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MCP1661
Isolated Flyback Converter
Reference Design

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ISBN: 978-1-63276-808-7

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Signed for and on behalf of Microchip Technology Inc. at Chandler, Arizona, USA


Derek Carlson
VP Development Tools

12-Sep-14
Date

MCP1661 Isolated Flyback Converter Reference Design

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MCP1661 Isolated Flyback Converter Reference Design

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MCP1661 ISOLATED FLYBACK CONVERTER REFERENCE DESIGN

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 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 on-line 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 MCP1661 Isolated Flyback Converter Reference Design. 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 MCP1661 Isolated Flyback Converter Reference Design as a development tool. The manual layout is as follows:

- **Chapter 1. “Product Overview”** – Important information about the MCP1661 Isolated Flyback Converter Reference Design.
- **Chapter 2. “Installation and Operation”** – Includes instructions on how to configure the board and important information about MCP1661 Isolated Flyback Converter and a description of the Reference Design.
- **Appendix A. “Schematic and Layouts”** – Shows the schematic and layout diagrams for MCP1661 Isolated Flyback Converter Reference Design.
- **Appendix B. “Bill of Materials”** – Lists the parts used to build the MCP1661 Isolated Flyback Converter Reference Design.

MCP1661 Isolated Flyback Converter Reference Design

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 MCP1661 Isolated Flyback Converter Reference Design. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

- **MCP1661** – *“High-Voltage Integrated Switch PWM Boost Regulator with UVLO”* (DS20005315)
- **MCP1662** – *“High-Voltage Step-Up LED Driver with UVLO and Open Load Protection”* (DS20005316)

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

Customers should contact their distributor, representative or field application engineer (FAE) for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document.

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

DOCUMENT REVISION HISTORY

Revision A (November 2014)

- Initial Release of this Document.

MCP1661 Isolated Flyback Converter Reference Design

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Chapter 1. Product Overview

1.1 INTRODUCTION

This chapter provides an overview of the MCP1661 Isolated Flyback Converter Reference Design and covers the following topics:

- MCP1661 Device Short Overview
- Flyback Converter Topology Overview
- What is The MCP1661 Isolated Flyback Converter Reference Design?
- What does The MCP1661 Isolated Flyback Converter Reference Design Kit include?

1.2 MCP1661 DEVICE SHORT OVERVIEW

MCP1661 is a constant Pulse-Width Modulation (PWM) frequency boost (step-up) converter (see Figure 1-1), based on a Peak Current mode architecture which delivers high efficiency over a wide load range from two-cell and three-cell Alkaline, Energizer® Ultimate Lithium, NiMH, NiCd and single-cell Li-Ion battery inputs. A high level of integration lowers total system cost, eases implementation and reduces board area.

1.2.1 MCP1661 Key Features

- 36V, 800 mΩ Integrated Switch
- Up to 92% Efficiency
- High Output Voltage Range: up to 32V
- 1.3A Peak Input Current Limit:
 - $I_{OUT} > 200 \text{ mA @ } 5.0\text{V } V_{IN}, 12\text{V } V_{OUT}$
 - $I_{OUT} > 125 \text{ mA @ } 3.3\text{V } V_{IN}, 12\text{V } V_{OUT}$
 - $I_{OUT} > 100 \text{ mA @ } 4.2\text{V } V_{IN}, 24\text{V } V_{OUT}$
- Input Voltage Range: 2.4V to 5.5V
- Undervoltage Lockout (UVLO):
 - UVLO@ V_{IN} Rising: 2.3V, typical
 - UVLO@ V_{IN} Falling: 1.85V, typical
- No Load Input Current: 250 μA , typical
- Sleep Mode with 200 nA Typical Quiescent Current
- PWM Operation with Skip Mode: 500 kHz
- Cycle-by-Cycle Current Limiting
- Internal Compensation
- Inrush Current Limiting and Internal Soft-Start
- Output Overvoltage Protection (OVP) in the event of:
 - Feedback pin shorted to GND
 - Disconnected feedback divider
- Overtemperature Protection
- Easy Configurable for SEPIC or Flyback Topologies
- Available Packages:
 - 5-Lead SOT-23
 - 2x3 8-Lead TDFN

MCP1661 Isolated Flyback Converter Reference Design

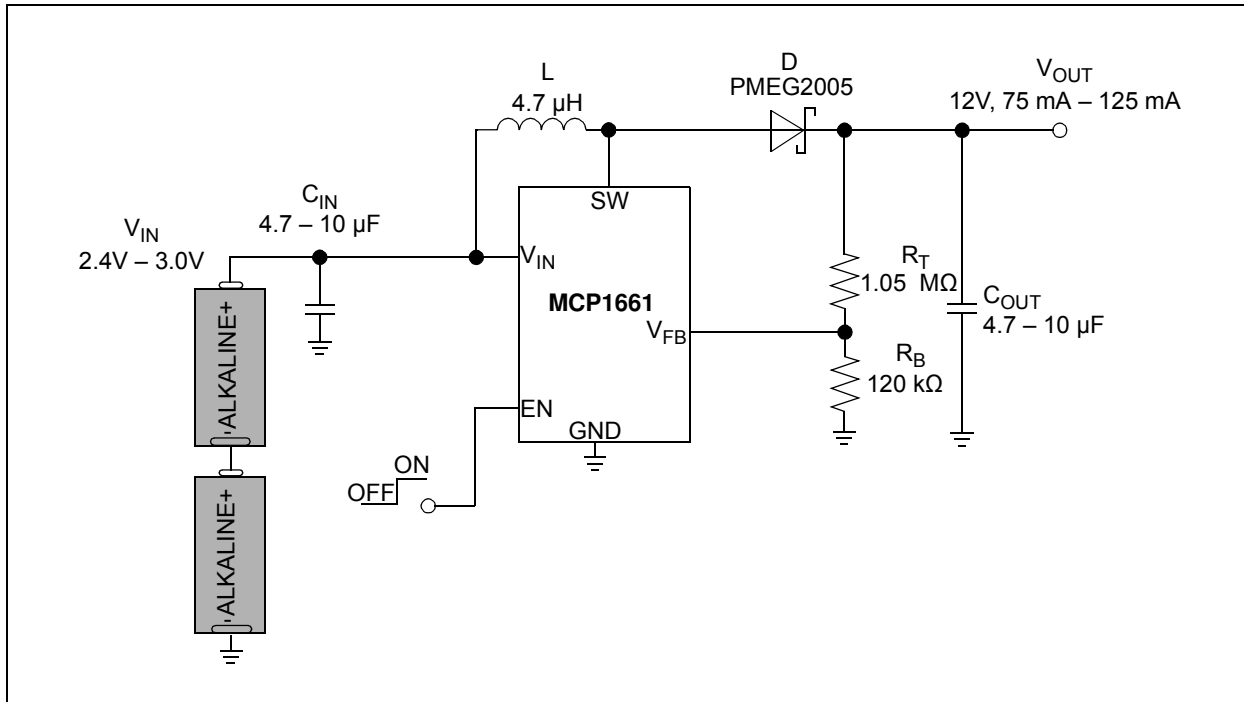


FIGURE 1-1: Typical MCP1661 Boost Converter

1.3 FLYBACK CONVERTER TOPOLOGY OVERVIEW

The flyback converter is used in both AC/DC and DC/DC conversion having galvanic isolation between the input and one or more outputs. This type of converter is a derivation from a buck-boost converter with a transformer replacing the inductor, so that the voltage ratios are multiplied.

