MCP16311/2 High Efficiency Buck-Boost Converter Reference Design User's Guide

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ISBN: 978-1-5224-7815-7

MCP16311/2 HIGH EFFICIENCY BUCK-BOOST CONVERTER REFERENCE DESIGN USER'S GUIDE

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Preface

NOTICE TO CUSTOMERS

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

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

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

INTRODUCTION

This chapter contains general information that will be useful to know before using the MCP16311/2 High Efficiency Buck-Boost Converter Reference Design. Items discussed in this chapter include:

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

DOCUMENT LAYOUT

This document describes how to use the MCP16311/2 High Efficiency Buck-Boost Converter Reference Design as a development tool for testing and measurements to observe the advantages over a conventional Buck-Boost converter. The document is organized as follows:

- **Chapter 1. "Product Overview"** – Provides important information about the MCP16311/2 High Efficiency Buck-Boost Converter Reference Design and shows the hardware details of its components.
- **Chapter 2. "Installation and Operation"** – Includes instructions on how to use, power and test the MCP16311/2 High Efficiency Buck-Boost Converter Reference Design.
- **Appendix A. "Schematics and Layouts"** – Shows the schematic and layout diagrams for the MCP16311/2 High Efficiency Buck-Boost Converter Reference Design.
- **Appendix B. "Bill of Materials (BOM)"** – Lists the parts used to build the MCP16311/2 High Efficiency Buck-Boost Converter Reference Design.

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

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

RECOMMENDED READING

This user's guide describes how to use the MCP16311/2 High Efficiency Buck-Boost Converter Reference Design. The following Microchip documents are available and recommended as supplemental reference resources:

- **MCP16311/2 Data Sheet – *"30V Input, 1A Output, High-Efficiency, Integrated Synchronous Switch Step-Down Regulator"* (DS20005255)**
- **AN2102 – *"Designing Applications with MCP16331 High-Input Voltage Buck Converter"* (DS00002102)**
- **TB3277 Technical Brief – *"MCP16311/2 High Efficiency Buck-Boost Converter"* (DS90003277)**

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

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

DOCUMENT REVISION HISTORY

Revision A (March 2021)

- Initial release of this document.

NOTES:

Chapter 1. Product Overview

1.1 INTRODUCTION

This chapter provides an overview of the MCP16311/2 High Efficiency Buck-Boost Converter Reference Design and covers the following topics:

- MCP16311/2 Short Overview
- What is the MCP16311/2 High Efficiency Buck-Boost Converter Reference Design?
- Contents of the MCP16311/2 High Efficiency Buck-Boost Converter Reference Design Kit

1.2 MCP16311/2 SHORT OVERVIEW

The MCP16311/2 is a compact, high-efficiency, fixed frequency, synchronous step-down DC-DC converter that operates from input voltage sources up to 30V. Integrated features include a high-side and a low-side switch, fixed frequency peak current mode control, internal compensation, peak current limit and overtemperature protection. The MCP16311/2 provides all the active functions for a local DC-DC conversion with fast transient response and accurate regulation.

The MCP16311/2 switching regulator's high-efficiency is achieved by integrating the current-limited, low resistance, high-speed, high-side and low-side switches, together with their associated driving circuitry. The MCP16311 can operate in Pulse Frequency Modulation/Pulse Width Modulation (PFM/PWM) mode; it switches in PFM mode for light load conditions and for large Buck conversion ratios. This results in a higher efficiency over all load ranges. The MCP16312 runs in PWM-only mode and is recommended for noise-sensitive applications.

The MCP16311/2 device family can supply up to 1A of continuous current while regulating the output voltage from 2V to 24V. An integrated high-performance peak current mode architecture keeps the output voltage tightly regulated even during input voltage steps and output current transient conditions, which are common in power systems.

The EN input is used to turn the device on and off. While off, only a few micro amps of current are drawn from the input.

Output voltage is set with an external resistive divider. The MCP16311/2 is offered in small MSOP-8 and 2 mm x 3 mm TDFN surface mount packages.

1.2.1 DEVICE FEATURES

- Up to 95% Efficiency
- Input Voltage Range: 4.4V to 30V
- 1A Output Current Capability
- Output Voltage Range: 2.0V to 24V
- Passes Automotive AEC-Q100 Reliability Testing
- Integrated N-Channel High-Side and Low-Side Switches:
  - 170 mΩ, Low Side
  - 300 mΩ, High Side

- Stable Reference Voltage: 0.8V
- Automatic Pulse Frequency Modulation/Pulse Width Modulation (PFM/PWM) Operation (MCP16311):
  - PFM Operation Disabled (MCP16312)
  - PWM Operation: 500 kHz
- Low Device Shutdown Current: 3 µA, typically
- Low Device Quiescent Current: 44 µA (Non-switching, PFM Mode)
- Internal Compensation
- Internal Soft-Start: 300 µs (EN Low-to-High)
- Peak Current Mode Control
- Cycle-by-Cycle Peak Current Limit
- Undervoltage Lockout (UVLO):
  - 4.1V, typically, to start
  - 3.6V, typically, to stop
- Thermal Shutdown:
  - +150°C
  - +25°C Hysteresis

