EVM User's Guide: LM644A2QEVM-S2100T

LM644A2QEVM-S2100T 36V, 12A, Single-Output, Dual-Phase, Synchronous Buck Converter Evaluation Board

Description

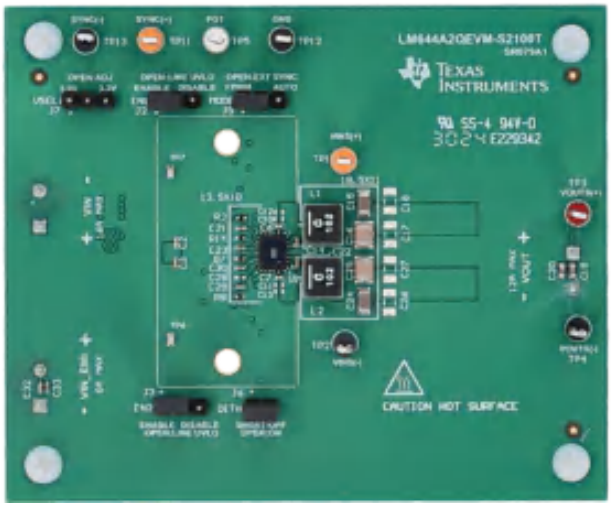
The LM644A2QEVM-S2100T evaluation board showcases the features and performance of the LM644A2-Q1, dual buck DC/DC converter with integrated power MOSFETs. The EVM provides a single 12A output with dual-phase interleaved configuration. The output voltages can be programmed to a fixed 3.3V, 5V or adjustable using external feedback resistors.

Features

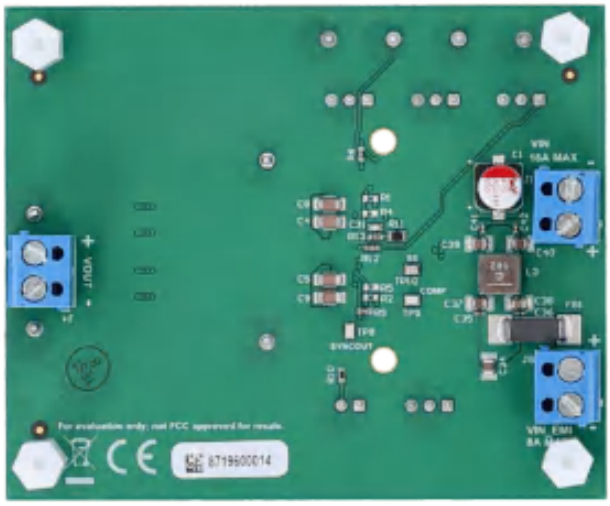
- 12A output dual-phase interleaved synchronous buck converter
- Wide operating range of up to 36V
- Default output voltage: 3.3V
- Default switching frequency: 2.1MHz
- High efficiency across a wide load-current range
- Input EMI filter with electrolytic capacitor for parallel damping (input filter can handle up to 8A input current)
- Clock synchronization and FPWM mode provide constant switching frequency across the full load range
- Integrated input capacitors enable low-noise switching performance
- Pin selectable spread spectrum
- Peak current-mode control architecture with external loop compensation.
- Peak current limiting with hiccup-mode overcurrent protection
- Thermal shutdown protection with hysteresis
- PGOOD indicator
- Programmable input UVLO
- 6-layer, 2-oz PC board design with mountable converter heat sink (heat sink provided)

Applications

- Automotive infotainment and cluster: head unit, media hub, USB charging, information display
- Automotive ADAS and body electronics
- General-purpose dual buck converters



LM644A2QEVM-S2100T (Top View)



LM644A2QEVM-S2100T (Bottom View)

1 Evaluation Module Overview

1.1 Introduction

The LM(Q)64480(-Q1), LM(Q)644A0(-Q1), and LM(Q)644A2(-Q1) Dual Buck DC/DC Converter family provides flexibility, scalability, and optimized solution size for a wide range of applications. With integrated power MOSFETs, the device is stackable up to 6 phases for higher output currents up to 36A, and uses a current-mode control architecture for easy loop compensation. The device supports input voltage surge up to 36V and dip as low as 3V. The switching frequency is adjustable from 100kHz to 2.2MHz using the RT pin and also can be synchronized to an external clock to eliminate beat frequencies in noise-sensitive applications. The output regulation target is programmed to a fixed 3.3V, 5V or adjustable using external feedback resistors. Available EMI mitigation features include spread spectrum and low package parasitic with enhanced QFN package. The QFN package has a cutout on the top exposing the converter semiconductor die allowing for heat sink (heat sink provided).

The switching frequency at the full load is programmed to 2.1MHz as a default. The switching mode at the light load is selectable between FPWM and AUTO mode. Also, spread spectrum can be enabled or disabled by a jumper selection. If an external pulse signal is applied to the SYNC pin, then the switching frequency is synchronized to the external clock.

CAUTION

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

1.2 Kit Contents

- LM644A2QEVM-S2100T
- SA000-12024 heat sink

1.3 Specification

Unless otherwise indicated, VIN = 12V, VOUT = 3.3V, IOUT = 12A and f_{SW} = 2.1MHz.

Table 1-1. Electrical Performance Specifications

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT CHARACTERISTICS					
Input supply voltage range	VIN range	6(2)		36	V
	VIN_EMI range	12		36	V
Input current	Input current at VIN			12	A
	Input current at VIN_EMI			8	A
OUTPUT CHARACTERISTICS (1)					
Output voltage	Default output is 3.3V	3.234	3.3	3.366	V
Output current		0		12	A
SYSTEM CHARACTERISTICS					
Default switching frequency, f_{SW}			2.1		MHz
Efficiency	VIN = 12V, IOUT = 8A VOUT = 3.3V		90.9		%
Full-load efficiency	VIN = 12V, IOUT = 12A		87		%
	VIN = 24V, IOUT = 12A		83.2		

(1) Default output voltages and switching frequency are 3.3V and 2.1MHz, respectively.
(2) The EVM operates when the input voltage is in the range of 3V to 6V, but enters a dropout mode if there is insufficient input voltage to regulate output voltages.

1.4 Device Information

Table 1-2. LM(Q)644xx(-Q1) Dual Buck DC/DC Converter Family

Part Number	RATED I_{OUT}	PACKAGE	DIMENSIONS
LMQ64480-Q1	4A per channel	Enhanced QFN (25)	5.0mm × 4.0mm
LMQ644A0-Q1	5A per channel		
LM644A2*	6A per channel	Thermally Enchanced QFN (25)*	
LMQ644A2-Q1			

2 Hardware

2.1 EVM Connections

Working at an ESD-protected workstation, make sure that any wrist straps, bootstraps, or mats are connected and referencing the user to earth ground before power is applied to the EVM.

