User's Guide

TPSF12C1QEVM Active EMI Filter Evaluation Module for Single-Phase AC Power Systems

ABSTRACT

The TPSF12C1QEVM evaluation module (EVM) is specifically designed to conveniently evaluate the performance of the TPSF12C1-Q1 active filter IC. The solution helps to improve the common-mode (CM) electromagnetic interference (EMI) signature in single-phase AC and three-wire DC power systems.

The TPSF12C1-Q1 provides a very low impedance path for CM noise in the frequency range of interest for EMI measurement and helps to meet prescribed limits for EMI standards, such as:

- CISPR 11, EN 55011 – Industrial, Scientific and Medical (ISM) applications
- CISPR 25, EN 55025 – Automotive applications
- CISPR 32, EN 55032 – Multimedia applications

Enabling up to 25 dB of CM noise reduction at the lower end of specified frequency ranges (for example, 150 kHz to 3 MHz) significantly reduces the size, cost and weight of the common-mode filter implementation, specifically the common-mode chokes. The device senses the high-frequency noise on each power line using a set of sense capacitors and injects noise-canceling currents back into the power lines using an injection capacitor.

A header on the EVM provides connections to the sense and inject capacitors, which are high-voltage rated components located off-board at or near the passive filter solution. Also included on the EVM are connections for the bias power supply (VDD and GND), which is set between 8 V and 16 V, and a remote enable (EN) signal. The GND terminal of the EVM refers to chassis or Earth ground of the system.

Note

The damping and compensation component values included with this EVM may require modification, depending on the specifics of the EMI filter implementation and the target application. Refer to the *TPSF12C1-Q1 Standalone Active EMI Filter for Common-mode Noise Mitigation in Single-Phase AC Automotive Power Systems* data sheet and *TPSF12C1-Q1 quickstart calculator* for additional guidance pertaining to AEF circuit operation, passive component selection and expected EMI performance.

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Trademarks

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1 High-Density EVM Description

The TPSF12C1QEVM features the TPSF12C1-Q1 active EMI filter (AEF) IC designed to reduce common-mode (CM) electromagnetic interference (EMI) in single-phase AC power systems. The AEF solution configured with voltage sense and current inject (VSCI) uses a capacitive multiplier circuit to emulate the Y-capacitors in a conventional passive filter design. The device senses the high-frequency noise on the two power lines (of a single-phase system) using a set of sense capacitors and injects a noise-canceling current back into the power lines using an injection capacitor. The effective active capacitance is set by the AEF circuit gain and the injection capacitance. The AEF sensing and injection impedances use relatively low capacitance values with small component footprints. The device includes integrated filtering, compensation and protection circuitry, and an enable input.

The TPSF12C1-Q1 provides a very low impedance path for CM noise in the frequency range of interest for EMI measurement. Enabling up to 25 dB of CM noise reduction at the lower end of specified frequency ranges (for example, 150 kHz to 3 MHz) significantly reduces the footprint, volume, weight and cost of the CM filter implementation, especially the CM choke components that are designed to attenuate lower-order harmonics – and hence are large size. The resultant lower size of the CM chokes implies reduced parasitic winding capacitance, which serves to improve attenuation at high frequencies.

Acting as a daughter board, this EVM provides a header to facilitate easy connection to the EMI filter passive components, which typically includes common-mode chokes and Y-capacitors. The header terminals provide connections to:

- Two sense capacitors
- An inject capacitor
- VDD bias supply: 8 V to 16 V (typical 12 V)
- A remote ON/OFF signal
- Chassis ground

The recommended PCB layout minimizes the overall noise signature and required board area.

