

EVM User's Guide: LM70880-Q1 LM70880QEVM

LM70880-Q1 Buck Converter Evaluation Module



Description

The LM70880QEVM high-density EVM is designed to use a regulated or non-regulated high-voltage input rail ranging from 8V to 72V to produce a tightly regulated output voltage of 5V at load currents up to 8A. This wide V_{IN} range DC/DC device offers outsized voltage rating and operating margin to withstand supply rail voltage transients.

The free-running switching frequency is 400kHz and is synchronizable to an external clock signal at a higher or lower frequency. The power-train passive components selected for this EVM, including buck inductors and ceramic input and output capacitors, are automotive AEC-Q200 rated and are available from multiple component vendors.

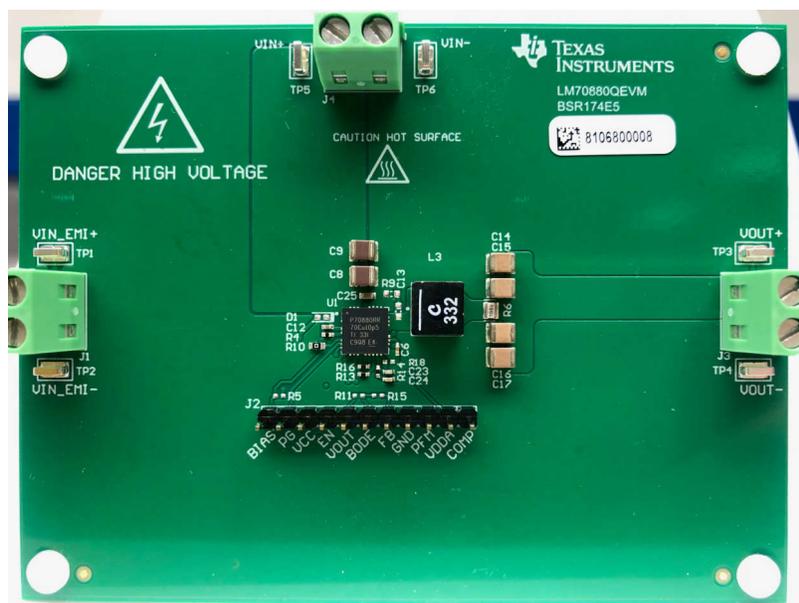
Features

- Wide input voltage operating range of 8V to 72V
- 1% accurate fixed 5V, 3.3V, or adjustable output down to 0.8V
- Switching frequency of 400kHz externally synchronizable up or down by 20%
- Full-load efficiency of 93.6% at 12V_{IN} and 90.5% at 48V_{IN}
- 260 μ A operating current at 48V_{IN}

- Optimized for low EMI
 - Dual-random spread spectrum EMI mitigation
 - Meets CISPR 25 Class 5 and UNECE Reg 10 EMI standards
- Peak current-mode control architecture provides fast line and load transient response
 - Integrated slope compensation adaptive with switching frequency
 - Forced PWM (FPWM) or pulsed-frequency modulation (PFM) operation
 - Optional internal or external loop compensation
- Integrated high-side and low-side power MOSFETs
- Overcurrent protection (OCP) with hiccup mode for sustained overload conditions
- SYNCOUT signal 180° out-of-phase with internal clock
- Power Good signal with 100k Ω pullup resistor to VCC
- Internal 3ms soft start
- Fully assembled, tested, and proven PCB layout

Applications

- High-current [automotive electronic systems](#)
- [ADAS](#) and [body](#) electronics
- [Infotainment systems](#) and [instrument clusters](#)
- [Automotive HEV/EV powertrain systems](#)



1 Evaluation Module Overview

1.1 Introduction

The [LM70880QEVM](#) evaluation module (EVM) is a synchronous buck DC/DC regulator that employs synchronous rectification to achieve high conversion efficiency in a small footprint. The EVM operates over a wide input voltage range of 8V to 72V, providing a regulated output of 5V. The output voltage has better than 1% setpoint accuracy and is adjusted by modifying the feedback resistor values, permitting the user to customize the output voltage as needed.

The [LM70880-Q1](#) synchronous buck controller used in the EVM has the following features:

- Wide input voltage (wide V_{IN}) range of 4.5V to 80V
- Spread spectrum modulation for lower EMI
- Wide duty cycle range with low $t_{ON(min)}$ and $t_{OFF(min)}$
- Ultra-low shutdown and no-load standby quiescent currents
- Multiphase capability
- Peak current-mode control loop architecture
- Integrated, high-current MOSFETs
- Cycle-by-cycle overcurrent protection with hiccup

1.2 Kit Contents

- LM70880QEVM Circuit Board
- EVM Disclaimer Read Me
- Prototype EVM Disclaimer Read Me
- High Voltage Read Me

1.3 Specification

Figure 1-1 shows the schematic of an LM70880-Q1-based synchronous buck converter.

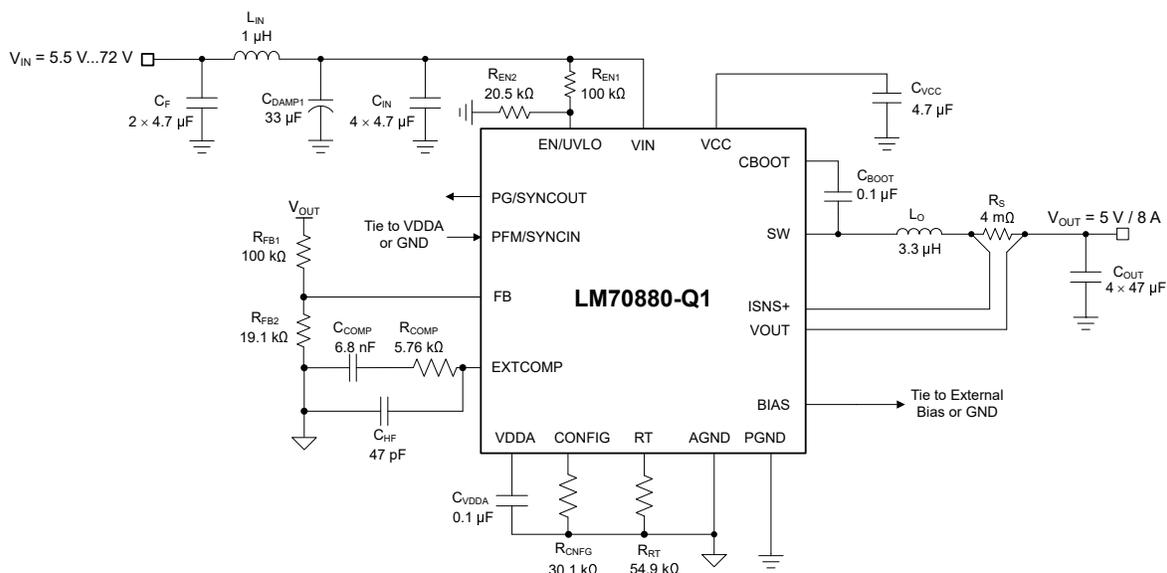


Figure 1-1. LM70880-Q1 Synchronous Buck Regulator Simplified Schematic

1.4 Device Information

The free-running switching frequency of the EVM is 400kHz and is synchronizable to a higher or lower frequency, if required. VCC and gate drive UVLO protects the regulator at low input voltage conditions, and EN pin supports application-specific power-up and power-down requirements. The [LM70880-Q1](#) is available in a 29-pin VQFN package with 6mm × 6mm footprint to enable DC/DC devices with high density and low component count. See the [LM70880-Q1 Automotive Buck Converter Optimized for Low EMI and High Power Density Data Sheet](#) for more information.

2 Hardware

2.1 Test Setup and Procedure

2.1.1 EVM Connections

Referencing the EVM connections described in [Table 2-1](#), the recommended test setup to evaluate the LM70880-Q1 is shown in [Figure 2-1](#). Working at an ESD-protected workstation, make sure that any wrist straps, boot straps, or mats are connected and referencing the user to earth ground before handling the EVM.

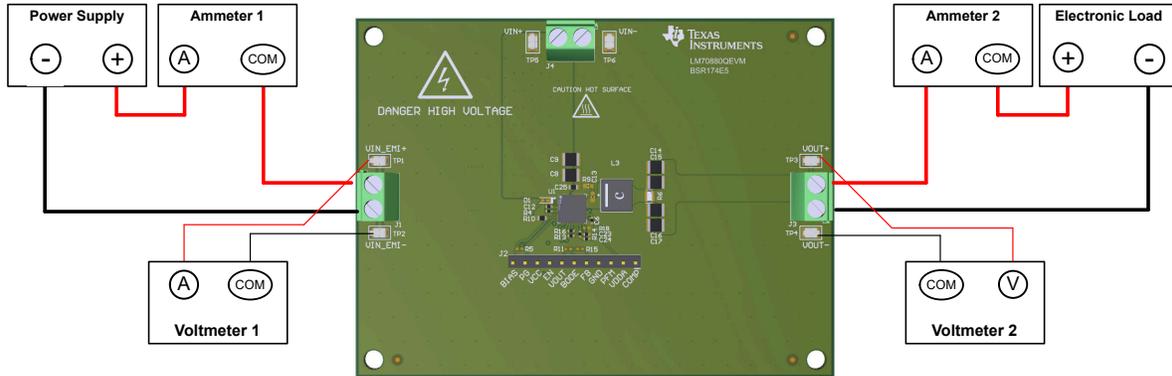


Figure 2-1. EVM Test Setup

CAUTION

Refer to the [LM70880-Q1 data sheet](#), [LM70880-Q1 Quickstart Calculator](#), and [WEBENCH® Power Designer](#) for additional guidance pertaining to component selection and controller operation.