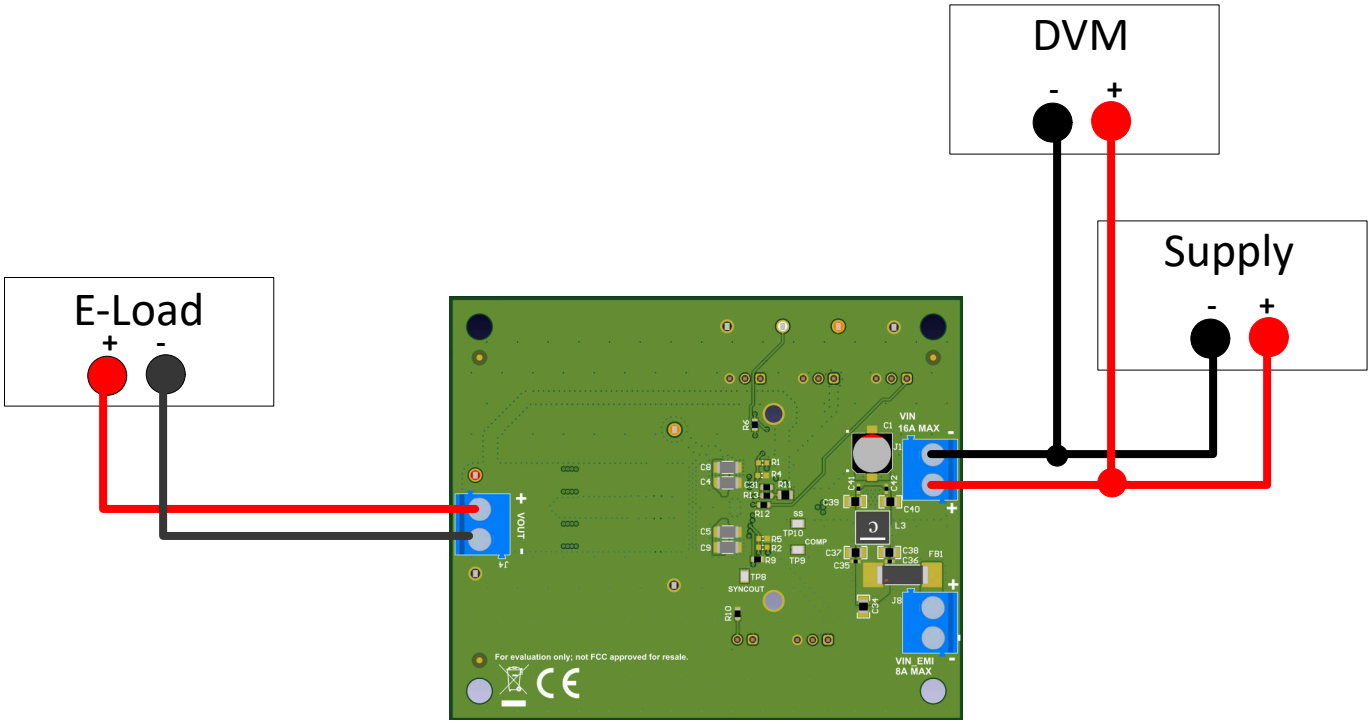


Figure 2-1. EVM Test Setup

Table 2-1. EVM Power Connections

LABEL	DESCRIPTION
VIN+	Positive input power connection.
VIN–	Negative input power connection.
VIN_EMI+	Positive input power connection for EMI test.
VIN_EMI-	Negative input power connection for EMI test.
VOUT+	Positive output power connection.
VOUT–	Negative output power connection.

Table 2-2. EVM Signal Connections

LABEL	DESCRIPTION
VINS+	Positive input sense pin for measuring efficiency.
VINS–	Negative input sense pin for measuring efficiency.
VOUTS+	Positive output sense pin for measuring efficiency, and line and load regulation.
VOUTS–	Negative output sense pin for measuring efficiency, and line and load regulation.
GND	Ground reference point
SYNC(+)	Positive synchronization pulse input.
SYNC(-)	Negative synchronization pulse input.
MODE	Light load switching mode selection. Connect pin1 and pin2 for a FPWM mode. Connect pin2 and pin3 for an AUTO mode. Remove any jumper when external synchronization pulse is applied to SYNC.
DITH	Spread spectrum enable, disable. Connect pin1 and pin2 to disable the spread spectrum. Remove any jumper to enable the spread spectrum. The EVM must restart after changing the jumper setting.
EN1	Primary enable, disable. Connect pin1 and pin2 to enable both channels. Connect pin2 and pin3 to disable both channels. Remove any jumper when programing the line UVLO using an external resistor divider. Populate the external UVLO resistor divider.
EN2	CH2 enable, disable. Connect pin1 and pin2 to enable CH2. Connect pin2 and pin3 to disable CH2. Remove any jumper when programing the line UVLO using an external resistor divider. Populate the external UVLO resistor divider.
VSEL	Output voltage selection. Remove any jumper when programing the regulation target using an external resistor divider. The default condition is open. Connect pin 1 and pin 2 for a fixed 5V output. Connect pin 2 and pin 3 for a fixed 3.3V output. The external feedback resistors must be unpopulated to use the fixed output options.
PG	Probe point for power good indicator. A pullup resistor is connected to VCC.
SYNCOUT	Probe point for SYNCOUT signal. SYNCOUT provide clock information from the primary to the secondary device in 4- or 6-phase configuration.
SS	Probe point for SS. The soft-start pin is also used for fault communication between the primary and the secondary device in 4- or 6-phase configuration.
COMP	Probe point for COMP. COMP is the output of error amplifier.

2.2 Test Equipment

Supply: Connect between VIN(+) and VIN(-) . The power supply must be capable of supplying 12A.

Digital Volt Meter: Measure the output voltage between VOUTS(+) and VOUT(–).

Electronic Load: Connect to VOUT+ and VOUT-. The electronic load must be capable of sinking 12A.

2.3 EVM Setup

Use the VINS+ and VINS– test points along with the VOUTS+, VOUTS– test points located near the power terminal blocks as voltage monitoring points where voltmeters are connected to measure the input and output voltages, respectively. *Do not use these sense terminals as the input supply or output load connection points.* The PCB traces connected to these sense terminals are not designed to support high currents. Before applying power to the EVM, make sure that the jumper is present and properly positioned for the intended output voltage. Always remove input power before changing the jumper settings. Always use caution when touching any circuits that can be live or energized.

CAUTION

Extended operation at high output current 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. Wire gauge for the input power supply and the output electric load must be 9 AWG minimum and no longer than 1 foot. Please tighten the input and output terminal screws to minimize contact resistance.

2.3.1 Input Connections

- Connect supply between VIN(+) and VIN(-)
- Note correct polarity before turning on supply

2.3.2 Output Connections

- Connect voltmeter between VOUTS+ and VOUTS– sense points to measure the output voltage.
  - There can be a voltage drop seen if measuring at the connector which is a result of the copper track resistance
- Connect load to VOUT+ and VOUT– connections as shown in Figure 2-1. Set the load to constant-resistance mode or constant-current mode at 0A before applying input voltage.

2.3.3 Heat Sink Setup

A heat sink is provided with this EVM. The heat sink reduces the temperature rise of the power converter. The thermal performance improvement can be examined and provide guidance to the thermal performance one can expect with a like-heat-sink in the end-application.

The heat sink can be mounted to the EVM after configuring the circuit to the particular application conditions. The heat sink has mounting holes on the EVM. To enable heat transfer, TI recommends to utilize thermally conductive tape between the IC and the heat sink. Make sure that the heat sink does not short out any of the passives the heat sink is hovering over. The thermal tape can also double as a insulator for quick evaluation. Use the best engineering judgment in setup.