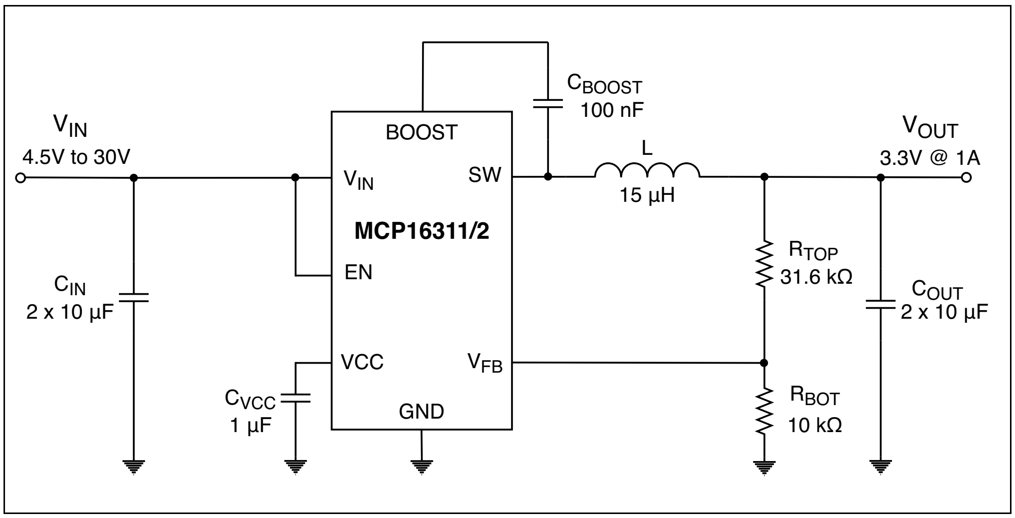


FIGURE 1-1: *Typical MCP16311/2 Step-Down Application*

1.3 WHAT IS THE MCP16311/2 HIGH EFFICIENCY BUCK-BOOST CONVERTER REFERENCE DESIGN?

The MCP16311/2 High Efficiency Buck-Boost Converter Reference Design is an application meant to demonstrate the versatility of a typical step-down switching regulator and uses a method of improving the converter's efficiency while enhancing the output current capabilities in particular conditions. The proposed method consists of providing a buck-only operation mode, as shown in Figure 2-1.

1.4 CONTENTS OF THE MCP16311/2 HIGH EFFICIENCY BUCK-BOOST CONVERTER REFERENCE DESIGN KIT

The MCP16311/2 High Efficiency Buck-Boost Converter Reference Design Kit includes:

- MCP16311/2 High Efficiency Buck-Boost Converter Reference Design Board
- Important Information Sheet

Chapter 2. Installation and Operation

2.1 INTRODUCTION

The MCP16311/2 High Efficiency Buck-Boost Converter Reference Design Board has been developed to demonstrate the MCP16311/2 step-down switching regulator's capabilities in a non-typical application. It also provides a solution for improving the converter's efficiency and maximum current that can be delivered to the output, compared to a typical noninverting buck-boost converter. Figure 2-1 shows a simplified block diagram of the circuit, while Figure 2-2 displays the simplified schematic of the proposed circuit.

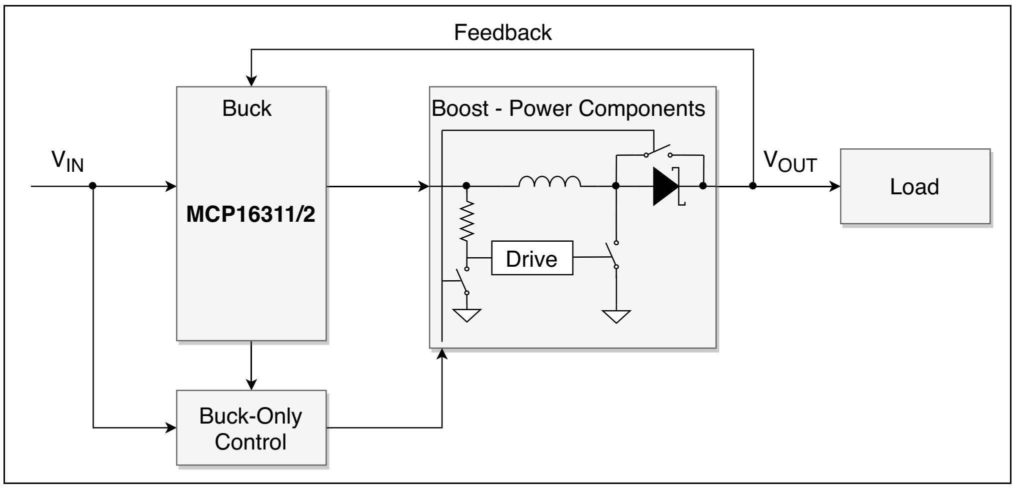


FIGURE 2-1: *MCP16311/2 High Efficiency Buck-Boost Converter Reference Design Simplified Block Diagram*

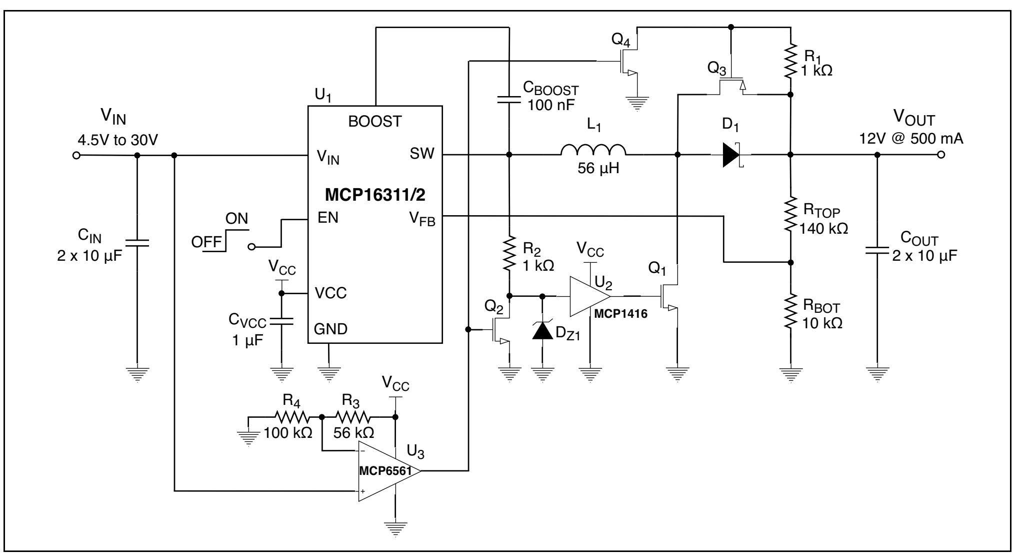


FIGURE 2-2: *MCP16311/2 High Efficiency Buck-Boost Converter Reference Design Simplified Schematic*

2.2 FEATURES

The MCP16311/2 High Efficiency Buck-Boost Converter Reference Design Board has the following features:

- 4.4V to 30V Input Voltage Range
- 1A (maximum) Continuous Output Current – Only in Buck Mode of Operation
- High Efficiency (up to 93% in Buck Mode of Operation)
- Buck-Boost to Buck Mode of Operation transition (hysteresis of ±200 mV) around 13.5V

2.3 MODE OF OPERATION

The proposed solution is a conventional noninverting buck-boost converter which uses a single inductor and has an additional MOSFET (Q_1) and an extra diode (D_1), compared to a classic inverting buck-boost or a step-down converter. By turning the internal high-side switch together with Q_1 on and off simultaneously, the converter operates in buck-boost mode. The ideal waveforms of a noninverting buck-boost converter operating in Buck-Boost Mode and Continuous Conduction Mode (CCM) are shown in Figure 2-3.