Table 2-1. EVM Power Connections

LABEL	DESCRIPTION
VIN_EMI+	Positive input voltage power and sense connection with EMI filter
VIN_EMI-	Positive input voltage power and sense connection with EMI filter
VIN+	Positive input voltage power and sense connection bypassing EMI filter
VIN-	Negative input voltage power and sense connection bypassing EMI filter
VOUT+	Positive output voltage power and sense connection
VOUT-	Negative output voltage power and sense connection

Table 2-2. EVM Signal Connections

LABEL	DESCRIPTION
BIAS	Optional external bias supply for higher efficiency
PG	Power Good indicator
VCC	Internally generated bias supply connection for the gate drivers
EN	ENABLE input – tie to GND to disable the device
VOUT	Output voltage
BODE	50Ω injection point for loop response
FB	FB node
GND	GND connection
PFM	PFM/FPWM selection and Synchronization input
VDDA	Bias supply connection for the analog circuits
COMP	Error amplifier output

2.1.2 Test Equipment

Voltage Source: Use an input voltage source capable of supplying 0V to 80V and 12A.

Multimeters:

- **Voltmeter 1:** Input voltage at VIN+ to VIN–. Set the voltmeter to an input impedance of 100M Ω .
- **Voltmeter 2:** Output voltage at VOUT to GND. Set the voltmeter to an input impedance of 100M Ω .
- **Ammeter 1:** Input current. Set the ammeter to 1-second aperture time.
- **Ammeter 2:** Output current. Set the ammeter to 1-second aperture time.

Electronic Load: The load must be an electronic constant-resistance (CR) or constant-current (CC) mode load capable of 0A_{DC} to 10A_{DC} at 5V. For a no-load input current measurement, disconnect the electronic load as the load can draw a small residual current.

Oscilloscope: With the scope set to 20MHz bandwidth and AC coupling, measure the output voltage ripple directly across an output capacitor with a short ground lead normally provided with the scope probe. Place the oscilloscope probe tip on the positive terminal of the output capacitor, holding the ground barrel of the probe through the ground lead to the negative terminal of the capacitor. TI does not recommend using a long-leaded ground connection because this can induce additional noise given a large ground loop. To measure other waveforms, adjust the oscilloscope as needed.

Safety: Always use caution when touching any circuits that can be live or energized.

2.1.3 Recommended Test Setup

2.1.3.1 Input Connections

1. Prior to connecting the DC input source, set the current limit of the input supply to 0.1A maximum. Make sure the input source is initially set to 0V and connected to the VIN+ and VIN– connection points as shown in [Figure 2-1](#).
2. Connect voltmeter 1 at VIN+ and VIN– connection points to measure the input voltage.
3. Connect ammeter 1 to measure the input current and set to at least 1-second aperture time.

2.1.3.2 Output Connections

1. Connect electronic load to VOUT connection. Set the load to constant-resistance mode or constant-current mode at 0A before applying input voltage.
2. Connect voltmeter 2 at VOUT and GND connections to measure the output voltage.
3. Connect ammeter 2 to measure the output current.

2.1.4 Test Procedure

2.1.4.1 Line and Load Regulation, Efficiency

1. Set up the EVM as previously described.
2. Set the load to constant resistance or constant current mode and to sink 0A.
3. Increase input source from 0V to 48V; use voltmeter 1 to measure the input voltage.
4. Increase the current limit of the input supply to 12A.
5. Using voltmeter 2 to measure the output voltage, V_{OUT} , vary the load current from 0A to 8A_{DC}; V_{OUT} must remain within the load regulation specification.
6. Set the load current to 4A (50% rated load) and vary the input source voltage from 8V to 72V; V_{OUT} must remain within the line regulation specification.
7. Decrease load to 0A. Decrease input source voltage to 0V.

3 Implementation Results

3.1 Performance Data and Results

Figure 3-1 through Figure 3-11 present typical performance curves for the LM70880QEVM. Because actual performance data can be affected by measurement techniques and environmental variables, these curves are presented for reference and can differ from actual field measurements.

3.1.1 EVM Characteristics

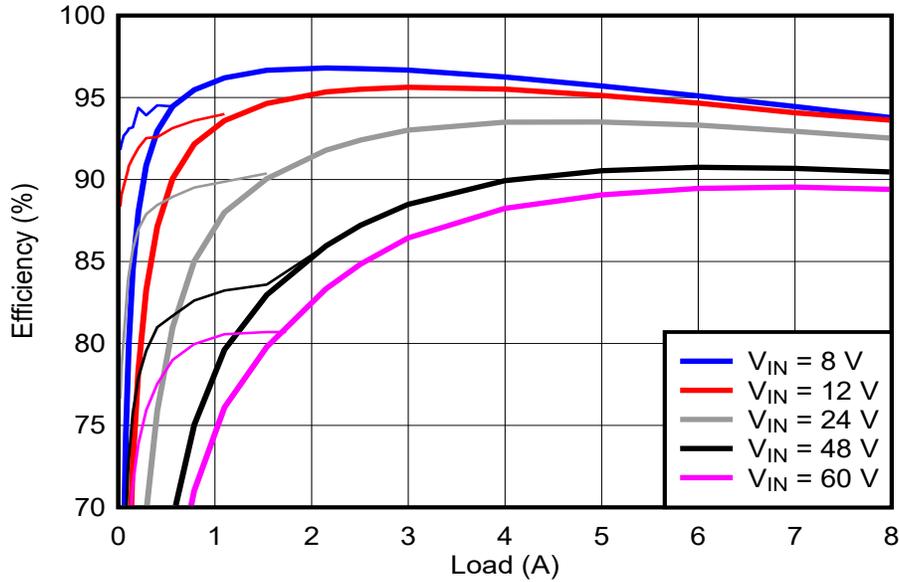
Table 3-1 lists the electrical characteristics.

Table 3-1. Electrical Performance Characteristics

Parameter	Test Conditions		MIN	TYP	MAX	Unit
INPUT CHARACTERISTICS						
Input voltage range, V_{IN}	Operating		8	48	72	V
Input current, no load, I_{IN-NL}	$I_{OUT} = 0A$, PFM tied to VDDA, UVLO removed	$V_{IN} = 24V$	37.5		μA	
		$V_{IN} = 48V$	35.4			
		$V_{IN} = 72V$	35.5			
Input current, shutdown, I_{IN-OFF}	$V_{EN} = 0V$	$V_{IN} = 48V$	5.5		μA	
OUTPUT CHARACTERISTICS						
Output voltage, V_{OUT} ⁽¹⁾			4.95	5	5.05	V
Output current, I_{OUT}	$V_{IN} = 8V$ to 72V, Airflow = 100 LFM ⁽²⁾		0		8	A
Output voltage regulation, ΔV_{OUT}	Load regulation	$I_{OUT} = 0A$ to 8A	0.1%			
	Line regulation	$V_{IN} = 8V$ to 72V	1%			
Output voltage ripple, V_{OUT-AC}	$V_{IN} = 48V$, $I_{OUT} = 8A$		10		mVrms	
Output overcurrent protection, I_{OCP}	$V_{IN} = 48V$		10		A	
Soft-start time, t_{SS}			3		ms	
SYSTEM CHARACTERISTICS						
Switching frequency, F_{SW-nom}	$V_{IN} = 48V$		400		kHz	
PFM Light-load efficiency, η_{LIGHT} ⁽¹⁾	$I_{OUT} = 1A$	$V_{IN} = 24V$	89.9%			
		$V_{IN} = 48V$	83.2%			
		$V_{IN} = 60V$	80.6%			
Half-load efficiency, η_{HALF}	$I_{OUT} = 4A$	$V_{IN} = 24V$	93.6%			
		$V_{IN} = 48V$	89.9%			
		$V_{IN} = 60V$	88.2%			
Full load efficiency, η_{FULL}	$I_{OUT} = 8A$	$V_{IN} = 24V$	92.5%			
		$V_{IN} = 48V$	90.5%			
		$V_{IN} = 60V$	89.4%			
LM70880-Q1 junction temperature, T_J			-40		150	°C