There is no easy way to measure the device's junction temperature with a heatsink mounted. The user must rely on simulation to estimate the junction temperature for the end-application's heatsink and corresponding airflow. For reference, at 125°C oven temperature, with the provided heat sink mounted on the EVM, the device is capable (not going into thermal shutdown) of supporting a continuous load 1A higher than without. In this example, the thermal (convection) oven had an approximate airflow of 300-400 LFM.

3 Implementation Results

3.1 Test Data and Performance Curves

Unless otherwise indicated, VIN = 12V, VOUT = 3.3V, IOUT = 12A, and f_{SW} = 2.1MHz.

3.1.1 Efficiency and Load Regulation Performance

This section provides efficiency and load regulation plots for the EVM.

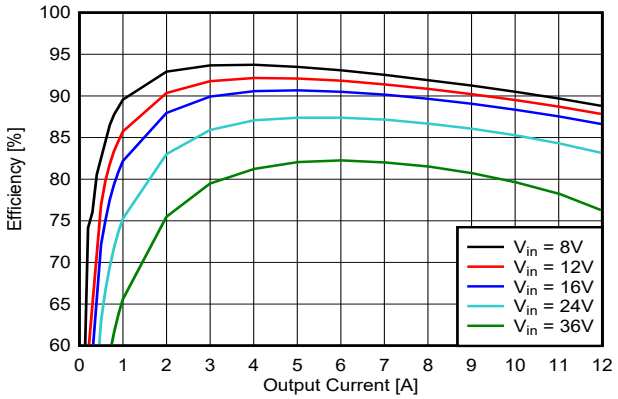


Figure 3-1. Efficiency, VOUT = 3.3V, FPWM Mode

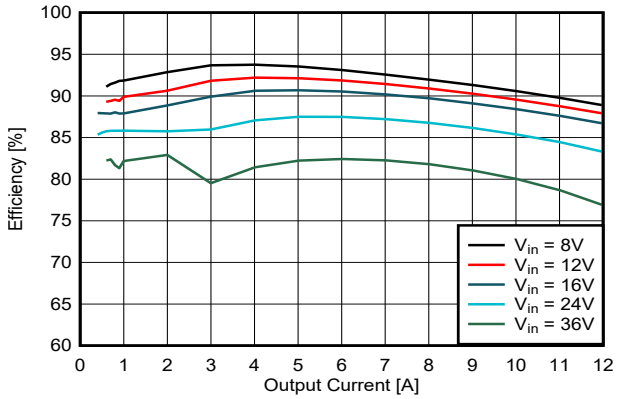


Figure 3-2. Efficiency, VOUT = 3.3V, AUTO Mode

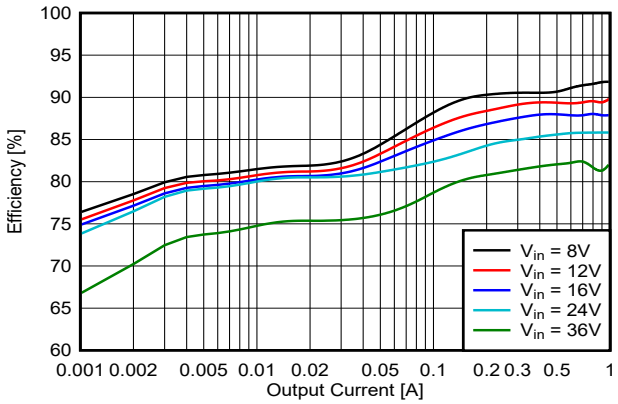


Figure 3-3. Efficiency, VOUT = 3.3V, AUTO Mode Light Load Operation

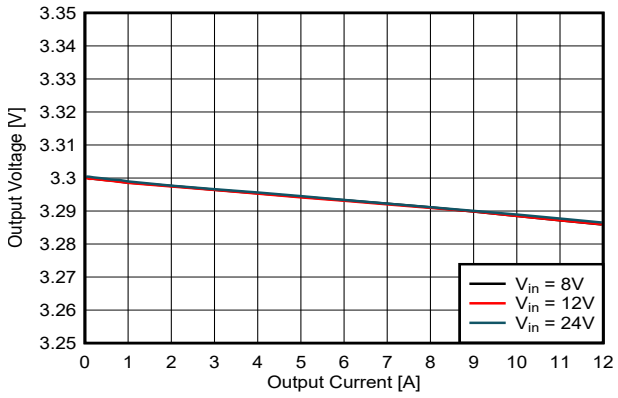


Figure 3-4. Load Regulation, VOUT = 3.3V, FPWM Mode

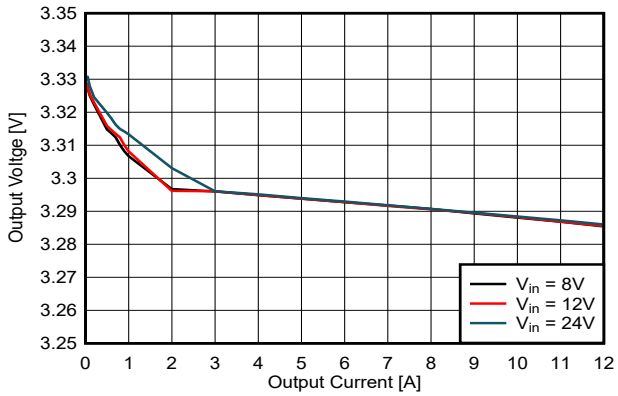


Figure 3-5. Load Regulation, VOUT = 3.3V, AUTO Mode

3.1.2 Waveforms and Plots

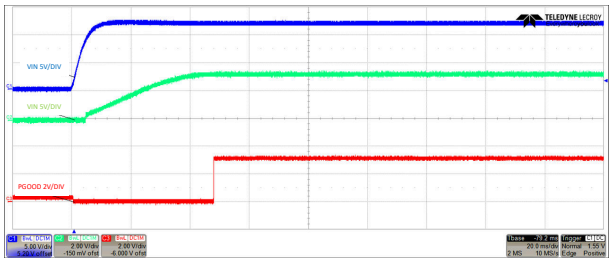


Figure 3-6. Start-Up

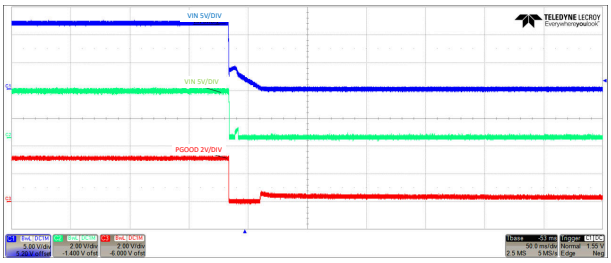


Figure 3-7. Shutdown

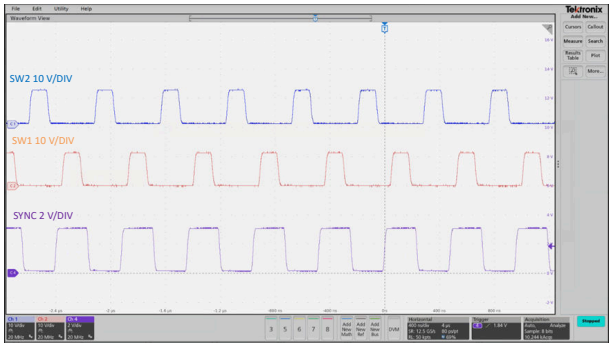


Figure 3-8. SYNC and Interleaving. No load

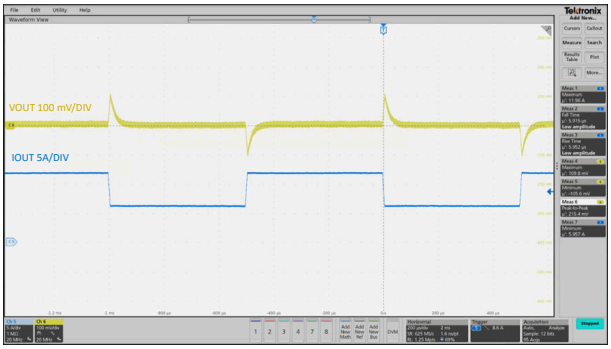


Figure 3-9. Load Transient, 6A to 12A

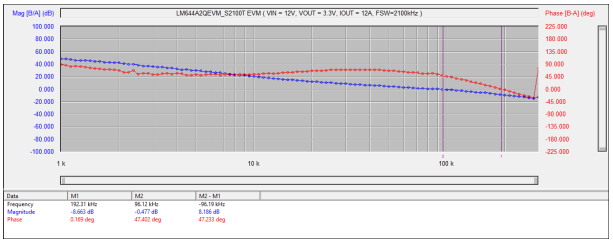


Figure 3-10. Bode Plot, VIN = 12V

3.1.3 EMI Performance

VIN = 12V, VOUT = 3.3V, IOUT = 12A, spread spectrum enabled.

