EVM User's Guide: LM72650QEVM

LM72650QEVM CC-CV Buck Converter Evaluation Module

Description

The LM72650QEVM evaluation module (EVM) is a synchronous, buck DC/DC regulator using the LM72650. The EVM is capable of constant-current constant-voltage (CC-CV) regulation with I2C interface. The EVM operates over a wide input voltage range of 24V to 70V, providing maximum 5A in CC mode and maximum 20V in CV mode. The regulation targets of the average inductor current limit and the output voltage are programmable by I2C. The free-running switching frequency is also programmable by I2C and is synchronizable to an external clock signal at a higher or lower frequency. The EVM is designed as a daughter card of TPS26742EQ1EVM.

Get Started

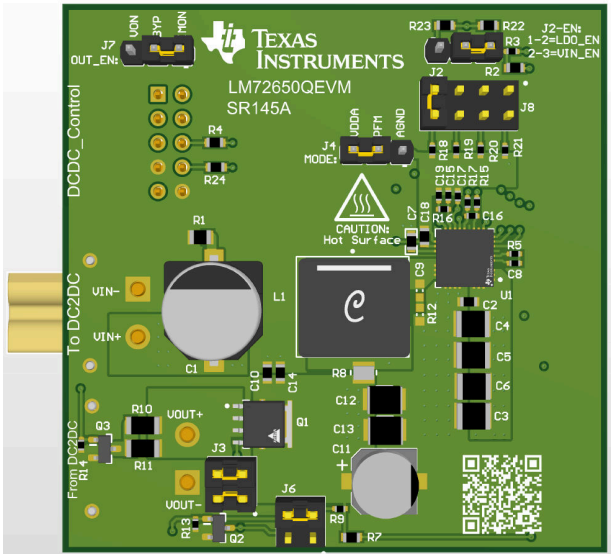
1. Order the TPS26742EQ1EVM.
2. Connect the LM72650QEVM to the TPS26742EQ1EVM.
3. Read the TPS26742EQ1EVM EVM user's guide.
4. Start evaluation with the graphical user interface.

Features

- Input voltage operating range: 24V to 70V
- Programmable output voltage up to 20V with programmable cable drop compensation (CDC)
- Programmable average current limit up to 5A
- Programmable output voltage slew rate
- Programmable soft-start time
- Optional active output discharge
- Optional spread spectrum
- Programmable switching mode (FPWM or PFM)
- Peak full-load efficiency of 98%
- Peak current limit with hiccup mode protection
- Programmable OVP threshold
- Programmable UV/OV warning threshold
- nINT indicator with pullup resistor to VDDA

Applications

- Automotive electronic systems
- Infotainment and cluster
- Automotive USB charging



LM72650QEVM

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1 Evaluation Module Overview

1.1 Introduction

The LM72650QEVM EVM is a synchronous, buck DC/DC regulator with constant-current constant-voltage (CC-CV) regulation and I2C interface. The EVM is designed for 400kHz switching frequency, operates over an input voltage range of 24V to 70V, providing a regulated current of 5A (maximum) in CC mode and a regulated voltage of 20V (maximum) in CV mode. The regulation targets of the average inductor current limit and the output voltage are programmable by I2C. The EVM features cable drop compensation, spread spectrum, selectable FPWM/PFM, active output discharge, output slew rate control, soft start, OVP, and peak current limit with hiccup mode protection.

The EVM is designed as a daughter card of TPS26742EQ1EVM which is using TPS26742E-Q1. The TPS26742E-Q1 is a dual port USB PD controller that has integrated flash and the ability to control external DC/DC converters and display port re-timers and switches. The TPS26742EQ1EVM is customizable by using the TPS26742EQ1EVM.

1.2 Kit Contents

- One LM72650QEVM EVM board
- EVM disclaimer Read Me

1.3 Specification

Table 1-1 table lists the electrical characteristics of the evaluation module. See the device specifications for more information. Efficiency and other performance metrics can change based on operating input voltage, load currents, externally-connected output capacitors, and the operation of the TPS26742EQ1EVM. The recommended airflow is 200 LFM when operating.

Table 1-1. Electrical Performance Characteristics

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
INPUT CHARACTERISTICS						
Input operating range, V_{SUPPLY}			24	48	70	V
Input current, I_{SUPPLY}					5	A
OUTPUT CHARACTERISTICS						
Rated output voltage, V_{LOAD}	CV mode			20		V
Average inductor current, I_{LOUT}	CC mode		0.5		5	A
SYSTEM CHARACTERISTICS						
Switching frequency, f_{SW}				400		kHz
Full load efficiency	I_{LOAD} = 5A	V_{SUPPLY} = 24V		98.1%		
		V_{SUPPLY} = 36V		97.5%		
		V_{SUPPLY} = 48V		96.9%		
		V_{SUPPLY} = 60V		96.4%		

1.4 Device Information

Table 1-2. LM72xx0(-Q1) Synchronous, Buck Regulator Family With Integrated CC-CV Control and I2C Interface

DC/DC	MAX VIN	OUTPUT RANGE	MAX IOUT	AUTOMOTIVE QUALIFICATION
LM72630-Q1	70V	1V – 24V / 3.3V – 24V	3A	AEC-Q100 Grade1
LM72650-Q1	70V	1V – 24V / 3.3V – 24V	5A	AEC-Q100 Grade1
LM72680-Q1	70V	1V – 24V / 3.3V – 48V	5A / 8A	AEC-Q100 Grdae1
LM72880-Q1	80V	1V – 24V / 3.3V – 48V	5A / 8A	AEC-Q100 Grade1
LM72880	80V	1V – 24V / 3.3V – 48V	5A / 8A	—

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2 Hardware

2.1 Test Setup and Procedure

2.1.1 EVM Connections

The recommended test setup is shown in Figure 2-1. Working at an ESD-protected workstation, make sure that any wrist straps, boot straps, or mats are connected and referencing the user to earth ground before handling the EVM. The TPS26742EQ1EVM is designed to support up to two LM72650QEVM EVMs.