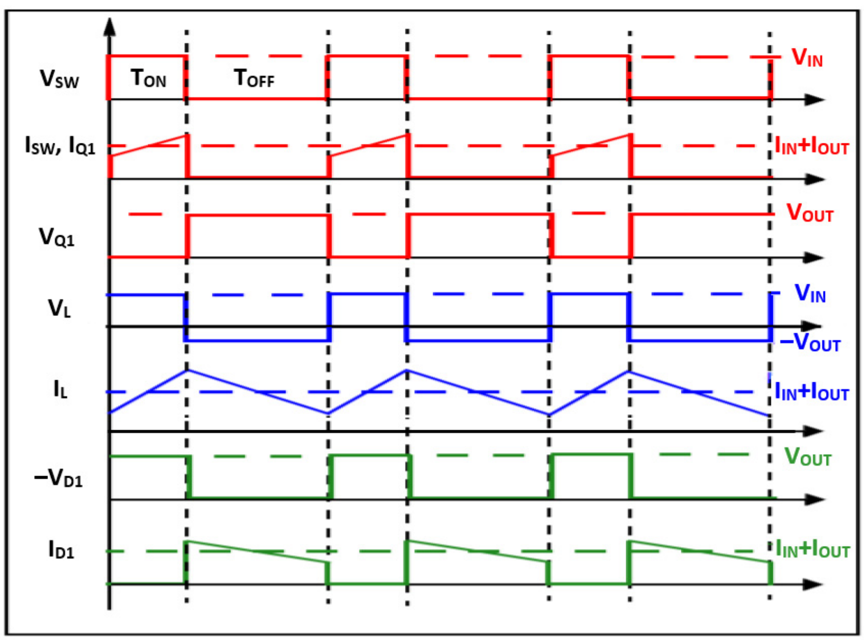


FIGURE 2-3: *Noninverting Buck-Boost Converter Waveforms in CCM*

Regarding the ratings, both the internal high-side and low-side switches see a voltage stress of V_{IN}, while Q_1 and D_1 see a voltage stress of V_{OUT}. The internal high-side and low-side switches, together with Q_1, D_1 and L_1, all see a current stress of $I_{IN} + I_{OUT}$, with the inductor's current ripple being neglected. The relatively large number of power devices and high-current stress in buck-boost mode of operation prevent the converter from being very efficient. The proposed noninverting buck-boost converter is a cascaded combination of a Buck converter followed by a Boost converter, both sharing the same inductor. The internal high-side switch and Q_1 have identical gate control signals. To increase the converter's efficiency and maximum output current capabilities, a few additional components are needed (Q_2, Q_3 and U_3) and represent a slight increase in complexity. The mode of operation for the proposed circuit is described in the following paragraphs.

When the input voltage is greater than the output voltage ($V_{IN} > V_{OUT}$), the output of the U_3 comparator (Figure 2-2) goes from low to high and turns on the Q_2 and Q_3 switches to disable the PWM signal for the main switch of the Boost leg and to bypass its rectifier (Schottky diode, D_1). As a result, Q_1 and D_1 are off and the circuit operates as a Buck converter. The comparator (U_3) has a hysteresis adjusted to approximately 400 mV, to avoid instability when the input voltage is very close to the threshold value. The output voltage of 12V is set by the R_{TOP} and R_{BOT} resistors.

2.4 GETTING STARTED

The MCP16311/2 High Efficiency Buck-Boost Reference Design Board is fully assembled and tested. For the evaluation of this board, it is required to use laboratory equipment, such as: an external power supply, voltmeter, ammeter, oscilloscope and electronic/resistive load.

2.4.1 Setup and Testing

2.4.1.1 SETTING UP THE BOARD

When the board is ready for evaluation, follow the steps below that describe the power-up procedure. Make sure that the power supply is connected to the input voltage connectors, while satisfying the correct polarity – positive to the VIN connector and negative to the GND connector. The maximum input voltage must not exceed 30V. Connect the positive voltage output connection of the electronic load to the VOUT connector and the negative output connection of the load to the GND connector of the board. If a resistive load is used, connect it to the VOUT and GND connectors of the board.

To test the board, follow the next steps:

1. Connect the power supply, voltmeter, ammeter and the load as shown in Figure 2-4. Set the ammeter to the 10A range (or to a range between 5A and 20A).
2. Set the input voltage to 9V and apply a load (resistive, 60Ω, or electronic) of 200 mA.
3. Make sure the EN switch is ON, as marked on the board silkscreen, then power up the unit.
4. Read the indication of the voltmeter connected to the output; it will display a value around 12V (±200 mV); the converter runs in Buck-Boost Mode of Operation.
5. Set the input voltage to 12V and keep the same load (resistive, 60Ω, or electronic) of approximately 200 mA.
6. Read the indication of the voltmeter connected to the output; it will display a value around 12V (±200 mV); the converter operates in Buck-Boost Mode, being close to the Buck Mode of Operation boundary.
7. Set the input voltage to 15V and keep the same load (resistive, 60Ω, or electronic) of approximately 200 mA.
8. Read the indication of the voltmeter connected to the output; it will display a value around 12V (±200 mV); now, the converter operates in Buck Mode.

Note: Do not exceed 30V on the input voltage and the maximum load, depending on the input voltage, as shown in Figure 2-8.

Optionally, for more advanced readings, follow the next steps:

9. Sweep the input voltage from 7V to 30V (1V step) and follow the reading of the voltmeter connected at the output.
10. Sweep the output load while not exceeding the values displayed in Figure 2-8.
11. For monitoring the switching waveforms, connect the CH1 probe of the oscilloscope to the SW test point.
12. For measuring the AC ripple of the output voltage, connect the CH2 probe of the oscilloscope on the VOUT connector and set the AC coupling for CH2 on the oscilloscope.
13. To monitor the control signal for the Buck-Only Mode of Operation, connect the CH3 probe of the oscilloscope to the GATE test point.

> **Note:** For a more accurate output voltage ripple measurement, it is recommended to use the probe tip and ground spring connections close to the output capacitor.

