MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design User's Guide

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MCP1630V BIDIRECTIONAL 4 CELL LI-ION CHARGER 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 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 "DSXXXXXA", where "XXXXX" 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 chapter contains general information that will be useful to know before using the MCP1630V Bidirectional 4 Cell Li-Ion Charger 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 MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design 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 MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design.
- **Chapter 2. "Installation and Operation"** – Includes instructions on how to get started with this user's guide and a description of the user's guide.
- **Appendix A. "Schematics and Board Layouts"** – Shows the schematic and layout diagrams for the MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design.
- **Appendix B. "Bill Of Materials (BOM)"** – Lists the parts used to build the MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design.
- **Appendix C. "Firmware"** – Provides information about the application firmware and where the source code can be found.

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	*File>Save*
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]`

RECOMMENDED READING

This user's guide describes how to use MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design. The following Microchip documents are available and recommended as supplemental reference resources.

MCP1630/MCP1630V Data Sheet, *"High-Speed, Microcontroller-Adaptable, Pulse Width Modulator"* (DS21896)

This data sheet provides detailed information regarding the MCP1630/MCP1630V, product family.

PIC16F88 Data Sheet, *"20-Pin Flash-Based, 8-Bit CMOS Microcontrollers with Nano Watt Technology"* (DS30487)

This data sheet provides detailed information regarding the PIC16F88 product family.

APEC Conference Paper, *"Bi-Directional Power System for Laptop Computers"*, 2005

This paper provides detailed information about powering laptop computers using 4 series cell Li-Ion batteries with a bidirectional laptop computer.

THE MICROCHIP WEB SITE

Microchip provides online support via our web site at www.microchip.com. This web site is used as a means to make files and information easily available to customers. Accessible by using your favorite Internet browser, the web site contains the following information:

- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user’s guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip consultant program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

CUSTOMER SUPPORT

Users of Microchip products can receive assistance through several channels:

- 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://support.microchip.com

DOCUMENT REVISION HISTORY

Revision A (November 2006)

- Initial Release of this Document.

NOTES:

MCP1630V BIDIRECTIONAL 4 CELL LI-ION CHARGER REFERENCE DESIGN USER'S GUIDE

Chapter 1. Product Overview

1.1 INTRODUCTION

As high power portable applications continue to gain in popularity, more innovative techniques are needed to charge the batteries while also providing a low regulated voltage to the system's high end digital electronics. For example, laptop computers, portable test equipment, portable printers, etc., all require more power than a single or two cell Li-Ion battery pack can efficiently store. As a result, three or four series Li-Ion cell packs are used to store the necessary that power these high end applications. The result is a high dc voltage used to store the energy requiring a difficult high voltage to low voltage dc-dc conversion. The MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design can be used to evaluate a design that boosts a low source voltage to charge four Li-Ion series cells while providing energy to the system simultaneously. When the source is removed, the same power train used to charge the battery pack provides a low regulated voltage to operate the system.

This chapter covers the following topics.

- What is the MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design?
- What the MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design Kit includes.

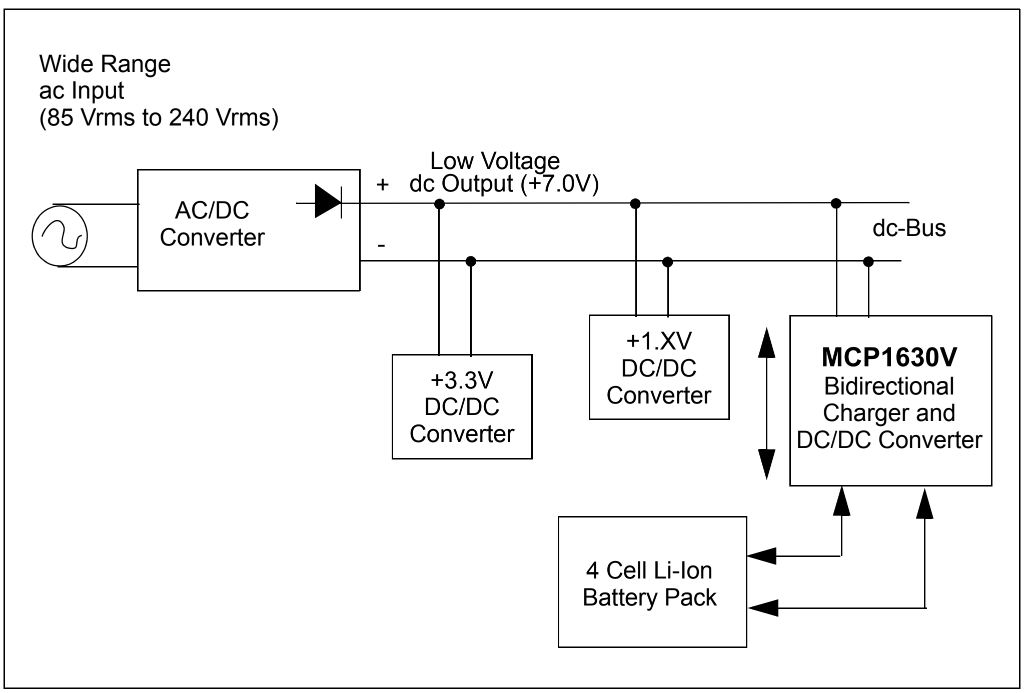


FIGURE 1-1: MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design shown in Laptop Computer system level block diagram.

1.2 WHAT IS THE MCP1630V BIDIRECTIONAL 4 CELL LI-ION CHARGER REFERENCE DESIGN?

The MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design demonstrates the use of a bidirectional buck-boost converter used to charge multiple series cell Li-Ion batteries with the presence of an input source (boost) and provide a regulated output voltage when the input source is removed (buck). The board also serves as a platform to evaluate the MCP1630V device.

The MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design inputs were developed to be easily attached to the I/O of a PIC® Microcontroller. The MCU supplies the oscillator (OSC_IN) and reference voltage (V_{REF}) to the MCP1630V creating a flexible and adaptable power system. The power system switching frequency and maximum duty cycle are set using the hardware PWM of the MCU. The reference input to the high speed analog PWM can be external, a D/A Converter (DAC) output or as simple as an I/O output from the MCU. This enables the power system to adapt to external signals and variables in order to optimize performance and facilitate calibration.

This board utilizes Microchip's MCP1630V (high-speed PIC MCU PWM MSOP8) with the PIC16F88 (Flash MCU) in a four cell Li-Ion charger combined with a synchronous buck regulator. Under normal operation, the input supply can range between 6.5V and 7.0V. The converter is capable of charging four Li-Ion cells connected in series when the 6.5V input is present and regulating the bulk input voltage to 6.0V when the input source voltage is removed by stepping, (bucking), down the battery pack voltage.

1.3 WHAT THE MCP1630V BIDIRECTIONAL 4 CELL LI-ION CHARGER REFERENCE DESIGN KIT INCLUDES

This MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design kit includes:

- MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design
- Analog and Interface Products Demonstration Boards CD-ROM (DS21912)
  - MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design User's Guide (DS51641)

Chapter 2. Installation and Operation

2.4 INTRODUCTION

The MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design demonstrates Microchip's high speed pulse width modulator (PWM) used in a four cell Li-Ion battery charger combined power supply application. When used in conjunction with a microcontroller, the MCP1630V will control the power system duty cycle to provide regulated output voltage or current. The PIC16F88 microcontroller oscillator output is used to provide pulses at switching frequency of 500 kHz. The MCP1630V generates duty cycle based on various external inputs. External signals include the input oscillator pulses from PIC16F88, the reference voltage and the feed back voltage. The output signal is a square wave pulse provided to the synchronous gate drive input. They synchronous gate driver is used to turn on and off the upper buck MOSFET and lower synchronous MOSFET.

