EVM User's Guide: TPSM64406EVM-4PH

TPSM64406 4-Phase, 36V, Single 12A Output, Synchronous, Buck Module Evaluation Module

Description

This TPSM64406 evaluation board showcases the features and performance of multiple TPSM64406 buck DC/DC modules with integrated power MOSFETs and inductors in a multi-phase, single output configuration. The EVM provides a single output capable of loading up to 12A. The output voltages can be individually programmed to a fixed 3.3V, 5V or adjustable using external feedback resistors and jumpers.

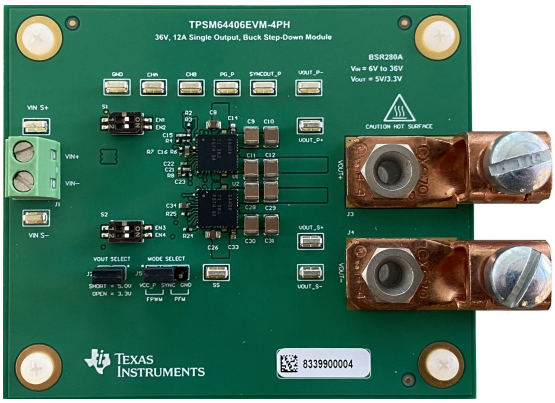
The default switching frequency at full load is programmed to 1MHz. The switching mode at the light load is selectable between FPWM and PFM mode. Each channel can be enabled or disabled by a jumper selection. Finally, spread spectrum can be enabled or disabled by a configuration resistor selection. The TPSM64406EVM-4PH is designed to demonstrate the full capabilities of two stacked devices on a single PCB design.

Features

- Functional Safety-Capable
  - Documentation available to aid functional safety system design
- Versatile dual output voltage or multiphase single output synchronous buck module
  - Integrated MOSFETs, inductor, and controller
  - Wide input voltage range of 6.3V to 36V
  - Adjustable output voltage from 0.8V to 16V
  - 6.5mm × 7.0mm × 2mm over-molded package
  - –40°C to 125°C junction temperature range
  - Negative output voltage capability
- Ultra-high efficiency across the full load range
  - Peak efficiency of 94%+
  - External bias option for improved efficiency
  - Exposed Pad for low thermal impedance. EVM θ_{JA} = 20 °C/W.
- Ultra-low conducted and radiated EMI signatures
  - Low-noise package with dual input paths and integrated capacitors reduces switch ringing
  - Input EMI filter with electrolytic capacitor for parallel damping
  - Resistor selectable spread spectrum
  - Constant-frequency FPWM mode of operation
  - Meets CISPR 11 and 32 Class B emissions
- An excellent choice for scalable power supplies
- 4-layer, 2-oz PCB design
- Inherent protection features for robust design
  - Precision enable input and open-drain PGOOD indicator for sequencing, control, and V_{IN} UVLO
  - Over-current and thermal shutdown protections
- Create a custom design using the TPSM64406 with the WEBENCH® Design Tool.

Applications

- Test and measurement, aerospace and defense
- Factory automation and control
- Buck and inverting buck-boost power supplies



TPSM64406EVM-4PH Board (Top View)

1 Evaluation Module Overview

1.1 Introduction

The TPSM64406 is a highly integrated 36V input capable, DC/DC design that combines power MOSFETs, a shielded inductor, and passives in an enhanced HotRod™ QFN package. The device supports either dual output or high current single output using an interleaved, stackable, current-mode control architecture for easy loop compensation, fast transient response, excellent load and line regulation, and accurate current sharing with an output clock supporting up to 6 phases for currents up to 18A. The module has VIN and VOUT pins located at the corners of the package for optimized input and output capacitor placement. A large thermal pad beneath the module enable a simple layout and easy handling in manufacturing. With an output voltage from 1V to 16iV, the TPSM64406 is designed to quickly and easily implement a low-EMI design in a small PCB footprint. The total design requires as few as six external components and eliminates the magnetics selection from the design process. Although designed for small size and simplicity in space-constrained applications, the TPSM64406 module offers many features for robust performance: precision enable with hysteresis for adjustable input voltage UVLO, and spread spectrum for improved EMI. Along with integrated VCC, bootstrap and input capacitors for increased reliability and higher density. The module can be configured for constant switching frequency over the full load current range (FPWM), or variable frequency (PFM) for higher light load efficiency, including a PGOOD indicator for sequencing, fault protection, and output voltage monitoring.

1.2 Kit Contents

- TPSM64406 devices (U1, U2)
- BSR280A 4 Phase Single Output EVM Board

1.3 Specification

Table 1-1. Electrical Performance Specifications

Unless otherwise indicated, VIN = 12V, VOUT = 5.0V, IOUT = 12A and f_{SW} = 1MHz.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT CHARACTERISTICS					
Input supply voltage range	VIN range	6(3)		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	Selectable 5.0V	4.9	5.0	5.1	V
Output voltage	Selectable 3.3V	3.234	3.3	3.366	V
Output current		0		6	A
SYSTEM CHARACTERISTICS					
Default switching frequency, f_{SW}			2.1		MHz
Full-load efficiency(2)	VIN = 12V, IOUT1 = 12A		91%		
	VIN = 24V, IOUT = 12A		87%		

(1) Default output voltages and switching frequency are 5V or 3.3V selectable and 1MHz, respectively.
(2) The recommended airflow is 200 LFM when operating
(3) 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. TPSM644xx(-Q1) Dual Buck DC/DC Converter Family

Part Number	Rated I_{OUT}	PACKAGE	DIMENSIONS
TPSM64404(-Q1)	Dual 2A / 2A or stackable 4A	Enhanced QFN (25)	6.50mm × 7.0mm
TPSM64406(-Q1)	Dual 3A / 3A or stackable 6A		

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.

