



MCP16301
High-Performance Low-Noise
5V Output Buck Converter
Evaluation Board
User's Guide

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Buck Converter Evaluation Board User's Guide

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VP Development Tools

07-Dec-11
Date



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Preface

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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 web site (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 “DSXXXXA”, where “XXXX” 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 MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board. Items discussed in this chapter include:

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

DOCUMENT LAYOUT

This document describes how to use the MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board as a development tool to emulate and debug firmware on a target board. The manual layout is as follows:

- **Chapter 1. “Product Overview”** – Important information about the MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board
- **Chapter 2. “Installation and Operation”** – Includes instructions on how to get started with the MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board and a description of the user's guide
- **Appendix A. “Schematic and Layouts”** – Shows the schematic and layout diagrams for the MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board
- **Appendix B. “Bill of Materials (BOM)”** – Lists the parts used to build the MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

Description	Represents	Examples
Arial font:		
Italic characters	Referenced books	<i>MPLAB[®] IDE User's Guide</i>
	Emphasized text	...is the <i>only</i> 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><i>File>Save</i></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	<i>file.o</i> , where <i>file</i> can be any valid filename
Square brackets []	Optional arguments	mcc18 [options] <i>file</i> [options]
Curly brackets 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 MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

- **MCP16301 Data Sheet – “High-Voltage Input Integrated Switch Step-Down Regulator” (DS25004)**
- **MCP16301 High-Voltage Buck-Boost Demo Board User’s Guide (DS52020)**
- **MCP16301 High-Voltage Buck Converter 600 mA Demo Board User’s Guide (DS51978)**

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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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- Field Application Engineer (FAE)
- Technical Support

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Technical support is available through the web site at:
<http://www.microchip.com/support>.

DOCUMENT REVISION HISTORY

Revision B (August 2013)

- Updated the board layout in [Figure 2-2](#).
- Updated the [A.3 “Board – Top Silk And Copper”](#) and [A.6 “Board – Bottom Copper and Pads”](#) layouts in [Appendix A. “Schematic and Layouts”](#).
- Updated [Appendix B. “Bill of Materials \(BOM\)”](#).

Revision A (June 2012)

- Initial Release of this Document.

NOTES:



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Chapter 1. Product Overview

1.1 INTRODUCTION

This chapter provides an overview of the MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board and covers the following topics:

- MCP16301 Short Overview
- What Is the MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board?
- MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board Kit Contents

1.2 MCP16301 SHORT OVERVIEW

The MCP16301 device is a highly integrated, high-efficiency, fixed frequency, step-down DC-DC converter in a popular 6-pin SOT-23 package, that operates from input voltage sources up to 30V. Integrated features include a high-side switch, fixed frequency peak current mode control, internal compensation, peak current limit and overtemperature protection.

All control system components necessary for stable operation over the entire device operating range are integrated.

High-converter efficiency is achieved by integrating the current-limited, low-resistance, high-speed N-Channel MOSFET and associated drive circuitry. High-switching frequency minimizes the size of the external filtering components, resulting in a small solution size.

The MCP16301 is a high-input voltage step-down regulator, capable of supplying a maximum of 600 mA to a regulated output voltage from 2.0V to 15V. An integrated precise 0.8V reference combined with an external resistor divider sets the desired converter output voltage. The internal reference voltage rate of rise is controlled during startup, minimizing the output voltage overshoot and the inrush current.

The internally trimmed 500 kHz oscillator provides a fixed frequency, while the peak current mode control architecture varies the duty cycle for output voltage regulation. An internal floating driver is used to turn the high side integrated N-Channel MOSFET on and off. The power for this driver is derived from an external boost capacitor whose energy is supplied from a fixed voltage ranging between 3.0V and 5.5V, typically the output voltage of the converter. For applications with $5.5V < V_{OUT} < 15V$ and $V_{IN} < 30V$, an alternative boost supply must be used (from input derived, output derived or an auxiliary system voltage). For more information and examples, see the MCP16301 data sheet.

The EN input is used to enable and disable the device. If disabled, the MCP16301 device consumes 7 μA (typical) from the input. An integrated Under Voltage Lockout (UVLO) prevents the converter from starting until the input voltage is high enough for normal operation. The converter will typically start at 3.5V and operate down to 3.0V.

An overtemperature protection limits the silicon die temperature to +150°C by turning the converter off. The normal switching resumes at +120°C.

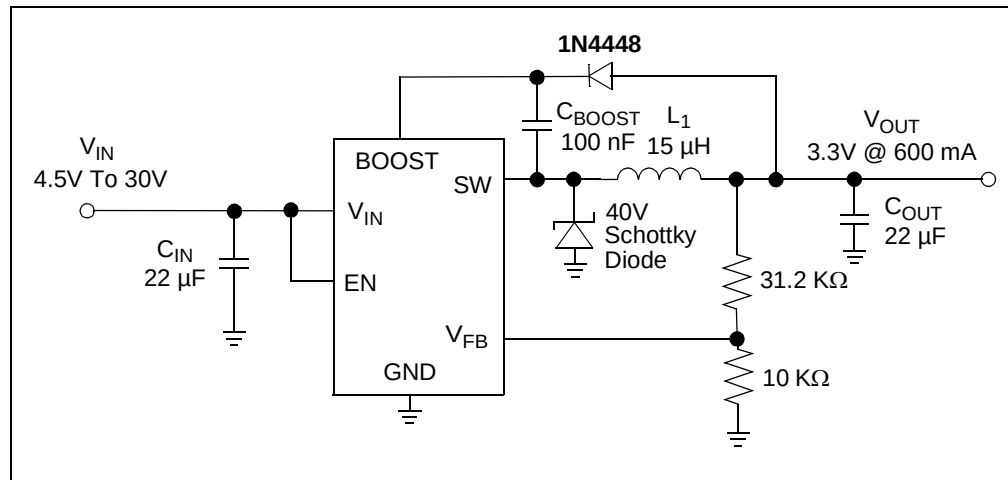


FIGURE 1-1: Typical MCP16301 3.3V OUT Application.