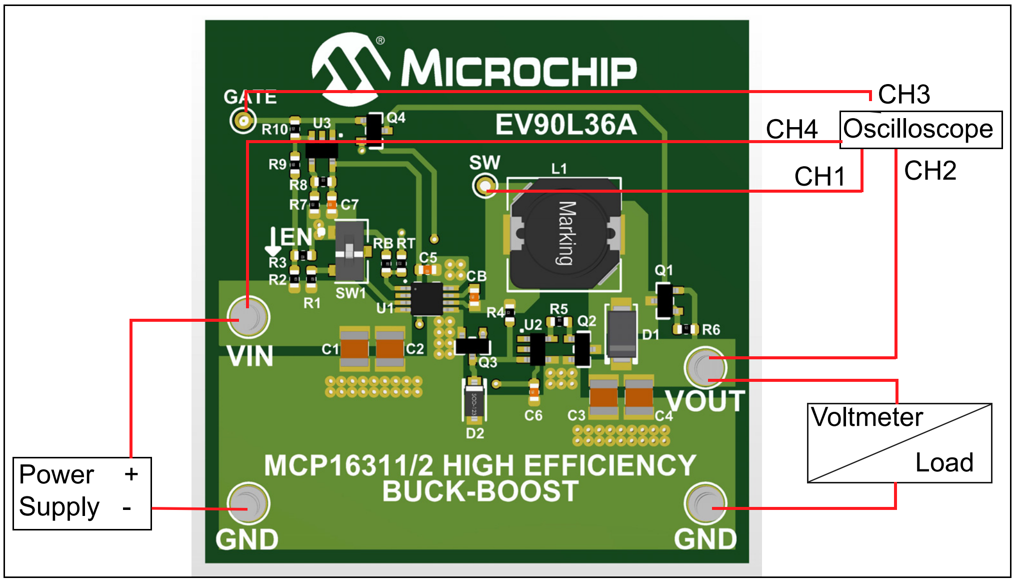


FIGURE 2-4: *MCP16311/2 High Efficiency Buck-Boost Converter Reference Design Board Test Setup*

2.4.1.2 BOARD TESTING

To detect the transition from Buck-Boost Mode of Operation to Buck Mode of Operation, connect the four probes of the oscilloscope on the following test points from the board: CH1 to SW test point (switch node), CH2 to VOUT connector, CH3 to GATE test point and CH4 to VIN connector.

Power up the board by applying less than 12V; then, slowly increase the input voltage (with 100 mV increments) between 12V and 13V, while monitoring the GATE signal. The transition from Buck-Boost to Buck Mode of Operation takes place at around 13.3V – 13.7V; to avoid instability, a hysteresis of 400 mV was set. When the GATE signal goes high and the switching devices from the Boost leg are bypassed, the duty cycle of the converter will increase due to the change in operating mode (from Buck-Boost to Buck Mode).

As an example, the oscilloscope screen capture displayed in Figure 2-5 shows the start-up waveforms for 18V Input, 12V Output and 500 mA Load.

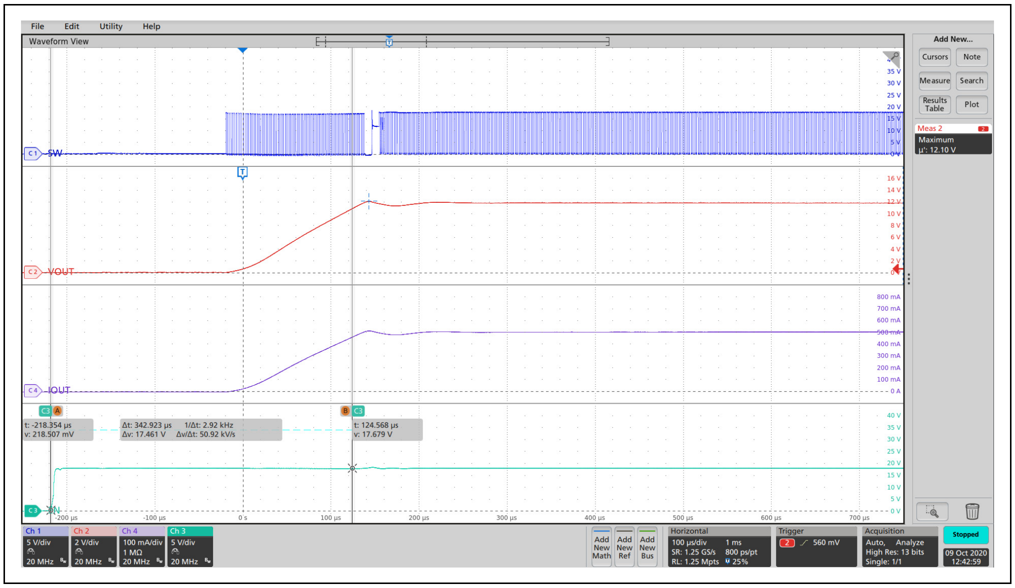


FIGURE 2-5: *Buck-Boost Startup from Enable Waveforms at 18V Input Voltage, 12V Output Voltage and 500 mA Load Current*

Figure 2-6 displays the MCP16311/2 High Efficiency Buck-Boost converter switching waveforms during Buck-Boost operation, when supplied from 9V V_{IN}, at 12V V_{OUT} and 200 mA output load current.

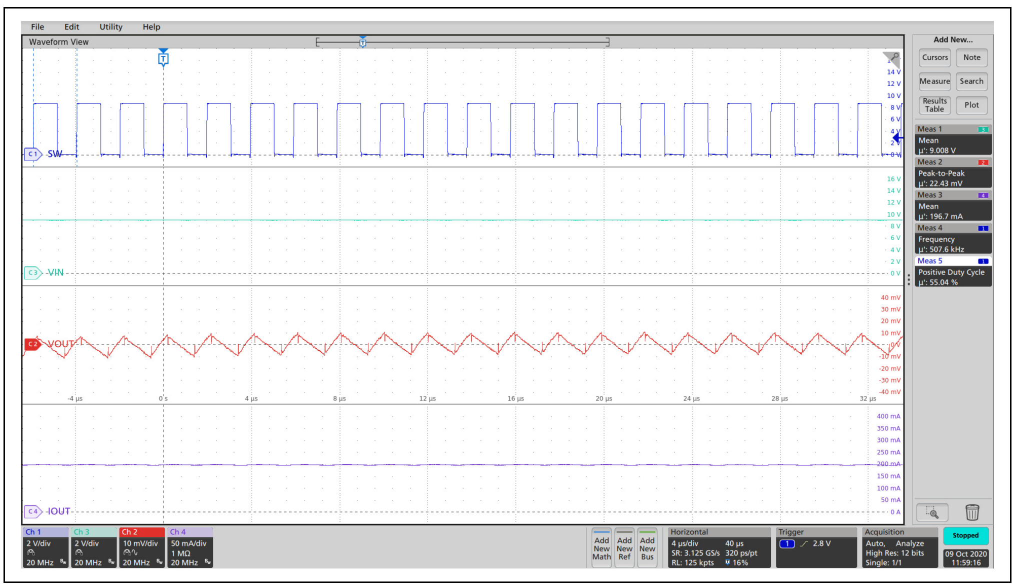


FIGURE 2-6: *Buck-Boost Operation Switching Waveforms at 9V Input Voltage, 12V Output Voltage and 200 mA Load Current*