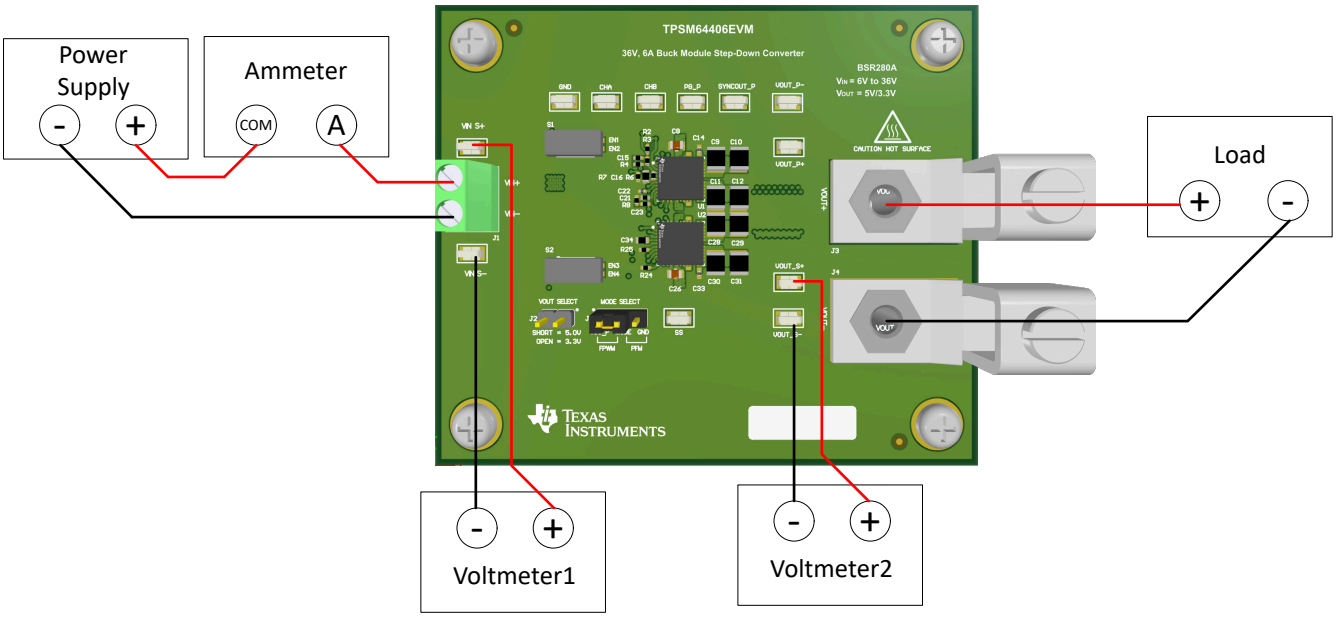


Figure 2-1. EVM Test Setup

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. The minimum operating voltage is 12V at this input.
VIN_EMI-	Negative input power connection for EMI test. The minimum operating voltage is 12V at this input.
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.
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.
VSEL	Output voltage selection. Connect pin1 and pin2 for a fixed 5V output. Connect pin2 and pin3 for a fixed 3.3V output. Remove any jumper when programing the regulation target using an external resistor divider. Populate the external feedback resistor divider.
PG	Probe point for power-good indicator. A pullup resistor is connected to VCC.

2.2 EVM Setup

Use the VINS+ and VINS– test points along with the VOUT1S+, VOUT1S–, VOUT2S+, VOUT2S–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 jumpers are 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 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.

2.2.1 Input Connections

- Connect voltmeter1 at VINS+ and VINS– .
- Connect ammeter1 to VIN+.
- Prior to connecting the power supply, set the current limit of the power supply to 0.3A maximum and make sure the initial output voltage is set to 0V. Connect to the VIN- and the ammeter1 as shown in Figure 2-1.

2.2.2 Output Connections

- Connect voltmeter at VOUTS+ and VOUTS– sense points to measure the output voltage.
- Connect load to the 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.

3 Implementation Results

3.1 Test Equipment

Power Supply: Connect to VIN(-) and Ammeter1. The power supply must be capable of supplying 16A. Adjustable voltage range must be from 6V to 36V.

Multimeters:

- **Voltmeter 1:** Measure the input voltage at VINS+ to VINS–.
- **Voltmeter 2:** Measure the output voltage at VOUTS+ to VOUTS–.
- **Ammeter:** Measure the input current. Connect to the power supply and VIN(+).

Electronic Load:

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

3.2 Test Data and Performance Curves

Unless otherwise indicated, VIN = 12V, VOUT= 5V, IOUT = 12A and F_{SW} = 1MHz.

