Four-Switch Buck-Boost 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 Four-Switch Buck-Boost 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 Four-Switch Buck-Boost Development Board. The document is organized as follows:

- **Chapter 1. "Overview"** – This chapter introduces the Four-Switch Buck-Boost Development Board and provides a brief overview of its features.
- **Appendix A. "Schematics"** – This appendix provides schematic diagrams for the Four-Switch Buck-Boost Development Board.
- **Appendix B. "4SW Buck-Boost Development Board Test Results"** – This appendix provides Four-Switch Buck-Boost Development Board test results.
- **Appendix C. "MPLAB® X Project Options"** – This appendix provides all MPLAB® X project options.
- **Appendix D. "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>#define START</td></tr>
<tr><td>Filenames</td><td>autoexec.bat</td></tr>
<tr><td>File paths</td><td>c:\mcc18\h</td></tr>
<tr><td>Keywords</td><td>_asm, _endasm, static</td></tr>
<tr><td>Command-line options</td><td>-Opa+, -Opa-</td></tr>
<tr><td>Bit values</td><td>0, 1</td></tr>
<tr><td>Constants</td><td>0xFF, ‘A’</td></tr>
<tr><td>Italic Courier New</td><td>A variable argument</td><td>file.o, where file can be any valid filename</td></tr>
<tr><td>Square brackets [ ]</td><td>Optional arguments</td><td>mcc18 [options] file [options]</td></tr>
<tr><td>Curly braces and pipe character: { | }</td><td>Choice of mutually exclusive arguments; an OR selection</td><td>errorlevel {0|1}</td></tr>
<tr><td rowspan="2">Ellipses...</td><td>Replaces repeated text</td><td>var_name [, var_name...]</td></tr>
<tr><td>Represents code supplied by user</td><td>void main (void)
{ ...
}</td></tr>
</table>

RECOMMENDED READING

This user's guide describes how to use the Four-Switch Buck-Boost 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.

- ***"dsPIC33CK256MP506 Digital Power PIM User's Guide"*** (DS50002819)
  This document is available for download from the Microchip website (www.microchip.com).

THE MICROCHIP WEBSITE

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- Field Application Engineer (FAE)
- Technical Support

Customers should contact their distributor, representative or field application engineer (FAE) 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: https://support.microchip.com

DOCUMENT REVISION HISTORY

Revision A (October 2020)

This is the initial released version of this document.

NOTES:

Chapter 1. Overview

1.1 INTRODUCTION

The Four-Switch Buck-Boost Development Board (4SW-BB) is a generic development board for this topology that supports rapid prototyping and code development based on dsPIC33 devices. The board provides 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 applicable to automotive requirements and can be used for these applications as well. For example, input power can be a standard 12V vehicle power rail and operate within the automotive ambient temperature range. 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.

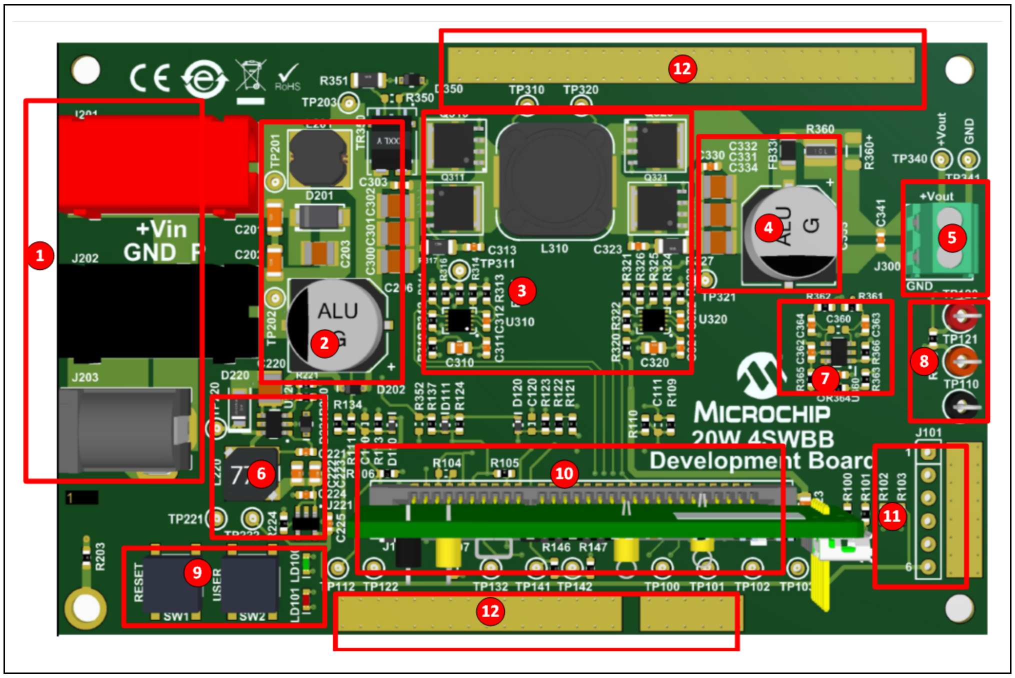
The topics covered in this chapter include:

- Features
- Electrical Characteristics
- Power Stage
- Signal Conditioning
- DC Input Connection
- 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 4SW-BB Development Board features are shown in Figure 1-1.

FIGURE 1-1: FOUR-SWITCH BUCK-BOOST DEVELOPMENT BOARD



1. DC Input Connectors:
   4 mm banana plugs
   2 mm power barrel jack
   Note: Do not use both connectors at the same time.
2. Input filter, overvoltage protection.
3. Four-switch power converter with gate drivers:
   Left Leg-Buck, Right Leg-Boost
4. Output filter.
5. Output connector.
6. Auxiliary power supply.
7. Output current shunt amplifier.
8. Test points for outer loop measurements.
9. HMI interface (push buttons and two LEDs).
10. dsPIC33-DSC DP-PIM socket with test points at the edge of the board.
11. AUX connector.
    Note: Supports UART communication, GPIO, analog input, DAC signal output and 3.3V analog AUX supply.
12. GND surface for ground clips connection.

1.3 ELECTRICAL CHARACTERISTICS

Table 1-1 shows the electrical characteristics of the 4SW-BB.

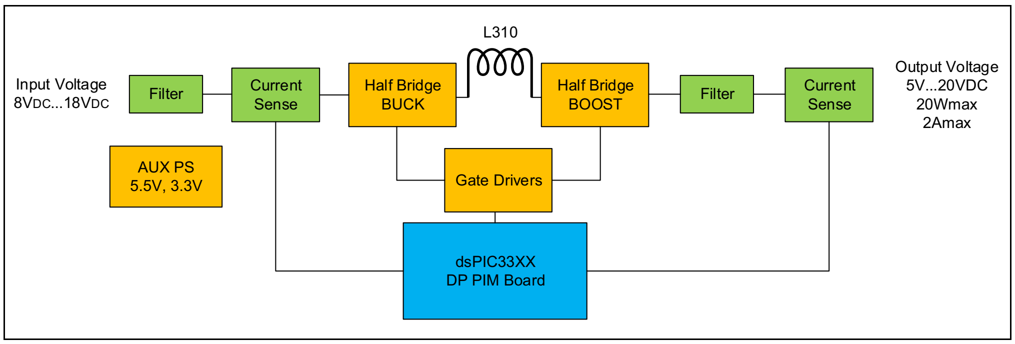
TABLE 1-1: 4SW-BB ELECTRICAL CHARACTERISTICS

Parameter	Value
Input Working Voltage Range	8 to 18 VDC
Load Dump	36V (for 1s)
Max. Output Power	20W
Max. Output Voltage	20V
Max. Output Current	2A
Steady-State Output Ripple Voltage	<2%
Spikes (50 Ohm, 20 MHz bandwidth)	<5%
Bidirectional Capability	Yes
Operating Ambient Temperature	-40 to +85°C
Board Size	103 mm x 66 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, proper power conversion and good EMI/EMC performance.

Half-Bridge Buck – A generic half-bridge stage (high-side control switch and low-side synchronous switch) running in Complementary mode at all times. This stage provides a power train of pulses at the left side of storage choke, L310. This allows energy to be stored up to a certain level. This stage is, by default, bidirectional (synchronous rectification).

Half-Bridge Boost – A generic half-bridge stage (low-side control switch and high-side synchronous switch) running in Complementary mode. Depending on the algorithm, the high-side MOSFET can be disabled. This stage provides a power train of pulses at the right side of storage choke, L310. This stage allows energy to be stored on top of the maximum energy provided by the Buck stage by extending and increasing the total volt-second product across the storage choke, L310, up to a certain level, and ensuring Boost Working mode. This stage is, by default, bidirectional (synchronous rectification).

Output Filter – A Pi filter at the output provides impedance matching, proper power conversion and meets the converter specification (requirements for output voltage ripple and spikes).

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 (TR350, D350, R351)

A high-frequency current transformer in single-ended configuration is used to detect current in the Buck leg. This information is unidirectional and CANNOT be used for backward operations. The current must stay discontinuous all the time, which means that the duty cycle of the high-side control switch (Q310) must remain less than 100%. Considering the shortest pulse width (gate drivers and switch on/off MOSFET capability-dependent), in this case, set to 200 ns, ends at ~90% duty cycle. This duty cycle is a reasonable number from the volt-second product and flux balance point of view. At switching frequencies (demo wise, 350 kHz), signal-level error coming from transformer magnetizing inductance is ~10%. This error is current sense level and duty cycle-dependent. However, this accuracy is acceptable for inner current loops. The same error will be compensated by the outer loop.

1.5.1.2 SHUNT AMPLIFIER (R360, U360)

A shunt resistor is placed in the V_{OUT} rail after the output filter to provide precise load current information. The shunt amplifier, MCP6C02-020, is amplifying the signal by a factor of 20 and adding an offset voltage of 1.65V (half of 3.3V ADC reference voltage). The information from the output is pure DC value and is bidirectional. 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 and bandwidth information are shown in Table 1-2.

TABLE 1-2: SHUNT AMPLIFIER

I_{OUT}/DC [A]	I_{OUT}_Sense [V]	I_{OUT}_Sensor Delta [A]	I_{OUT}_Sensor [A]	Error [%]
0.00	1.609	0	0	0
0.25	1.710	0.253	0.253	1.0
0.50	1.815	0.263	0.515	3.0
0.75	1.917	0.255	0.770	2.7
1.00	2.020	0.258	1.028	2.8
1.25	2.125	0.263	1.290	3.2
1.50	2.227	0.255	1.545	3.0
1.75	2.332	0.263	1.808	3.3
2.00	2.433	0.253	2.060	3.0

1.5.2 Voltage Sensing

1.5.2.1 VDD SENSING (R111, R134, R113)

A simple voltage divider with an 8:1 scaling factor is used to provide input voltage information. Voltage sensing information is shown in Table 1-3.

TABLE 1-3: VOLTAGE SENSING

Parameter	Value	Comment
Rhigh [Ohm]	23200	
Rlow [Ohm]	3300	
C_low [pF]	5600	Capacitance on DP_PIM, at ADC Input
Divider Gain	0.125	
Bias Current [mA]	1.0	At full-scale 3.3V
R_thevenin [Ohm]	3039	Including 150R on DP_PIM
Fc [Hz]	9357	Frequency Corner (-3 dB)

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

A simple voltage divider with an 8:1 scaling factor is used to provide information about output voltage. R120, including TP110, TP120 and TP121, are for open-loop measurement purposes only. Connect a signal injector across R120 for Bode plot measurements.

Voltage sensing information can be found in Table 1-3.

1.5.2.3 VAUX SENSING

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 1-4.

TABLE 1-4: 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)

TABLE 1-5: MATING SOCKET PINOUT

Name	Pin Number	Description
AGND	1	Analog Ground
AGND	2	Analog Ground
DAC OUT	3	DAC Output
AN15	4	General Purpose Analog Input
FB_VDD	5, 17, 15 (optional)	Input Voltage Sense
FB_I_IN	12, 18	Current Sense Input- Current Transformer
FB_I_OUT	9, 13	Current Sense Input- Shunt (Output Current)
FB_VOUT	6, 8 (optional), 10	Output Voltage Sense
FB_AUX	20	AUX Voltage Sense
RX	34	UART RX
TX	36	UART TX
PWM_Boost_L	40	PWM Driving Signal for Switching Elements
PWM_Boost_H	42	PWM Driving Signal for Switching Elements LED (Green)
PWM_Buck_H	45	
PWM_Buck_L	47	
LED0	53	
LED1	55	LED (Red)
+5V5	57, 59	Power Supply for Control Card
GND_P	58, 60	Power (Digital) Ground
NC	7, 11, 19, 23, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 14, 16, 24, 26, 28, 30, 32, 38, 44, 46, 50, 52, 54	Pins are not used

TABLE 1-6: TEST POINTS

Signal Group	Designator	Signal Description
Loop Measurement	TP120	Test Point Pair for Loop Measurement
	TP121	
	TP141	Test Point Pair for Loop Measurement (Current Loop)
	TP142	
	TP110	Analog Ground
Buck Stage	TP100	PWM_BUCK_HIGH
	TP101	PWM_BUCK_LOW
	TP310	Buck Switching Node
Boost Stage	TP102	PWM_BOOST_HIGH
	TP103	PWM_BOOST_LOW
	TP320	Boost Switching Node
Feedback Lines	TP122	+VOUT Feedback Signal
	TP112	+VDD Feedback Signal
	TP132	Current Transformer – Current Sense Feedback Signal
	TP141	Shunt Amplifier – Current Sense Feedback Signal

 Advance Information

TABLE 1-6: TEST POINTS (CONTINUED)

Signal Group	Designator	Signal Description
Efficiency Measurement Lines	TP201	+V_{IN} (Sense Line for efficiency measurements)
	TP202	GND_P (Sense Line for efficiency measurements)
	TP340	+V_{OUT} (Sense Line for efficiency measurements)
	TP341	GND_P (Sense Line for efficiency measurements)
AUX Supply	TP220	Switching Node AUX Supply (~500 kHz, 50% duty cycle at 11V_V_{IN})
	TP221	+5.5V (DC AUX rail voltage)
	TP222	+3.3V (DC AUX rail voltage)
	TP110	Analog Ground

1.6 DC INPUT CONNECTION

The input power can be injected on J201 (Red Banana Jack, K31 in automotive) and J202 (Black Banana Jack), the return line (K30 in automotive) or on the 2 mm Power Jack, J203, where inner connector must be (+) line and the outer connector must be (-) line. Please note that the maximum load current at the J203 connector is 2A. **Do not use both connectors at the same time.**

1.6.1 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 1-7.

TABLE 1-7: PINOUT CONNECTIONS

Name	Pin Number	Description
DAC OUT	1	DAC Output
AN15	2	General Purpose Analog Input
AGND	3	(Analog/Digital Ground) Negative Rail of Vehicle Power System
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 PIM User’s Guide”* (DS50002819) available at www.microchip.com.