2.4.1.3 RESULTS

After performing efficiency measurements, the results were summarized in Figure 2-7. For an 8V input voltage and 12V output voltage, the efficiency is slightly improved in the range of 100 mA – 200 mA, compared to 12V input voltage; however, for higher loads, the best results are achieved for 16V input voltage, due to the small difference between the input and output voltage, as well as the reduced losses associated with the Buck Mode of Operation.

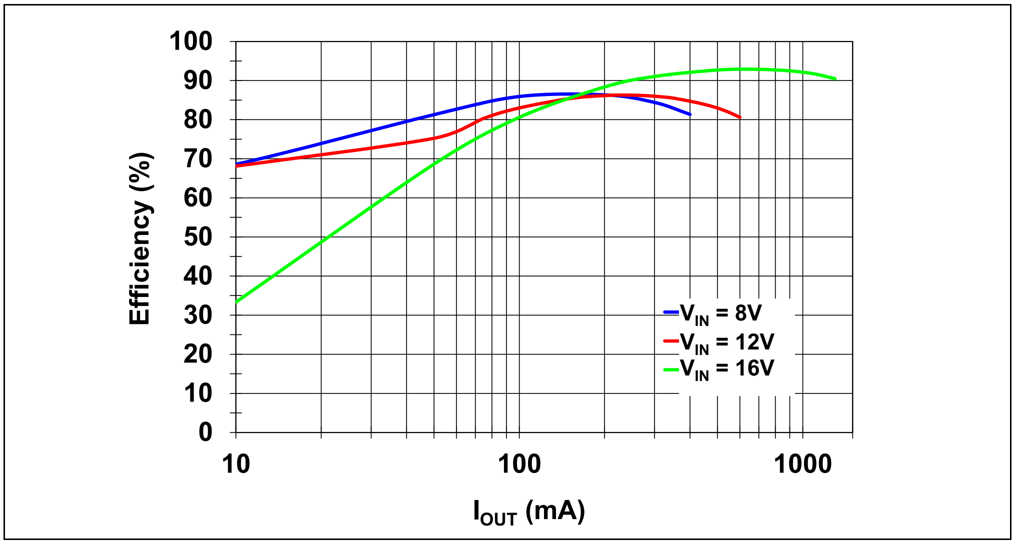


FIGURE 2-7: MCP16311/2 High Efficiency Buck-Boost Converter Reference Design Efficiency vs. Load

The maximum output current versus the input voltage graph is shown in Figure 2-8 and it is recommended that it be considered when testing the board and increasing the load, to avoid triggering current limit protection.

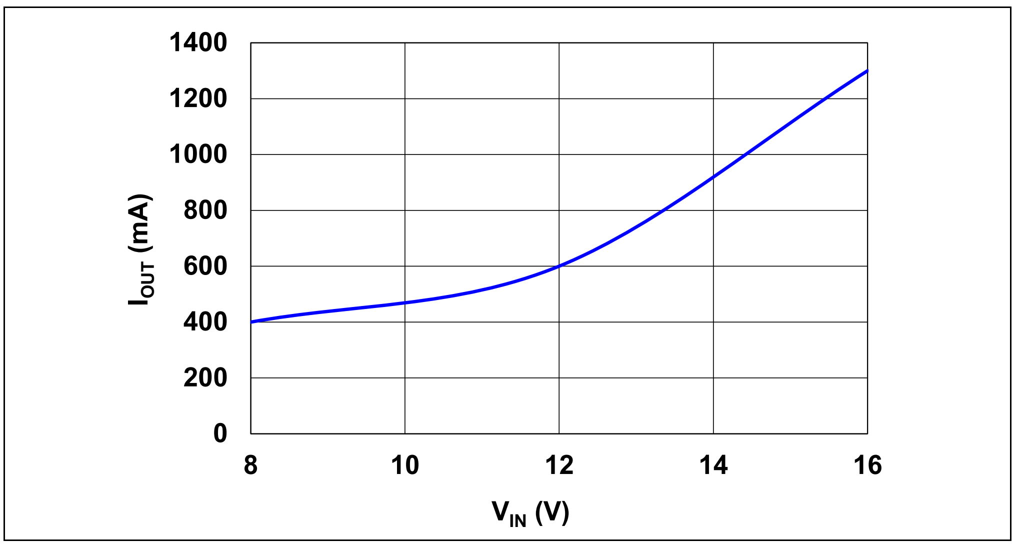


FIGURE 2-8: MCP16311/2 High Efficiency Buck-Boost Converter Reference Design Maximum Output Current vs. Input Voltage

2.4.1.4 PCB LAYOUT CONSIDERATIONS WHEN DESIGNING WITH MCP16311/2

For the best performance with minimum board space utilization, it is recommended that some proper layout techniques be applied. Below are a few guidelines to follow when designing with MCP16311/2.

It is important that the input and output capacitors be placed as close as possible to the MCP16311/2, to minimize the loop area. The small loops help to prevent injected switching noise in those loops and to ensure a low input and output voltage ripple. The feedback resistors must be routed away from the switching node and from the switching current loop, to avoid noise being coupled into the high-impedance V_{FB} input. Ground planes and traces must be used to shield the feedback signal, to minimize the noise and electromagnetic interference; the planes also have the role of minimizing the input and output current loops. The best placement for the inductor is as close as possible to the SW pin of the IC, as well as to the boost capacitor (C_{BOOST}). The best placement for the boost capacitor is between the BOOST pin and the SW pin.