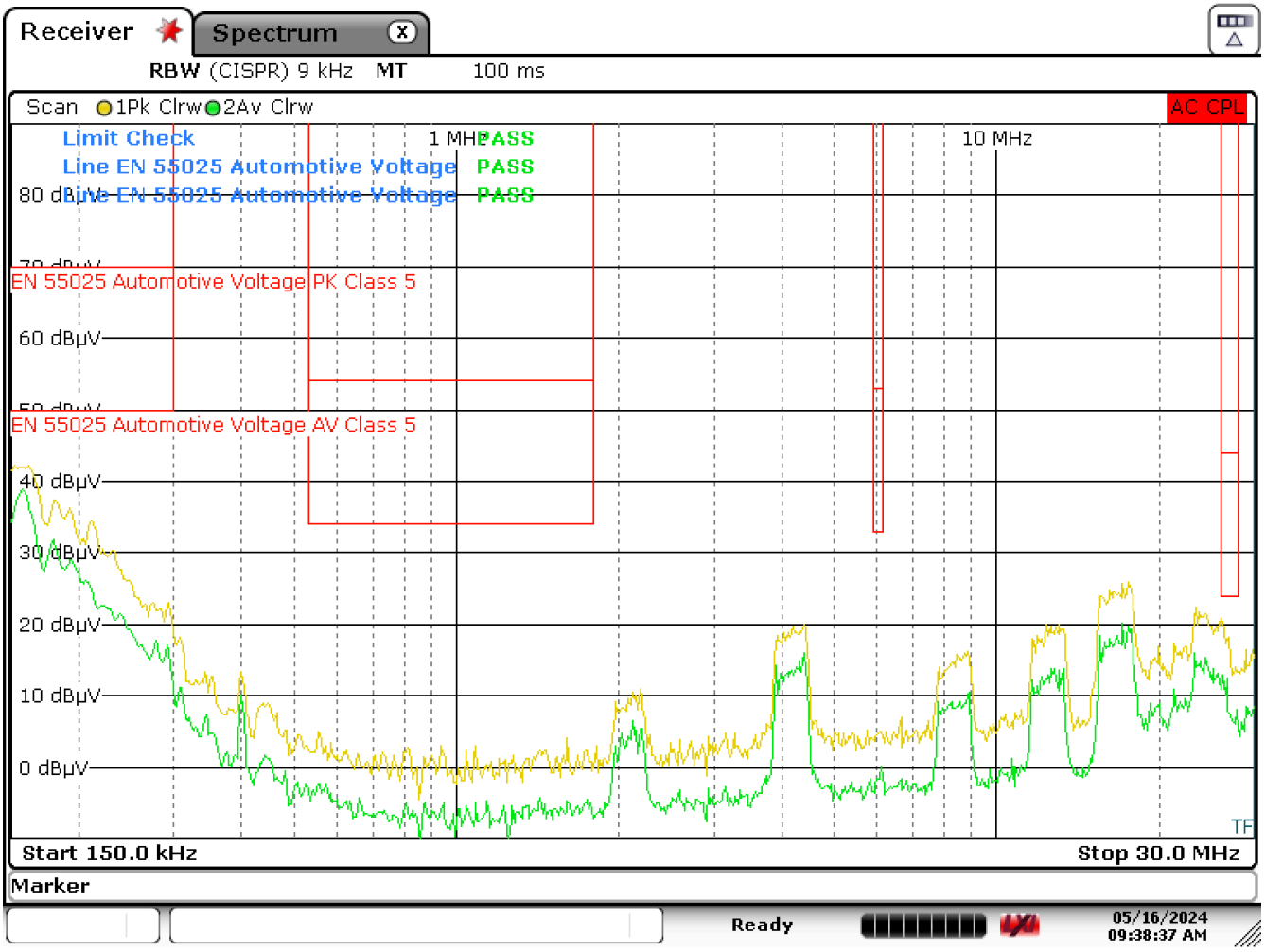


Figure 3-11. CISPR 25 Conducted Emissions: 150kHz to 30MHz

3.1.4 Thermal Performance

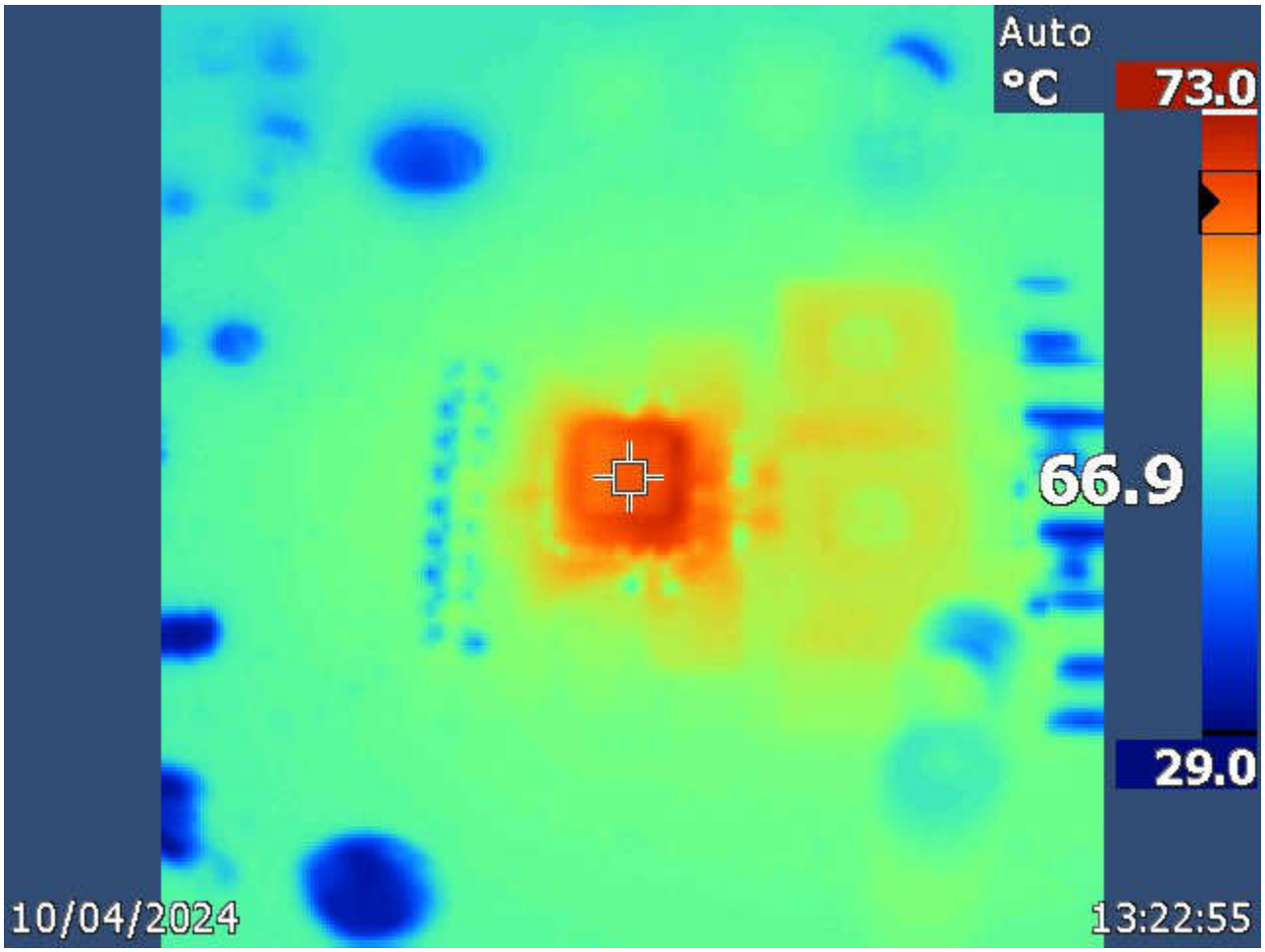


Figure 3-12. 13.5VIN to 3.3VOUT, 8A CC load, 2.2MHz Operation Top Case Temperature

4 Hardware Design Files