The PIC16F88 microcontroller is programmable, allowing the user to modify or develop their own firmware routines to further evaluate the MCP1630V in this application.

2.5 FEATURES

The MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design has the following features:

- Four Cell Li-Ion Battery Charger, operates stand alone. (Additional firmware added allows the charger to communicate with smart battery packs)
- Charges four cell Li-Ion battery pack from 6.5V to 7.0V Input (complete precondition, constant current and constant voltage charge algorithm in firmware)
- Regulates input dc bus voltage, (steps battery pack voltage down), to 6.0V when input source is removed (providing uninterrupted power source for system)
- ON/OFF button used to enable and disable system, low I_Q drain on the battery when disabled (< 10 µA)
- Output over-voltage protection in the event of open battery connections
- High efficiency over entire operating input voltage range (94% typical)
- PIC16F88 is used to generate ref Voltage and Oscillator signal at 500 kHz frequency at maximum duty cycle
- Proprietary features can be added by modifying the firmware contained in the PIC16F88
- Factory programmed source code is available

2.6 GETTING STARTED

The MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design is fully assembled and tested for charging a four series cell Li-Ion battery pack (Battery Pack should have internal overvoltage, overcurrent and overtemperature protection). The board requires the use of an external input voltage source (+7.0V) for charging.

2.6.1 Power Input and Output Connection

2.6.1.1 POWERING THE MCP1630V BIDIRECTIONAL 4 CELL LI-ION CHARGER REFERENCE DESIGN

1. Connect the positive side of the +6.5V to +7.0V input to J2 Pin 2, connect the negative side (or ground) to Pin 1 of J2. This source voltage should not exceed 7.0 and be rated for 8A minimum supply current.
2. Connect the positive side of the Four cell Li-Ion battery pack voltage to J1 Pin 1, connect the battery pack return to the negative side of J1 Pin 2.

> **Note:** Both supplies should have a separate isolated return (ground), there is a current sense resistor between the +7.0V (V_{BULK}) and +14V(V_{BATT}) supply returns. If the returns are connected, the charge current can not be controlled.

3. Once the SW1 push button is pressed, the MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design is powered. When powered, a charge cycle will start automatically if the 7.0V is connected and all preconditions are meet, (see **Appendix C. "Firmware"**).
4. LED D3 will be illuminated when the board is running, (charging or bucking).
5. LED D5 will flash only when a charge cycle is in progress.
6. Again, a subsequent pressing of the SW1 push button during normal operation of the MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design will power-off the converter.

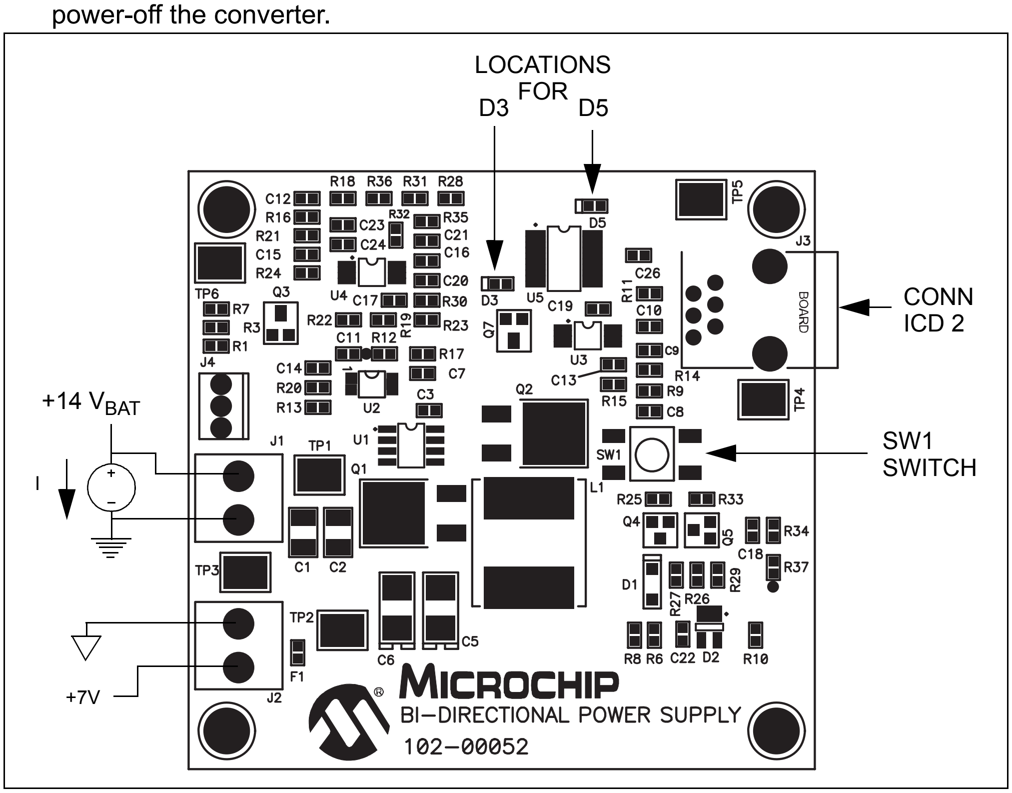


FIGURE 2-2: *Board Top Assembly and Connections*

2.6.1.2 APPLYING BATTERY TO MCP1630V BIDIRECTIONAL 4 CELL LI-ION CHARGER REFERENCE DESIGN

A four cell battery pack (with internal protection) is connected to the J1 connector before applying input power and pressing SW1 to start the charge cycle. Once the battery pack is connected, SW1 can be pressed to start the synchronous buck converter (assuming there is no 7.0V input applied to J2). With the battery pack connected, the source for J2 can be “hot” plugged in and out, a voltage will always be present on J2 until SW1 is pressed shutting off the converter.

2.6.1.3 ALTERNATIVE BATTERY PACK SIMULATOR

As an alternative to the four cell Li-Ion battery pack, a battery pack simulation circuit can be used, (Figure 2-3). This simulation circuit consists of an adjustable metal wound power load resistor (10Ω, 100W), Aluminum Electrolytic Capacitor (3,300 µF 25V) and Schottky Diode (10V, 30V). For evaluating the bidirectional converter design, the battery simulator circuit is recommended. When using the battery pack simulator, the operating point for charging and discharging can be easily be adjusted using the V_{BATT} power supply and load resistor value.

2.6.1.4 LED STATUS INDICATION

Two LED’s are connected to the I/O of the PIC16F88 to provide status of the charger. LED D3 provides indication that the converter is running while LED D5 flashing provides indication that the converter is charging. With a 6.5V to 7.0V source applied to J2 while the converter is running, a charge cycle is initiated. Once the charge cycle is complete, the charger will continue to operate providing 0 mA of current to the battery. If the source is removed from J2, the converter will regulate the V_{BULK} voltage to 6.0V with a load up to 6A.

Evaluating the Application

The best way to evaluate the MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design is to operate the bidirectional power system over a wide range using the battery pack simulator. The simulator consists of a 10Ω power resistor, diode and variable voltage source. When configured as shown in Figure 2-3, the circuit will simulate a battery. The load resistor is used to sink current from the charger while a large capacitor is used to simulate the battery voltage (V_{SIM}). By adjusting the V_{SIM} voltage, different operating points in the charge cycle can be evaluated.

Once evaluated using the battery pack simulator, the bi-directional reference design can be used to run charge and discharge cycles using a four cell Li-ion battery pack. If using an actual Li-ion battery pack, it must have the proper protection features including, (overvoltage, overcurrent, overtemperature, etc.).