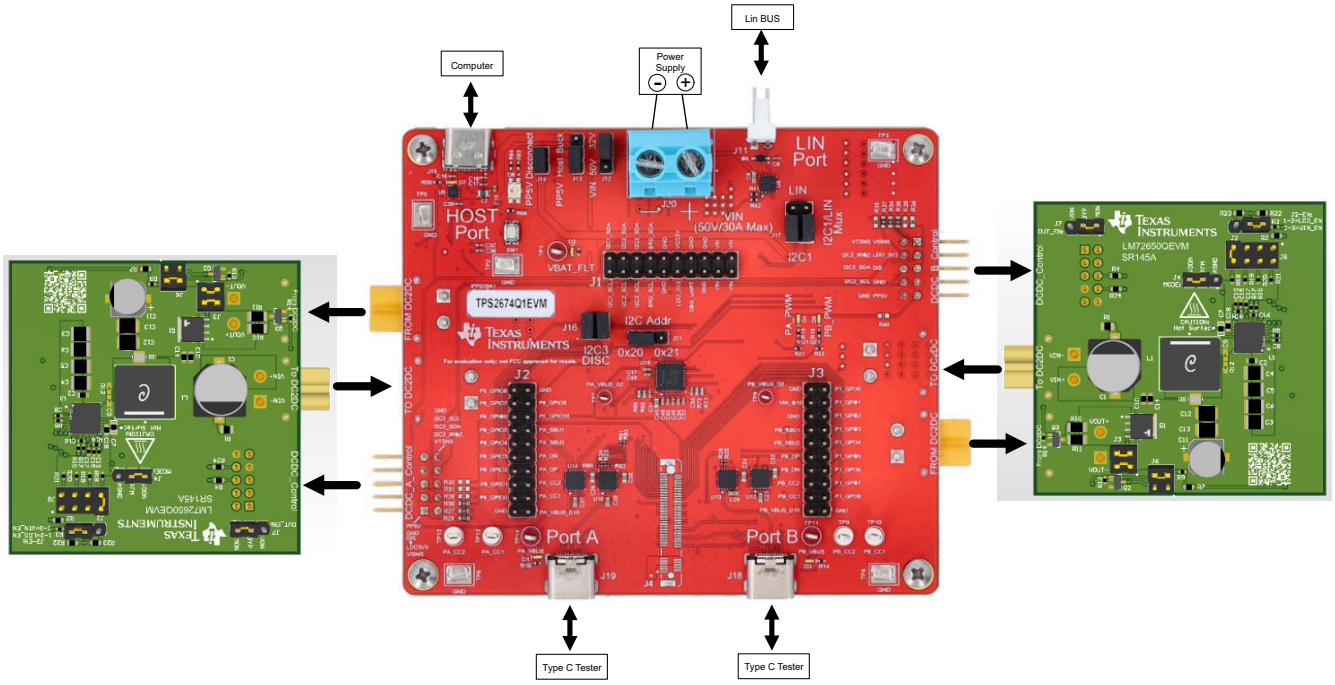

Figure 2-1. EVM Test Setup

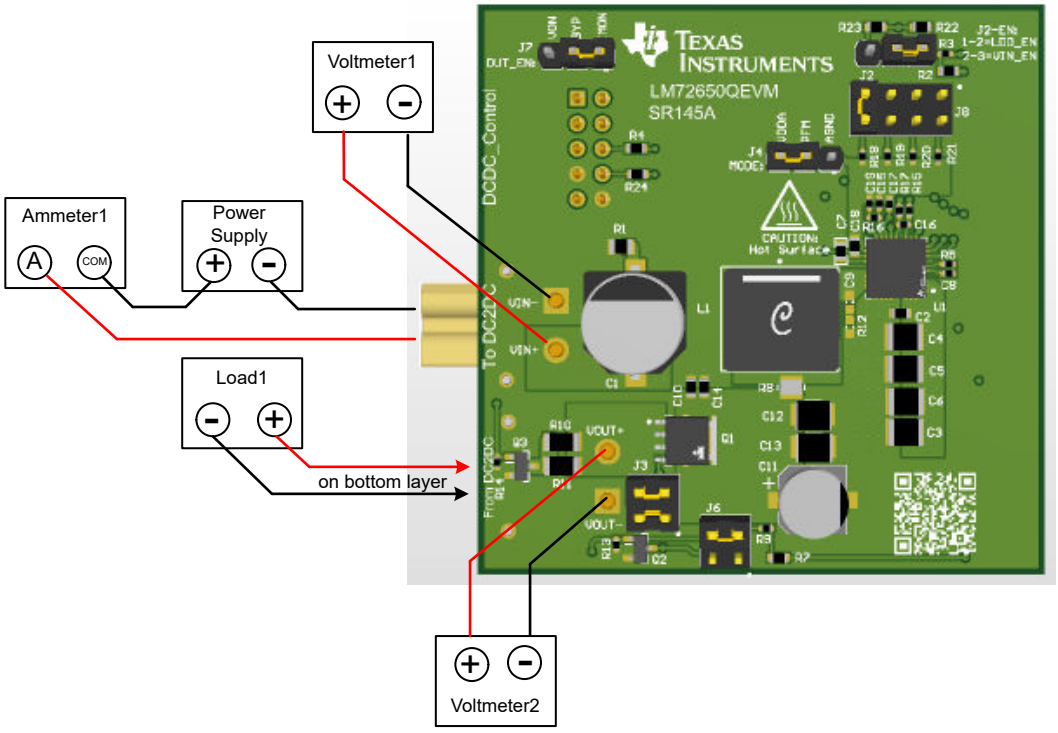

Figure 2-2. EVM Test Setup for Efficiency Measurement

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CAUTION

Hot surface. Contact can cause burns. Do not touch.