1.7 POWERING UP THE DEMO BOARD

Before powering up the 4SW-BB 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 only the USB connection. Using only the USB connection will allow the DP-PIM and demo board to be powered without powering the power stage. When the board is powered on, the green LED will light up.

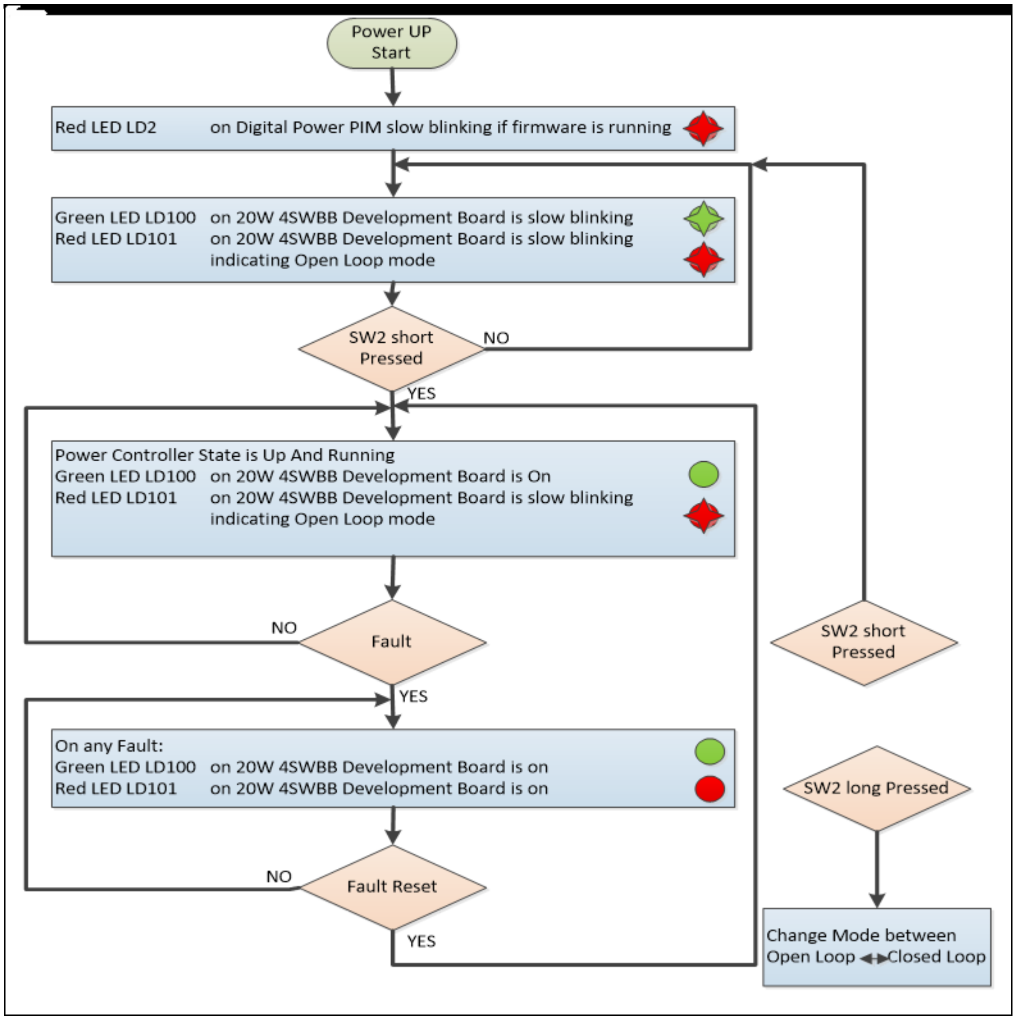
Using the provided demo code, after power-up and if software is running, the red LED on DP PIM will slowly blink. On the power board, the green LED (LD100) and the red LED (LD101) are blinking. PWM signals are disabled.

The USER button (SW2) 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 1-3 shows the state machine.

FIGURE 1-3: STATE MACHINE FLOW CHART

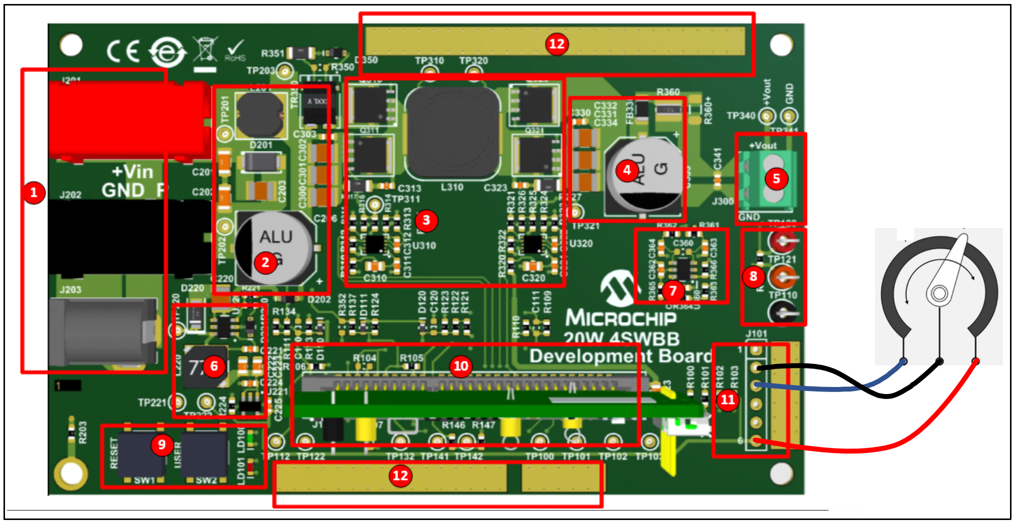


 Advance Information

1.8 TESTING THE BOARD IN OPEN LOOP

1. Connect a DC source to either the input, Banana Jack OR Barrel Jack (Number 1 in Figure 1-4) and a load (Number 5 Figure 1-4). Make sure to use correct polarities. Use a Micro-USB cable to connect a PC and DP-PIM (Number 10 in Figure 1-4) and run the SMPS GUI. This allows voltage and current reading/plotting, and to set parameters.
2. Without using the GUI, connect a potentiometer (e.g., 10 kΩ) as shown in Figure 1-4.
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 1-4: 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 1-5.

FIGURE 1-5: 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 in the 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 dSMPS GUI

A Graphic User Interface (GUI) displays analog values of the converter, as well as the status flags. The reference for output voltage can be set by a digital slider instead of an 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.

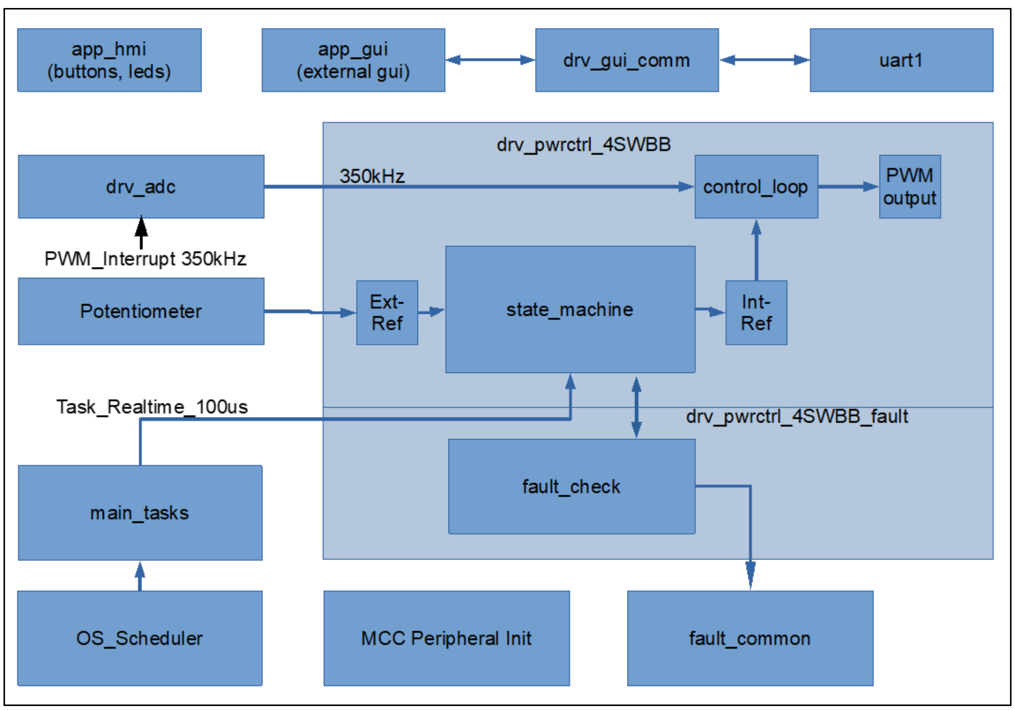
Note: Output voltage can be adjusted from 5V to 20V.

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. "4SW Buck-Boost Development Board Test Results"** for stability measurement results.

1.10 FIRMWARE COMPONENTS

Figure 1-6 shows a high-level overview of the firmware blocks.

FIGURE 1-6: FIRMWARE BLOCK DIAGRAM



 Advance Information

Table 1-8 explains the firmware blocks with basic functionality. Detailed firmware specification and how the blocks are used in power supplies will be described in an Application Note.

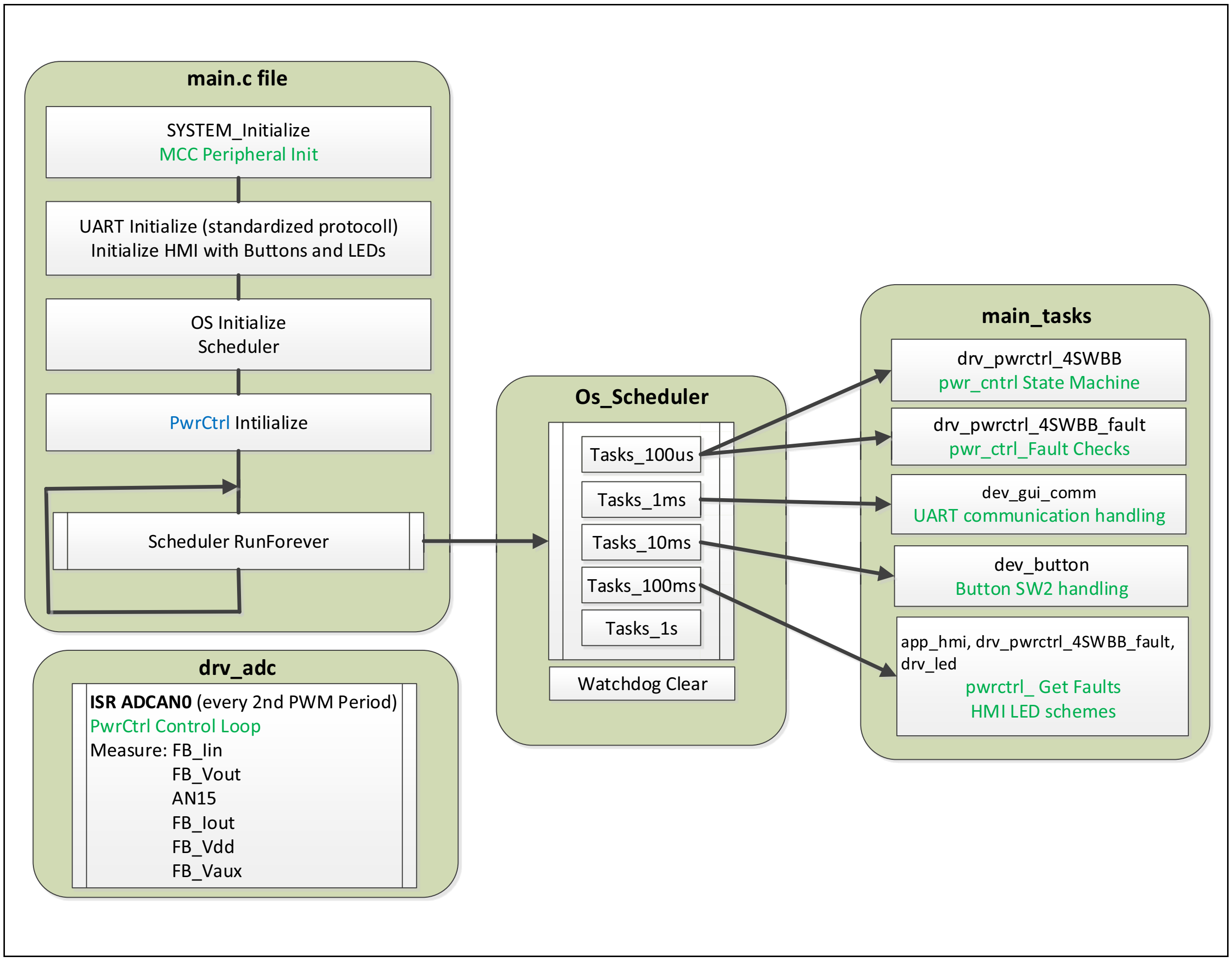
TABLE 1-8: FIRMWARE BLOCKS

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 4SWBB.
main_tasks	Contains all functions that are called by the scheduler. Main point where other important functions are being called.
drv_pwrctrl_4SWBB_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 4SWBB state machine.
drv_pwrctrl_4SWBB	Main component of the 4SWBB. Contains the state machine and the control loop.
Potentiometer	The potentiometer position is being used as a reference voltage for the 4SWBB.
drv_adc	Handles the analog/digital conversion synchronous to the PWM and calls the control loop of the 4SWBB.
app_gui, drv_gui_comm, uart1	Contains the UART communication with the GUI to visualize the status of the 4SWBB.
app_hmi	Contains the Human Machine Interface to control the application with the USER button and sets the status of the LEDs.

1.11 FIRMWARE STRUCTURE

Figure 1-7 shows an overview of the firmware structure.

FIGURE 1-7: 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 a switching frequency of 350 kHz.

A state machine (see Figure 1-3) 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.

