TPSM64406EVM 36-V, Dual, 3-A Output, Synchronous, Buck Module

TEXAS INSTRUMENTS

Description

The TPSM64406 evaluation board showcases the features and performance of the TPSM64406, dual buck DC/DC module with integrated power MOSFETs and inductor. The EVM provides dual 3-A outputs. The output voltages can be individually programmed to a fixed 3.3-V, 5-V or adjustable using external feedback resistors.

The default switching frequency at full load is programmed to 1 MHz. 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 is designed to demonstrate the full capabilities of the device 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 6.3-V to 36-V
  - Adjustable output voltage from 0.8-V to 16-V
  - 6.5-mm × 7.0-mm × 2-mm 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} = 18.2 °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
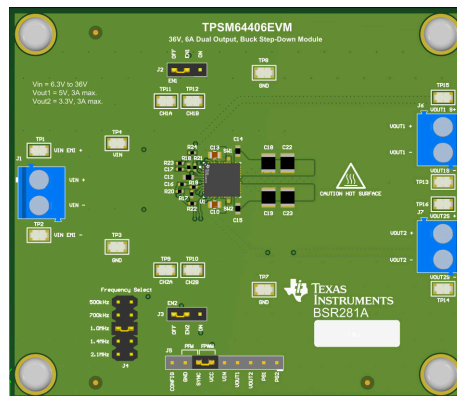
TPSM64406EVM Board (Top View)

1 Evaluation Module Overview

1.1 Introduction

The TPSM64406 is a highly integrated 36-V 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 18-A. 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. See Figure 2-1 for a more detailed description.

With an output voltage from 1-V to 16-V, 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 magnetic selection from the design process. An example dual output solution can be shown by Figure 2-2.

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.

⚠ (hot surface warning symbol)	**CAUTION** Hot surface. Contact can cause burns. Do not touch.

1.2 Kit Contents

- TPSM64406 device (U1)
- BSR281A Dual Output EVM Board

1.3 Specification

Unless otherwise indicated, VIN = 12-V, VOUT1 = 5-V, VOUT2 = 3.3-V, IOUT1 = 3-A, IOUT2 = 3-A, f_{SW} = 1 MHz.

Table 1-1. Electrical Performance Specifications

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT CHARACTERISTICS					
Input supply voltage range	VIN range	6.3[3]		36	V
	VIN_EMI range	12		36	V
Input current	Input current at VIN			4.5	A
	Input current at VIN_EMI			2.5	A
OUTPUT CHARACTERISTICS [1]					
CH1 output voltage	Default output is 5.0 V	4.9	5.0	5.1	V
CH1 output current		0		3	A
CH2 output voltage	Default output is 3.3 V	3.2	3.3	3.4	V
CH2 output current		0		3	A
SYSTEM CHARACTERISTICS					
Default switching frequency, f_{SW}			1000		kHz

Table 1-1. Electrical Performance Specifications (continued)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Minimum switching frequency for specific V_{out}	V_{out} = 3.3-V		500		kHz
	V_{out} = 5-V		700		
	V_{out} = 12-V		1700		
	V_{out} = 16-V		1900		
Full-load efficiency[2]	CH1, VOUT1 = 5-V, VIN = 12-V, IOUT1 = 3-A		91.2%		
	CH1, VOUT1 = 5-V, VIN = 24-V, IOUT1 = 3-A		89.6%		
	CH2, VOUT2 = 3.3-V, VIN = 12-V, IOUT2 = 3-A		87.5%		
	CH2, VOUT2 = 3.3-V, VIN = 24-V, IOUT2 = 3-A		85.5%		

(1)   Default output voltages and switching frequency are 5-V (CH1), 3.3-V (CH2) and 1 MHz, respectively.
(2)   The recommended airflow is 200 LFM when operating
(3)   The EVM operates when the input voltage is in the range of 3-V to 6-V, but enters a dropout mode if there is insufficient input voltage to regulate output voltages.

1.4 Device Information

Table 1-2. TPSM6440X Dual Buck DC/DC Module Family

DEVICE	ORDERABLE PART NUMBER	RATED OUTPUT CURRENT	PACKAGE	JUNCTION TEMPERATURE RANGE
TPSM64404	TPSM64404RCHR	Dual 2-A / 2-A or stackable 4-A	RCH (28)	–40°C to 125°C
TPSM64406	TPSM64406RCHR	Dual 3-A / 3-A or stackable 6-A	RCH (28)	–40°C to 125°C

2 Hardware

2.1 Additional Images

Figure 2-1. Device Pin-out (Top View)

Typical Schematic
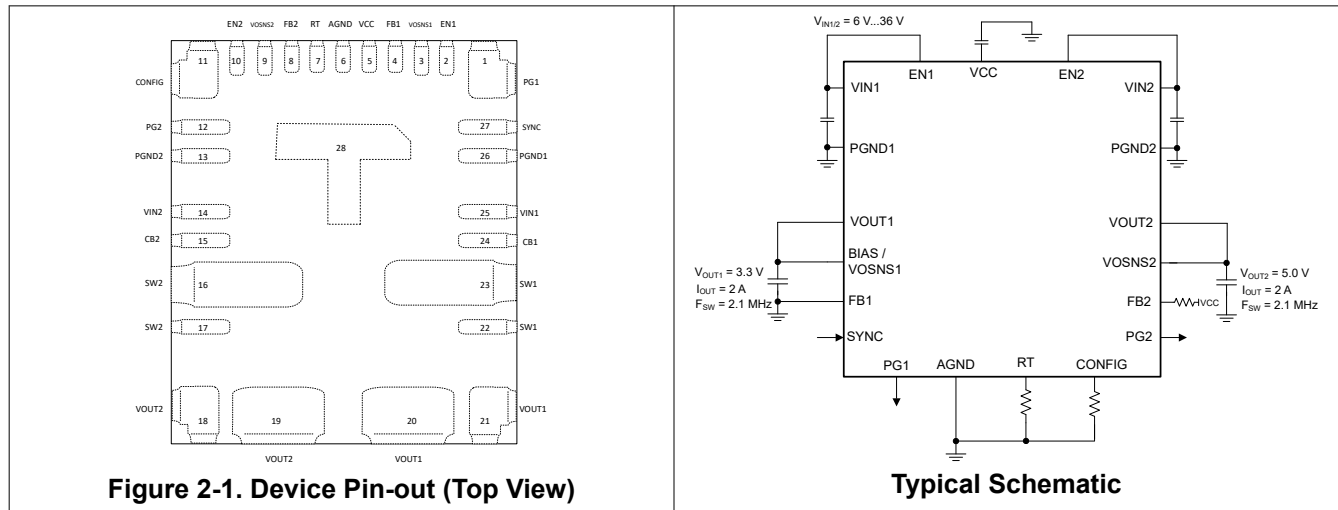
2.2 EVM Connections

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.

Refer to the connections depicted in Figure 2-2 for a visual guide on powering up the EVM.