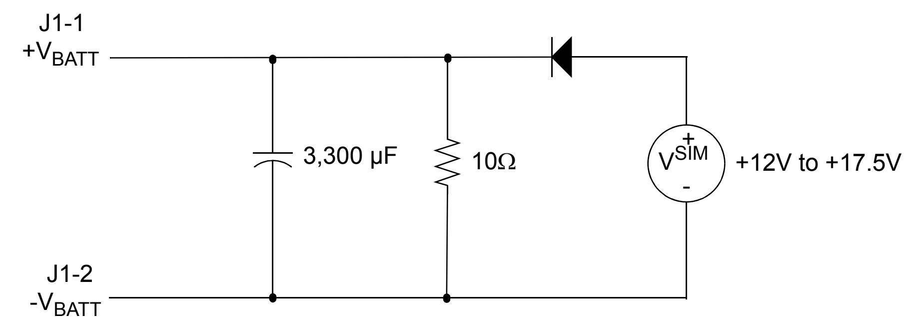


FIGURE 2-3: *Battery Simulator Circuit.*

Firmware

The PIC16F88 comes pre programmed with firmware to operate the system as described above. The file listing and firmware flow diagram are shown in **Appendix C. "Firmware"**.

Programming

Header J4 is provided for In-Circuit Serial Programming™ (ICSP™). This is an optional feature since the demo board comes preprogrammed with firmware to operate the system. The PIC16F88 can be reprogrammed with the Baseline Flash Microcontroller Programmer (BFMP).

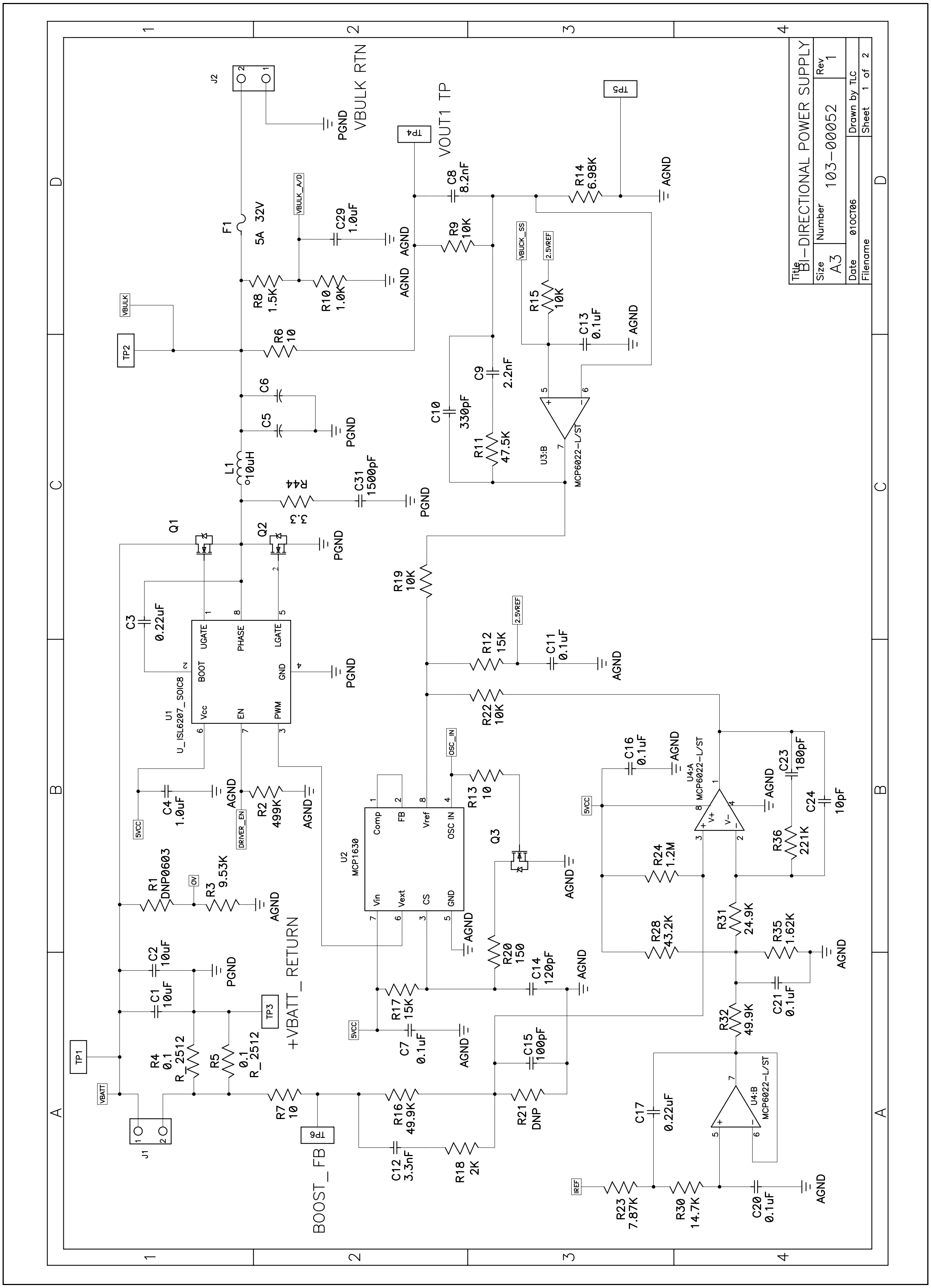
Appendix A. Schematics and Board Layouts

A.1 INTRODUCTION

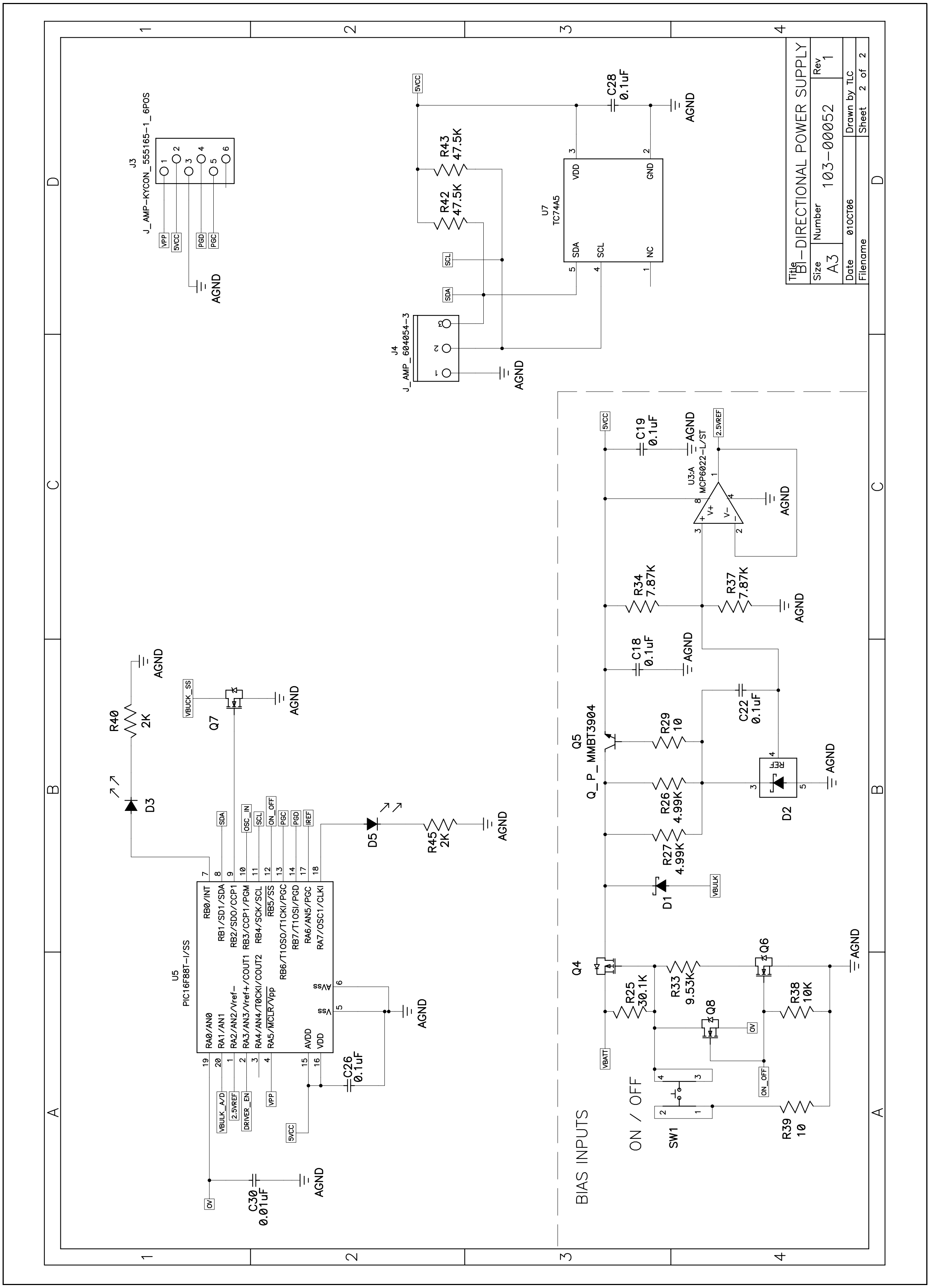
This appendix contains the following schematics and layouts for the MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design:

- Board – Schematic Sheet 1
- Board – Schematic Sheet 2
- Board – Top Silk Layer
- Board – Top Metal Layer
- Board – Internal MidLayer 1
- Board – Internal MidLayer 2
- Board – Metal Layer
- Board – Bottom Silk Layer

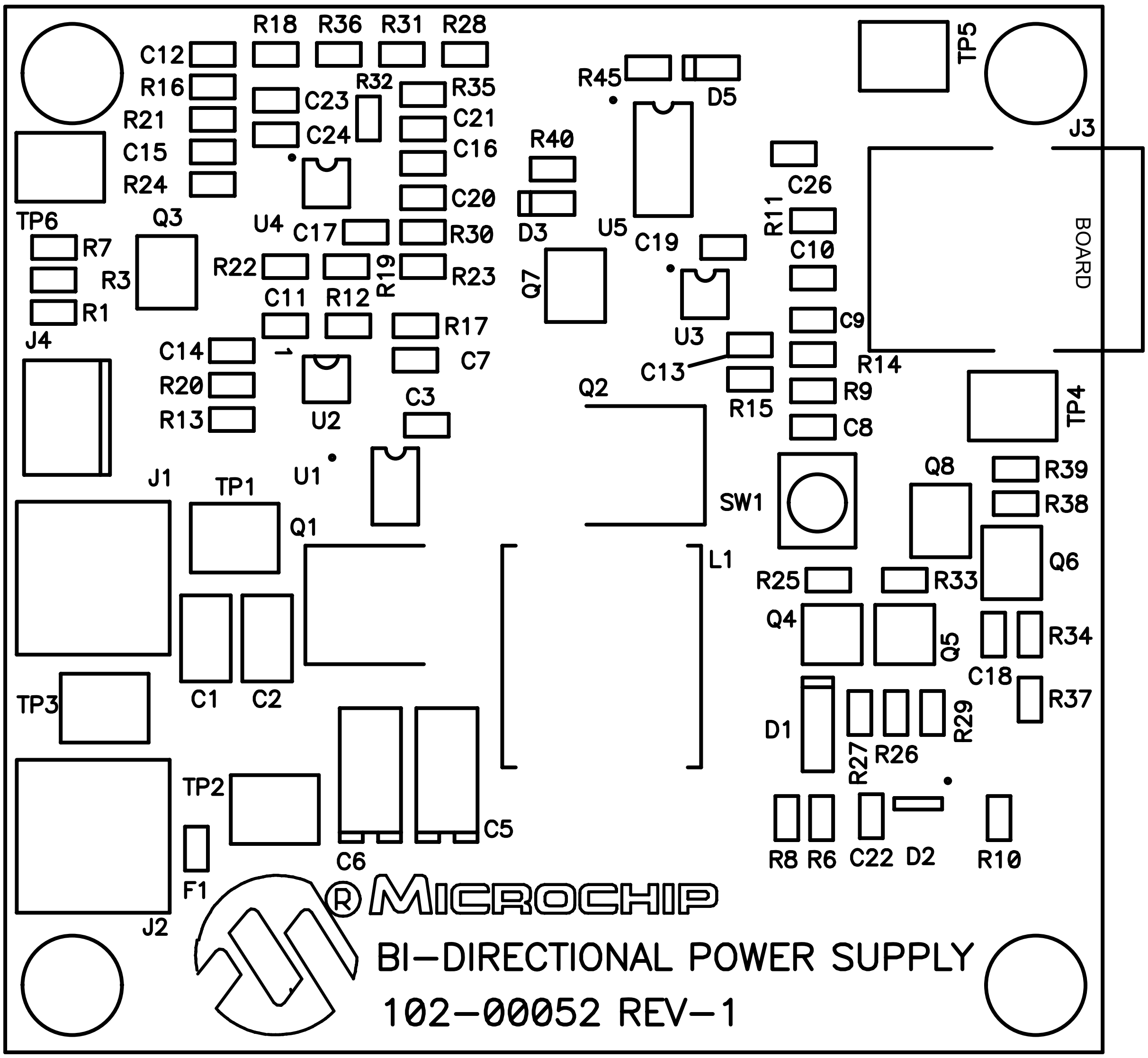
A.2 SCHEMATIC - SHEET 1



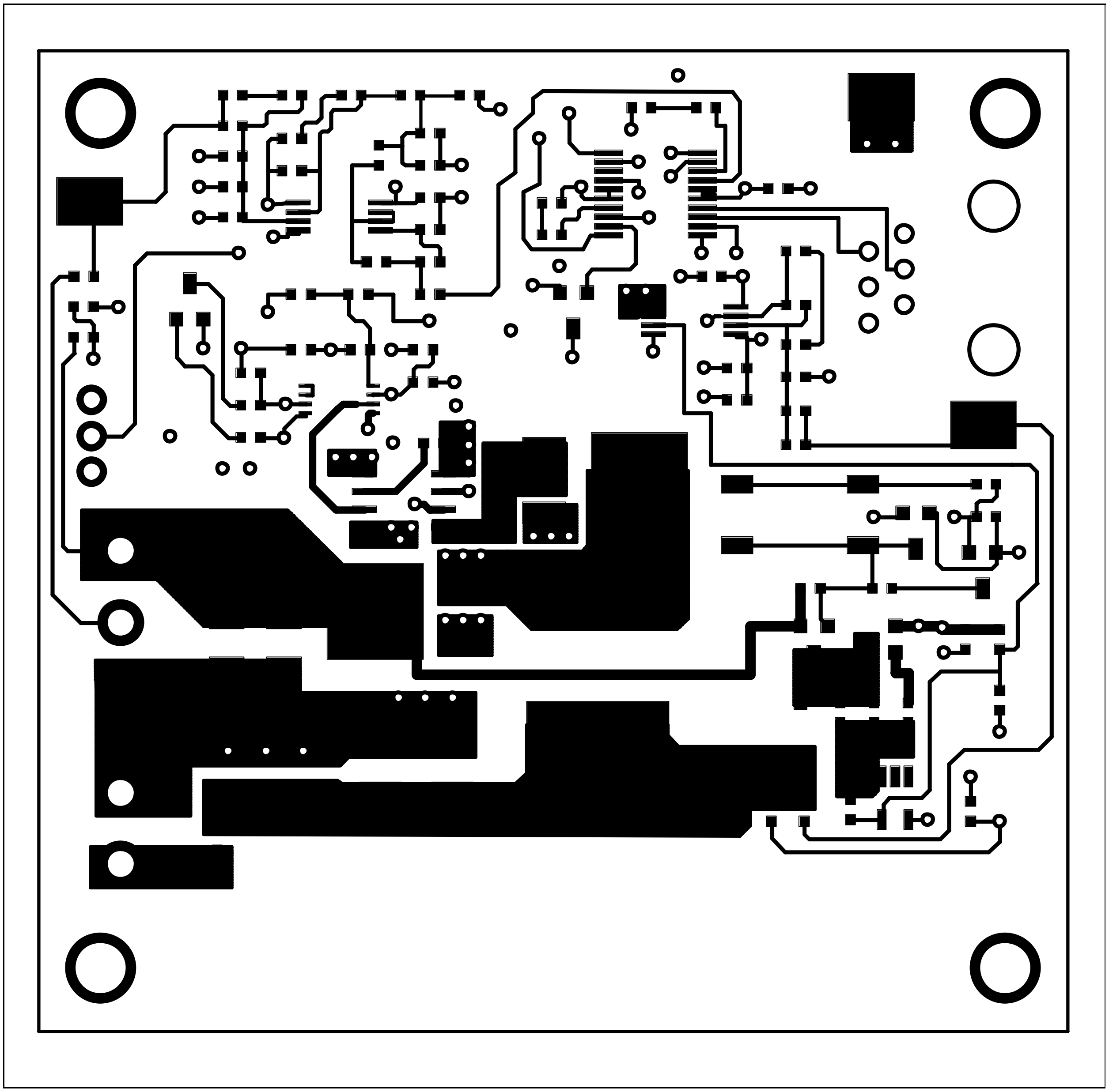
A.3 SCHEMATIC - SHEET 2



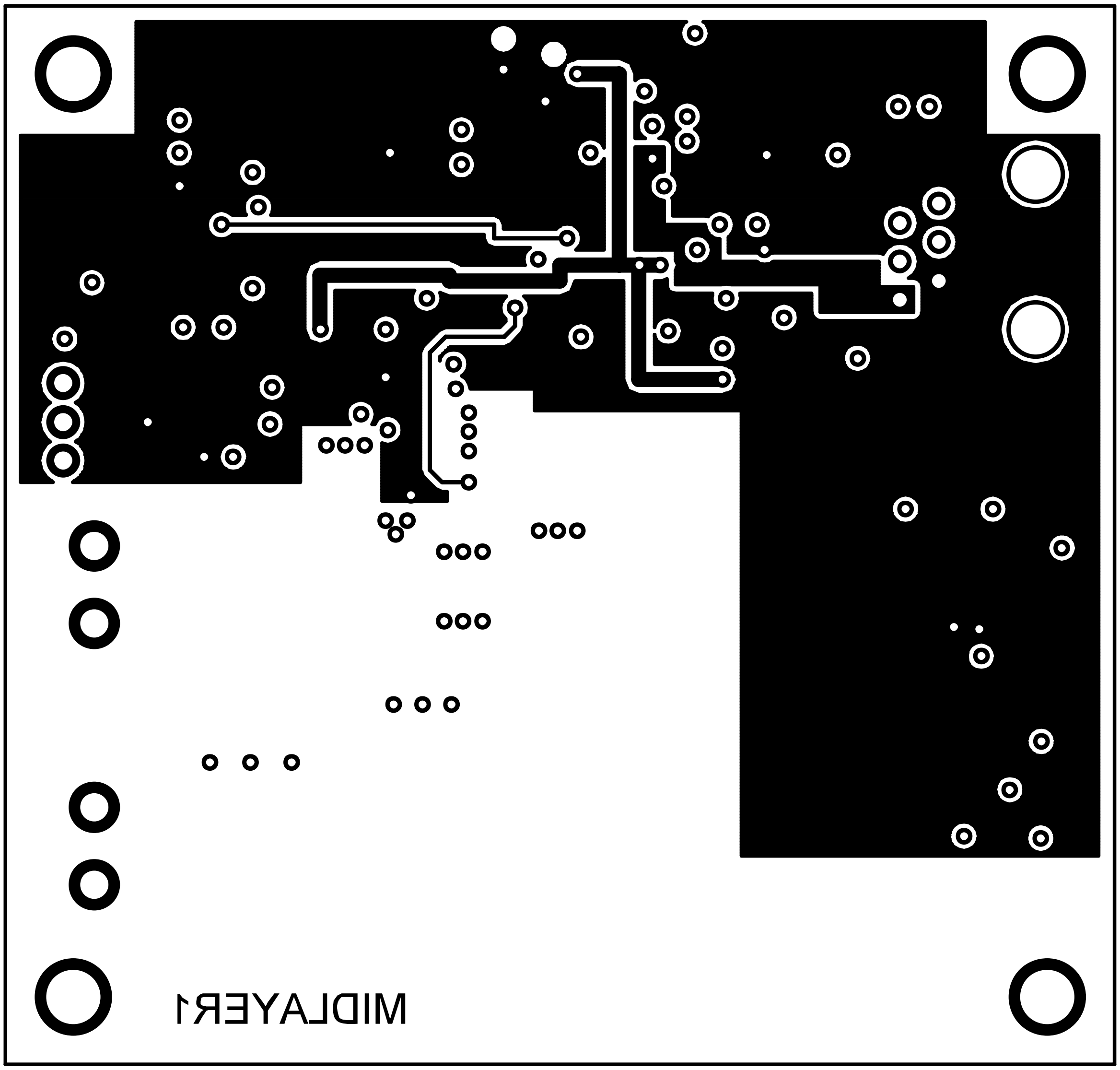
A.4 BOARD – TOP SILK LAYER



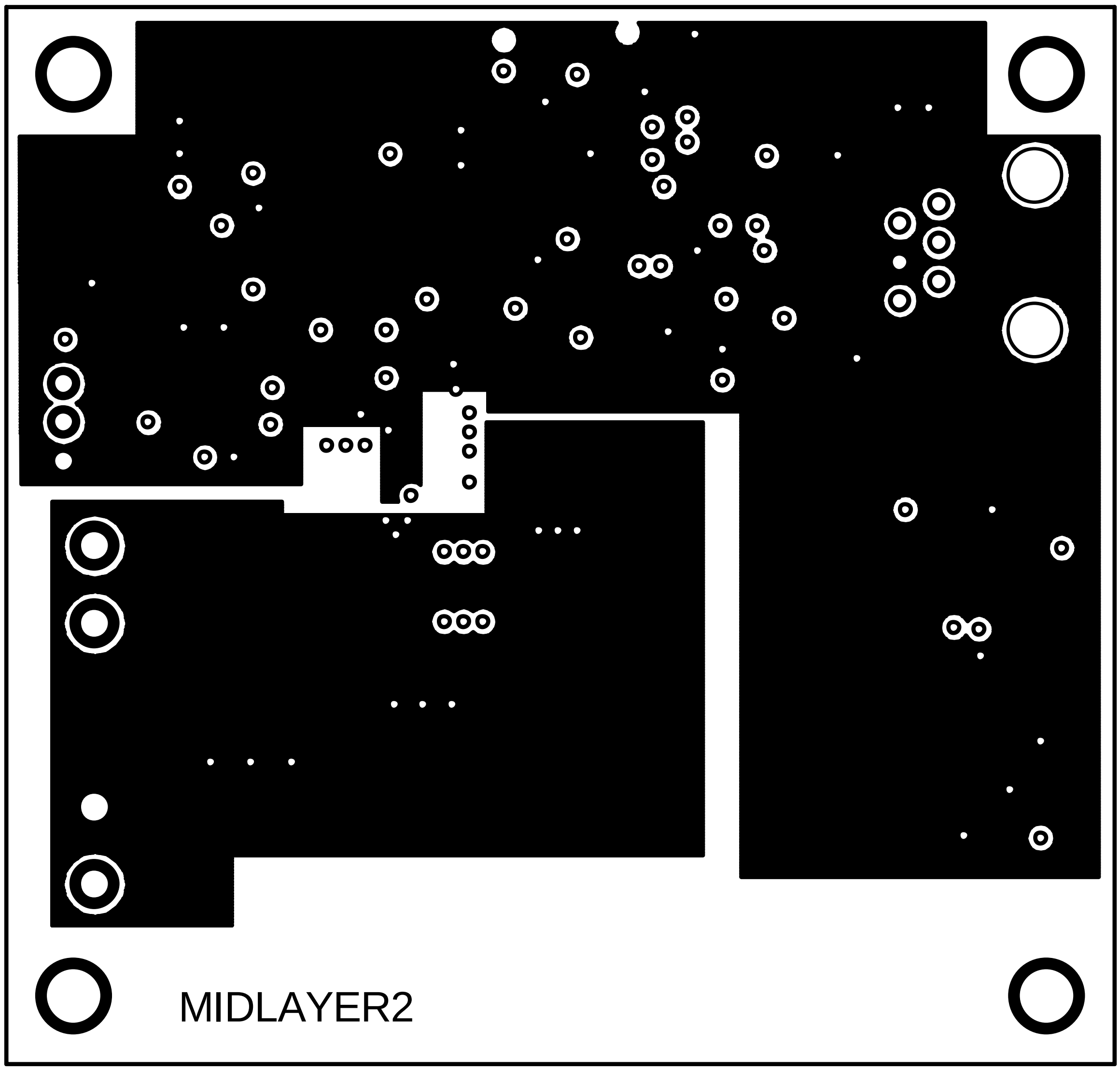
A.5 BOARD – TOP METAL LAYER



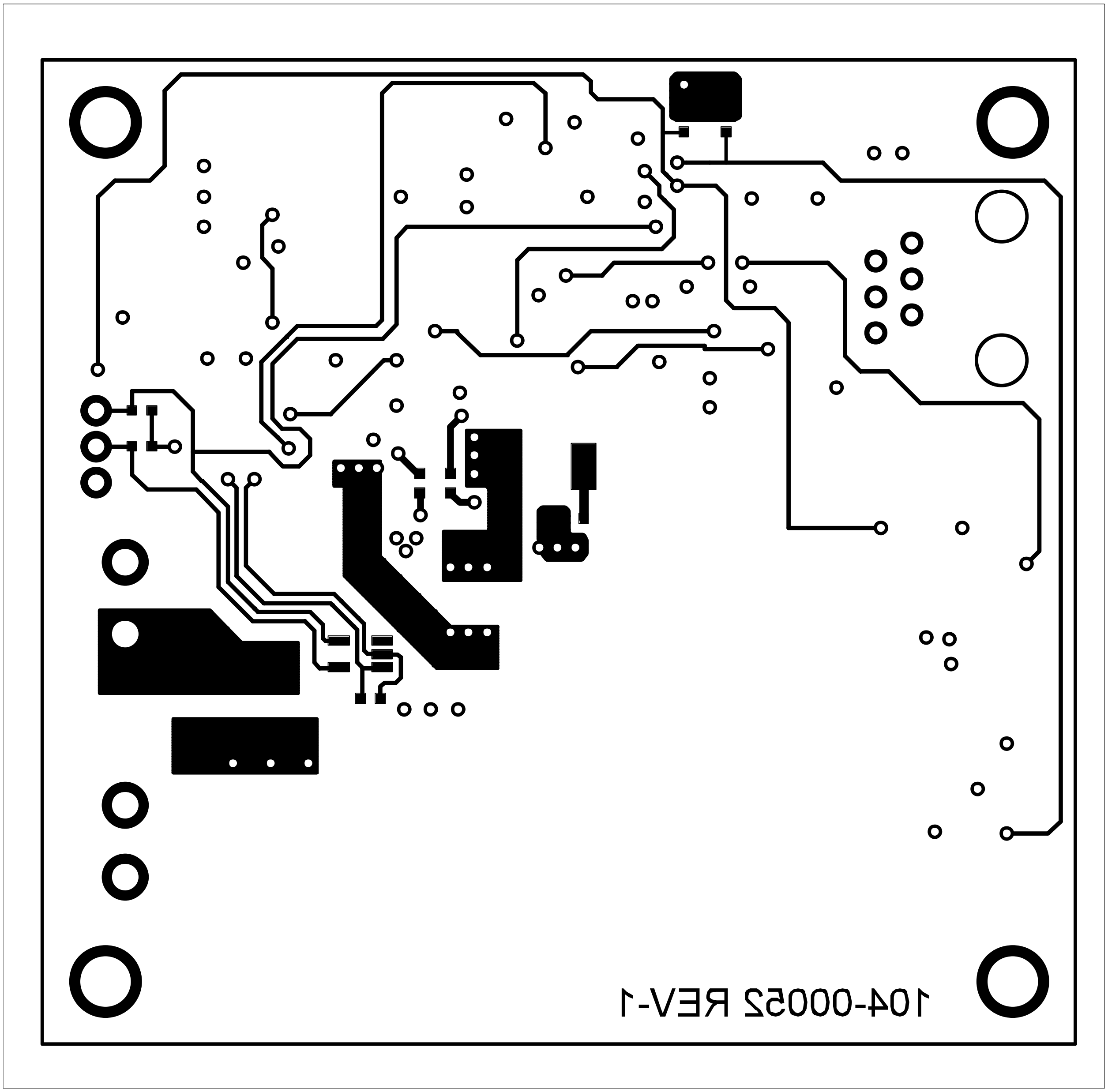
A.6 BOARD – MID LAYER1



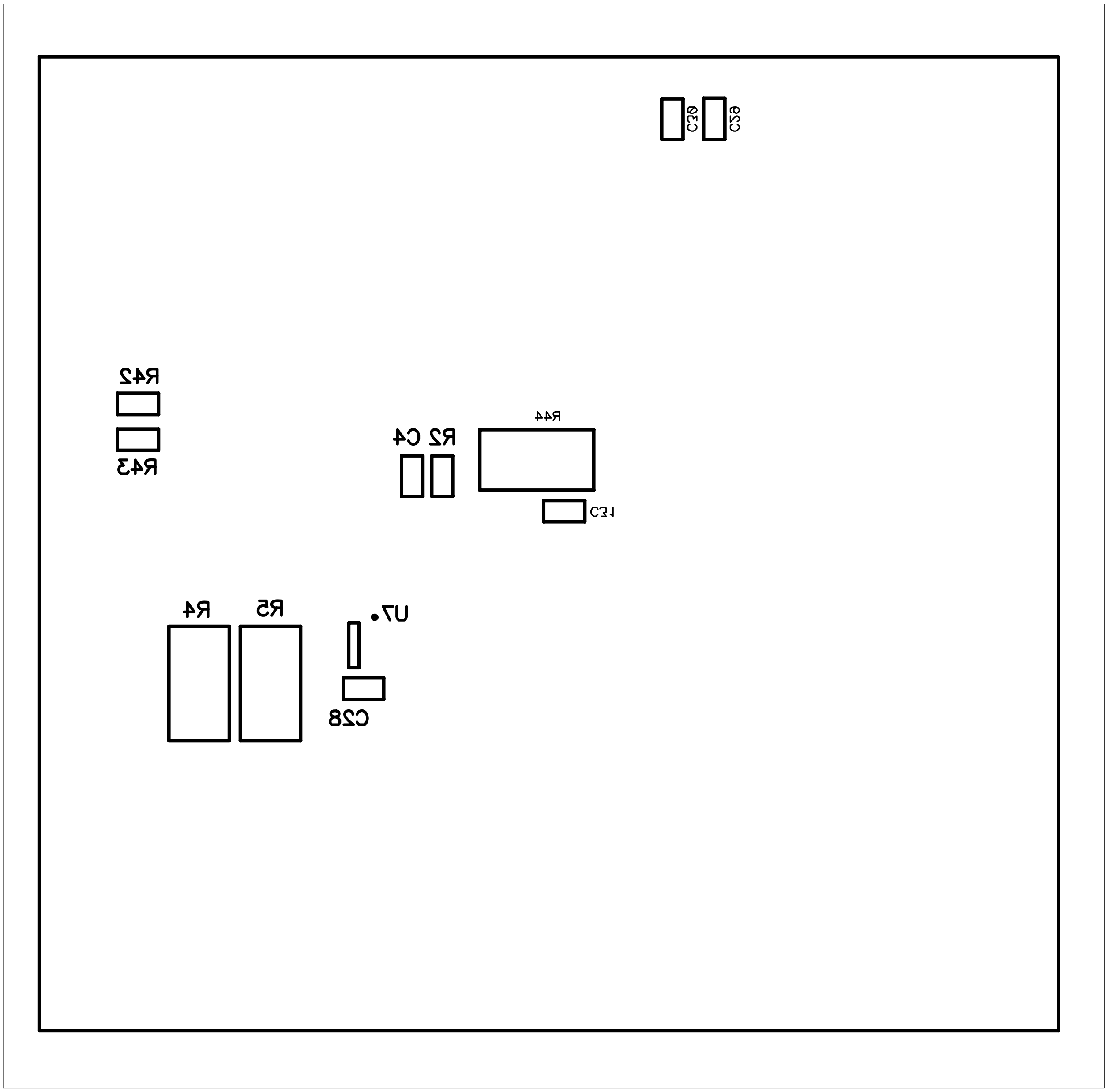
A.7 BOARD – MID LAYER2



A.8 BOARD – METAL LAYER



A.9 BOARD – BOTTOM SILK LAYER



NOTES:

Appendix B. Bill Of Materials (BOM)

TABLE B-1: BILL OF MATERIALS (BOM)

QTY	Reference Designator	Description	Manufacturer	Part Number
2	C1, C2	CAP CER 10UF 25V X5R 1210	Taiyo Yuden®	TMK325BJ106MN-T
2	C3, C17	CAP CERM.22UF 10% 10V X7R 0603	AVX Corporation	0603ZC224KAT2A
2	C4, C29	CAP CERAMIC 1.0UF 10V X5R 0603	Kemet® Electronics Corp	C0603C105K8PACTU
2	C5, C6	CAP TANT 100UF 10V 20% POLY SMD	EPCOS Inc.	B76010V1079M055
12	C7, C11, C13, C16, C18, C19, C20, C21, C22, C26, C28	CAP .10UF 10V CERAMIC X7R 0603	Kemet Electronics Corp	C0603C104K8RACTU
1	C8	CAP CERM 8200PF 10% 50V X7R 0603	AVX Corporation	06035C822KAT2A
1	C9	CAP CER 2200PF 50V C0G 5% 0603	TDK Corporation	C1608C0G1H222J