1.2.1 MCP16301 Features

- Up to 96% Typical Efficiency
- Input Voltage Range: 4.0V to 30V
- Output Voltage Range: 2.0V to 15V
- 2% Output Voltage Accuracy
- 600 mA Output Current
- Quiescent Current (Switching Mode, No Load): 2 mA Typical
- Quiescent Current (Shutdown, EN = 0): 7 μA Typical
- 500 kHz Fixed Frequency
- Peak Current Mode Control
- Internal Compensation
- Internal Soft-Start
- Cycle-by-Cycle Peak Current Limit
- Undervoltage Lockout (UVLO): 3.5V to Start, 3.0V to Stop
- Overtemperature Protection
- Package type: SOT-23-6

1.3 WHAT IS THE MCP16301 HIGH-PERFORMANCE LOW-NOISE 5V BUCK CONVERTER EVALUATION BOARD?

The MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board is designed to operate from a 6V to 30V input and regulate the output to 5V, while delivering a maximum 600 mA of load current.

The evaluation board is optimized for a high-efficiency and low-output noise and ripple, especially at 12V Input and 100 mA load current. Because the MCP16301 is switching fast to achieve high efficiency, high-frequency noise is generated and may affect some RF systems. This evaluation board demonstrates a low-noise, high-performance design.

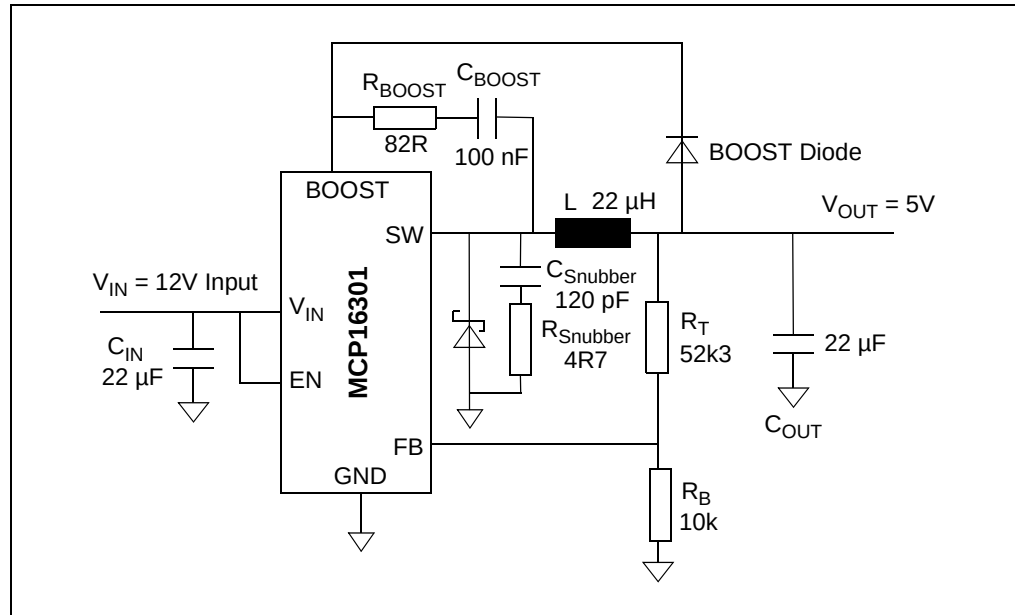


FIGURE 1-2: MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board Block Diagram.

1.4 MCP16301 HIGH-PERFORMANCE LOW-NOISE 5V BUCK CONVERTER EVALUATION BOARD KIT CONTENTS

The MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board kit includes:

- MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board
- Important Information Sheet

NOTES:



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Chapter 2. Installation and Operation

2.1 INTRODUCTION

The MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board is used to demonstrate a high-voltage input DC-DC converter design, that can deliver high efficiency, while minimizing high-frequency switching noise. The board steps down high-input voltages, up to 30V, to a low-output voltage, having more than 90% efficiency and a minimum of 30 mV output ripple.

High-frequency input/output noise generated by the switching converters can reach high-noise levels that interfere with other devices powered from the same source. The high amplitude of high-frequency noise can disturb some RF systems.

High efficiency is achieved with the MCP16301 buck converter by switching the integrated N-Channel MOSFET at a high speed. This high speed can cause disturbances to other system components if the high-speed switching edges of the converter are not minimized. The designer must be concerned with:

- good PCB layout practice
- choosing high-quality shielded inductors and low Equivalent Series Resistance (ESR) capacitors
- choosing an RC snubber or a R_{BOOST} resistor to properly limit the speed of the internal N-Channel MOSFET switch (see [Figure 1-2](#)).

The evaluation board is optimized for 12V Input and 100 mA load.

2.1.1 MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board Features

The MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board has the following key features:

- Input Voltage: 6 to 30V
- Output Voltage: 5V
- Output Capability: 600 mA Load Current
- Output Ripple Plus Noise: 30 mV_{p-p} @ 12V Input and 100 mA Load
- Low-Radiated Noise
- Efficiency: Up to 91% @ 12V Input (see [Figure 2-1](#))

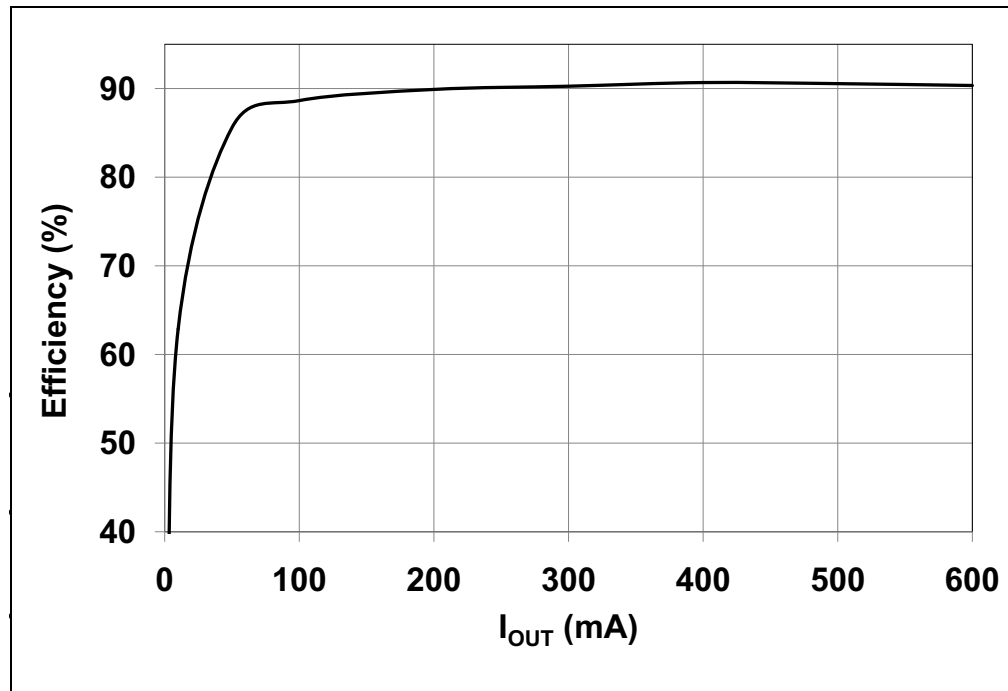


FIGURE 2-1: Efficiency vs. Load Current at 12V Input.