3.2.1 Efficiency and Load Regulation Performance

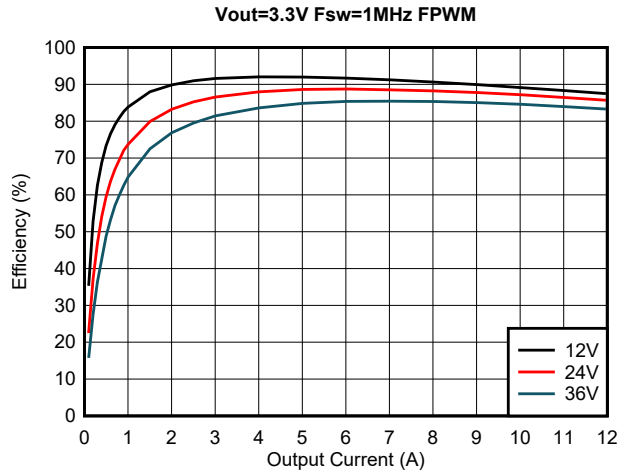


Figure 3-1. Efficiency, VOUT = 3.3V, FPWM Mode

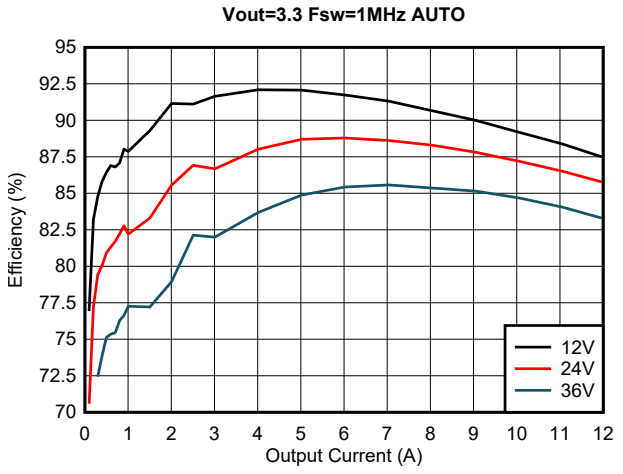


Figure 3-2. Efficiency, VOUT = 3.3V, AUTO Mode

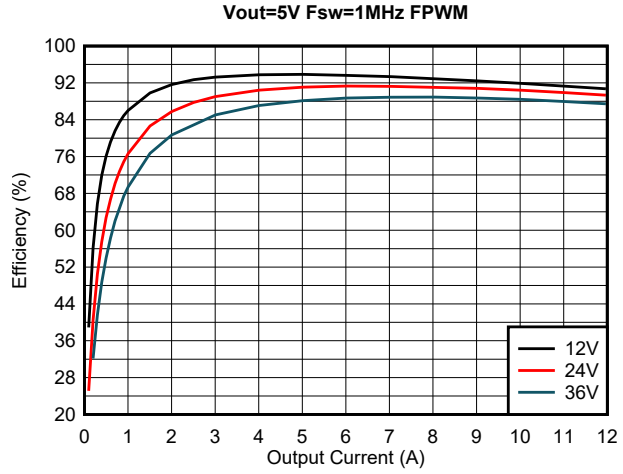


Figure 3-3. Efficiency, VOUT = 5.0V, FPWM Mode

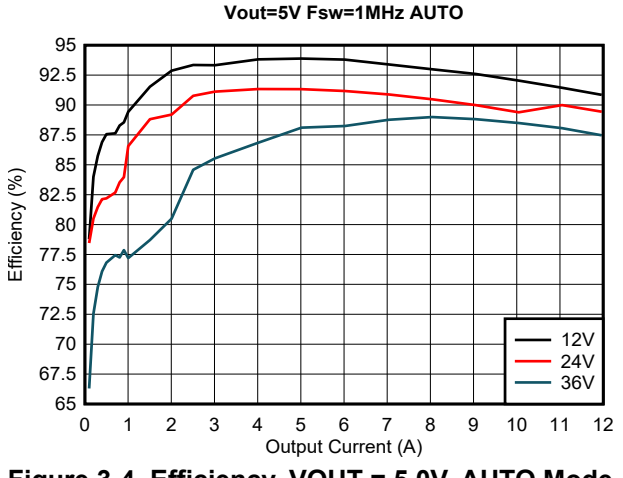


Figure 3-4. Efficiency, VOUT = 5.0V, AUTO Mode

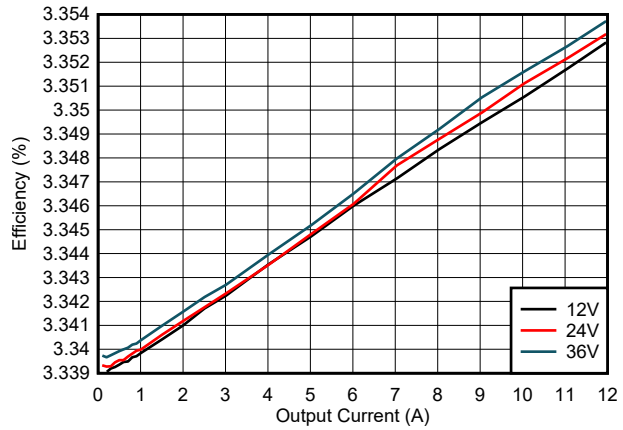


Figure 3-5. Load Regulation, VOUT = 3.3V, FPWM Mode

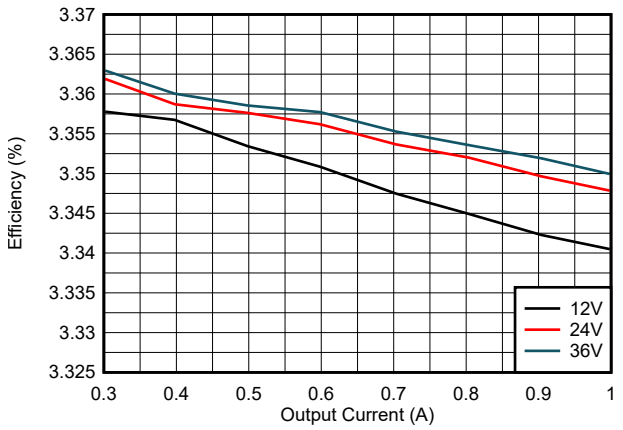


Figure 3-6. Load Regulation, VOUT = 3.3V, AUTO Mode

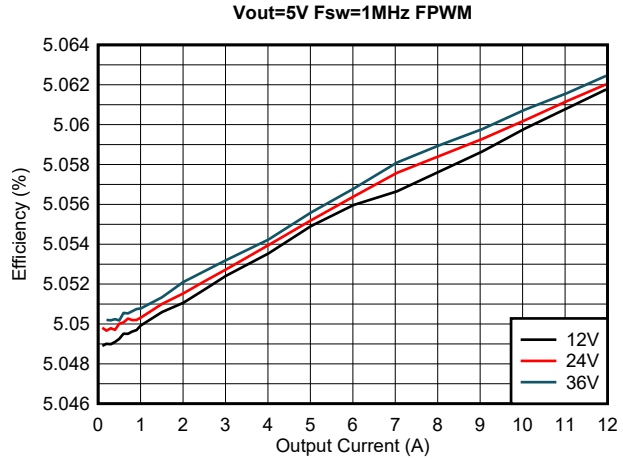


Figure 3-7. Load Regulation, VOUT = 5.0V, FPWM Mode

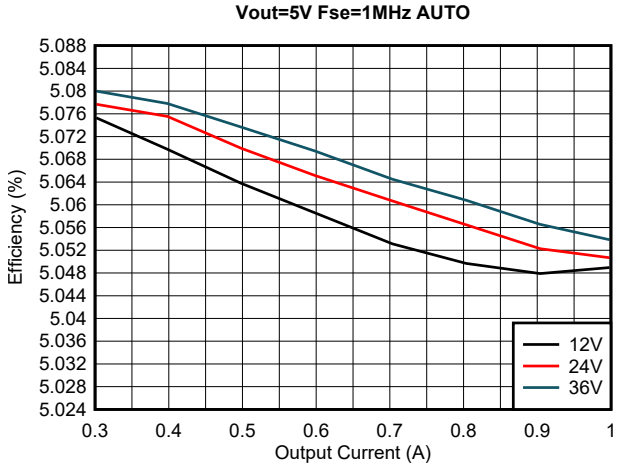


Figure 3-8. Load Regulation, VOUT = 5.0V, AUTO Mode