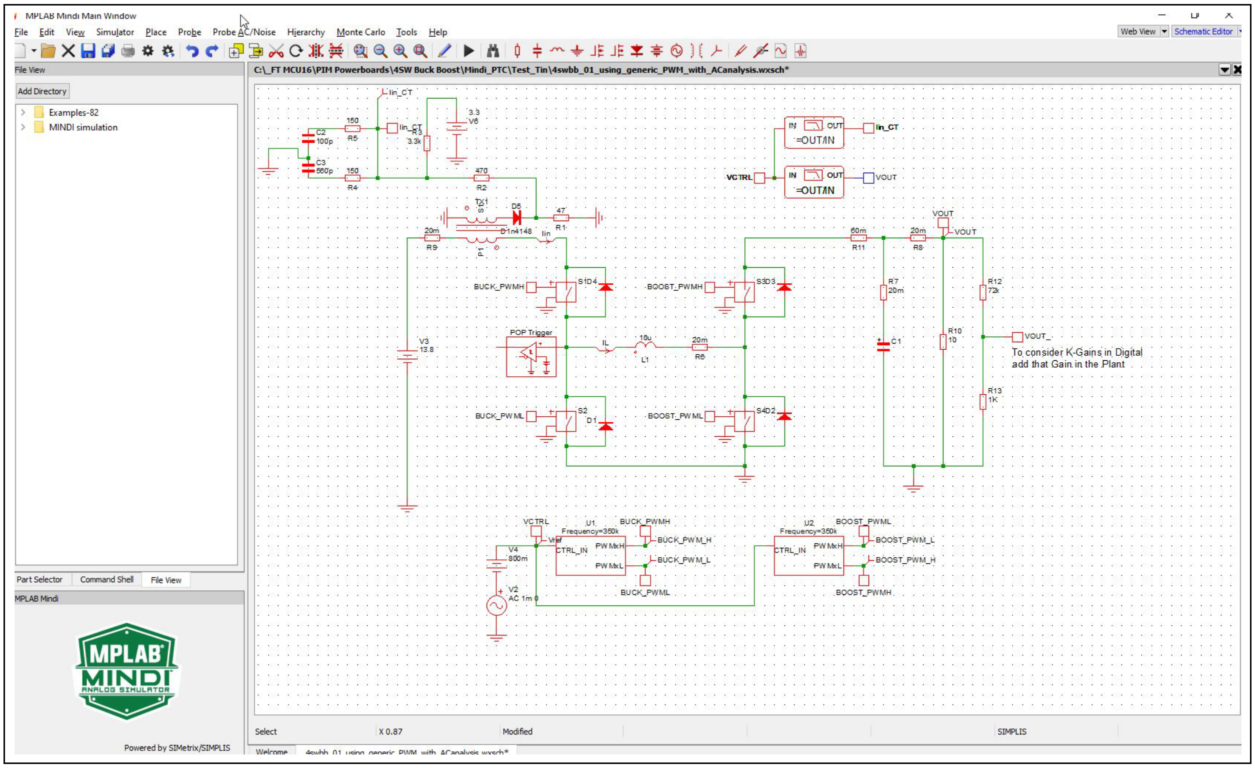
The UART protocol used for communication with a Graphical User Interface is described within the PC GUI software.

1.12 MISCELLANEOUS

1.12.1 MPLAB® Mindi™ Analog Simulation

Figure 1-8 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 1-8: MPLAB® Mindi™ ANALOG SIMULATION



Additional MPLAB Mindi Analog Simulator files for dedicated usage of the 4SWBB board are available at the Microchip website: https://www.microchip.com/mplab/mplab-mindi.

NOTES:

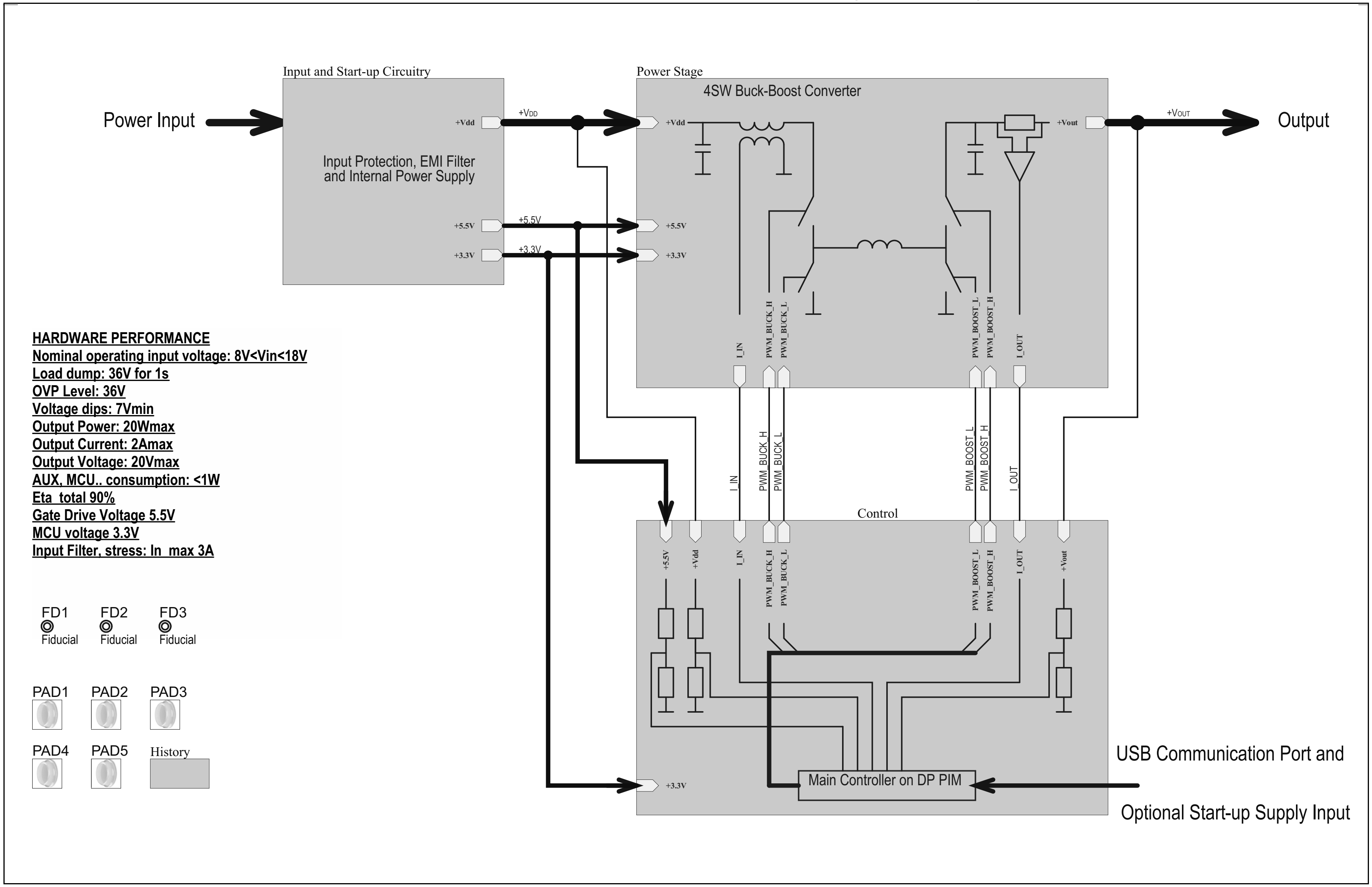
Appendix A. Schematics

This appendix contains the schematics and board layouts for the Four-Switch Buck-Boost Development Board. The schematics in this appendix include:

- **Figure A-1: "Four-Switch Buck-Boost Development Board Schematic (Sheet One)"**
- **Figure A-2: "Four-Switch Buck-Boost Development Board Schematic (Sheet Two)"**
- **Figure A-3: "Four-Switch Buck-Boost Development Board Schematic (Sheet Three)"**
- **Figure A-4: "Four-Switch Buck-Boost Development Board Schematic (Sheet Four)"**
- **Figure A-5: "Four-Switch Buck-Boost Development Board PCB Top Assembly"**
- **Figure A-6: "Four-Switch Buck-Boost Development Board PCB Bottom Assembly"**

FOUR-SWITCH BUCK BOOST DEVELOPMENT BOARD SCHEMATICS

FIGURE A-1: FOUR-SWITCH BUCK-BOOST DEVELOPMENT BOARD SCHEMATIC (SHEET ONE)



Advance Information

FIGURE A-2: FOUR-SWITCH BUCK-BOOST DEVELOPMENT BOARD SCHEMATIC (SHEET TWO)

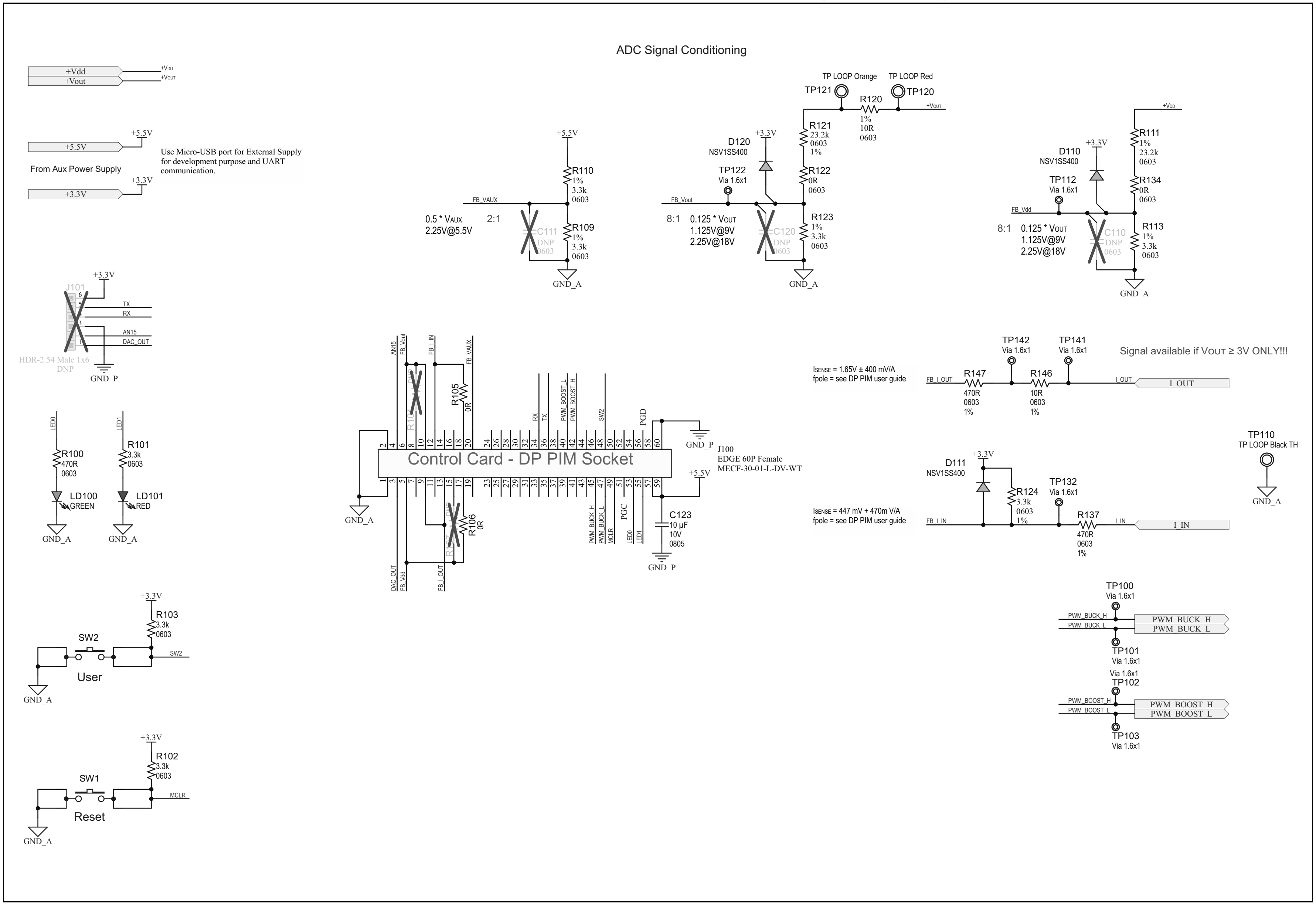


FIGURE A-3: FOUR-SWITCH BUCK-BOOST DEVELOPMENT BOARD SCHEMATIC (SHEET THREE)

