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD PCB BOTTOM ASSEMBLY



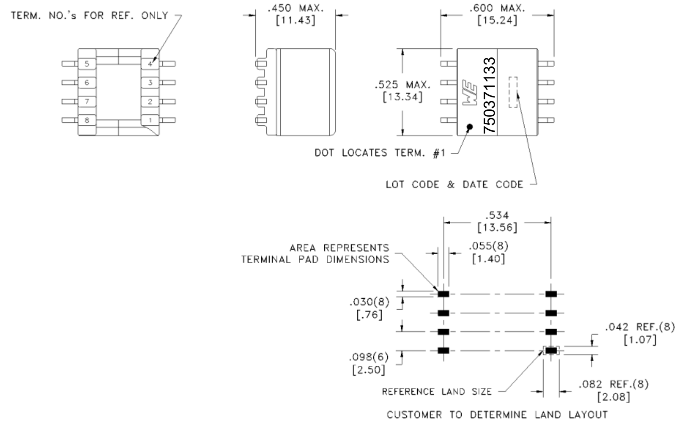
A.2 CUSTOM PARTS SPECIFICATIONS

FIGURE A-11: ELECTRICAL SPECIFICATIONS

CUSTOMER TERMINAL	RoHS	LEAD(Pb)--FREE
Sn 96%, Ag 4%	Yes	Yes

more than you expect

WÜRTH ELEKTRONIK

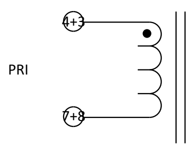


ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	4,3-7,8	tie(3+4, 7+8), @20ºC	0.014 ohms max.
INDUCTANCE	4,3-7,8	10kHz, 10mV, Ls	2.00µH ±5%
SATURATION CURRENT	4,3-7,8	20% rolloff from initial	8.5A

GENERAL SPECIFICATIONS:

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



Application of the transformer allows for the leadwires between terminals 3&4 and 7&8 to solder bridge.

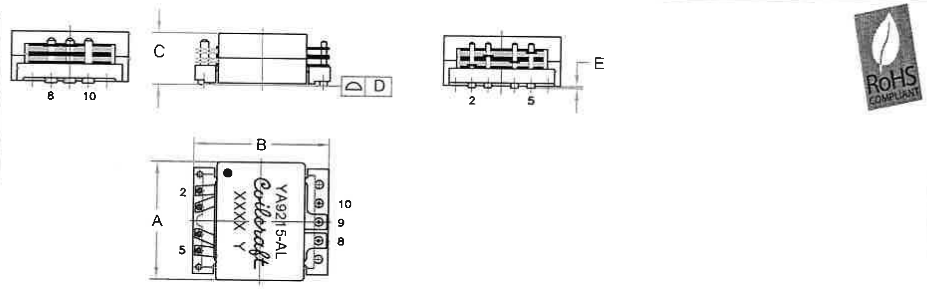
Customer to tie terminals 3+4 and 7+8 on PC board.

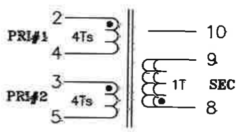
Wire insulation & RoHS status not affected by wire color. Wire insulation color may vary depending on availability.

DFM	SP	Packaging Specifications	CONVENTION PLACEMENT	Tolerances unless otherwise specified:	DRAWING TITLE	PART NO.
DATE	1/14/2020	Method: Tape & Reel		Angles: ±1° Decimals: ±.005 [.13]	INDUCTOR	750371133
ENG	ANI	PKG-0328		Fractions: ±1/64 Footprint: ± .005 [.13]		
REV.	00			This drawing is dual dimensioned. Dimensions in brackets are in millimeters.		
DATE	2/4/2021	www.we-online.com/midcom				SPECIFICATION SHEET 1 OF 1

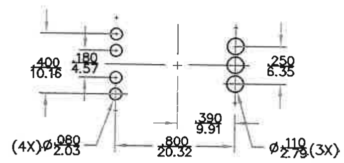
FIGURE A-12: CUSTOMER DRAWING AND TEST DATA (SHEET ONE)

MECHANICAL SPECIFICATIONS		
DIMENSIONS	MIN	MAX
PHYSICAL PARAMETERS(inch/mm)		
A: WIDTH		.820/20.83
B: LENGTH		.920/23.37
C: HEIGHT		.352/8.94
D: COPLANARITY WITHIN .004/0.10 (100%)		
E: SEATING PLANE	.009/0.229	





SCHEMATIC



Suggest Land Pattern

S/N: YA9215-AL_("_" means suffix for package)

Coilcraft Cary, IL 60013
Coil Design Data
FORM-CW027 Rev J

Customer	Coilcraft
Customer P/N	YA9215-AL_
Rev.	
CCI Sample#/ID#	YA9215-AL_
EWO	
Date	2018/11/06
Engineer	R.R PAN.
Layers	CDD,Logo

APPROVAL	DATE
Eng.Mgr.	

REVISION RECORD	
ECN#	DESCRIPTION

Scale: 1:1

ELECTRICAL SPECIFICATIONS "ALL ELECTRICAL SPECIFICATIONS @ 25°C"

INDUCTANCE (uH) (CSC)
800KHz 0.8VRMS INPUT 0ADC

PINS	MIN	MAX
2 – 4	2.88	3.52

DC RESISTANCE(mOHMS)

PINS		MAX
2 – 4		14.7
3 – 5		14.7
8 – 9		0.65

HI POT (Leakage current can not exceed 3mA)
VAC TO BE APPLIED FOR 60 SECONDS

VOLTAGE	FROM PINS	TO PINS
500	2, 3	8
500	2	3
500	2,3,8	CORE

TURN RATIO – TRL
APPLY 10KHz 1.0VRMS TO PIN2–4

MEASURE PINS	MIN	MAX
3 – 5	0.960	1.040
8 – 9	0.240	0.260

LEAKAGE INDUCTANCE (uH)
800KHz 0.8VRMS

TEST PINS	SHORT PINS	MAX
2,3 – 4,5	8, 9	0.105

LAYER:

WARNING! THIS DRAWING, AND ALL INFORMATION CONTAINED WITHIN, IS PROPRIETARY TO COILCRAFT AND SHOULD NOT BE DIVULGED WITHOUT PRIOR ENGINEERING CONSENT

FIGURE A-13: CUSTOMER DRAWING AND TEST DATA (SHEET TWO)

Coilcraft

TEST DATA SHEET

Customer: Microchip-Ismaning
Part Number:
Sample Number: YA9215-AL
EWO Number: 58473
Page