1	C10	CAP CERAMIC 330PF 50V NP0 0603	Kemet Electronics Corp	C0603C331J5GACT
1	C12	CAP 3300PF 50V CERAMIC X7R 0603	Kemet Electronics Corp	C0603C332K5RACTU
2	C14	CAP CERAMIC 120PF 50V NP0 0603	Kemet Electronics Corp	C0603C121J5GACTU
1	C15	CAP CERAMIC 100PF 50V NP0 0603	Kemet Electronics Corp	C0603C101J5GACTU
1	C23	CAP CERAMIC 180PF 50V NP0 0603	Kemet Electronics Corp	C0603C181J5GACTU
1	C24	CAP CERAMIC 10PF 50V NP0 0603	Kemet Electronics Corp	C0603C100J5GACTU
1	C30	CAP 10000PF 50V CERAMIC X7R 0603	Kemet Electronics Corp	C0603C103K5RACTU
1	C31	CAP 1500PF 50V CERAMIC X7R 0603	Kemet Electronics Corp	C0603C152K5RACTU
2	D1	DIODE SCHOTTKY 30V 200MW SOD123	Diodes Inc.	BAT42W-7-F
1	D2	IC ADJ SHUNT REGULATOR SOT-23-5	Texas Instruments	TL431IDBVR
2	D3, D5	LED 660NM SUPER RED DIFF 0603SMD	Lumex® Opto/ Components Inc	SML-LX0603SRW-TR
1	F1	FUSE 5.0A 32V FAST SMD 0603	Tyco® Electronics/ Raychem Circuit Protection	0603SFF500F/32-2
2	J1, J2	CONN TERM BLOCK 2POS 5MM PCB	Phoenix Contact	1715022
1	J3	CONN MOD JACK 6-6 RT/A PCB 50AU	Tyco Electronics/Amp	5555165-1
1	J4	CONN HEADER VERT 3POS.100 TIN	Tyco Electronics/Amp	640454-3
1	L1	INDUCTOR POWER HI CURR 10UH SMD	Coiltronics/Div of Cooper/Bussmann	HC1-100-R
1	Q1	MOSFET N-CH 30V 35A DPAK	International Rectifier	IRLR3303PBF
1	Q2	MOSFET N-CH 30V 91A DPAK	International Rectifier	IRLR8103VPBF