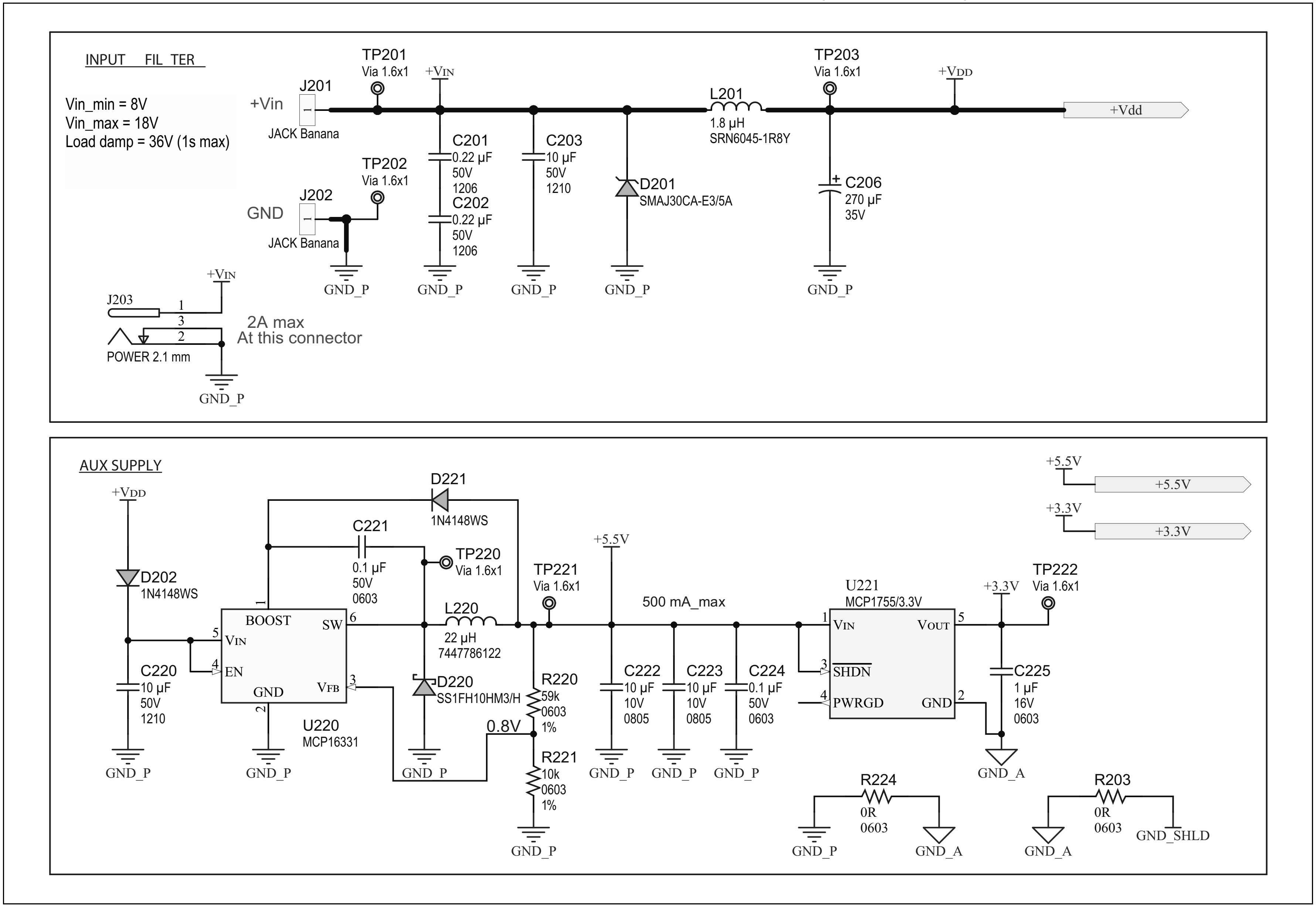
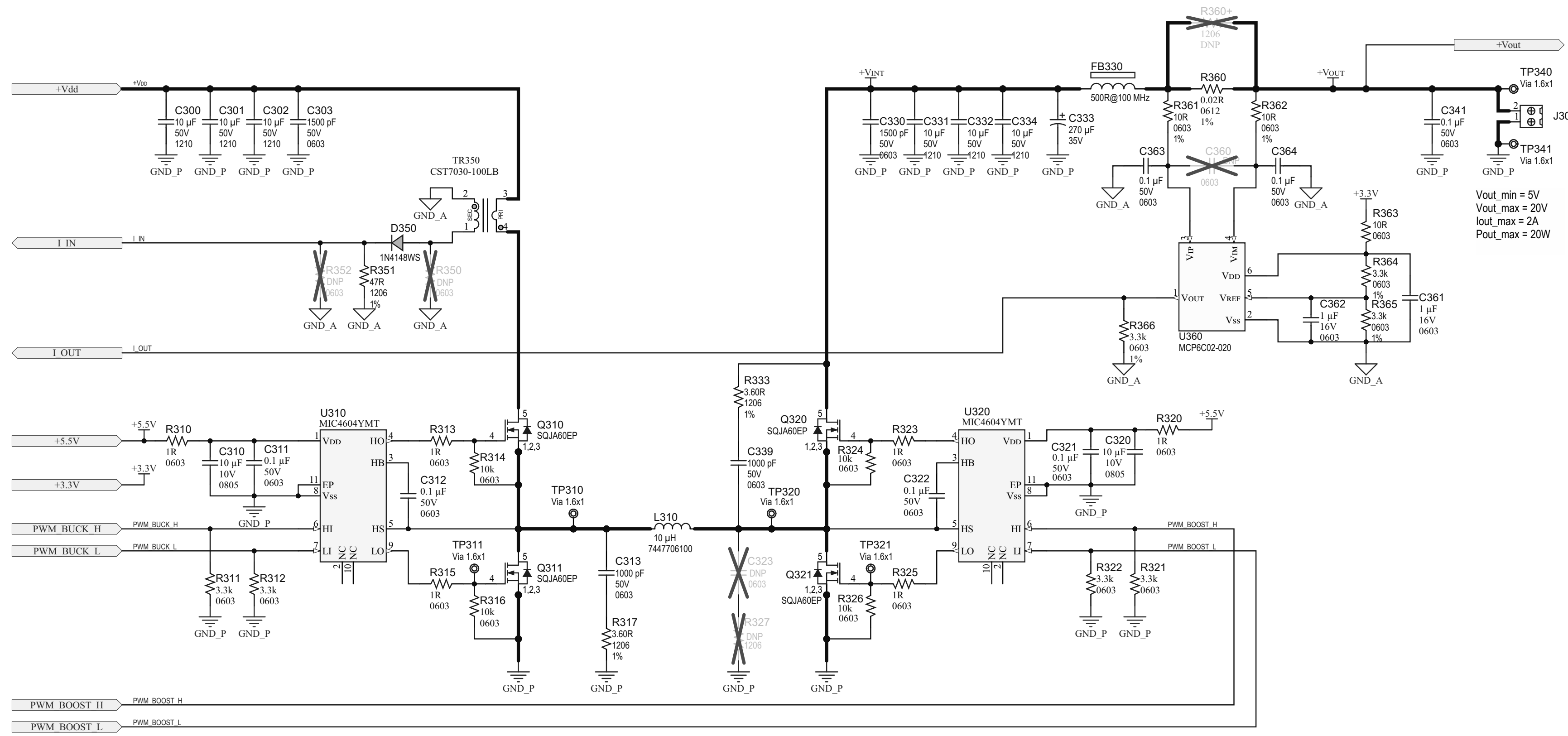


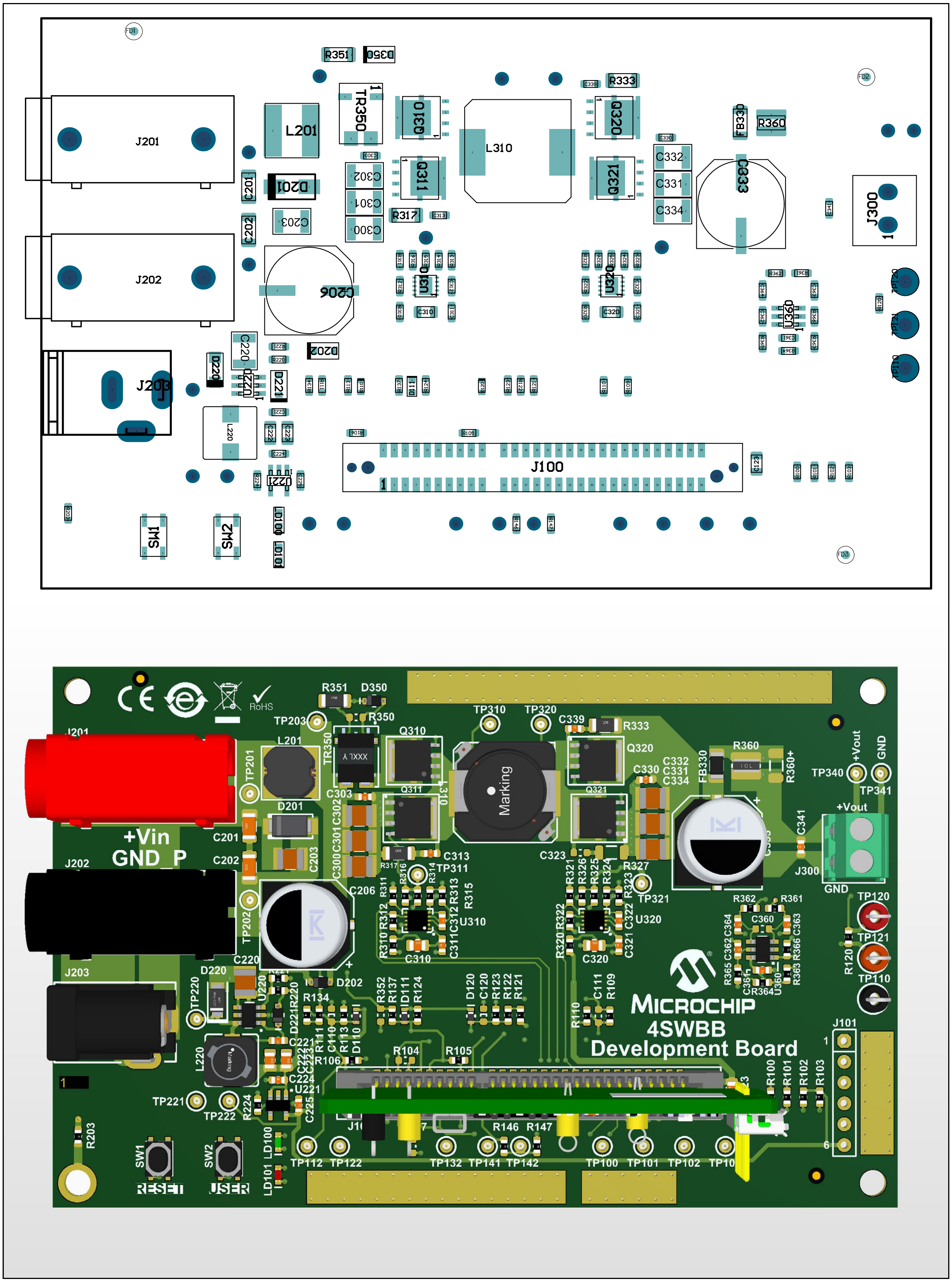
FIGURE A-4: FOUR-SWITCH BUCK-BOOST DEVELOPMENT BOARD SCHEMATIC (SHEET FOUR)



Controller:
Fsw = 350 kHz
Buck: DFmax = 90%, Tmin = 200 ns
Boost: DFmax = 80% Tmin = 200 ns
Peak current or Average Current mode
RHPZ_min 17 kHz
RHPZ @ 13.8V 50 kHz

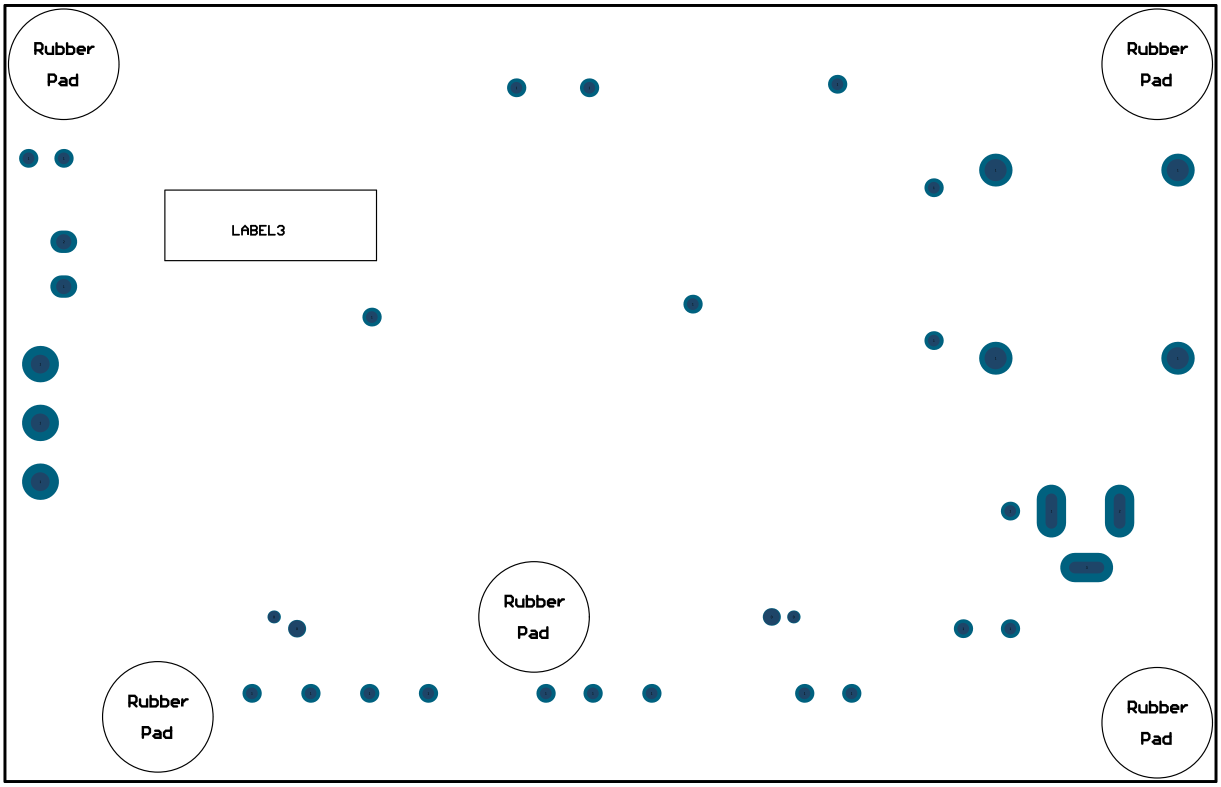
Topology can be reduced to 3&half switches
up to 1A range of the output current
This can simplify stage and reduce the costs