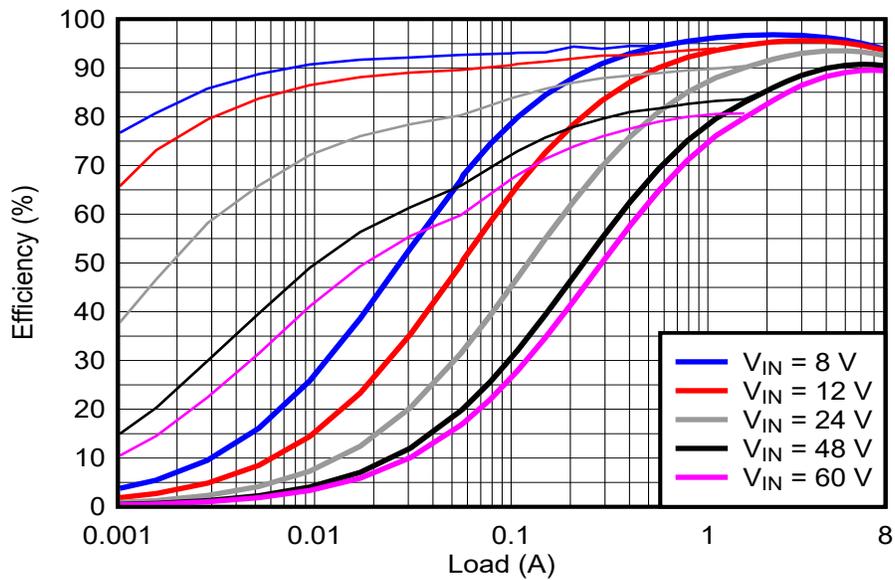
- (1) The default output voltage of this EVM is 12V. Efficiency and other performance metrics can change based on operating input voltage, load currents, externally-connected output capacitors, and other parameters.
- (2) The recommended airflow when operating at input voltages greater than 60V is 100 LFM.

3.1.2 Conversion Efficiency



The curves with higher efficiency at light load correspond to when diode emulation is enabled (PFM tied to VDDA).

Figure 3-1. Efficiency, $V_{IN} = 48V$, $V_{OUT} = 5V$



The curves with higher efficiency at light load correspond to when diode emulation is enabled (PFM tied to VDDA).

