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

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

	Represents code supplied by user	`void main (void)`
		`{ ...`
		`}`

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).

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- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip consultant program member listing
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- Technical Support

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

DOCUMENT REVISION HISTORY

Revision A (November 2020)

This is the initial released version of this document.

Revision B (September 2021)

Figure A-1, Figure A-2, Figure A-3 and Figure A-4 have been updated.

Table D-1 has been updated.

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.

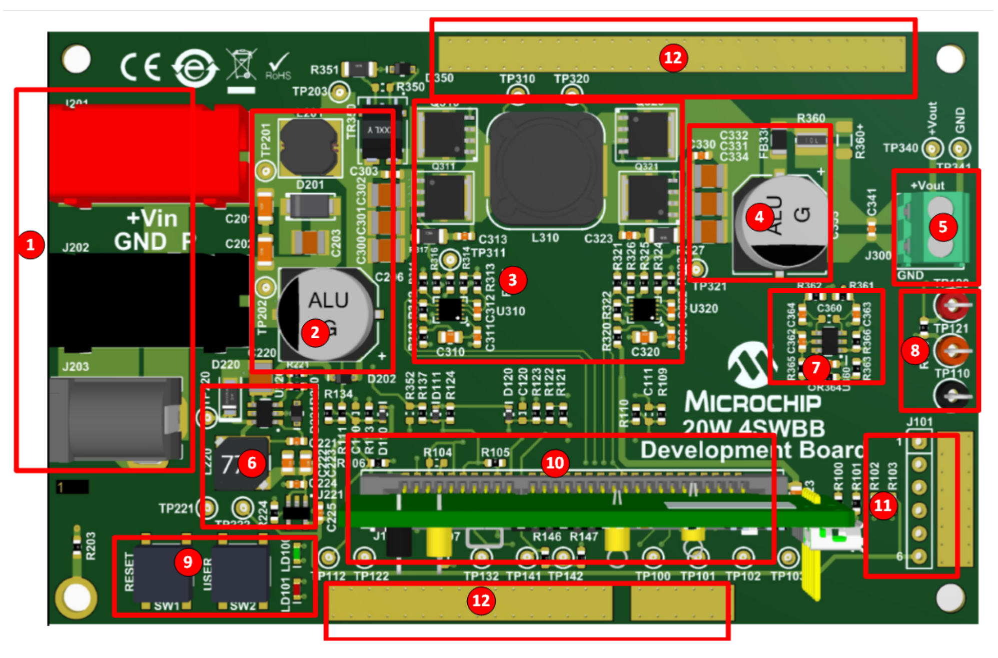
The topics covered in this chapter include:

- 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


12
1
+Vin
GND
2
3
4
+Vout
5
GND
6
7
8
MICROCHIP
20W 4SWBB
Development Board
9
RESET
USER
SW1
SW2
10
11
12

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.

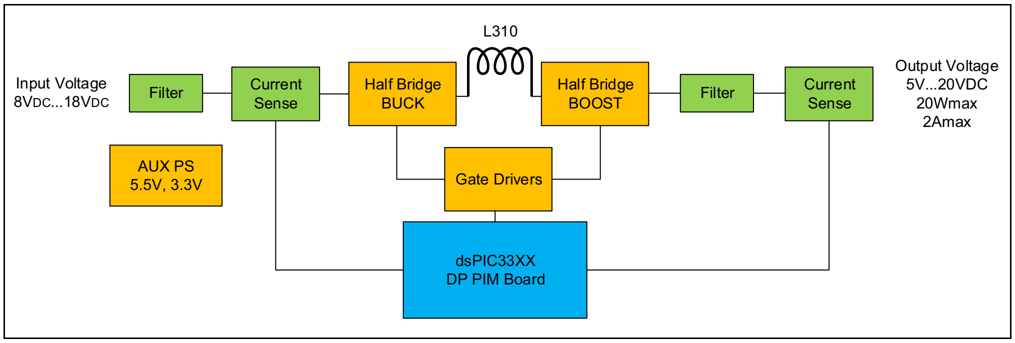
TABLE 1-1: 4SW-BB ELECTRICAL CHARACTERISTICS

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 VOUT 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

IOUT/DC [A]	IOUT_Sense [V]	IOUT_Sensor Delta [A]	IOUT_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

TABLE 1-6: TEST POINTS (CONTINUED)

Signal Group	Designator	Signal Description
Efficiency Measurement Lines	TP201	+VIN (Sense Line for efficiency measurements)
	TP202	GND_P (Sense Line for efficiency measurements)
	TP340	+VOUT (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_VIN)
	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	VAUX 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.

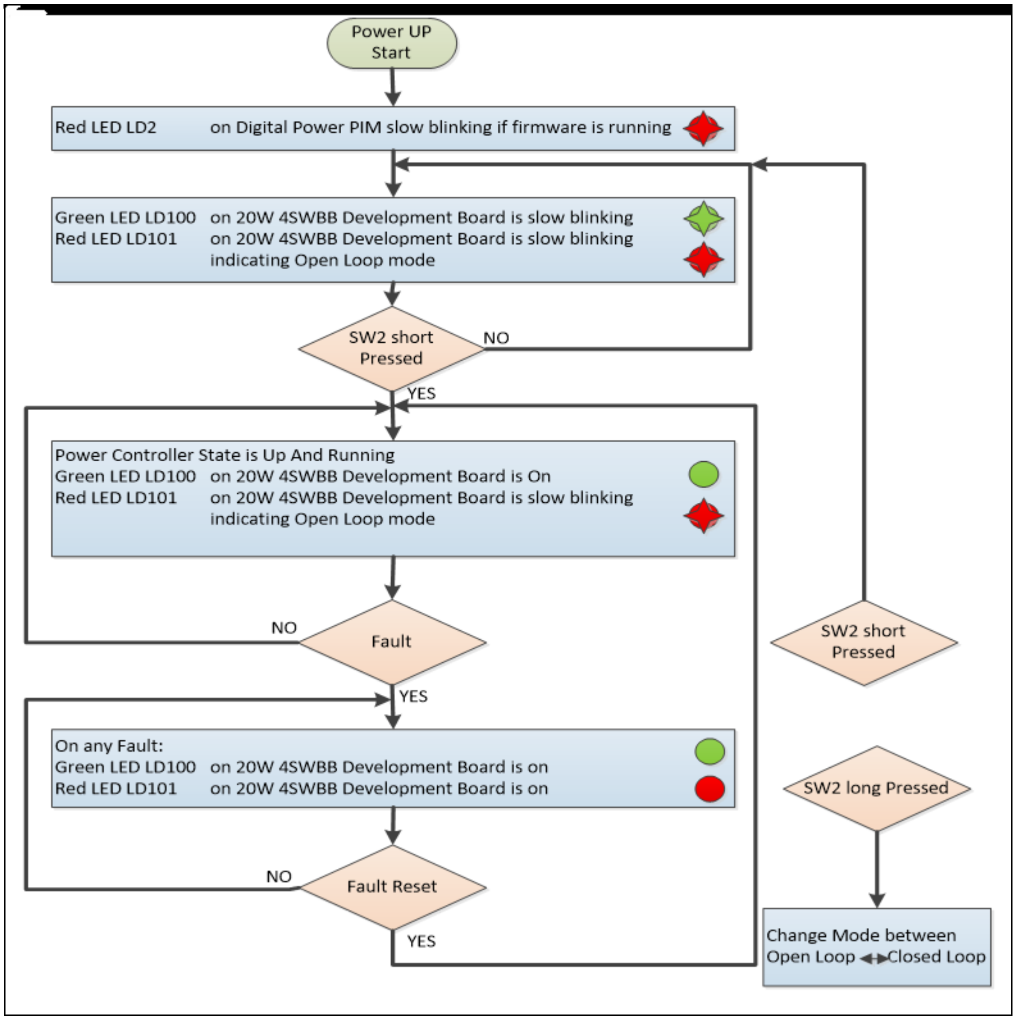
Using the provided demo code, after power-up and if software is running, the red LED on DP PIM will slowly blink. On the power board, the green LED (LD100) and the red LED (LD101) are blinking. PWM signals are disabled.

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.

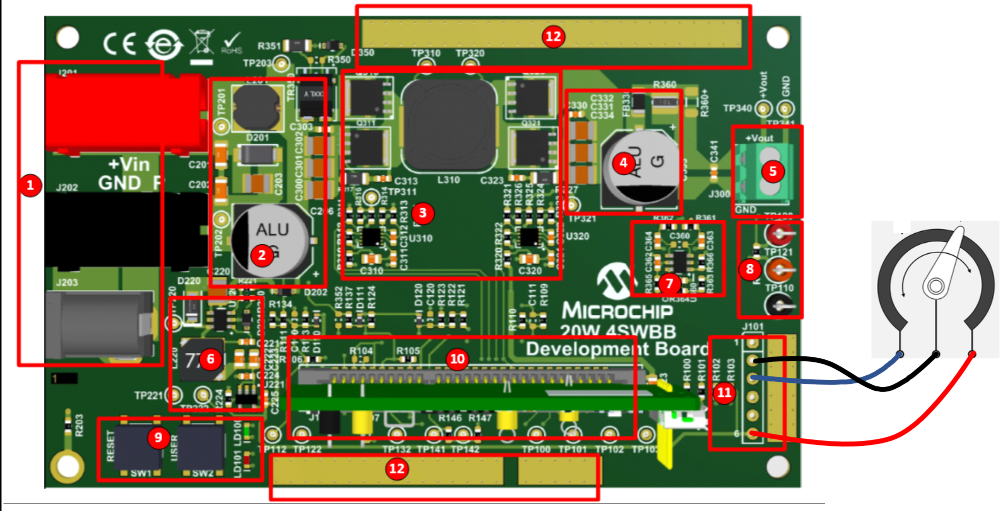
FIGURE 1-3: STATE MACHINE FLOW CHART


Power UP Start
Red LED LD2 on Digital Power PIM slow blinking if firmware is running
Green LED LD100 on 20W 4SWBB Development Board is slow blinking
Red LED LD101 on 20W 4SWBB Development Board is slow blinking indicating Open Loop mode
SW2 short Pressed
NO
YES
Power Controller State is Up And Running
Green LED LD100 on 20W 4SWBB Development Board is On
Red LED LD101 on 20W 4SWBB Development Board is slow blinking indicating Open Loop mode
NO
Fault
YES
SW2 short Pressed
On any Fault:
Green LED LD100 on 20W 4SWBB Development Board is on
Red LED LD101 on 20W 4SWBB Development Board is on
SW2 long Pressed
NO
Fault Reset
YES
Change Mode between Open Loop ↔ Closed Loop

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

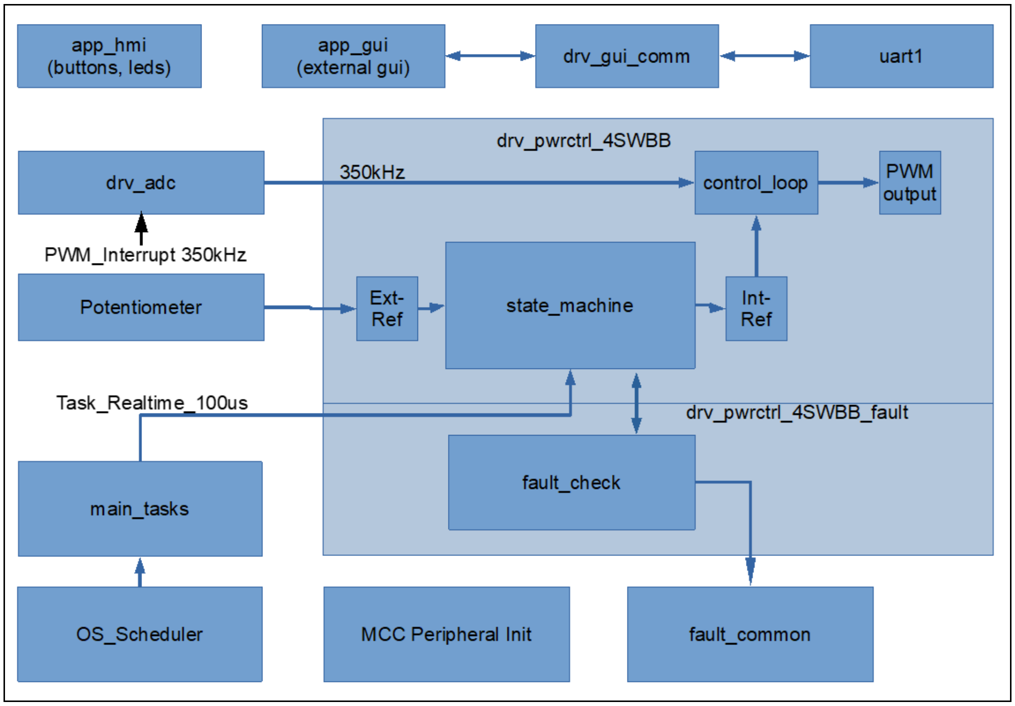

app_hmi
(buttons, leds)
app_gui
(external gui)
drv_gui_comm
uart1
drv_pwrctrl_4SWBB
drv_adc
350kHz
control_loop
PWM
output
PWM_Interrupt 350kHz
Potentiometer
Ext-
Ref
state_machine
Int-
Ref
Task_Realtime_100us
drv_pwrctrl_4SWBB_fault
fault_check
main_tasks
OS_Scheduler
MCC Peripheral Init
fault_common

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.

