

## ***bq24610EVM-603 >7-Cell, Li-Ion Battery Charger***

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The bq24610 is an integrated Li-ion or Li-polymer switch-mode battery charge controller. It offers a constant-frequency synchronous switching PWM controller with high-accuracy charge current and voltage regulation. Other features include charge preconditioning, termination, and charge status monitoring. At present, no single chip solution exists to charge more than a 7-cell Li-ion battery. This bq24610EVM-603 provides a practical solution using the bq24610, the TPS54060, UCC2701, INA169, and LM2903. Detail design ideas are available in the Texas Instruments application report [SLUA580](#).

### **Contents**

1	Introduction .....	2
	1.1 EVM Features .....	2
	1.2 General Description .....	2
	1.3 Input/Output Description .....	2
	1.4 Control and Key Parameters Setting .....	2
	1.5 Recommended Operating Conditions .....	2
2	Test Summary .....	3
	2.1 Definitions .....	3
	2.2 Equipment .....	3
	2.3 Equipment Setup .....	4
	2.4 Procedure .....	4
3	PCB Layout Guideline .....	5
4	Bill of Materials, Board Layouts, and Schematic .....	6
	4.1 Bill of Materials .....	6
	4.2 Board Layouts .....	8
	4.3 Schematic .....	14

### **List of Figures**

1	Original Test Setup for bq24610EVM-HV .....	4
2	Top Layer .....	8
3	Second Layer .....	9
4	Third Layer .....	10
5	Bottom Layer .....	11
6	Top Assembly .....	12
7	Bottom Assembly .....	13
8	Schematic .....	14

### **List of Tables**

1	Input/Output Description .....	2
2	Control and Key Parameters Setting .....	2
3	Bill of Materials .....	6

## 1 Introduction

### 1.1 EVM Features

- Evaluation module for 8-cell Li-ion battery. To support other voltage battery configurations, the output voltage set point can be altered by changing the feedback voltage divider.
- High-efficiency, synchronous buck charger
- User-programmable battery voltage
- Test points for key signals available for testing purpose. Easy probe hook-up
- Jumpers available. Easy-to-change connections.

### 1.2 General Description

The bq24610EVM-603 provides a solution to charge more than a 7-cell Li-ion battery. It uses the bq24610, TPS54060, UCC27201, INA169, and the LM2903.

The bq24610 is a highly integrated, Li-ion or Li-polymer, switch-mode battery charge controller. It offers a constant-frequency synchronous PWM controller with high-accuracy charge current and voltage regulation, termination, charge preconditioning, and charge status monitoring,

The bq24610EVM-603 charges the battery in three phases: preconditioning, constant current, and constant voltage. Charge is terminated when the current reaches a minimum user-selectable level. A programmable charge timer provides a safety backup for charge termination. The bq24610EVM-603 automatically restarts the charge cycle if the battery voltage falls below an internal threshold, and enters a low-quiescent current sleep mode when the input voltage falls below the battery voltage.

For details, see the bq24610 ([SLUS892](#)) data sheet.

### 1.3 Input/Output Description

**Table 1. Input/Output Description**

Jack	Description
J1–Vin	Input positive terminal
J1–PGND	Input ground terminal
J2–BAT	Output positive terminal
J2–PGND	Output ground
J2–TS	Temperature qualification voltage input
J2–TS1	Temperature qualification voltage input 1
JP1–CE	Charge enable pin
JP1–GND	Ground

### 1.4 Control and Key Parameters Setting

**Table 2. Control and Key Parameters Setting**

Jack	Description	Factory Setting
JP1	Charge disable setting Installed : Disable charge, Not installed: Allow charge	Jumper installed: disable charge

### 1.5 Recommended Operating Conditions

		Min	Typ	Max	Unit	Notes
Supply voltage, $V_{IN}$	Input voltage from ac adapter input	33	48	60	V	
Battery voltage, $V_{BAT}$	Voltage applied at VBAT terminal	0	33.6	50	V	
Supply current, $I_{AC}$	Maximum input current from ac adapter input	0		4.5	A	
Charge current, $I_{chrg}$	Battery charge current	1	3	4	A	
Operating junction temperature range, $T_J$		0		125	°C	

## 2 Test Summary

### 2.1 Definitions

This procedure details how to configure the HPA603 evaluation board. On the test procedure, the following naming conventions are followed. For details, see the HPA603 schematic ([Figure 8](#)).

VXXX :	External voltage supply name (VADP, VBT, VSBT)
LOADW:	External load name (LOADR, LOADI)
V(TPyyy):	Voltage at internal test point TPyyy. For example, V(TP12) means the voltage at TP12.
V(Jxx):	Voltage at jack terminal Jxx.
V(TP(XXX)):	Voltage at test point XXX. For example, V(ACDET) means the voltage at the test point which is marked as ACDET.
V(XXX, YYY):	Voltage across point XXX and YYY.
I(JXX(YYY)):	Current going out from the YYY terminal of jack XX.
Jxx(BBB):	Terminal or pin BBB of jack xx
Jxx ON :	Internal jumper Jxx terminals are shorted.
Jxx OFF:	Internal jumper Jxx terminals are open.
Jxx (-YY-) ON:	Internal jumper Jxx adjacent terminals marked as YY are shorted.
<i>Measure</i> → A,B:	Check specified parameters A, B. If measured values are not within specified limits, the unit under test has failed.
<i>Observe</i> → A,B:	Observe if A, B occur. If they do not occur, the unit under test has failed.

Assembly drawings have location for jumpers, test points, and individual components.

### 2.2 Equipment

#### 2.2.1 Power Supplies

Power Supply #1 (PS#1): a power supply capable of supplying 60 V at 5 A is required.

Power Supply #2 (PS#2): a power supply capable of supplying 5 V at 1 A is required.

Power Supply #3 (PS#3): a power supply capable of supplying 60 V at 6 A is required.