1.1 Typical Applications

- On-board charger (OBC) and isolated DC/DC for EVs
- Welders and other industrial systems
- AC/DC regulators for servers and telecom
- Inverters and motor drives

1.2 Features and Electrical Performance

- Improved common-mode EMI performance for applications with single-phase AC or 3-wire DC inputs
  - Helps to meet EMI standards, such as CISPR 11 and CISPR 32 Class B (for ISM and multimedia applications, respectively) or CISPR 25 Class 5 (for automotive)
  - Voltage-sense, current-inject AEF solution presents low impedance over the EMI frequency range
    - Up to 25 dB reduction in the common-mode EMI signature from 150 kHz to 3 MHz
    - Reduces the size, weight and cost of the common-mode chokes
- Simple external configuration for single-phase AC power systems
  - Integrated sensing filter and summing network
  - Low Y-capacitor leakage current to chassis ground at line frequency maintains safety
  - Simplified compensation network
- Inherent protection features for robust and reliable design
  - Withstands 5-kV surge with minimal external component count
    - Helps meet IEC 61000-4-5 surge immunity specification when operating in the electrical installation
    - Integrated surge protection at the SENSE inputs
  - Wide VDD supply voltage range of 8 V to 16 V, nominally 12 V
    - VDD undervoltage lockout (UVLO) set to turn on and off at 7.7 V and 6.7 V, respectively
  - 175°C thermal shutdown protection with hysteresis
  - Integrated VDD-to-EN pullup allows use of an open-drain or open-collector device for disable function
- Fully assembled, tested and proven 4-layer PCB design with 1" × 0.8" (25.4 mm × 20.3 mm) total footprint
- The EVM includes a right-angle header for easy hookup to an EMI filter board

2 EVM Performance Specifications

Unless otherwise indicated, V_{VDD} = 12 V.

Table 2-1. Electrical Performance Specifications

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
INPUT CHARACTERISTICS					
Supply voltage, V_{VDD} (1)	Operating range	8	12	16	V
UVLO turn-on threshold, $V_{VDD(on)}$	V_{VDD} rising		7.7		
UVLO turn-off threshold, $V_{VDD(off)}$	V_{VDD} falling		6.7		
UVLO hysteresis, $V_{VDD(hys)}$			1		
Supply current, disabled, $I_{VDD(off)}$	EN tied to GND		50		µA
Supply current, enabled, $I_{VDD(on)}$	EN open		12.5		mA
OUTPUT CHARACTERISTICS					
Inject voltage, V_{INJ}	Operating range	2		V_{VDD} – 2	V
Inject current, I_{INJ}	V_{VDD} = 8 V to 16 V	–80		80	mA
SYSTEM CHARACTERISTICS					
EMI reduction(2)	150 kHz to 1 MHz		25		dB
Ambient temperature, T_A		–40		105	°C
Junction temperature, T_J		–40		150	

(1) The nominal supply voltage (relative to chassis GND) of this EVM is 12 V.
(2) The expected EMI reduction with this EVM is up to 25 dB (device enabled vs. disabled) when swept from 150 kHz to 3 MHz. This performance metric can change based on the operating supply voltage, ambient temperature, passive filter component values, compensation and damping component values, and other parameters.

3 EVM Photo

Figure 3-1 highlights the AEF solution and the connection interface using header J1 to the EMI filter in the application circuit.