Table 2-1. Power Connections

REF DES	LABEL	DESCRIPTION
J1	VIN+	Positive input voltage power connection
J1	VIN–	Negative input voltage power connection
J5	VOUT+	Positive output voltage power connection
J5	VOUT–	Negative output voltage power connection

Table 2-2. J9 Connections

Number	LABEL	DESCRIPTION
1	IMON/Bypass	IMON connection / bypass MOSFET control
2	PTC	Temperature sensing
3	LDO_3V3	3.3V LDO output from TPS26742EQ1EVM
4	nINT	Interrupt indicator pin
5	Discharge	External discharge MOSFET control
6	SDA	I2C data connection
7	GND	Ground connection
8	SCL	I2C clock connection
9	VDDA	VDDA output to TPS26742EQ1EVM
10	GND	Ground connection

Table 2-3. J8 Jumper

NUMBER	LABEL	DESCRIPTION
1,3,5,7	CONFIG/IMON	CONFIG/IMON connection
2	R18	41.2kΩ configuration resistor connection. Default connection is #1 – #2.
4	R19	54.9kΩ configuration resistor connection
6	R20	71.5kΩ configuration resistor connection
8	R21	90.9kΩ configuration resistor connection

Table 2-4. J4 Jumper

NUMBER	LABEL	DESCRIPTION
1	AGND	Ground connection
2	PFM	PFM connection. Connect #1 to #2 for FPWM . Connect #2 to #3 for PFM. Default connection is #2 – #3.
3	VDDA	VDDA connection

Table 2-5. J7 Jumper

NUMBER	LABEL	DESCRIPTION
1	IMON	IMON connection
2	BYP	Connect #1 to #2 for IMON sensing. Connect #2 to #3 for external bypass switch control. Default connection is #1 – #2.
3	VON	Bypass MOSFET control

Table 2-6. J2 Jumper

NUMBER	LABEL	DESCRIPTION
1	LDO_3V3_EN	LDO_3V3_EN from TPS26742EQ1EVM

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Table 2-6. J2 Jumper (continued)

NUMBER	LABEL	DESCRIPTION
2	EN	Connect #1 to #2 for LDO_3V3_EN enable. Connect #2 to #3 for VIN enable. Default connection is #2 – #3.
3	R2	VIN connection through R2

Table 2-7. J3 Jumper

NUMBER	LABEL	DESCRIPTION
1,3	Q1 #5	Q1 drain connection.
2,4	Q1 #3	Q1 source connection. Bypass the Q1 switch by connecting #1 – #2, and #2 – #4.

Table 2-8. J6 Jumper

NUMBER	LABEL	DESCRIPTION
1,3	Q1 #5	Q1 drain connection
2,4	J7 #3	J7 #3 pin connection. Connect #3 – #4 to enable the bypass switch automatically. Default connection is #3 – #4

2.1.2 Efficiency Test Equipment

- **Power Supply:** Use an input voltage source capable of supplying 0V to 70V and 7A.
- **Voltmeter 1:** Measure the input voltage at J1 terminal.
- **Voltmeter 2:** Measure the output voltage at J5 terminal.
- **Ammeter 1:** Measure the input current.
- **Load 1:** The electronic load must be capable of sinking 8A at 20V and below.
- **Oscilloscope:** With the scope set to 20MHz bandwidth and AC coupling, measure the output voltage ripple directly across an output capacitor with a short ground lead normally provided with the scope probe. TI does not recommend using a long-leaded ground connection because this can induce additional noise given a large ground loop. To measure other waveforms, adjust the oscilloscope as needed. Always use caution when touching any circuits that can be live or energized.

2.1.3 Recommended Test Setup

LM72650QEVM is designed as a daughter card and requires TPS26742EQ1EVM as a motherboard to operate normally. Please follow the test setup guidelines in the TPS26742EQ1EVM RVM user's guide. Before applying power to the boards, make sure that the J2, J3, J4, J6, J7 and J8 jumpers are present and properly positioned.

CAUTION

Extended operation at high output current and high input voltage can raise component temperatures above 55°C. To avoid risk of a burn injury, do not touch the components until the components have cooled sufficiently after disconnecting power.

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3 Implementation Results

3.1 Test Data and Performance Curves

Unless otherwise indicated, V_{SUPPLY} = 48V and f_{SW} = 400kHz.