#### 2.2.2 Load #1

A 60-V (or greater), 5-A (or greater) electronic load that can operate at constant current mode

#### 2.2.3 Meters

Four Fluke 75 multimeters, (equivalent or better)

The current meters must be capable of measuring 5-A+ current.

#### 2.2.4 Oscilloscope

Tektronix TDS3054 scope or equivalent, 10X voltage probe.

## 2.3 Equipment Setup

1. Set the power supply #1 for 0 V  $\pm$ 100 mVdc, with the current limit set to >5 A and then turn off supply.
2. Connect the output of power supply #1 in series with a current meter (multimeter) to J1 (VIN, GND).
3. Connect a voltage meter across J1 (VIN, GND).
4. Set the power supply #2 for 0 V  $\pm$ 100 mVdc, 0.2-A  $\pm$ 0.1-A current limit, and then turn off supply.
5. Connect the output of the power supply #2 to J2 (TS, GND).
6. Connect Load #1 in series with a current meter to J2 (BAT, GND). Turn off Load #1.
7. Connect power supply #3 in series with a current meter to J2 (BAT, GND). Turn off power supply #3.
8. Connect a voltage meter across J2 (BAT, GND).
9. Connect an oscilloscope's probe across J2 (BAT, GND).
10. If JP1 is not installed, install the jumper.
11. After the preceding steps are done, the test setup for HPA603 looks like that shown in [Figure 1](#).

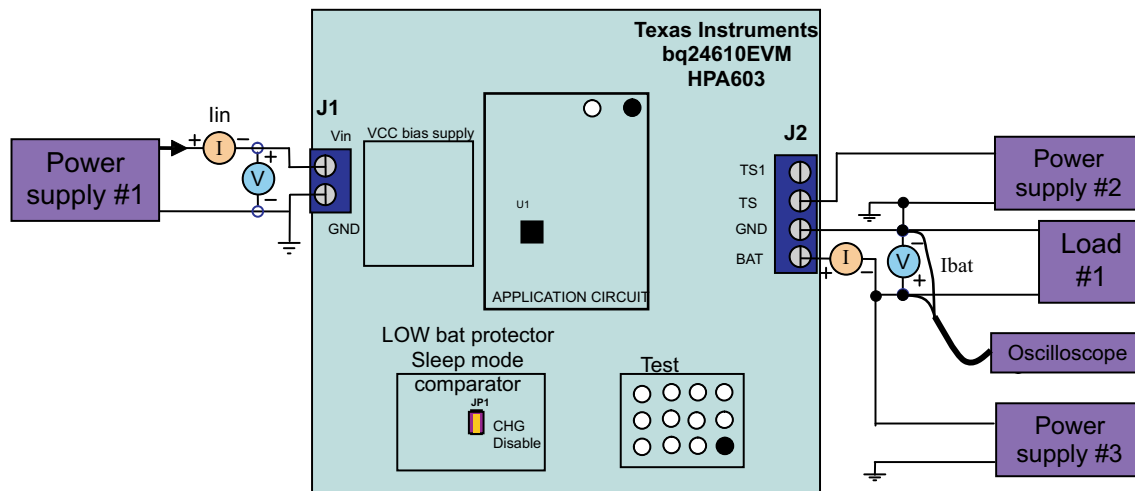


Figure 1. Original Test Setup for bq24610EVM-HV

## 2.4 Procedure

### 2.4.1 Vcc Bias Supply Power Up

Turn on PS#1. Set the power supply #1 to 48 V  $\pm$ 1 Vdc

Increase the output voltage of PS#1  $\pm$ 0.1 V.

Measure  $\rightarrow$  V(TP(VREF)) = 3.3 V  $\pm$ 0.1 V

Measure  $\rightarrow$  V(TP(REGN)) = 0 V  $\pm$ 0.5 V

V(TP(Vcc)) = 8.5 V  $\pm$ 0.5 V

### 2.4.2 Charge Voltage Regulation

Turn on PS#2. Set the power supply #1 to 1.8 V  $\pm$ 100 mVdc

Take JP1 off (Enable the charging).

Oscilloscope Measure  $\rightarrow$  Peak V(J2(BAT)) = 33.6 V  $\pm$ 1 V

Measure  $\rightarrow$  V(TP(REGN)) = 6 V  $\pm$ 500 mV

### 2.4.3 Charge Current Regulation

Turn on the Power supply #3: Set the output voltage to 15V/6A.

Turn on the Load #1: Set the load current to 5A. Enable the output of the Load #1.

*Measure* →  $I_{bat} = 500 \text{ mA} \pm 200 \text{ mA}$

Set the PS#3 output voltage to 28V.

*Measure* →  $I_{bat} = 4150 \text{ mA} \pm 300 \text{ mA}$

During normal operation, some circuit components may have case temperatures greater than 85°C. The EVM is designed to operate properly with certain components above 85°C as long as the input and output ranges are maintained. If the case temperature goes higher than 120°C, disable the charge (install JP1) or shut down the input power supply.

### 2.4.4 Charge Cutoff by Thermistor

Slowly increase the output voltage of PS2 until  $I_{bat} = 0 \pm 10 \text{ mA}$

*Measure* →  $V(J4(TS)) = 2.44 \text{ V} \pm 200 \text{ mV}$

*Measure* →  $I_{bat} = 0 \text{ mA} \pm 100 \text{ mA}$

Slowly decrease the output voltage of PS2 to  $1.8 \text{ V} \pm 100 \text{ mV}$

*Measure* →  $I_{bat} = 4150 \text{ mA} \pm 300 \text{ mA}$

## 3 PCB Layout Guideline

The switching node rise and fall times must be adjusted for minimum switching loss. Proper layout of the components to minimize the high-frequency, current-path loop is important to prevent electrical and magnetic field radiation and high-frequency resonant problems. A printed-circuit board (PCB) layout priority list follows. Laying out a PCB according to this specific order is essential.