Parameter	L	LL	DCR	DCR	DCR	T/R	T/R	HI-POT 500VAC/60SEC/ 3mA	HI-POT 500VAC/60SEC/ 3mA	HI-POT 500VAC/60SEC/ 3mA		
Pins TYP	2-4	2，3-4，5 SHORT8，9	2-4	3-5	8-9	3-5	8-9	2，3-8	2-3	2，3，8-CORE		
Min Spec	2.88					0.96	0.24	Pass	Pass	Pass		
Max Spec	3.52	0.105	14.7	14.7	0.65	1.04	0.26	FaiL	FaiL	FaiL		
Units	µH	µH	mΩ	mΩ	mΩ							
1	2.99	0.094	12.35	12.71	0.59	0.996	0.25	Pass	Pass	Pass		
2	2.97	0.096	12.46	12.67	0.6	0.995	0.244	Pass	Pass	Pass		
3	3.04	0.092	12.37	12.73	0.6	0.997	0.251	Pass	Pass	Pass		
4	2.96	0.089	12.35	12.64	0.59	0.995	0.25	Pass	Pass	Pass		
5	2.96	0.088	12.58	12.9	0.6	0.995	0.251	Pass	Pass	Pass		
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
Average	2.984	0.0918	12.422	12.73	0.596	0.9956	0.2492					

Test Instruments Used:

Tester for L	Tester for LL	Tester for C	Tester for DCR	Tester for V/R	Tester for L.B.	Tester for SRF	Q tester
HP4284A	HP4284A	N/A	CH-502	VT AT3600	N/A	N/A	N/A

Note: For additional information see product specifications

Comments:

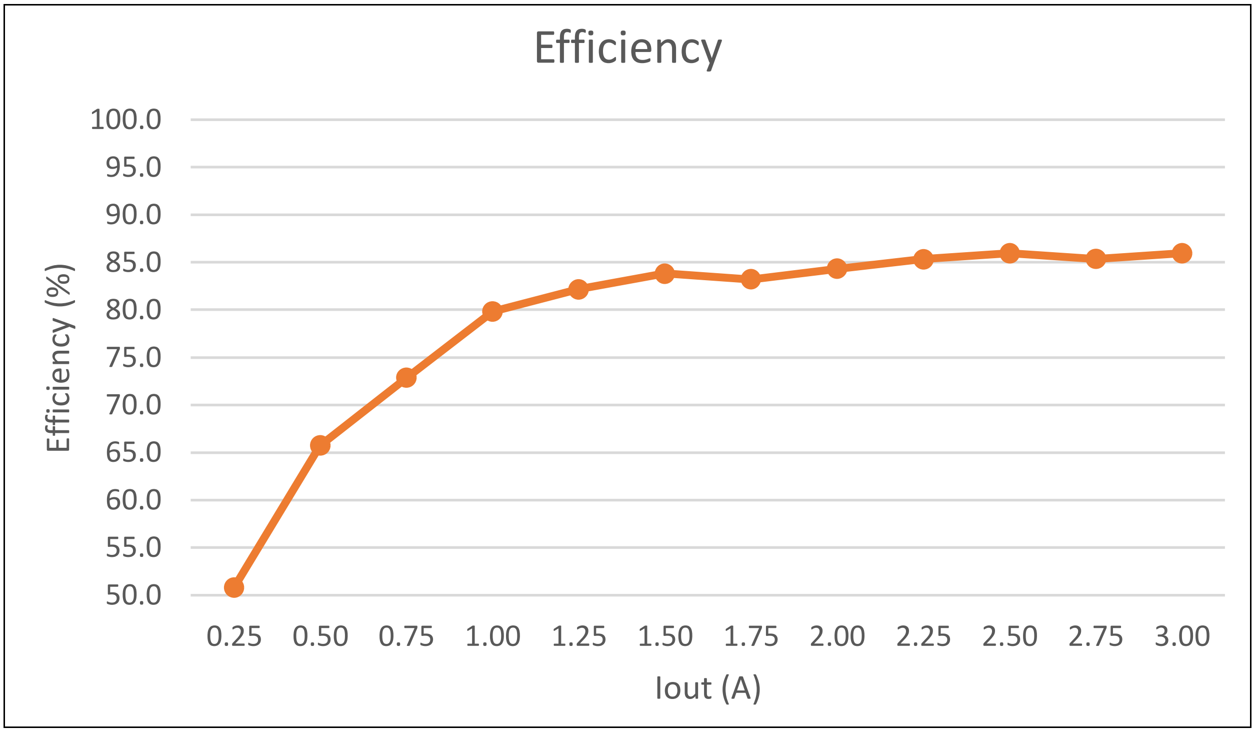
TESTED BY: SHAN DATE: 2018-11-6
VALIDATED BY: PAN DATE: 2018-11-6

Appendix B. Test Results

B.1 EFFICIENCY

This converter has the following efficiency performance: All measurements are done at 40V input and 9V output.

FIGURE B-1: EFFICIENCY IN FUNCTION OF OUTPUT CURRENT



Note:	This curve represents efficiency measurement on the single power stage only. DP PIM consumption and related AUX effort are also included (plug to plug measurement).