3.1.1 Efficiency

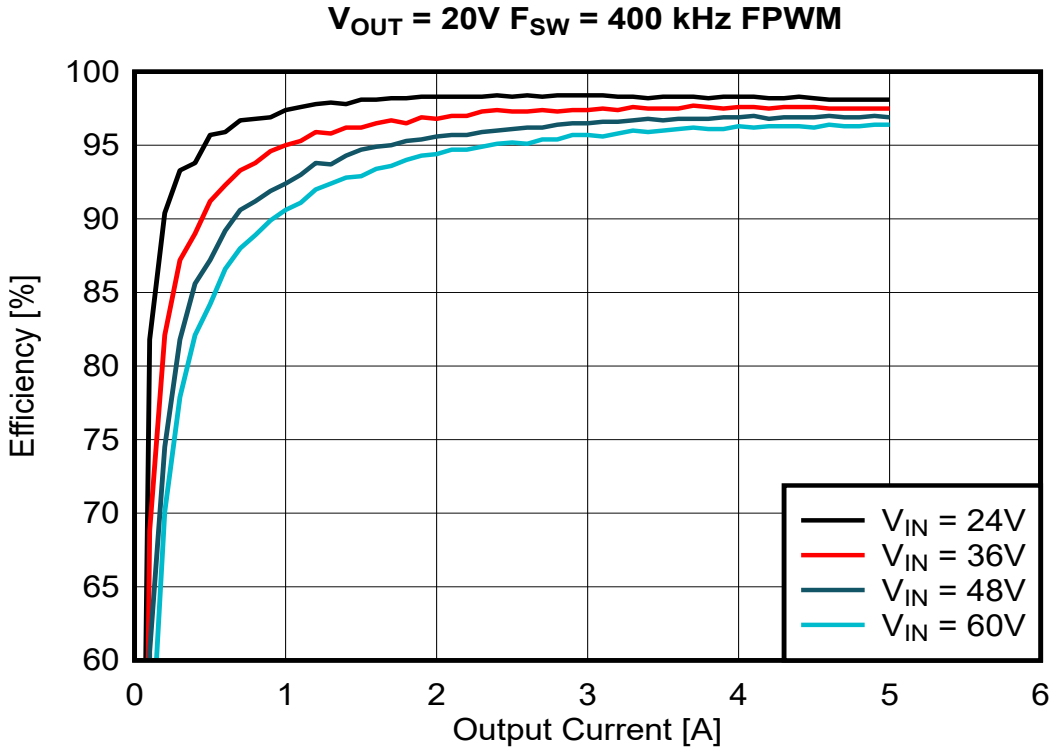

Figure 3-1. FPWM Mode, Linear Scale

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3.1.2 Operating Waveforms

3.1.2.1 Start-Up and Shutdown

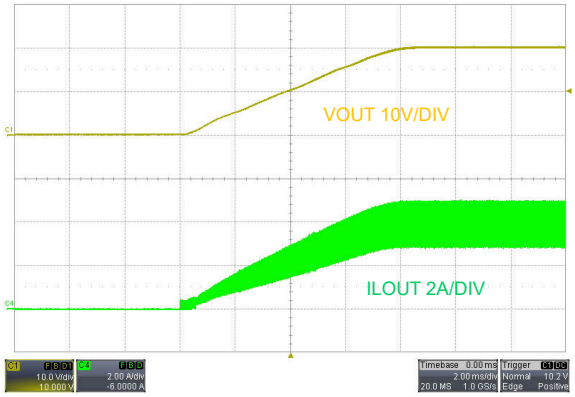

Figure 3-2. V_{SUPPLY} = 48V, I_{LOAD} = 4A

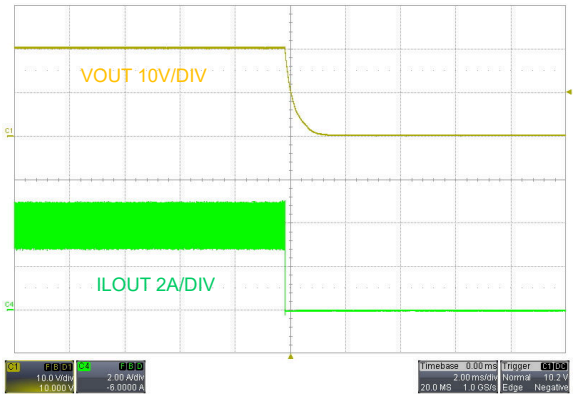

Figure 3-3. V_{SUPPLY} = 48V, I_{LOAD} = 4A

3.1.2.2 Switching

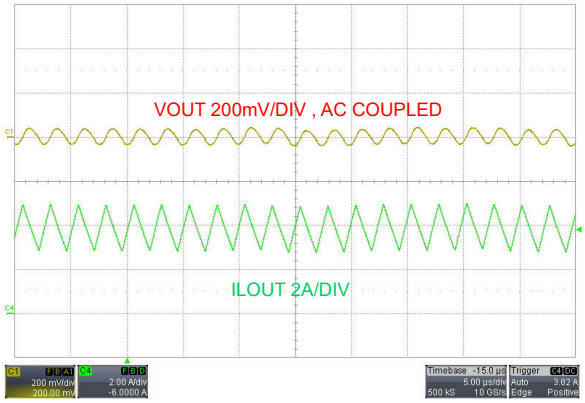

Figure 3-4. Output Ripple, V_{SUPPLY} = 48V, I_{LOAD} = 4A

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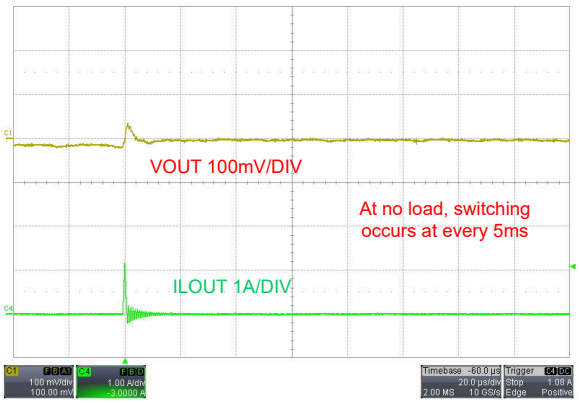