1. Place the input ceramic capacitor as close as possible to the switching MOSFET's supply and ground connections, and use the shortest copper-trace connection possible.
2. Place the gate drive integrated circuit (IC), UCC27201, close to the switching MOSFET's gate terminals, and keep the gate drive signal traces short for a clean MOSFET drive. The IC can be placed on the other side of the PCB of switching MOSFETs.
3. Place inductor input terminal to switching MOSFET's output terminal as close as possible. Minimize the copper area of this trace to lower electrical and magnetic field radiation, but make the trace wide enough to carry the charging current. Do not use multiple layers in parallel for this connection. Minimize parasitic capacitance from this area to any other trace or plane.
4. The charging current sensing resistor must be placed next to the inductor output. Route the sense lead nets close to each other (minimize loop area), and do not route the sense leads through a high-current path.
5. Place the output capacitor next to the sensing resistor output and ground.
6. The output capacitor ground connections need to be tied to the same copper that connects to the input capacitor ground before connecting to system ground.
7. Route the analog ground separately from the power ground. Connect analog ground and power ground separately. Connect the analog ground and the power ground together using the power pad as the single ground connection point, or use a 0-Ω resistor to tie analog ground to power ground (power pad must tie to analog ground in this case, if possible).
8. Decoupling capacitors must be placed next to the IC pins; make trace connection as short as possible.
9. It is critical that the exposed power pad on the backside of the IC package be soldered to the PCB ground. Ensure that sufficient thermal vias are directly under the IC, connecting to the ground plane on the other layers.

## 4 Bill of Materials, Board Layouts, and Schematic

### 4.1 Bill of Materials

**Table 3. Bill of Materials**

Count	RefDes	Value	Description	Size	Part Number	MFR
2	C1, C4	0.22 $\mu$ F	Capacitor, Ceramic, 100V, X7R, 10%	1206	STD	STD
1	C2	33 $\mu$ F	Capacitor, Radial, Aluminum, 100V, 20%	0.492 inch	UPW2A330MPD	Nichicon
2	C3, C37	2.2 $\mu$ F	Capacitor, Ceramic, 100V, X7R, 10%	1812	STD	STD
2	C5, C6	2.2 $\mu$ F	Capacitor, Ceramic, 50V, X7R, 20%	1812	STD	STD
6	C7, C10, C13, C16, C18, C28	0.1 $\mu$ F	Capacitor, Ceramic, 16V, X7R, 10%	0603	STD	STD
1	C8	0.1 $\mu$ F	Capacitor, Ceramic, 100V, X7R, 10%	1206	STD	STD
3	C9, C15, C23	1.0 $\mu$ F	Capacitor, Ceramic, 16V, X7R, 20%	0805	STD	STD
4	C11, C17, C20, C24	0.1 $\mu$ F	Capacitor, Ceramic, 50V, X7R, 10%	0603	STD	STD
2	C12, C36	4.7 $\mu$ F	Capacitor, Ceramic, 16V, X7R, 20%	1206	STD	STD
2	C14, C19	22 pF	Capacitor, Ceramic, 50V, X7R, 10%	0603	STD	STD
0	C21, C22	Open	Capacitor, Ceramic, 50V, X7R, 10%	0603	STD	STD
1	C25	3.3 nF	Capacitor, Ceramic, 50V, X7R, 10%	0603	STD	STD
1	C26	10 $\mu$ F	Capacitor, Radial, Aluminum, 100V, 20%	0.492 inch	RFS-100V100MH4#5	Elna America
2	C27, C29	100 pF	Capacitor, Ceramic, 16V, X7R, 5%	0603	STD	STD
1	C30	1.0 $\mu$ F	Capacitor, Ceramic, 16V, X7R, 10%	0603	STD	STD
1	C31	15 pF	Capacitor, Ceramic, 50V, X5R, 10%	0402	Std	Std
1	C32	2.2 $\mu$ F	Capacitor, Ceramic, 100V, X7R, 10%	1210	Std	Std
2	C33, C35	0.1 $\mu$ F	Capacitor, Ceramic, 16V, X7R, 10%	0402	Std	Std
1	C34	3300 pF	Capacitor, Ceramic, 6.3V, X5R, 20%	0402	Std	Std
0	C38	Open	Capacitor, Ceramic, 100V, X7R, 20%	0805	STD	STD
1	D1	BZX84C15-TP	Diode, Zener, 15-V, 350-mW	SOT-23	BZX84C15-TP	Micro Commercial
1	D2	MMSD701T1G	Schottky Barrier Diodes, 70-V, 200-mA, 225mW,	SOD-123	MMSD701T1G	On Semi
0	D3, D4	Open	Diode, Signal, 300-mA, 75-V, 350-mW	SOD-123	1N4148W-7-F	Diodes
1	D5, D8	1N4148W-7-F	Diode, Signal, 300-mA, 75-V, 350-mW	SOD-123	1N4148W-7-F	Diodes
0	D6	Open	Diode, Schottky Barrier Rectifier, 2A, 100V	SMB	B2100-13	Diodes
1	D7	DDZ5V6BS	Diode, Zener, 5.6V, 900mA, 200mW	SOD-323	DDZ5V6BS-F	Diodes
0	D9	Open	Diode, Schottky, 200-mA, 30-V	SOT-23	BAT54-V-G	Vishay
3	D10-D12	Green	Diode, LED, Green, 2.1V, 20mA, 6mcd	0603	LTST-C190GKT	Lite On
1	J1	ED120/2DS	Terminal Block, 2 pin, 15A, 5.1mm	0.40 x 0.35 inch	ED120/2DS	OST
1	J2	ED120/4DS	Terminal Block, 4 pin, 15A, 5.1mm	0.80 x 0.35 inch	ED120/4DS	OST
1	JP1	PEC02SAAN	Header, Male 2-pin, 100mil spacing,	0.100 inch x 2	PEC02SAAN	Sullins
1	L1	22 $\mu$ H	Inductor, Low Profile High Current, 6A, 20%	0.51 x 0.52 inch	7443551221	Würth
1	L2	100 $\mu$ H	Inductor, SMT, 2.48A, 89 m $\Omega$	0.402 x 0.394 inch	MSS1038-104ML	Coilcraft
2	Q1, Q2	SI7852DP or FDMS3572	MOSFET, NChan, 80V, 10.9A, 22 m $\Omega$ MOSFET, Nchan, 80V, 22A, 24 m $\Omega$	PWRPAK S0-8	SI7852DP-T1 or FDMS3572	Vishay-Siliconix or Fairchild
0	Q3, Q5	Open	MOSFET, NChan, 80V, 10.9A, 22 m $\Omega$	PWRPAK S0-8	SI7852DP	Vishay-Siliconix
1	Q4	SI7469DP	MOSFET, PChan, 80V, 28A, 29 m $\Omega$	PWRPAK S0-8	SI7469DP	Vishay
0	Q6	Open	MOSFET, PChan, 80V, 28A, 29 m $\Omega$	PWRPAK S0-8	SI7469DP	Vishay
1	R1	200k	Resistor, Metal Film, 1/4 watt, 5%	1206	Std	Std
1	R2	51.1	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R3	40.2	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R4	9.31k	Resistor, Chip, 1/16W, 1%	0402	Std	Std
1	R5	432k	Resistor, Chip, 1/16W, 1%	0402	Std	Std