1. Connect the input voltage supply between VIN_EMI and GND (J1) terminals using short thick wires.
2. Connect the load for the 5-V output between VOUT1 and GND (J6) terminals using short thick wires.
3. Connect the load for the 3.3-V output between VOUT2 and GND (J7) terminals using short thick wires.
4. Connect the input voltage sense lines to TP1 (VIN_EMI) and TP2 (GND).
5. Connect 5-V output voltage sense lines to TP15 (VOUT1_S+) and TP13 (VOUT1_S-).
6. Connect 3.3-V output voltage sense lines to TP16 (VOUT2_S+) and TP14 (VOUT2_S-).
7. Set the input voltage (VIN) at the appropriate level between 6.3-V to 36-V.
8. Set the current limit of the input supply to an appropriate level depending on the connected output load.
9. Make sure VOUT1 ENABLE is set to ON by having the jumper in appropriate position on J2.
10. Make sure VOUT2 ENABLE is set to ON by having the jumper in appropriate position on J3.
11. Make sure Frequency Select is set to desired operating frequency by having the jumper in appropriate position on J4.
12. Make sure SYNC is set to desired mode by having the jumper in appropriate position on J5.
    a. Short SYNC to GND for PFM Mode operation.
    b. Short SYNC to VCC for FPWM Mode operation.
13. Turn on the power supply. The default configuration of the EVM must power up to VOUT1 = 5-V, VOUT2 = 3.3-V
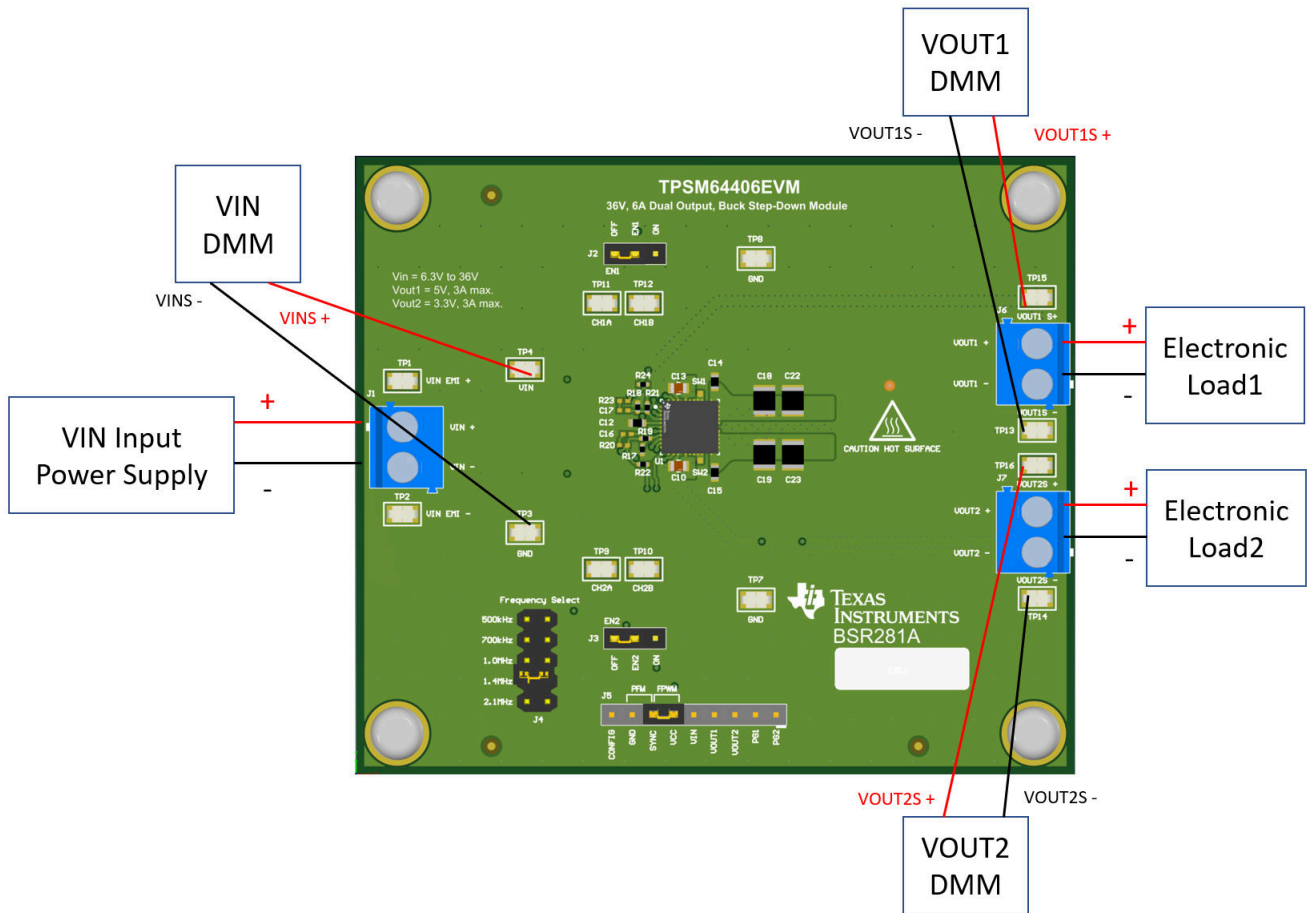14. Monitor the output voltage and current. The maximum rated load current for each output is 3-A.

Figure 2-2. 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.
VOUT1+	CH1 Positive output power connection.
VOUT1–	CH1 Negative output power connection.
VOUT2+	CH2 Positive output power connection.
VOUT2–	CH2 Negative output power connection.

Table 2-2. EVM Signal Connections

LABEL	DESCRIPTION
VIN	TP4: Positive input sense pin for measuring efficiency.
GND	TP3: Negative input sense pin for measuring efficiency.
VOUT1S+	TP15: CH1 positive output sense pin for measuring efficiency, and line and load regulation.
VOUT1S–	TP13: CH1 negative output sense pin for measuring efficiency, and line and load regulation.
VOUT2S+	TP16: CH2 positive output sense pin for measuring efficiency, and line and load regulation.
VOUT2S–	TP14: CH2 negative output sense pin for measuring efficiency, and line and load regulation.
GND	Ground reference point.
SYNC	Light load switching mode selection. Connect SYNC and VCC for a FPWM mode . Connect SYNC and GND for an AUTO mode.
CONFIG	Spread spectrum enable, disable. Connect CONFIG to GND to disable the spread spectrum. Modify R14 for proper configuration according to TODO The EVM needs to restart after changing the jumper setting.
EN1	CH1 enable, disable. Connect pin 1 and pin 2 to enable CH1. Connect pin 2 and pin 3 to disable CH1. Remove any jumper when programing the line UVLO using a resistor divider. Populate the external UVLO resistor divider.
EN2	CH2 enable, disable. Connect pin 1 and pin 2 to enable CH2. Connect pin 2 and pin 3 to disable CH2. Remove any jumper when programing the line UVLO using a resistor divider. Populate the external UVLO resistor divider.
PG1	Probe point for CH1 power-good indicator. A pullup resistor is connected to VCC.
PG2	Probe point for CH2 power-good indicator. A pullup resistor is connected to VCC.

Table 2-3. EVM Configurations

$R_{Config}(k\Omega)$	Mode
0	Dual output spread spectrum **disabled**
121	Dual output spread spectrum **enabled**

3 Implementation Results

3.1 Test Data and Performance Curves

Unless otherwise indicated, VIN = 12-V, VOUT1 = 5-V, VOUT2 = 3.3-V, IOUT1 = 3-A, IOUT2 = 3-A and f_{SW} = 1 MHz.