Figure 3-5. No Load Operation in PFM Mode, V_{SUPPLY} = 48V, I_{LOAD} = 0A

3.1.2.3 Load Transient

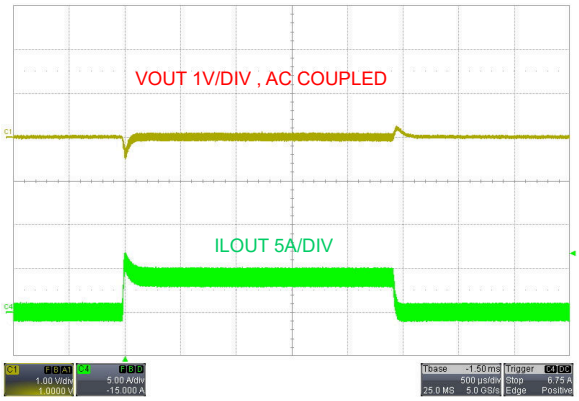

Figure 3-6. Load Transient Response, V_{SUPPLY} = 48V, FPWM, 0A to 4A

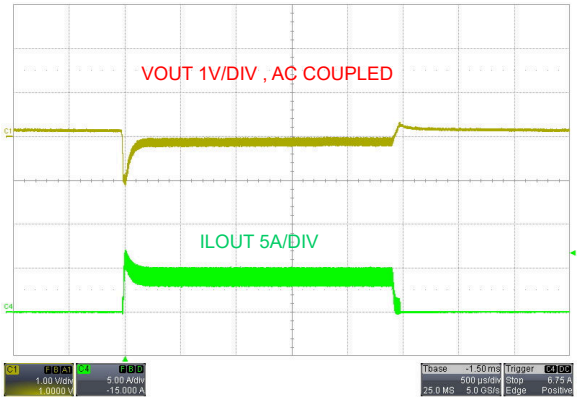

Figure 3-7. Load Transient Response, V_{SUPPLY} = 48V, PFM, 0A to 4A

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3.1.3 Thermal Performance

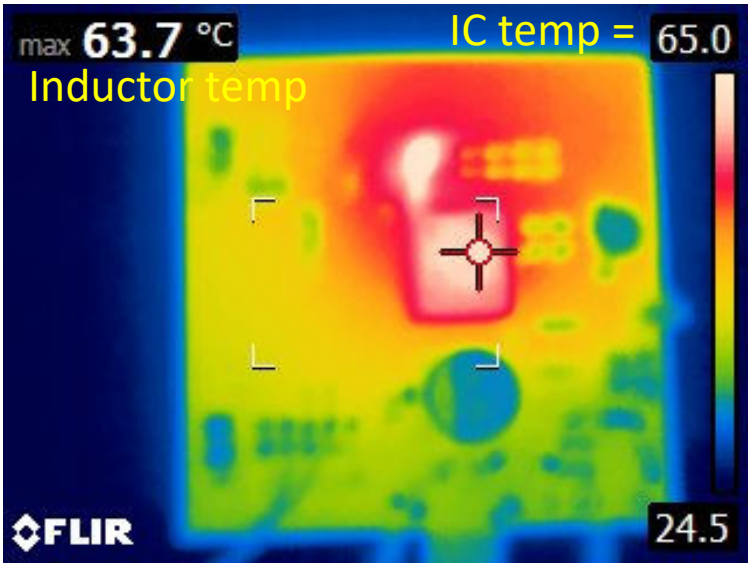

Figure 3-8. Thermal Performance, V_{SUPPLY} = 48V, I_{LOAD} = 5A, T_A = 25°C, No Airflow

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4 Hardware Design Files

4.1 Schematic

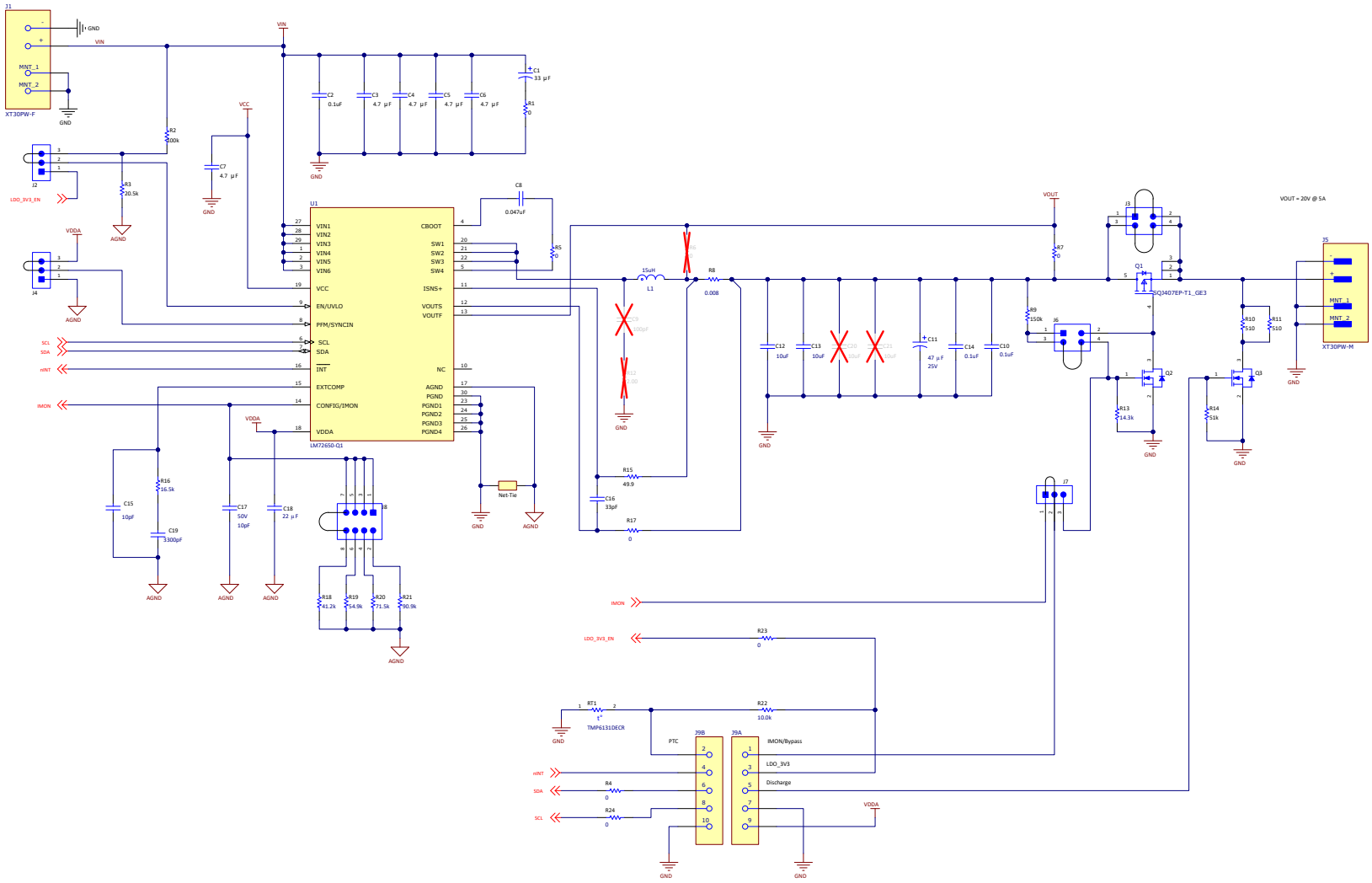

Figure 4-1. EVM Schematic

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4.2 PCB Layout

LM72650QEVM uses a 4-layer PCB with 2oz copper thickness.

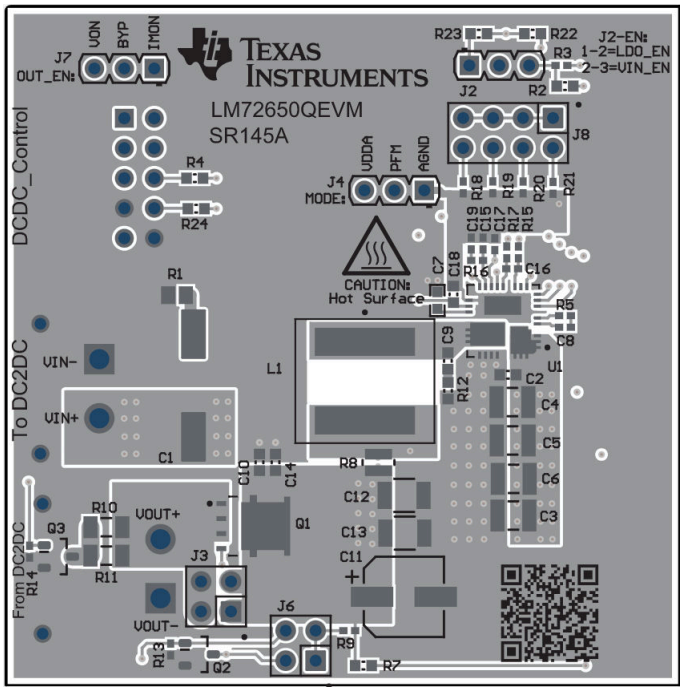

Figure 4-2. Top Components (Top View)