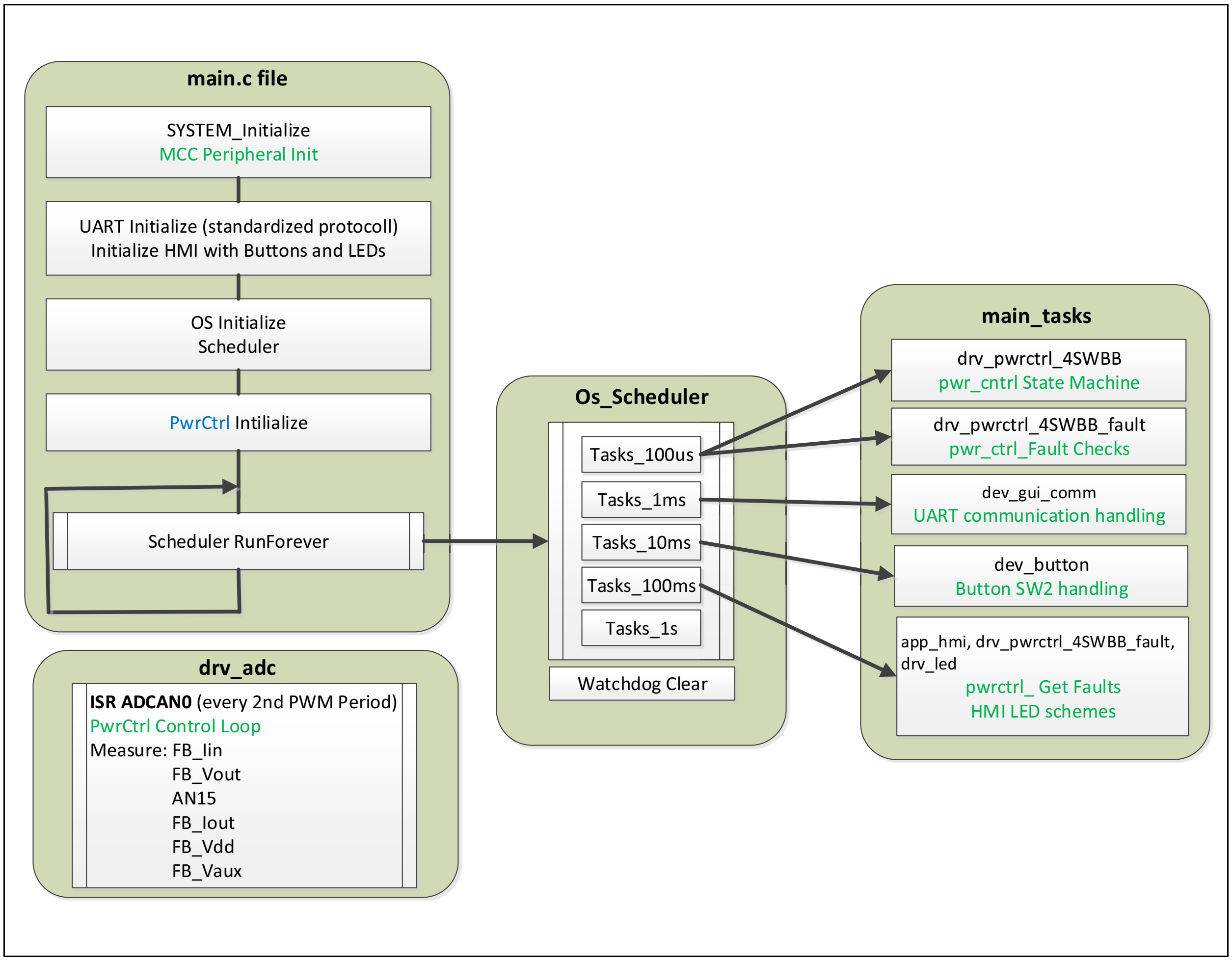
TABLE 1-8: FIRMWARE BLOCKS

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


main.c file
SYSTEM_Initialize
MCC Peripheral Init
UART Initialize (standardized protocoll)
Initialize HMI with Buttons and LEDs
OS Initialize
Scheduler
PwrCtrl Initilialize
Scheduler RunForever
drv_adc
ISR ADCAN0 (every 2nd PWM Period)
PwrCtrl Control Loop
Measure: FB_Iin
FB_Vout
AN15
FB_Iout
FB_Vdd
FB_Vaux
Os_Scheduler
Tasks_100us
Tasks_1ms
Tasks_10ms
Tasks_100ms
Tasks_1s
Watchdog Clear
main_tasks
drv_pwrctrl_4SWBB
pwr_cntrl State Machine
drv_pwrctrl_4SWBB_fault
pwr_ctrl_Fault Checks
dev_gui_comm
UART communication handling
dev_button
Button SW2 handling
app_hmi, drv_pwrctrl_4SWBB_fault, drv_led
pwrctrl_ Get Faults
HMI LED schemes

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.

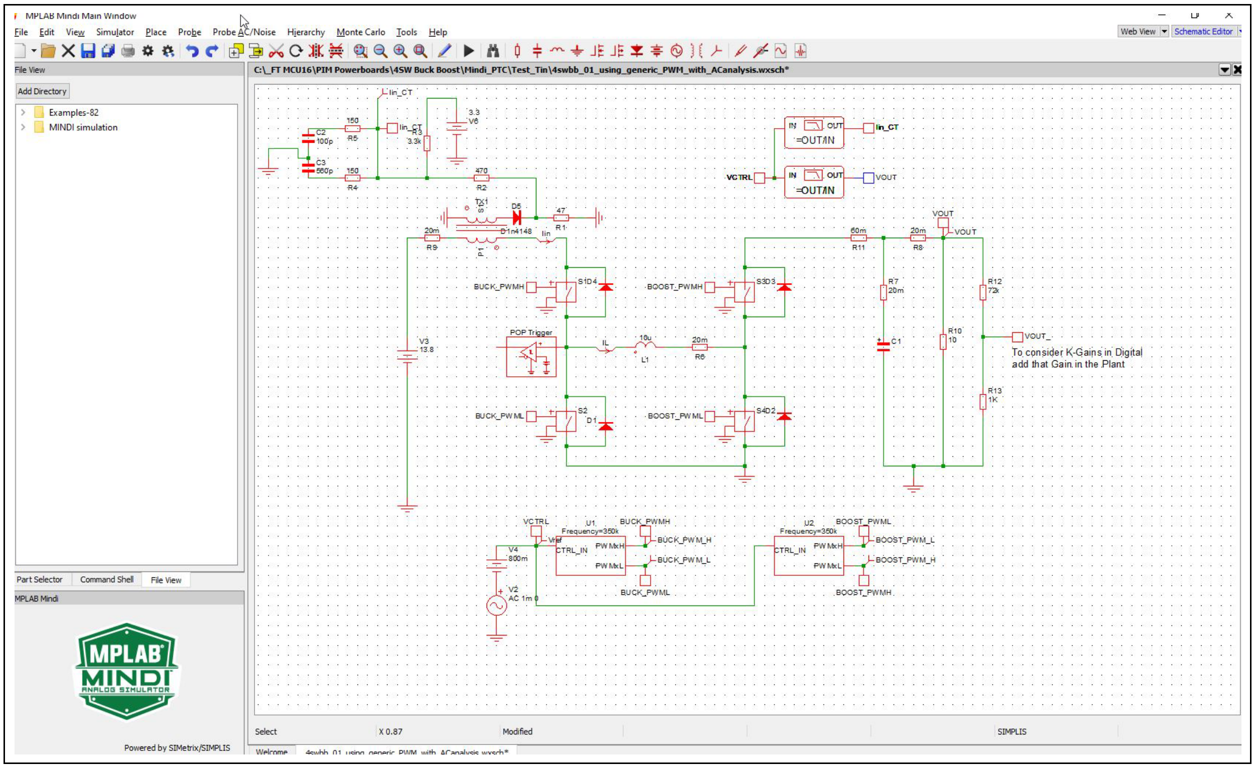
The UART protocol used for communication with a Graphical User Interface is described within the PC GUI software.

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


MPLAB Mindi Main Window
File Edit View Simulator Place Probe Probe AC/Noise Hierarchy Monte Carlo Tools Help
Web View
Schematic Editor
File View
Add Directory
Examples-82
MINDI simulation
C:_FT MCU16\PIM Powerboards\4SW Buck Boost\Mindi_PTC\Test_Tin\4swbb_01_using_generic_PWM_with_ACanalysis.wxsch*
Iin_CT
VCTRL
VOUT
BUCK_PWMH
BOOST_PWMH
BUCK_PWML
BOOST_PWML
POP Trigger
V3 13.8
L1 10u
To consider K-Gains in Digital add that Gain in the Plant
U1 Frequency=350k
U2 Frequency=350k
V4 800m
V2 AC 1m 0
Part Selector
Command Shell
File View
MPLAB Mindi
MPLAB MINDI ANALOG SIMULATOR
Powered by SIMetrix/SIMPLIS
Select
X 0.87
Modified
SIMPLIS
Welcome
4swbb_01_using_generic_PWM_with_ACanalysis.wxsch*

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:

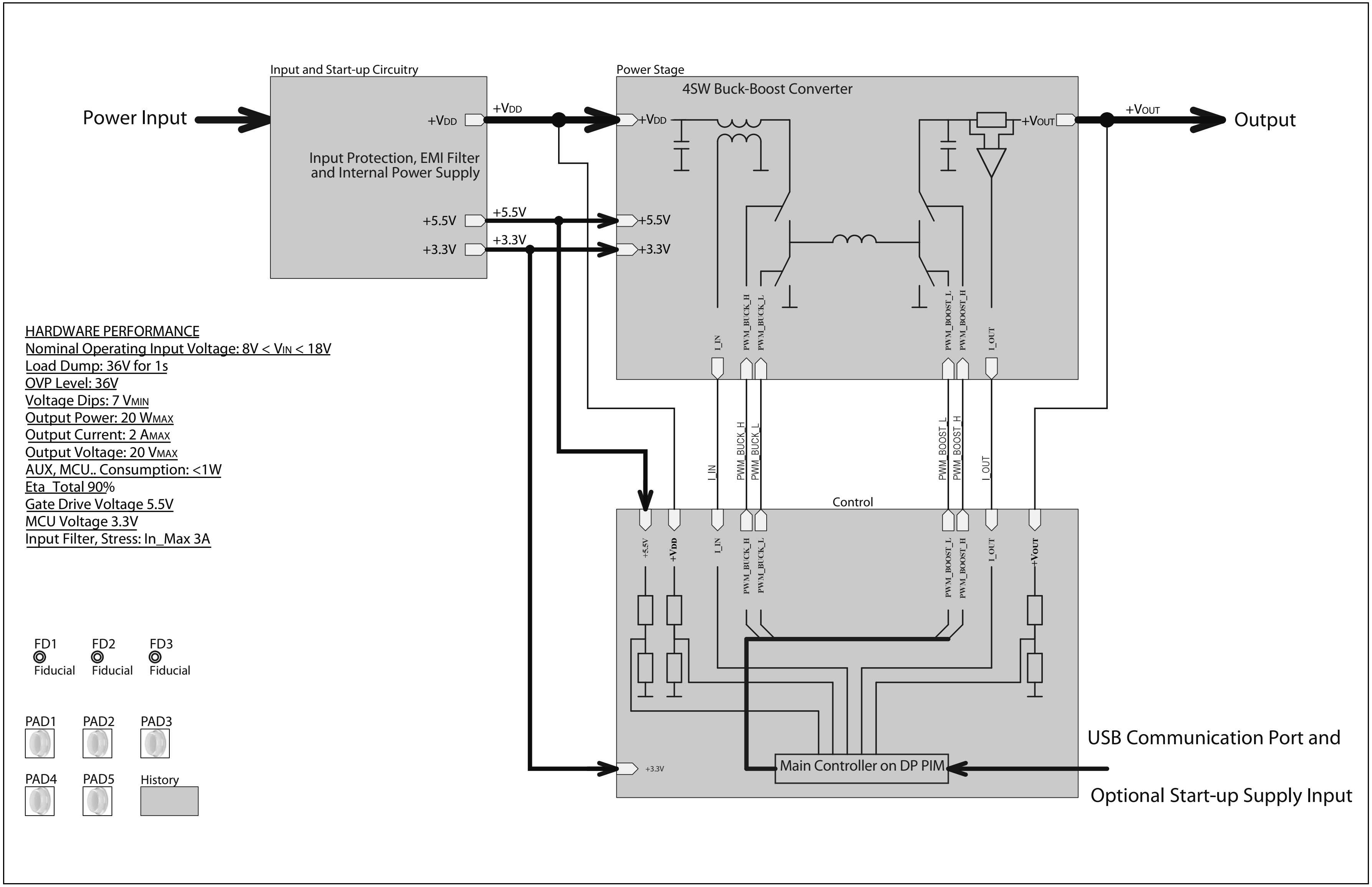
Appendix A. Schematics

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)


Input and Start-up Circuitry
Power Input
+VDD
+VDD
Input Protection, EMI Filter and Internal Power Supply
+5.5V
+5.5V
+3.3V
+3.3V
Power Stage
4SW Buck-Boost Converter
+VDD
+VOUT
+VOUT
Output
+5.5V
+3.3V
I_IN
PWM_BUCK_H
PWM_BUCK_L
PWM_BOOST_L
PWM_BOOST_H
I_OUT
Control
+5.5V
+VDD
I_IN
PWM_BUCK_H
PWM_BUCK_L
PWM_BOOST_L
PWM_BOOST_H
I_OUT
+VOUT
+3.3V
Main Controller on DP PIM
USB Communication Port and
Optional Start-up Supply Input
FD1
Fiducial
FD2
Fiducial
FD3
Fiducial
PAD1
PAD2
PAD3
PAD4
PAD5
History

HARDWARE PERFORMANCE
Nominal Operating Input Voltage: 8V < V_{IN} < 18V
Load Dump: 36V for 1s
OVP Level: 36V
Voltage Dips: 7 V_{MIN}
Output Power: 20 W_{MAX}
Output Current: 2 A_{MAX}
Output Voltage: 20 V_{MAX}
AUX, MCU.. Consumption: <1W
Eta_Total 90%
Gate Drive Voltage 5.5V
MCU Voltage 3.3V
Input Filter, Stress: In_Max 3A