3.1.3 Operating Waveforms

3.1.3.1 Switching

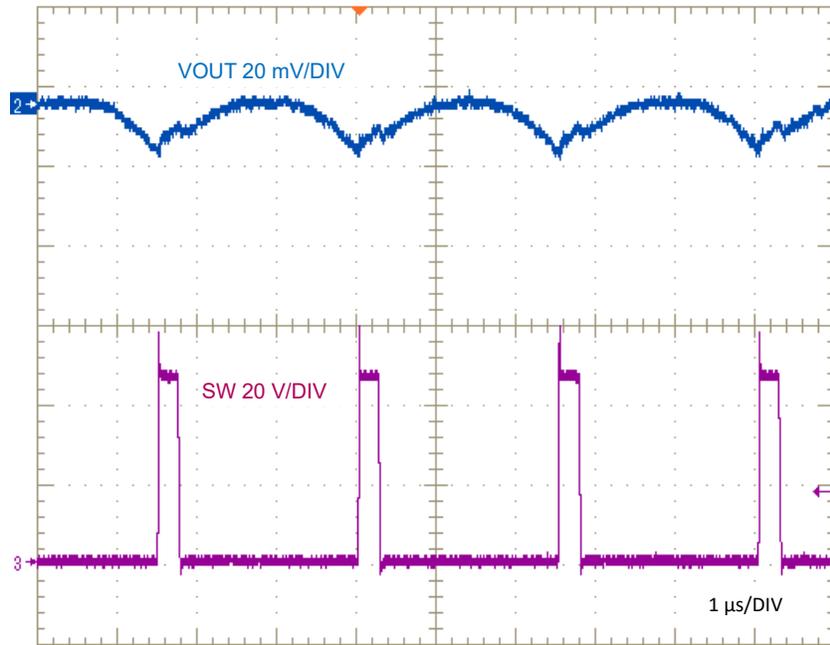


Figure 3-2. Steady State Operation, $V_{IN} = 48V$, $I_{OUT} = 8A$

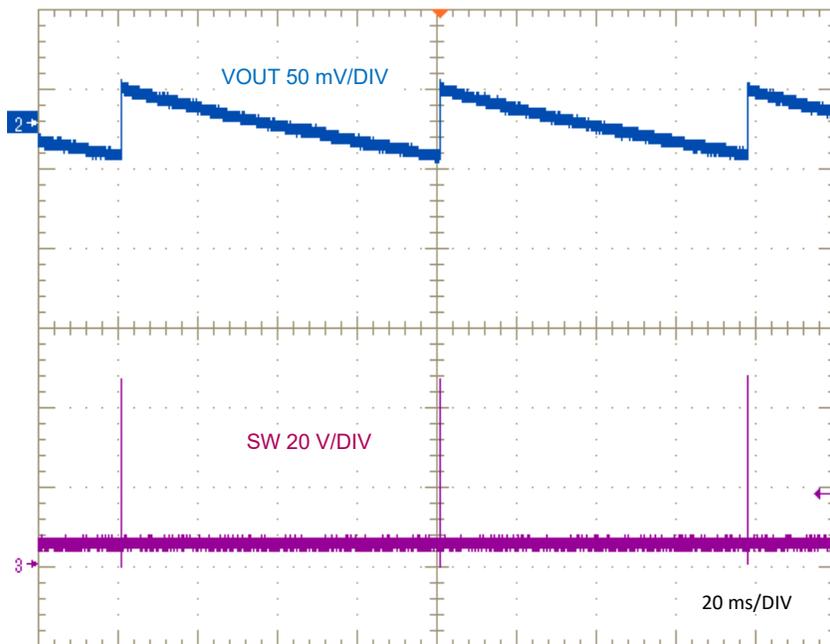


Figure 3-3. Steady State Operation in PFM Mode, $V_{IN} = 48V$, $I_{OUT} = 0A$

3.1.3.2 Load Transient Response

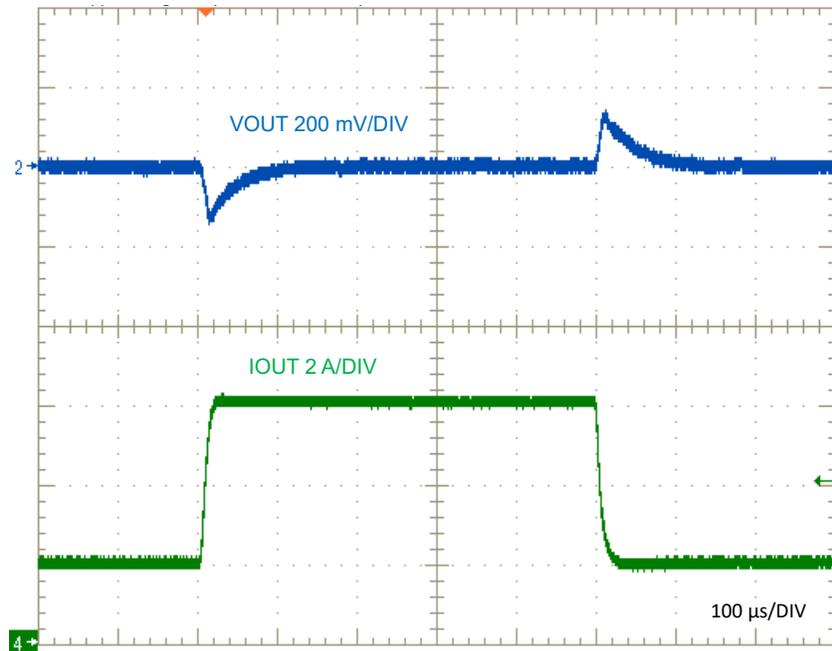


Figure 3-4. Load Transient Response, $V_{IN} = 48V$, FPWM, 2A to 6A at 1A/μs

3.1.3.3 Line Transient Response

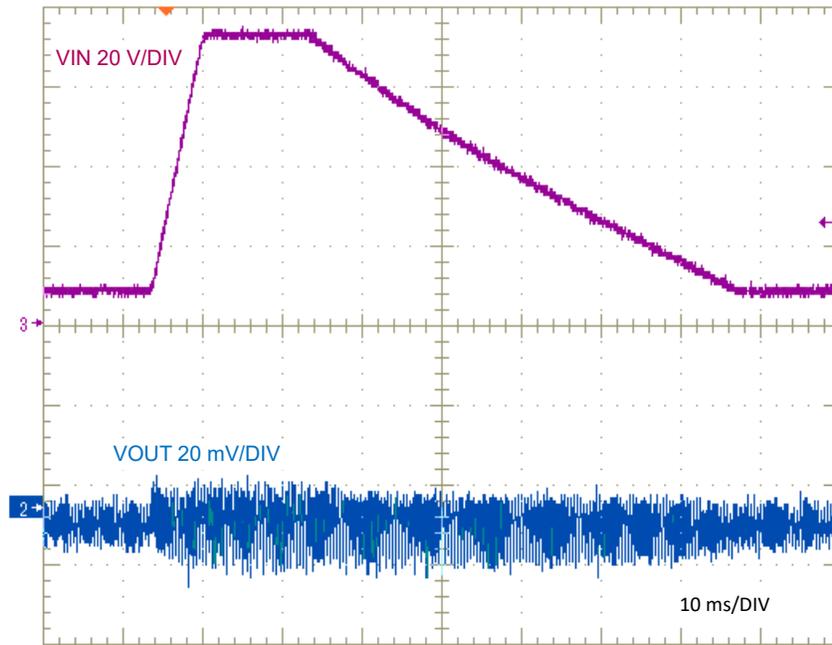


Figure 3-5. Line Transient Response to $V_{IN} = 8V$ to $72V$, $I_{OUT} = 4A$

3.1.3.4 Start-Up and Shutdown With EN

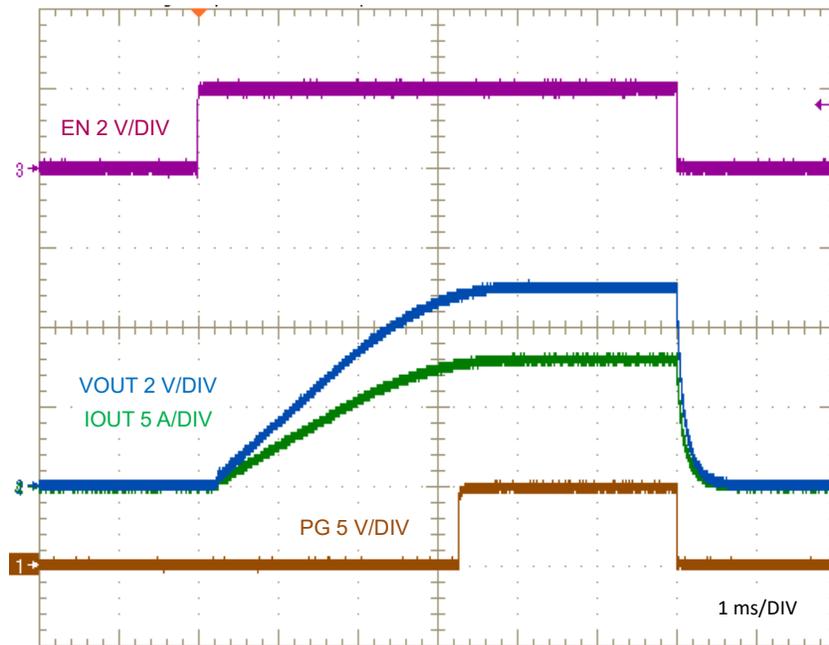


Figure 3-6. EN ON and OFF, $V_{IN} = 48V$, $I_{OUT} = 8A$ Resistive Load

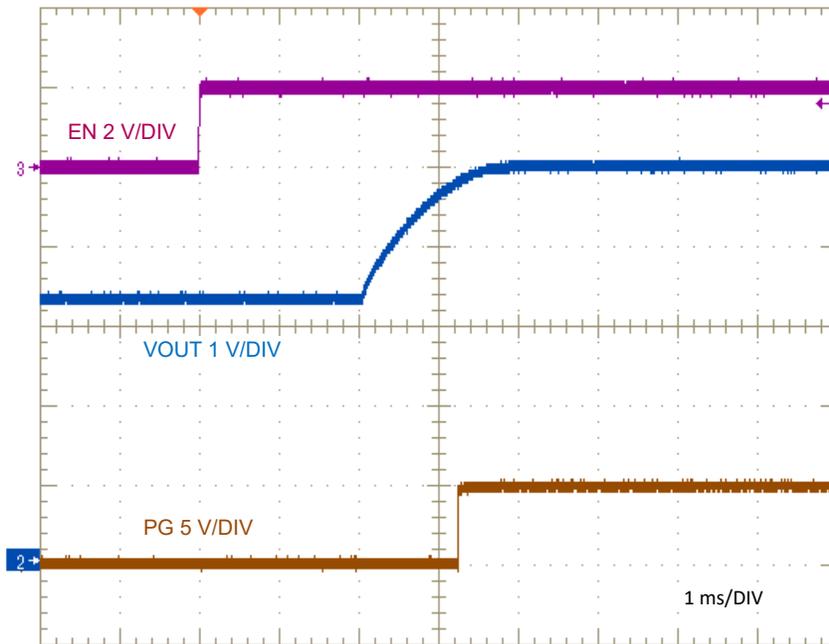


Figure 3-7. EN ON, $V_{IN} = 48V$, V_{OUT} Prebiased at 3.3V

3.1.3.5 Start-Up with VIN

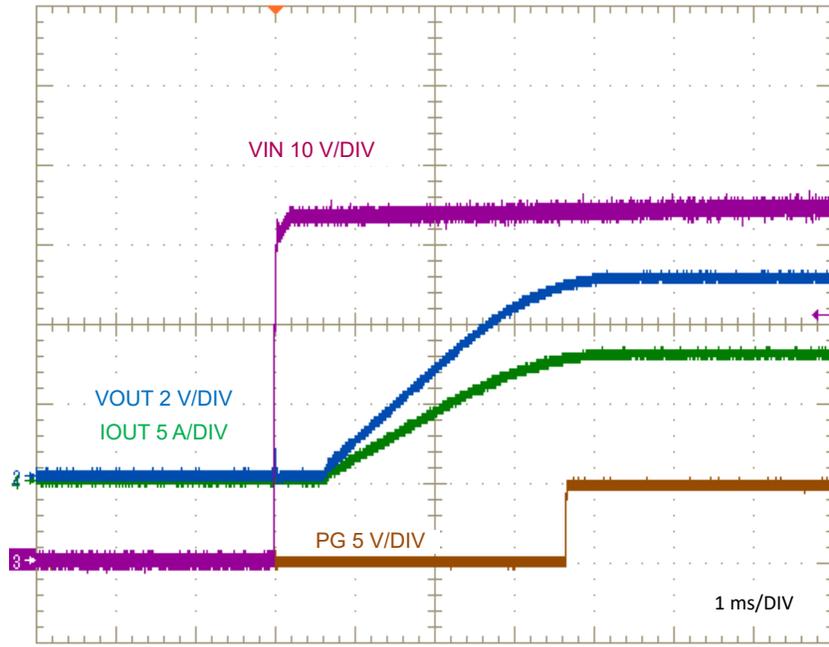
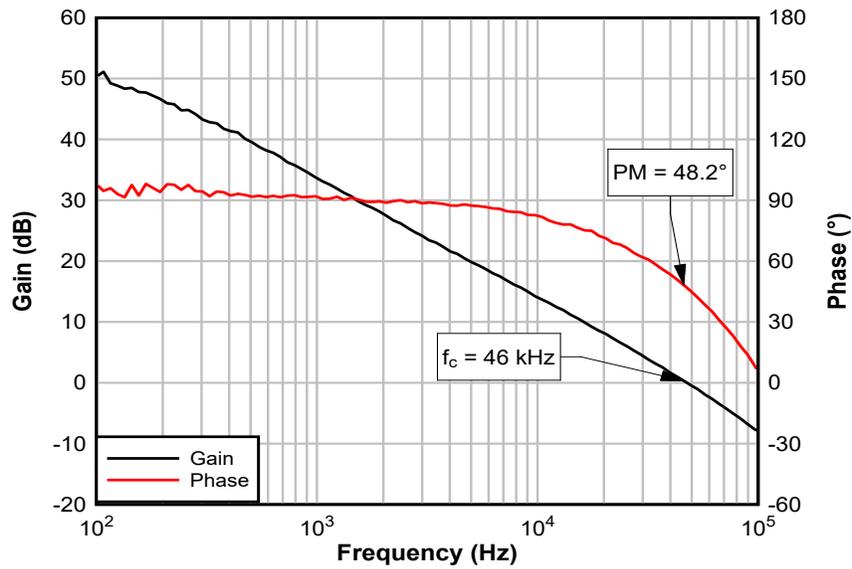


Figure 3-8. Start-Up, $V_{IN} = 48V$, $I_{OUT} = 8A$ Resistive Load

3.1.4 Bode Plot



f_c = crossover frequency, PM = phase margin.

Figure 3-9. Bode Plot, $V_{IN} = 48V$, $V_{OUT} = 5V$, $I_{OUT} = 8A$ Resistive Load

3.1.5 CISPR 25 EMI Performance

Figure 3-10 presents the EMI performance of the LM70880-Q1 EVM at 48V input with DRSS EMI mitigation disabled. Conducted emissions are measured over a frequency range of 150kHz to 30MHz using a 5µH LISN according to the CISPR 25 low-frequency specification. CISPR 25 Class 5 peak and average limit lines are denoted in red. The yellow and green spectra are measured using peak and average detection, respectively.