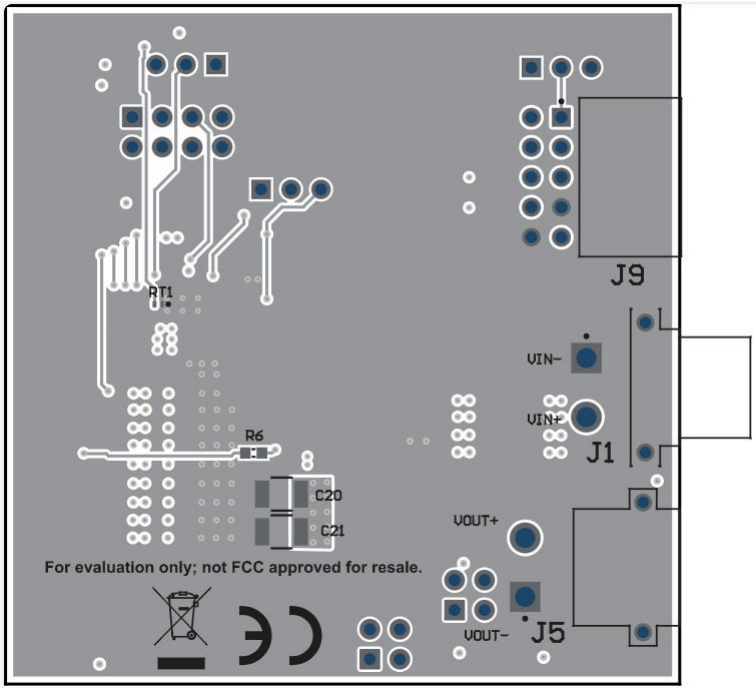

Figure 4-3. Bottom Components (Bottom View)

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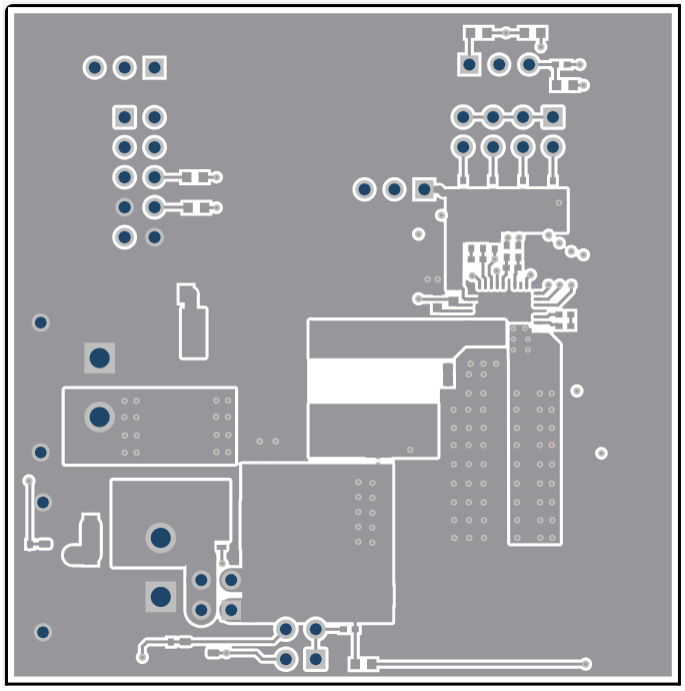

Figure 4-4. Top Layer Copper (Top View)

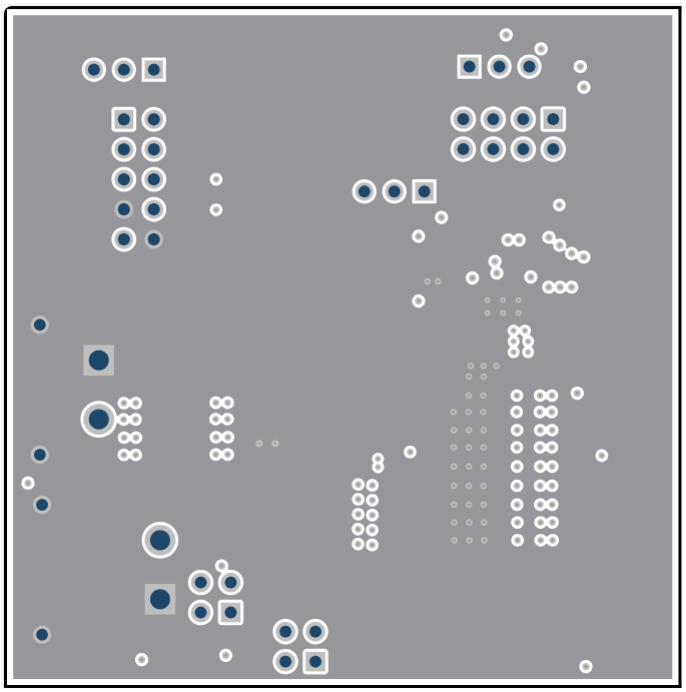

Figure 4-5. Layer 2 Copper (Top View)