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

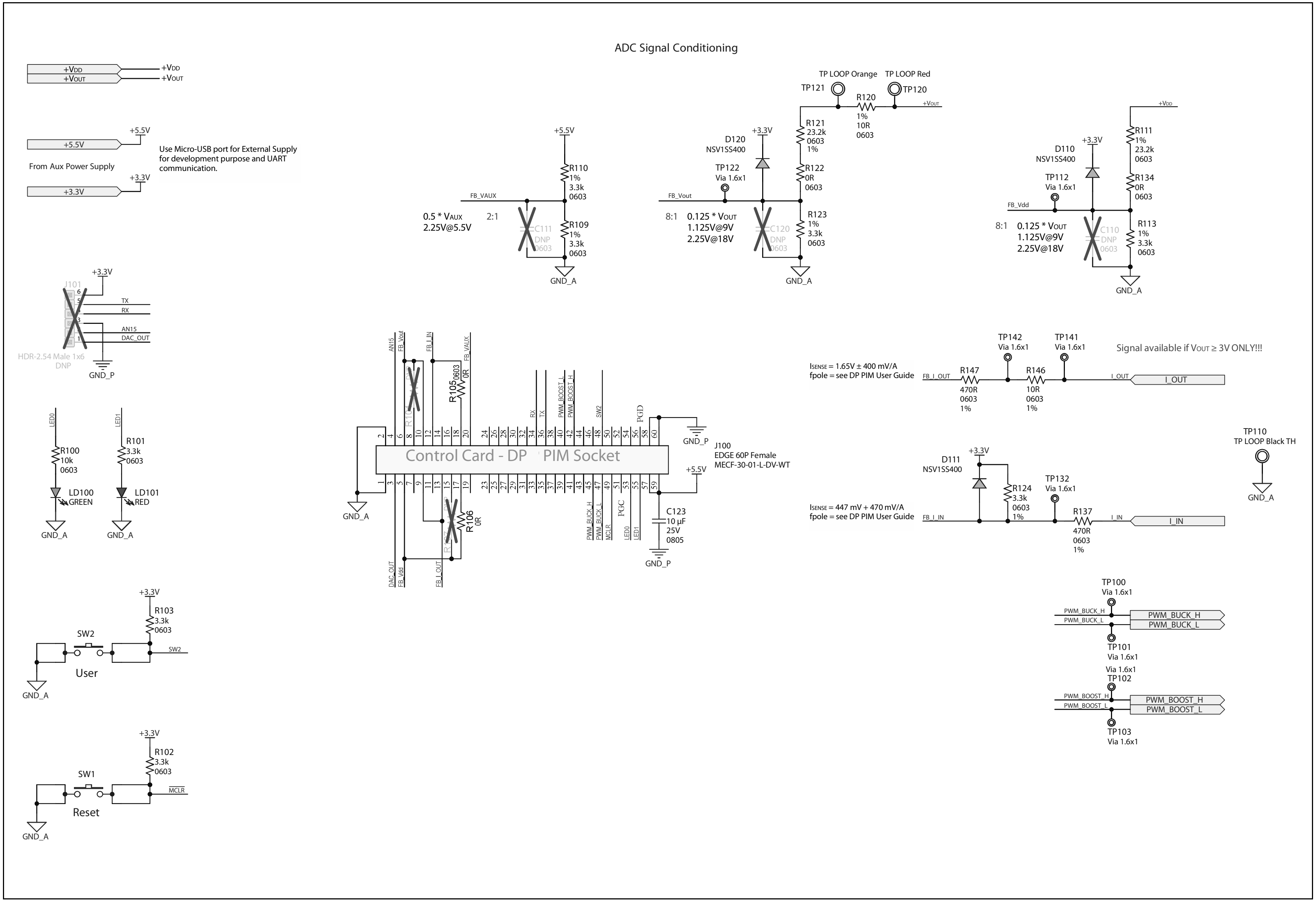

ADC Signal Conditioning
+VDD
+VOUT
+5.5V
From Aux Power Supply
+3.3V
Use Micro-USB port for External Supply for development purpose and UART communication.
J101
HDR-2.54 Male 1x6
DNP
TX
RX
AN15
DAC_OUT
GND_P
LED0
LED1
R100
10k
0603
LD100
GREEN
R101
3.3k
0603
LD101
RED
GND_A
SW2
User
R103
3.3k
0603
SW1
Reset
R102
MCLR
R110
1%
3.3k
0603
FB_VAUX
0.5 * VAUX
2.25V@5.5V
2:1
C111
DNP
R109
TP LOOP Orange
TP LOOP Red
TP121
TP120
R120
1%
10R
R121
23.2k
D120
NSV1SS400
TP122
Via 1.6x1
R122
0R
FB_Vout
8:1
0.125 * VOUT
1.125V@9V
2.25V@18V
C120
R123
R111
D110
TP112
R134
FB_Vdd
C110
R113
Control Card - DP PIM Socket
J100
EDGE 60P Female
MECF-30-01-L-DV-WT
FB_Vout
FB_I_IN
FB_VAUX
R105
0R
R106
PWM_BOOST_L
PWM_BOOST_H
PGD
PGC
PWM_BUCK_H
PWM_BUCK_L
DAC_OUT
FB_Vdd
FB_I_OUT
C123
10 µF
25V
0805
TP142
TP141
Signal available if VOUT ≥ 3V ONLY!!!
ISENSE = 1.65V ± 400 mV/A
fpole = see DP PIM User Guide
FB_I_OUT
R147
470R
R146
10R
I_OUT
TP110
TP LOOP Black TH
D111
NSV1SS400
R124
TP132
ISENSE = 447 mV + 470 mV/A
FB_I_IN
R137
I_IN
TP100
PWM_BUCK_H
PWM_BUCK_L
TP101
TP102
PWM_BOOST_H
PWM_BOOST_L
TP103

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

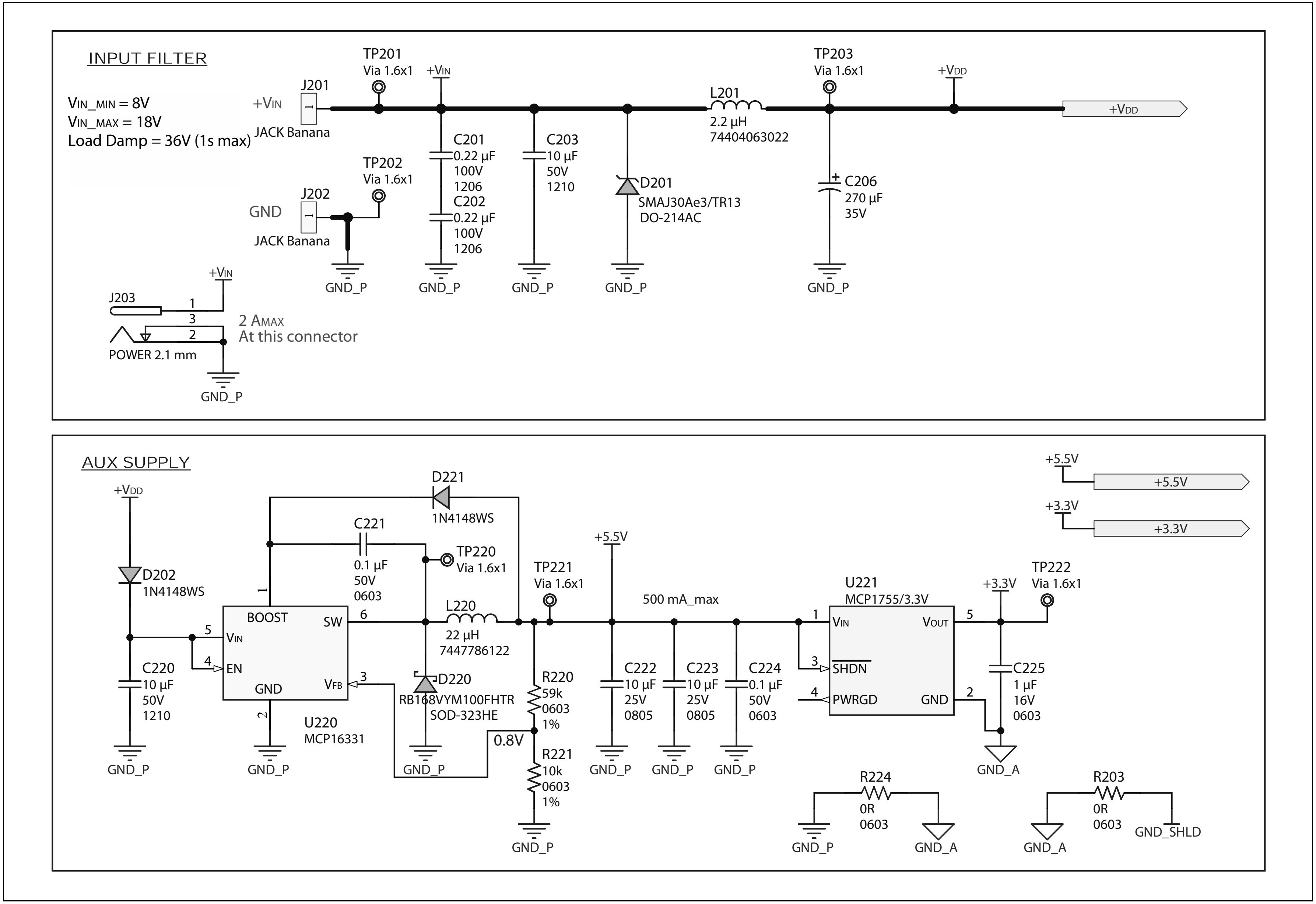
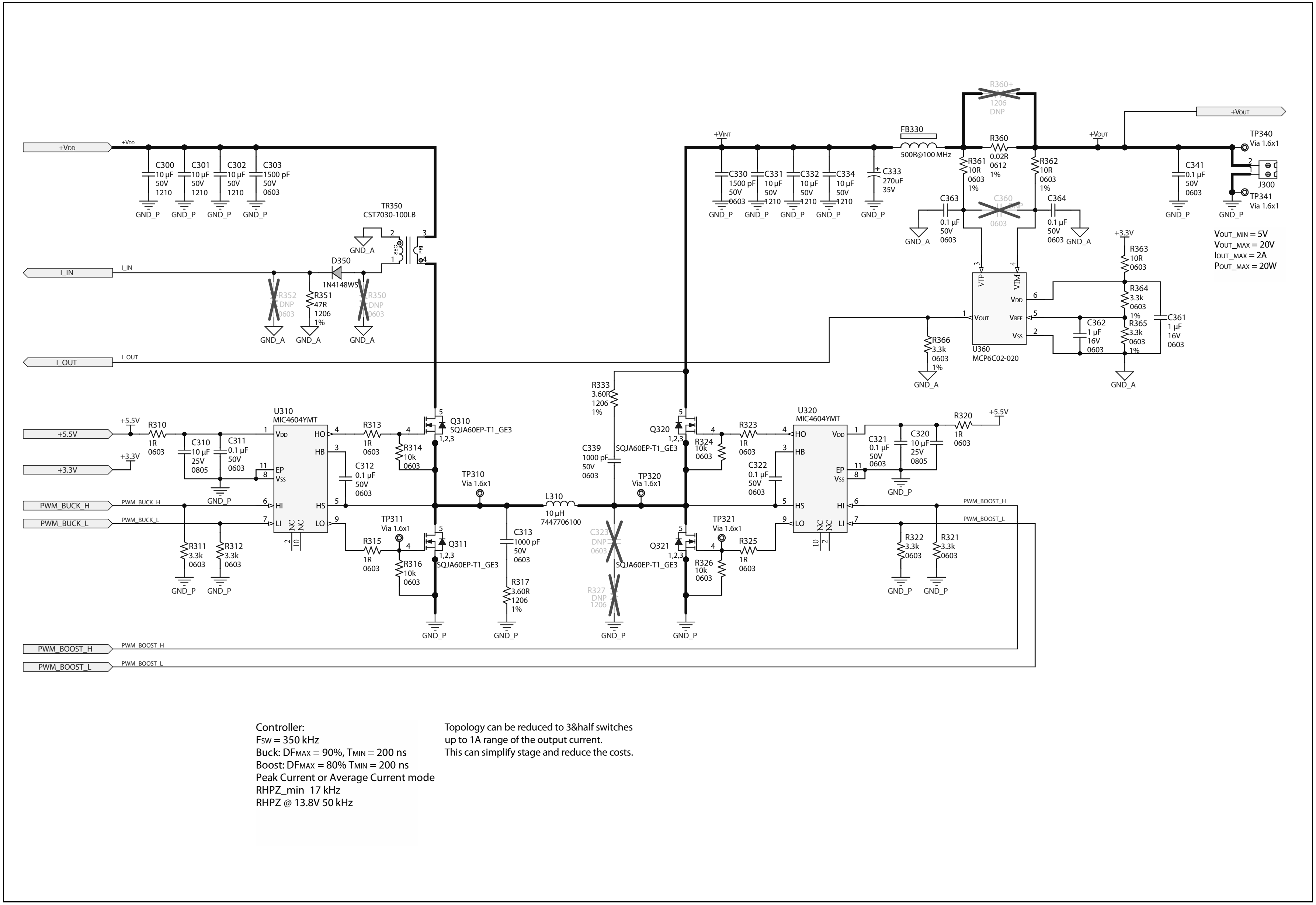

INPUT FILTER
VIN_MIN = 8V
VIN_MAX = 18V
Load Damp = 36V (1s max)
+VIN
J201
JACK Banana
TP201
Via 1.6x1
+VIN
C201
0.22 µF
100V
1206
C202
0.22 µF
100V
1206
C203
10 µF
50V
1210
D201
SMAJ30Ae3/TR13
DO-214AC
L201
2.2 µH
74404063022
TP203
Via 1.6x1
+VDD
C206
270 µF
35V
+VDD
GND
J202
JACK Banana
TP202
Via 1.6x1
GND_P
GND_P
GND_P
GND_P
GND_P
+VIN
J203
1
3
2
POWER 2.1 mm
2 AMAX
At this connector
GND_P
AUX SUPPLY
+VDD
D202
1N4148WS
C220
10 µF
50V
1210
GND_P
D221
1N4148WS
C221
0.1 µF
50V
0603
TP220
Via 1.6x1
1
BOOST
SW
6
5
VIN
4
EN
GND
VFB
3
2
U220
MCP16331
GND_P
L220
22 µH
7447786122
D220
RB168VYM100FHTR
SOD-323HE
GND_P
0.8V
TP221
Via 1.6x1
R220
59k
0603
1%
R221
10k
0603
1%
GND_P
+5.5V
500 mA_max
C222
10 µF
25V
0805
C223
10 µF
25V
0805
C224
0.1 µF
50V
0603
GND_P
GND_P
GND_P
U221
MCP1755/3.3V
1
VIN
3
SHDN
4
PWRGD
VOUT
5
GND
2
+3.3V
TP222
Via 1.6x1
C225
1 µF
16V
0603
GND_A
+5.5V
+5.5V
+3.3V
+3.3V
R224
0R
0603
GND_P
GND_A
R203
0R
0603
GND_A
GND_SHLD

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


+VDD
C300 10 µF 50V 1210
C301 10 µF 50V 1210
C302 10 µF 50V 1210
C303 1500 pF 50V 0603
GND_P
TR350 CST7030-100LB
SEC
PRI
GND_A
D350 1N4148WS
I_IN
R352 DNP 0603
R351 47R 1206 1%
R350 DNP 0603
I_OUT
+5.5V
R310 1R 0603
C310 10 µF 25V 0805
C311 0.1 µF 50V 0603
+3.3V
U310 MIC4604YMT
VDD HO HB EP VSS HI HS LI LO NC NC
R313 1R 0603
R314 10k 0603
C312 0.1 µF 50V 0603
Q310 SQJA60EP-T1_GE3
TP310 Via 1.6x1
L310 10 µH 7447706100
TP311 Via 1.6x1
R315 1R 0603
R316 10k 0603
Q311 SQJA60EP-T1_GE3
C313 1000 pF 50V 0603
R317 3.60R 1206 1%
PWM_BUCK_H
PWM_BUCK_L
R311 3.3k 0603
R312 3.3k 0603
PWM_BOOST_H
PWM_BOOST_L
R333 3.60R 1206 1%
C339 1000 pF 50V 0603
C323 DNP 0603
R327 DNP 1206
Q320 SQJA60EP-T1_GE3
Q321 SQJA60EP-T1_GE3
TP320 Via 1.6x1
TP321 Via 1.6x1
R324 10k 0603
R323 1R 0603
R326 10k 0603
R325 1R 0603
C322 0.1 µF 50V 0603
U320 MIC4604YMT
R320 1R 0603
C321 0.1 µF 50V 0603
C320 10 µF 25V 0805
R322 3.3k 0603
R321 3.3k 0603
+VINT
C330 1500 pF 50V 0603
C331 10 µF 50V 1210
C332 10 µF 50V 1210
C334 10 µF 50V 1210
C333 270uF 35V
FB330 500R@100 MHz
R360+ 1206 DNP
R360 0.02R 0612 1%
R361 10R 0603 1%
R362 10R 0603 1%
C363 0.1 µF 50V 0603
C360 DNP 0603
C364 0.1 µF 50V 0603
+VOUT
C341 0.1 µF 50V 0603
TP340 Via 1.6x1
TP341 Via 1.6x1
J300
U360 MCP6C02-020
VIP VIM VDD VREF VSS VOUT
R366 3.3k 0603 1%
R363 10R 0603
R364 3.3k 0603 1%
R365 3.3k 0603 1%
C362 1 µF 16V 0603
C361 1 µF 16V 0603
GND_A