2.2 GETTING STARTED

The MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board is fully assembled and tested to evaluate and demonstrate the MCP16301 design.

2.2.1 Power Input and Output Connection

2.2.1.1 POWERING THE MCP16301 HIGH-PERFORMANCE LOW-NOISE 5V BUCK CONVERTER EVALUATION BOARD

When the board is ready for evaluation, apply positive input voltage to the V_{IN} terminal and the corresponding return to the ground terminal. The maximum input voltage should not exceed 30V. An electronic load or resistive load can be used for evaluation. The electronic loads attempt to sink current at 0V during startup. A resistive load or constant resistance is recommended for startup evaluation. Connect the positive voltage terminal of the load to the V_{OUT} terminal on the evaluation board, and connect the negative or return side of the load to the ground terminal.

Connectors are placed on the bottom side of board:

- V_{IN} for positive power
- Two grounds for negative power
- V_{OUT} connector for output load

2.2.2 Board Testing

To test the board, follow these steps:

1. Apply the input voltage.
2. An external pull up resistor is connected from V_{IN} to the EN input of the MCP16301. Once the input voltage is greater than 3.5V, the device begins to switch. Apply greater than 6V supply to the input for proper operation. A minimum load is required to regulate the output to 5V. For minimum load requirements (light load conditions), see the device data sheet for detailed information.
3. The measured output voltage should be 5V typical. Adjusting the input voltage and load should not cause the output to vary more than a few mV over the operating range of the converter.
4. Typical conditions for evaluating the board are: 12V input, 100 mA load. Using an oscilloscope, measure the AC ripple of the output without any bandwidth limitation. V_{OUT} ripple plus noise should be approximately 30 mV. To avoid errors, remove the ground lead of the scope probe and measure the output ripple on the output capacitors pads. Use a short wire wrapped around the ground barrel of the probe to touch the capacitor's ground pad.

Note: The V_{OUT} ripple plus noise value varies with the input and output parameters.

Additional analysis can be performed by changing the RC snubber and R_{BOOST} resistor values (see Figure 2-1). These additional circuits lower the efficiency, but reduce switching noise.

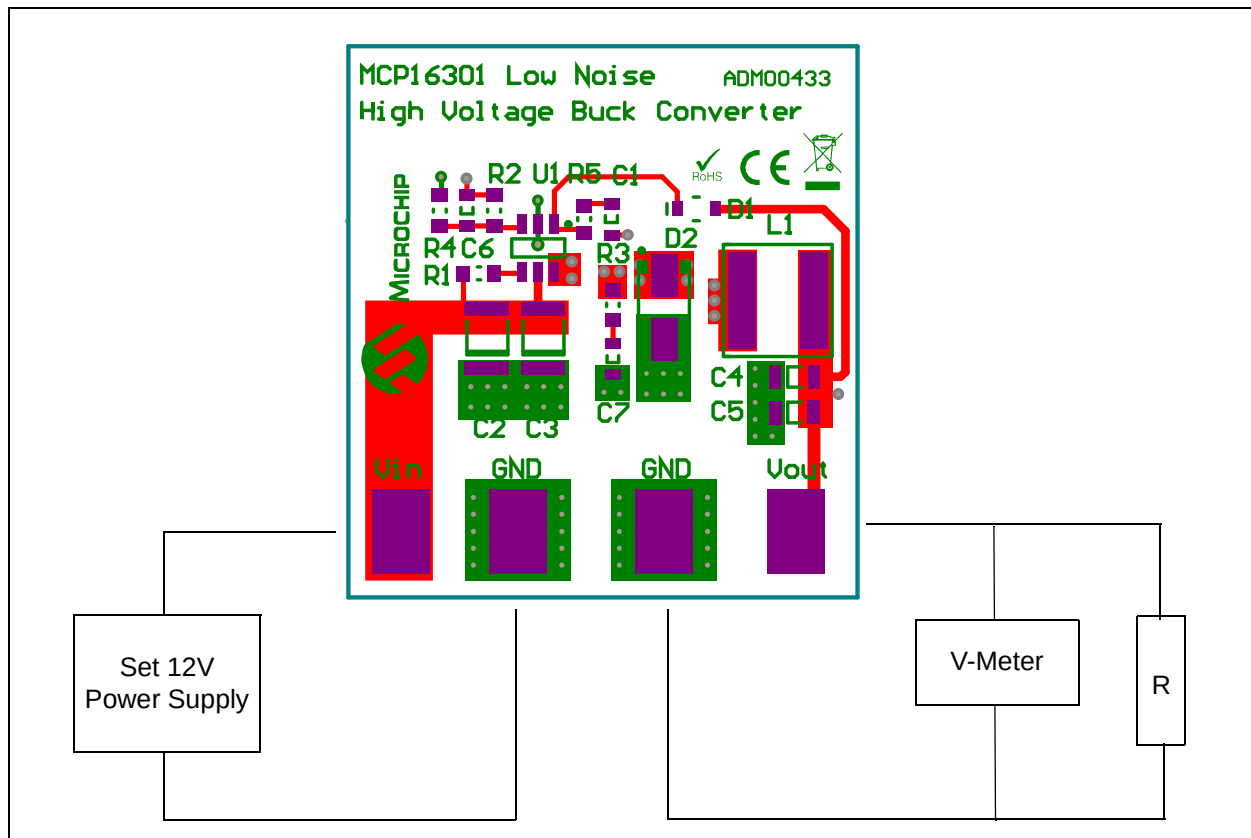


FIGURE 2-2: MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board Setup Circuit.

2.2.3 How Does the MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board Work?

The MCP16301 integrates a low resistance N-Channel MOSFET (typically 460 mΩ). A high-side or floating supply is needed to drive the gate of the N-Channel MOSFET above the input voltage (to turn it on). The evaluation board uses the 5V output voltage to charge the boost capacitor (C_{BOOST}), while the inductor current flows, clamping the SW node to a diode drop below ground. Prior to start up, there is no inductor current, so an internal precharge circuit charges the boost cap up to a minimum threshold. Once C_{BOOST} is charged, the N-Channel MOSFET can be turned on, ramping current into the inductor. The BOOST diode is used to provide a charging path for the C_{BOOST} capacitor, while current is flowing through the inductor.