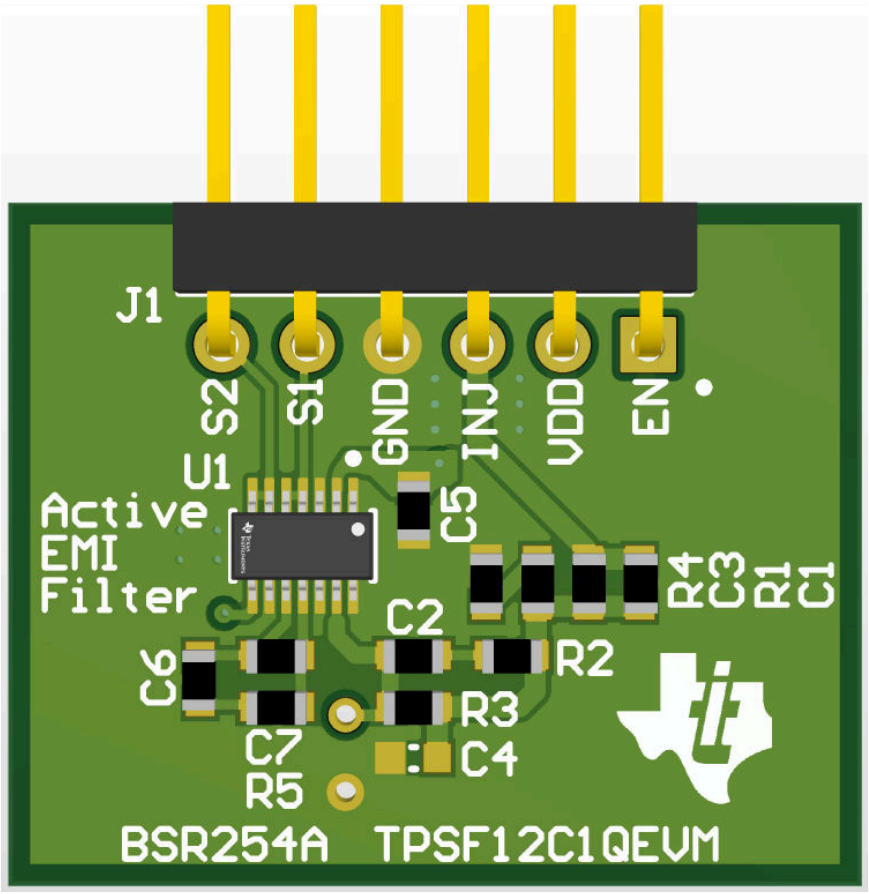

Figure 3-1. TPSF12C1QEVM Photo

CAUTION

Caution Hot surface.
Contact may cause burns.
Do not touch.

4 EVM Setup, Connections and Validation

4.1 EVM Setup

Referencing the header connections described in Table 4-1, use the recommended setup from the schematic of Figure 4-1 to evaluate the performance of the TPSF12C1-Q1, where the EVM daughter-card mounts to the main EMI filter solution. The AEF circuit effectively replaces the two Y-capacitors normally placed between the CM chokes (and tied to chassis ground) in a conventional 2-stage, 4th-order CLCL passive CM filter design.(1) (2)