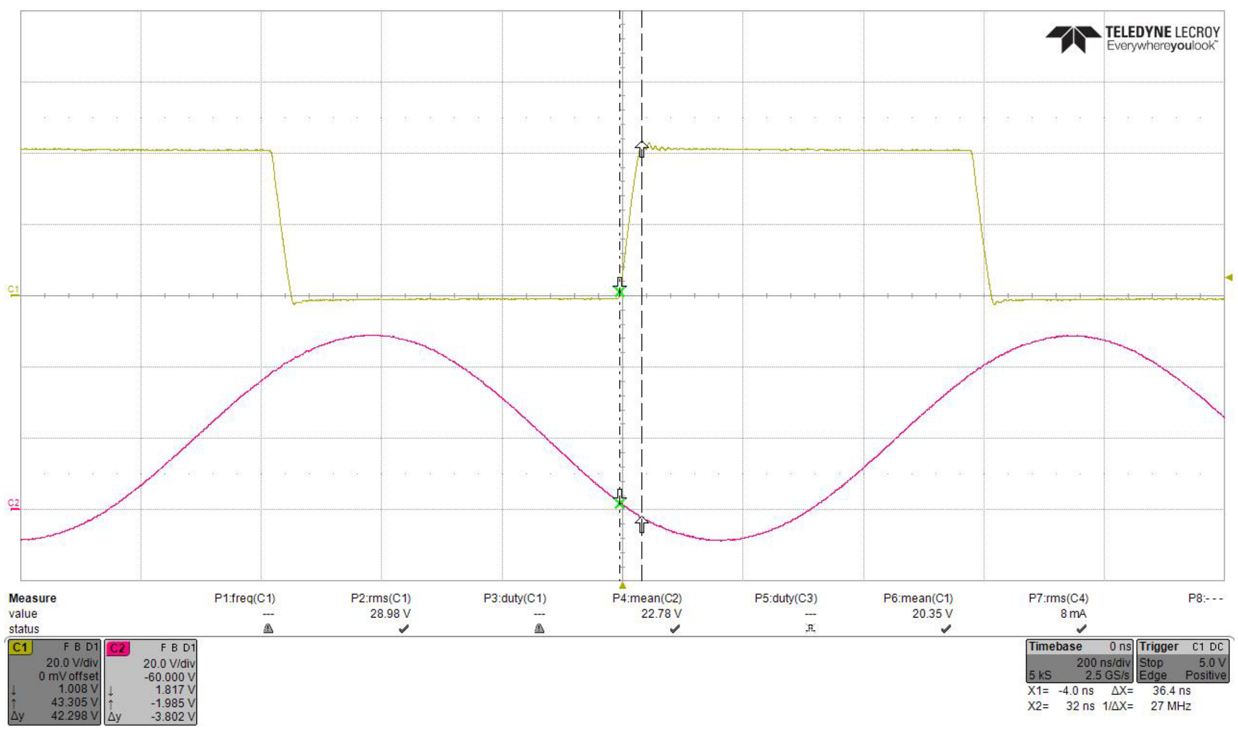
B.2 NO LOAD CONSUMPTION PERFORMANCE

At No Load conditions, the converter has the following consumption performance (V_{OUT} = 9V).

Conditions	V_{IN} [V]	Pin [W]
No PIM Inserted	40	0.56
PIM Inserted, No PWM	40	1.36
850 kHz PWM	40	2.04

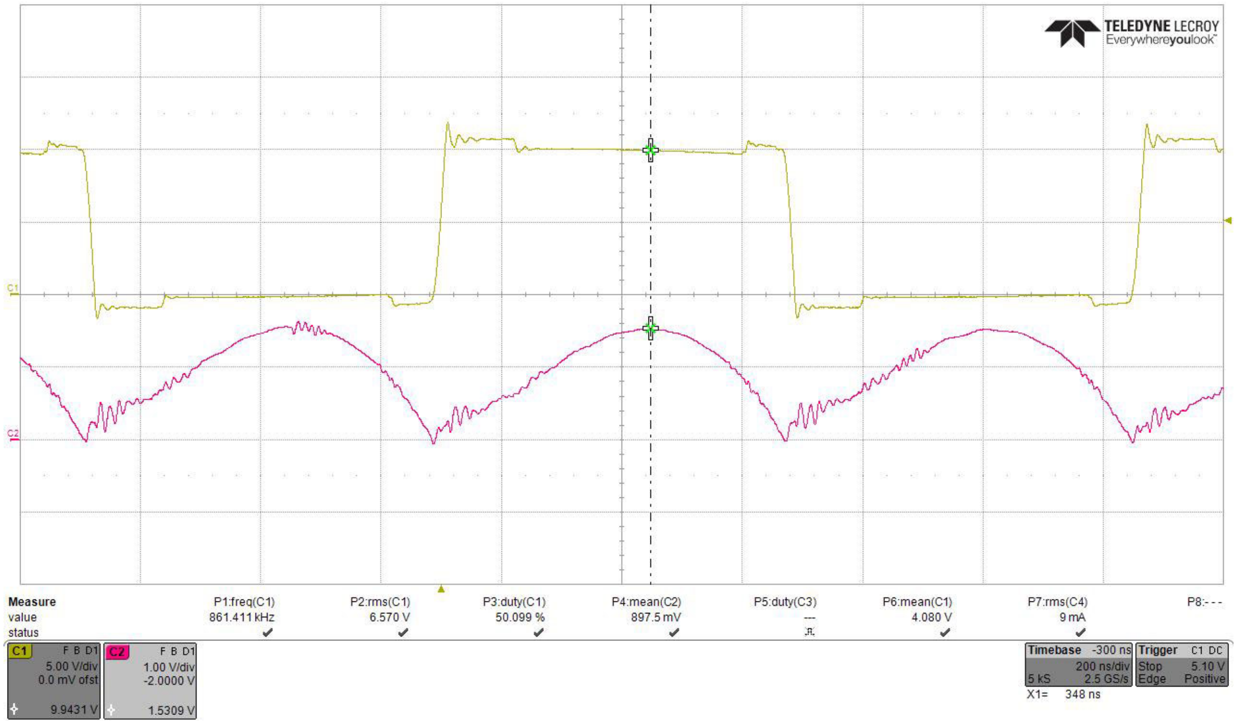
B.3 MEASUREMENT RESULTS

FIGURE B-2: SWITCHING NODES PRIMARY SIDE



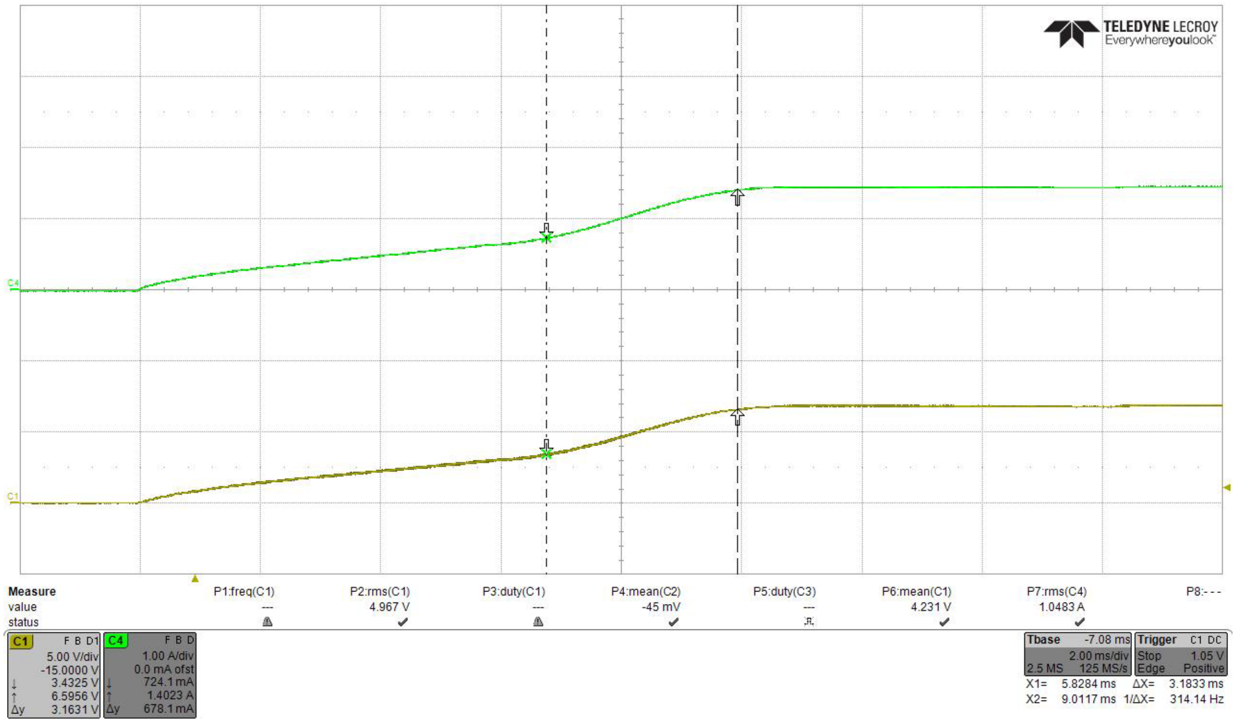
Legend: V_{IN} = 40V, V_{OUT} = 9V, I_{OUT} = 2A
Ch1 (yellow) – Half-Bridge Switching Node (TP400)
CH2 (red) – Resonant Capacitor Voltage (TP402)