The two sense resistors (R_T and R_B in [Figure 2-1](#)) set the output (V_{OUT}) at 5.0V according to the following equation:

EQUATION 2-1:

$$R_{TOP} = R_{BOT} \times \left(\frac{V_{OUT}}{V_{FB}} - 1 \right)$$

where $V_{FB} = 0.8V$ is the reference voltage of the FB pin. The transconductance error amplifier gain is controlled by its internal impedance. The external divider resistors have no effect on system gain, so a wide range of values can be used. A 10 kΩ resistor is recommended as a good trade-off for quiescent current and noise immunity.

The MCP16301 device features integrated slope compensation to prevent the bimodal operation of the pulse-width modulation (PWM) duty cycle. Internally, approximately half of the inductor current down slope is summed with the internal current sense signal. For the proper amount of slope compensation, it is recommended to keep the inductor down-slope current constant by varying the inductance with V_{OUT} . For 5.0V output, a 22 μH inductor is recommended.

The input capacitor must filter the high input ripple current, as a result of pulsing or chopping the input voltage. The MCP16301 input voltage pin is used to supply voltage for the power train and as a source for internal bias. A low Equivalent Series Resistance (ESR), preferably a ceramic capacitor, is recommended. The necessary capacitance is dependent upon the maximum load current and source impedance. Minimum capacitance at light load is 2.2 μF.

The output capacitor helps in providing a stable output voltage during sudden load transients, and reduces the output voltage ripple. The minimum value of the output capacitance is limited to 20 μF, due to the integrated compensation of the MCP16301.

The freewheeling diode creates a path for inductor current flow after the internal switch is turned off. The efficiency of the converter is a function of the forward drop voltage value and speed of the freewheeling Schottky diode.

For detailed information, see the MCP16301 Data Sheet (DS25004).

2.2.4 Reduction of the High Frequency Switching Noise

Because the MCP16301's internal MOSFET is switching at 500 kHz, high-frequency noise may appear. This can affect the circuitry in close proximity. Parasitic elements generate ringing. There are two main noise sources. The first source occurs at the fundamental switching frequency and is called "Output Ripple". The second source, associated with high-frequency ringing, occurs during the ON-OFF transition of the integrated N-Channel MOSFET switch. This results in a high-frequency noise that can be in the range of 100s of MHz and up to 500 mV peak-to-peak voltage ripple. Both noise components require separate filtering. Figure 2-3 shows an example of the two noise components.

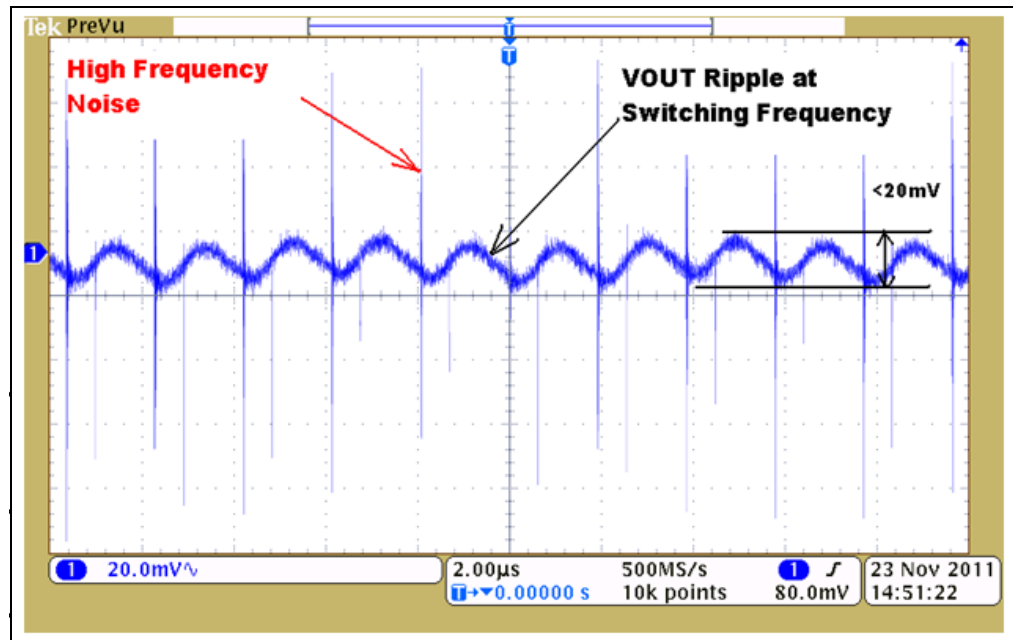


FIGURE 2-3: V_{OUT} Ripple and Noise for an MCP16301 Buck Converter Without Any Noise Reduction Components.

The low-frequency output ripple of the MCP16301 is generally less than 20 mV peak-to-peak, and it depends on the output capacitor value and capacitor dielectric type. Low ESR and Equivalent Series Inductance (ESL) ceramic capacitors significantly decrease the output voltage low-frequency ripple.

Additional output capacitance does not remove the high-frequency noise. Ceramic capacitors have high-impedance in the frequency band in which this noise occurs. The ringing frequency is very high, and the output capacitor alone or an extra low-value capacitor in parallel with it are ineffective in attenuating this noise. First, the noise can be attenuated by good PCB design practices. A four-layer board is recommended in this case. The solution is to place the SW node of the MCP16301 pin into the inner layer (Mid-Layer 2) as an individual plane between two ground planes (Mid-Layer 1 and Layer 4 - Bottom plane).

High-quality shielded inductors reduce the spreading of electromagnetic fields, a desirable characteristic of any power supply. An example of a high-quality shielded inductor is the CoilCraft Inc. XAL6060.

The third and most effective method to reduce switching noise is to slow down the turn-on of the integrated N-Channel MOSFET switch, addressing the noise at its source. This method lowers the efficiency of the converter insignificantly (see [Figure 2-6](#)), but the noise in the system is significantly reduced. A R_{BOOST} resistance value between 47 and 100 Ohms was typical for this analysis.

Placing an RC snubber in parallel with the external Schottky diode is another method that can be used to reduce high-frequency noise. Some basic equations are used to calculate the RC snubber values.