4	Q3, Q6, Q7, Q8	MOSFET N-CH 30V 1.2A SSOT3	Fairchild Semiconductor	NDS351AN

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.

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

QTY	Reference Designator	Description	Manufacturer	Part Number
1	Q4	MOSFET P-CH 30V 610MA SOT-23	International Rectifier	IRLML5103TRPBF
1	Q5	TRANSISTOR GP NPN AMP SOT-23	Fairchild Semiconductor®	MMBT3904
0	R1, R21	SMT0603 RESISTOR DO NOT POPULATE	—	—
1	R2	RES 499K OHM 1/10W 1% 0603 SMD	Panasonic® - ECG	ERJ-3EKF4993V
2	R3, R33	RES 9.53K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF9531V
2	R4, R5	RESISTOR .100 OHM 1W 1% 2512	Panasonic - ECG	ERJ-L1WKF10CU
5	R6, R7, R13, R29, R39	RES 10.0K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1002V
1	R8	RES 1.50K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1501V
6	R9, R15, R19, R22, R38	RES 10.0K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1002V
1	R10	RES 1.00K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1001V
3	R11, R42, R43	RES 47.5K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF4752V
1	R12, R17	RES 15.0K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1502V
1	R14	RES 6.98K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF6981V
2	R16, R32	RES 49.9K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF4992V
3	R18, R40, R45	RES 2.00K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF2001V