3.2.2 Waveforms and Plots

Figure 3-9. Start-Up Shut-Down, VOUT = 5V

Figure 3-10. Start-Up Shut-Down, VOUT = 3.3V

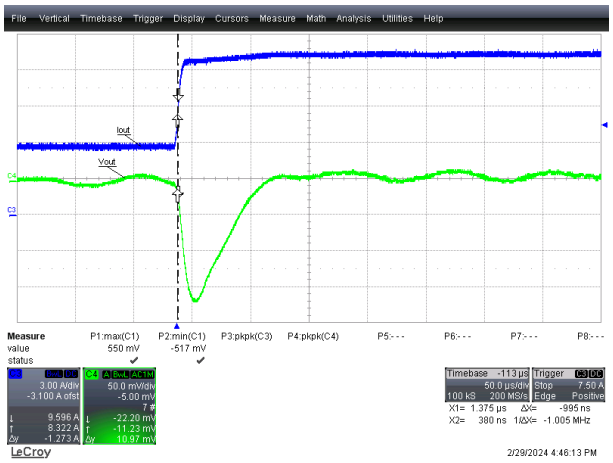


Figure 3-11. Load Transient Rising, VOUT = 5V, IOUT = 6A to 12A

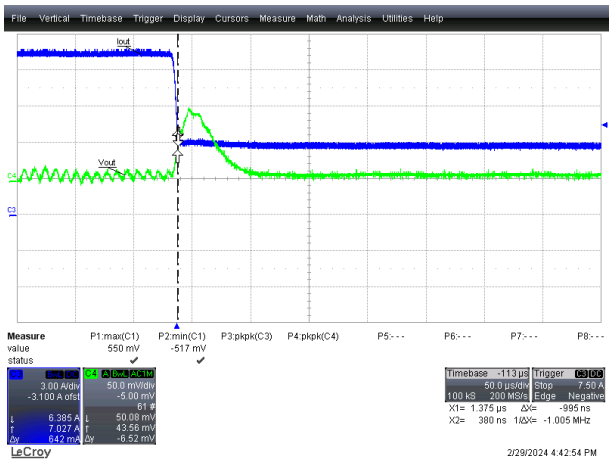


Figure 3-12. Load Transient Falling, VOUT = 5V, IOUT = 12A to 6A

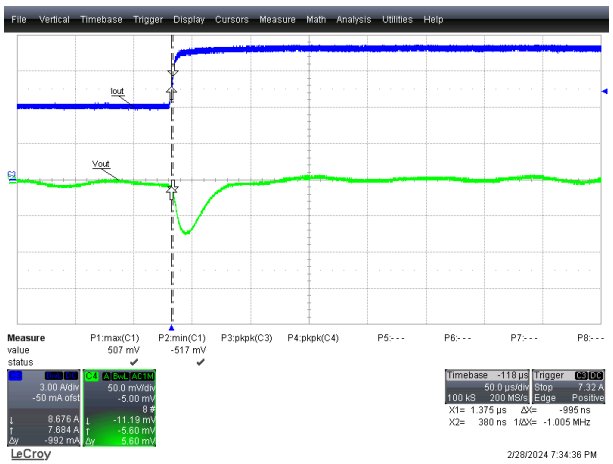


Figure 3-13. Load Transient Rising, VOUT = 3.3V, IOUT = 6A to 12A

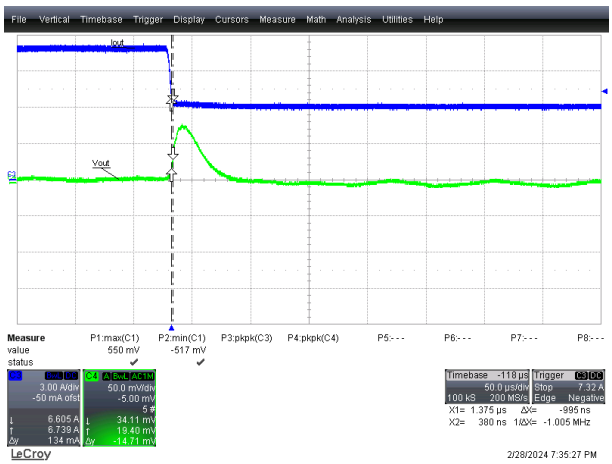


Figure 3-14. Load Transient Falling, VOUT = 3.3V, IOUT = 12A to 6A

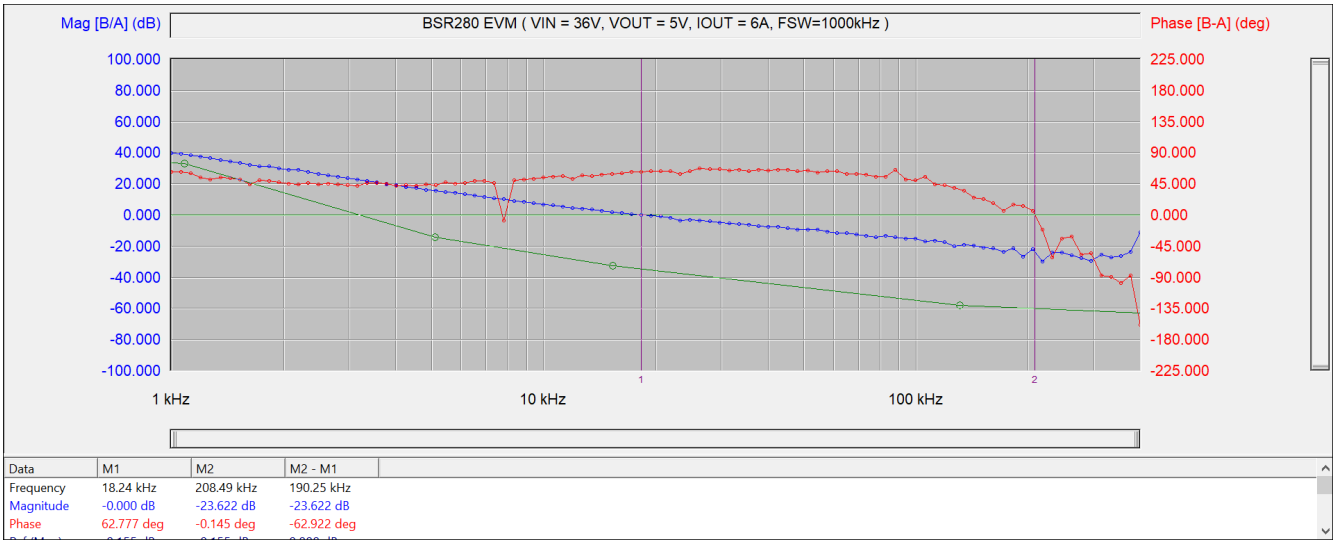


Figure 3-15. Bode Plot (VOUT = 5V)

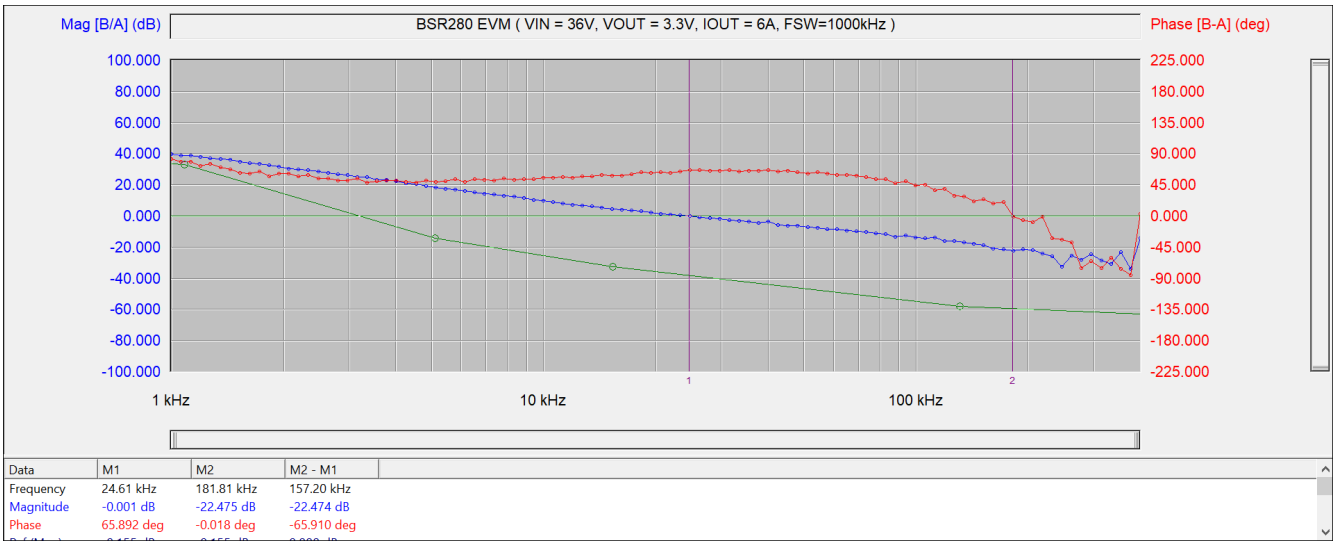


Figure 3-16. Bode Plot (VOUT = 3.3V)

3.2.3 EMI Performance

VIN = 12V, VOUT = 5V, IOUT =12A, Spread spectrum enabled.