V_{OUT_MIN} = 5V
V_{OUT_MAX} = 20V
I_{OUT_MAX} = 2A
P_{OUT_MAX} = 20W

Controller:
F_{SW} = 350 kHz
Buck: DF_{MAX} = 90%, T_{MIN} = 200 ns
Boost: DF_{MAX} = 80% T_{MIN} = 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

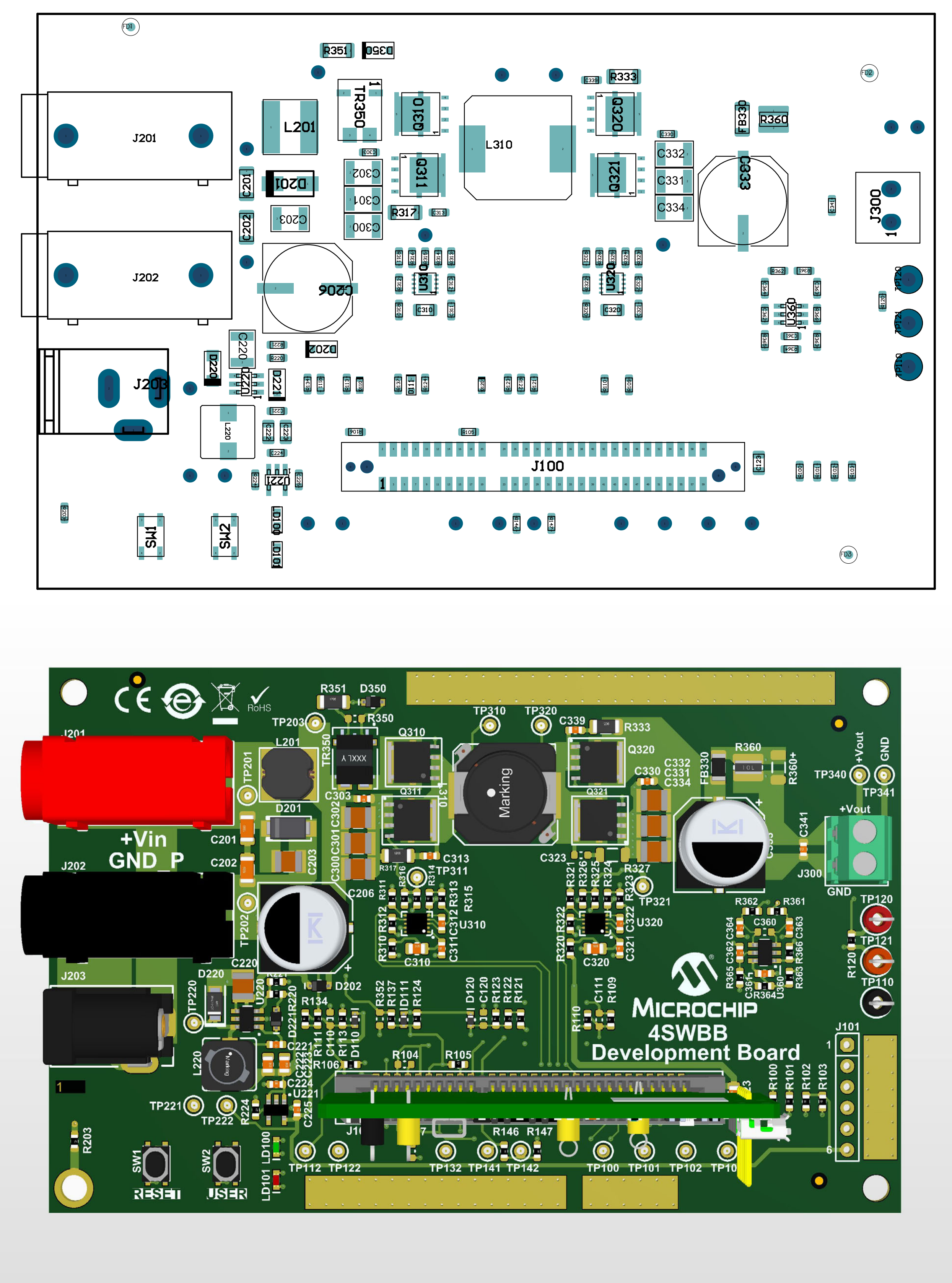
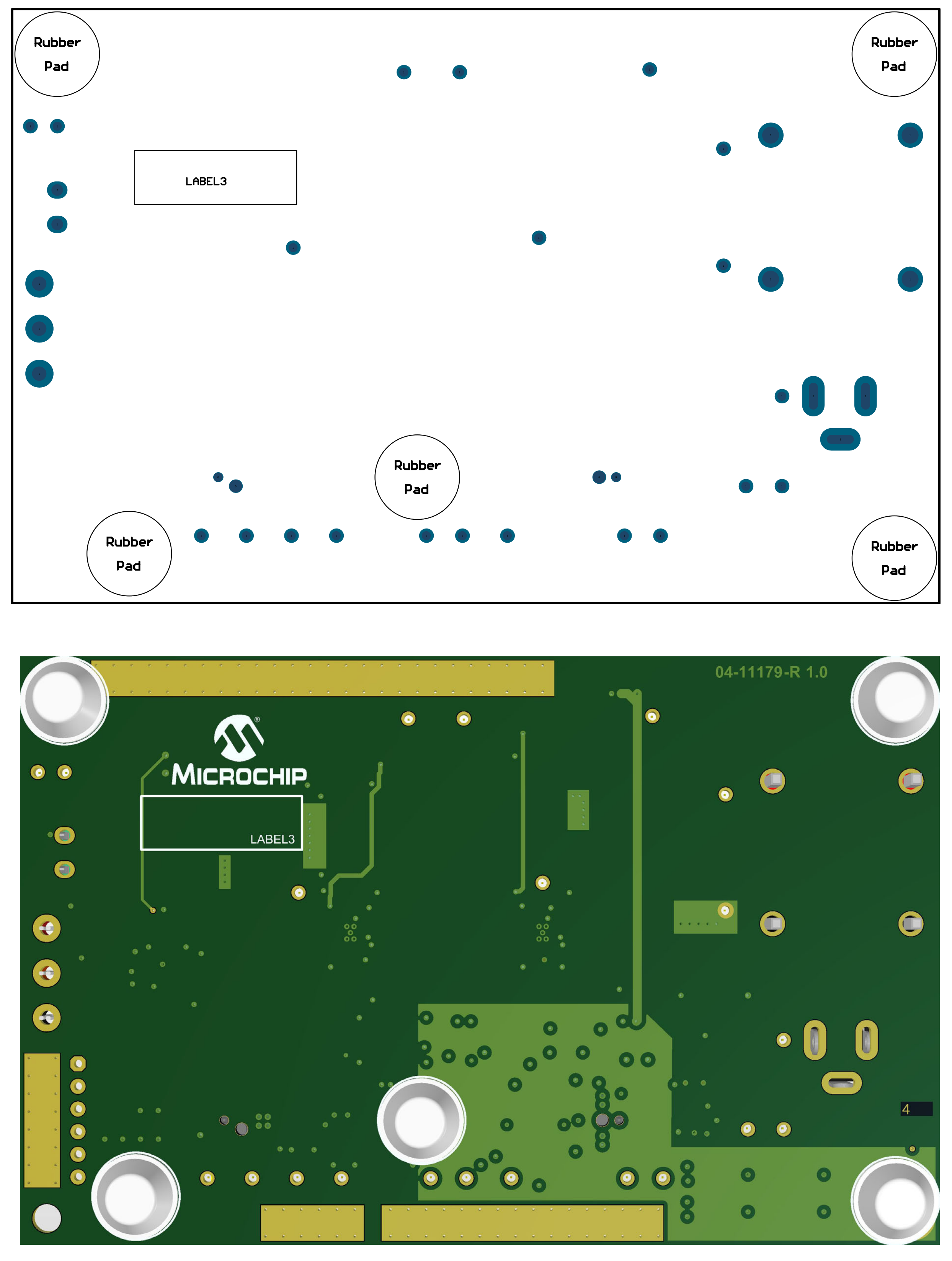

R351
D350
TR350
Q310
L310
R333
Q320
FB330
R360
L201
J201
Q311
Q321
C332
C331
C334
C333
J300
C201
D201
C302
C301
C300
R317
C202
C203
J202
C206
U310
U320
U360
TP120
TP121
TP110
C220
D220
D202
U220
D221
J203
L220
J100
U221
SW1
SW2
LD100
LD101
+Vin
GND_P
RoHS
TP203
TP310
TP320
C339
TP201
TP202
C313
TP311
C323
R327
TP321
TP340
TP341
+Vout
GND
C341
R362
R361
C360
R364
TP220
TP221
TP222
R203
RESET
USER
TP112
TP122
TP132
TP141
TP142
TP100
TP101
TP102
R146
R147
R104
R105
J101
R100
R101
R102
R103
R120
MICROCHIP
4SWBB
Development Board
Marking

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


Rubber Pad
Rubber Pad
LABEL3
Rubber Pad
Rubber Pad
Rubber Pad
04-11179-R 1.0
MICROCHIP
LABEL3
4

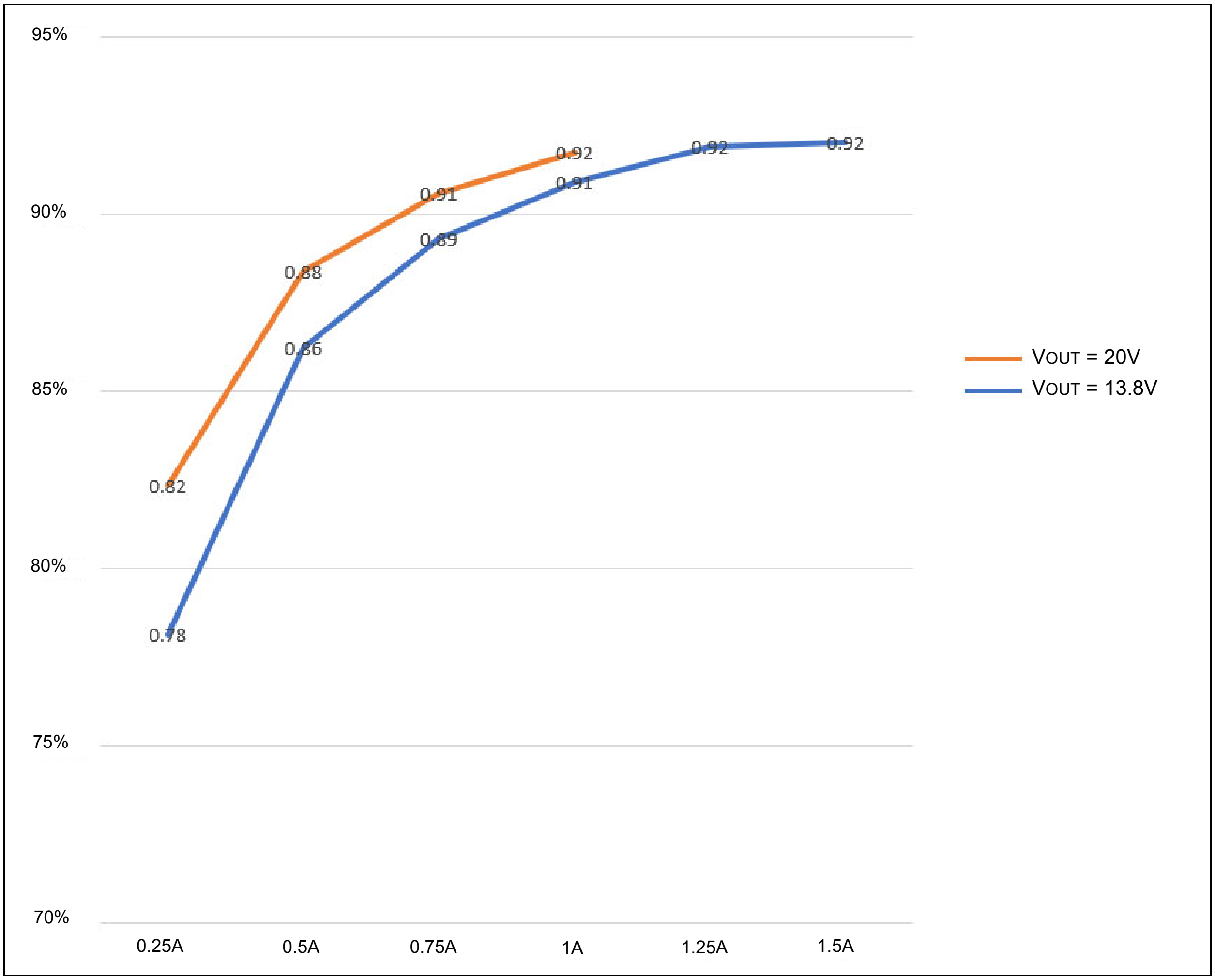
NOTES:

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



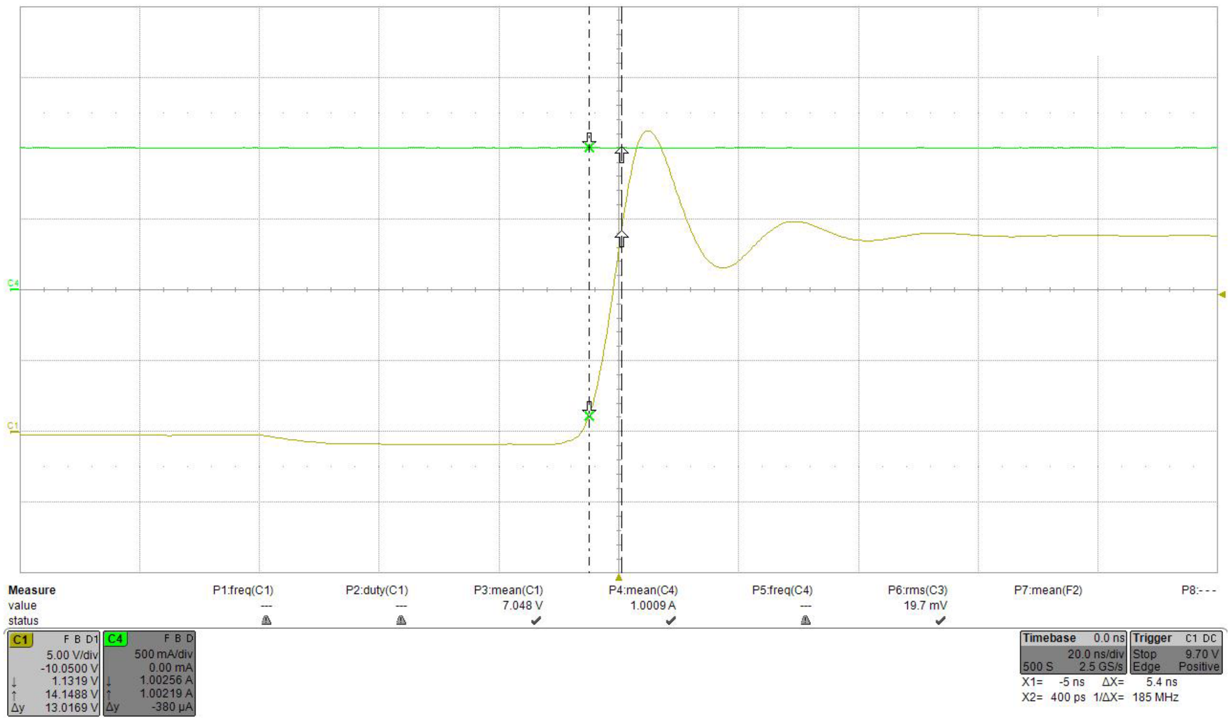
B.2 NO LOAD CONSUMPTION PERFORMANCE

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



Measure	P1:freq(C1)	P2:duty(C1)	P3:mean(C1)	P4:mean(C4)	P5:freq(C4)	P6:rms(C3)	P7:mean(F2)	P8:- - -
value	---	---	7.048 V	1.0009 A	---	19.7 mV		
status	⚠	⚠	✓	✓	⚠	✓		

C1 F B D1
5.00 V/div
-10.0500 V
↓ 1.1319 V
↑ 14.1488 V
Δy 13.0169 V

C4 F B D
500 mA/div
0.00 mA
↓ 1.00256 A
↑ 1.00219 A
Δy -380 µA

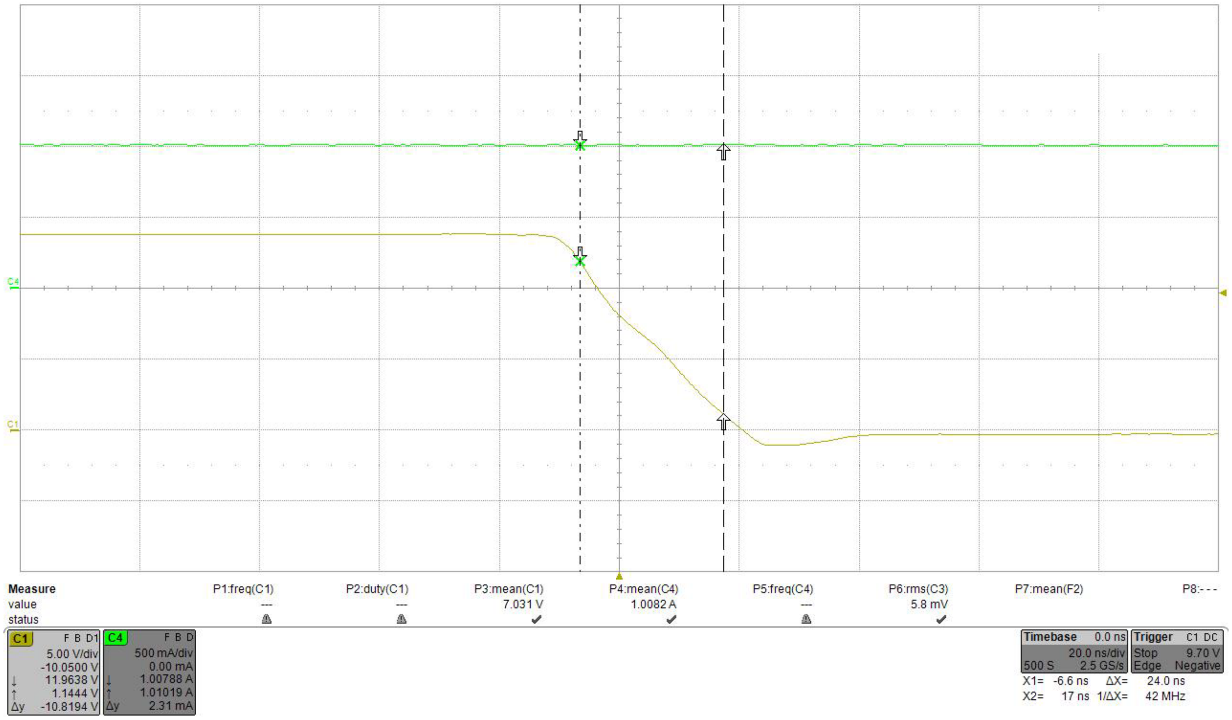
Timebase 0.0 ns
20.0 ns/div
500 S 2.5 GS/s

Trigger C1 DC
Stop 9.70 V
Edge Positive

X1= -5 ns ΔX= 5.4 ns
X2= 400 ps 1/ΔX= 185 MHz

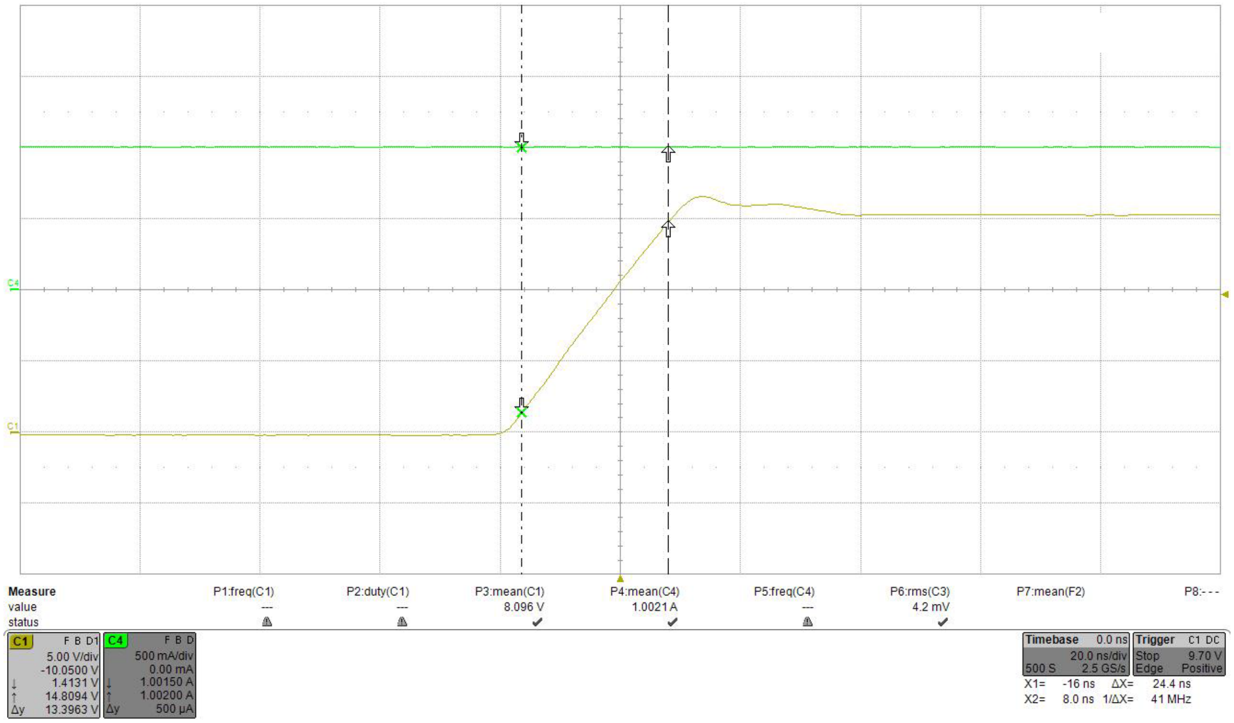
Legend: V_{IN} =13.8V, V_{OUT} = 13.8V, I_{OUT} = 1A
Ch1 (yellow) – PWM_H (TP310)
CH4 (green) – Output Current
20 ns/div

FIGURE B-3: SWITCHING NODES BUCK, FALL TIME



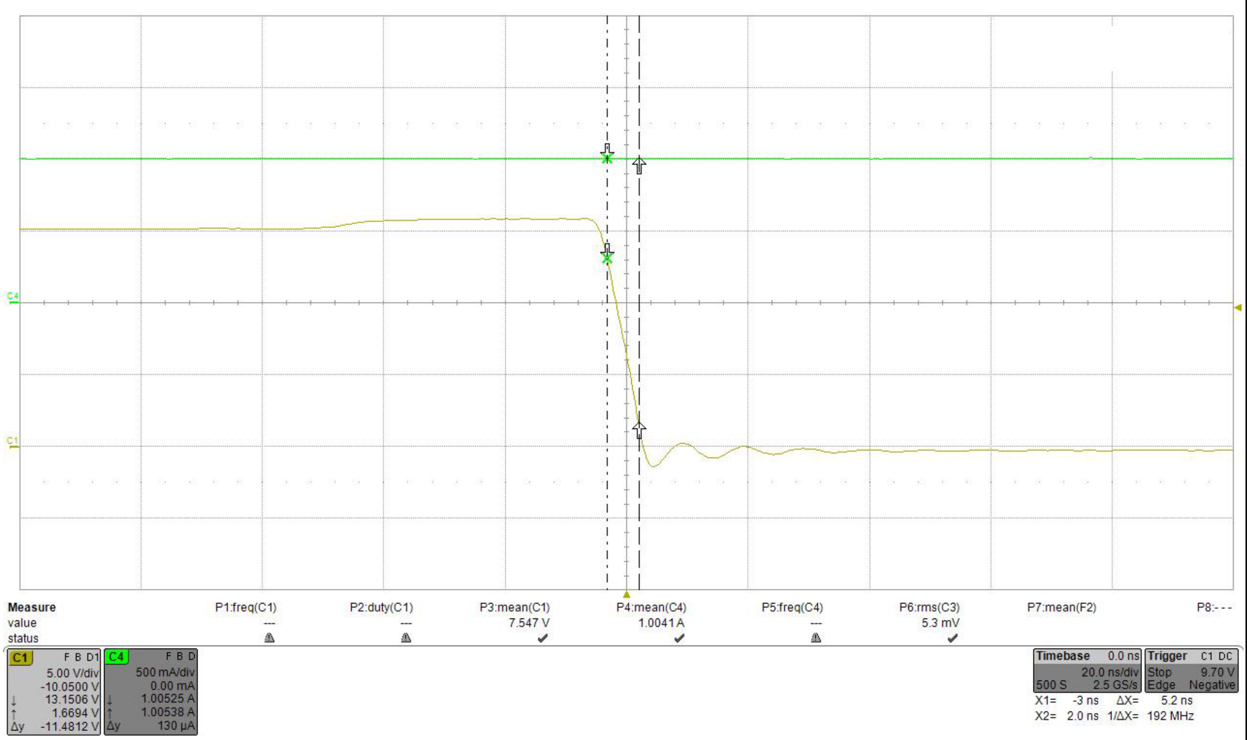
Legend: V_{IN} = 13.8V, V_{OUT} = 13.8V, I_{OUT} = 1A
Ch1 (yellow) – PWM_H (TP310)
CH4 (green) – Output Current
Time Base: 20 ns/div

FIGURE B-4: SWITCHING NODES BOOST, RISE TIME



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

FIGURE B-5: SWITCHING NODES BOOST, FALL TIME



Measure	P1:freq(C1)	P2:duty(C1)	P3:mean(C1)	P4:mean(C4)	P5:freq(C4)	P6:rms(C3)	P7:mean(F2)	P8:- - -
value	---	---	7.547 V	1.0041 A	---	5.3 mV		
status	⚠	⚠	✓	✓	⚠	✓		

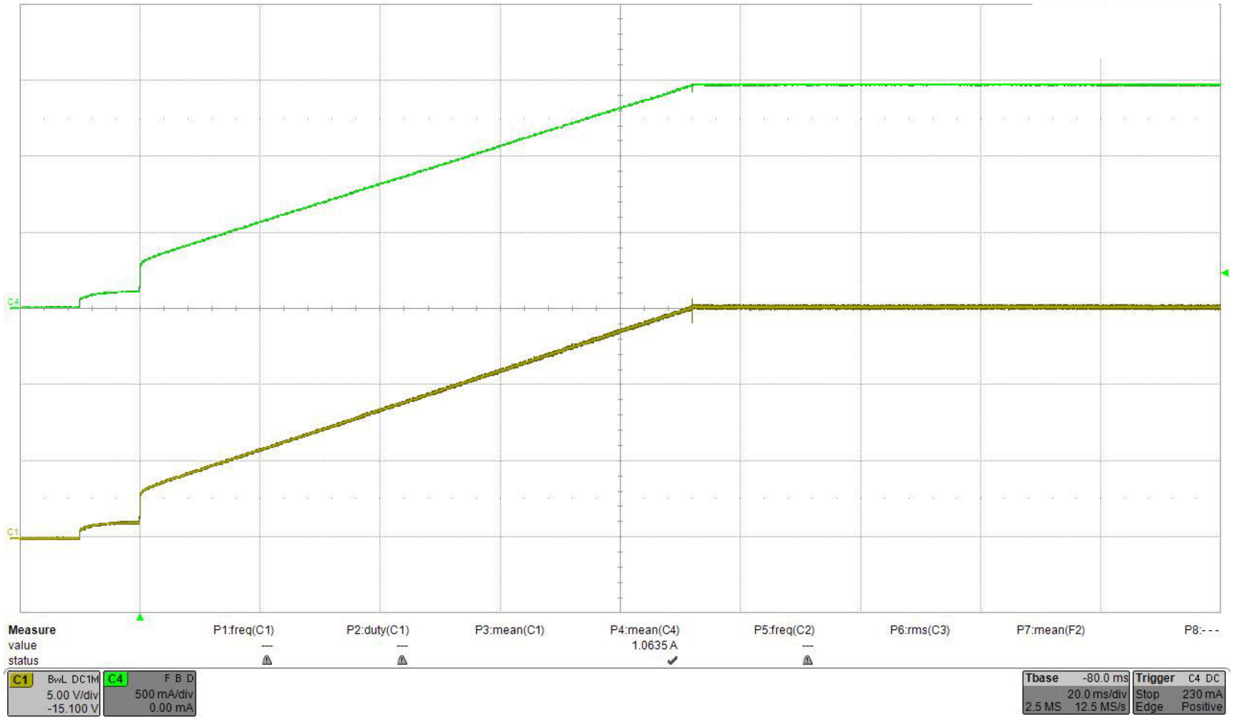
C1 F B D1	C4 F B D
5.00 V/div	500 mA/div
-10.0500 V	0.00 mA
↓ 13.1506 V	↓ 1.00525 A
↑ 1.6694 V	↑ 1.00538 A
Δy -11.4812 V	Δy 130 µA