4.1 Schematic

The EVM schematic is illustrated in Figure 4-1.

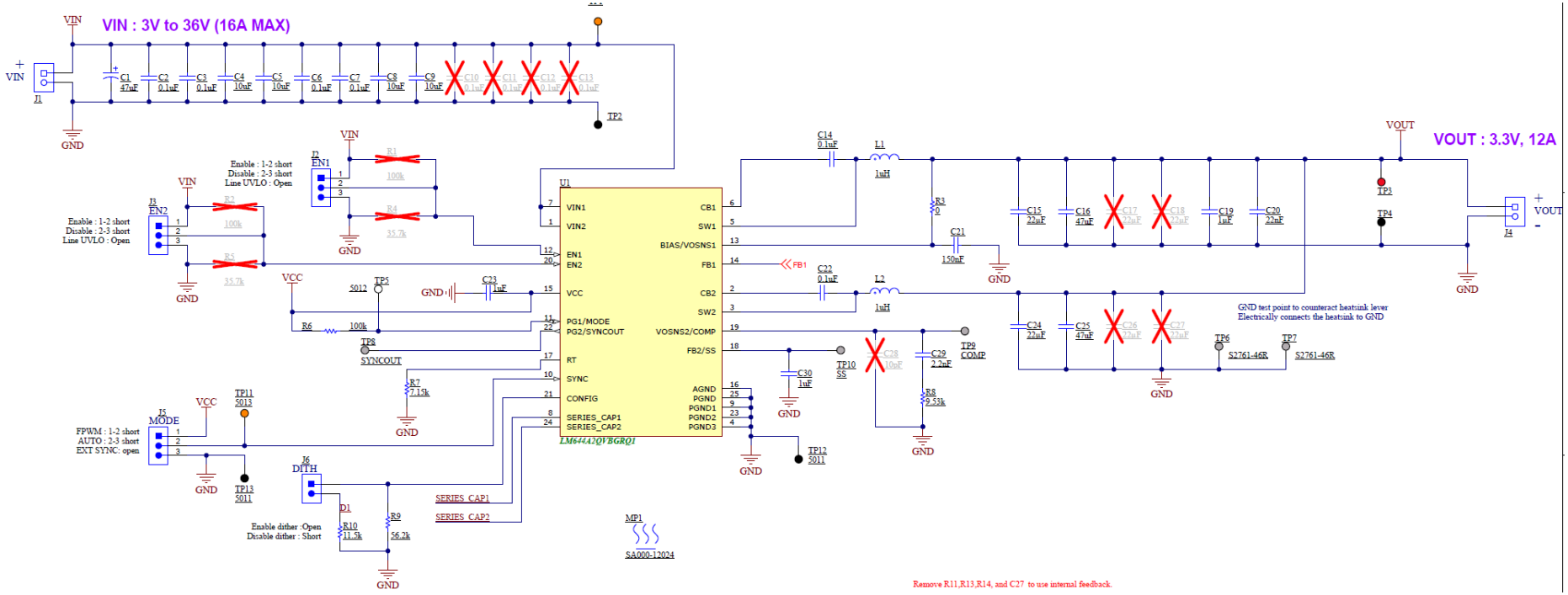


Figure 4-1. EVM Schematic

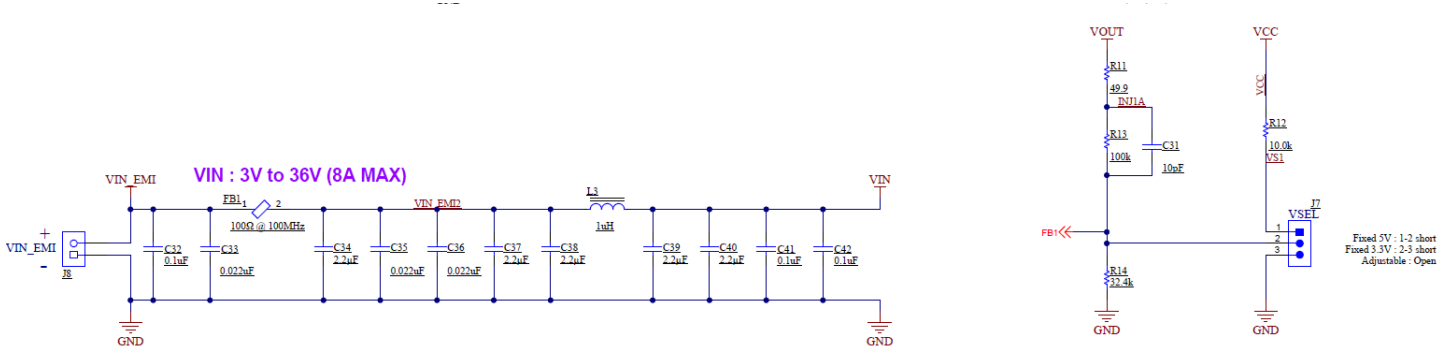


Figure 4-2. EVM Schematic

4.2 PCB Layout

The PCB is 62-mils standard thickness with 2-oz copper on all layers.