1	R20	RES 150 OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1500V
3	R23, R34, R37	RES 7.87K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF7871V
1	R24	RESISTOR 1.20M OHM 1/10W 1% 0603	Panasonic - ECG	ERJ-3EKF1204V
1	R25	RES 30.1K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF3012V
3	R26, R27	RES 4.99K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF4991V
1	R28	RES 43.2K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF4322V
1	R30	RES 14.7K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1472V
1	R31	RES 24.9K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF2492V
1	R35	RES 1.62K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1621V
1	R36	RES 221K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF2213V
1	R44	RES 3.3 OHM 1W 1% 2512 SMD	Panasonic - ECG	ERJ-1TRQF3R3U
1	SW1	SWITCH TACT 6MM 260GF SMT	E-Switch	TL3301NF260QG
6	TP1, TP2, TP3, TP4, TP5, TP6	PC TEST POINT COMPACT SMT	Keystone Electronics®	5016
1	U1	IC DRIVER MOSFET DUAL SYNC 8SOIC	Intersil	ISL6207CBZ
1	U2	MCP1630V HIGH SPEED ANALOG PWM	Microchip Technology Inc.	MCP1630V-E/MS
2	U3, U4	DUAL10MHz AMPLIFIER 8 PIN TSSOP PACKAGE	Microchip Technology Inc.	MCP6022-I/ST
1	U5	IC MCU FLASH 4KX14 EEPROM 20SSOP	Microchip Technology Inc.	PIC16F88T-I/SS
1	U7	IC DGTL THERM SENSOR 5V SOT23A-5	Microchip Technology Inc.	TC74A5-5.0VCTTR

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.