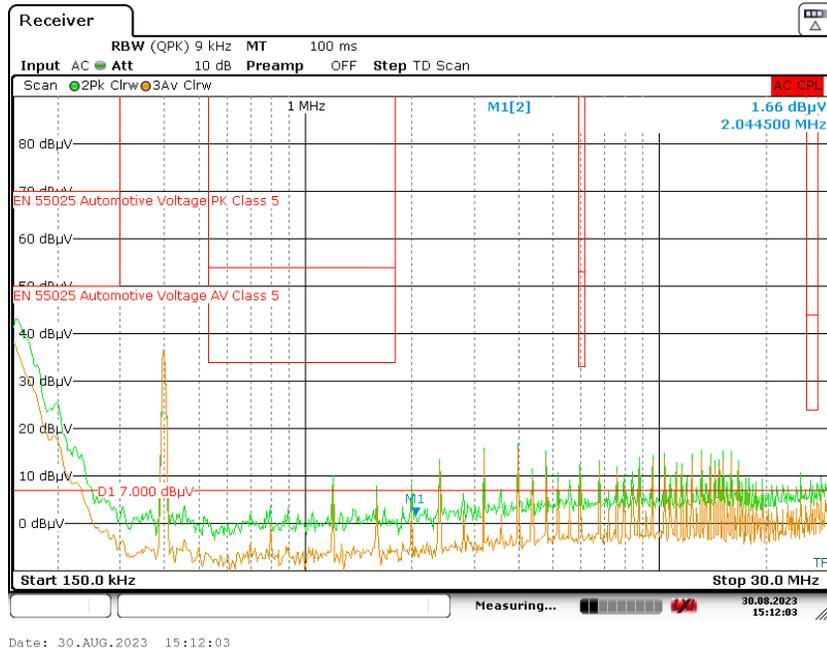


Figure 3-10. CISPR 25 Class 5 Conducted Emissions Plot, 150kHz to 30MHz, $V_{IN} = 48V$, $I_{OUT} = 5A$ Resistive Load

3.1.6 Thermal Performance

Figure 3-11 shows the thermal performance image.

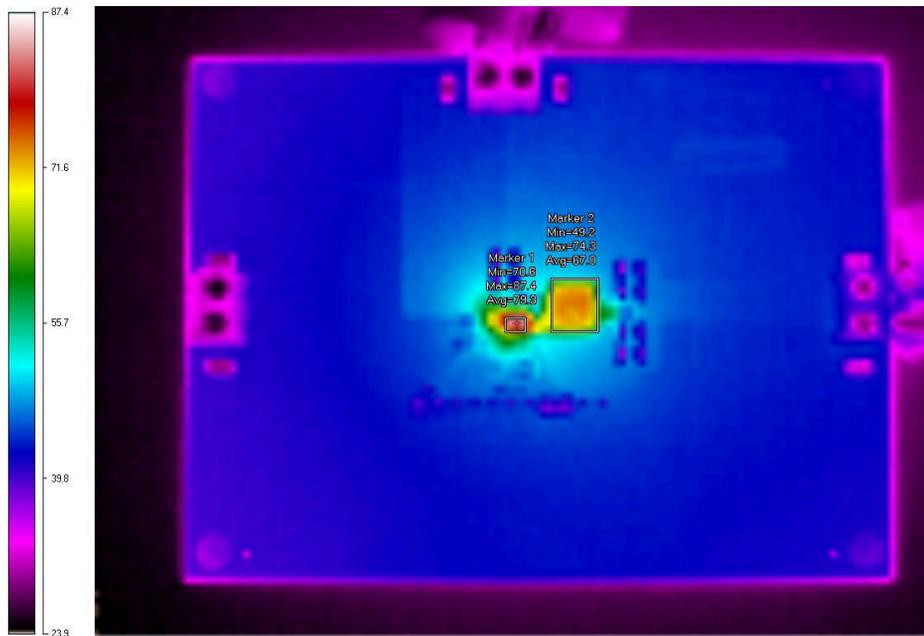


Figure 3-11. Thermal Performance, $V_{IN} = 48V$, $I_{OUT} = 8A$, $T_{amb} = 25^{\circ}C$, No Airflow

4 Hardware Design Files

4.1 Schematic

Figure 4-1 shows the EVM schematic.

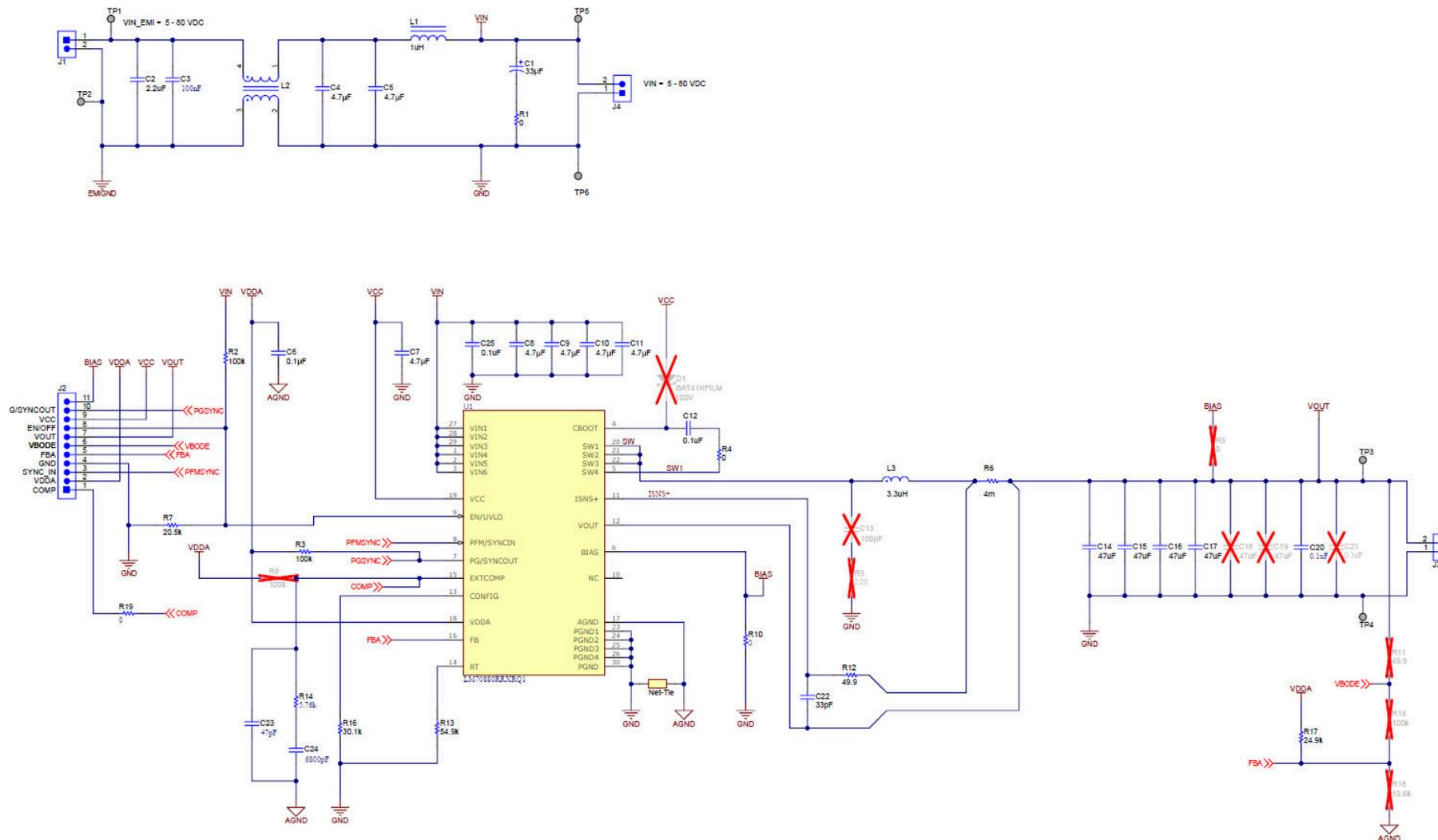


Figure 4-1. EVM Schematic

4.2 PCB Layout

Figure 4-2 through Figure 4-9 show the design of the LM70880-Q1 EVM using a six-layer PCB with 2-oz copper thickness.