**Table 3. Bill of Materials (continued)**

Count	RefDes	Value	Description	Size	Part Number	MFR
2	R6, R27	1.00k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R7	10	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R8	100	Resistor, Chip, 1/16W, 1%	0402	Std	Std
0	R9	OPEN	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R10	100k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	R11, R12	15.0k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
4	R13, R14, R25, R26	0	Resistor, Chip, 1/16W, 5%	0603	Std	Std
3	R15, R32, R34	23.2k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
4	R16, R31, R38, R48	10.0k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R36	10.0k	Resistor, Chip, 1/16W, 1%	0402	Std	Std
1	R18	0.02	Resistor, Chip, 1/2W, 1%	2010	WSL2010R0100FEA	Dale
1	R20	100k	Resistor, Chip, 1/10W, 1%	0805	Std	Std
1	R21	4.02k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
3	R17, R19, R22	2.00k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R23	464k	Resistor, Chip, 1/10W, 1%	0805	Std	Std
1	R24	30.9k	Resistor, Chip, 1/10W, 1%	0805	Std	Std
2	R28, R29	1.00M	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	R30, R33	866k	Resistor, Chip, 1/10W, 1%	0805	Std	Std
1	R35	750k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R37	100k	Resistor, Chip, 1/16W, 1%	0402	Std	Std
1	R39	5.49k	Resistor, Chip, 1/16W, 1%	0402	Std	Std
1	R40	154k	Resistor, Chip, 1/16W, 1%	0402	Std	Std
1	R41	88.7K	Resistor, Chip, 1/16W, 1%	0402	Std	Std
1	R42	113k	Resistor, Chip, 1/16W, 1%	0402	Std	Std
0	R43, R44	Open	Resistor, Chip, 1/2W, 1%	2010	STD	STD
1	R45	3.3	Resistor, Chip, 1/10W, 1%	0805	Std	Std
2	R46, R47	200	Resistor, Chip, 1/2W, 1%	2010	Std	Std
0	TP1, TP18, TP19	OPEN	Test Point, 0.020 Hole		STD	STD
2	TP3, TP13	5001	Test Point, Black, Thru Hole Color Keyed	0.100 x 0.100 inch	5001	Keystone
14	TP10, TP11, TP12, TP14, TP15, TP17, TP2, TP4, TP5, TP16, TP6, TP7, TP8, TP9	5002	Test Point, White, Thru Hole Color Keyed	0.100 x 0.100 inch	5002	Keystone
1	U1	bq24610RGE	IC, NMOS-NMOS Synchronous Buck Converter with 300KHz/600kHz/800kHz/1.2MHz Switching Frequency	QFN-24	bq24610RGE	TI
1	U2	INA169	IC, 2.7V to 60V High-Side Current Shunt Monitor	SOT23-5	INA169	TI
1	U3	UCC27201QDD	IC, High Freq. Half Bridge Driver, 120V 3A Peak	EPSON-8	UCC27201QDD	TI
1	U4	LM2903PW	IC, Dual Differential Comparators, 2-36 V <sub>in</sub>	TSSOP-8 (PW)	LM2903PW	TI
1	U5	LM358AD	IC, Dual Operational Amplifiers	SO-8	LM358AD	TI
1	U6	TPS54060DGQ	IC, DC-DC Converter, 60V, 0.5A	MSOP-10	TPS54060DGQ	TI
1	-	HPA603	PCB, 4 In x 4 In x 0.062 In		HPA603	Any
4			Bumper foot (install after final wash)	0.440 x 0.2	SJ-5303	3M
1			Shunt, 100-mil, Black	0.100	929950-00	3M