Being an isolated power converter, the control circuit needs to be isolated as well. There are two control types used for this converter: Voltage mode control and Current mode control. Both require a signal related to the output voltage. This can be achieved using an optocoupler on the secondary circuitry to send a signal to the controller, or using a separate winding on the coil and rely on the cross regulation of the design.

The first approach involving an optocoupler is used to obtain very good voltage and current regulation, whereas the second was developed for cost-sensitive applications where the output does not need to be as precisely controlled, but simplifies the overall design considerably. In applications where reliability is critical, optocouplers should be avoided.

In this application, a simpler technique (explained in the following chapters), was used, but the main disadvantage is that the voltage regulation is poor. To improve this, an LDO was added at the isolated output, in order to provide smooth regulation.

1.3.1 Flyback Converter Working Principle

The schematic of a flyback converter can be seen in Figure 2-1. It derives from the buck-boost topology but uses a transformer instead of the inductor. A very important aspect is that flyback transformers have an air gap which allows energy storing without the risk of core saturation occurrence. Therefore, the operating principle of both converters is very close:

- When the switch is closed (Figure 1-2, a), the primary winding of the transformer is connected to the input voltage source. The primary current and magnetic flux in the transformer increases, storing energy in the transformer's core. The voltage induced in the secondary winding is negative, so the diode is reverse-biased. In this phase, the output capacitor supplies energy to the output load (LDO's input, in this application).
- When the switch is opened (Figure 1-2, b), the primary current and magnetic flux drops. The secondary voltage is positive, forward-biasing the diode, allowing current to flow from the transformer to the capacitor and to the load.

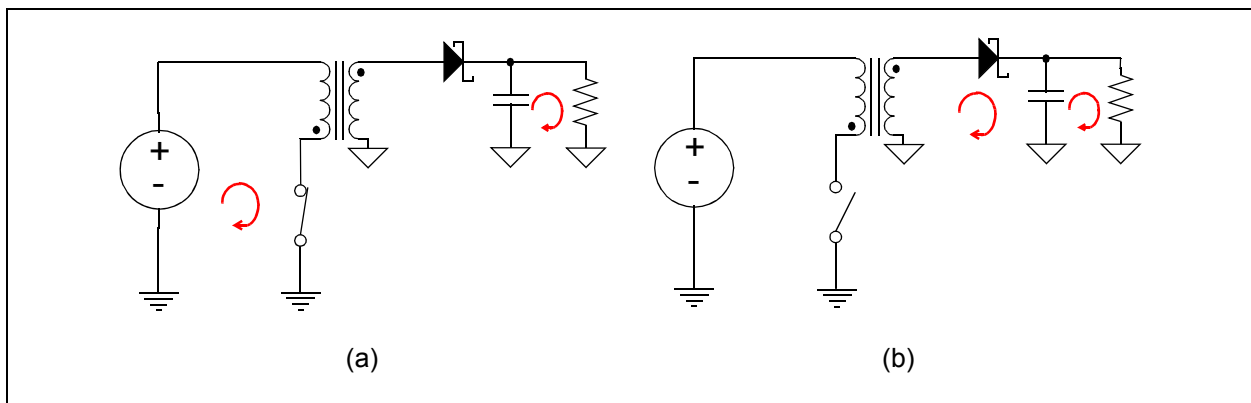


FIGURE 1-2: The Two Configurations of the Flyback Converter In Operation.

1.4 WHAT IS THE MCP1661 ISOLATED FLYBACK CONVERTER REFERENCE DESIGN?

The MCP1661 Isolated Flyback Converter Reference Design is used to evaluate and demonstrate Microchip Technology's MCP1661 in the following topology:

- 5V output Isolated Flyback Converter application supplied from 5V typical input voltage.

It is used to evaluate the 5-Lead SOT-23 package.

By changing the LDO, a lower/higher output voltage than 5V will be obtained, but with different capabilities regarding maximum output current and efficiency.

1.5 WHAT DOES THE MCP1661 ISOLATED FLYBACK CONVERTER REFERENCE DESIGN KIT INCLUDE?

This MCP1661 Isolated Flyback Converter Reference Design kit includes:

- MCP1661 Isolated Flyback Converter Reference Design (ARD00598)
- Important Information Sheet

MCP1661 Isolated Flyback Converter Reference Design

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Chapter 2. Installation and Operation

2.1 INTRODUCTION

MCP1661 device is a non-synchronous, fixed-frequency step-up DC-DC converter which has been developed for applications that require higher output voltage capabilities. MCP1661 can regulate the output voltage up to 32V and can deliver 125 mA typical load at 3.3V input and 12V output. At light loads, MCP1661 skips pulses in order to keep the output voltage in regulation, but the voltage ripple is maintained low. The regulated output voltage should be greater than the input voltage.

2.1.1 Board Features

The MCP1661 Flyback Converter has the following features:

- Input Voltage: 4.25V-5.25V, Typical
 - USB standard input voltage range
- Output Capability:
 - Over 200 mA (at $V_{OUT} = 5V$)
 - Galvanic isolation
 - Short-circuit protection
- Efficiency: up to 75%
- PWM Operation at 500 kHz