Timebase 0.0 ns	Trigger C1 DC
20.0 ns/div	Stop 9.70 V
500 S 2.5 GS/s	Edge Negative

X1= -3 ns ΔX= 5.2 ns
X2= 2.0 ns 1/ΔX= 192 MHz

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

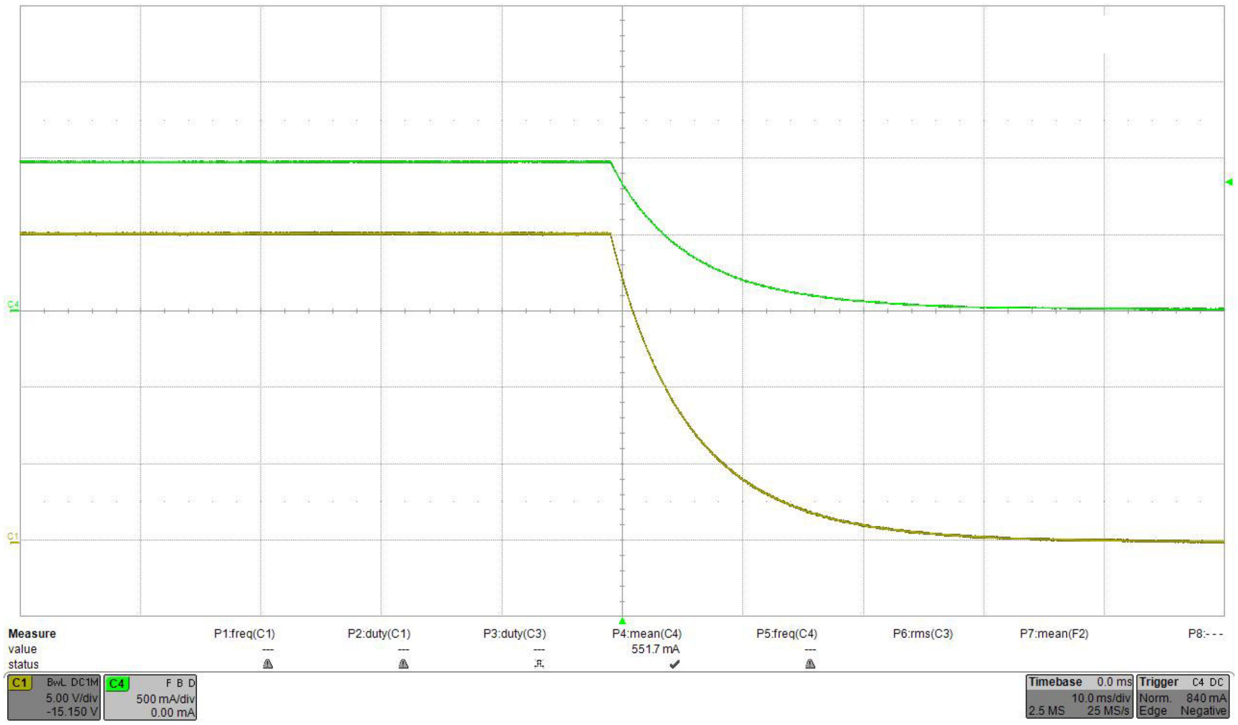
FIGURE B-6: SWITCH ON BEHAVIOR AT FULL LOAD AT THE OUTPUT



Measure	P1:freq(C1)	P2:duty(C1)	P3:mean(C1)	P4:mean(C4)	P5:freq(C2)	P6:rms(C3)	P7:mean(F2)	P8:- - -
value	---	---		1.0635 A	---			
status	⚠	⚠		✓	⚠			

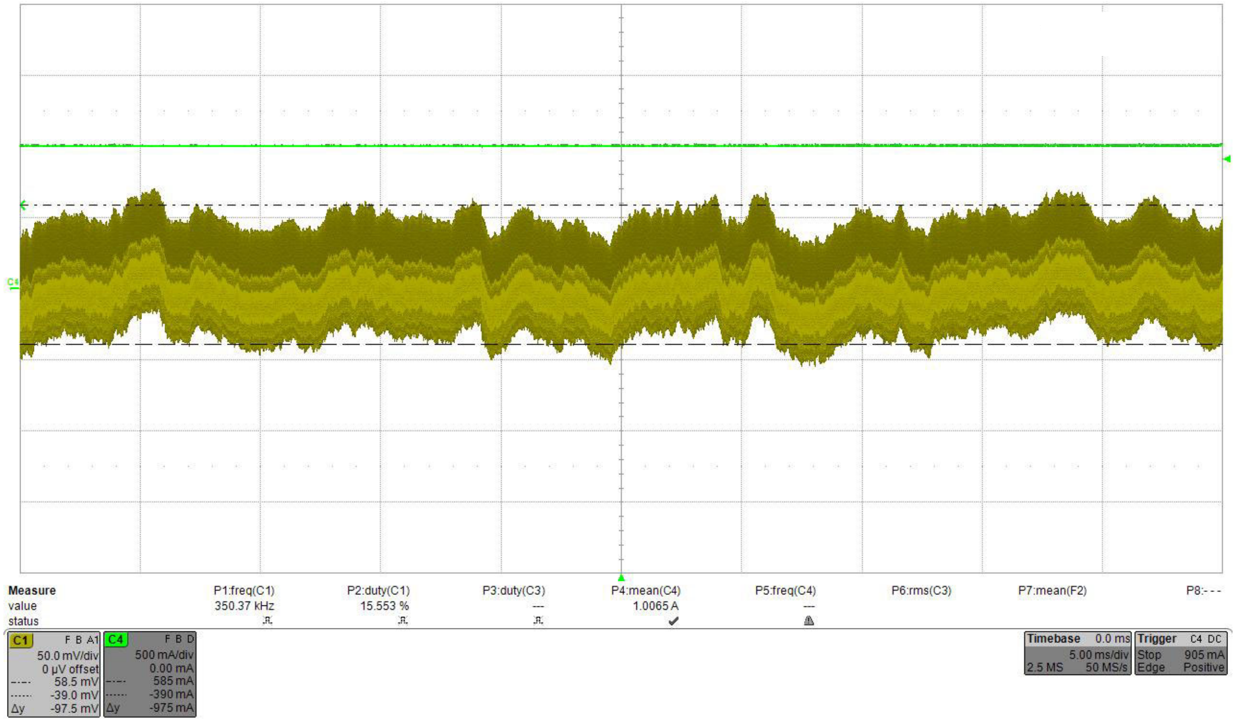
Legend: VIN = 20V, VOUT = 13.8V, IOUT = 1A
Ch1 (yellow) – Output Voltage
Ch4 (green) – Output Current
Time Base: 50 ms/div

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

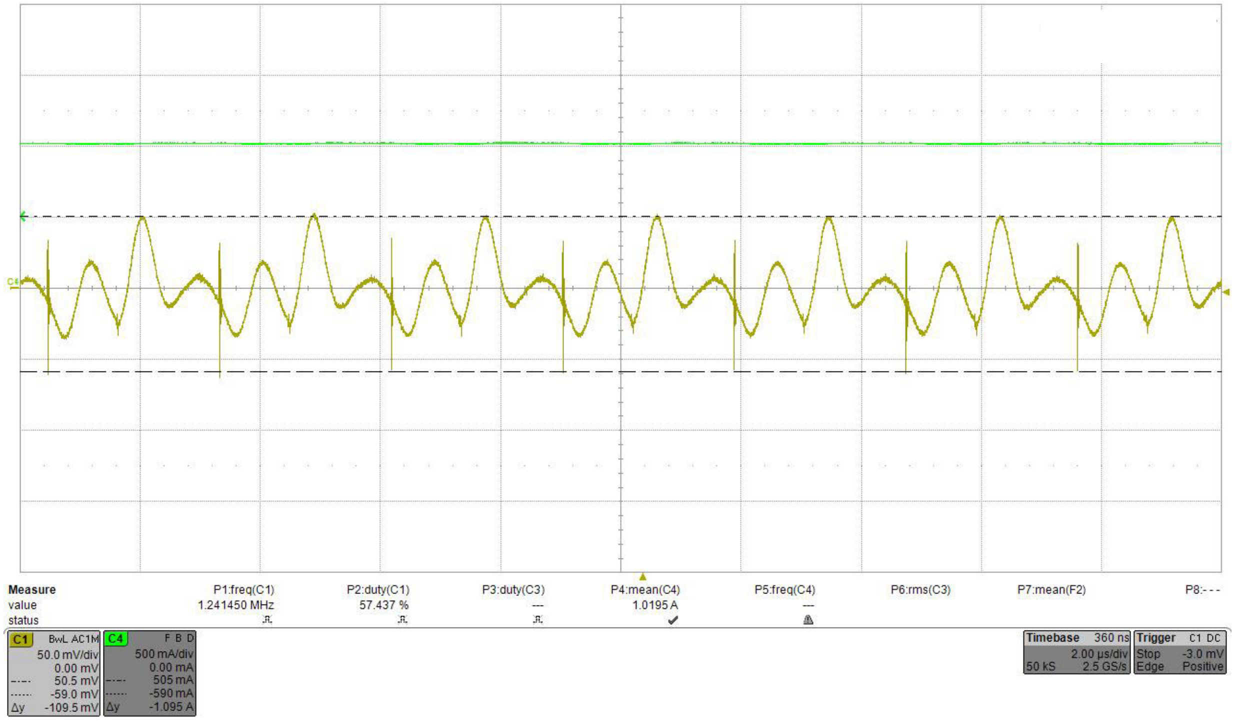


Measure	P1:freq(C1)	P2:duty(C1)	P3:duty(C3)	P4:mean(C4)	P5:freq(C4)	P6:rms(C3)	P7:mean(F2)	P8:- - -
value	350.37 kHz	15.553 %	---	1.0065 A	---			
status	⎍	⎍	⎍	✓	⚠			

C1 F B A1
50.0 mV/div
0 µV offset
58.5 mV
-39.0 mV
Δy -97.5 mV
C4 F B D
500 mA/div
0.00 mA
585 mA
-390 mA
Δy -975 mA
Timebase 0.0 ms
5.00 ms/div
2.5 MS 50 MS/s
Trigger C4 DC
Stop 905 mA
Edge Positive

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



Measure	P1:freq(C1)	P2:duty(C1)	P3:duty(C3)	P4:mean(C4)	P5:freq(C4)	P6:rms(C3)	P7:mean(F2)	P8:- - -
value	1.241450 MHz	57.437 %	---	1.0195 A	---			
status	⎍	⎍	⎍	✓	⚠			

C1 BwL AC1M
50.0 mV/div
0.00 mV
50.5 mV
-59.0 mV
Δy -109.5 mV

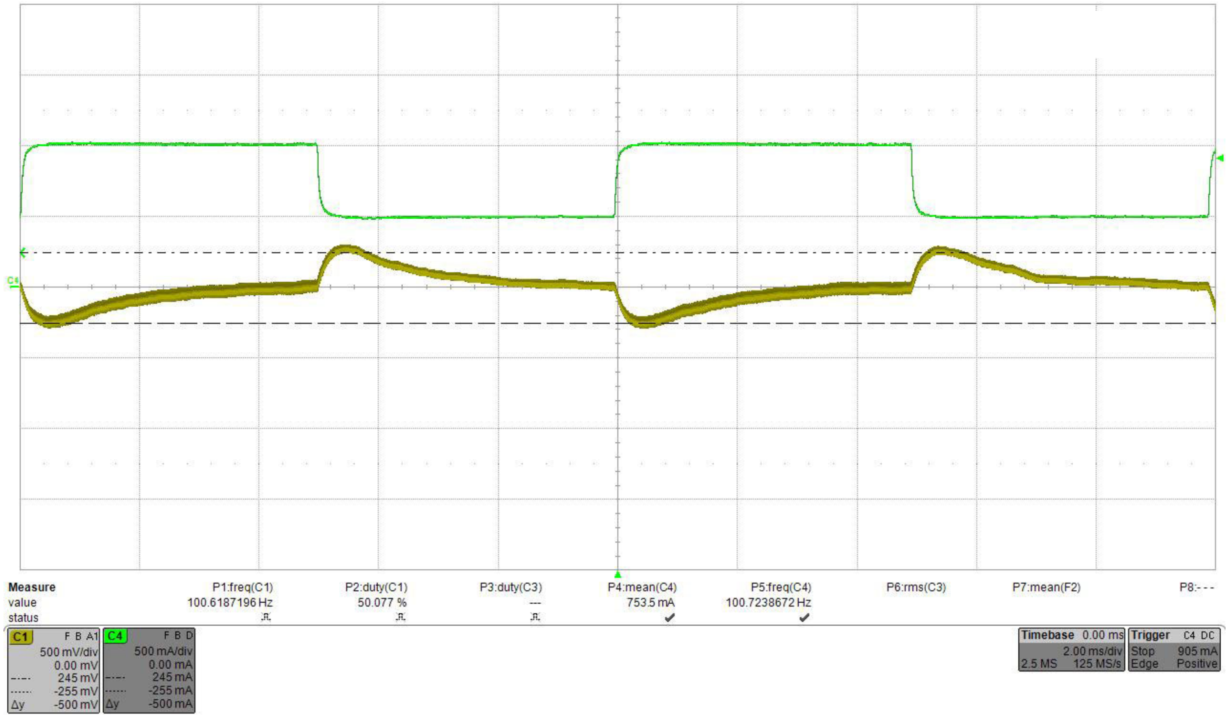
C4 F B D
500 mA/div
0.00 mA
505 mA
-590 mA
Δy -1.095 A