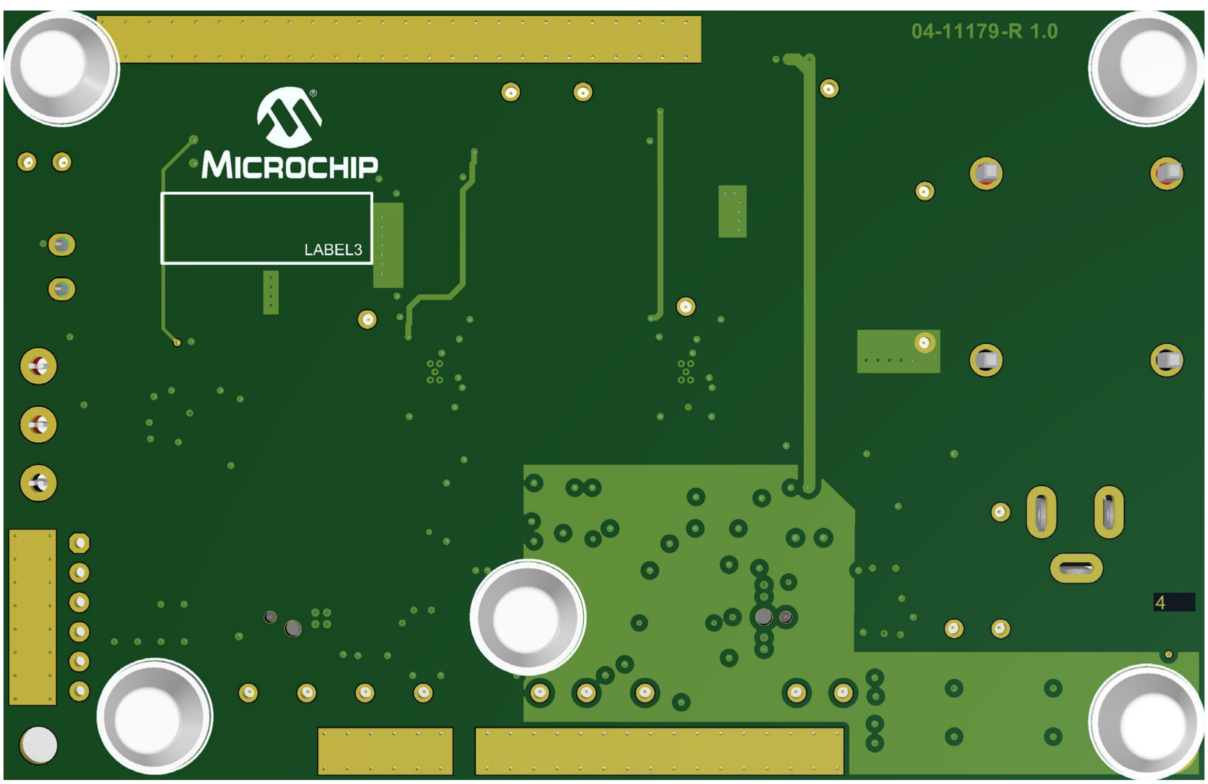
FIGURE A-5: FOUR-SWITCH BUCK-BOOST DEVELOPMENT BOARD PCB TOP ASSEMBLY



 Advance Information

FIGURE A-6: FOUR-SWITCH BUCK-BOOST DEVELOPMENT BOARD PCB BOTTOM ASSEMBLY





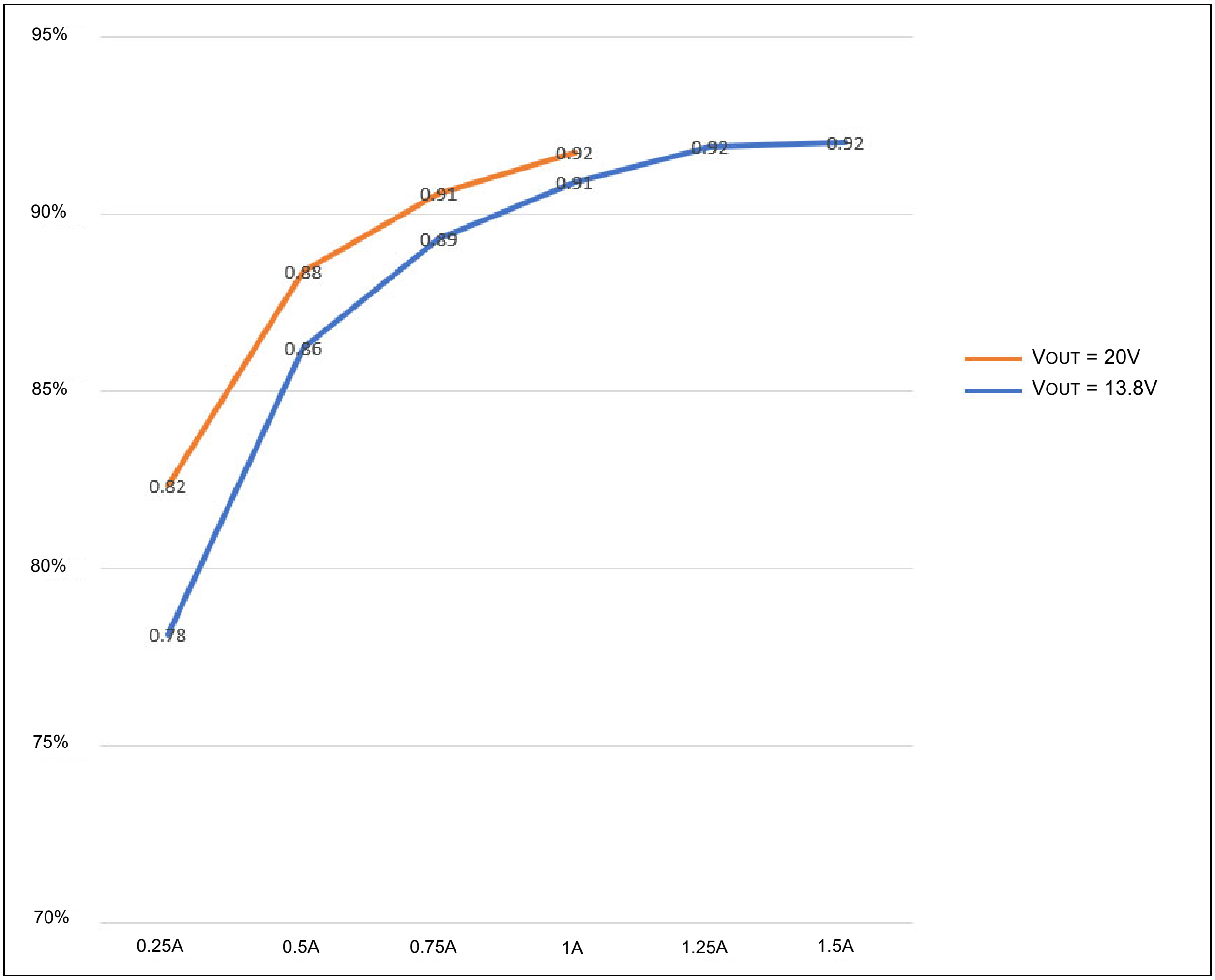
NOTES:

Appendix B. 4SW Buck-Boost Development Board Test Results

B.1 EFFICIENCY

This converter has the following efficiency performance. If no other measurements are noted, all measurements are done at 13.8V input.

FIGURE B-1: EFFICIENCY IN FUNCTION OF OUTPUT CURRENT



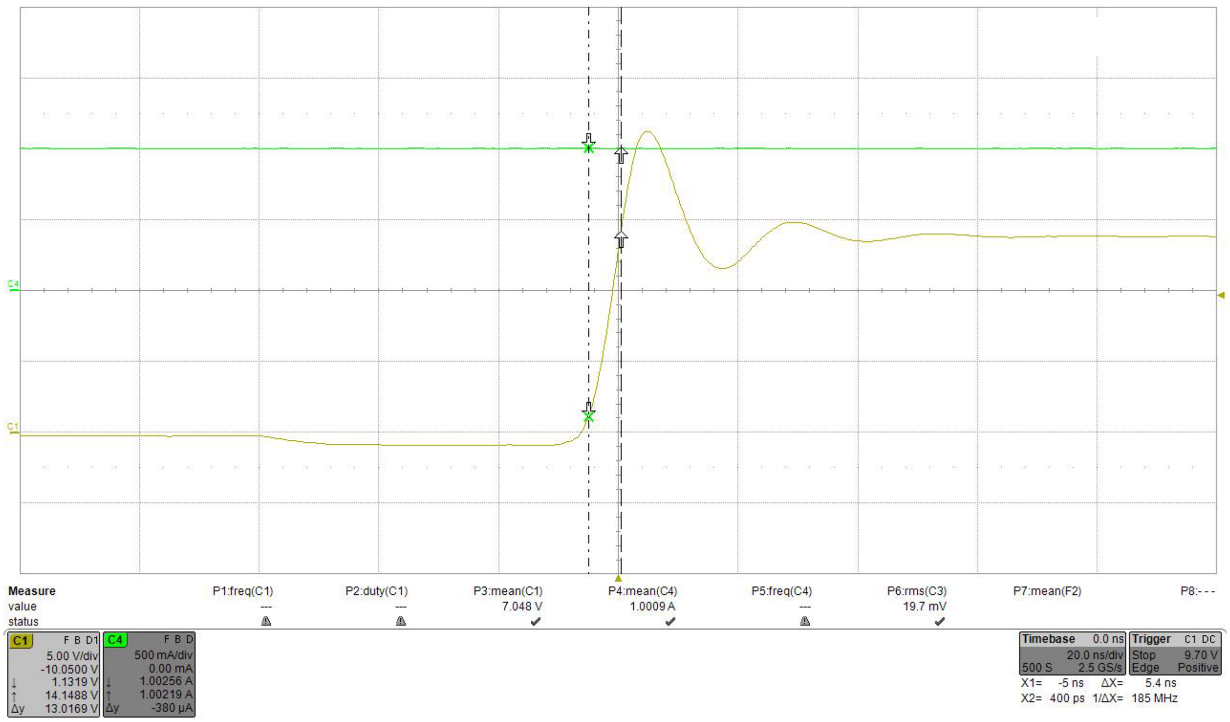
B.2 NO LOAD CONSUMPTION PERFORMANCE

At No Load conditions, the converter has the following consumption performance (V_{OUT} = 20V).

V_{IN} [V]	Pin [W]
8	0.64
13.8	0.55
18	0.52

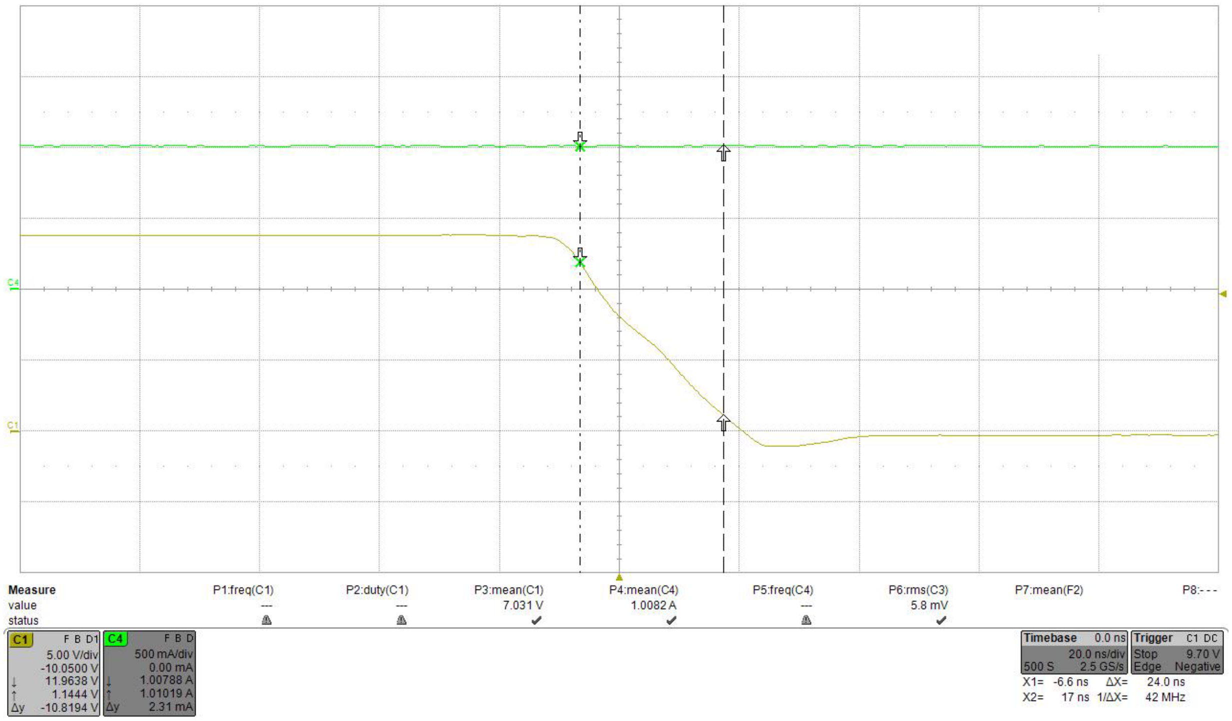
B.3 MEASUREMENT RESULTS

FIGURE B-2: SWITCHING NODES BUCK, RISE TIME



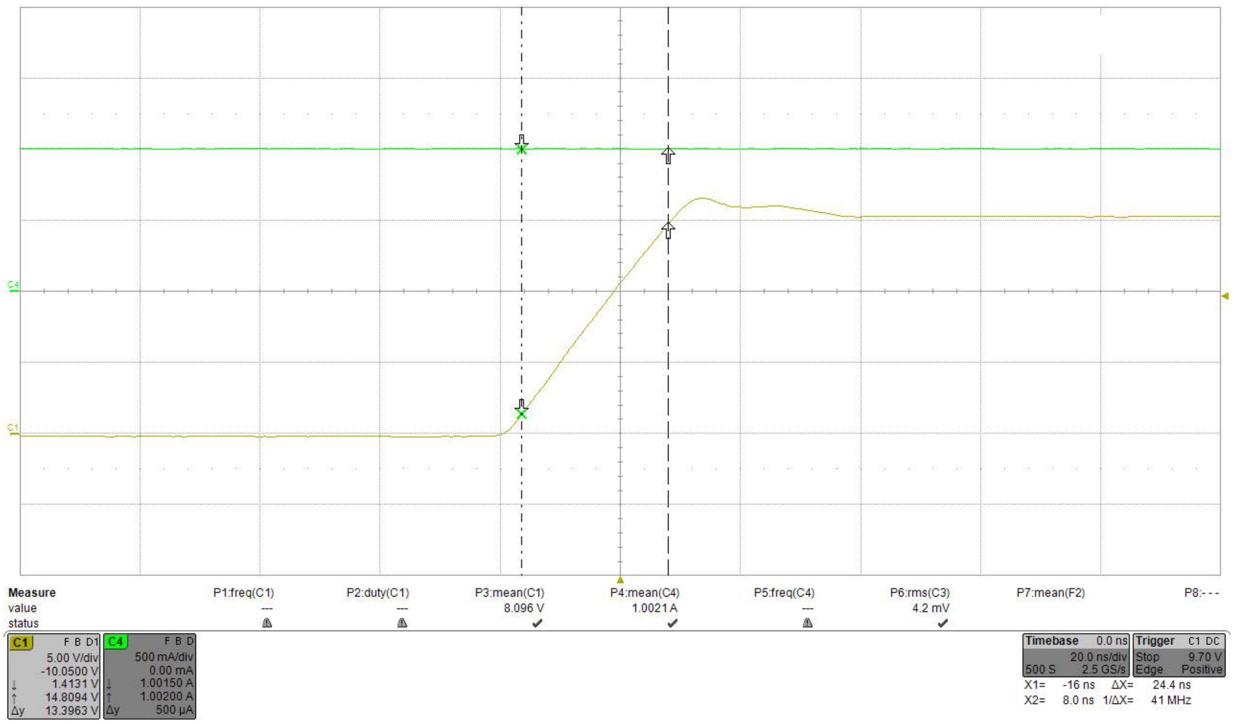
Legend: V_{IN} =13.8V, V_{OUT} = 13.8V, I_{OUT} = 1A
Ch1 (yellow) – PWM_H (TP310)
CH4 (green) – Output Current
20 ns/div

FIGURE B-3: SWITCHING NODES BUCK, FALL TIME



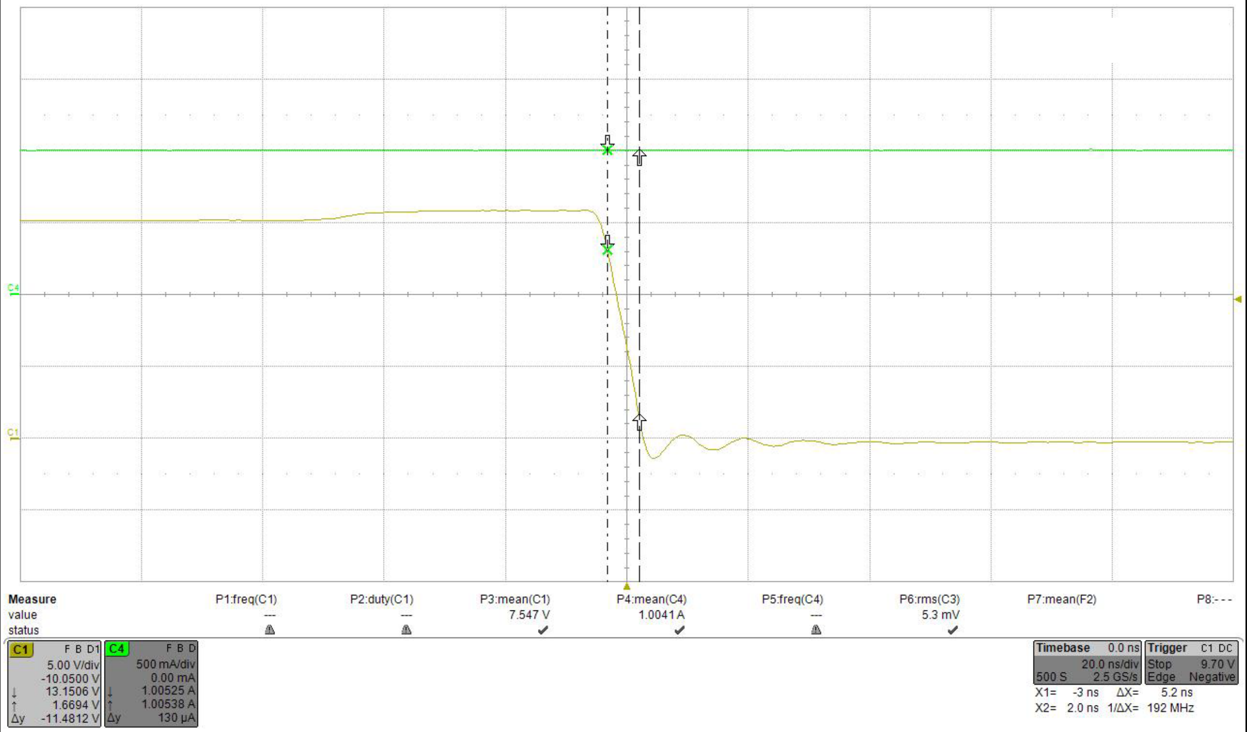
Legend: V_{IN} = 13.8V, V_{OUT} = 13.8V, I_{OUT} = 1A
Ch1 (yellow) – PWM_H (TP310)
CH4 (green) – Output Current
Time Base: 20 ns/div