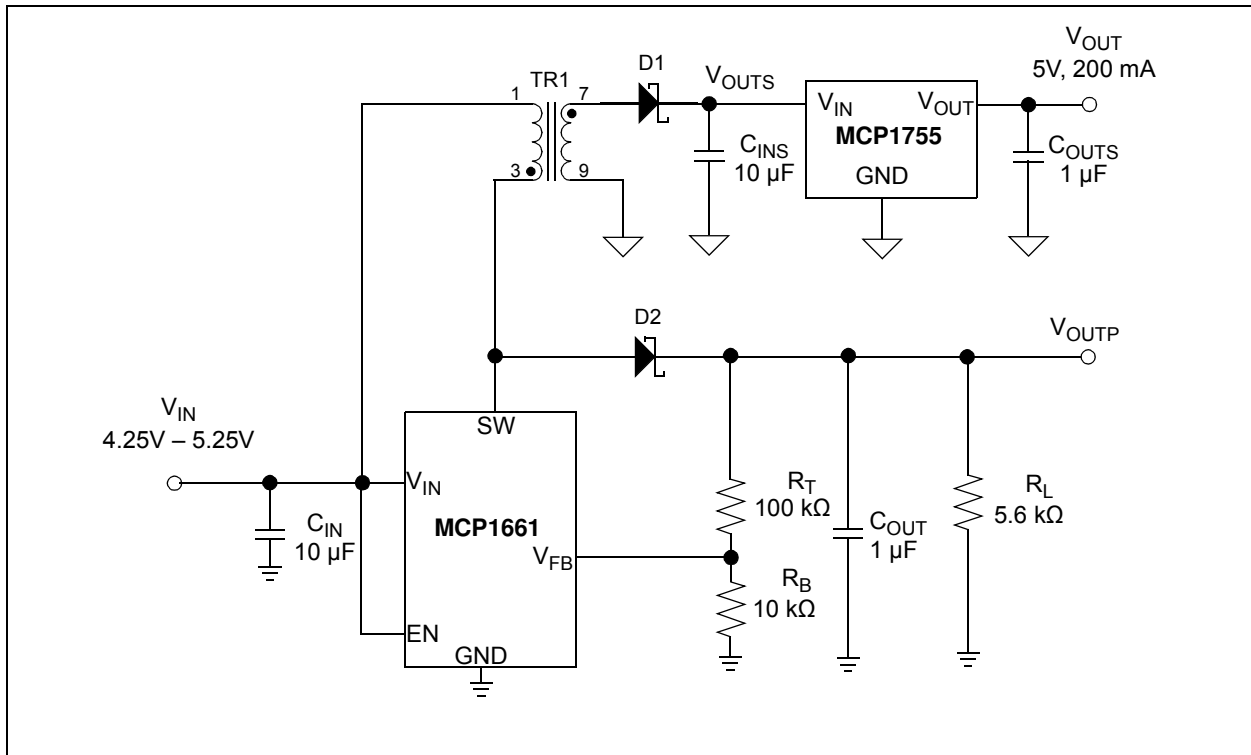


FIGURE 2-1: MCP1661 Isolated Flyback Converter.

MCP1661 Isolated Flyback Converter Reference Design

This application uses MCP1661 as an open-loop flyback converter, the primary winding of the transformer being used as inductor for the boost converter that clamps the primary output voltage (V_{OUTP}) at around 13.5V. It is very important (for a normal operation of the entire circuitry and to avoid damaging some electronic components) not to connect any additional load between V_{OUTP} and GND. The output voltage of the flyback converter (V_{OUTS}) drops with the increasing of output current, due to the fact that the feedback is taken from the primary side.

In order to achieve a very good output voltage regulation in the secondary side (V_{OUT}), a 5V LDO is placed after the rectifying diode of the flyback converter, therefore the decrease of V_{OUTS} when increasing the load is not critical.

The MCP1661 Isolated Flyback Converter Reference Design can be used for USB-powered applications, where a positive, regulated 5V output voltage is needed from an isolated input voltage that varies from 4.75V to 5.25V.

2.1.2 How Does the MCP1661 Isolated Flyback Converter Reference Design Work?

The converter is configured as non-synchronous; an external diode (D2) is connected between the inductor (primary winding of the transformer) and the high-voltage output (V_{OUTP}). The transformation ratio chosen was 1:1, because the difference between the input voltage range (V_{IN}) and the output voltage (V_{OUT}) is small.

The output voltage of the flyback converter (V_{OUTS}) decreases by increasing the load current, due to the lack of feedback from the secondary side of the transformer. The amount of voltage drop (V_{OUTS}) on the entire range of loads can be controlled by changing the load resistor R_L . Charging the primary side of the flyback transformer with a higher current corresponds to a lower voltage drop in the secondary side (V_{OUTS}) over the entire load range, but the overall efficiency of the converter will decrease. There is a compromise between the maximum output current capabilities, input voltage range and efficiency, by varying the values of the load resistor (R_L) and feedback resistors (R_T and R_B). In this case, those components were chosen in order to achieve good efficiency at 200 mA load current up to 5.25V input voltage.

The two sense resistors (R_T and R_B) set the output (V_{OUTP}) at 13.5V according to the following equation:

EQUATION 2-1: FEEDBACK RESISTORS RELATIONSHIP

$$R_T = R_B \times \left(\frac{V_{OUTP}}{V_{FB}} - 1 \right)$$

Where:

V_{FB} = 1.227V

V_{FB} = Reference voltage of the FB pin

V_{OUTP} = 13.5V

R_B = Resistor's value is selected by the designer

Attention should be paid to the values of the feedback resistors. When testing the board for other output voltage, a potential issue with higher value resistors is the environmental contamination, which can create a leakage current path on the Printed Circuit Board (PCB). This will affect the feedback voltage and the output voltage regulation.

Engineers should use with precaution resistors that are larger than 1 M Ω . In normal humidity conditions, the V_{FB} input leakage is very low and the resistors' values will not affect the stability of the system.

All compensation and protection circuitry is integrated to minimize the number of external components. Ceramic input and output capacitors are used.

Good efficiency is obtained at high load currents due to the decreasing of the output voltage before the LDO (V_{OUTS}).

2.2 GETTING STARTED

The MCP1661 Flyback Converter Reference Design is fully assembled and tested to evaluate and demonstrate the MCP1661 family of products.

2.2.1 Powering the MCP1661 Isolated Flyback Converter Reference Design

Input power connectors are placed on the left side of the board:

- V_{IN} for positive power
- GND for negative power

The maximum input voltage should not exceed 5.5V. This can cause damage to the MCP1661.

The output connector is called V_{OUT} , is referenced to SGND and is isolated from GND.

2.2.2 Board Testing

The variable power supply for testing requires output capability of at least 1A and a voltage range of 4.0V to 6V.

To test the board, follow these steps:

1. Connect the power supply at V_{IN} and GND terminals of the board.
2. Set the power supply to 5.0V.
3. Connect a voltmeter and a 100 Ω /1W resistor between V_{OUT} and SGND connectors, as shown in Figure 2-2. Check to be sure the voltmeter indicates approximately 5V.
4. Set the power supply to 4.75V and verify with the voltmeter if the output of the converter stays regulated ($V_{OUT} = 5V$).
5. Set the power supply to 5.25V and verify with the voltmeter if the output of the converter stays regulated ($V_{OUT} = 5V$).