For example, the Schottky rectifier diode MBRA140T (1A/40V) has a parasitic $L_p = 2$ nH and $C_p = 38$ pF (see the MBRA140T data sheet for details). When measuring the MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board circuit without an RC snubber (for 12V Input and 100 mA load), the ringing frequency is approximately 250 MHz. Considering the parasitic inductance equal to L_p , calculate the parasitic impedance, using the following equation:

EQUATION 2-2:

$$Z = 2\pi f L_p$$

For this example, Z is approximately 3Ω . Choose a snubber resistor to be similar or greater than this value (4.7Ω standard value).

EQUATION 2-3:

$$R_{Snubber} \geq Z$$

Where:

$$R_{Snubber} = 4.7\Omega$$

With the value of $R_{Snubber}$ established, the snubber's capacitor value results from the following equation:

EQUATION 2-4:

$$C_{Snubber} = \frac{1}{2\pi f R_{Snubber}}$$

Where:

$$C_{Snubber} = 120 \text{ pF}$$

Installation and Operation

Figures 2-4 – 2-6 show the results for the MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board:

- AC output ripple for board with RC snubber only (Figure 2-4)
- AC output ripple for RC snubber and R_{BOOST} on board (Figure 2-5)
- Efficiency comparison with RC snubber and R_{BOOST} (Figure 2-6)

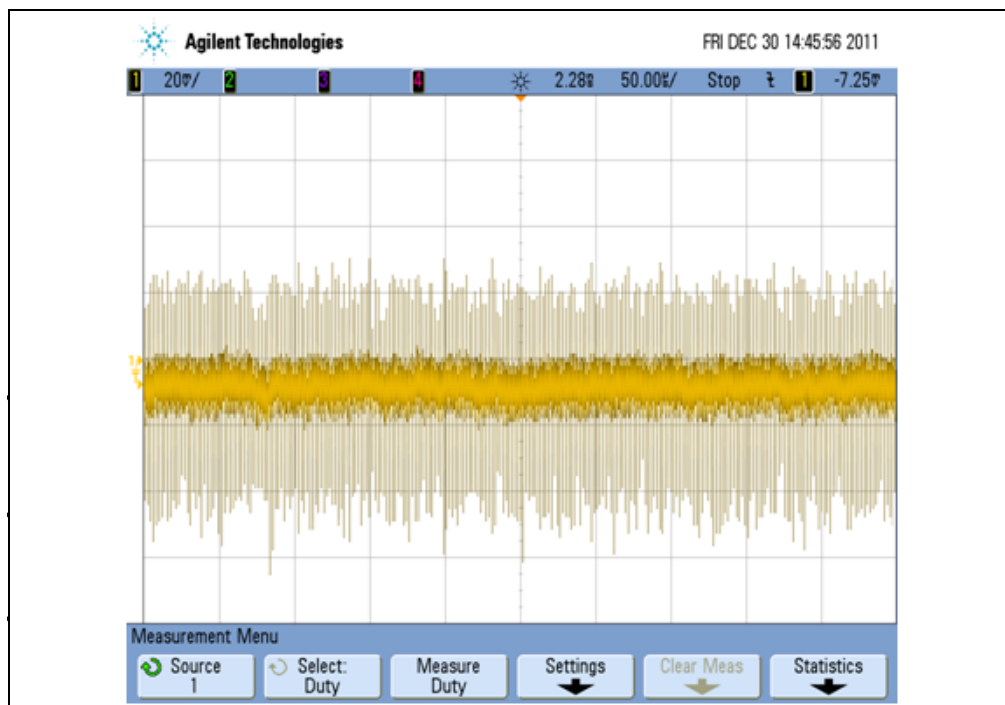


FIGURE 2-4: V_{OUT} Ripple of the Evaluation Board is less than 80 mV_{p-p} using RC Snubber only (12V Input, 100 mA Load). Compare to Figure 2-3.



FIGURE 2-5: V_{OUT} Ripple of the Evaluation Board is less than 30 mV_{p-p} using RC Snubber and R_{BOOST} (12V Input, 100 mA Load). Compare to Figures 2-3 and 2-4.

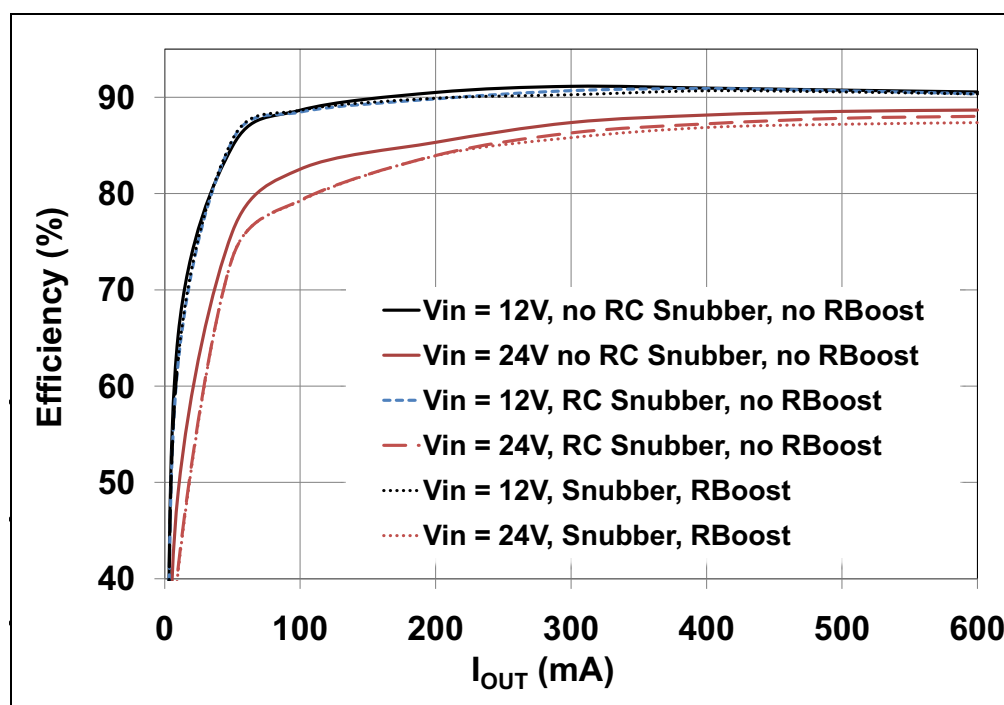


FIGURE 2-6: Efficiency Comparison for the MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board (12V and 24V Input).