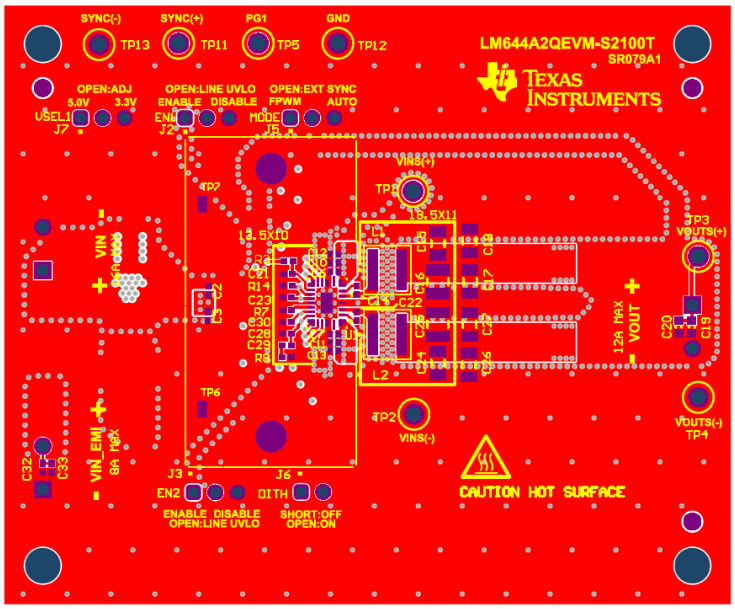


Figure 4-3. Top Component View

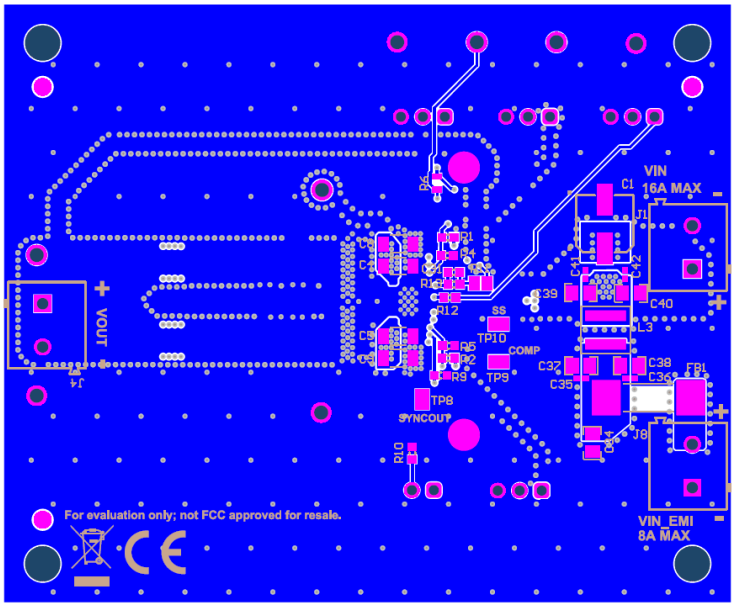


Figure 4-4. Bottom Component View

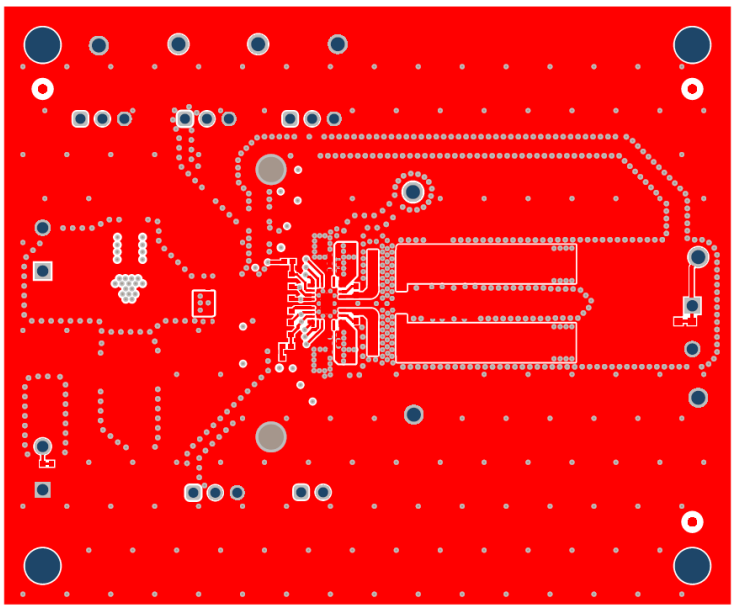


Figure 4-5. Top Layer Copper

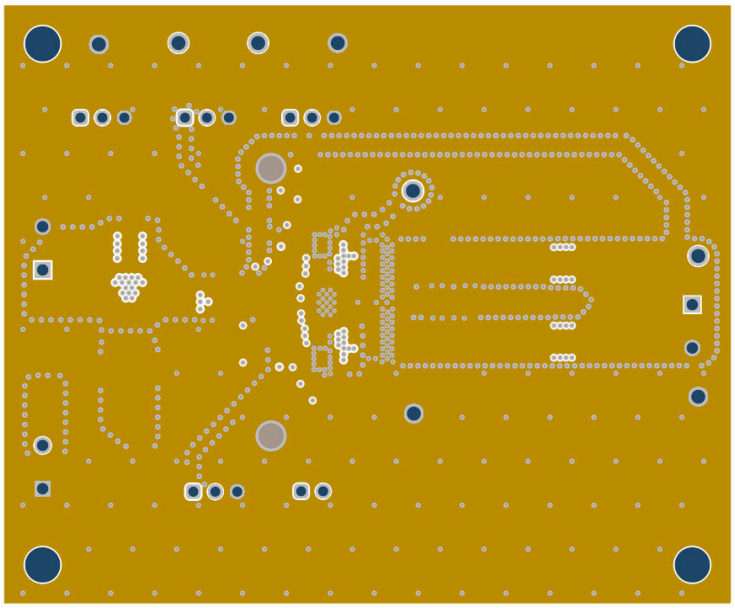


Figure 4-6. Layer 2 Copper

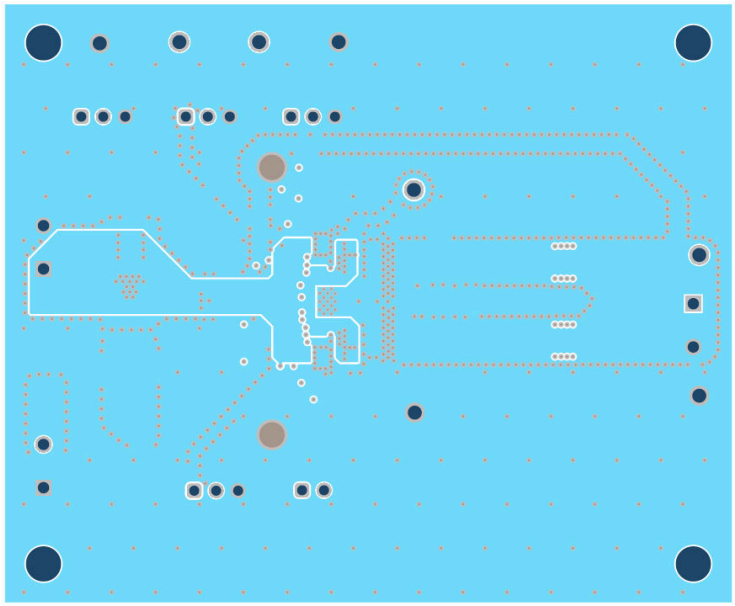


Figure 4-7. Layer 3 Copper

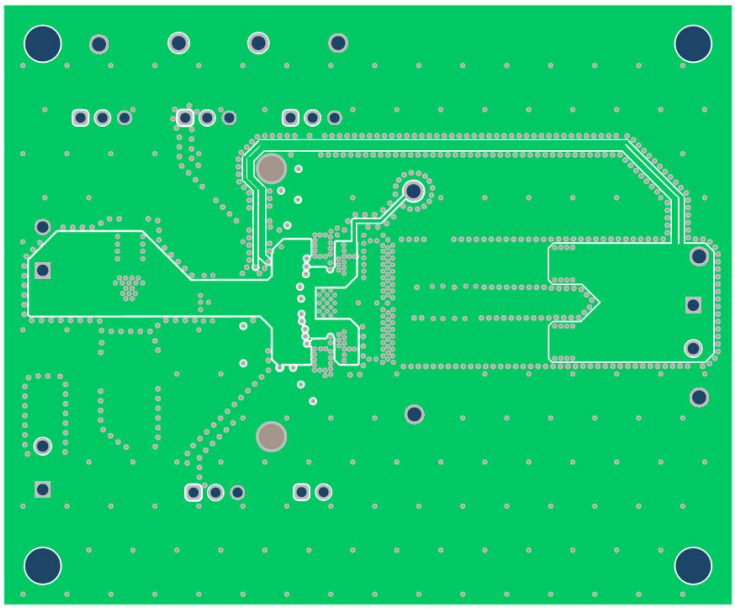


Figure 4-8. Layer 4 Copper

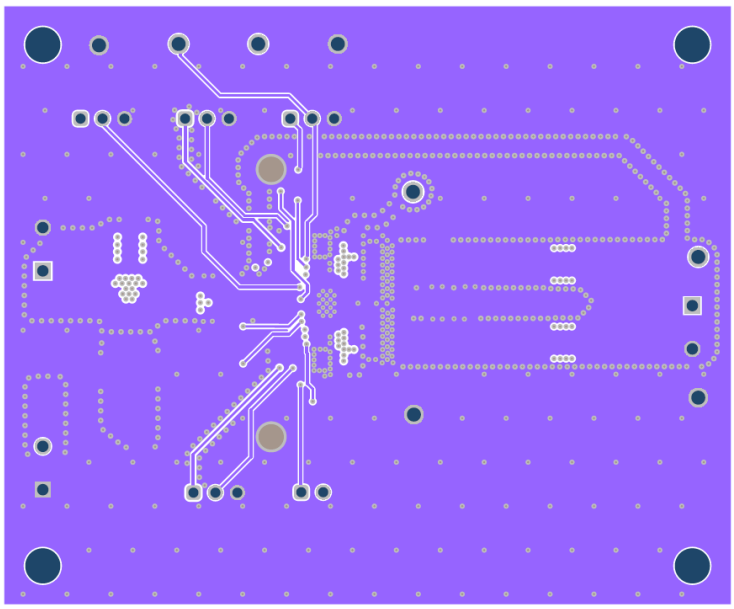


Figure 4-9. Layer 5 Copper

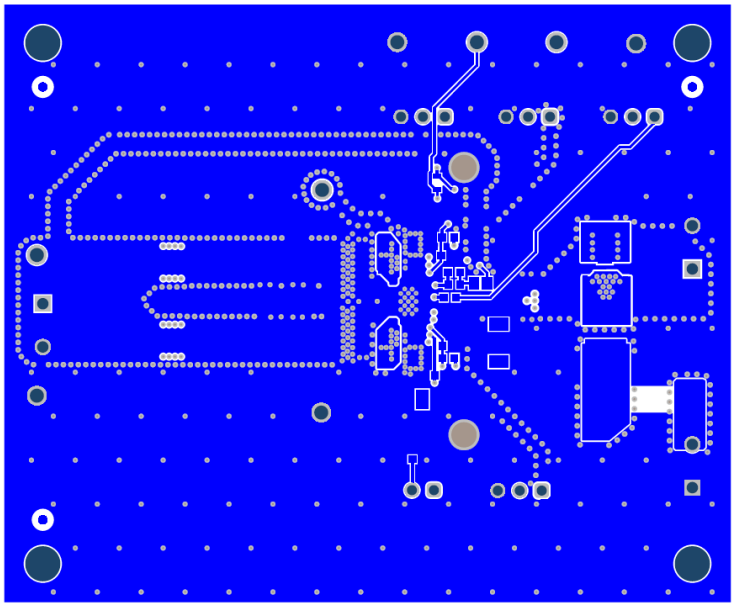


Figure 4-10. Bottom Layer Copper (Viewed From Top)

4.3 Bill of Materials

Table 4-1. Bill of Materials

Designator	Quantity	Value	Description	Part Number	Manufacturer	Package Reference
SH-J1, SH-J2, SH-J3, SH-J4	5		Single Operation 2.54mm Pitch Open Top Jumper Socket	M7582-05	Harwin	Single Operation 2.54mm Pitch Open Top Jumper Socket
C1	1	47uF	CAP, AL, 47uF, 50V, +/- 20%, SMD	865080645012	Wurth Elektronik	D6.3xL7.7mm
C2, C3, C6, C7, C32, C41, C42	7	0.1uF	CAP, CERM, 0.1uF, 50V, +/- 10%, X7R, AEC-Q200 Grade 1, 0402	GCM155R71H104KE02D	MuRata	0402
C4, C5, C8, C9	4	10uF	CAP, CERM, 10uF, 50V, +/- 10%, X7R, 1206	CL31B106KBHNNNE	Samsung	1206
C14, C22	2	0.1uF	CAP, CERM, 0.1uF, 16V, +/- 10%, X7R, AEC-Q200 Grade 1, 0402	C0402C104K4RACAUTO	Kemet	0402