NOTES:

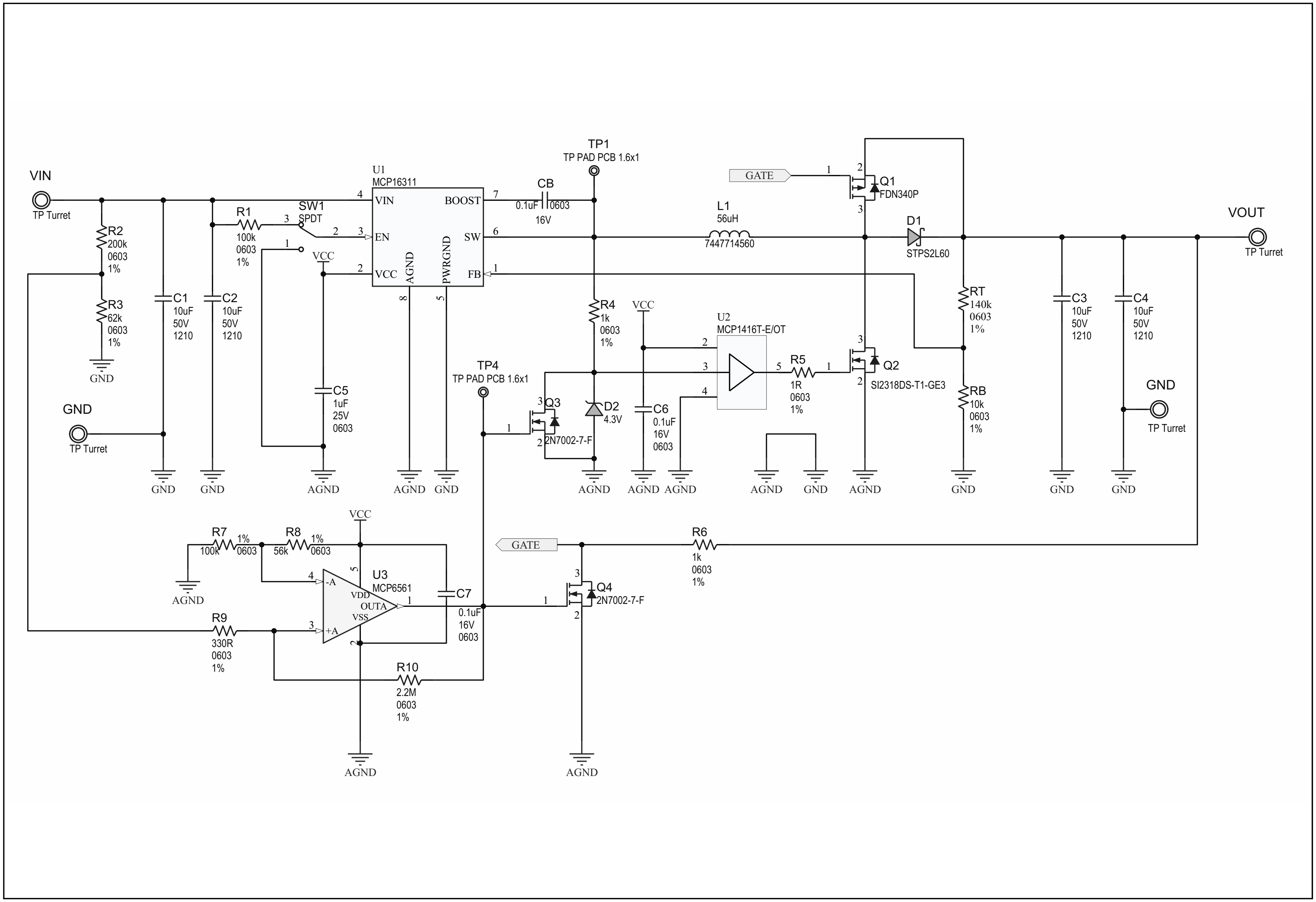
Appendix A. Schematics and Layouts

A.1 INTRODUCTION

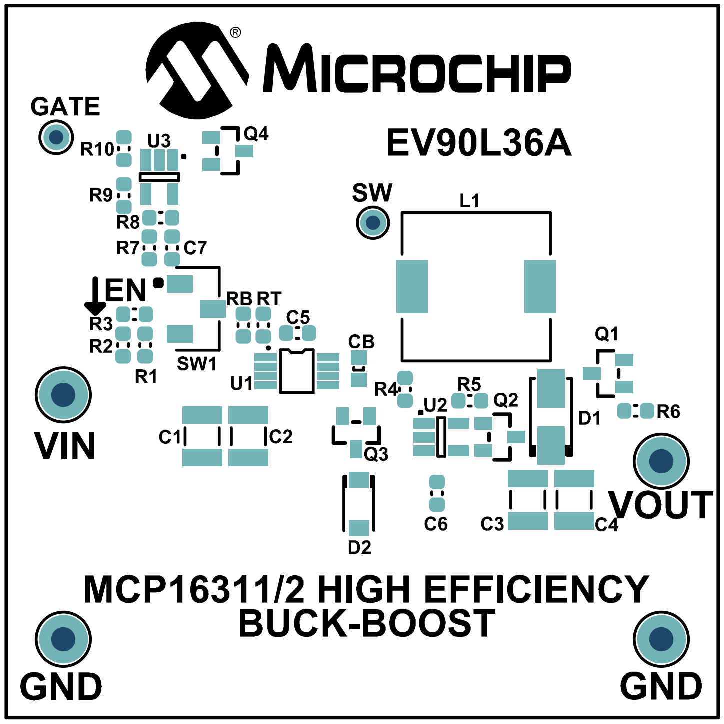
This appendix contains the following schematics and layouts for the MCP16311/2 High Efficiency Buck-Boost Converter Reference Design:

- Board – Schematic
- Board – Top Silk
- Board – Top Copper and Silk
- Board – Top Copper
- Board – Bottom Copper
- Board – Bottom Copper & Silk
- Board – Bottom Silk