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Appendix A. Schematic and Layouts

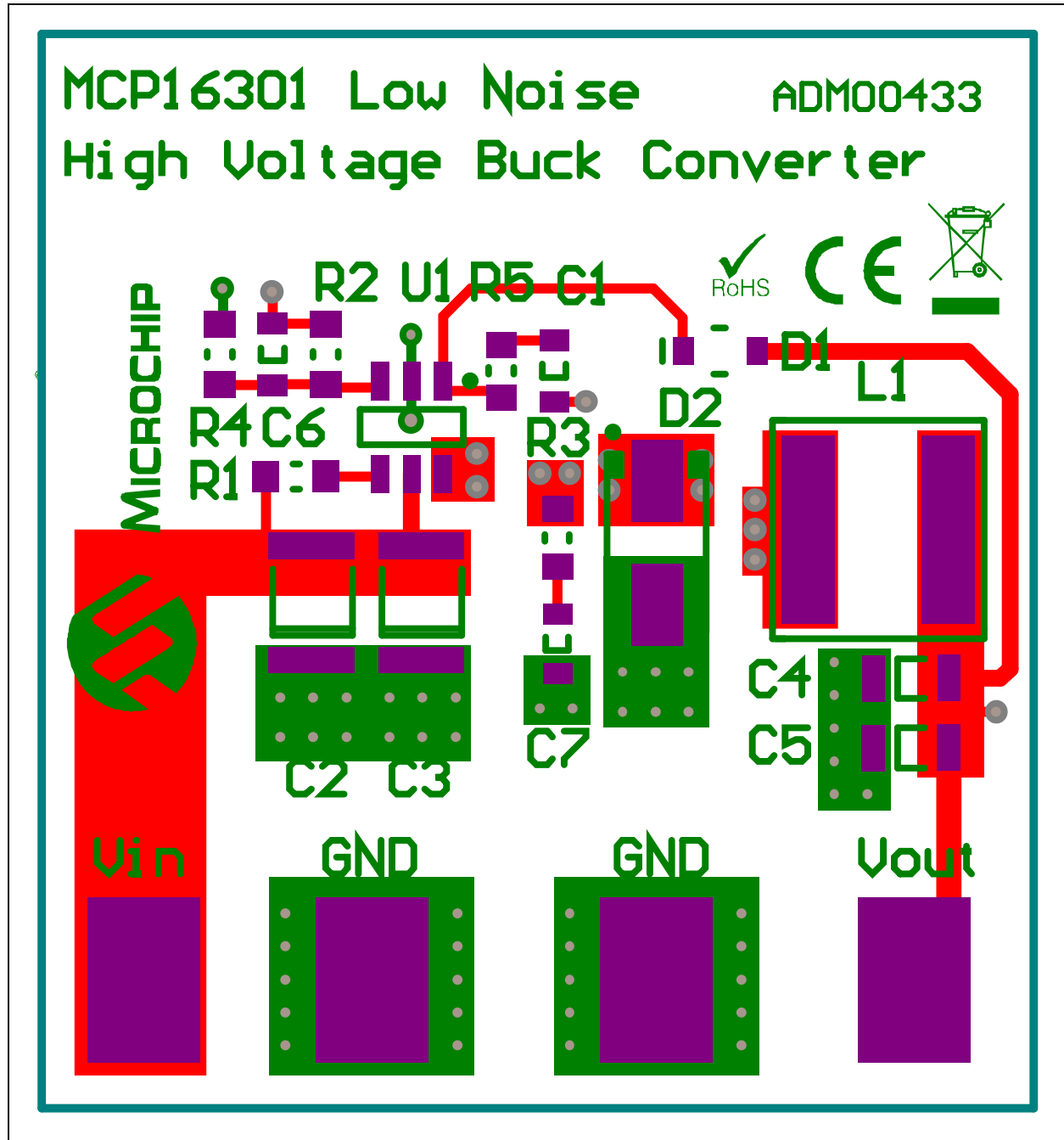
A.1 INTRODUCTION

This appendix contains the following schematics and layouts for the MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board:

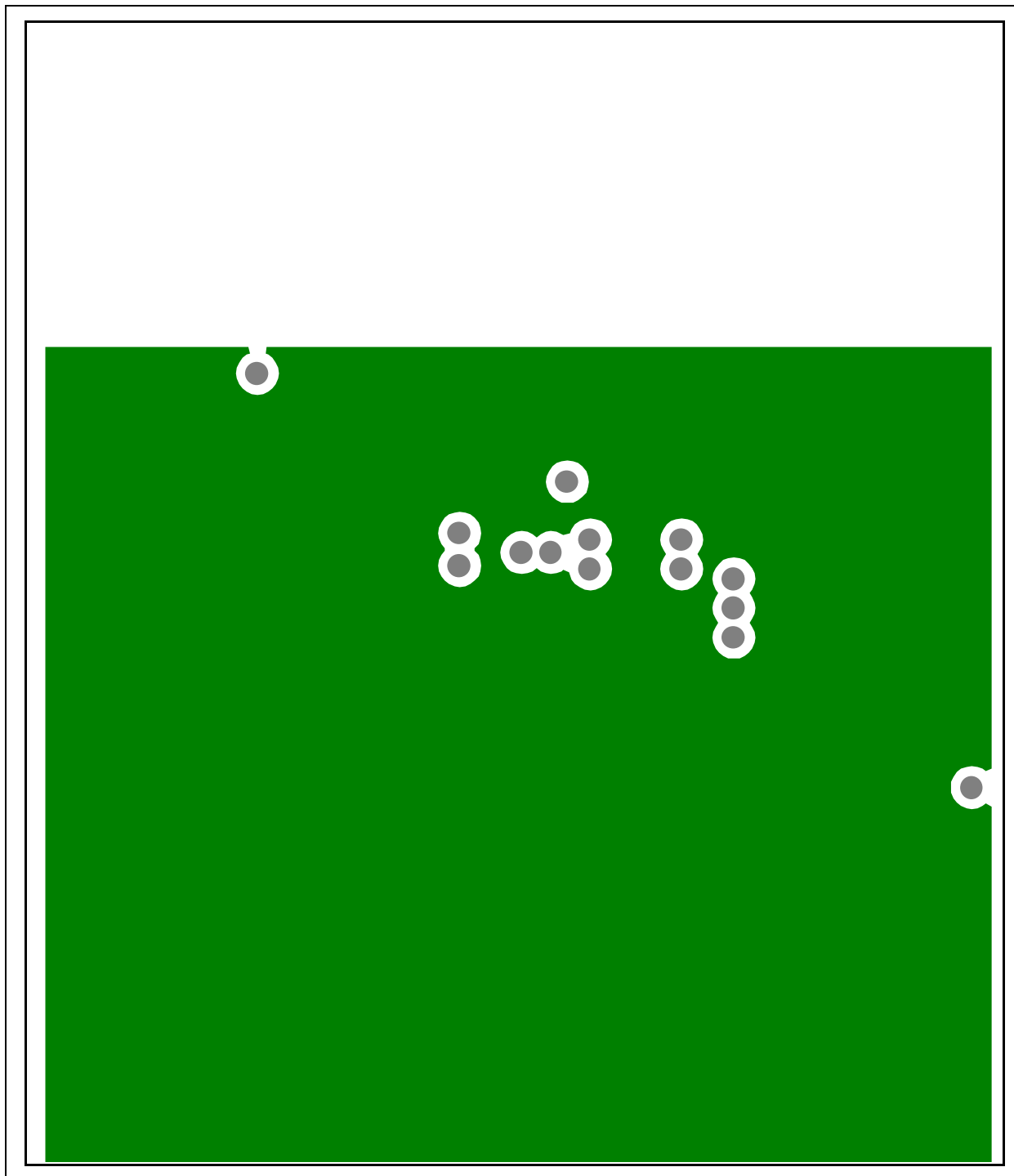
- Board – Schematic
- Board – Top Silk And Copper
- Board – Mid-Inner Layer 1
- Board – Mid-Inner Layer 2
- Board – Bottom Copper and Pads