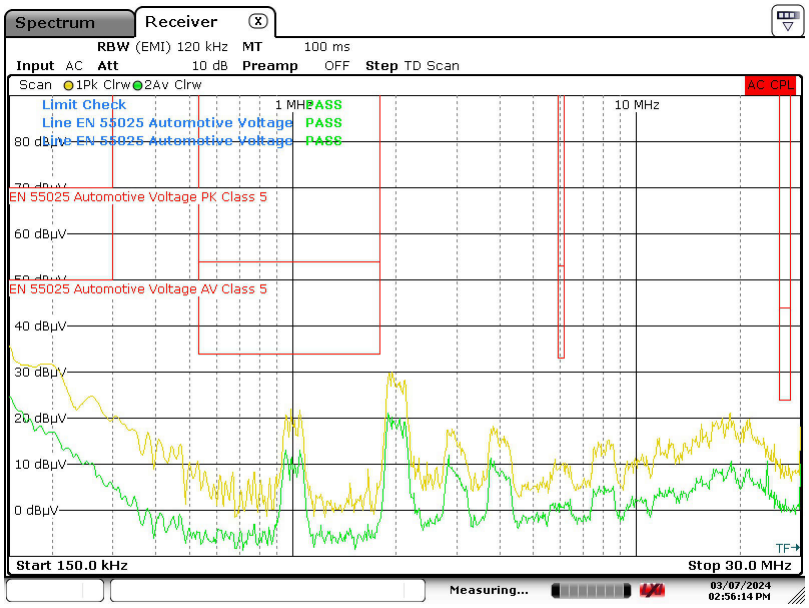


Figure 3-17. CISPR 25 Conducted Emissions: 150kHz to 30MHz

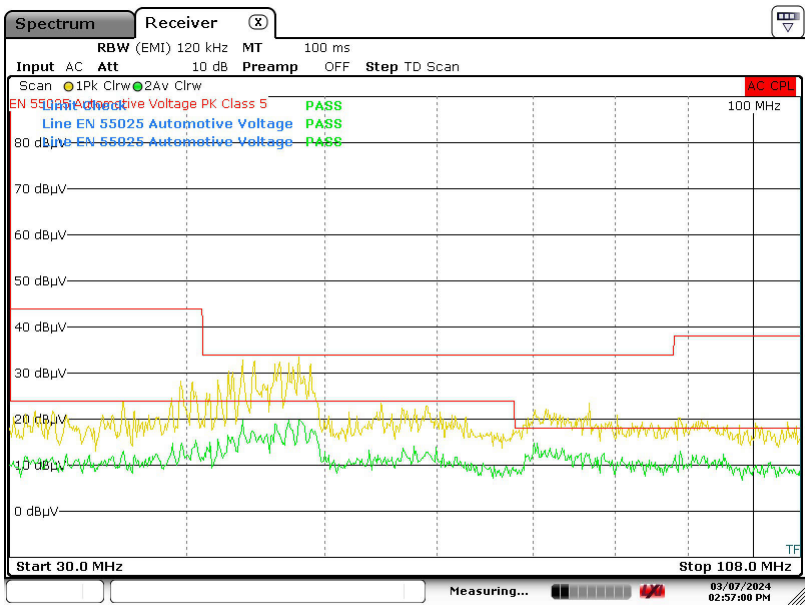


Figure 3-18. CISPR 25 Conducted Emissions: 30MHz to 108MHz

3.2.4 Thermal Performance

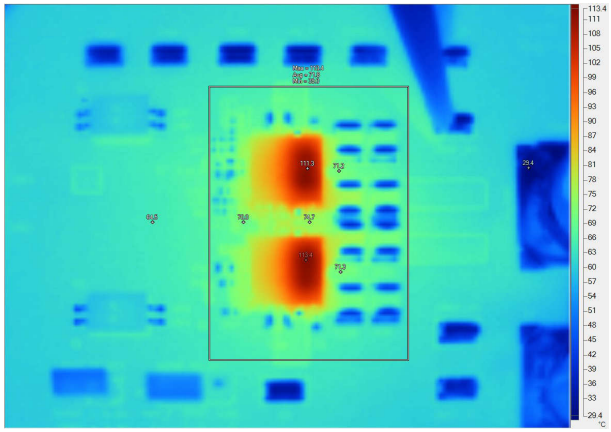


Figure 3-19. Infrared Thermal Image: VIN = 12V, IOUT = 12A

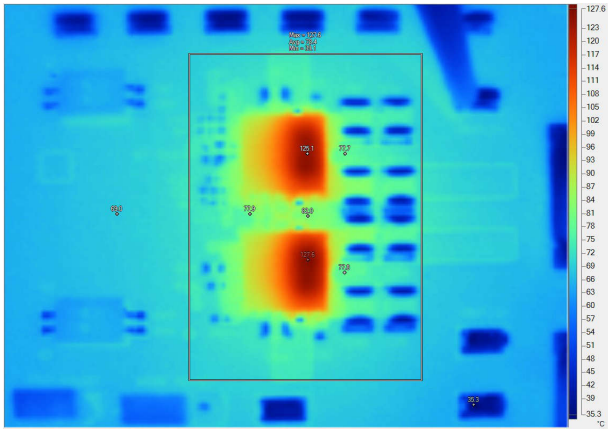


Figure 3-20. Infrared Thermal Image: VIN = 24V, IOUT = 12A

4 Hardware Design Files

4.1 Schematics

Figure 4-1 illustrates the EVM schematic.

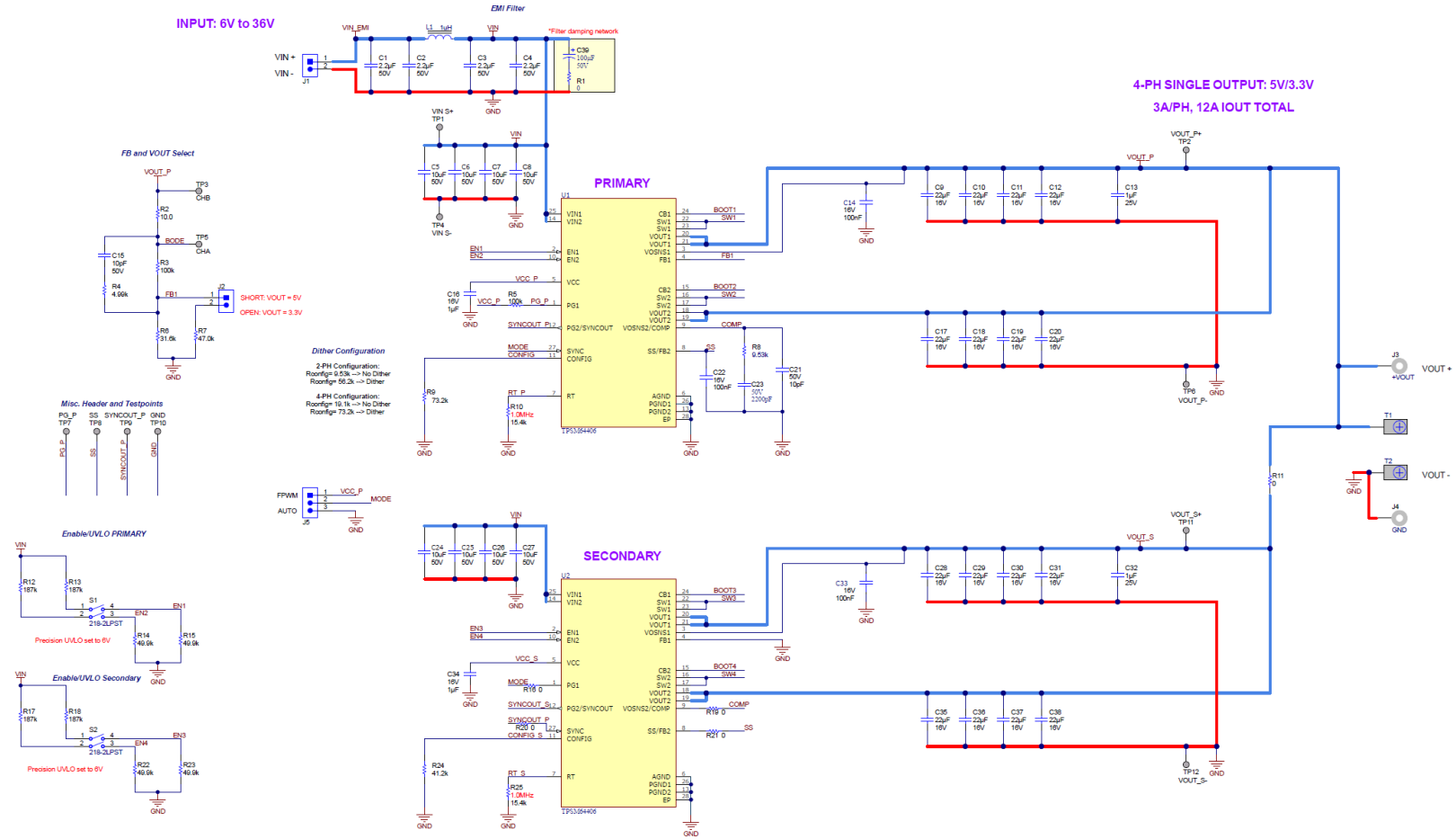


Figure 4-1. EVM Schematic

4.2 PCB Layouts

The PCB is 62-mils standard thickness with 2-oz copper on all 6 layers.