## 4.2 Board Layouts

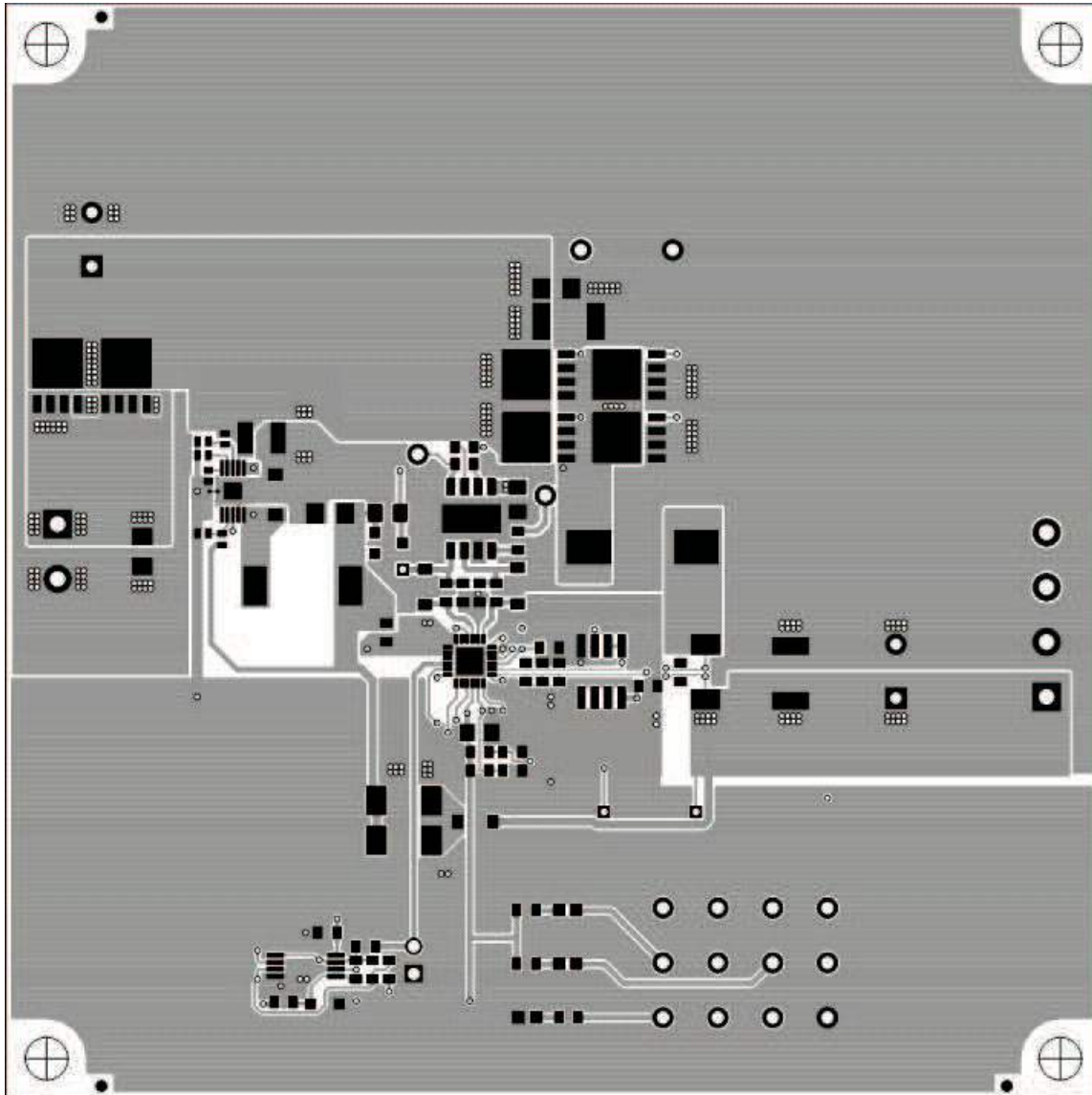


Figure 2. Top Layer