3.1.1 Efficiency and Load Regulation Performance
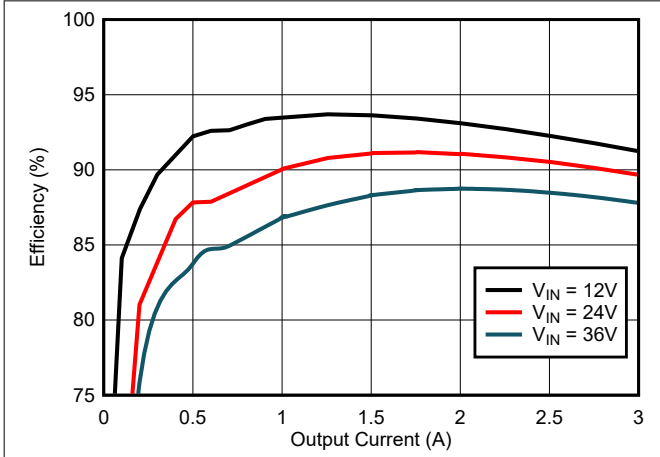
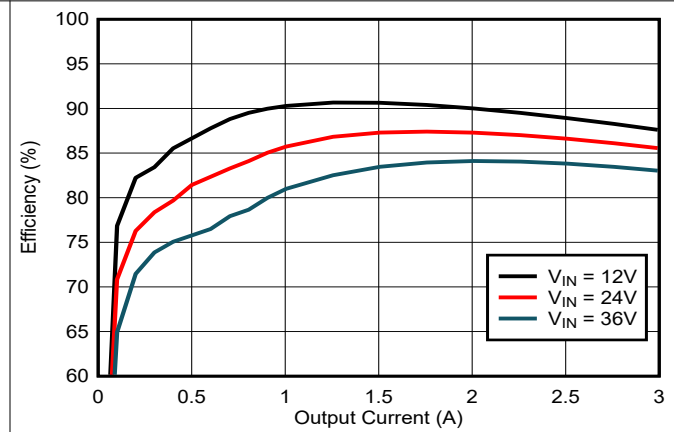**Figure 3-1. Efficiency, VOUT = 5-V, PFM Mode, FSW = 1 MHz**

Figure 3-2. Efficiency, VOUT = 3.3-V, PFM Mode, FSW = 1 MHz
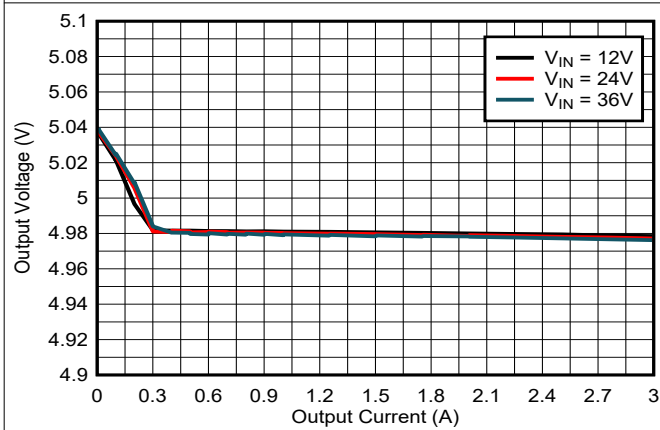
Figure 3-3. Load Regulation, VOUT = 5-V, FPWM Mode
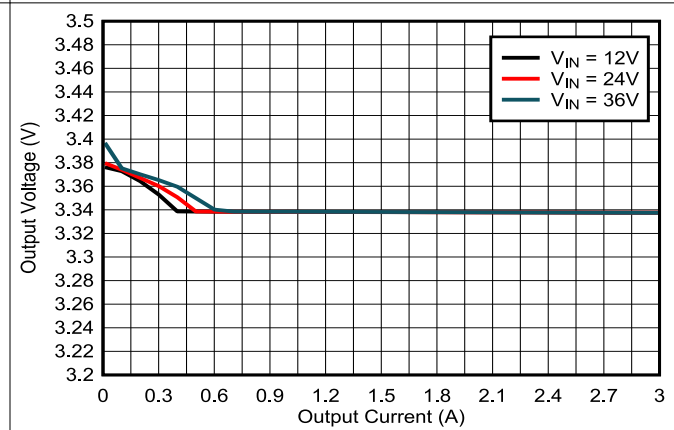
Figure 3-4. Load Regulation, VOUT = 3.3-V, FPWM Mode
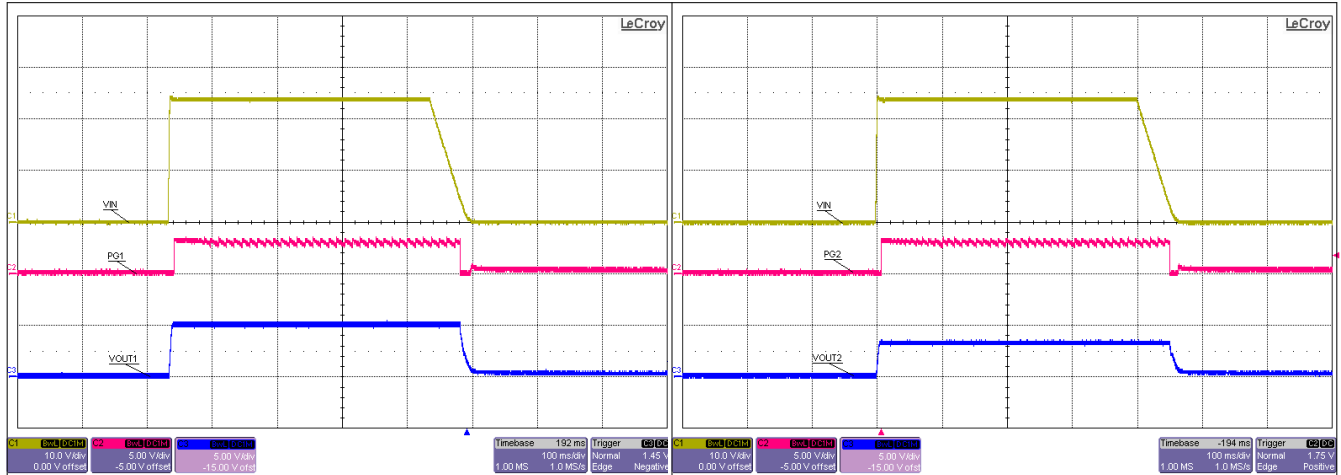
3.1.2 Waveforms and Plots