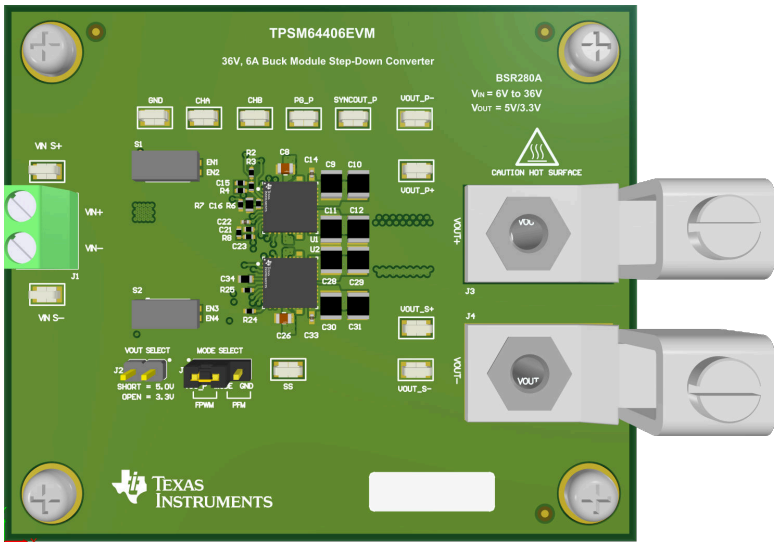


Figure 4-2. Top 3D View

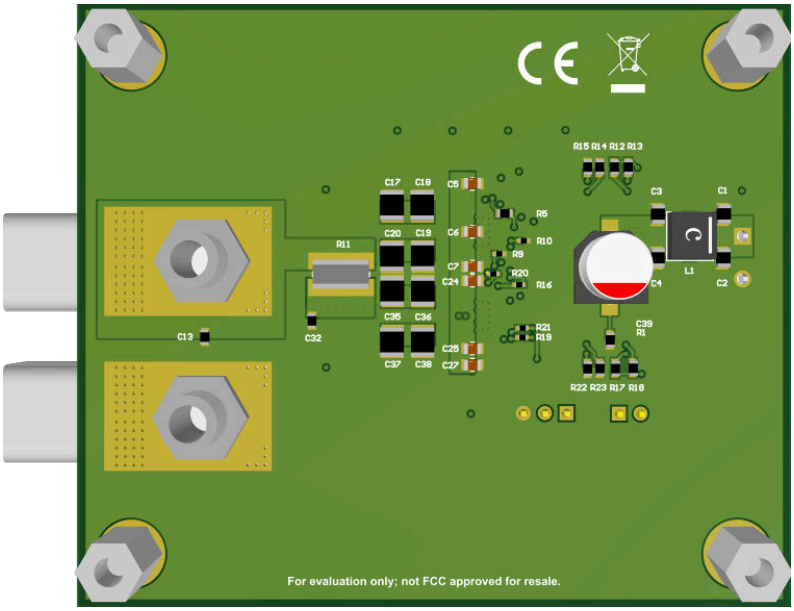


Figure 4-3. Bottom 3D View

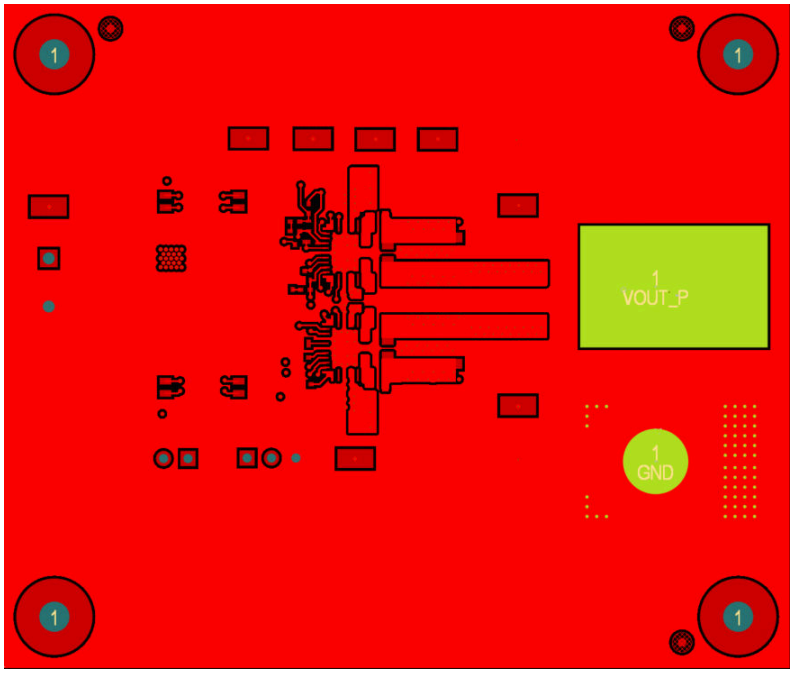


Figure 4-4. Top Layer Copper

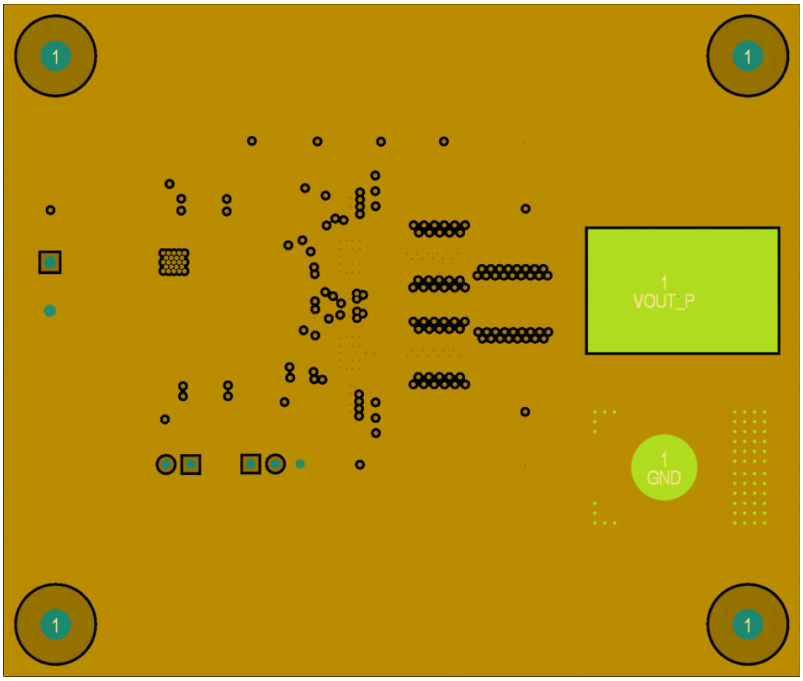


Figure 4-5. Layer 2 Copper

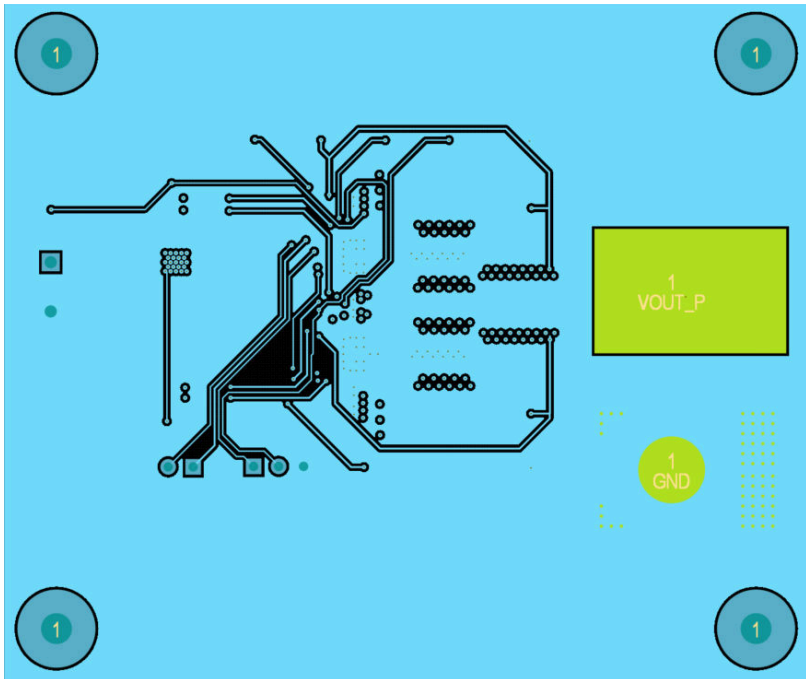


Figure 4-6. Layer 3 Copper

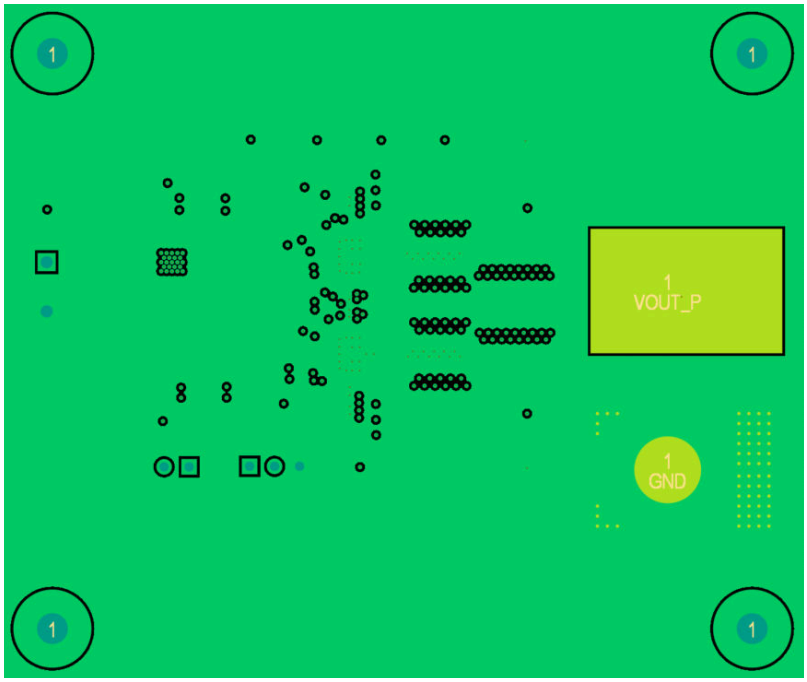


Figure 4-7. Layer 4 Copper

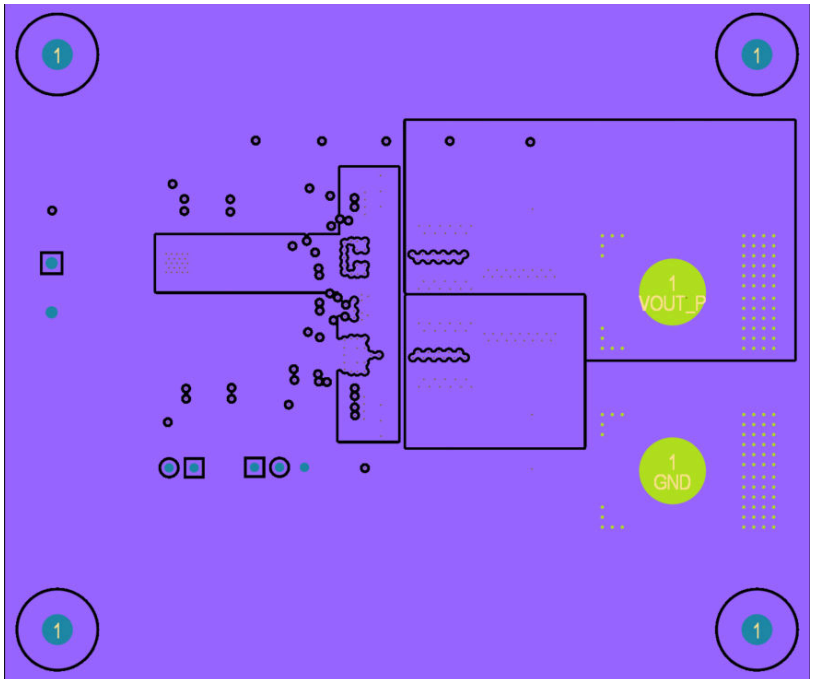


Figure 4-8. Layer 5 Copper

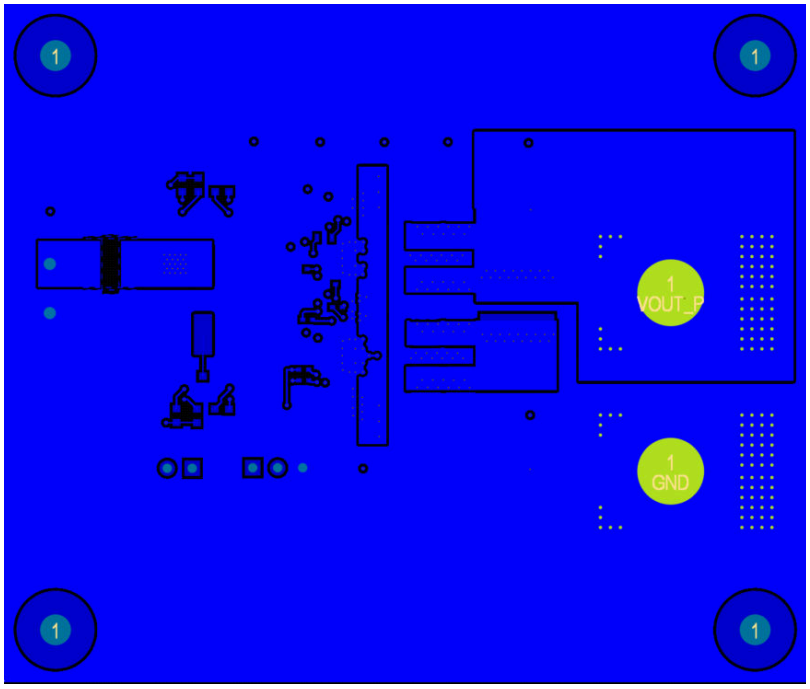


Figure 4-9. Layer 6 Copper

#	Name	Material	Type	Weight	Thickness	Dk
	Top Overlay		Overlay			
	Top Solder	Solder Resist	Solder Mask		0.4mil	3.5
1	Top Layer		Signal	2oz	2.8mil	
	Dielectric 1	FR-4 High Tg	Prepreg		5mil	4.2
2	GND Layer 1		Signal	2oz	2.8mil	
	Dielectric 2	FR-4 High Tg	Core		9mil	4.2
3	Signal Layer 1		Signal	2oz	2.8mil	
	Dielectric 3	FR-4 High Tg	Prepreg		16.4mil	4.2
4	GND Layer 2		Signal	2oz	2.8mil	
	Dielectric4	FR-4 High Tg	Core		9mil	4.2
5	Signal Layer 2		Signal	2oz	2.8mil	
	Dielectric6	FR-4 High Tg	Prepreg		5mil	4.2
6	Bottom Layer		Signal	2oz	2.8mil	
	Bottom Solder	Solder Resist	Solder Mask		0.4mil	3.5
	Bottom Overlay		Overlay			