The schematic illustrates a boost converter circuit using the MCP16301 IC. The input voltage is $V_{IN} = 12V$, connected to the VIN pin (pin 5) of the IC. The EN pin (pin 4) is connected to the same input line through a 1MΩ resistor (R1). The GND pin (pin 2) is connected to ground. The output of the converter is taken from the SW pin (pin 6), which is connected to the VFB pin (pin 3) through a feedback network consisting of a 22μH/5A inductor (L1), a 52.3KΩ resistor (R2), and a 10kΩ resistor (R4). The output voltage is $V_{OUT} = 5V$. The circuit includes several passive components: two 10μF capacitors (C2, C3) at the input, a 0.1μF capacitor (C1) at the SW pin, a 120pF capacitor (C7) at the VFB pin, and two 10μF capacitors (C4, C5) at the output. The diode D1 (1N4148WS) is connected between the SW pin and the VFB pin. The diode D2 (MBRA140T3G) is connected between the VFB pin and ground. The IC is labeled MCP16301 U1.

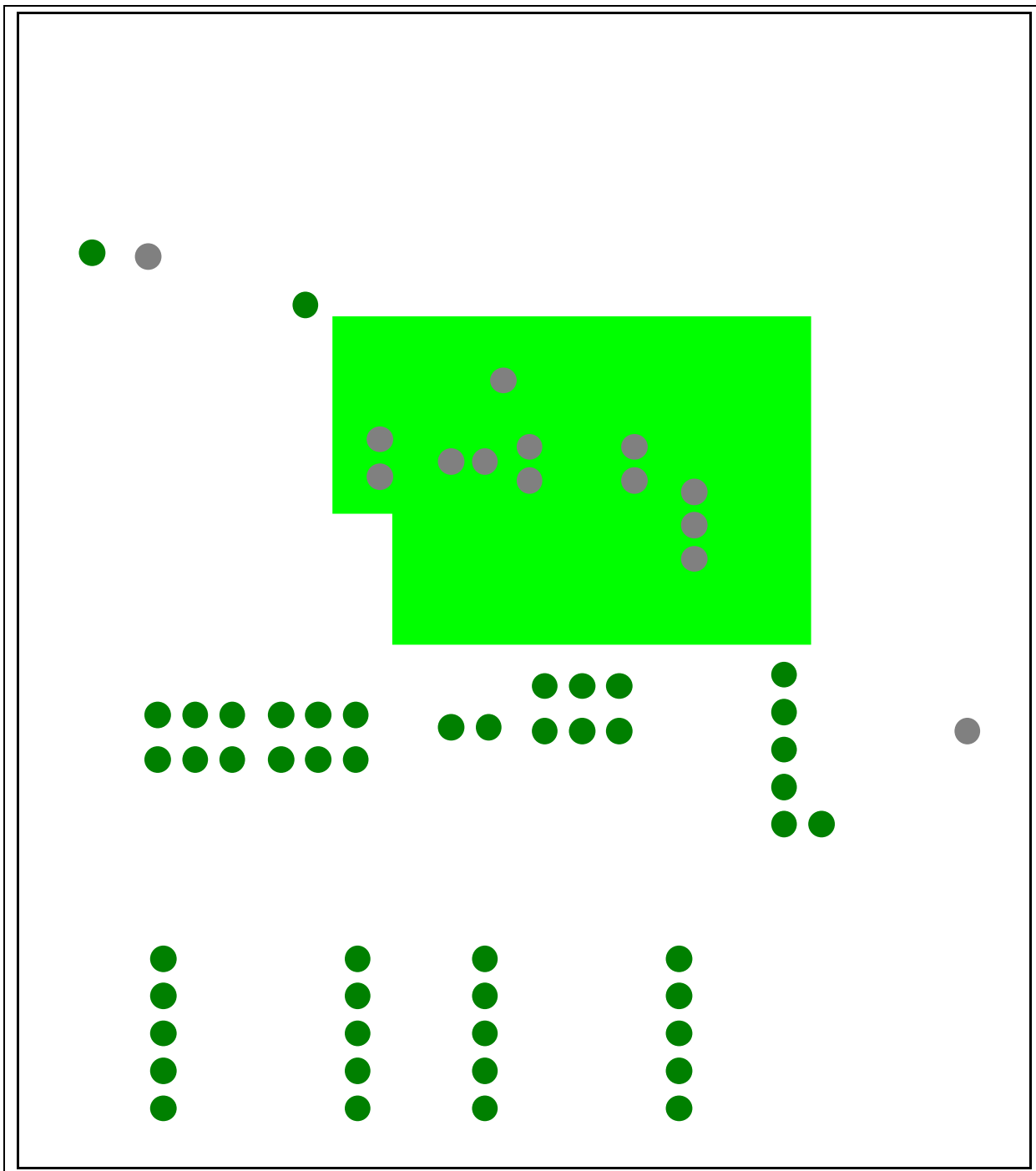
A.3 BOARD – TOP SILK AND COPPER



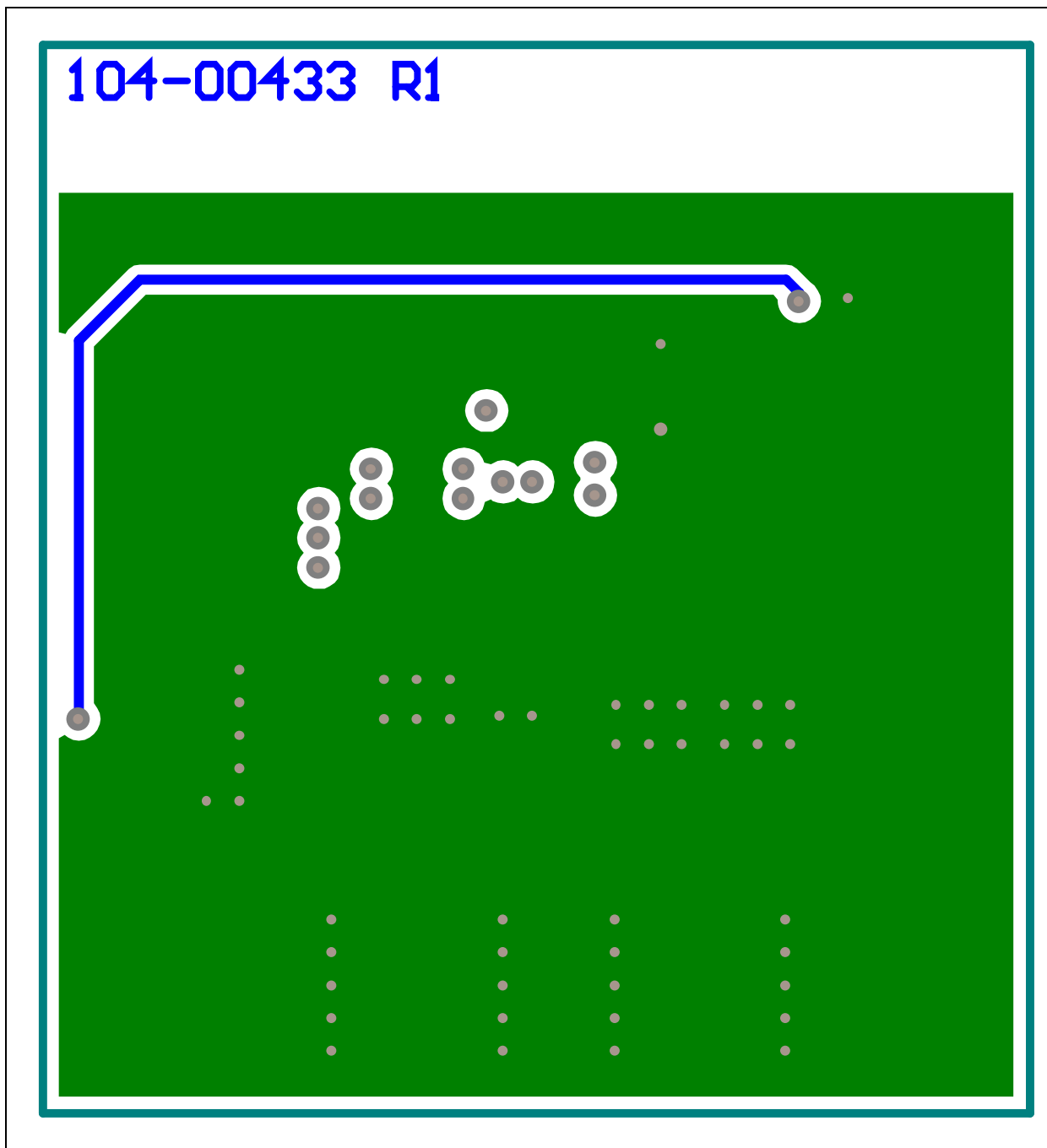
A.4 BOARD – MID-INNER LAYER 1



A.5 BOARD – MID-INNER LAYER 2



A.6 BOARD – BOTTOM COPPER AND PADS



**MICROCHIP**

MCP16301 HIGH-PERFORMANCE LOW-NOISE 5V BUCK CONVERTER EVALUATION BOARD USER'S GUIDE

Appendix B. Bill of Materials (BOM)

TABLE B-1: BILL OF MATERIALS (BOM)