FIGURE B-3: SWITCHING NODES SECONDARY SIDE



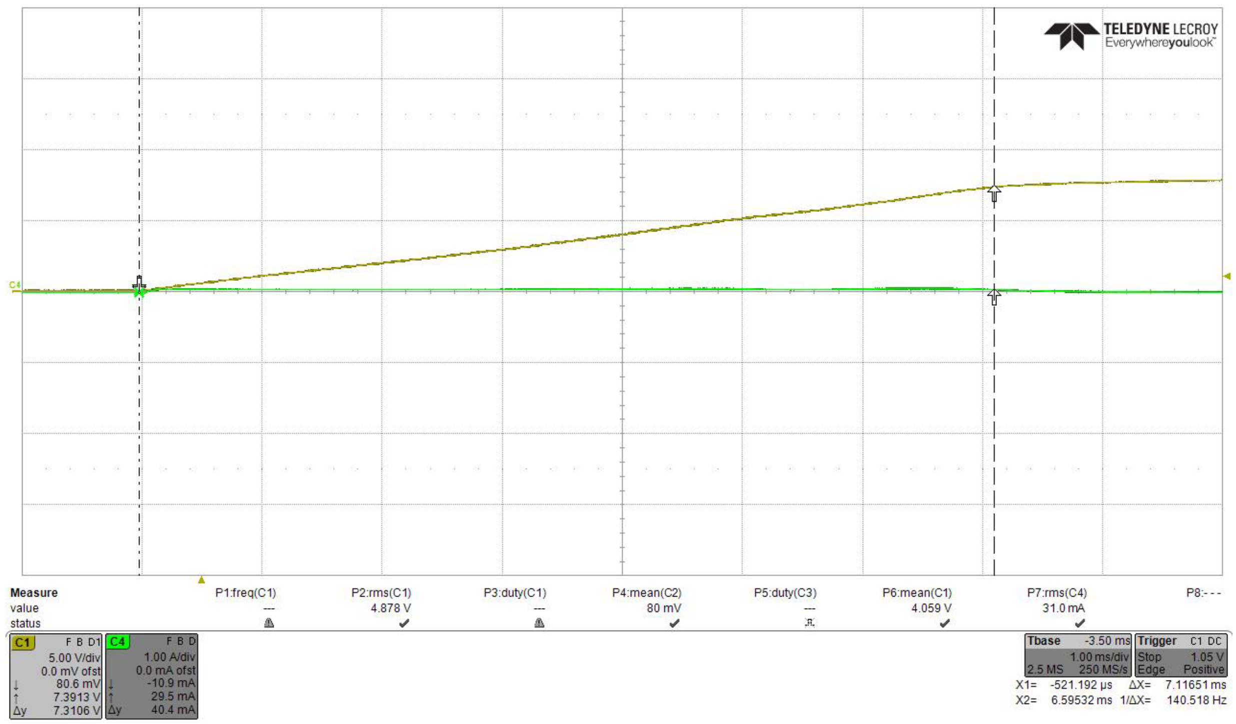
Legend: V_{IN} = 40V, V_{OUT} = 9V, I_{OUT} = 2A
Ch1 (yellow) – Switching Node Half-Bridge Secondary Side
CH2 (red) – Rectified Current, Directly after CT Secondary

FIGURE B-4: SWITCH ON BEHAVIOR WITH RESISTIVE LOAD AT THE OUTPUT



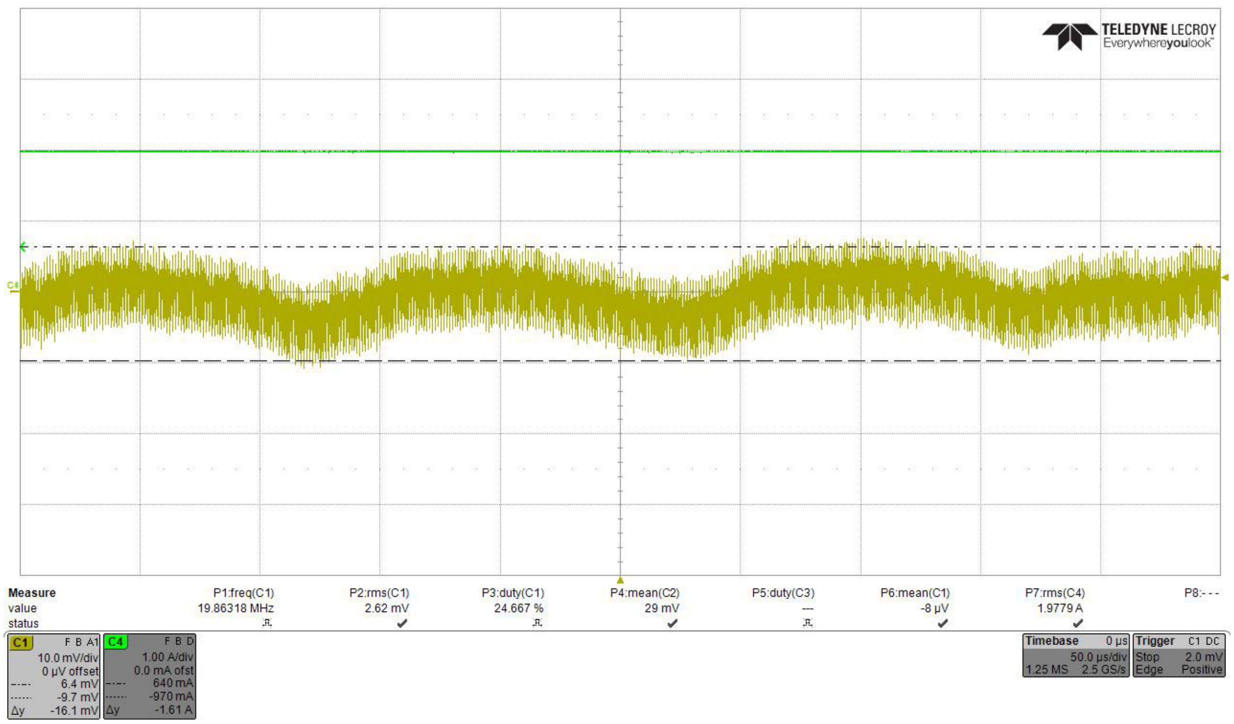
Legend: V_{IN} = 40V, V_{OUT} = 9V, I_{OUT} = 1.5A
Ch1 (yellow) – Output Voltage
Ch4 (green) – Output Current
Time Base: 2 ms/div