Figure 3-5. Start-Up Shut-Down, VOUT1 = 5-V

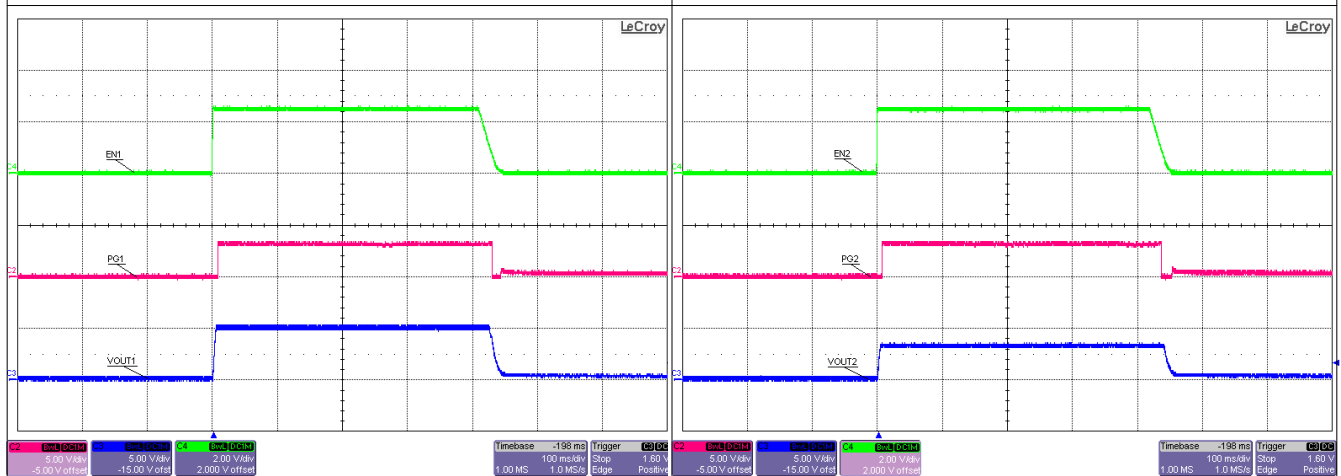**Figure 3-6. Start-Up Shut-Down, VOUT2 = 3.3-V**

Figure 3-7. Enable ON and OFF, VOUT1 = 5-V, VIN = 24-V

Figure 3-8. Enable ON and OFF, VOUT2 = 3.3-V, VIN = 24-V
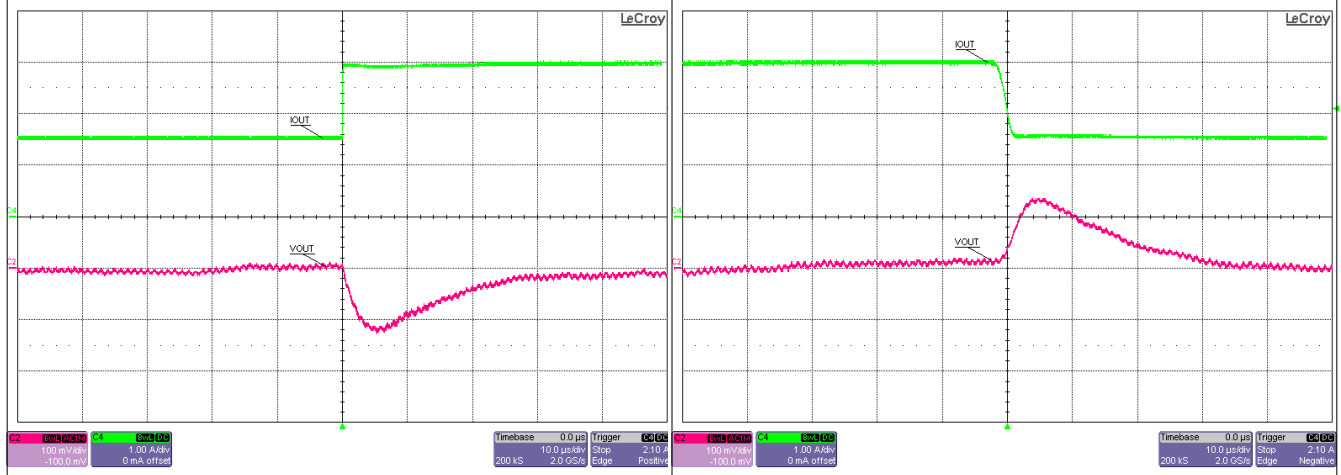

Figure 3-9. Load Transient Rising (CH1), VOUT1 = 5-V, IOUT1 = 3-A to 6-A

Figure 3-10. Load Transient Falling (CH1), VOUT1 = 5-V, IOUT1 = 6-A to 3-A
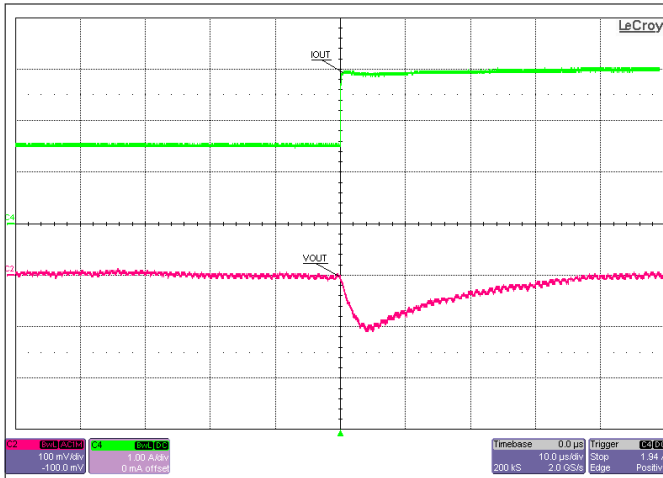
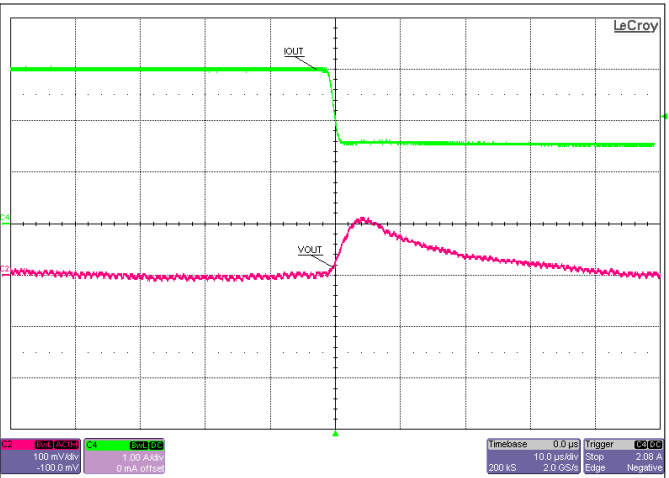**Figure 3-11. Load Transient Rising (CH2), VOUT2 = 3.3-V, IOUT2 = 3-A to 6-A**

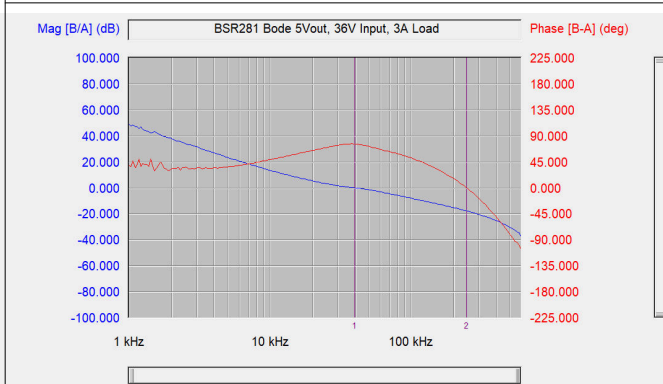**Figure 3-12. Load Transient Falling (CH2), VOUT2 = 3.3-V, IOUT2 = 6-A to 3-A**

Data	M1	M2	M2 - M1
Frequency	39.84 kHz	246.47 kHz	206.63 kHz
Magnitude	-0.001 dB	-17.745 dB	-17.744 dB
Phase	76.021 deg	-0.009 deg	-76.030 deg