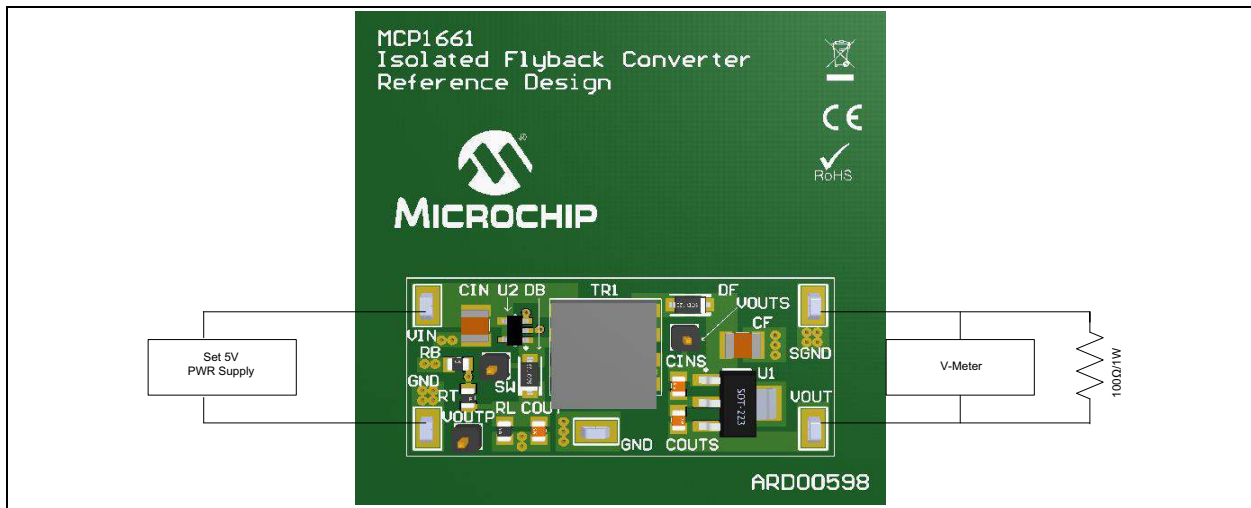


FIGURE 2-2: MCP1661 Isolated Flyback Converter Reference Design.

MCP1661 Isolated Flyback Converter Reference Design

The board has several test points that help engineers analyze the switch node's waveforms or MCP1661's output:

- The test point of the MCP1661 device's switch node (SW).
- V_{OUTP} test point shows the MCP1661 boost's output voltage (this output is regulated).
- V_{OUTS} test point shows the MCP1661 flyback's output voltage (this output is unregulated and is referenced to SGND).

The regulated output voltage of the boost is about 13.5V and is referenced to GND.

2.2.3 Results

MCP1661 Isolated Flyback Converter uses an uncommon design, because the feedback voltage is taken from the primary side, so the output voltage in the secondary side (V_{OUTS}) drops down as long as the load current increases (see Figure 2-3). However, the overall efficiency is still high, even if the LDO wastes some energy in order to keep the output voltage (V_{OUT}) stable at 5V.

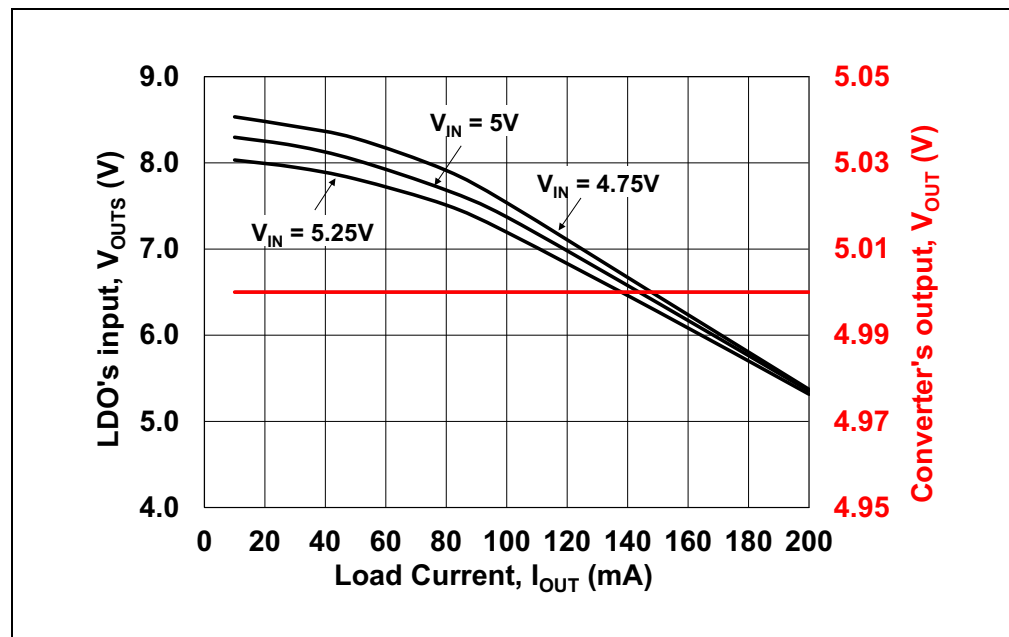


FIGURE 2-3: V_{OUTS} vs. I_{OUT} & V_{OUT} vs. I_{OUT} Graphs.

Installation and Operation

Refer to Figure 2-4 for the efficiency that can be obtained for different input voltages.