FIGURE B-5: SWITCH ON BEHAVIOR WITH NO LOAD AT THE OUTPUT



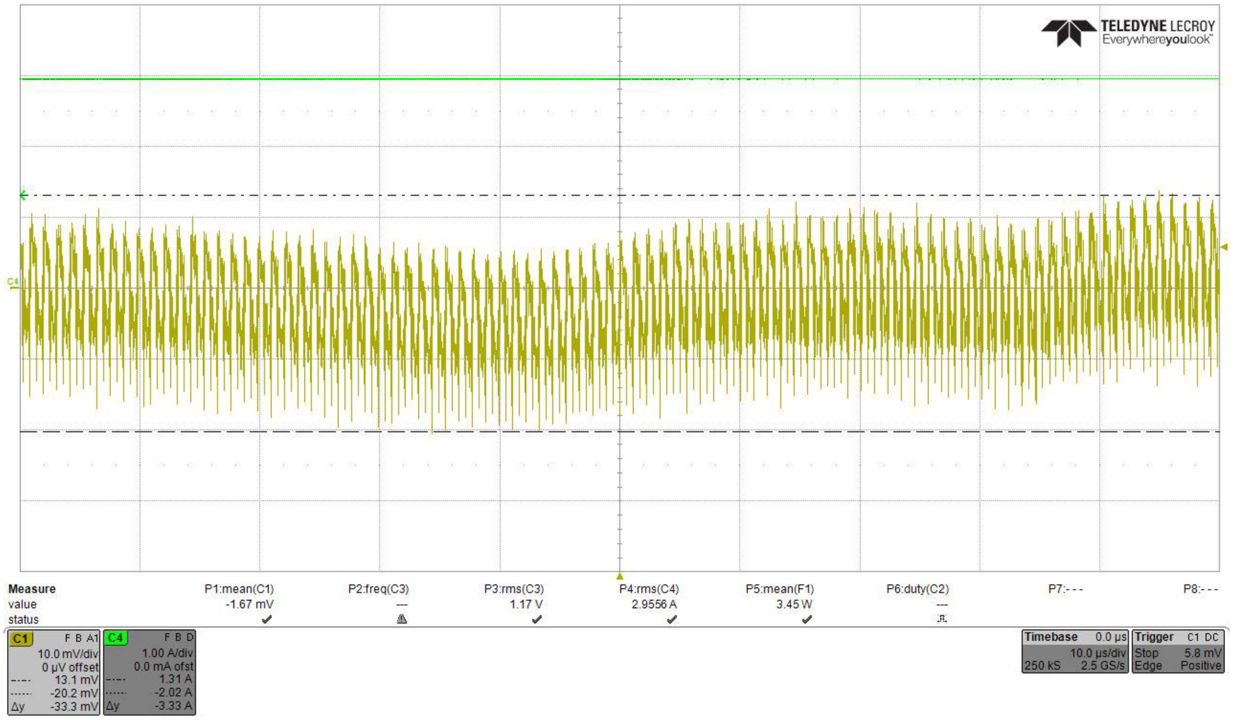
Legend: V_{IN} = 40V, V_{OUT} = 9V, I_{OUT} = 0A
Ch1 (yellow) – Output Voltage
Ch4 (green) – Output Current

FIGURE B-6: RIPPLE AT THE OUTPUT



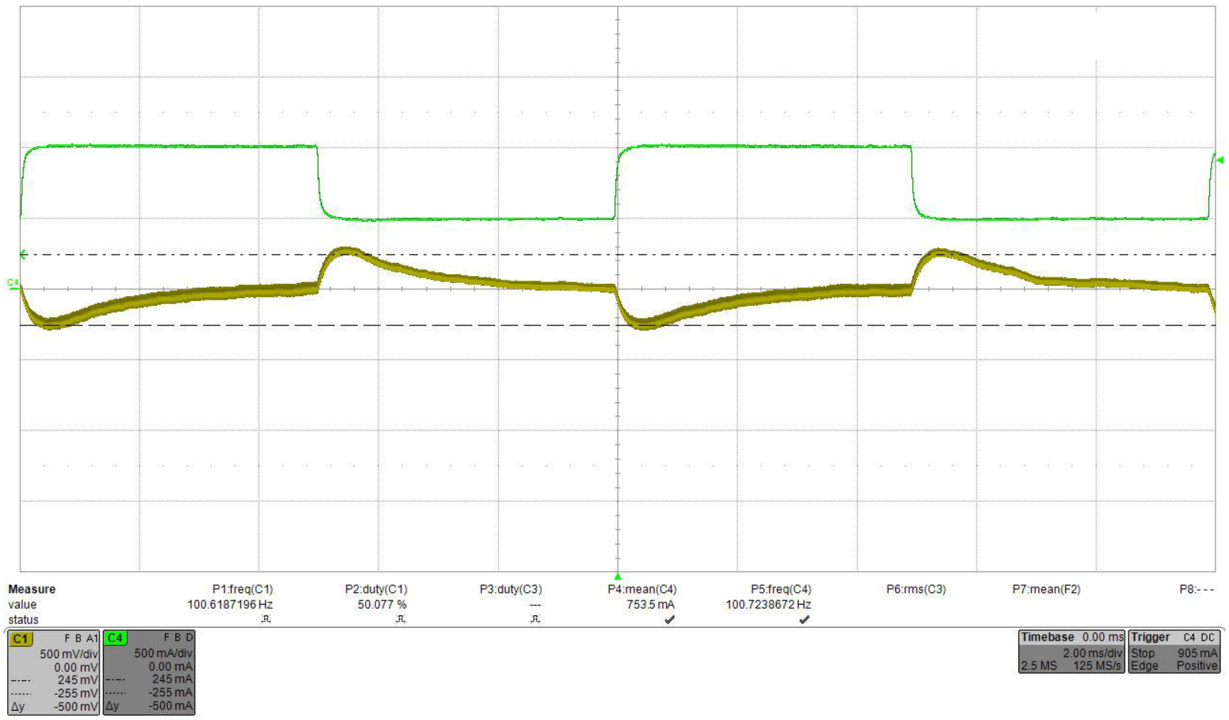
Legend: V_{IN} = 40V, V_{OUT} = 9V, I_{OUT} = 2A
Output Ripple Voltage < 20 mVpp
Ch1 (yellow) – Output Voltage (AC coupled; 20 MHz bandwidth)
Ch4 (green) – Output Current