Figure 3-13. Bode Plot (CH1)

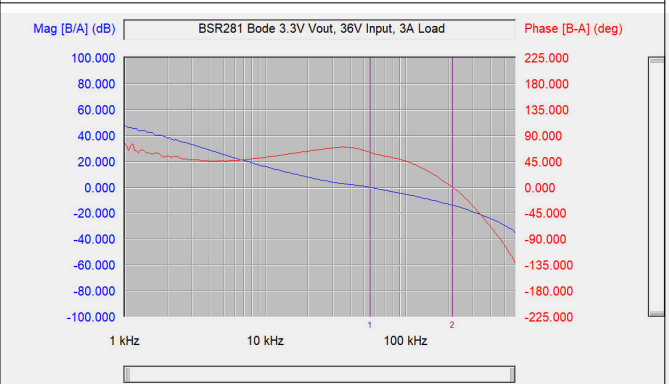| Data	M1	M2	M2 - M1
Frequency	55.54 kHz	215.14 kHz	159.60 kHz
Magnitude	-0.017 dB	-13.835 dB	-13.818 dB
Phase	60.811 deg	-0.004 deg	-60.815 deg

Figure 3-14. Bode Plot (CH2)
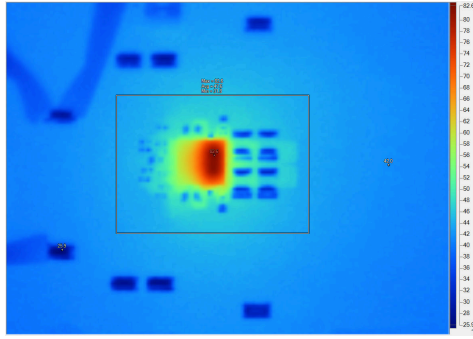
3.1.3 Thermal Performance

Figure 3-15. Infrared Thermal Image: VIN = 12-V, IOUT1 = 3-A, IOUT2 = 3-A, FSW = 1 MHz
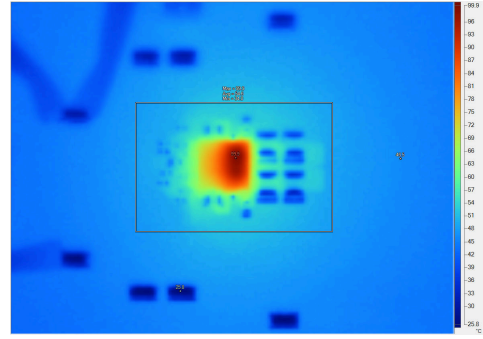

Figure 3-16. Infrared Thermal Image: VIN = 36-V, IOUT1 = 3-A, IOUT2 = 3-A, FSW = 1 MHz

3.1.4 EMI Performance

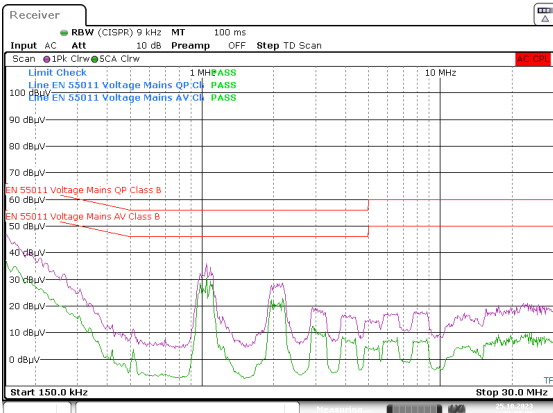See Section 4.1 and Section 4.3 for details of the input EMI filter components.

Figure 3-17. CISPR 11/32 Class B Conducted Emissions: V_{IN} = 12-V, V_{OUT} = 5 -V, I_{OUT1} = 3-A, I_{OUT2} = 3-A, F_{SW} = 1 MHz
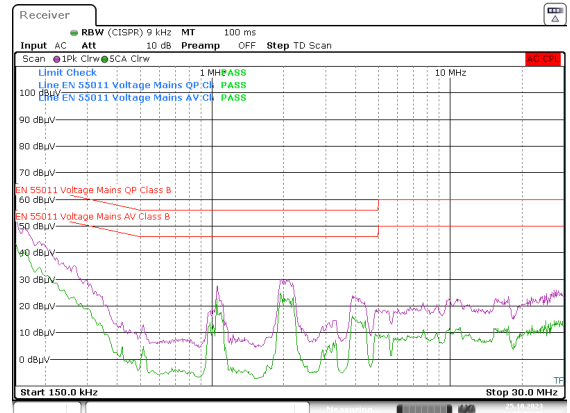
Figure 3-18. CISPR 11/32 Class B Conducted Emissions: V_{IN} = 24-V, V_{OUT1} = 5-V, V_{OUT2} = 3.3-V, I_{OUT1} = 3-A, I_{OUT2} = 3-A, F_{SW} = 1 MHz
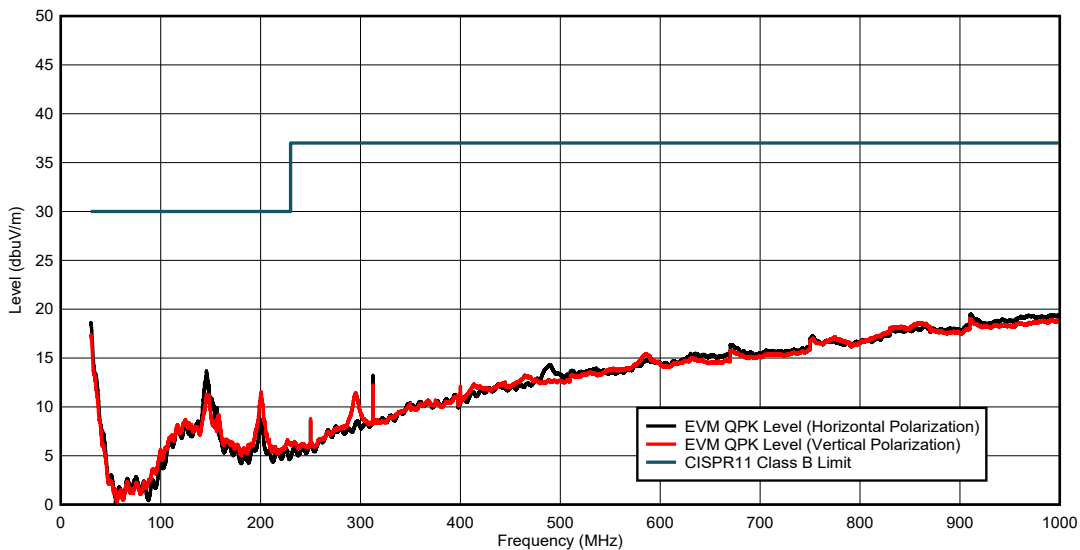
Figure 3-19. CISPR 11/32 Class B Radiated Emissions: V_{IN} = 24-V, V_{OUT} = 5-V, V_{OUT2} = 3.3-V, I_{OUT1} = 3-A, I_{OUT2} = 3-A, F_{SW} = 1 MHz

4 Hardware Design Files

4.1 Schematic

Figure 4-1 illustrates the EVM schematic.