Appendix C. Firmware

C.1 DEVICE FIRMWARE - FLOWCHART

For the latest copy of the MCP1630V Bidirectional 4 Cell Li-Ion Charger Reference Design User's Guide firmware, visit our web site at www.microchip.com.

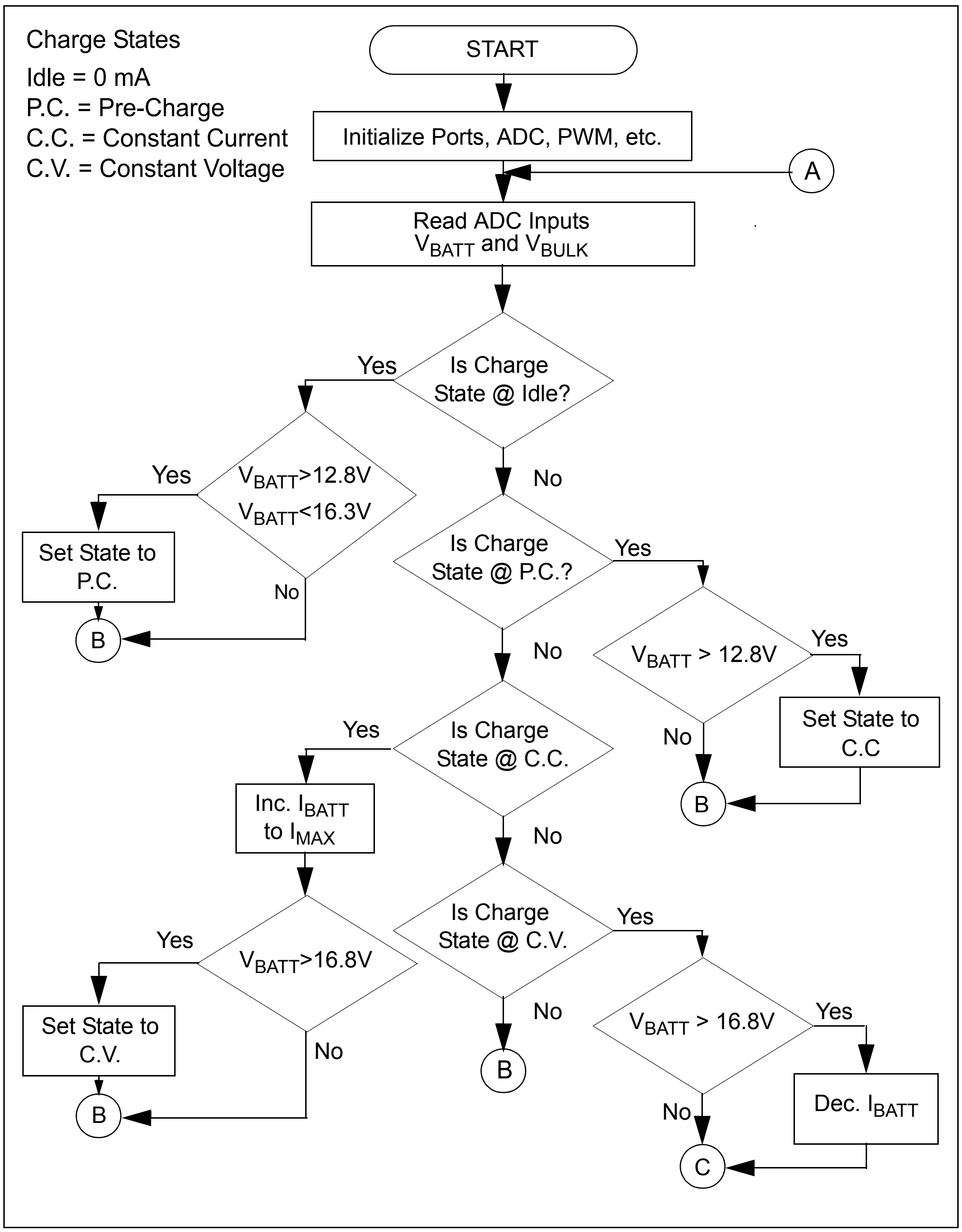


FIGURE C-1: *Firmware Flowchart, page 1.*

C.2 DEVICE FIRMWARE - FLOWCHART (CONTINUED)

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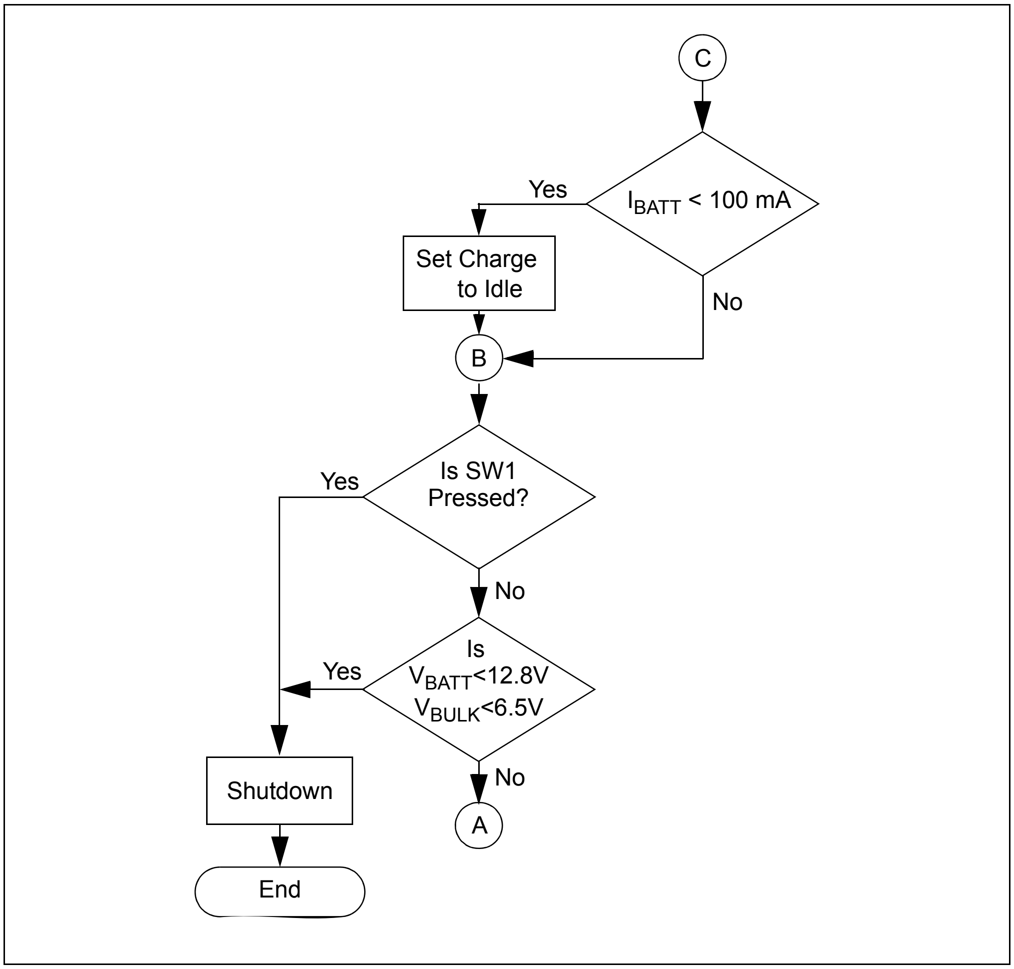

FIGURE C-2: *Firmware Flowchart, page 2.*

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