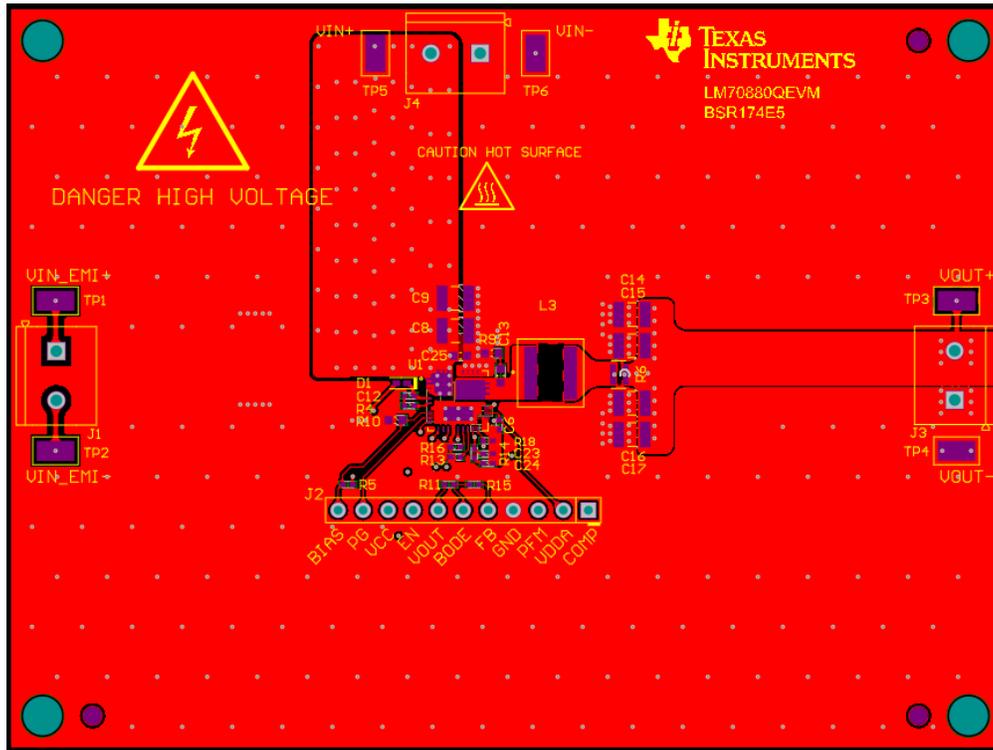


Figure 4-2. Top Copper (Top View)

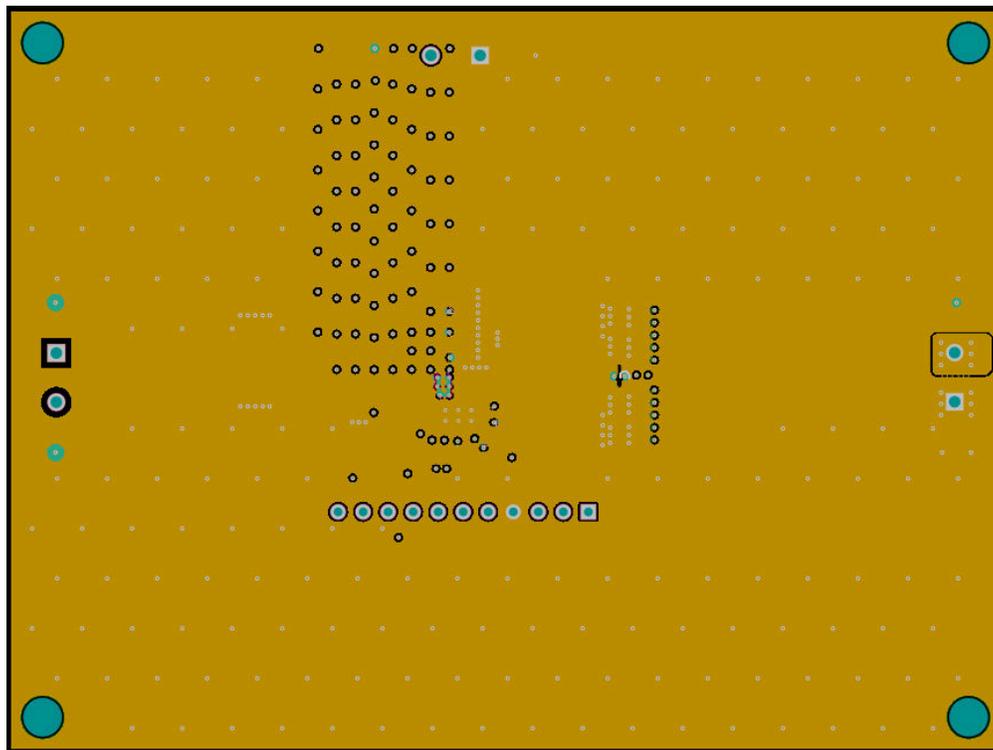


Figure 4-3. Layer 2 Copper (Top View)

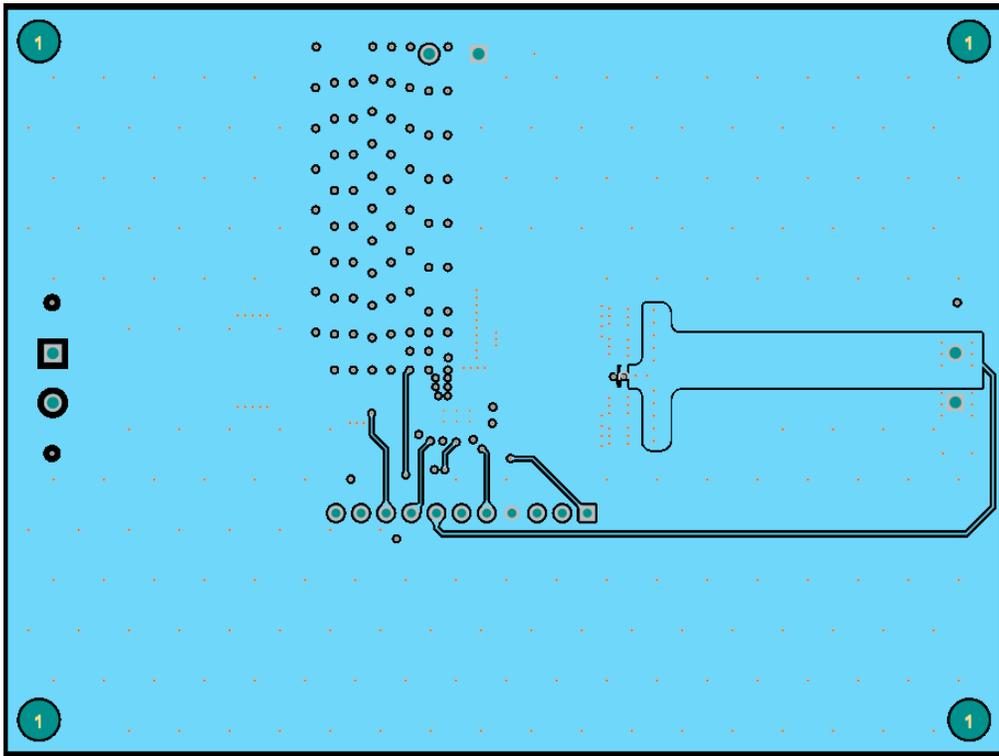


Figure 4-4. Layer 3 Copper (Top View)

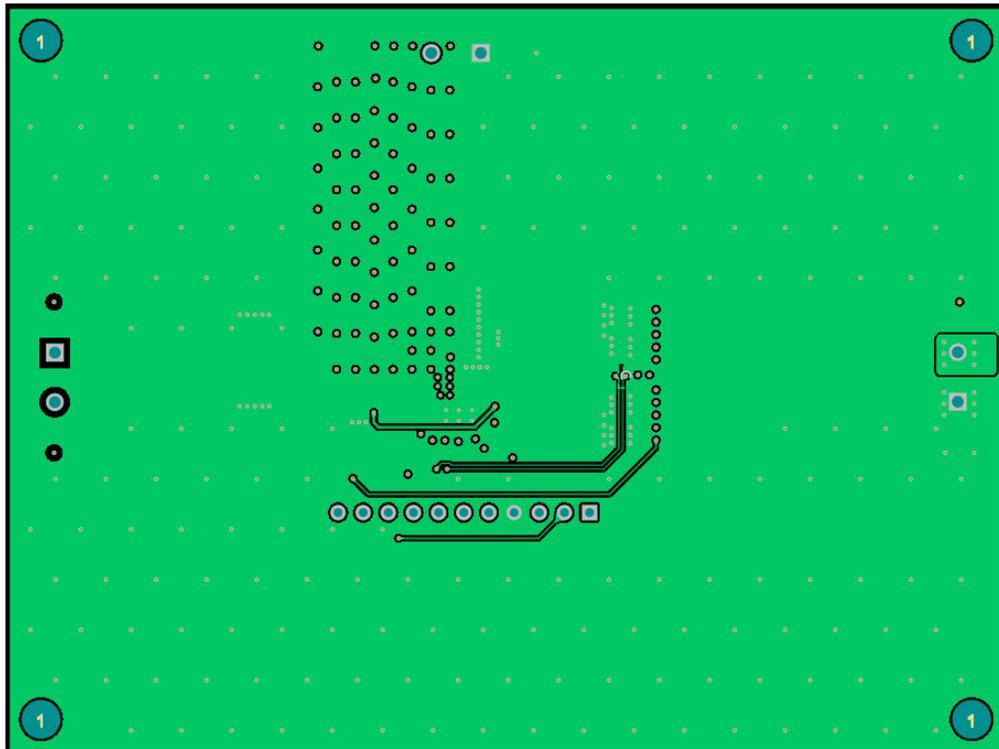


Figure 4-5. Layer 4 Copper (Top View)