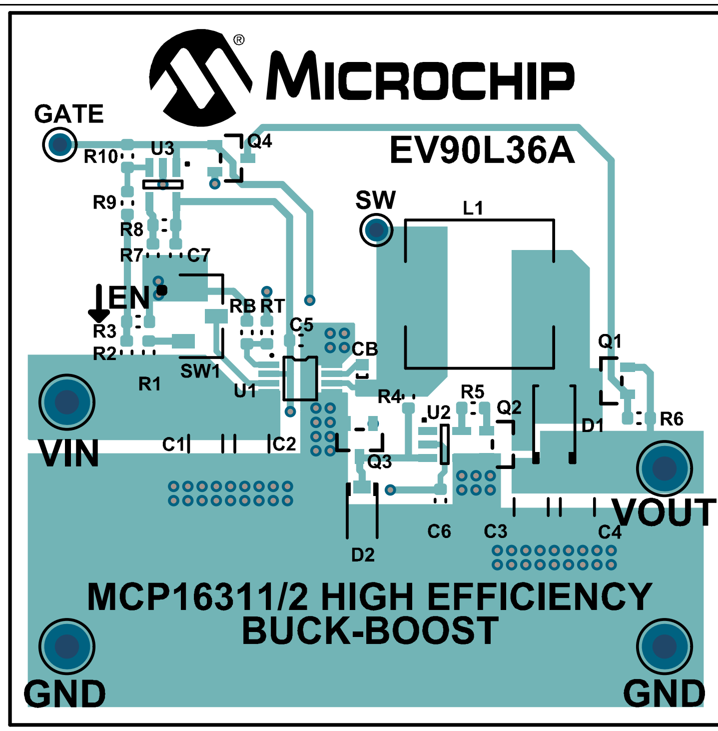
A.2 BOARD – SCHEMATIC



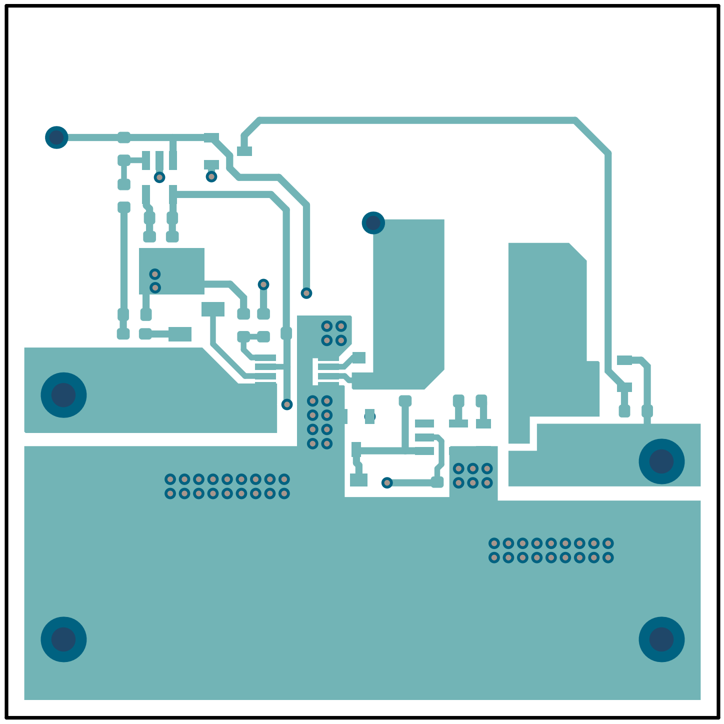
A.3 BOARD – TOP SILK



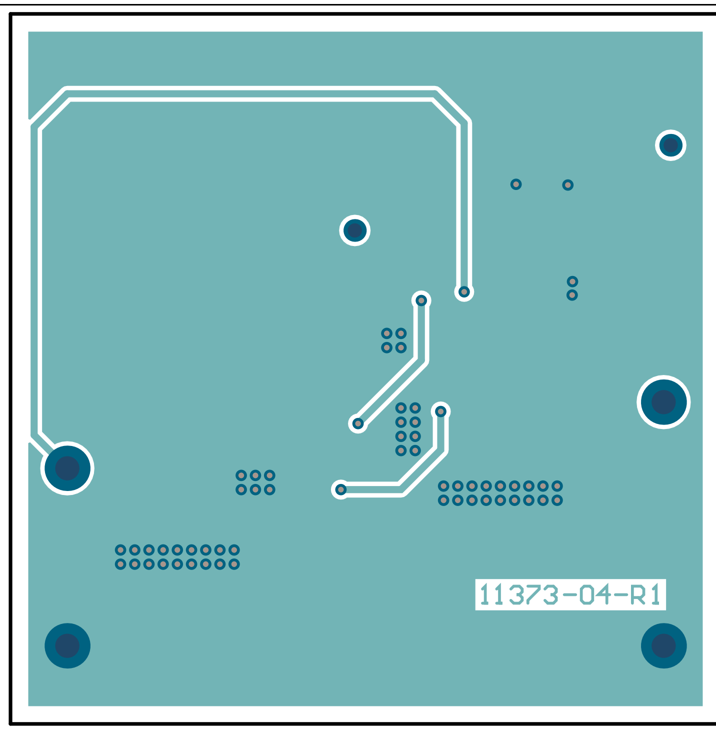
A.4 BOARD – TOP COPPER AND SILK



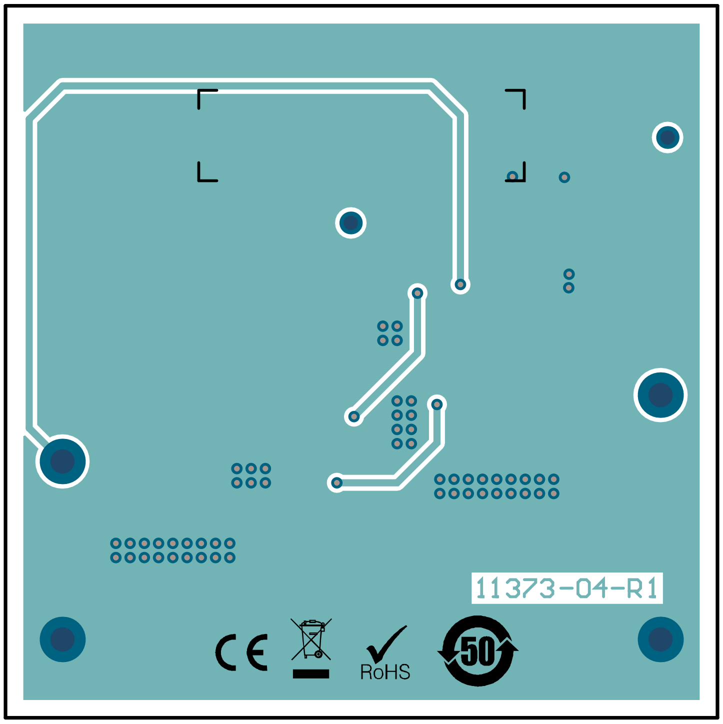
A.5 BOARD – TOP COPPER



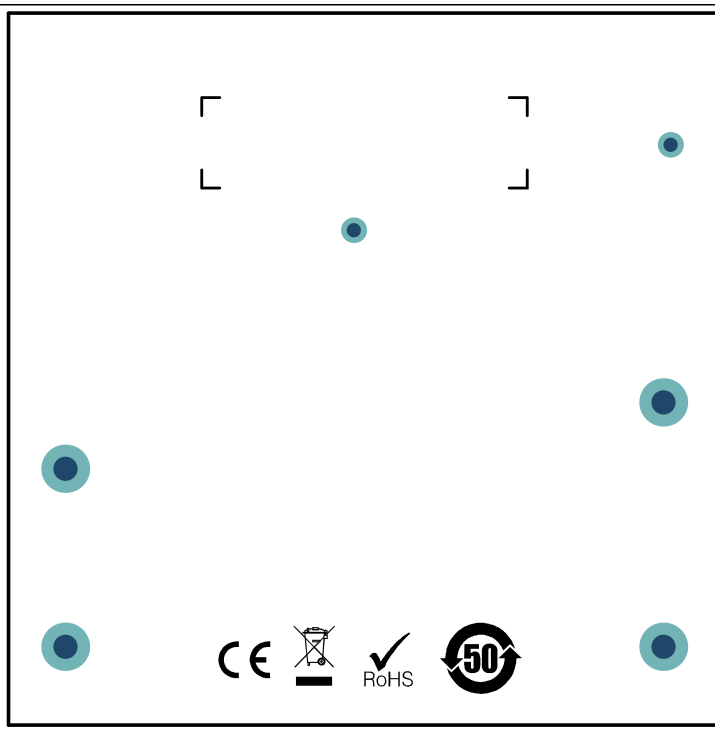
A.6 BOARD – BOTTOM COPPER



A.7 BOARD – BOTTOM COPPER & SILK



A.8 BOARD – BOTTOM SILK



NOTES:

Appendix B. Bill of Materials (BOM)

TABLE B-1: BILL OF MATERIALS (BOM)

Qty.	Reference	Description	Manufacturer	Part Number
4	C1, C2, C3, C4	Capacitor, Ceramic,10 µF, 50V, 20%, X7R, SMD, 1210	TDK Corporation	C3225X7R1H106M250AC
1	C5	Capacitor, Ceramic, 1 µF, 25V, 10%, X7R, SMD, 0603	TDK Corporation	CGA3E1X7R1E105K080AC
3	C6, C7, CB	Capacitor, Ceramic, 0.1 µF, 16V, 10%, X7R, SMD, 0603	Taiyo Yuden Co. Ltd.	EMK107B7104KA-T
1	D1	Diode, Schottky, STPS2L60A, 60V, 2A, DO214AC	STMicroelectronics	STPS2L60A
1	D2	Diode, Zener, MMSZ5229B, 4.3V, 500 mW, SMD, SOD-123	Diodes Incorporated®	MMSZ5229B-7-F
1	L1	Inductor, 56 µH, 2.3A, 20%, SMD, L10W10H5	Wurth Elektronik	7447714560
1	PCB	Printed Circuit Board	Microchip Technology Inc.	11373-04-R1
1	Q1	Transistor, FET, P-CH, FDN340P, 20V, 2A, 0.07R, 0.5W, SSOT-3	Fairchild Semiconductor	FDN340P
1	Q2	Transistor, FET, N-CH, SI2318DS-T1-GE3, 40V, 3A, 750 mW, SOT-23-3	Vishay Siliconix	SI2318DS-T1-GE3
2	Q3, Q4	Transistor, FET, N-CH, 2N7002-7-F, 60V, 170 mA, 370 mW, SOT-23-3	Diodes Incorporated®	2N7002-7-F