Timebase 360 ns
2.00 µs/div
50 kS 2.5 GS/s

Trigger C1 DC
Stop -3.0 mV
Edge Positive

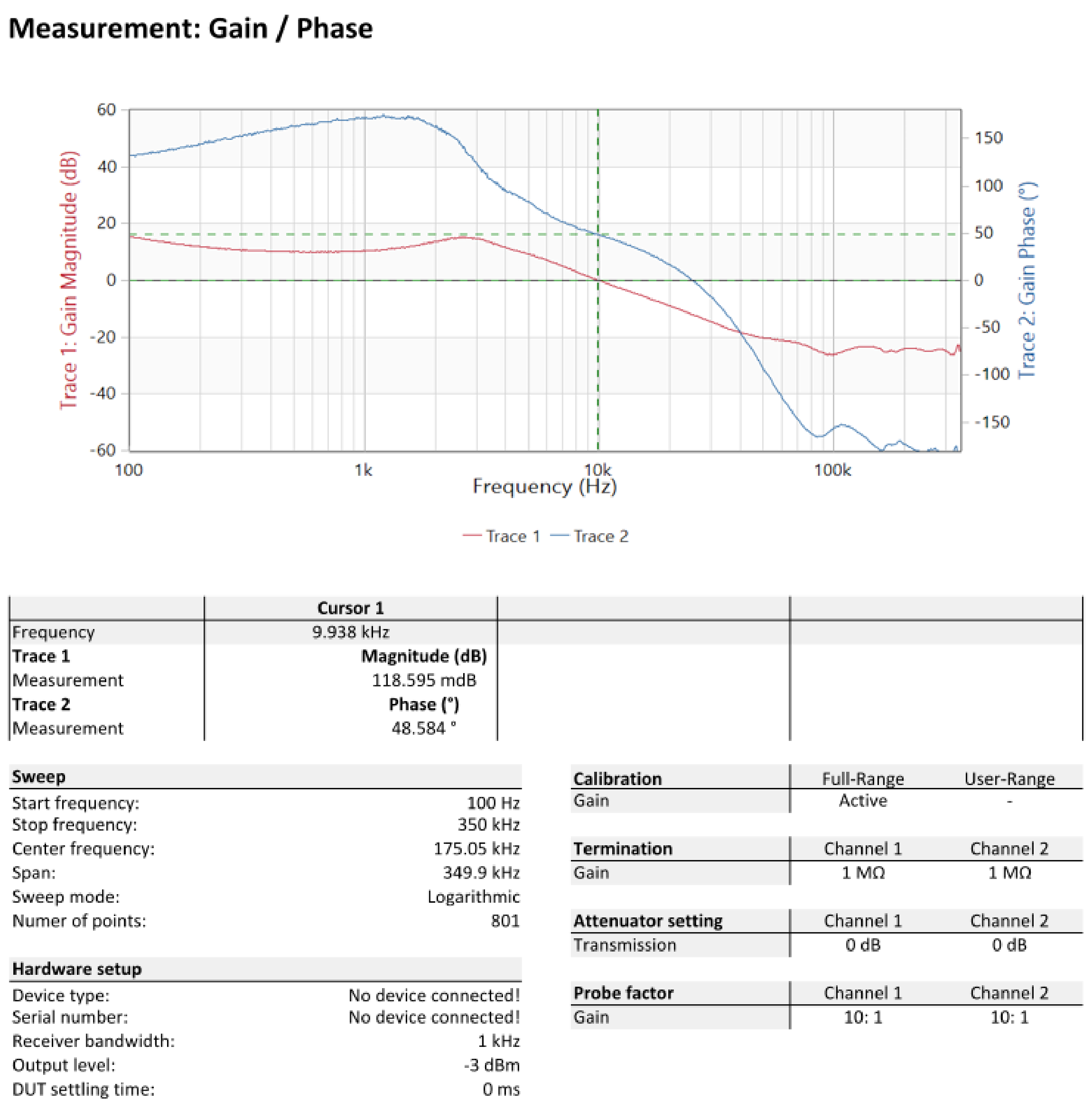
Legend: VIN = 13.8V, VOUT = 20V, IOUT = 1A
Output Ripple Voltage < 100 mVpp
Ch1 (yellow) – Output Voltage (AC Coupled, 20 MHz Bandwidth)
Time Base: 50 ms/div

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



Legend: VIN = 13.8V, VOUT = 20V, IOUT = 1A
Ch1 (yellow) – Output Voltage (AC Coupled, Bandwidth Limit 20 MHz)
Ch4 (green) – Output Current
Time Base: 2 ms/div

FIGURE B-11: LOOP STABILITY – INNER LOOP



Measurement: Gain / Phase

60
40
20
0
-20
-40
-60
Trace 1: Gain Magnitude (dB)
150
100
50
0
-50
-100
-150
Trace 2: Gain Phase (°)
100
1k
10k
100k
Frequency (Hz)
Trace 1
Trace 2

	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	-

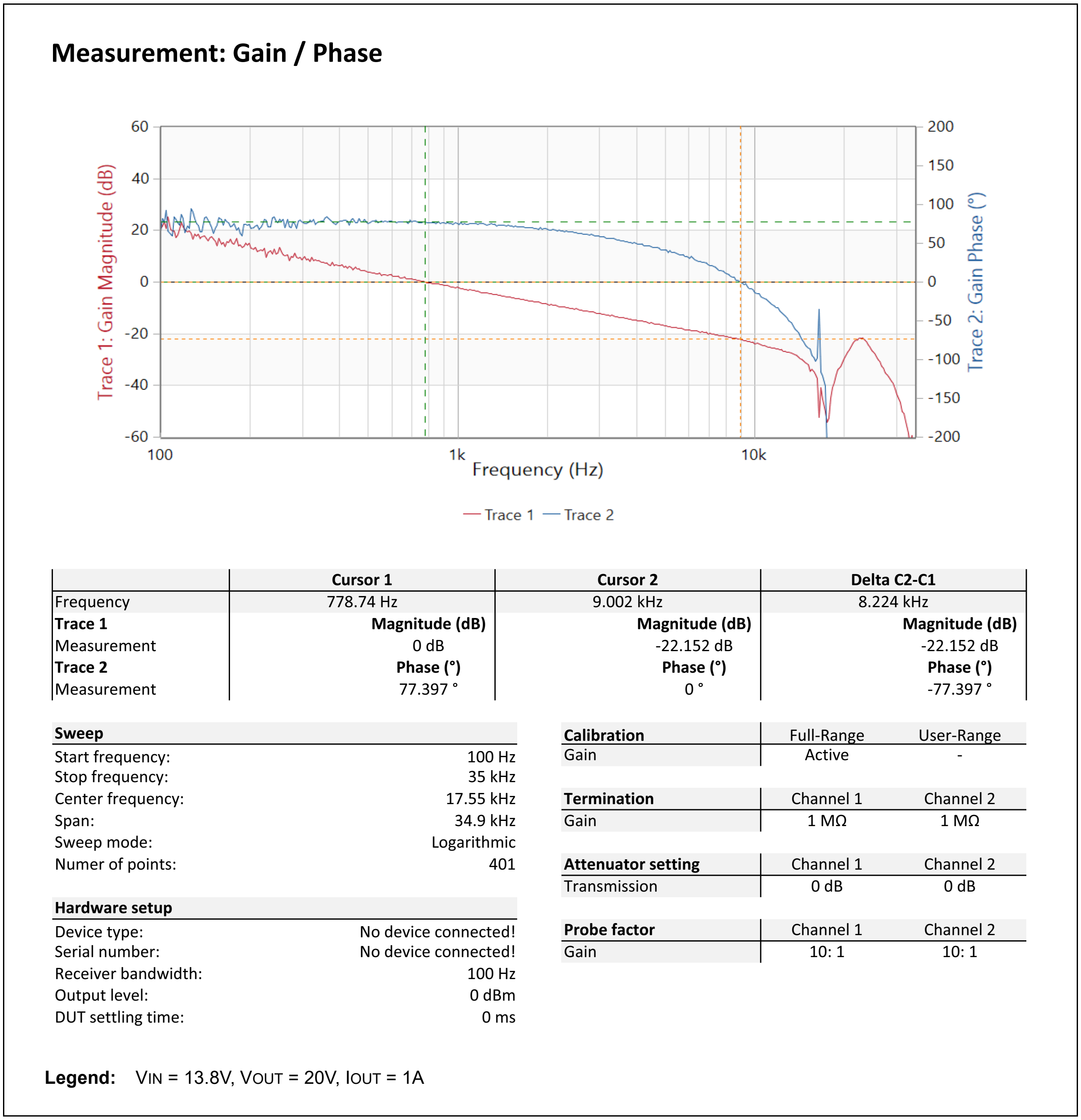
Termination	Channel 1	Channel 2
Gain	1 MΩ	1 MΩ

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	-

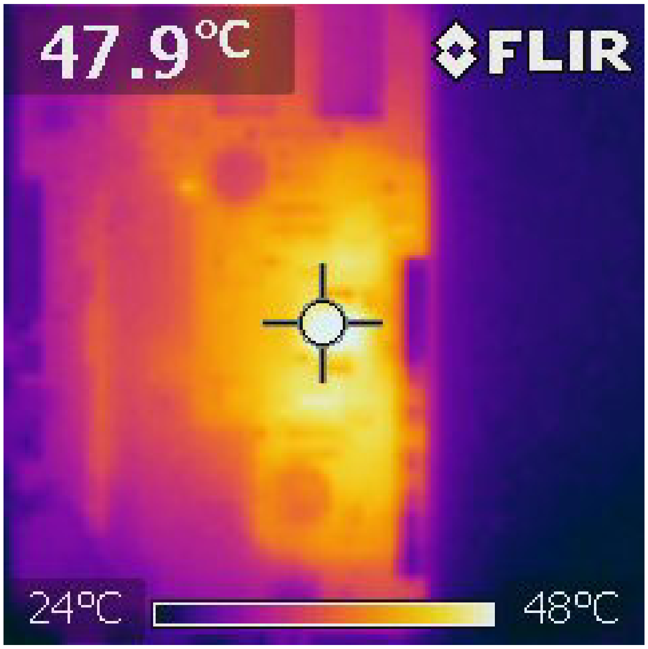
Termination	Channel 1	Channel 2
Gain	1 MΩ	1 MΩ

Attenuator setting	Channel 1	Channel 2
Transmission	0 dB	0 dB

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

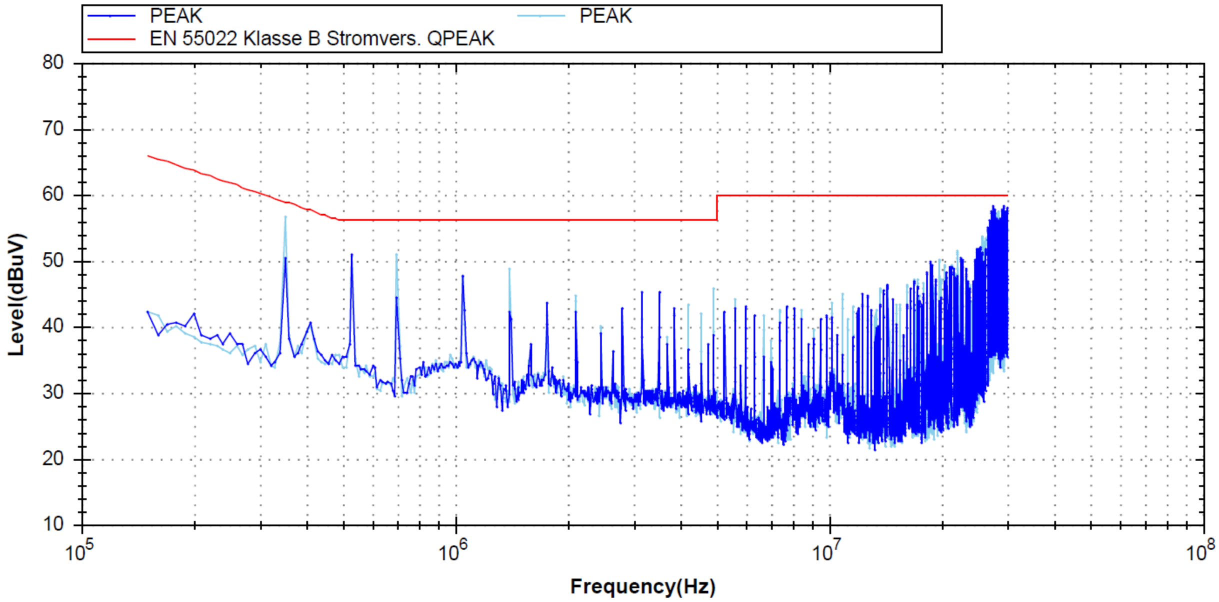
Legend: V_{IN} = 13.8V, V_{OUT} = 20V, I_{OUT} = 1A

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

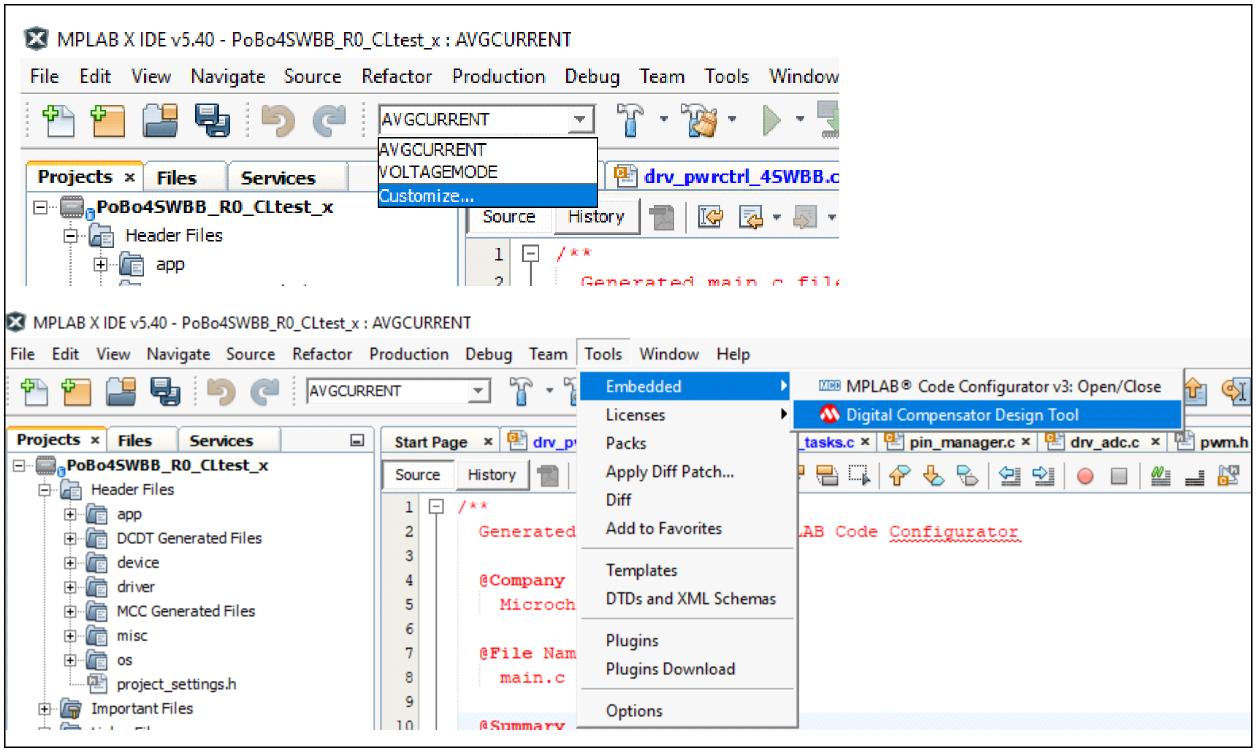
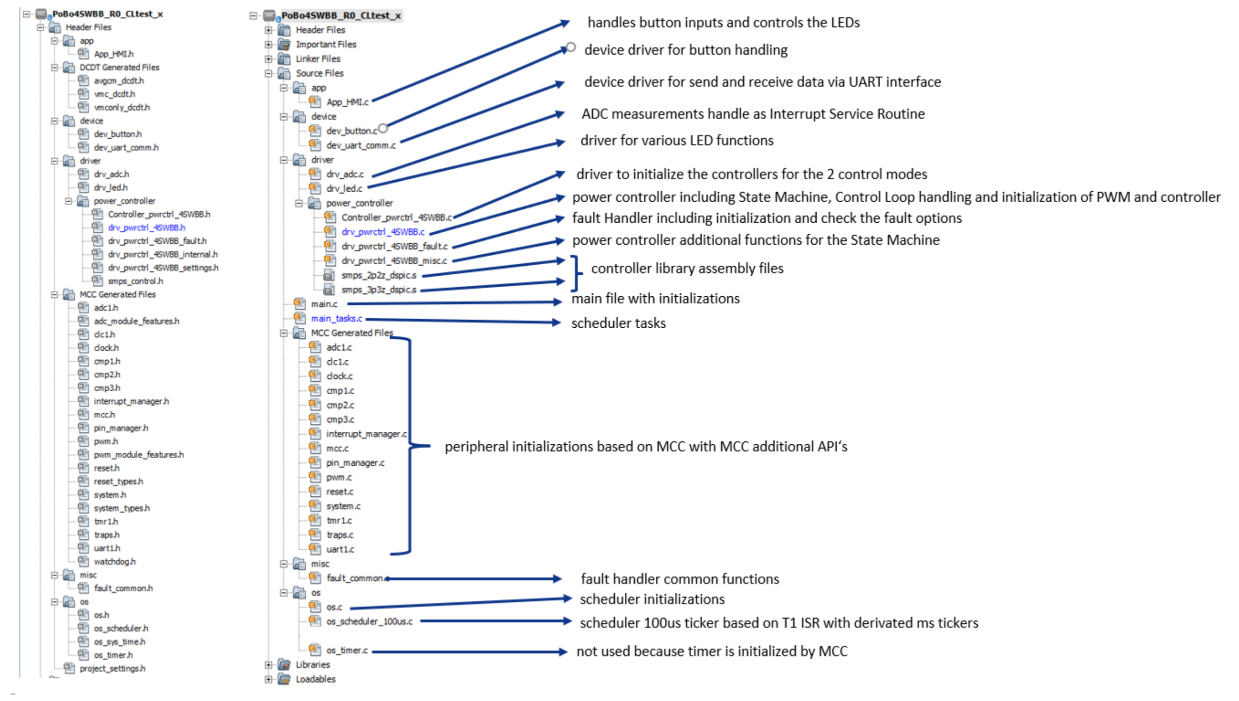