FIGURE B-4: SWITCHING NODES BOOST, RISE TIME



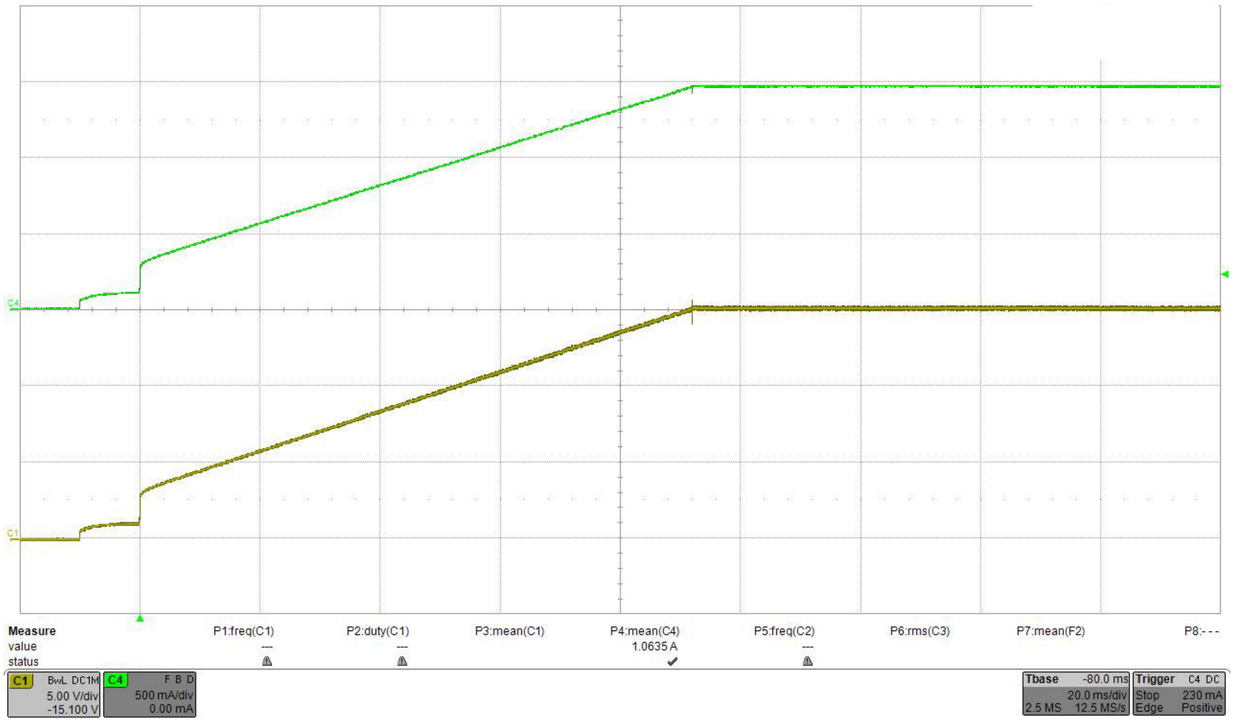
Legend: V_{IN} = 13.8V, V_{OUT} = 15V, I_{OUT} = 1A
Ch1 (yellow) – PWM_H (TP320)
CH4 (green) – Output Current
Time Base: 20 ns/div

FIGURE B-5: SWITCHING NODES BOOST, FALL TIME



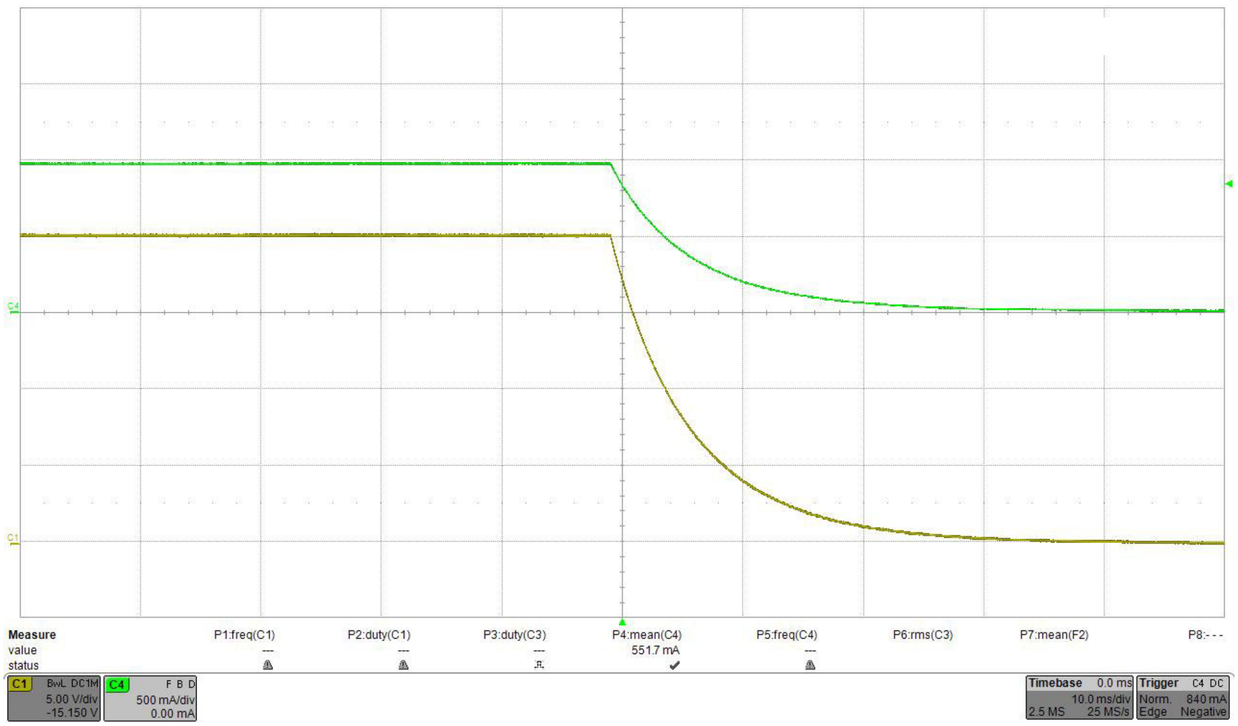
Legend: VIN = 13.8V, VOUT = 15V, IOUT = 1A
Ch1 (yellow) – PWM_H (TP320)
CH4 (green) – Output Current
Time Base: 20 ns/div

FIGURE B-6: SWITCH ON BEHAVIOR AT FULL LOAD AT THE OUTPUT



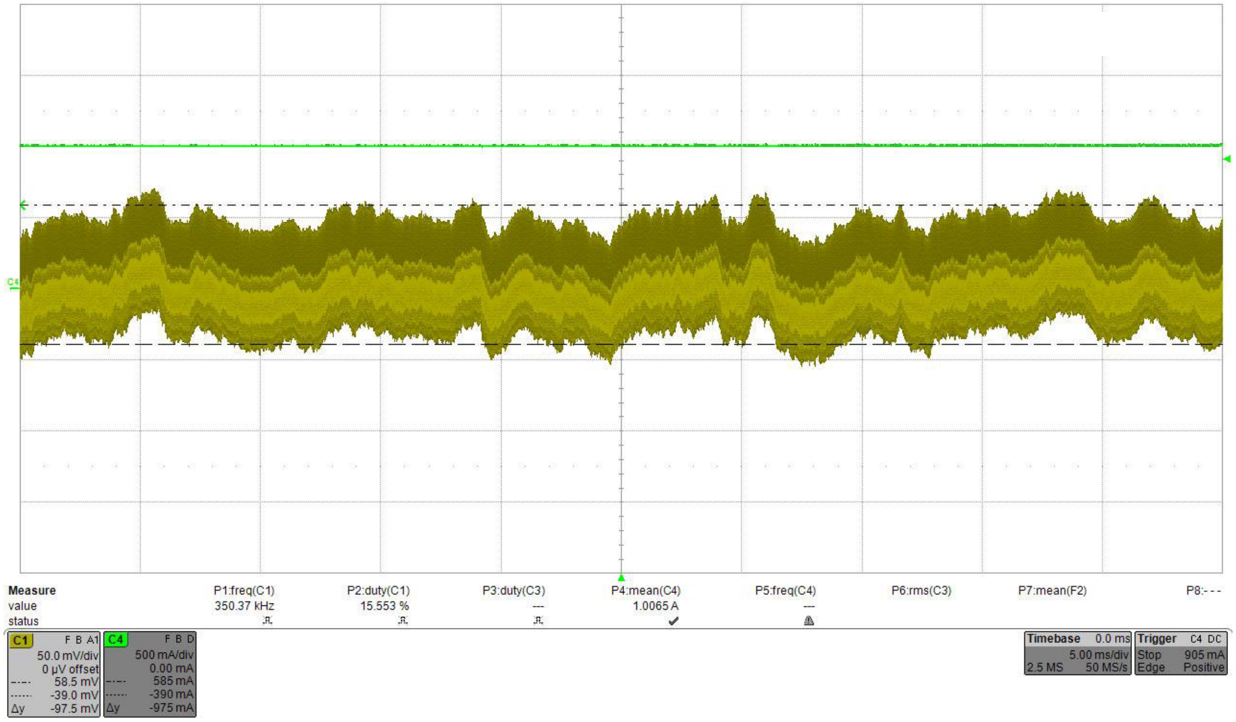
Legend: V_{IN} = 20V, V_{OUT} = 13.8V, I_{OUT} = 1A
Ch1 (yellow) – Output Voltage
Ch4 (green) – Output Current
Time Base: 50 ms/div

FIGURE B-7: SWITCH OFF BEHAVIOR AT FULL LOAD AT THE OUTPUT



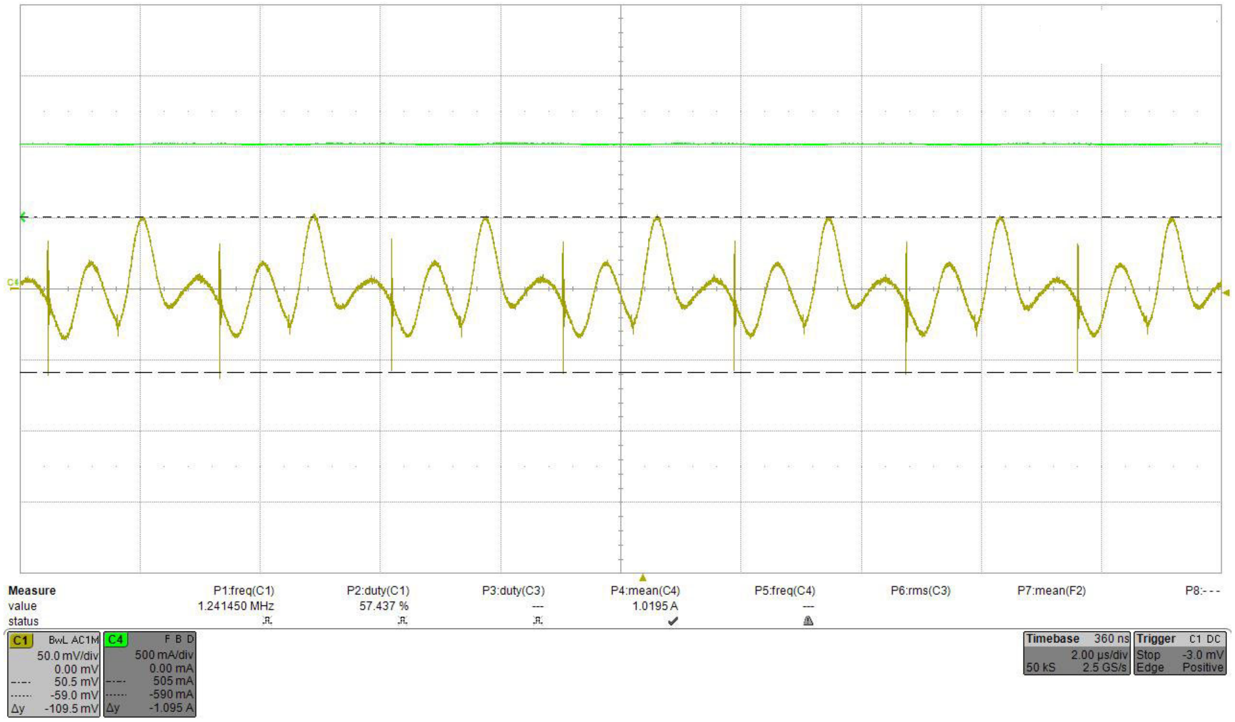
Legend: V_{IN} = 20V, V_{OUT} = 13.8V, I_{OUT} = 1A
Ch1 (yellow) – Output Voltage
Ch4 (green) – Output Current
Time Base: 10 ms/div