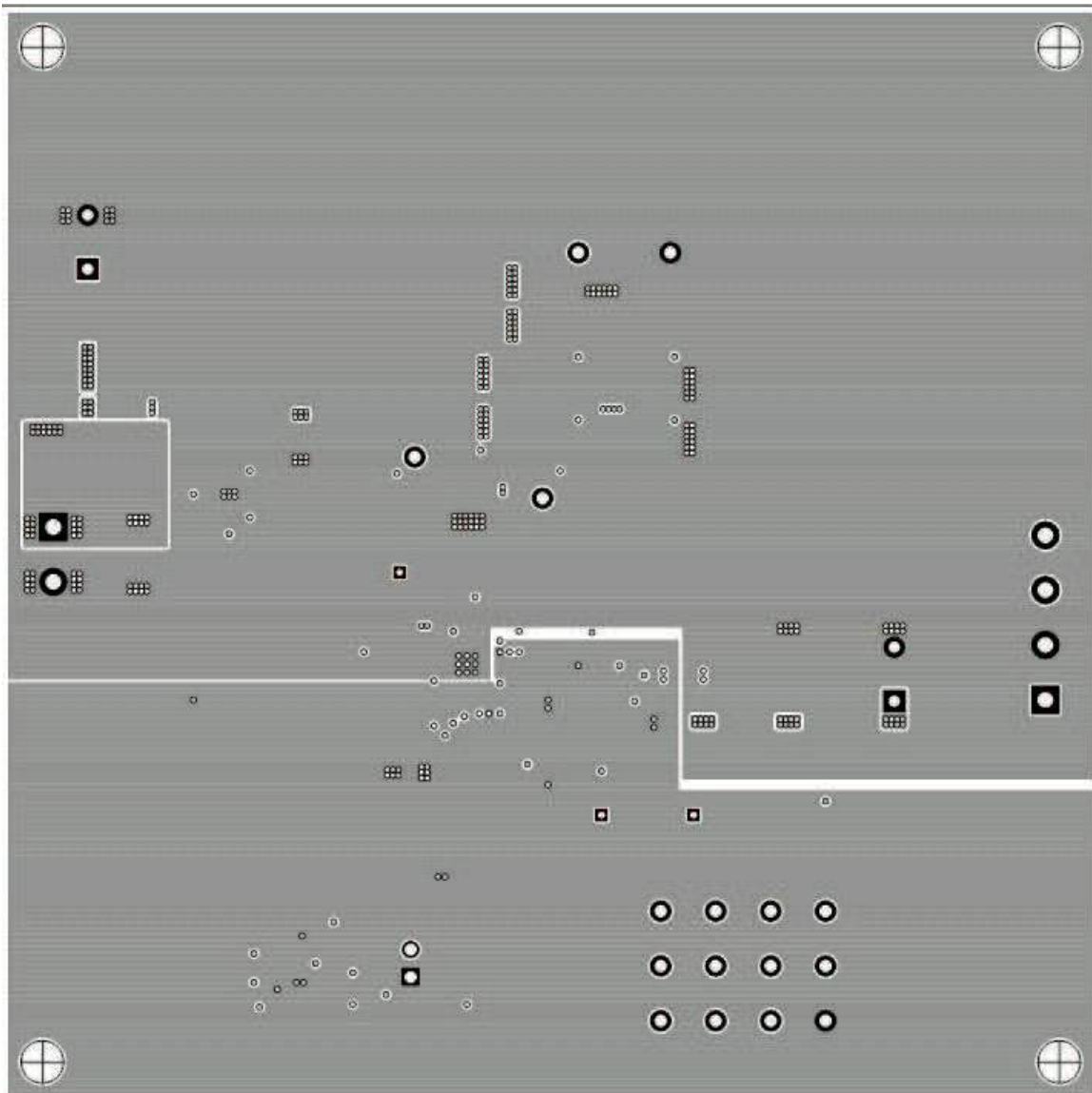
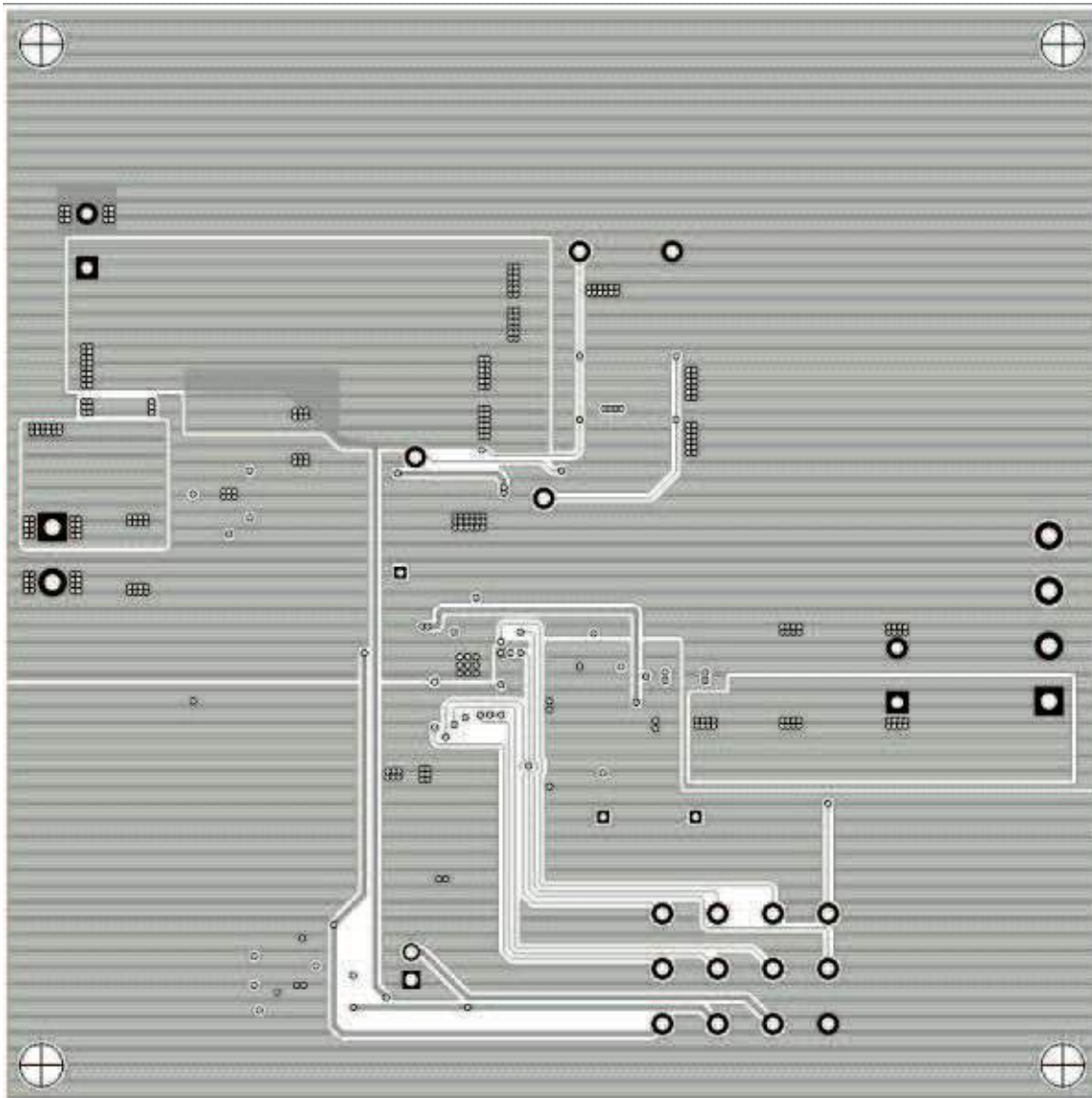