MPLAB X IDE v5.40 - PoBo4SWBB_R0_CLtest_x : AVGCURRENT
File Edit View Navigate Source Refactor Production Debug Team Tools Window
AVGCURRENT
AVGCURRENT
VOLTAGEMODE
Customize...
Projects
Files
Services
PoBo4SWBB_R0_CLtest_x
Header Files
app
drv_pwrctrl_4SWBB.c
Source
History
MPLAB X IDE v5.40 - PoBo4SWBB_R0_CLtest_x : AVGCURRENT
File Edit View Navigate Source Refactor Production Debug Team Tools Window Help
Embedded
Licenses
Packs
Apply Diff Patch...
Diff
Add to Favorites
Templates
DTDs and XML Schemas
Plugins
Plugins Download
Options
MPLAB® Code Configurator v3: Open/Close
Digital Compensator Design Tool
Start Page
tasks.c
pin_manager.c
drv_adc.c
pwm.h
DCDT Generated Files
device
driver
MCC Generated Files
misc
os
project_settings.h
Important Files

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

FIGURE C-2: PROJECT DIRECTORY TREE


PoBo4SWBB_R0_CLtest_x
Header Files
app
App_HMI.h
DCDT Generated Files
avgcm_dcdt.h
vmc_dcdt.h
vmconly_dcdt.h
device
dev_button.h
dev_uart_comm.h
driver
drv_adc.h
drv_led.h
power_controller
Controller_pwrctrl_4SWBB.h
drv_pwrctrl_4SWBB.h
drv_pwrctrl_4SWBB_fault.h
drv_pwrctrl_4SWBB_internal.h
drv_pwrctrl_4SWBB_settings.h
smps_control.h
MCC Generated Files
adc1.h
adc_module_features.h
clc1.h
clock.h
cmp1.h
cmp2.h
cmp3.h
interrupt_manager.h
mcc.h
pin_manager.h
pwm.h
pwm_module_features.h
reset.h
reset_types.h
system.h
system_types.h
tmr1.h
traps.h
uart1.h
watchdog.h
misc
fault_common.h
os
os.h
os_scheduler.h
os_sys_time.h
os_timer.h
project_settings.h
PoBo4SWBB_R0_CLtest_x
Header Files
Important Files
Linker Files
Source Files
app
App_HMI.c
device
dev_button.c
dev_uart_comm.c
driver
drv_adc.c
drv_led.c
power_controller
Controller_pwrctrl_4SWBB.c
drv_pwrctrl_4SWBB.c
drv_pwrctrl_4SWBB_fault.c
drv_pwrctrl_4SWBB_misc.c
smps_2p2z_dspic.s
smps_3p3z_dspic.s
main.c
main_tasks.c
MCC Generated Files
adc1.c
clc1.c
clock.c
cmp1.c
cmp2.c
cmp3.c
interrupt_manager.c
mcc.c
pin_manager.c
pwm.c
reset.c
system.c
tmr1.c
traps.c
uart1.c
misc
fault_common.c
os
os.c
os_scheduler_100us.c
os_timer.c
Libraries
Loadables

handles button inputs and controls the LEDs

device driver for button handling

device driver for send and receive data via UART interface

ADC measurements handle as Interrupt Service Routine

driver for various LED functions

driver to initialize the controllers for the 2 control modes

power controller including State Machine, Control Loop handling and initialization of PWM and controller

fault Handler including initialization and check the fault options

power controller additional functions for the State Machine

controller library assembly files

main file with initializations

scheduler tasks

peripheral initializations based on MCC with MCC additional API's

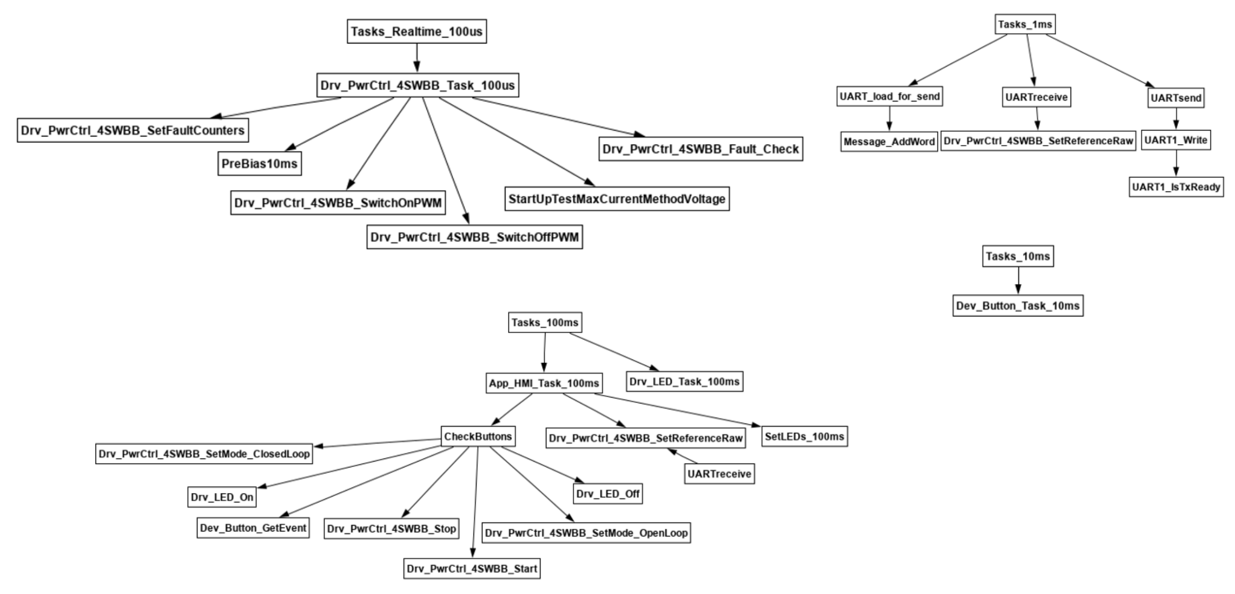
fault handler common functions

scheduler initializations

scheduler 100us ticker based on T1 ISR with derivated ms tickers

not used because timer is initialized by MCC

FIGURE C-3: FUNCTION CALL GRAPH


Tasks_Realtime_100us
Drv_PwrCtrl_4SWBB_Task_100us
Drv_PwrCtrl_4SWBB_SetFaultCounters
PreBias10ms
Drv_PwrCtrl_4SWBB_SwitchOnPWM
Drv_PwrCtrl_4SWBB_SwitchOffPWM
StartUpTestMaxCurrentMethodVoltage
Drv_PwrCtrl_4SWBB_Fault_Check
Tasks_1ms
UART_load_for_send
UARTreceive
UARTsend
Message_AddWord
Drv_PwrCtrl_4SWBB_SetReferenceRaw
UART1_Write
UART1_IsTxReady
Tasks_10ms
Dev_Button_Task_10ms
Tasks_100ms
App_HMI_Task_100ms
Drv_LED_Task_100ms
CheckButtons
Drv_PwrCtrl_4SWBB_SetReferenceRaw
SetLEDs_100ms
UARTreceive
Drv_PwrCtrl_4SWBB_SetMode_ClosedLoop
Drv_LED_On
Dev_Button_GetEvent
Drv_PwrCtrl_4SWBB_Stop
Drv_LED_Off
Drv_PwrCtrl_4SWBB_SetMode_OpenLoop
Drv_PwrCtrl_4SWBB_Start

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	TDK Corporation	C2012X5R1E106K125AB
2	C201, C202	Capacitor Ceramic, 0.22 µF, 50V, 10%, X7R, SMD, 1206	TDK Corporation	C3216X7R2A224K115AE
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	Würth 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	TDK Corporation	C1608X5R1C105K080AA
2	C303, C330	Capacitor Ceramic, 1500 pF, 50V, 10%, X7R, SMD, 0603	TDK Corporation	CGA3E2X7R1H152K080AA
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, 30V, 400W, SMD, DO-214AC, AEC-Q101	Microsemi	SMAJ30AE3/TR13
3	D202, D221, D350	Diode Rect, 1N4148WS, 1.25V, 150 mA, 75V, SOD-323	Diodes® Incorporated	1N4148WS-7-F
1	D220	Diode Schottky, 840 mV, 1A, 100V, SMD, SOD-323HE, AEC-Q101	ROHM Semiconductor	RB168VYM100FHTR
1	FB330	Ferrite, 500R@100 MHz, 2.5A, SMD, 1206	Würth Elektronik	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	DEM Manufacturing	571-0500
1	J202	Connector Jack Banana, Black, Female, 4.0 mm, Through-Hole, R/A	DEM Manufacturing	571-0100
1	J203	Connector Power, 2.1 mm, 5.5 mm, Switch, Through-Hole, R/A	Würth Elektronik	694106301002
1	J300	Connector Terminal, 3.81 mm, 1x2, Female, 16-24AWG, 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	L220	Inductor, 22 µH, 2A, 25%, AEC-Q200, SMD, 6.2x6.2x5.1	Würth Elektronik	7447786122

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

Qty	Designator	Description	Manufacturer 1	Manufacturer Part Number
1	L310	Inductor, 10 µH, 5.8A, 20%, SMD, AEC-Q200, SMD, 12x12x6	Würth Elektronik	7447706100
1	LD100	Diode, LED, Green, 3.2V, 20 mA, 430 mcd, Clear, SMD, 0603	Würth Elektronik	150060GS75000
1	LD101	Diode, LED, Red, 2V, 20 mA, 250 mcd, Clear, SMD, 0603	Würth Elektronik	150060RS75000
4	Q310, Q311, Q320, Q321	Transistor, FET, N-CH, 60V, 30A, 0.016R, 45W, PowerPAK, SO-8L, AEC-Q101	Vishay General Semiconductor	SQJA60EP-T1_GE3
6	R100, R221, R314, R316, R324, R326	Resistor, Thick Film, 10k, 1%, 1/8W, SMD, 0603	Vishay General Semiconductor	MCT06030C1002FP500
15	R101, R102, R103, R109, R110, R113, R123, R124, R311, R312, R321, R322, R364, R365, R366	Resistor, TKF, 3.3k, 1%, 1/10W, SMD, 0603	Panasonic®	ERJ-3EKF3301V
6	R105, R106, R122, R134, R203, R224	Resistor, TKF, 0R, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603ZT0R00
2	R111, R121	Resistor, TKF, 23.2k, 1%, 1/10W, SMD, 0603, AEC-Q200	Panasonic	ERJ-S03F2322V
5	R120, R146, R361, R362, R363	Resistor, TKF, 10R, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT10R0
2	R137, R147	Resistor, TKF, 470R, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT470R
1	R220	Resistor, TKF, 59k, 1%, 1/10W, SMD, 0603	Panasonic	ERJ-3EKF5902V
6	R310, R313, R315, R320, R323, R325	Resistor, TKF, 1R, 1%, 1/10W, SMD, 0603	Vishay/Dale	CRCW06031R00FKEA
2	R317, R333	Resistor, Thick Film, 3.6R, 1/4W, SMD, 1206, AEC-Q200	Panasonic	ERJ-U08F3R60V
1	R351	Resistor, TKF, 47R, 1%, 1/4W, SMD, 1206	Yageo Corporation	RC1206FR-0747RL
1	R360	Resistor, TKF, 0.02R, 1%, 1W, SMD, 0612, AEC-Q200	Panasonic	ERJ-B2CFR02V
2	SW1, SW2	Switch, Tactile, SPST-NO, 16 VDC, 50 mA, SMD	Würth Elektronik	434123025826
1	TP110	Connector, Test Point, Loop, Black, Through-Hole	Keystone Electronics	5011
1	TP120	Connector, Test Point, Loop, Red, Through-Hole	Keystone Electronics	5010
1	TP121	Connector, Test Point, Loop, Orange, Through-Hole	Keystone Electronics	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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China - Guangzhou
Tel: 86-20-8755-8029

China - Hangzhou
Tel: 86-571-8792-8115

China - Hong Kong SAR
Tel: 852-2943-5100

China - Nanjing
Tel: 86-25-8473-2460

China - Qingdao
Tel: 86-532-8502-7355

China - Shanghai
Tel: 86-21-3326-8000

China - Shenyang
Tel: 86-24-2334-2829

China - Shenzhen
Tel: 86-755-8864-2200

China - Suzhou
Tel: 86-186-6233-1526

China - Wuhan
Tel: 86-27-5980-5300

China - Xian
Tel: 86-29-8833-7252

China - Xiamen
Tel: 86-592-2388138

China - Zhuhai
Tel: 86-756-3210040

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