FIGURE B-8: RIPPLE AT THE OUTPUT



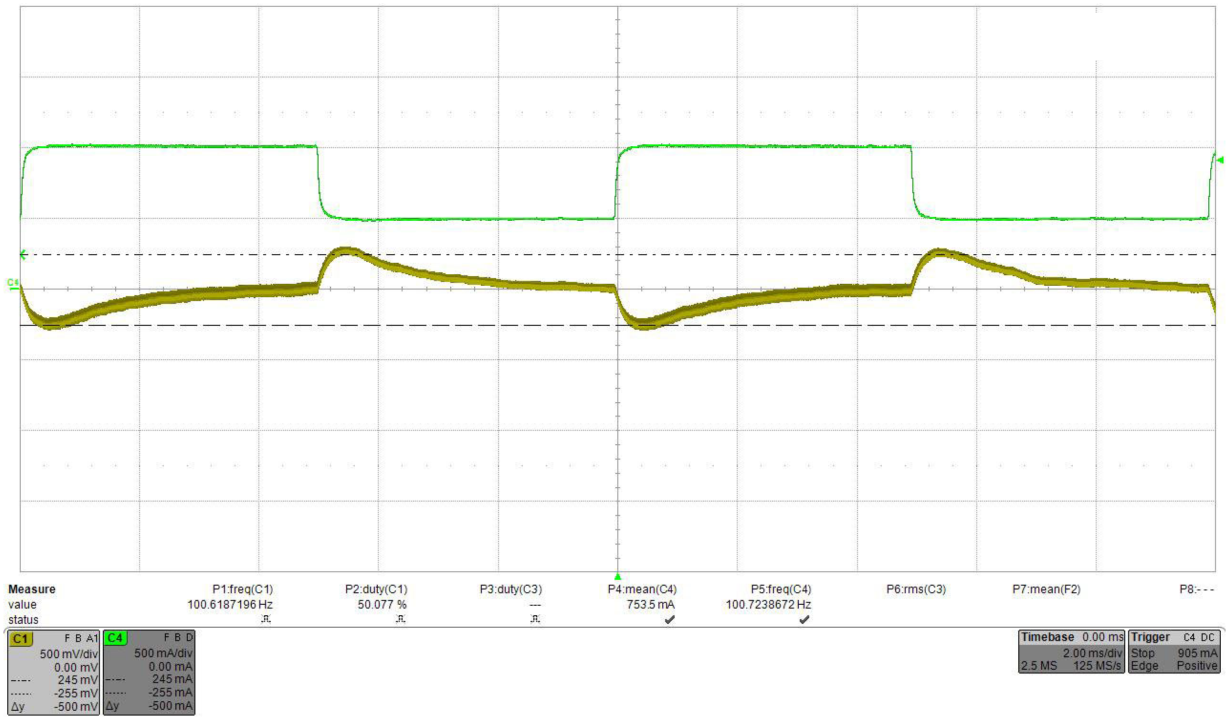
Legend: V_{IN} = 13.8V, V_{OUT} = 20V, I_{OUT} = 1A
Output Ripple Voltage < 100 mVpp
Ch1 (yellow) – Output Voltage (AC Coupled, 20 MHz Bandwidth)
Time Base: 50 ms/div

FIGURE B-9: SPIKES AT THE OUTPUT



Legend: V_{IN} = 13.8V, V_{OUT} = 20V, I_{OUT} = 1A
Output Ripple Voltage < 100 mVpp
Ch1 (yellow) – Output Voltage (AC Coupled, 20 MHz Bandwidth)
Time Base: 50 ms/div

FIGURE B-10: LOAD STEP RESPONSE 50%-100%-50%

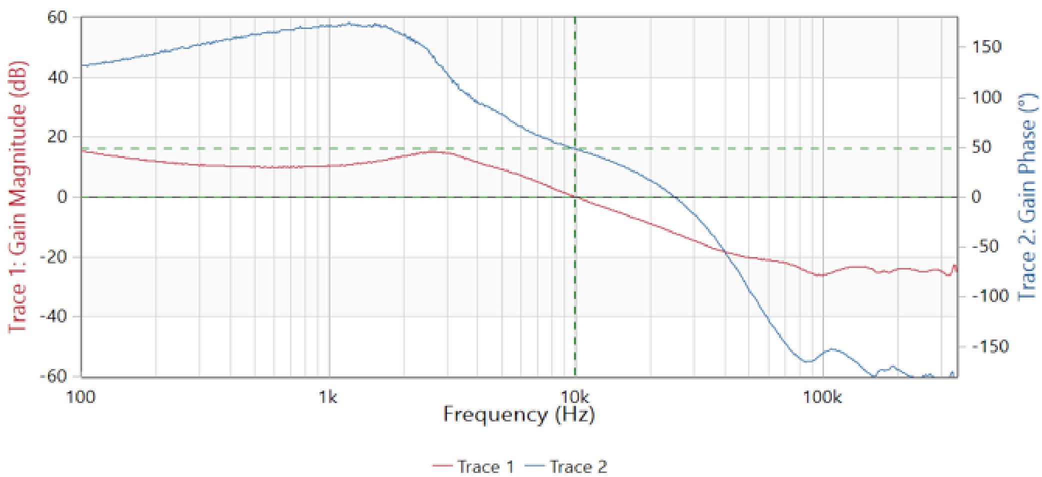


Legend: V_{IN} = 13.8V, V_{OUT} = 20V, I_{OUT} = 1A
Ch1 (yellow) – Output Voltage (AC Coupled, Bandwidth Limit 20 MHz)
Ch4 (green) – Output Current
Time Base: 2 ms/div

 Advance Information

FIGURE B-11: LOOP STABILITY – INNER LOOP

Measurement: Gain / Phase



	Cursor 1		
Frequency	9.938 kHz		
Trace 1	**Magnitude (dB)**		
Measurement	118.595 mdB		
Trace 2	**Phase (°)**		
Measurement	48.584 °		

Sweep	
Start frequency:	100 Hz
Stop frequency:	350 kHz
Center frequency:	175.05 kHz
Span:	349.9 kHz
Sweep mode:	Logarithmic
Numer of points:	801

Hardware setup	
Device type:	No device connected!
Serial number:	No device connected!
Receiver bandwidth:	1 kHz
Output level:	-3 dBm
DUT settling time:	0 ms

Calibration	Full-Range	User-Range
Gain	Active	-

Termination	Channel 1	Channel 2
Gain	1 MΩ	1 MΩ

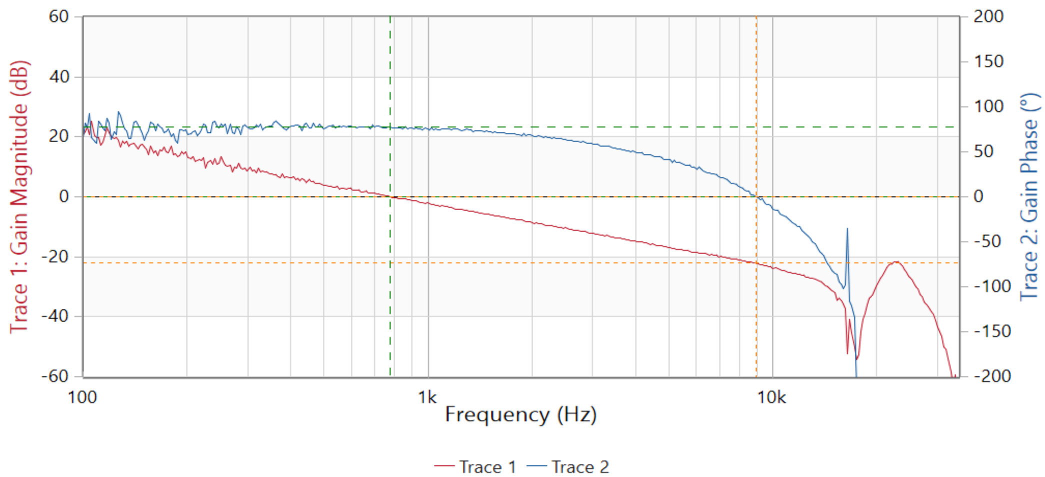
Attenuator setting	Channel 1	Channel 2
Transmission	0 dB	0 dB

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

Legend: V_{IN} = 13.8V, V_{OUT} = 20V, I_{OUT} = 1A

FIGURE B-12: LOOP STABILITY – OUTER LOOP

Measurement: Gain / Phase



	Cursor 1	Cursor 2	Delta C2-C1
Frequency	778.74 Hz	9.002 kHz	8.224 kHz
Trace 1	**Magnitude (dB)**	**Magnitude (dB)**	**Magnitude (dB)**
Measurement	0 dB	-22.152 dB	-22.152 dB
Trace 2	**Phase (°)**	**Phase (°)**	**Phase (°)**
Measurement	77.397 °	0 °	-77.397 °

Sweep	
Start frequency:	100 Hz
Stop frequency:	35 kHz
Center frequency:	17.55 kHz
Span:	34.9 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:	0 dBm
DUT settling time:	0 ms

Calibration	Full-Range	User-Range
Gain	Active	-

Termination	Channel 1	Channel 2
Gain	1 MΩ	1 MΩ

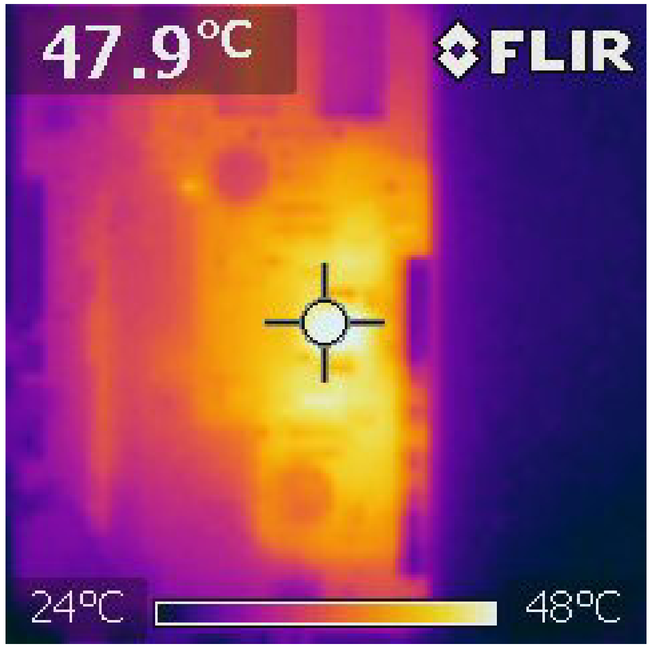
Attenuator setting	Channel 1	Channel 2
Transmission	0 dB	0 dB

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

Legend: V_{IN} = 13.8V, V_{OUT} = 20V, I_{OUT} = 1A

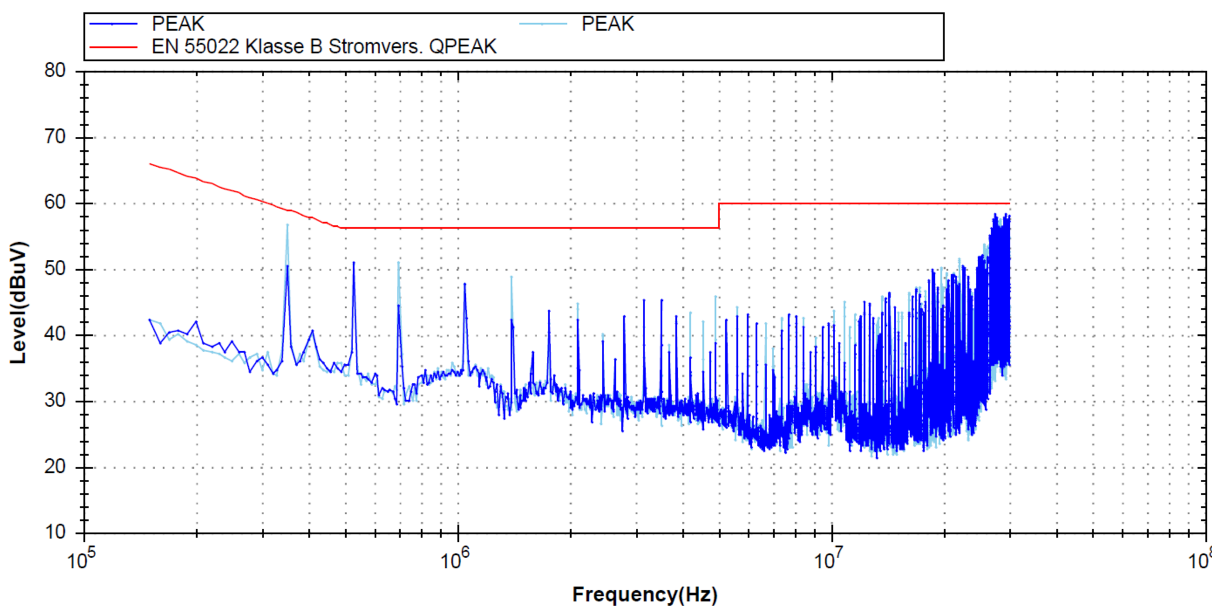
 Advance Information

FIGURE B-13: THERMAL MEASUREMENTS



Legend: V_{IN} = 8V, V_{OUT} = 20V, I_{OUT} = 1A, Cursor pointing on Storage Choke

FIGURE B-14: CONDUCTED EMISSIONS



Legend: V_{IN} = 13.8V, V_{OUT} = 11V @ 2A
These measurements are done in non-certified laboratory as precompliance measurements.

NOTES:

Appendix C. MPLAB® X Project Options

This demo project has two compile options for different control modes:

- AVGCURRENTMODE runs the power stage with two control loops. An inner loop average current controller (2p2z) and an outer loop voltage controller (2p2z).
- VOLTAGEMODE runs a voltage controller only (3p3z).

The control loops are designed with the Digital Compensator Design Tool. The settings can be found in the project under **Tools**, **Embedded**, **Digital Compensator Design Tool**. This tool is available as an MPLAB X plug-in (Figure C-1).

FIGURE C-1: MPLAB® X PROJECT OPTIONS

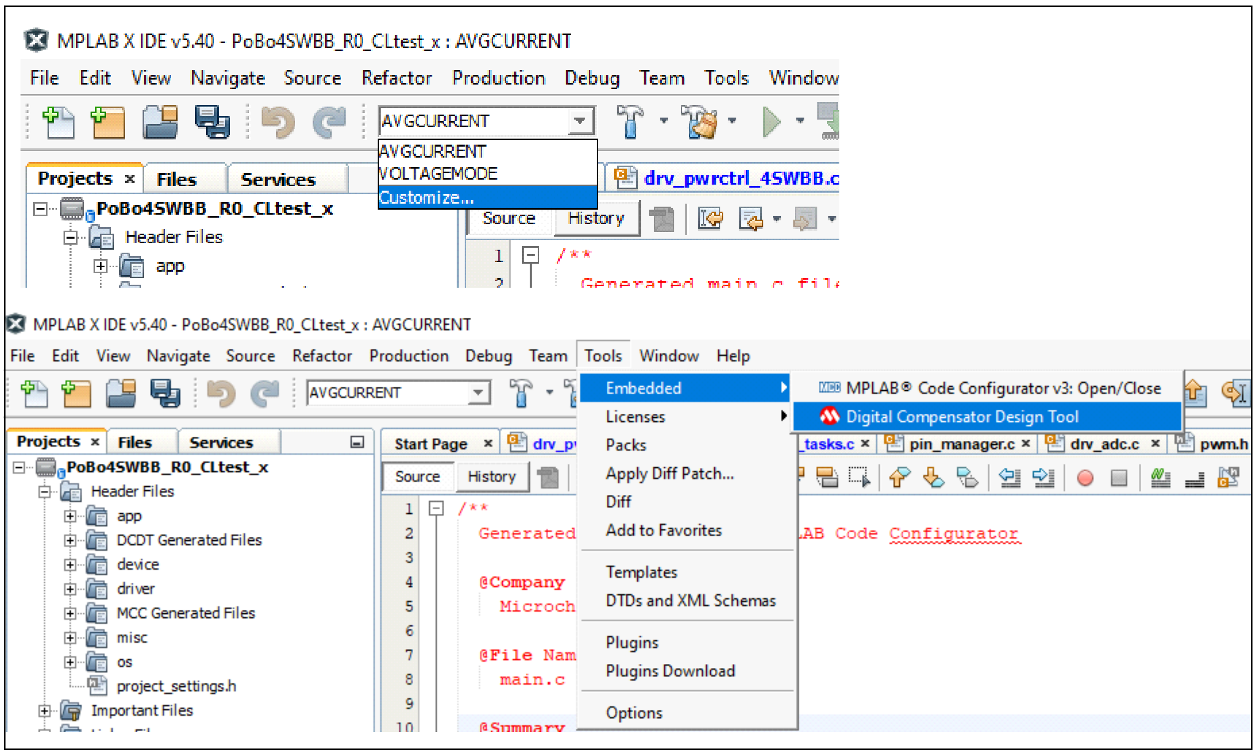


Figure C-2 shows the project directory tree that contains all the source and header files.