C15, C24	2	22uF	CAP, CERM, 22µF, 16V,+/- 20%, X7S, 1206	GRM31CC71C226ME11L	MuRata	1206
C16, C25	2	47uF	CAP, CERM, 47uF, 10V, +/- 20%, X7R, 1210	GRM32ER71A476ME15L	MuRata	1210
C19	1	1uF	CAP, CERM, 1uF, 25V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	GCM188R71E105KA64D	MuRata	0603
C20	1	0.022uF	CAP, CERM, 0.022uF, 50V, +/- 10%, X7R, 0603	C0603C223K5RACTU	Kemet	0603
C21	1	0.15uF	CAP, CERM, 0.15uF, 16V,+/- 10%, X7R, 0402	GRM155R71C154KA12D	MuRata	0402
C23, C30	2	1uF	CAP, CERM, 1uF, 16V, +/- 10%, X6S, 0402	C1005X6S1C105K050BC	TDK	0402
C29	1	2200pF	CAP, CERM, 2200pF, 50V, +/- 10%, X7R, 0402	GRM155R71H222KA01D	MuRata	0402
C31	1	10pF	CAP, CERM, 10pF, 100V,+/- 5%, C0G/NP0, 0603	885012006073	Wurth Elektronik	0603
C33, C35, C36	3	0.022uF	CAP, CERM, 0.022uF, 50V, +/- 10%, X7R, AEC-Q200 Grade 1, 0402	CGA2B3X7R1H223K050BB	TDK	0402
C34, C37, C38, C39, C40	5	2.2uF	CAP, CERM, 2.2uF, 50V, +/- 20%, X7R, 0805	C2012X7R1H225M125AC	TDK	0805
FB1	1		100 Ohms at 100MHz 1 Power Line Ferrite Bead 3312 (8531 Metric) 10A 4mOhm	78279225101	Wurth Electronics	3312
H1, H2, H3, H4	4		Machine Screw, Round, #4-40 x 1/4, Nylon, Philips panhead	NY PMS 440 0025 PH	B&F Fastener Supply	Screw
H5, H6, H7, H8	4		Standoff, Hex, 0.5"L #4-40 Nylon	1902C	Keystone	Standoff
J1, J4, J8	3		Terminal Block, 5mm, 2x1, Tin, TH	691 101 710 002	Wurth Elektronik	Terminal Block, 5mm, 2x1, TH