Figure 4-10. Layer Thickness

4.3 Bill of Materials (BOM)

Table 4-1. Bill of Materials

Designator	Quantity	Value	Description	Package Reference	Part Number	Manufacturer
C1, C2, C3, C4	4	2.2uF	CAP, CERM, 2.2uF, 50V, +/- 10%, X7R, AEC-Q200 Grade 1, 0805	0805	CGA4J3X7R1H225K125AB	TDK
C5, C6, C7, C8, C24, C25, C26, C27	8	10µF	Chip Multilayer Ceramic Capacitors for General Purpose, 0805, 10uF, X5R, 15%, 20%, 50V	0805	GRM21BR61H106ME43L	Murata
C9, C10, C11, C12, C17, C18, C19, C20, C28, C29, C30, C31, C35, C36, C37, C38	16	22uF	CAP, CERM, 22µF, 16V,+/- 10%, X7R, AEC-Q200 Grade 1, 1210	1210	CL32B226KOJVPNE	Samsung Electro-Mechanics
C13, C32	2	1uF	CAP, CERM, 1uF, 25V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	0603	GCM188R71E105KA64D	MuRata
C14, C22, C33	3	100nF	0.1µF ±10% 16V Ceramic Capacitor X7R 0402 (1005 Metric)	0402	ATC530L104KT16T	American Technical Ceramics
C15	1	10pF	CAP, CERM, 10pF, 50V, +/- 5%, C0G/NP0, AEC-Q200 Grade 1, 0402	0402	CGA2B2C0G1H100D050BA	TDK
C16, C34	2	1uF	CAP, CERM, 1uF, 16V, +/- 20%, X7R, AEC-Q200 Grade 1, 0603	0603	GCM188R71C105MA64D	MuRata
C21	1	10pF	CAP, CERM, 10pF, 50V,+/- 1%, C0G/NP0, 0402	0402	GRM1555C1H100FA01D	MuRata
C23	1	2200pF	CAP, CERM, 2200pF, 50V, +/- 10%, X7R, 0402	0402	GRM155R71H222KA01D	MuRata
C39	1	100uF	CAP, AL, 100µF, 50V, +/- 20%, SMD	D8xL10.5mm	865060653010	Wurth Elektronik
FID1, FID2, FID3	3		Fiducial mark. There is nothing to buy or mount.	N/A	N/A	N/A
H1, H2, H3, H4	4		Machine Screw, Round, #4-40 x 1/4, Nylon, Philips panhead	Screw	NY PMS 440 0025 PH	B&F Fastener Supply
H5, H6, H7, H8	4		Standoff, Hex, 0.5"L #4-40 Nylon	Standoff	1902C	Keystone
J1	1		TERM BLOCK 2POS 5mm, TH	10x10x8.1 mm	1729018	Phoenix Contact
J2	1		Header, 100mil, 2x1, Gold, TH	Sullins 100mil, 1x2, 230 mil above insulator	PBC02SAAN	Sullins Connector Solutions
J3, J4	2		Standard Banana Jack, Uninsulated, 15A	Banana Jack	108-0740-001	Cinch Connectivity
J5	1		Header, 100mil, 3x1, Gold, TH	PBC03SAAN	PBC03SAAN	Sullins Connector Solutions
L1	1		Inductor, Shielded, Composite, 1.0H, 16.9A, 0.0084 ohm, AEC-Q200 Grade 1	SMT_5MM28_5MM48	XEL5030-102MEB	Coilcraft
LBL1	1		Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	PCB Label 0.650 x 0.200 inch	THT-14-423-10	Brady

Table 4-1. Bill of Materials (continued)

Designator	Quantity	Value	Description	Package Reference	Part Number	Manufacturer
R1	1	0	RES, 0, 5%, 0.1 W, AEC-Q200 Grade 0, 0603	0603	CRCW06030000Z0EA	Vishay-Dale
R2	1	10.0	RES, 10.0, 1%, 0.063 W, 0402	0402	CRCW040210R0FKED	Vishay-Dale
R3	1	100k	RES, 100 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW0402100KFKED	Vishay-Dale
R4	1	4.99k	RES, 4.99 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW04024K99FKED	Vishay-Dale
R5	1	100k	RES, 100 k, 1%, 0.1 W, 0603	0603	RC0603FR-07100KL	Yageo
R6	1	31.6k	RES, 31.6 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW040231K6FKED	Vishay-Dale
R7	1	47.0k	RES, 47.0 k, 1%, 0.0625 W, 0402	0402	RC0402FR-0747KL	Yageo America
R8	1	9.53k	RES, 9.53 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW04029K53FKED	Vishay-Dale
R9	1	73.2k	RES, 73.2 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW040273K2FKED	Vishay-Dale
R10, R25	2	15.4k	RES, 15.4 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW040215K4FKED	Vishay-Dale
R11	1	0	RES, 0, 5%, 2 W, 2512 WIDE	2512 WIDE	RCL12250000Z0EG	Vishay Draloric
R12, R13, R17, R18	4	187k	RES, 187 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	0603	CRCW0603187KFKEA	Vishay-Dale
R14, R15, R22, R23	4	49.9k	RES, 49.9 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0603	0603	CRCW060349K9FKEA	Vishay-Dale
R16, R19, R20, R21	4	0	RES, 0, 0%, 0.2 W, AEC-Q200 Grade 0, 0402	0402	CRCW04020000Z0EDHP	Vishay-Dale
R24	1	41.2k	RES, 41.2 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW040241K2FKED	Vishay-Dale
S1, S2	2		Switch, SPST, 2 Pos, 25mA, 24VDC, SMD	3.71x5.8mm	218-2LPST	CTS Electrocomponents
SH-J1, SH-J2	2	1x2	Shunt, 100mil, Gold plated, Black	Shunt	SNT-100-BK-G	Samtec
T1, T2	2		Terminal 70A Lug	LUG, 32.3x14.5x11.7	CXS70-14-C	Panduit
TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP12	12		Test Point, Miniature, SMT	Test Point, Miniature, SMT	5019	Keystone
U1, U2	2		3V to 36V, Dual 3A or stackable 6A Power Module in 6.5mm x 7mm x 2mm Package	QFN-FCMOD28	TPSM64406	Texas Instruments

5 Additional Information

5.1 Trademarks

HotRod™ is a trademark of Texas Instruments.
WEBENCH® is a registered trademark of Texas Instruments.
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6 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

6.1 Supplemental Content

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

6.2 Custom Design With WEBENCH Tools

Click here to create a custom design using the TPSM66406 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.

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.

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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:*

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   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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