FIGURE C-2: PROJECT DIRECTORY TREE

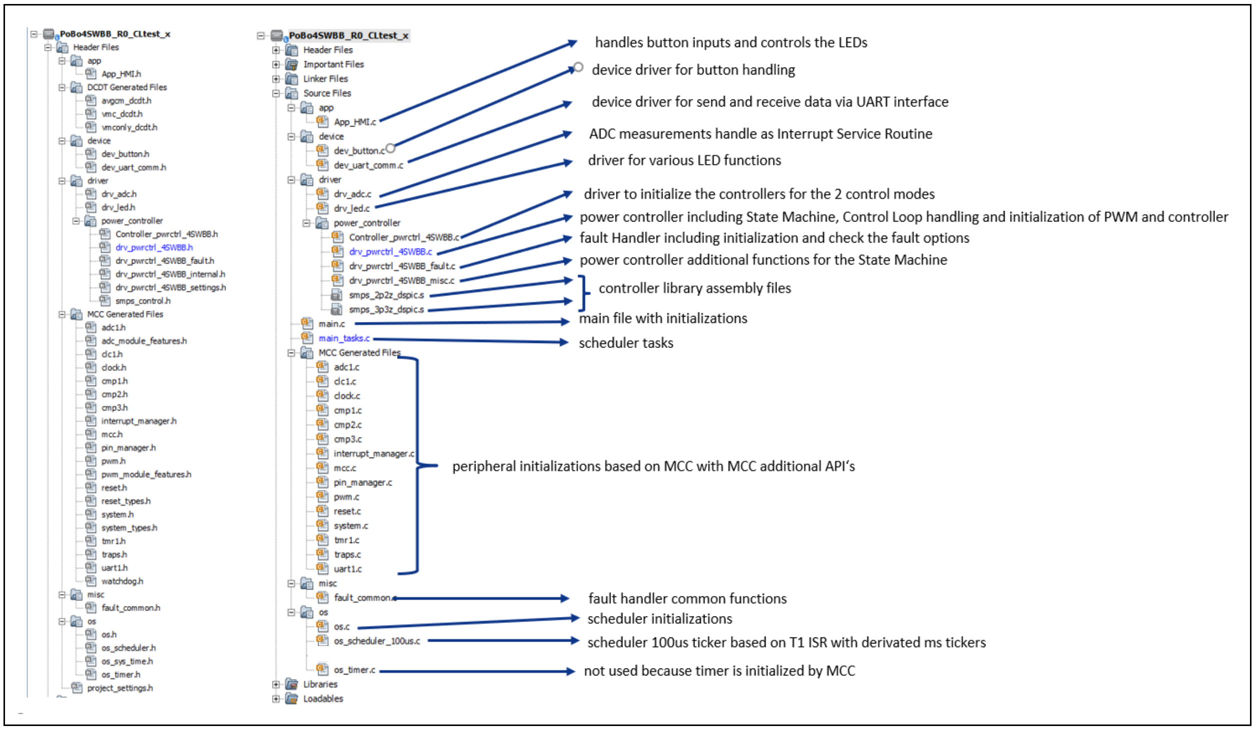
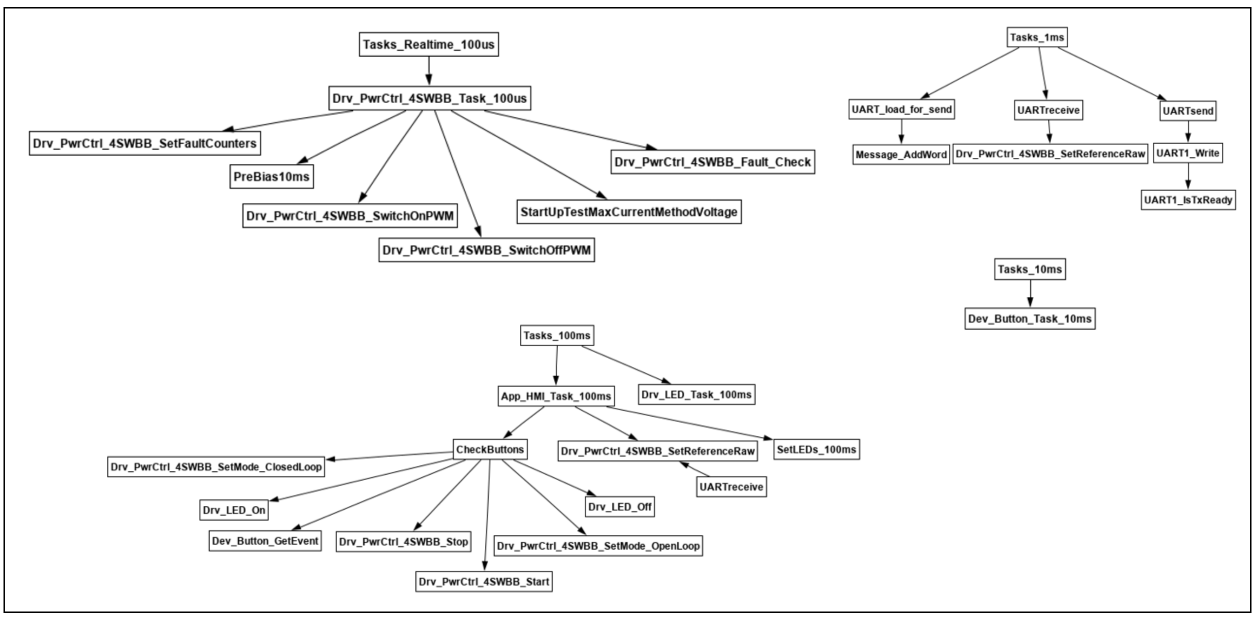


FIGURE C-3: FUNCTION CALL GRAPH



 Advance Information

Appendix D. Bill of Materials (BOM)

This appendix contains the Bill of Materials (BOMs) for the Four-Switch Buck-Boost Development Board.

D.1 BILL OF MATERIALS

Table D-1 shows the Bill of Materials for the Four-Switch Buck-Boost Development Board.

TABLE D-1: BILL OF MATERIALS (BOM) — FOUR-SWITCH BUCK-BOOST DEVELOPMENT BOARD

Qty	Designator	Description	Manufacturer 1	Manufacturer Part Number
5	C123, C222, C223, C310, C320	Capacitor Ceramic, 10 µF, 10V, 10%, X7R, SMD, 0805	Samsung Group	CL21B106KPQNFNE
2	C201, C202	Capacitor Ceramic, 0.22 µF, 50V, 10%, X7R, SMD, 1206	Kyocera AVX	12065C224K4T2A\4K
8	C203, C220, C300, C301, C302, C331, C332, C334	Capacitor Ceramic, 10 µF, 50V, 20%, X7R, SMD, 1210	TDK Corporation	C3225X7R1H106M250AC
2	C206, C333	Capacitor Aluminum Poly, 270 µF, 35V, 20%, SMD, 10.3x10.3	Wurth Elektronik	875075661009
9	C221, C224, C311, C312, C321, C322, C341, C363, C364	Capacitor Ceramic, 0.1 µF, 50V, 20%, X7R, SMD, 0603	TDK Corporation	C1608X7R1H104M080AA
3	C225, C361, C362	Capacitor Ceramic, 1 µF, 16V, 10%, X5R, SMD, 0603	Kyocera AVX	0603YD105KAT2A/4K
2	C303, C330	Capacitor Ceramic, 1500 pF, 50V, 10%, X7R, SMD, 0603	Murata Electronics®	GRM188R71H152KA01D
2	C313, C339	Capacitor Ceramic, 1000 pF, 10%, 50V, X7R, SMD, 0603, AEC-Q200	TDK Corporation	CGA3E2X7R1H102K080AA
3	D110, D111, D120	Diode Rect, NSV1SS400T1G, 1.2V, 200 mA, 100V, SMD, SOD-523, AEC-Q101	ON Semiconductor®	NSV1SS400T1G
1	D201	Diode TVS, SMAJ30CA-E3/5A, 30V, 400W, SMD, DO-214AC_SMA	Vishay Semiconductors	SMAJ30CA-E3/5A
3	D202, D221, D350	Diode Rect, 1N4148WS, 1.25V, 150 mA, 75V, SOD-323	Diodes	1N4148WS-7-F
1	D220	Diode Schottky, SS1FH10HM3/H, 800 mV, 1A, 100A, SMD, DO-219AB, AEC-Q101	Vishay Semiconductors	SS1FH10HM3/H
1	FB330	Ferrite, 500R@100 MHz, 2.5A, SMD, 1206	Wurth Electronics	742792116
1	J100	Connector Edge MECF, 1.27 mm, 60P, Female, SMD, Vertical	Samtec	MECF-30-01-L-DV-WT
1	J201	Connector Jack Banana, Red, 4.0 mm, Female, Through-Hole, R/A	Multicomp	24.243.1
1	J202	Connector Jack Banana, Black, Female, 4.0 mm, Through-Hole, R/A	Multicomp	24.243.2
1	J203	Connector Power, 2.1 mm, 5.5 mm, Switch, Through-Hole, R/A	Wurth Elektronik	694106301002
1	J300	Connector Terminal, 3.81 mm, 1x2, Female, 16-24AWG, 10A, Through-Hole, R/A	Amphenol Commercial	YO0221500000G
1	L201	Inductor, 1.8 µH, 3.7A, 30%, SMD, L6W6H4.5	Bourns®, Inc.	SRN6045-1R8Y

TABLE D-1: BILL OF MATERIALS (BOM) — FOUR-SWITCH BUCK-BOOST DEVELOPMENT BOARD (CONTINUED)

Qty	Designator	Description	Manufacturer 1	Manufacturer Part Number
1	L220	Inductor, 22 µH, 2A, 25%, AEC-Q200, SMD, 6.2x6.2x5.1	Wurth Elektronik	7447786122
1	L310	Inductor, 10 µH, 5.8A, 20%, AEC-Q200, SMD, 12x12x6	Wurth Elektronik	7447706100
1	LABEL3	Label PCBA, 18x6 mm, BarCode-AssyID-Rev-Serno		
1	LD100	Diode LED, Green, 2V, 30 mA, 35 mcd, Clear, SMD, 0603	Vishay Lite-On	LTST-C190KGKT
1	LD101	Diode LED, Red, 1.8V, 40 mA, 10 mcd, Clear, SMD, 0603	Vishay Lite-On	LTST-C190KRKT
5	PAD1, PAD2, PAD3, PAD4, PAD5	Mechanical Hardware Rubber Pad, Cylindrical, D9.4, H4.8, Clear	Multicomp VOLTREX	2565
4	Q310, Q311, Q320, Q321	Transistor FET, N-CH, SQJA60EP-T1_GE3, 60V, 30A, 0.016R, PowerPAK, SO-8L	Vishay Semiconductors	SQJA60EP-T1-GE3
3	R100, R137, R147	Resistor, Thick Film, 470R, 1%, 1/10W, SMD, 0603	Panasonic®	ERJ3EKF4700V
15	R101, R102, R103, R109, R110, R113, R123, R124, R311, R312, R321, R322, R364, R365, R366	Resistor, Thick Film, 3.3k, 1%, 1/10W, SMD, 0603	Panasonic	ERJ-3EKF3301V
6	R105, R106, R122, R134, R203, R224	Resistor, Thick Film, 0R, 1/10W, SMD, 0603	Panasonic	ERJ-3GEY0R00V
2	R111, R121	Resistor, Thick Film, 23.2k, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT23K2
5	R120, R146, R361, R362, R363	Resistor, Thick Film, 10R, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT10R0
1	R220	Resistor, Thick Film, 59k, 1%, 1/10W, SMD, 0603	Panasonic	ERJ-3EKF5902V
5	R221, R314, R316, R324, R326	Resistor, Thick Film, 10k, 1%, 1/8W, SMD, 0603	Vishay Semiconductors	MCT06030C1002FP500
6	R310, R313, R315, R320, R323, R325	Resistor, Thick Film, 1R, 1%, 1/10W, SMD, 0603	ROHM Semiconductor	KTR03EZPF1R00
2	R317, R333	Resistor, Thick Film, 3.6R, 1%, 1/4W, SMD, 1206	Yageo Corporation	RC1206FR-073R6L
1	R351	Resistor, Thick Film, 47R, 1%, 1/4W, SMD, 1206	Panasonic	ERJ-8ENF47R0V
1	R360	Resistor, Thick Film, 0.02R, 1%, 1W, SMD, 0612, AEC-Q200	Panasonic	ERJ-B2CFR02V
2	SW1, SW2	Switch Tactical, SPST-NO, 16 VDC, 50 mA, 434123025826, SMD	Wurth Elektronik	434123025826
1	TP110	Connector, Test Point, Loop, Black, Through-Hole	Keystone Electronics Corp.	5011
1	TP120	Connector, Test Point, Loop, Red, Through-Hole	Ohmite	5010
1	TP121	Connector, Test Point, Loop, Orange, Through-Hole	Keystone Electronics Corp.	5013
1	TR350	Transistor Current, 1:100, 1 MHz, 20A, SMD	Coilcraft	CST7030-100LB
		Microchip Parts Listed Below		
1	U220	Microchip Analog Switcher, Buck, 2 to 24V, MCP16331T-E/CH, SOT-23-6	Microchip Technology Inc.	MCP16331T-E/CH
1	U221	Microchip Analog LDO, 3.3V, MCP1755T-3302E/OT, SOT-23-5	Microchip Technology Inc.	MCP1755T-3302E/OT
2	U310, U320	Microchip Analog FET Driver, Half-Bridge, Noninverting, MIC4604YMT-TR, TDFN-10	Microchip Technology Inc.	MIC4604YMT-TR
1	U360	Microchip Analog Current Sense Amplifier, MCP6C02T-020E/CHY, SOT-23-6	Microchip Technology Inc.	MCP6C02T-020E/CHY

NOTES:

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02/28/20