Figure 4-1. EVM Schematic

4.2 PCB Layout

The PCB is 62-mils standard thickness with 2-oz copper on all 4 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

4.3 Bill of Materials

Table 4-1. Bill of Materials

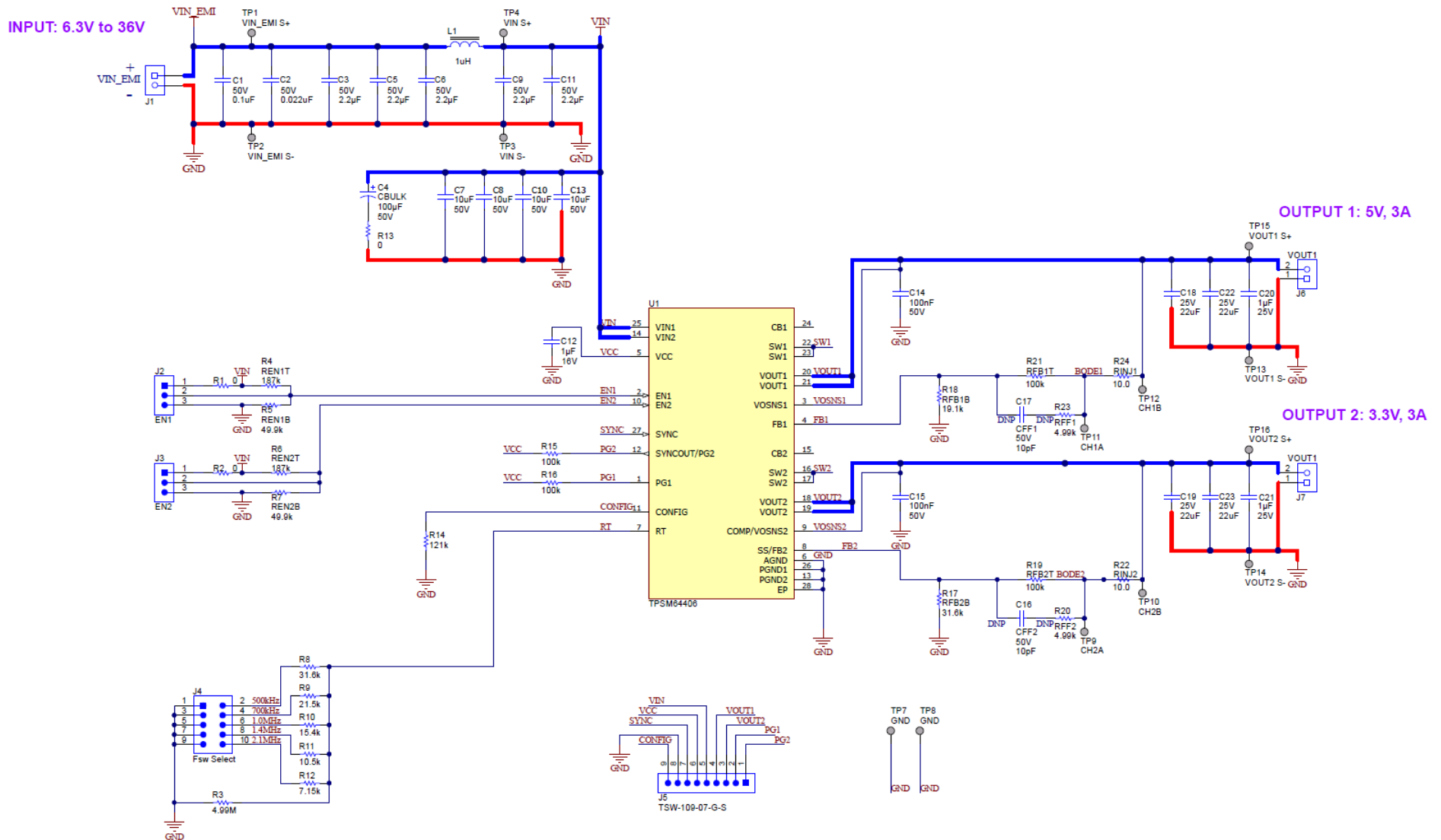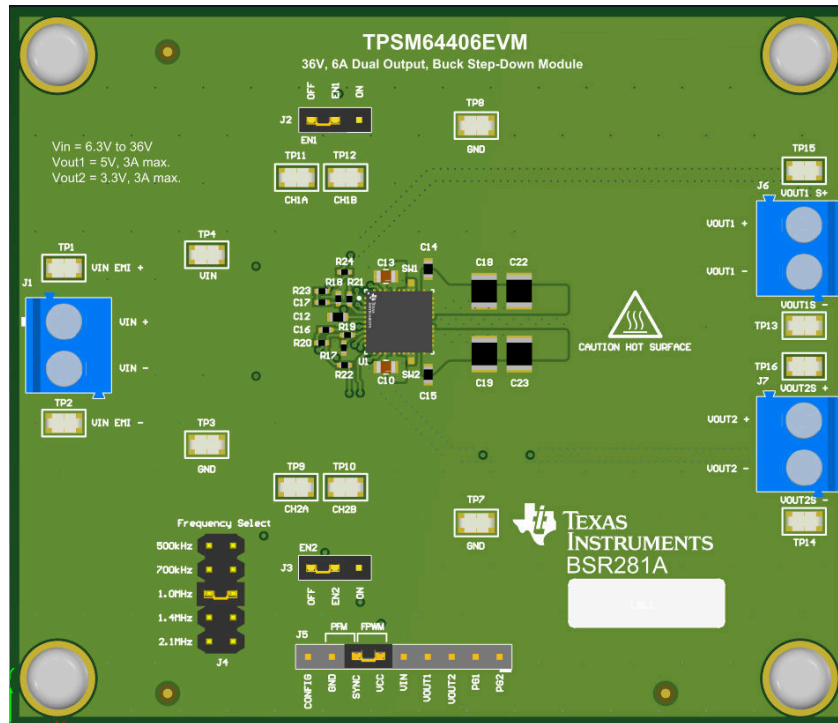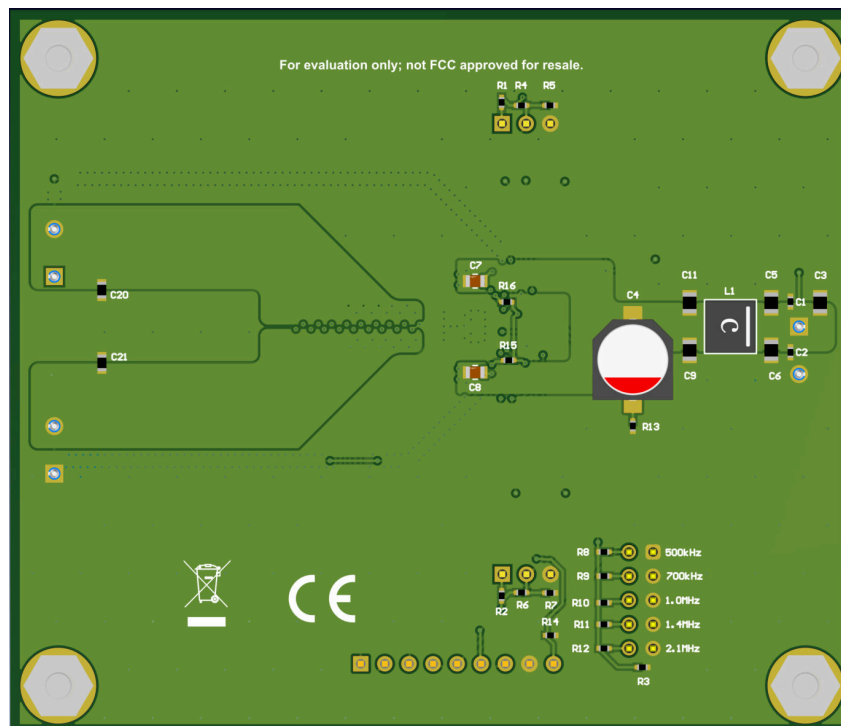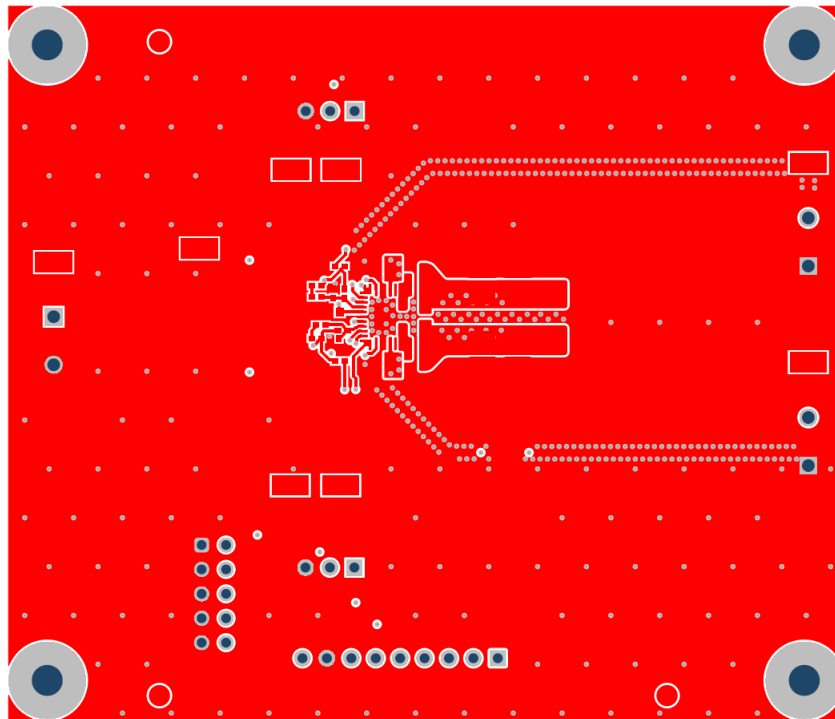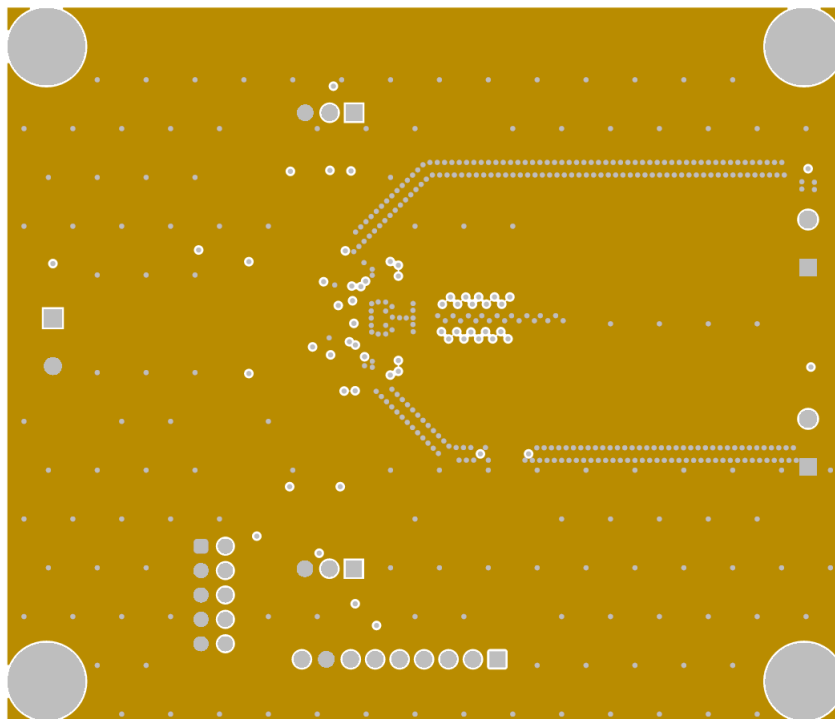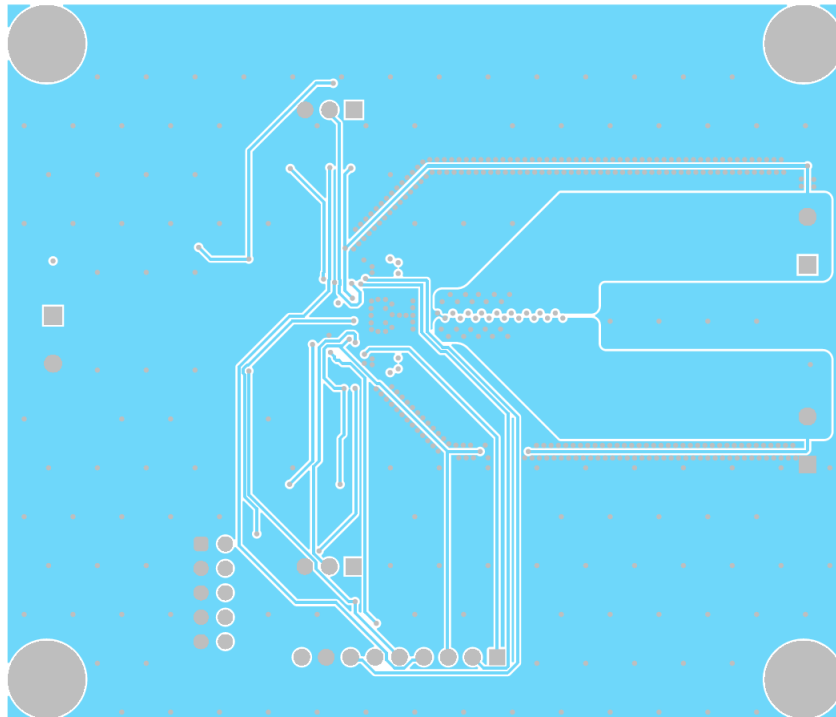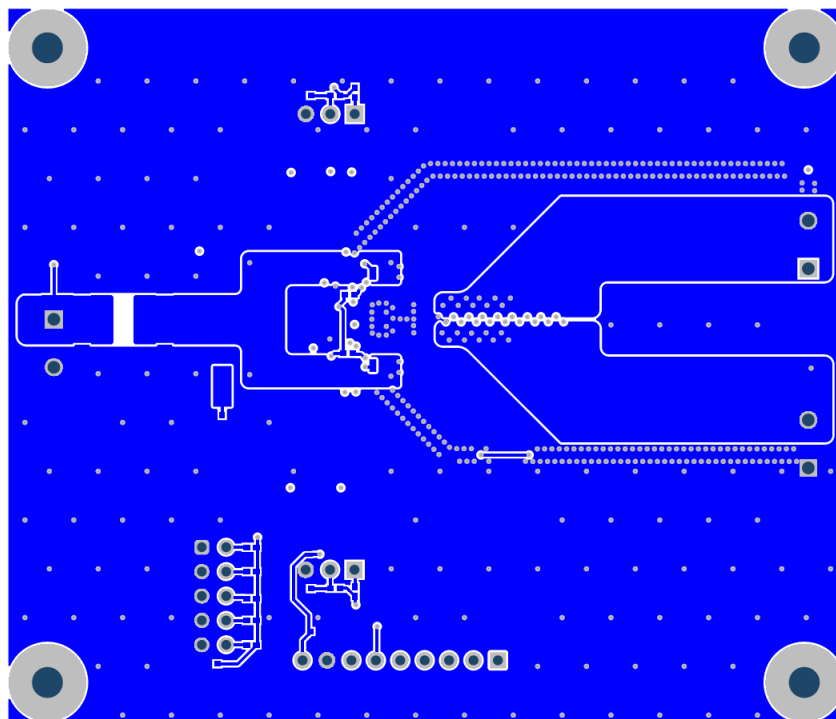| Designator	Quantity	Value	Description	Package Reference	Part Number	Manufacturer
C1	1	0.1uF	CAP, CERM, 0.1 uF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0402	0402	GCM155R71H104KE02D	MuRata
C2	1	0.022uF	CAP, CERM, 0.022 uF, 50 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0402	0402	CGA2B3X7R1H223K050BB	TDK
C3, C5, C6, C9, C11	5	2.2uF	CAP, CERM, 2.2 uF, 50 V, +/- 20%, X7R, 0805	0805	C2012X7R1H225M125AC	TDK
C4	1	100uF	CAP, AL, 100 µF, 50 V, +/- 20%, SMD	D8xL10.5mm	865060653010	Wurth Elektronik
C7, C8, C10, C13	4	10 µF	Chip Multilayer Ceramic Capacitors for General Purpose, 0805, 10 uF, X5R, 15%, 20%, 50 V	0805	GRM21BR61H106ME43L	Murata
C12	1	1uF	CAP, CERM, 1 µF, 16 V,+/- 10%, X7R, AEC-Q200 Grade 1, 0603	0603	EMK107B7105KAHT	Taiyo Yuden