FIGURE B-7: SPIKES AT THE OUTPUT



Legend: V_{IN} = 40V, V_{OUT} = 9V, I_{OUT} = 3A
Output Ripple and Spikes Voltage < 35 mVpp
Ch1 (yellow) – Output Voltage (AC coupled; 20 MHz bandwidth)
Time Base: 10 µs/div

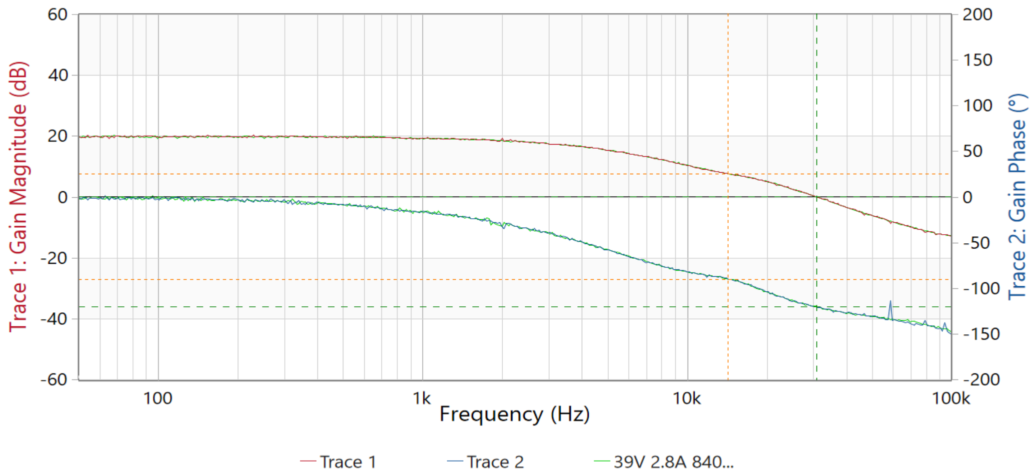
FIGURE B-8: LOAD STEP RESPONSE 50%-100%-50%



Legend: V_{IN} = 40V, V_{OUT} = 9V, I_{OUT} = 1A
Ch1 (yellow) – Output Voltage (AC coupled; 20 MHz bandwidth limit)
Ch4 (green) – Output Current
Time Base: 2 ms/div

FIGURE B-9: LOOP STABILITY – PLANT MEASUREMENT

Measurement: Gain / Phase



	Cursor 1	Cursor 2	Delta C2-C1
Frequency	31,008 kHz	14,331 kHz	-16,677 kHz
Trace 1	**Magnitude (dB)**	**Magnitude (dB)**	**Magnitude (dB)**
Measurement	0 dB	7,725 dB	7,725 dB
Trace 2	**Phase (°)**	**Phase (°)**	**Phase (°)**
Measurement	-120,184 °	-90 °	30,184 °

Sweep	
Start frequency:	50 Hz
Stop frequency:	100 kHz
Center frequency:	50,025 kHz
Span:	99,95 kHz
Sweep mode:	Logarithmic
Numer of points:	401

Hardware setup	
Device type:	No device connected!
Serial number:	No device connected!
Receiver bandwidth:	100 Hz
Output level:	-17 dBm
DUT settling time:	0 ms

Calibration	Full-Range	User-Range
Gain	Active	-

Termination	Channel 1	Channel 2
Gain	1 MΩ	1 MΩ

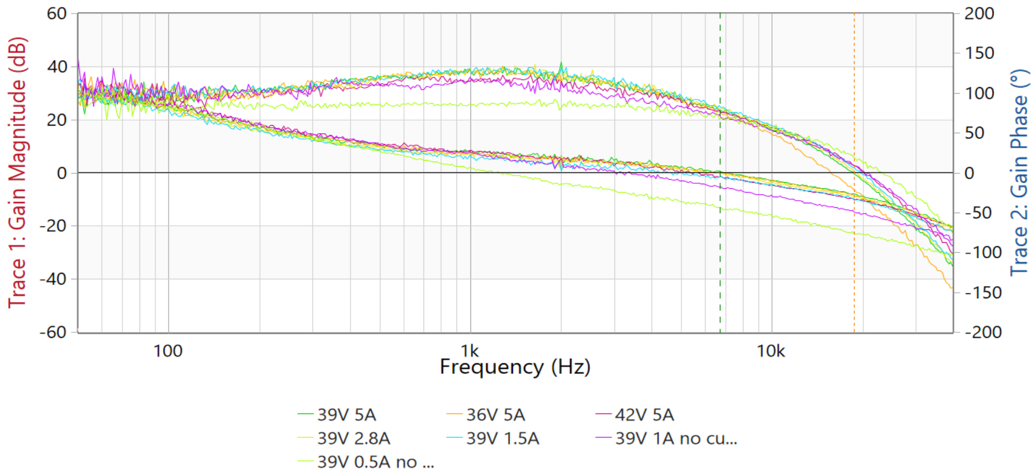
Attenuator setting	Channel 1	Channel 2
Transmission	0 dB	0 dB

Probe factor	Channel 1	Channel 2
Gain	10: 1	10: 1

Legend: V_{IN} = 40V, Vout = 9V, I_{OUT} = 3A

FIGURE B-10: LOOP STABILITY – VOLTAGE LOOP

Measurement: Gain / Phase



	Cursor 1	Cursor 2	Delta C2-C1
Frequency	6,756 kHz	18,834 kHz	12,078 kHz

Sweep	
Start frequency:	50 Hz
Stop frequency:	40 kHz
Center frequency:	20,025 kHz
Span:	39,95 kHz
Sweep mode:	Logarithmic
Numer of points:	401

Hardware setup	
Device type:	No device connected!
Serial number:	No device connected!
Receiver bandwidth:	100 Hz
Reference level	-3 dBm
DUT settling time:	0 ms

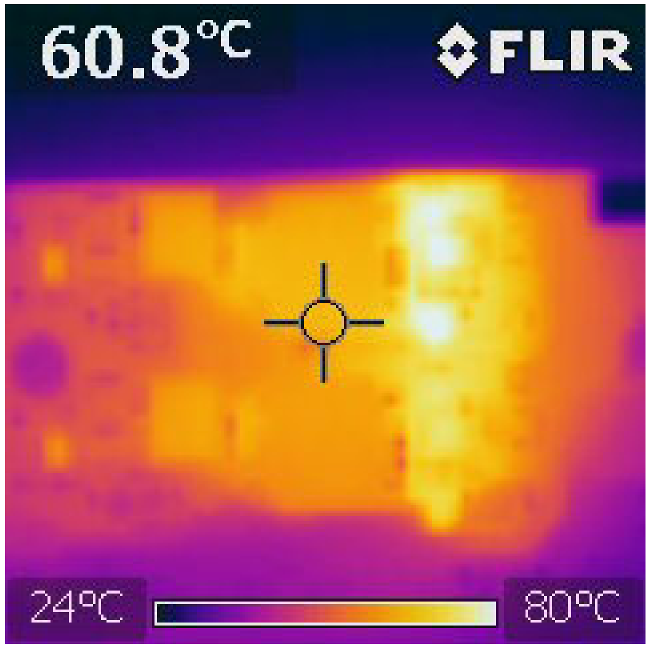
Calibration	Full-Range	User-Range
Gain	-	-

Termination	Channel 1	Channel 2
Gain	1 MΩ	1 MΩ

Attenuator setting	Channel 1	Channel 2
Transmission	0 dB	0 dB

Probe factor	Channel 1	Channel 2
Gain	10: 1	10: 1

FIGURE B-11: THERMAL MEASUREMENTS



Legend: V_{IN} = 40V, V_{OUT} = 9V, I_{OUT} = 3A, Cursor Pointing on Power Transformer Phase A.