Qty.	Reference	Description	Manufacturer	Part Number
1	C1	Cap. ceramic 0.1 μ F 50V X7R 10% 0603	TDK [®] Corporation	C1608X7R1H104K
2	C2, C3	Cap. ceramic 10 μ F 50V X7S 1210	TDK Corporation	C3225X7S1H106M
2	C4, C5	Cap. ceramic 10 μ F 10V X7R 10% 0805	Murata Electronics [®]	GRM21BR71A106KE51L
0	C6	DO NOT POPULATE	—	—
1	C7	Capacitor, NP0, 0603, 100V, 120 pF	KEMET [®] Corp.	C0603C121J1GACTU
1	D1	Diode switch 75V 200 mW SOD323	Diodes [®] Incorporated	1N4148WS-7-F
1	D2	Diode Schottky 40V 1A SMA	ON Semiconductor [®]	MBRA140T3G
4	J1, J2, J3, J4	PC test point tin SMD	Harwin Plc.	S1751-46R
1	L1	Inductor 22 μ H 5A SMD	Coilcraft [®]	XAL6060-223MEB
1	PCB	Printed Circuit Board - MCP16301 High-Performance Low-Noise 5V Buck Converter Evaluation Board	—	104-00433
1	R1	Res. 1.0M Ohm 1/10W 5% 0603 SMD	Panasonic [®] - ECG	ERJ-3GEYJ105V
1	R2	Res. 52.3k Ohm 1/10W .1% 0603 SMD	Panasonic - ECG	ERA-3AEB5232V
1	R4	Res. 10k Ohm 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1002V
1	R5	Res. 82 Ohm 1/10W 5% 0603 SMD	Panasonic - ECG	ERJ-3GEYJ820V
1	R3	Res. 4.7 Ohm 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3RQF4R7V
1	U1	High-Voltage Input Integrated Switch Step-Down Regulator	Microchip Technology Inc.	MCP16301T-E/CH

Note 1: 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.



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