C14, C15	2	0.1uF	CAP, CERM, 0.1 µF, 50 V,+/- 10%, X7R, AEC-Q200 Grade 1, 0603	0603	06035C104KAZ2A	AVX
C18, C19, C22, C23	4	22uF	CAP, CERM, 22 uF, 25 V, +/- 10%, X7R, 1210	1210	GRM32ER71E226KE15L	MuRata
C20, C21	2	1uF	CAP, CERM, 1 uF, 25 V, +/- 10%, X7R, AEC-Q200 Grade 1, 0603	0603	GCM188R71E105KA64D	MuRata
FID1, FID2, FID3	3		Fiducial mark. There is nothing to buy or mount.	N/A	N/A	N/A
H2, H5, H8, H11	4		Standoff, Hex, 0.5"L #4-40 Nylon	Standoff	1902C	Keystone
H3, H6, H9, H12	4		Machine Screw, Round, #4-40 x 1/4, Nylon, Philips panhead	Screw	NY PMS 440 0025 PH	B&F Fastener Supply
J1, J6, J7	3		Terminal Block, 5 mm, 2x1, Tin, TH	Terminal Block, 5 mm, 2x1, TH	691 101 710 002	Wurth Elektronik
J2, J3	2		Header, 100mil, 3x1, Gold, TH	PBC03SAAN	PBC03SAAN	Sullins Connector Solutions
J4	1		Header, 2.54mm, 5x2, Gold, TH	Header, 2.54mm, 5x2, TH	PRPC005DAAN-RC	Sullins Connector Solutions
J5	1		Header, 100mil, 9x1, Gold, TH	9x1 Header	TSW-109-07-G-S	Samtec
L1	1		Inductor, Shielded, Composite, 1.0H, 16.9 A, 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
R1, R2, R13	3	0	RES, 0, 0%, 0.2 W, AEC-Q200 Grade 0, 0402	0402	CRCW04020000Z0EDHP	Vishay-Dale
R3	1	4.99Meg	RES, 4.99 M, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW04024M99FKED	Vishay-Dale