Note: Due to active phase current balancing, one or another power stage will run with higher dead time which will immediately cause a small amount of higher power loss at synchronous rectifiers. In this case, Phase A is correcting, therefore the synchronous rectifiers run at a higher temperature.

NOTES:

Appendix C. Bill of Materials (BOM)

This appendix contains the Bill of Materials (BOMs) for the 50W Interleaved LLC Converter Development Board.

C.1 BILL OF MATERIALS

Table C-1 shows the Bill of Materials for the 50W Interleaved LLC Converter Development Board.

TABLE C-1: BILL OF MATERIALS (BOM) – 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD

Qty.	Designator	Description	Manufacturer	Manufacturer Part Number
16	C101, C102, C103, C104, C105, C211, C301, C308, C310, C314, C401, C402, C414, C501, C502, C514	Capacitor Ceramic, 100 nF, 50V, 10%, X7R, SMD, 0603, AEC-Q200	TDK Corporation	CGA3E2X7R1H104K080AA
5	C130, C140, C160, C170, C313	Capacitor Ceramic, 330 pF, 50V, 5%, C0G, SMD, 0603	KEMET	C0603C331J5GACTU
3	C201, C403, C503	Capacitor Ceramic, 2.2 µF, 100V, 10%, X7R, SMD, 1210	AVX Kyocera	12101C225KAT2A
1	C202	Capacitor Aluminum Poly, 56 µF, 63V, 20%, SMD, F	Nichicon Corporation	PCR1J560MCL1GS
1	C203	Capacitor Ceramic, 0.1 µF, 100V, 10%, X7R, SMD, 0805	TDK Corporation	C2012X7R2A104K125AA
2	C204, C205	Capacitor Ceramic, 10 µF, 50V, 20%, X7R, SMD, 1210	TDK Corporation	C3225X7R1H106M250AC
7	C212, C213, C312, C400, C415, C500, C515	Capacitor Ceramic, 10 µF, 25V, 10%, X5R, SMD, 0805	TDK Corporation	C2012X5R1E106K125AB
8	C300, C601, C750, C760, C761, C762, C763, C764	Capacitor Ceramic, 1 µF, 16V, 10%, X5R, SMD, 0603	TDK Corporation	C1608X5R1C105K080AA
2	C302, C303	Capacitor Ceramic, 10 pF, 50V, 5%, NP0, SMD, 0603	KEMET	C0603C100J5GACTU
2	C304, C311	Capacitor Aluminum, 33 µF, 16V, 20%, 0.03R (P1.4XW5.3XL5.3XH5.8), SMD	Würth Elektronik	875105359004
1	C305	Capacitor Ceramic, 1000 pF, 1000V, 10%, X7R, SMD, 1206	KEMET	C1206C102KDRACAUTO
1	C306	Capacitor Ceramic, 10000 pF, 500V, 10%, X7R, SMD, 1210	KEMET	C1210C103KCRACTU
12	C404, C405, C406, C407, C408, C409, C504, C505, C506, C507, C508, C509	Capacitor Ceramic, 2700 pF, 100V, 5%, NP0, SMD, 1206	KEMET	C1206C272J1GAC7800

TABLE C-1: BILL OF MATERIALS (BOM) – 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD (CONTINUED)

Qty.	Designator	Description	Manufacturer	Manufacturer Part Number
8	C410, C411, C412, C413, C510, C511, C512, C513	Capacitor Ceramic, 22 µF, 10V, 10%, X7R, SMD, 1206, AEC-Q200	Taiyo Yuden	LMJ316BB7226KLHT
1	C600	Capacitor Aluminum, 330 µF, 16V, 20%, 0.01R, SMD	Würth Elektronik	875075355004
19	D120, D211, D301, D401, D402, D403, D404, D405, D406, D407, D408, D501, D502, D503, D504, D505, D506, D507, D508	Diode Rectifier, 1N4148WS, 1.25V, 150 mA, 75V, SOD-323	Diodes Inc.	1N4148WS-7-F
3	D200, D201, D210	Diode Schottky, 840 mV, 1A, 100V, SMD, SOD-323HE, AEC-Q101	ROHM Semiconductor	RB168VYM100FHTR
1	D203	Diode Zener, 47V, 590 mW, SOD-123	Nexperia USA	BZT52-B47J
2	D300, D312	Diode Zener, BZX84-C5V1, 5.1V, 250 mW, SOT-23-3	Nexperia USA	BZX84-C5V1,215
2	D310, D311	Diode Schottky, BAT54, 900 mV, 300 mA, 40V, SOD-323	STMicroelectronics	BAT54JFILM
1	J100	Connector Edge, MECF, 1.27 mm, 60P, Female, SMD, Vertical	Samtec Inc.	MECF-30-01-L-DV-WT
3	J200, J201, J600	Connector Terminal, 3.81 mm, 1x2, Female, 16-28 AWG, 10A, Through-Hole, R/A	Adam Equipment	EBWA-02-B
1	L201	Inductor, 2.2 µH, 3.75A, 30%, SMD, L6W6H2.8, AEC-Q200	Würth Elektronik	74404063022
1	L202	Inductor, 22 µH, 0.7A, 20%, SMD, LPS4012	Coilcraft	LPS4012-223MRC
1	L300	Inductor, 4.7 µH, 920 mA, 260 mOhm	Taiyo Yuden	CBC2518T4R7M
2	L401, L501	Inductor, 2.1 µH, 8.5A, 5%, SMD, L13.34W15.24H11.43	Würth Elektronik	750371133
2	L410, L510	Inductor, 120 nH, 13.2A, 20%, 5.88 mR, SMD, L4W4H1.2	Coilcraft	XFL4012-121MEB
1	LD100	Diode LED, Green, 3.2V, 20 mA, 430 mcd, Clear, SMD, 0603	Würth Elektronik	150060GS75000
2	LD101, LD700	Diode LED, Red, 2V, 20 mA, 250 mcd, Clear, SMD, 0603	Würth Elektronik	150060RS75000
1	Q201	Transistor FET, N-Ch, 100V, 2A, 3.1W, SOT-223-3	Alpha & Omega Semiconductor Inc.	AOH3106
2	Q300, Q301	Transistor FET, N-Ch, 60V, 360 mA, 350 mW, SOT-23-3	Nexperia USA	2N7002P,215
4	Q400, Q401, Q500, Q501	Transistor FET, N-Ch, 60V, 30A, 0.016R, 45W, PowerPAK, SO-8L, AEC-Q101	Vishay General Semiconductor	SQJA60EP-T1_GE3