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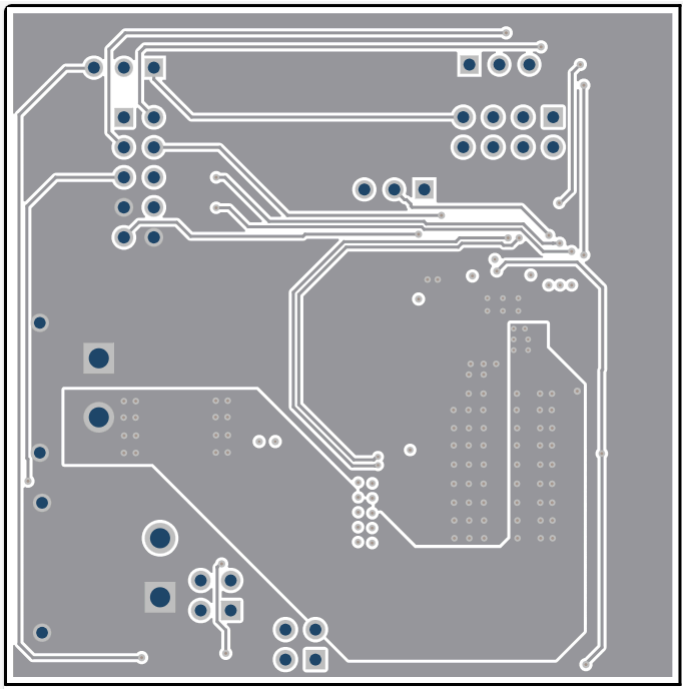

Figure 4-6. Layer 3 Copper (Top View)

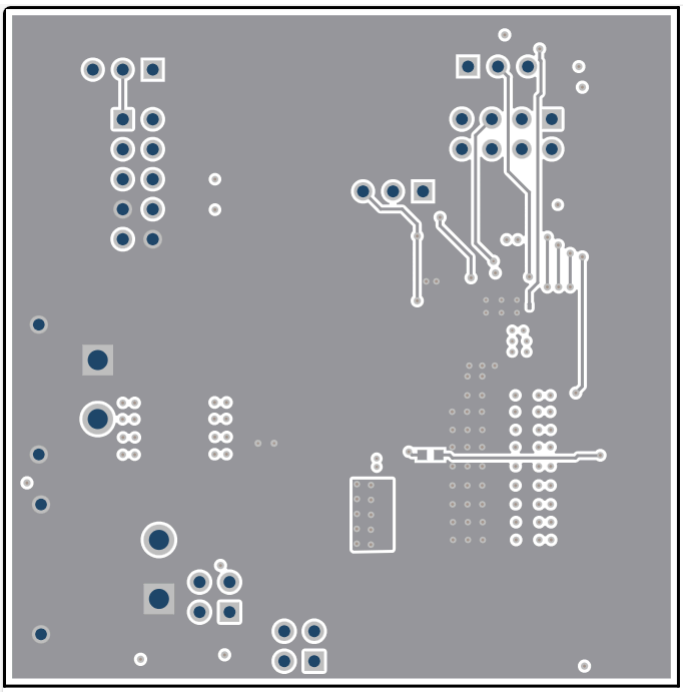

Figure 4-7. Bottom Copper (Top View)

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4.3 Bill of Materials

Table 4-1. Bill of Materials

REF DES	DESCRIPTION	MFR	PART NUMBER	QTY
C1	CAP, AL, 33µF, 100V, +/– 20%, 1ohm, AEC-Q200 Grade 1, SMD	Panasonic	EEE-TG2A330P	1
C2	CAP, CERM, 0.1uF, 100V,+/– 10%, X7R, AEC-Q200 Grade 1, 0603	MuRata	GCJ188R72A104KA01D	1
C3, C4, C5, C6	CAP, CERM, 4.7µF, 100V,+/– 10%, X7S, AEC-Q200 Grade 1, 1210	MuRata	GCM32DC72A475KE02L	4
C7	CAP, CERM, 4.7uF, 10V, +/– 20%, X7R, 0603	MuRata	GRM188Z71A475ME15D	1
C8	CAP, CERM, 0.047uF, 50V, +/– 10%, X7R, AEC-Q200 Grade 1, 0402	TDK	CGA2B3X7R1H473K050BB	1
C10, C14	CAP, CERM, 0.1uF, 50V, +/– 10%, X7R, AEC-Q200 Grade 1, 0603	TDK	CGA3E2X7R1H104K080AA	2
C11	CAP, AL, 47µF, 25V, +/– 20%, 0.05ohm, AEC-Q200 Grade 1, SMD	Chemi-Con	HHXC250ARA470MF61G	1
C12, C13	CAP, CERM, 10uF, 25V, +/– 20%, X7R, AEC-Q200 Grade 1, 1210	TDK	CGA6P1X7R1E106M250AC	2
C15, C17	CAP, CERM, 10pF, 50V, +/– 5%, C0G/NP0, AEC-Q200 Grade 1, 0402	TDK	CGA2B2C0G1H100D050BA	2
C16	CAP, CERM, 33pF, 50V,+/– 5%, C0G/NP0, AEC-Q200 Grade 1, 0402	MuRata	GCM1555C1H330JA16D	1
C18	CAP, CERM, 22µF, 6.3V,+/– 20%, X6S, 0603	MuRata	GRM188C80J226ME15D	1
C19	CAP, CERM, 3300pF, 50V, +/– 10%, X7R, AEC-Q200 Grade 1, 0402	TDK	CGA2B2X7R1H332K050BA	1
J1	Socket, DC supply, XT30, female, PIN: 2, on PCBs, THT, yellow, 15A	Amass	XT30PW-F	1
J2, J4, J7	Header, 2.54mm, 3x1, Tin, TH	FCI	68001-403HLF	3
J3, J6	Header, 100mil, 2x2, Gold, TH	Samtec	TSW-102-07-G-D	2
J5	Socket, DC supply, XT30, male, PIN: 2, on PCBs, THT, yellow, 15A, 500V	Amass	XT30PW-M	1
J8	Header, 100mil, 4x2, Gold, TH	Samtec	TSW-104-07-G-D	1
J9	10 Position Receptacle Connector 0.100" (2.54mm) Through Hole, Right Angle Gold	Samtec	SSW-105-02-G-D-RA	1
L1	15µH Shielded Molded Inductor 15.4A 15.2mOhm Max Nonstandard	Coilcraft	XGL1010-153MED	1
Q1	MOSFET P-CH 30V 60A POWERPAKSO-8	Vishay	SQJ407EP-T1_GE3	1
Q2, Q3	MOSFET, N-CH, 60V, 0.24A, SOT-23	Vishay-Siliconix	2N7002E-T1-E3	2
R1	RES, 0, 5%, 0.125W, AEC-Q200 Grade 0, 0805	Panasonic	ERJ-6GEY0R00V	1
R2	RES, 100k, 1%, 0.1W, AEC-Q200 Grade 0, 0603	Vishay-Dale	CRCW0603100KFKEA	1
R3	RES, 20.5k, 1%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040220K5FKED	1
R4, R7, R23, R24	RES, 0, 5%, 0.1W, 0603	Yageo	RC0603JR-070RL	4
R5, R17	RES, 0, 5%, 0.063W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW04020000Z0ED	2
R8	RES, 0.008, 1%, 1W, AEC-Q200 Grade 0, 0508	Susumu Co Ltd	KRL2012M-R008-F-T1	1
R9	RES, 150 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW0402150KFKED	1
R10, R11	RES, 510, 5%, 0.25 W, 1206	Vishay-Dale	CRCW1206510RJNEA	2
R13	RES, 14.3 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040214K3FKED	1
R14	RES, 51 k, 5%, 0.063 W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040251K0JNED	1
R15	RES, 49.9, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040249R9FKED	1
R16	RES, 16.5 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040216K5FKED	1
R18	RES, 41.2 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040241K2FKED	1
R19	RES, 54.9 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	Vishay-Dale	CRCW040254K9FKED	1
R20	RES, 71.5 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0402	Panasonic	ERJ-2RKF7152X	1
R21	RES, 90.9 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0402	Panasonic	ERJ-2RKF9092X	1
R22	RES, 10.0 k, 0.05%, 0.1 W, AEC-Q200 Grade 0, 0603	Panasonic	ERA-3ARW103V	1
RT1	Thermistor, DEC0002A (X1SON-2)	Texas Instruments	TMP6131DECR	1
SH-J1, SH-J2, SH-J3, SH-J4, SH-J5, SH-J6, SH-J7	Shunt, 100mil, Gold plated, Black	Samtec	SNT-100-BK-G	7
U1	70V, 3A, High Efficiency CC-CV Buck Converter with I2C	Texas Instruments	LM72650-Q1	1