Figure 3. Second Layer



**Figure 4. Third Layer**

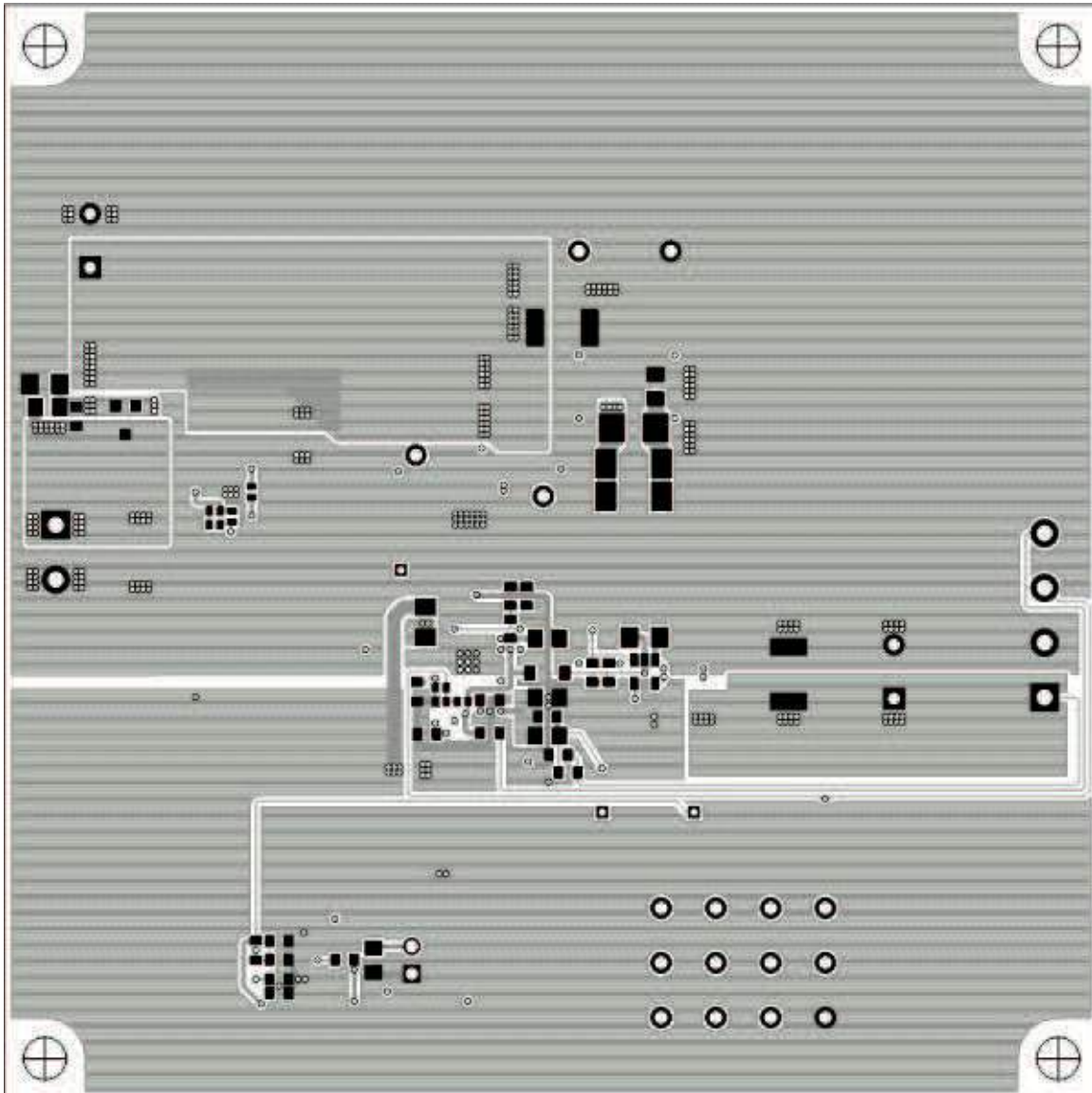


Figure 5. Bottom Layer

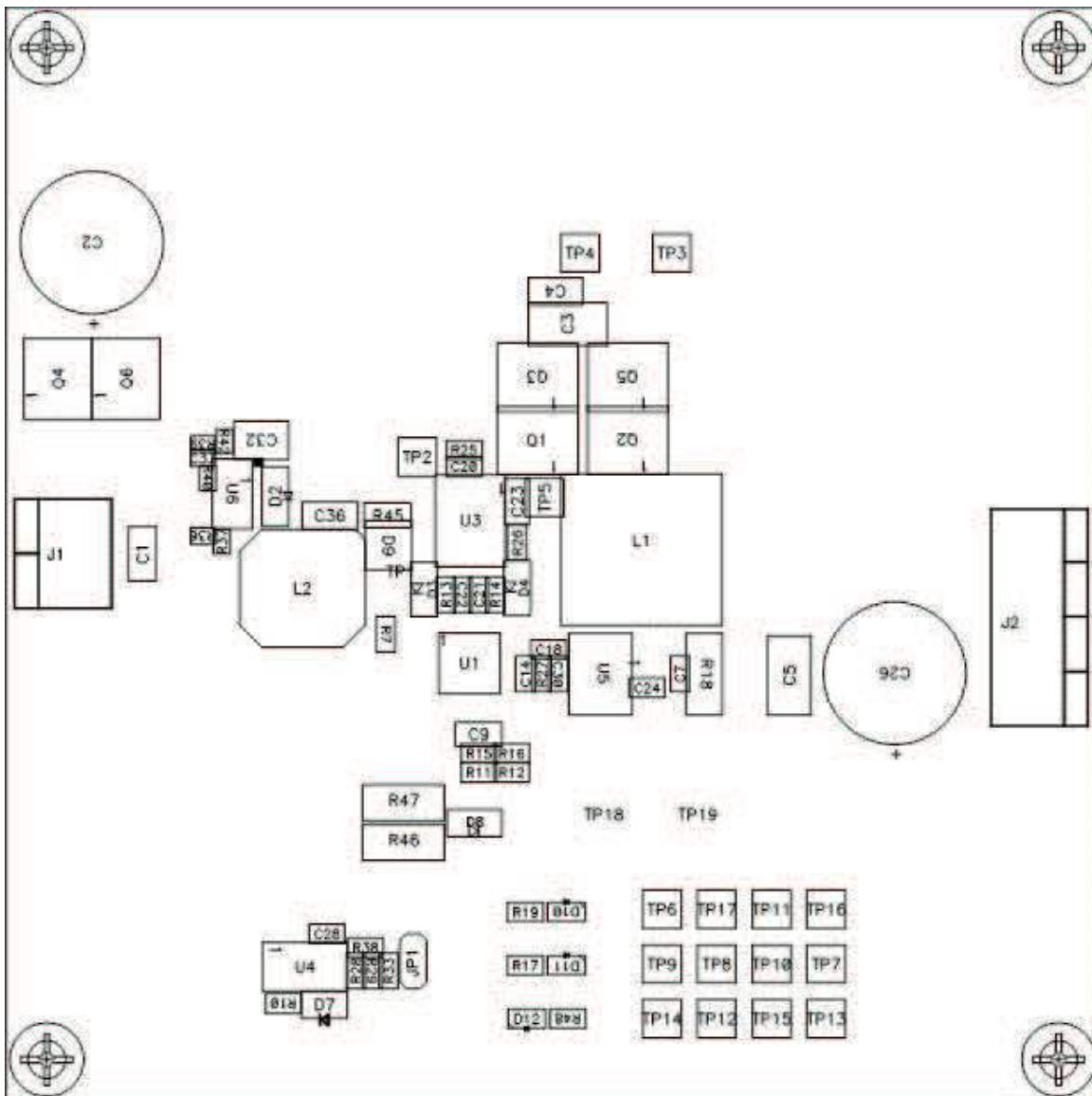
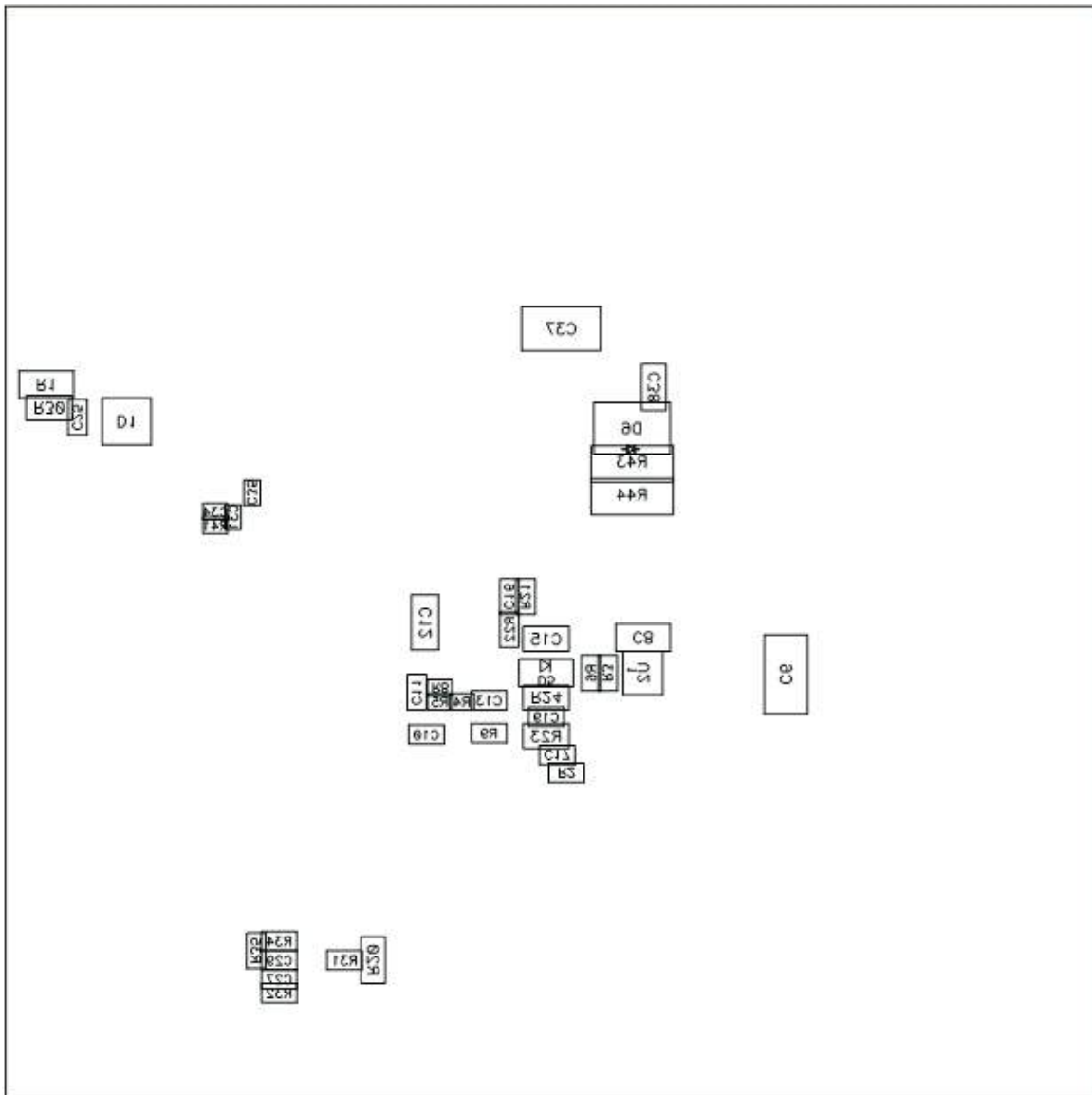


Figure 6. Top Assembly



**Figure 7. Bottom Assembly**



## Evaluation Board/Kit Important Notice

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## EVM Warnings and Restrictions

It is important to operate this EVM within the input voltage range of 30 V to 57 V and the output voltage range of 0 V to 50.4 V .

Exceeding the specified input range may cause unexpected operation and/or irreversible damage to the EVM. If there are questions concerning the input range, please contact a TI field representative prior to connecting the input power.

Applying loads outside of the specified output range may result in unintended operation and/or possible permanent damage to the EVM. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative.

During normal operation, some circuit components may have case temperatures greater than 120°C. The EVM is designed to operate properly with certain components above 85°C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during operation, please be aware that these devices may be very warm to the touch.

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