TABLE C-1: BILL OF MATERIALS (BOM) – 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD (CONTINUED)

Qty.	Designator	Description	Manufacturer	Manufacturer Part Number
4	Q410, Q411, Q510, Q511	Transistor FET, N-Ch, 30V, 63A, 0.0052R, PDFN-8	Alpha & Omega Semiconductor Inc.	AONS36306
1	Q700	Transistor BJT, Dual, NPN+PNP, MMDT2227M, 40V, -60V, 0.6A-0.6A, 0.3W, SOT-23-6	Diodes Inc.	MMDT2227M-7
27	R100, R201, R211, R304, R305, R313, R314, R404, R406, R411, R413, R504, R506, R511, R513, R701, R703, R711, R713, R721, R723, R731, R733, R741, R743, R758, R763	Resistor TKF, 10k, 1%, 1/8W, SMD, 0603	Vishay General Semiconductor	MCT06030C1002FP500
23	R101, R102, R103, R109, R110, R121, R190, R191, R192, R193, R194, R195, R196, R197, R302, R315, R425, R427, R525, R527, R744, R750, R755	Resistor TKF, 3.3k, 1%, 1/10W, SMD 0603	Panasonic®	ERJ-3EKF3301V
17	R104, R123, R130, R140, R160, R170, R303, R700, R710, R720, R730, R740, R751, R752, R753, R754, R756	Resistor TKF, 1k, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT1K00
14	R115, R122, R150, R180, R306, R312, R403, R405, R424, R426, R503, R505, R524, R526	Resistor TKF, 0R, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603ZT0R00
2	R120, R137	Resistor TKF, 20R, 1%, 1/10W, SMD, 0603	Panasonic	ERJ-3EKF20R0V
4	R131, R135, R136, R161	Resistor TKF, 5.6k, 1%, 1/10W, SMD, 0603	Yageo Corporation	RC0603FR-075K6L
1	R202	Resistor TKF, 10R, 1%, 1/4W, SMD, 1206	Panasonic	ERJ8ENF10R0V
1	R210	Resistor TKF, 68k, 1%, 1/10W, SMD, 0603	Yageo Corporation	RC0603FR-0768KL
2	R300, R311	Resistor TKF, 100R, 1%, 1/4W, SMD, 1206	Yageo Corporation	RC1206FR-07100RL
2	R301, R308	Resistor TKF, 39.2k, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT39K2
1	R310	Resistor TKF, 47R, 1%, 1/4W, SMD, 1206	Yageo Corporation	RC1206FR-0747RL
8	R400, R410, R412, R414, R500, R510, R512, R514	Resistor TKF, 1R, 1%, 1/10W, SMD, 0603	Vishay Dale	CRCW06031R00FKEA
2	R420, R520	Resistor TKF, 62R, 1%, 1/4W, SMD, 1206, AEC-Q200	Panasonic	ERJ-8ENF62R0V

TABLE C-1: BILL OF MATERIALS (BOM) – 50W INTERLEAVED LLC CONVERTER DEVELOPMENT BOARD (CONTINUED)

Qty.	Designator	Description	Manufacturer	Manufacturer Part Number
2	R422, R522	Resistor TKF, 22R, 1%, 1/4W, SMD, 1206	Yageo Corporation	RC1206FR-0722RL
1	R757	Resistor TKF, 100k, 1%, 1/10W, SMD, 0603, AEC-Q200	Stackpole Electronics, Inc.	RMCF0603FG100K
1	R760	Resistor TKF, 10R, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT10R0
2	R761, R765	Resistor TKF, 100R, 1%, 1/10W, SMD, 0603	Yageo Corporation	RC0603FR-07100RL
3	SW101, SW102, SW700	Switch Tactile, SPST-NO, 16 V_{DC}, 50 mA, SMD	Würth Elektronik	434123025826
1	TR300	Transistor SMPS, 1:1.1, 5V, 350 mA, 340 µH, SMD, AEC-Q200	Würth Elektronik Midcom	750313734
2	TR400, TR500	Transistor SMPS, 4:1, 30W, Ferrite, SMD, CFT	Coilcraft	YA9215-AL
4	TR401, TR402, TR501, TR502	Transistor Current, 1:100, 1 MHz, 20A, SMD	Coilcraft	CST7030-100LB
2	U100, U101	IC Isolator, Dual Channel Digital Isolators, 2.5 kV, SOIC-8	Silicon Labs	Si8620BB-B-IS
1	U102	IC Optoisolator, 3.75 KV, Push-Pull Output, SOIC-6-5	Toshiba	TLP2361(V4,E
2	U703, U704	IC Logic, 4-Ch, 2IN and SMD, TSSOP-14	Diodes Inc.	74LVC08AT14-13
1	U705	IC Logic, NOR, 1-Ch, 2-INP, SOT-353	Diodes Inc.	74AHC1G02SE-7
Microchip Parts				
1	Q701	Microchip Analog MOSFET, P-Ch, TP2104, 40V, 160 mA, 360 mW, 6R, SOT23-3	Microchip Technology Inc. (Supertex)	**TP2104K1-G**
1	U210	Microchip Analog Switcher Buck, 2 to 24V, SOT-23-6	Microchip Technology Inc.	**MCP16331T-E/CH**
1	U300	Microchip MCU, 8-Bit, 7 KB, 512B, QFN-16	Microchip Technology Inc.	**PIC16F1764-E/ML**
1	U310	Microchip Analog LDO, 3.3V, SOT-23-5	Microchip Technology Inc.	**MCP1755T-3302E/OT**
2	U400, U500	Microchip Analog FET Driver, Dual, Noninverting, SOIC-8	Microchip Technology Inc.	**MIC4604YM-T5**
2	U410, U510	Microchip Analog FET Driver, Single, Noninverting	Microchip Technology Inc.	**MCP14700-E/MF**
1	U700	Microchip Analog Comparator, 4-Ch, TSSOP-14	Microchip Technology Inc.	**MCP6569T-E/ST**
1	U701	Microchip Analog Comparator, 1-Ch, SOT-23-5	Microchip Technology Inc.	**MIC6270YM5-TR**
1	U702	IC Compensator w/Ref, 1.25%, MIC841N, SC-70-5	Microchip Technology Inc.	**MIC841NYC5-TR**
1	U706	Microchip Analog Temperature Sensor, -40ºC to +150ºC, SOT-23-3	Microchip Technology Inc.	**MCP9700T-E/TT**

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