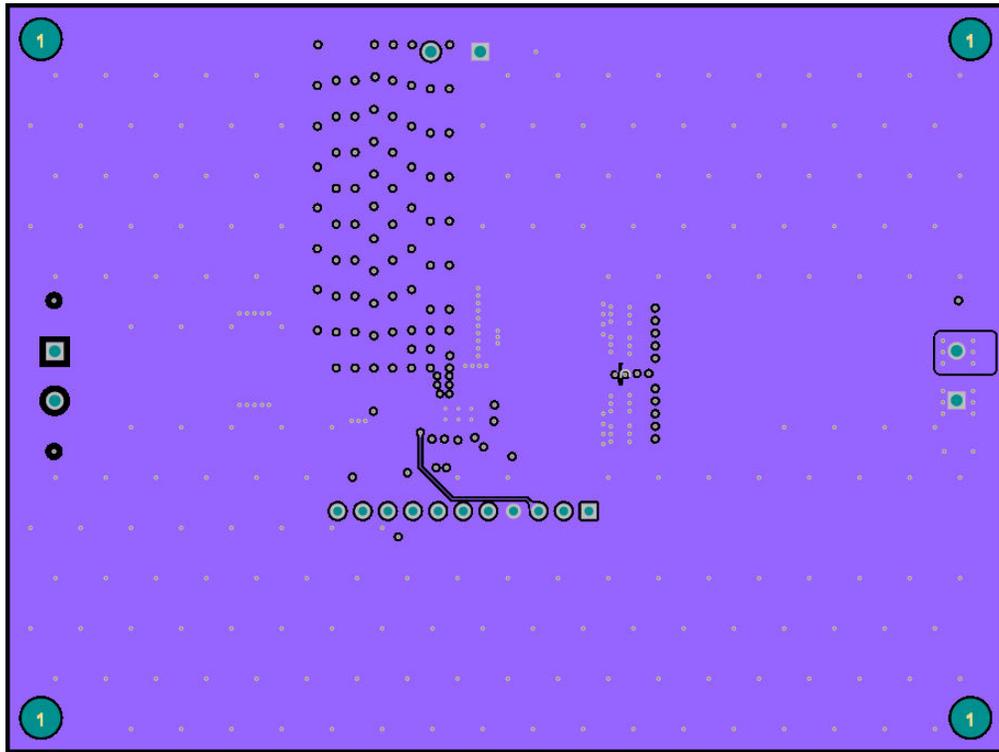


Figure 4-6. Layer 5 Copper (Top View)

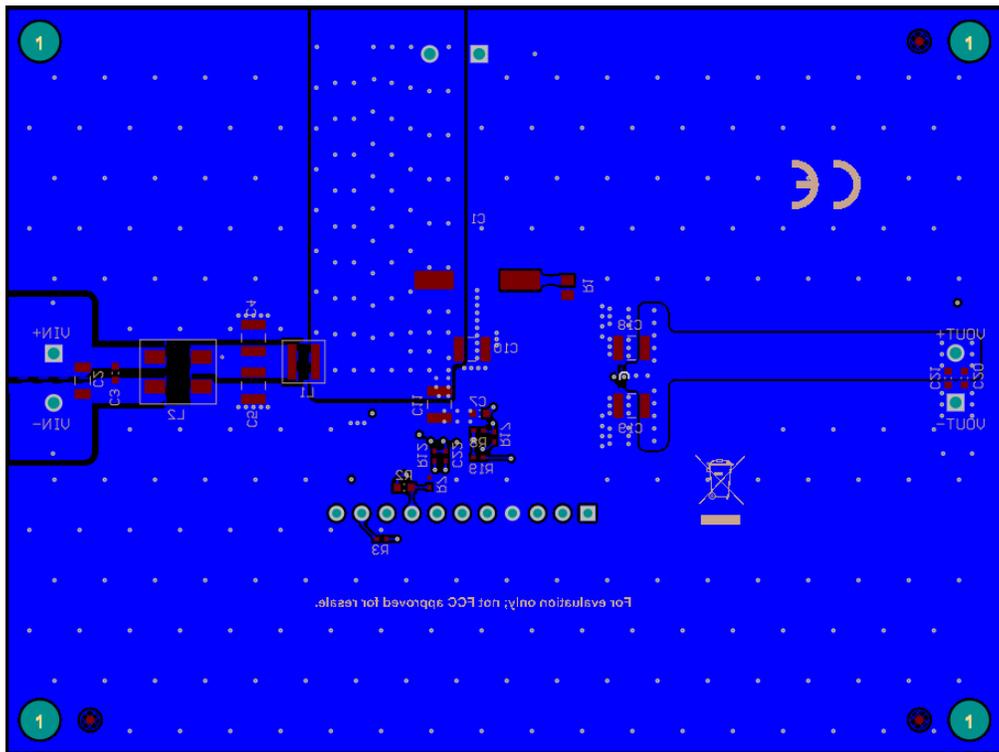


Figure 4-7. Bottom Copper (Top View)