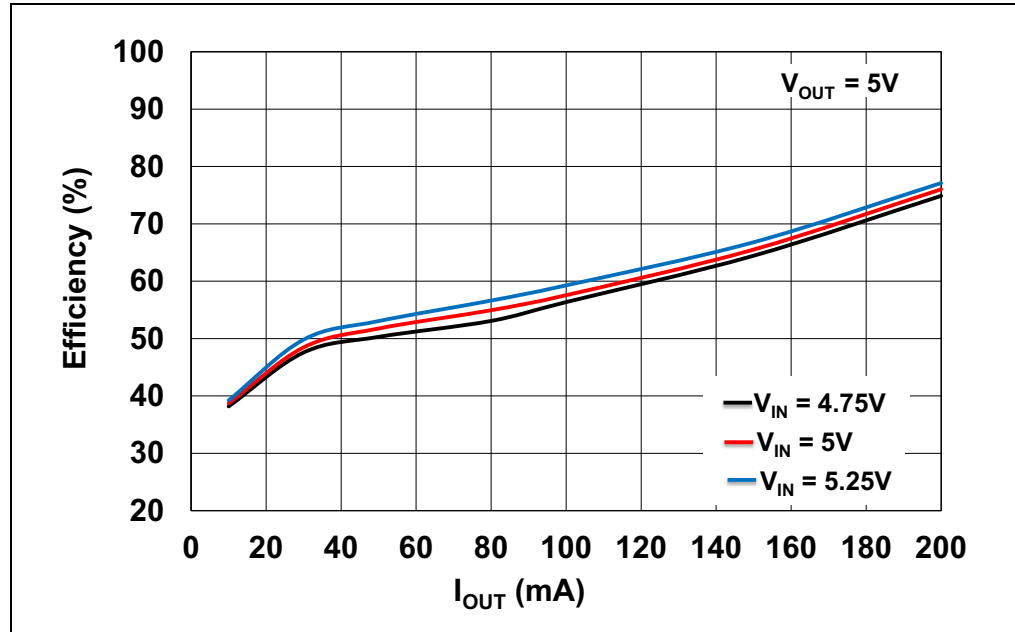


FIGURE 2-4: Efficiency vs. I_{OUT} Graph for Different Input Voltages.

Figures 2-5 and 2-6 show the Discontinuous (at no load, 5V V_{IN}) and Continuous mode waveforms (50 mA load at 5V input voltage).

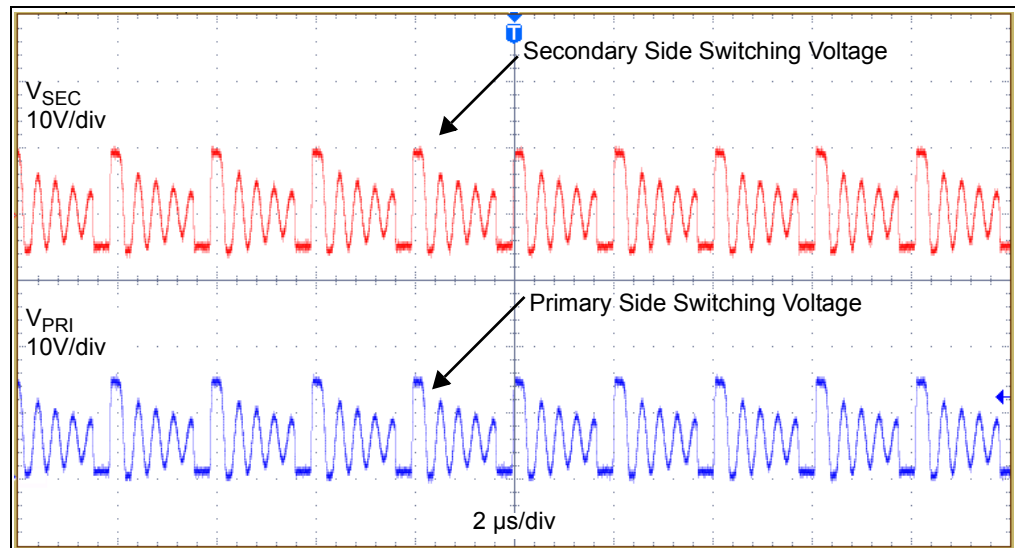


FIGURE 2-5: Switching Nodes (Primary Side and Secondary Side) in Discontinuous Conduction Mode (No Load).

MCP1661 Isolated Flyback Converter Reference Design

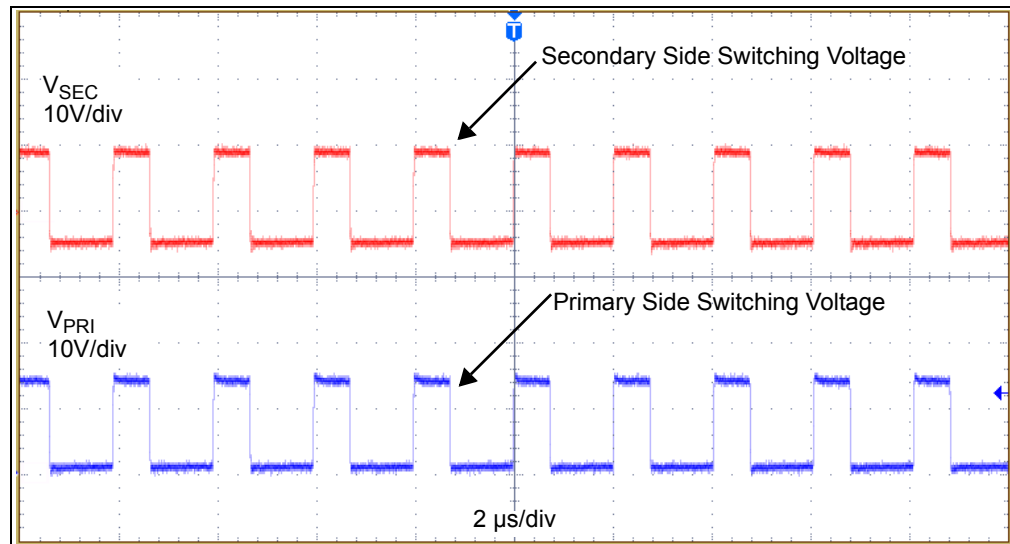


FIGURE 2-6: Switching Nodes (Primary Side and Secondary Side) in Continuous Conduction Mode (50 mA Load Current).

Figure 2-7 shows the start-up waveforms for MCP1661 Isolated Flyback Converter at 150 mA load current.

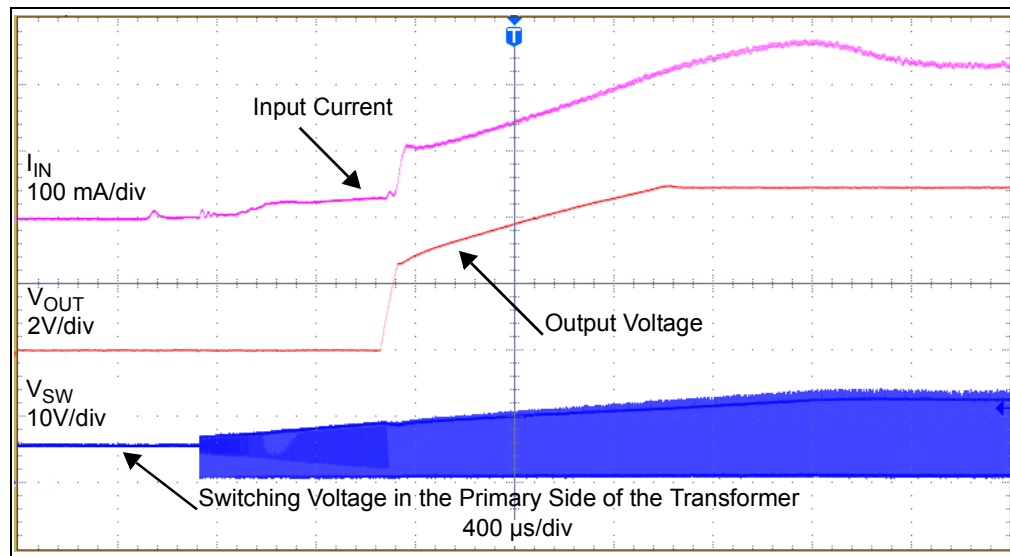


FIGURE 2-7: Start-up Waveforms (Input Current, Output Voltage and Switching Voltage).