Table 4-1. Bill of Materials (continued)

Designator	Quantity	Value	Description	Package Reference	Part Number	Manufacturer
R4, R6	2	187k	RES, 187 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0402	0402	ERJ-2RKF1873X	Panasonic
R5, R7	2	49.9k	RES, 49.9 k, 1%, 0.1 W, AEC-Q200 Grade 0, 0402	0402	ERJ-2RKF4992X	Panasonic
R8, R17	2	31.6k	RES, 31.6 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW040231K6FKED	Vishay-Dale
R9	1	21.5k	RES, 21.5 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW040221K5FKED	Vishay-Dale
R10	1	15.4k	RES, 15.4 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW040215K4FKED	Vishay-Dale
R11	1	10.5k	RES, 10.5 k, 1%, 0.063 W, 0402	0402	RC0402FR-0710K5L	Yageo America
R12	1	7.15k	RES, 7.15 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW04027K15FKED	Vishay-Dale
R14	1	121k	RES, 121 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW0402121KFKED	Vishay-Dale
R15, R16, R19, R21	4	100k	RES, 100 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	RMCF0402FT100K	Stackpole Electronics Inc
R18	1	19.1k	RES, 19.1 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW040219K1FKED	Vishay-Dale
R22, R24	2	10.0	RES, 10.0, 1%, 0.063 W, 0402	0402	MCR01MZPF10R0	Rohm
SH-J1, SH-J2, SH-J3, SH-J4	4	1x2	Shunt, 100mil, Gold plated, Black	Shunt	SNT-100-BK-G	Samtec
TP1, TP2, TP3, TP4, TP7, TP8, TP9, TP10, TP11, TP12, TP13, TP14, TP15, TP16	14		Test Point, Miniature, SMT	Test Point, Miniature, SMT	5019	Keystone
U1	1		3 V to 36 V, Dual 3 A or stackable 6 A Power Module in 6.5mm x 7 mm x 2 mm Package	QFN-FCMOD28	TPSM64406	Texas Instruments
C16, C17	0	10 pF	CAP, CERM, 10 pF, 50 V, +/- 5%, C0G/NP0, AEC-Q200 Grade 1, 0402	0402	CGA2B2C0G1H100D050BA	TDK
R20, R23	0	4.99k	RES, 4.99 k, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	0402	CRCW04024K99FKED	Vishay-Dale

5 Additional Information

Trademarks

HotRod™ is a trademark of Texas Instruments.

WEBENCH® is a registered trademark of Texas Instruments.

All trademarks are the property of their respective owners.

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, *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.

6.2 Custom Design With WEBENCH® Tools

Click here to create a custom design using the TPSM64406 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.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けて

いないものがあります。 技術適合証明を受けていないもののご使用に際しては、電波法遵守のため、以下のいずれかの

措置を取っていただく必要がありますのでご注意ください。

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。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。 日本テキサス・イ

ンスツルメンツ株式会社

東京都新宿区西新宿６丁目２４番１号

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.

IMPORTANT NOTICE AND DISCLAIMER