4.2.1 Component Drawings

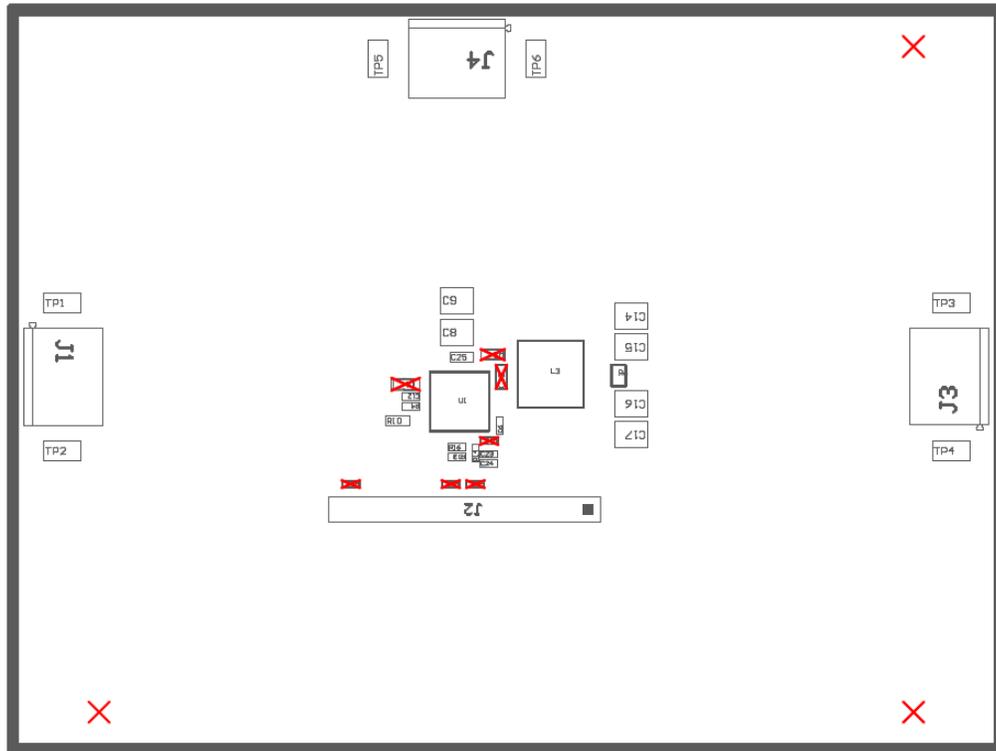


Figure 4-8. Top Component Drawing

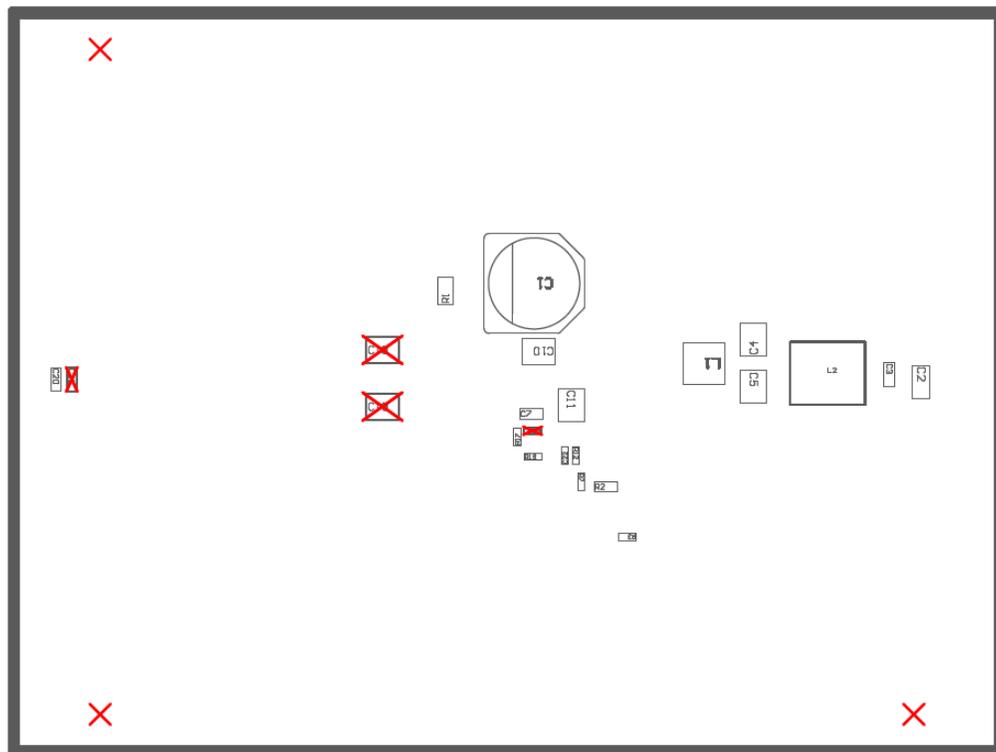


Figure 4-9. Bottom Component Drawing

4.2.2 Multi-Layer Stackup

#	Name	Type	Material	Weight	Thickness	Dk
	Top Overlay	Overlay				
	Top Solder	Solder Mask	Solder Resist		0.4mil	3.5
1	Top Layer	Signal		2oz	2.8mil	
	Dielectric1	Core	FR4 Hi Tg		9mil	4.8
2	Signal Layer 1	Signal		2oz	2.8mil	
	Dielectric 2	Prepreg	FR4 Hi Tg		9mil	4.2
3	Signal Layer 2	Signal		2oz	2.8mil	
	Dielectric 3	Core	FR4 Hi Tg		9mil	4.2
4	Signal Layer 3	Signal		2oz	2.8mil	
	Dielectric 4	Prepreg	FR4 Hi Tg		9mil	4.2
5	Signal Layer 4	Signal		2oz	2.8mil	
	Dielectric 5	Core	FR4 Hi Tg		9mil	4.2
6	Bottom Layer	Signal		2oz	2.8mil	
	Bottom Solder	Solder Mask	Solder Resist		0.4mil	3.5
	Bottom Overlay	Overlay				

Figure 4-10. Layer Stackup

4.3 Bill of Materials

Table 4-1. Bill of Materials

QTY	REF DES	DESCRIPTION	PART NUMBER	MFR
1	C1	Capacitor, Aluminum, 33 μ F, 100V, 1 Ω , AEC-Q200	EEE-TG2A330P	Panasonic
1	C2	Capacitor, Ceramic, 2.2 μ F, 100V, X7S, 1206, AEC-Q200	CGA5L3X7S2A225K160AB	TDK
2	C3, C25	Capacitor, Ceramic, 0.1 μ F, 100V, X7R, 0603, AEC-Q200	GCJ188R72A104KA01D	Murata
6	C4, C5, C8, C9, C10, C11	Capacitor, Ceramic, 4.7 μ F, 100V, X7S, 1210, AEC-Q200	GCM32DC72A475KE02L	Murata
			CGA6M3X7S2A475K200AB	TDK
1	C6	Capacitor, Ceramic, 0.1 μ F, 10V, X7R, 0402, AEC-Q200	C0402C104K8RACAUTO	Kemet
1	C7	Capacitor, Ceramic, 4.7 μ F, 10V, X7R, 0603	GRM188Z71A475ME15D	Murata
1	C12	Capacitor, Ceramic, 0.1 μ F, 25V, X7R, 0402	Std	Std
4	C14, C15, C16, C17	Capacitor, Ceramic, 47 μ F, 10V, X7R, 1210	GRM32ER71A476KE15L	Murata
1	C20	Capacitor, Ceramic, 0.1 μ F, 50V, X7R, 0603 AEC-Q200	CGA3E2X7R1H104K080AA	TDK
1	C22	Capacitor, Ceramic, 33pF, 50V, C0G/NP0, 0402, AEC-Q200	GCM1555C1H330JA16D	Murata
1	C23	Capacitor, Ceramic, 47pF, 50V, C0G/NP0, 0402, AEC-Q200	CGA2B2C0G1H470J050BA	TDK
1	C24	Capacitor, Ceramic, 6800pF, 50V, X7R, 0402, AEC-Q200	CGA2B2X7R1H682K050BA	TDK
3	J1, J3, J4	Terminal Block, 2 position, 5mm, TH	Std	Std
1	J2	Header, 100 mil, 11 \times 1, Au, TH	Std	Std
1	L1	Inductor, 1 μ H, 12m Ω typical, 5.3A, 4.1 \times 4.1 \times 2.1mm typ, AEC-Q200	74438356010	Würth
1	L2	Common Mode Choke, 700 Ω at 100MHz, 4A, 15m Ω , 7.0 \times 6.0 \times 3.8mm typical, AEC-Q200	CM7060P701R-10	Laird
1	L3	Inductor, 3.3 μ H, 5.9m Ω , 10.1A, 6.71 \times 6.51 \times 6.1mm typical, AEC-Q200	XGL6060-332MEC	Coilcraft
1	R1	Resistor, Chip, 0 Ω , 1/8 W, 1%, 0805	Std	Std
1	R2	Resistor, Chip, 100k Ω , 1/10 W, 1%, 0603	Std	Std
1	R3	Resistor, Chip, 100k Ω , 1/16 W, 1%, 0402	Std	Std
2	R4, R19	Resistor, Chip, 0 Ω , 1/5 W, 1%, 0402	Std	Std
1	R5	Resistor, Chip, 4m Ω , 1 W, 1%, 0508, AEC-Q200	KRL2012E-M-R004-F-T5	Susumu
1	R7	Resistor, Chip, 20.5k Ω , 1/16 W, 1%, 0402	Std	Std
1	R10	Resistor, Chip, 0 Ω , 1/10 W, 1%, 0603	Std	Std
1	R12	Resistor, Chip, 49.9 Ω , 1/16 W, 1%, 0402	Std	Std
1	R13	Resistor, Chip, 54.9k Ω , 1/16 W, 1%, 0402	Std	Std
1	R14	Resistor, Chip, 5.76k Ω , 1/16 W, 1%, 0402	Std	Std
1	R16	Resistor, Chip, 30.1k Ω , 1/16 W, 1%, 0402	Std	Std
1	R17	Resistor, Chip, 24.9k Ω , 1/16 W, 1%, 0402	Std	Std
6	TP1, TP2, TP3, TP4, TP5, TP6	Test Point, Miniature, SMT	5019	Keystone
1	U1	IC, LM70880-Q1 , 80V, 8A Synchronous DC/DC Buck Controller with Ultra-Low IQ, VQFN-29	LM70880QRRXRQ1	TI
1	PCB1	PCB, FR4, 6 layer, 2 oz	PCB	–

5 Compliance Information

5.1 Compliance and Certifications

- [LM70880QEVM EU Declaration of Conformity \(DoC\) for Restricting the use of Hazardous Substances \(RoHS\)](#)

6 Related Documentation

For related documentation see the following:

- [LM70880-Q1 3.5V to 80V Synchronous Buck DC/DC Converter with Ultra-Low IQ Data Sheet](#)
- [Reduce Buck Converter EMI and Voltage Stress by Minimizing Inductive Parasitics Analog Applications Journal](#)
- [AN-2162 Simple Success with Conducted EMI from DC-DC Converters Application Report](#)
- White Papers:
 - [Valuing Wide \$V_{IN}\$, Low EMI Synchronous Buck Circuits for Cost-driven, Demanding Applications](#)
 - [An Overview of Conducted EMI Specifications for Power Supplies](#)
 - [An Overview of Radiated EMI Specifications for Power Supplies](#)

6.1 Supplemental Content

6.1.1 Development Support

For development support see the following:

- For TI's reference design library, visit [TI reference designs](#)
- For TI's WEBENCH Design Environments, visit the [WEBENCH® Design Center](#)
- LM70880-Q1 DC/DC Converter [Quickstart Calculator](#)

6.1.2 PCB Layout Resources

- [AN-1149 Layout Guidelines for Switching Power Supplies Application Report](#)
- [AN-1229 Simple Switcher PCB Layout Guidelines Application Report](#)
- [Constructing Your Power Supply – Layout Considerations Power Supply Design Seminar](#)
- [Low Radiated EMI Layout Made SIMPLE with LM4360x and LM4600x Application Report](#)
- Power House Blogs:
 - [High-Density PCB Layout of DC-DC Converters](#)

6.1.3 Thermal Design Resources

- [AN-2020 Thermal Design by Insight, Not Hindsight Application Report](#)
- [AN-1520 A Guide to Board Layout for Best Thermal Resistance for Exposed Pad Packages Application Report](#)
- [Semiconductor and IC Package Thermal Metrics Application Report](#)
- [Thermal Design Made Simple with LM43603 and LM43602 Application Report](#)
- [PowerPAD Thermally Enhanced Package Application Report](#)
- [PowerPAD Made Easy Application Brief](#)
- [Using New Thermal Metrics Application Report](#)

7 Additional Information

7.1 Trademarks

All trademarks are the property of their respective owners.

8 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (September 2023) to Revision A (March 2024)	Page
• First public release.....	1

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 DEGRADATION 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/lstds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

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

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

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

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

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

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3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lstds/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.

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- 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.
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 - 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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8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY USE OF AN EVM PROVIDED HEREUNDER, INCLUDING FROM ANY WARRANTY, INDEMNITY 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.

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