2	R1, R7	Resistor, TF, 100k, 1%, 1/8W, SMD, 0603	Vishay	MCT06030C1003FP500
1	R2	Resistor, TKF, 200k, 1%, 1/10W, SMD, 0603	Vishay	CRCW0603200KFKEA
1	R3	Resistor, TKF, 62k, 1%, 1/10W, SMD, 0603	Stackpole Electronics Inc	RMCF0603FT62K0
2	R4, R6	Resistor, TKF, 1k, 1%, 1/10W, SMD, 0603	Panasonic	ERJ-3EKF1001V
1	R5	Resistor, TKF, 1R, 1%, 1/10W, SMD, 0603	Panasonic	ERJ-3RQF1R0V
1	R8	Resistor, TKF, 56k, 1%, 1/10W, SMD, 0603	Panasonic	ERJ-3EKF5602V
1	R9	Resistor, TKF, 330R, 1%, 1/10W, SMD, 0603	Panasonic	ERJ-3EKF3300V
1	R10	Resistor, TKF, 2.2M, 1%, 1/10W, SMD, 0603	Panasonic	ERJ-3EKF2204V
1	RB	Resistor, TF, 10k, 1%, 1/8W, SMD, 0603	Vishay Beyschlag	MCT06030C1002FP500
1	RT	Resistor, TKF, 140k, 1%, 1/10W, SMD, 0603	Panasonic	ERJ-3EKF1403V
1	SW1	Switch, Slide, SPDT, 6V, 0.1A, TH	Nidec Copal Electronics	CJS-1200TA
4	TP2, TP3, TP5, TP6	Connector, TestPoint Turret, Tin, TH	Harwin	H2121-01

Note: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

TABLE B-1: BILL OF MATERIALS (BOM) (CONTINUED)

Qty.	Reference	Description	Manufacturer	Part Number
1	U1	Microchip Analog Switcher, Buck, 2V to 24V MCP16311-E/MS, MSOP-8	Microchip Technology Inc.	**MCP16311-E/MS**
1	U2	Microchip Analog FET Driver, Single Noninverting, MCP1416T-E/OT, SOT-23-5	Microchip Technology Inc.	**MCP1416T-E/OT**
1	U3	Microchip Analog Comparator, 1-Ch, MCP6561T-E/OT, SOT-23-5	Microchip Technology Inc.	**MCP6561T-E/OT**

Note: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

NOTES:

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