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5 Additional Information

5.1 Trademarks

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6 Device and Documentation Support

6.1 Device Support

6.1.1 Development Support

For development support, see the following:

- For TI's reference design library, visit TI reference designs.
- For TI's WEBENCH® Design Environments, visit the WEBENCH® Design Center.

6.2 Documentation Support

6.2.1 Related Documentation

For related documentation, see the following:

- Texas Instruments, *Improve High-current DC/DC Regulator Performance for Free with Optimized Power Stage Layout* application brief
- Texas Instruments, *Reduce Buck Converter EMI and Voltage Stress by Minimizing Inductive Parasitics* analog applications journal
- Texas Instruments, *AN-2162 Simple Success with Conducted EMI from DC-DC Converters* application note
- White papers:
  - Texas Instruments, *Valuing Wide V_{IN}, Low EMI Synchronous Buck Circuits for Cost-driven, Demanding Applications*
  - Texas Instruments, *An Overview of Conducted EMI Specifications for Power Supplies*
  - Texas Instruments, *An Overview of Radiated EMI Specifications for Power Supplies*

6.2.1.1 PCB Layout Resources

- *AN-1149 Layout Guidelines for Switching Power Supplies* application note
- *AN-1229 Simple Switcher PCB Layout Guidelines* application note
- *Constructing Your Power Supply – Layout Considerations Power Supply* design seminar
- *Low Radiated EMI Layout Made SIMPLE with LM4360x and LM4600x* application note
- Power house blogs:
  - *High-Density PCB Layout of DC-DC Converters*

6.2.1.2 Thermal Design Resources

- *AN-2020 Thermal Design by Insight, Not Hindsight* application note
- *AN-1520 A Guide to Board Layout for Best Thermal Resistance for Exposed Pad Packages* application note
- *Semiconductor and IC Package Thermal Metrics* application note
- *Thermal Design Made Simple with LM43603 and LM43602* application note
- *PowerPAD™ Thermally Enhanced Package* application note
- *PowerPAD™ Made Easy* application brief
- *Using New Thermal Metrics* application note

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STANDARD TERMS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an “EVM” or “EVMs”) to the User (“User”) in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.

   1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM (“Software”) shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms that accompany such Software

   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

2 *Limited Warranty and Related Remedies/Disclaimers*:

   2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.

   2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING

Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.

User shall operate the Evaluation Kit within TI’s recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI’s recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI’s instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGREDATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 *Regulatory Notices:*

3.1 *United States*

3.1.1 *Notice applicable to EVMs not FCC-Approved:*

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan may not be certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

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西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html

3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive)*:

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user 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, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*

6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY MATERIALS PROVIDED WITH THE EVM (INCLUDING, BUT NOT LIMITED TO, REFERENCE DESIGNS AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY EPIDEMIC FAILURE WARRANTY OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.

6.2 EXCEPT FOR THE LIMITED RIGHT TO USE THE EVM SET FORTH HEREIN, NOTHING IN THESE TERMS SHALL BE CONSTRUED AS GRANTING OR CONFERRING ANY RIGHTS BY LICENSE, PATENT, OR ANY OTHER INDUSTRIAL OR INTELLECTUAL PROPERTY RIGHT OF TI, ITS SUPPLIERS/LICENSORS OR ANY OTHER THIRD PARTY, TO USE THE EVM IN ANY FINISHED END-USER OR READY-TO-USE FINAL PRODUCT, OR FOR ANY INVENTION, DISCOVERY OR IMPROVEMENT, REGARDLESS OF WHEN MADE, CONCEIVED OR ACQUIRED.

7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

8. *Limitations on Damages and Liability:*

   8.1 *General Limitations*. IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS OR THE USE OF THE EVMS , REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN TWELVE (12) MONTHS AFTER THE EVENT THAT GAVE RISE TO THE CAUSE OF ACTION HAS OCCURRED.

   8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY USE OF AN EVM PROVIDED HEREUNDER, INCLUDING FROM ANY WARRANTY, INDEMITY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS, , EXCEED THE TOTAL AMOUNT PAID TO TI BY USER FOR THE PARTICULAR EVM(S) AT ISSUE DURING THE PRIOR TWELVE (12) MONTHS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

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