Table 4-1. Bill of Materials (continued)

Designator	Quantity	Value	Description	Part Number	Manufacturer	Package Reference
J2, J3, J5, J7	4		Header, 2.54mm, 3x1, Gold, TH	61300311121	Wurth Elektronik	Header, 2.54mm, 3x1, TH
J6	1		Header, 2.54mm, 2x1, Gold, TH	61300211121	Wurth Elektronik	Header, 2.54mm, 2x1, TH
L1, L2	2	1uH	Shielded Power Inductor, 1uH, 20%, 17.8A IRMS, 5.8mOhm DCR max, AECQ200 Grade1, 5.28x5.48x3.1mm	XGL5030-102MEC	Coilcraft	SMT_IND_5MM28_5MM48
L3	1		Inductor, Shielded, Composite, 1.0H, 16.9A, 0.0084 ohm, AEC-Q200 Grade 1	XEL5030-102MEB	Coilcraft	SMT_5MM28_5MM48
MP1	1		Heat Sink Aluminum Top Mount	SA000-12024	Sunon	HEATSINK
R3	1	0	RES, 0, 5%, 0.063 W, 0402	RC0402JR-070RL	Yageo America	0402
R6	1	100k	RES, 100 k, 1%, 0.1 W, 0603	RC0603FR-07100KL	Yageo	0603
R7	1	7.15k	RES, 7.15 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04027K15FKED	Vishay-Dale	0402
R8	1	9.53k	RES, 9.53 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04029K53FKED	Vishay-Dale	0402
R9	1	56.2k	RES, 56.2 k, 1%, 0.1 W, 0603	RC0603FR-0756K2L	Yageo	0603
R10	1	11.5k	RES, 11.5 k, 1%, 0.1 W, 0603	RC0603FR-0711K5L	Yageo	0603
R11	1	49.9	RES, 49.9, 1%, 0.125 W, AEC-Q200 Grade 0, 0805	CRCW080549R9FKEA	Vishay-Dale	0805
R12	1	10.0k	RES, 10.0 k, 1%, 0.1 W, 0603	RC0603FR-0710KL	Yageo	0603
R13	1	100k	RES, 100 k, 0.1%, 0.1 W, AEC-Q200 Grade 1, 0603	TNPW0603100KBEEA	Vishay-Dale	0603
R14	1	32.4k	RES, 32.4 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW040232K4FKED	Vishay-Dale	0402
TP1, TP11	2		Test Point, Multipurpose, Orange, TH	5013	Keystone Electronics	Orange Multipurpose Test point
TP2, TP4, TP12, TP13	4		Test Point, Multipurpose, Black, TH	5011	Keystone Electronics	Black Multipurpose Test point
TP3	1		Test Point, Multipurpose, Red, TH	5010	Keystone Electronics	Red Multipurpose Test point
TP5	1		Test Point, Multipurpose, White, TH	5012	Keystone Electronics	White Multipurpose Test point

Table 4-1. Bill of Materials (continued)

Designator	Quantity	Value	Description	Part Number	Manufacturer	Package Reference
TP6, TP7	2		Natural PC Test Point Brass, SMT	S2761-46R	Harwin	Natural PC Test Point Brass, SMT
TP8, TP9, TP10	3		Test Point, SMT	S2751-46R	Harwin	Test Point, SMT
U1	1		3V to 36V, low IQ, dua Automotive Buck Converter Optimized for Power Density and Low EMI	LM644A2QVBGRQ1	Texas Instruments	WQFN-FCRL24
C10, C11, C12, C13	0	0.1uF	CAP, CERM, 0.1uF, 50V, +/- 10%, X7R, AEC-Q200 Grade 1, 0402	GCM155R71H104KE02D	MuRata	0402
C17, C18, C26, C27	0	22uF	CAP, CERM, 22µF, 16V,+/- 20%, X7S, 1206	GRM31CC71C226ME11L	MuRata	1206
C28	0	10pF	CAP, CERM, 10pF, 50V,+/- 5%, C0G/NP0, AEC-Q200 Grade 1, 0402	GCM1555C1H100JA16D	MuRata	0402
FID1, FID2, FID3	0		Fiducial mark. There is nothing to buy or mount.	N/A	N/A	N/A
R1, R2	0	100k	RES, 100 k, 1%, 0.1 W, 0603	RC0603FR-07100KL	Yageo	0603
R4, R5	0	35.7k	RES, 35.7 k, 1%, 0.1 W, 0603	RC0603FR-0735K7L	Yageo	0603

5 Additional Information

5.1 Trademarks

WEBENCH® is a registered trademark of Texas Instruments.
All trademarks are the property of their respective owners.

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 Designs.
- For TI's WEBENCH Design Environment, visit the WEBENCH® Design Center.
- To design a low-EMI power supply, review TI's comprehensive EMI Training Series.
- Technical Articles:
  - *How Device-level Features And Package Options Can Help Minimize EMI In Automotive Designs*
  - *Optimizing Flip-chip IC Thermal Performance In Automotive Designs*

6.1.1.1 Custom Design With WEBENCH® Tools

Click here to create a custom design using the LM644A2-Q1 device with WEBENCH® Power Designer.

1. Start by entering the input voltage (V_{IN}), output voltage (V_{OUT}), and output current (I_{OUT}) requirements.
2. Optimize the design for key parameters such as efficiency, footprint, and cost using the optimizer dial.
3. Compare the generated design with other possible designs from Texas Instruments.

The WEBENCH Power Designer provides a customized schematic along with a list of materials with real-time pricing and component availability.

In most cases, these actions are available:

- Run electrical simulations to see important waveforms and circuit performance.
- Run thermal simulations to understand board thermal performance.
- Export customized schematic and layout into popular CAD formats.
- Print PDF reports for the design, and share the design with colleagues.

Get more information about WEBENCH tools at www.ti.com/WEBENCH.

6.2 Documentation Support

6.2.1 Related Documentation

For related documentation, see the following:

- Texas Instruments, *An Engineer's Guide To EMI In DC/DC Regulators* e-book
- Texas Instruments, *EMI Filter Components And Their Nonidealities For Automotive DC/DC Regulators* technical brief
- Texas Instruments, *Designing High Performance, Low-EMI, Automotive Power Supplies* application report
- Texas Instruments, *AN-2020 Thermal Design By Insight, Not Hindsight* application report
- Texas Instruments, *AN-2162 Simple Success With Conducted EMI From DC/DC Converters Application Report* application report
- Texas Instruments, *Practical Thermal Design With DC/DC Power Modules* application report

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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2. 実験局の免許を取得後ご使用いただく。
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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

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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.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

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