MCP1661 ISOLATED FLYBACK CONVERTER REFERENCE DESIGN

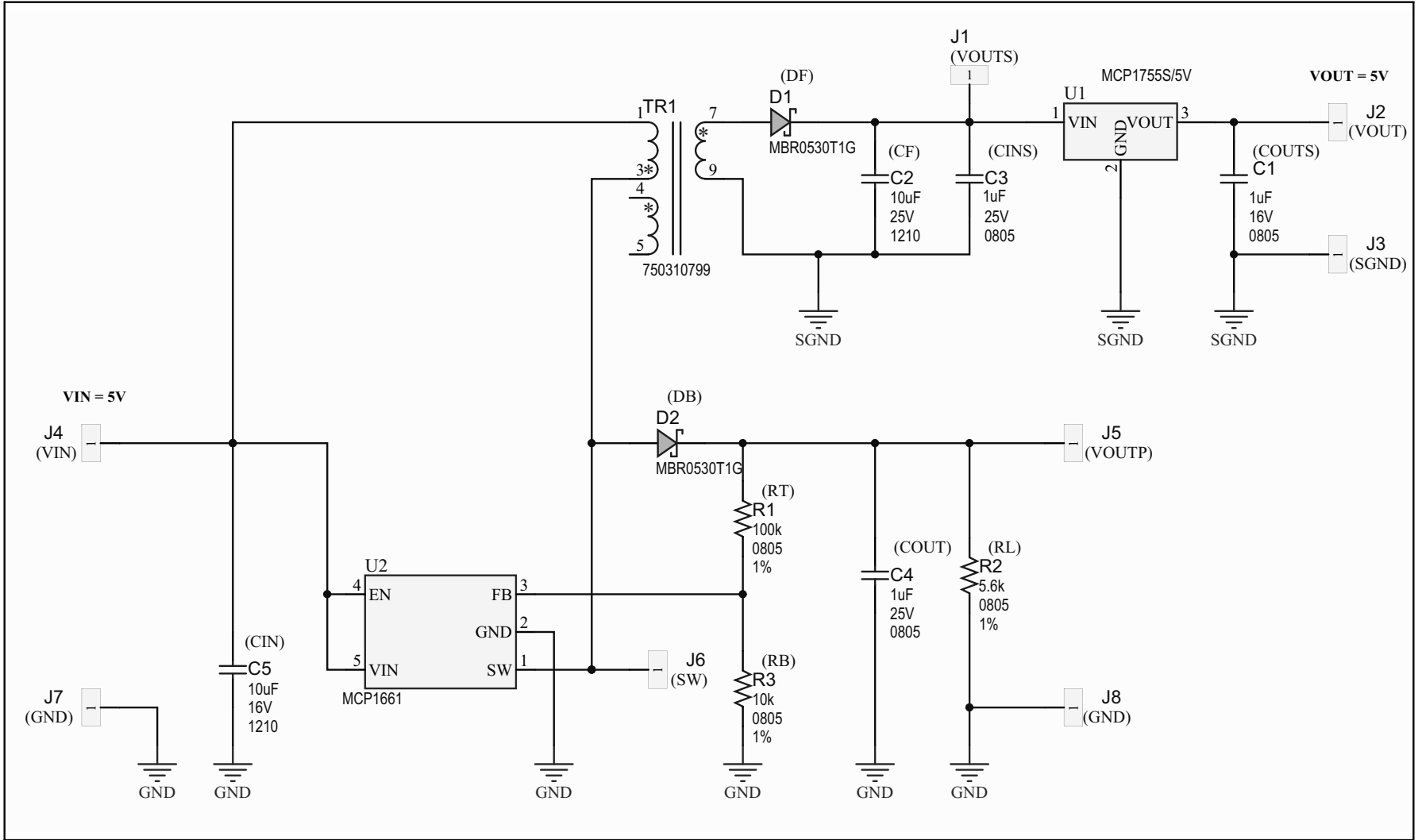
Appendix A. Schematic and Layouts

A.1 INTRODUCTION

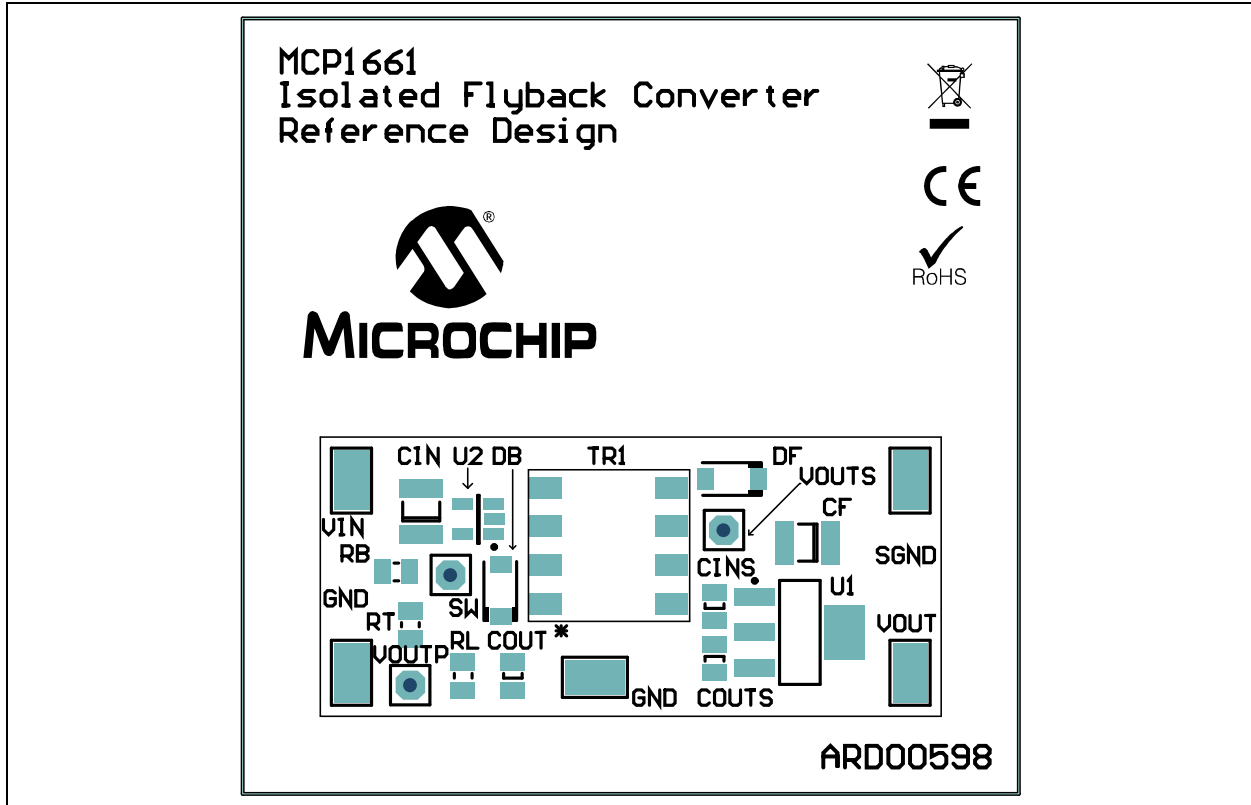
This appendix contains the following schematics and layouts for the MCP1661 Flyback Converter Reference Design:

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

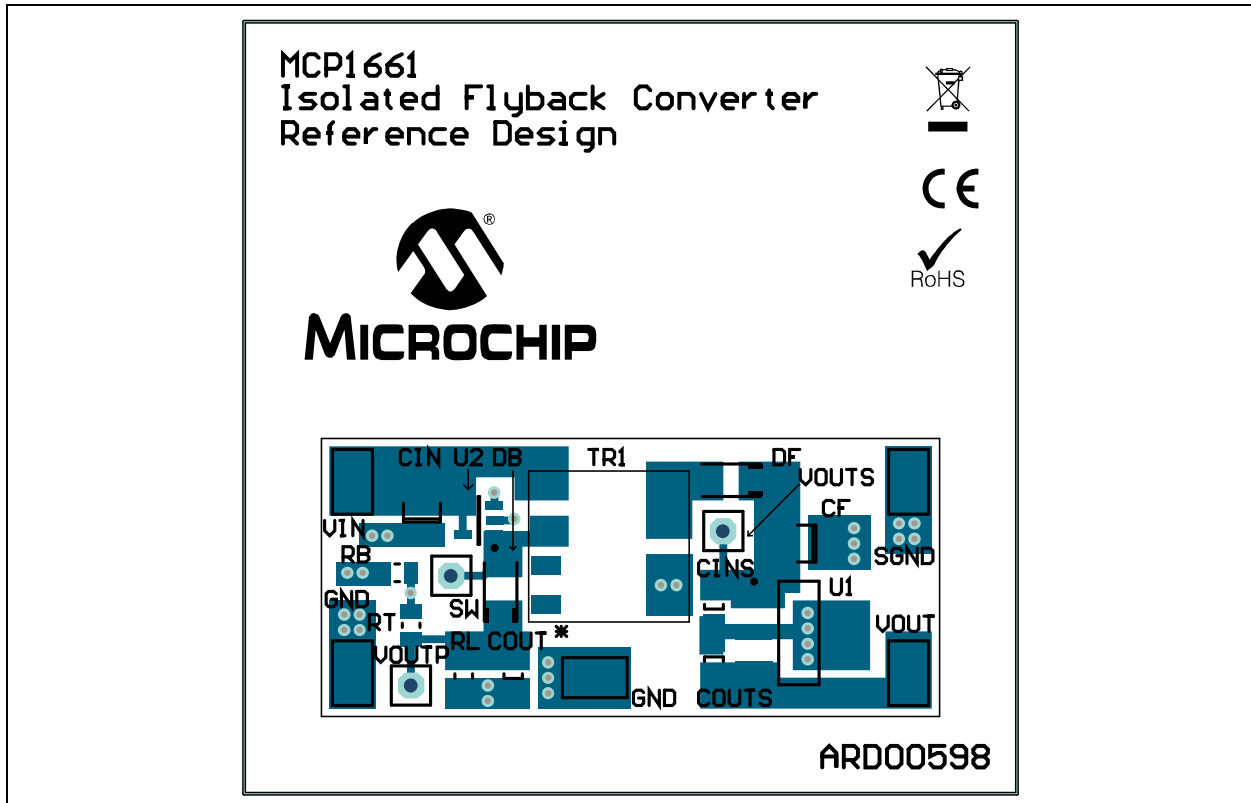
A.2 BOARD – SCHEMATIC



A.3 BOARD – TOP SILK

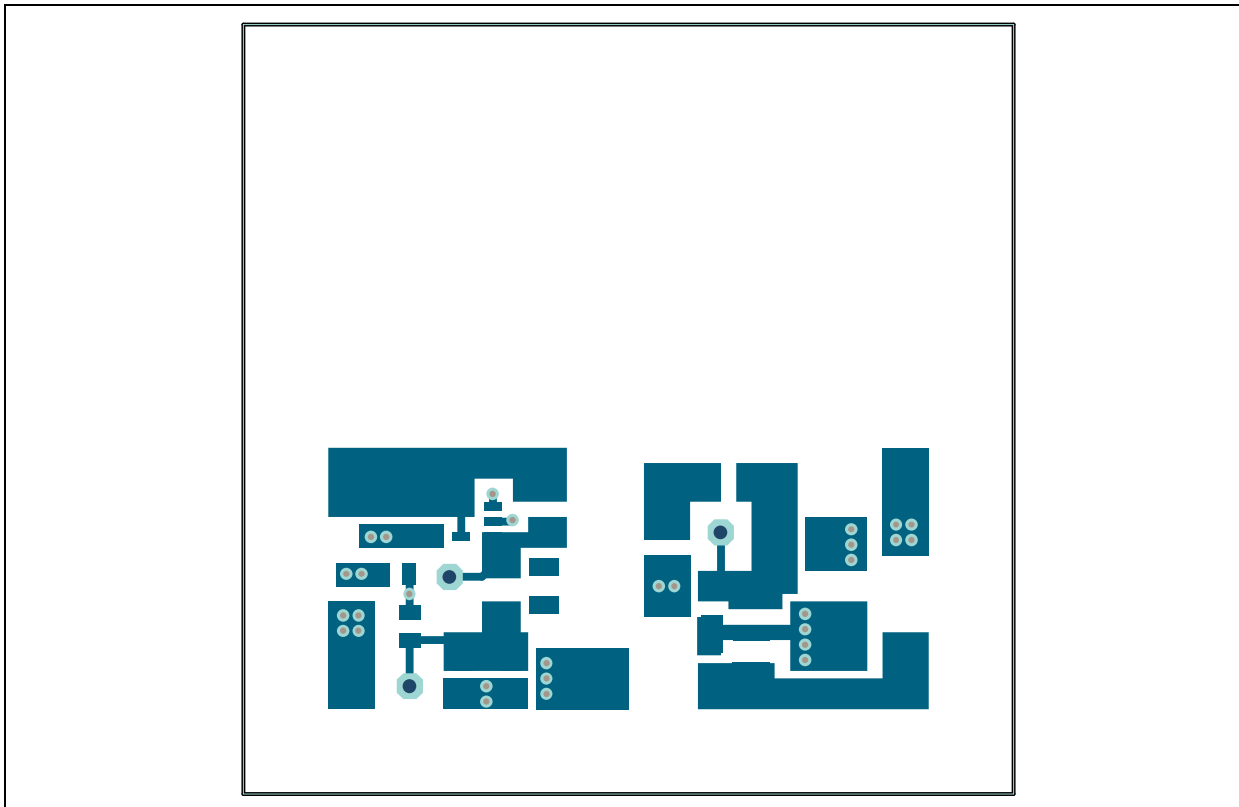


A.4 BOARD – TOP COPPER AND SILK

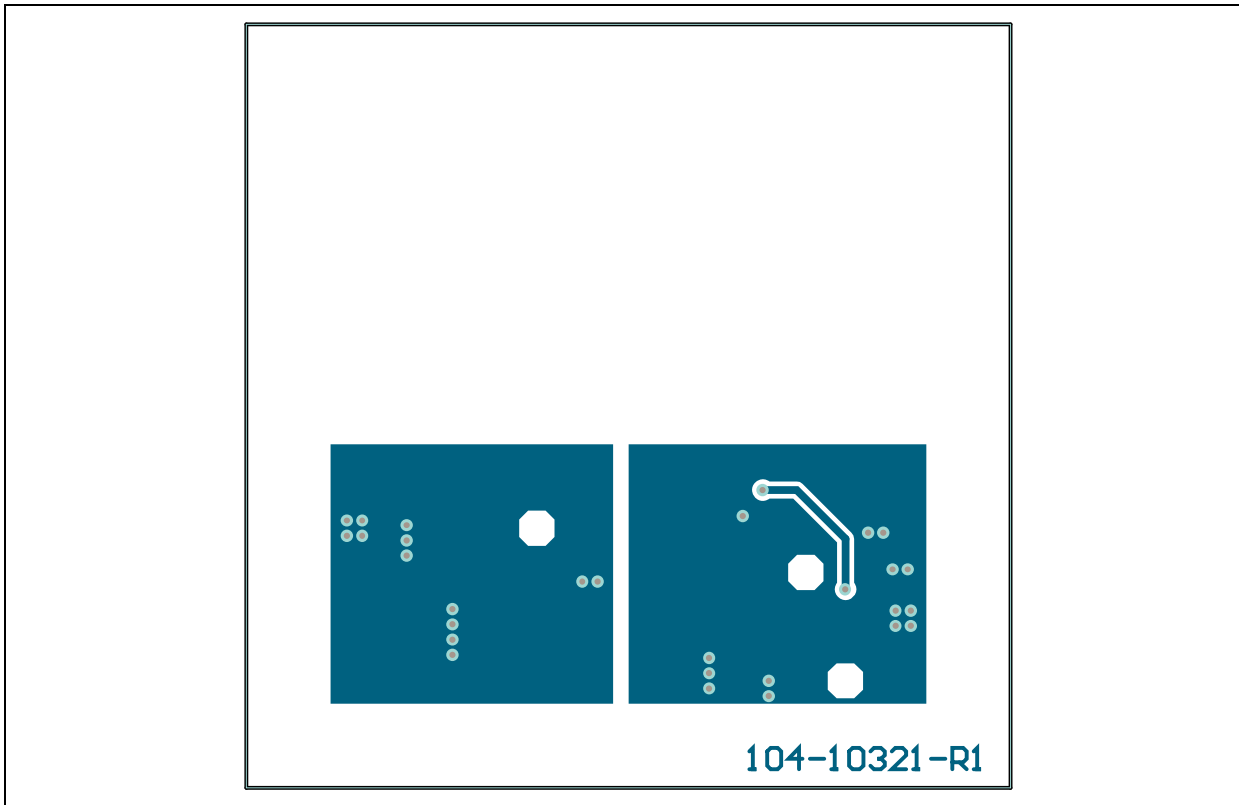


MCP1661 Isolated Flyback Converter Reference Design

A.5 BOARD – TOP COPPER



A.6 BOARD – BOTTOM COPPER



Appendix B. Bill of Materials

TABLE B-1: BILL OF MATERIALS (BOM)

Qty.	Reference	Description	Manufacturer	Part Number
1	C1	CAP. CER 1 μ F 16V X7R 0805	TDK Corporation	C2012X7R1C105K125AA
1	C2	CAP. CER 10 μ F 25V X7R 1210	TDK Corporation	C3225X7R1E106K250AC
2	C3, C4	CAP. CER 1 μ F 25V X7R 0805	TDK Corporation	C2012X7R1E105K125AB
1	C5	CAP. CER 10 μ F 16V X7R 1210	TDK Corporation	C3225X7R1C106K200AB
2	D1, D2	SCHOTTKY RECT. 40V 0.5A SOD123	ON Semiconductor®	MBR0540T1G
5	J2, J3, J4, J7, J8	PC TEST POINT TIN SMD	HARWIN Plc.	S1751-46R
1	PCB	MCP1661 Flyback Reference Design – Printed Circuit Board	Microchip Technology Inc.	104-10321
1	R1	RES. 100 k Ω 1/8W 1% 0805 SMD	Vishay Draloric	CRCW0805100KFKEA
1	R2	RES. 5.6 k Ω , 1/8W 1% 0805 SMD	Vishay Draloric	CRCW08055K60FKEA
1	R3	RES. 10 k Ω 1/8W 1% 0805 SMD	Vishay Draloric	CRCW080510K0FKEA
1	TR1	Flyback Transformer, 25 μ H, 15V, 1:1	WURTH Elektronik	750310799
1	U1	MCP1755S LDO 5V Output	Microchip Technology Inc.	MCP1755S-5002E/DB
1	U2	MCP1661 High Voltage Boost Switcher, 500 kHz	Microchip Technology Inc.	MCP1661T-E/OT
0	J1, J5, J6	DO NOT POPULATE, Header, 2.54 mm, Vertical, THT	Samtec, Inc.	TSW-101-05-T-S

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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