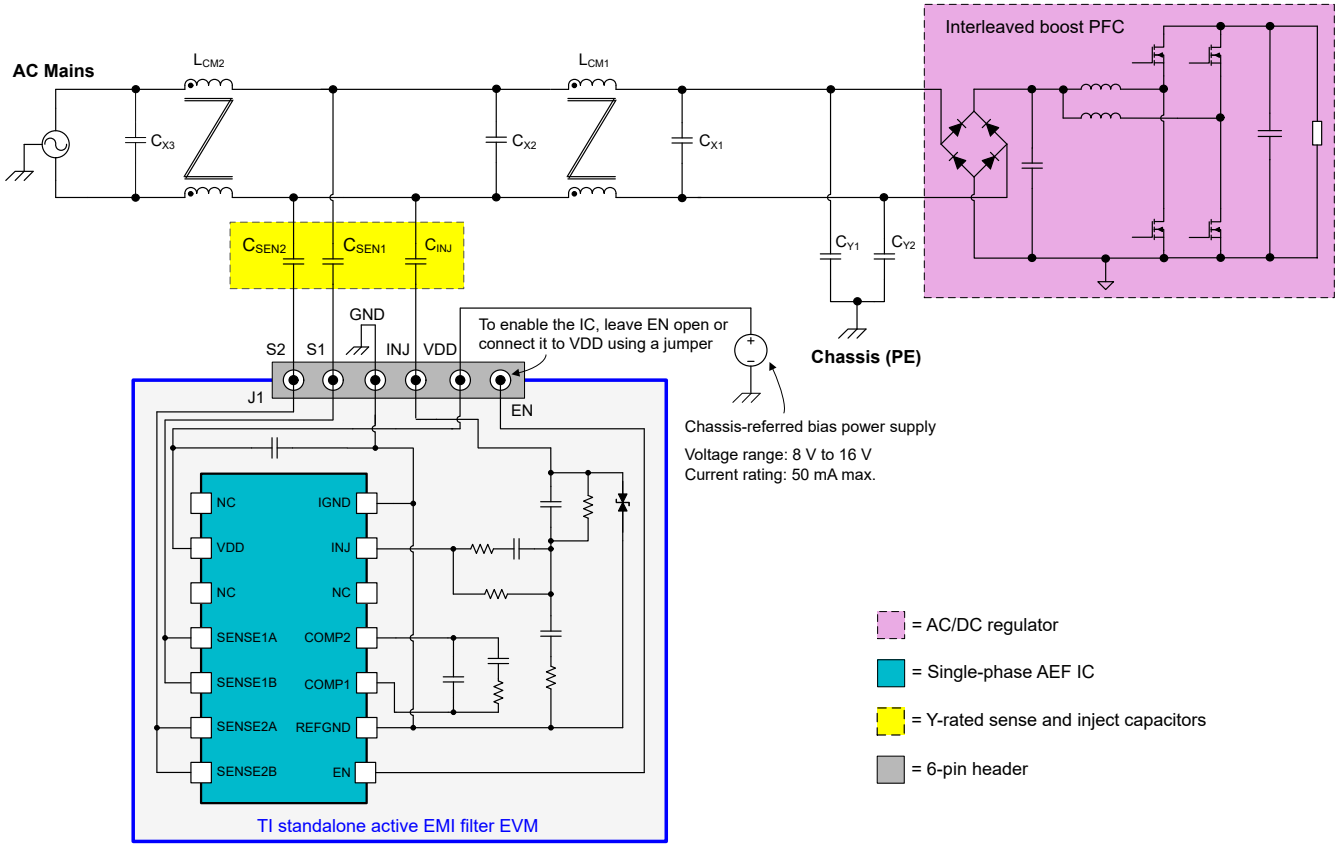

Figure 4-1. EVM Setup Schematic

An interleaved boost PFC topology in Figure 4-1 represents a typical single-phase AC/DC regulator and is drawn here for illustrative purposes. The setup is essentially agnostic to regulator topology.

Table 4-1. EVM Header Connections

POSITION(3)	LABEL	DESCRIPTION
1	EN	Enable input – leave open or tie high to enable the IC; tie to GND to disable
2	VDD	Supply voltage connection – connect to a 12-V bias power supply referenced to GND
3	INJ	Inject output – connect to a Y-rated inject capacitor, C_{INJ}
4	GND	Ground – connect to the chassis ground of the system
5	S1	Sense 1 input – connect to a Y-rated sense capacitor, C_{SEN1}
6	S2	Sense 2 input – connect to a Y-rated sense capacitor, C_{SEN2}

(1) Refer to the *TPSF12C1-Q1 Standalone Active EMI Filter for Common-mode Noise Mitigation in Single-Phase AC Automotive Power Systems* data sheet for absolute maximum and operating ratings associated with the features of this IC.
(2) Working at an ESD-protected workstation, ensure that any wrist straps, bootstraps or mats are connected and referencing the user to earth ground before power is applied to the EVM.
(3) Pin positions of header J1 are designated right to left when viewed from the top side of the EVM.

As illustrated in Figure 4-1, a 6-pin right-angle header, part number TSW-106-08-G-S-RA, connects the EVM to a corresponding female receptacle, part number SSW-106-01-G-S, which mounts on the EMI filter board that

carries the passive filter components – CM chokes and Y-capacitors – as well as the sense and inject capacitors. Both header and receptacle, manufactured by Samtec, are included with the EVM. See *Bill of Materials*.

4.2 EVM Connections

As highlighted in Table 4-1, header J1 provides an interface from the EVM to the EMI filter board with access to the following terminals:

- EN
- VDD
- INJ
- GND
- S1
- S2

Connect S1 and S2 to the two voltage sense capacitors, designated as C_{SEN1} and C_{SEN2} in Figure 4-1. Connect the opposite terminals of the sense capacitors to the LIVE and NEUTRAL lines between the CM chokes, L_{CM1} and L_{CM2}. Connect INJ to the inject capacitor, C_{INJ}, whose opposite terminal then connects to either the LIVE or NEUTRAL line as shown. The X-capacitor at this position, designated as C_{X2} in Figure 4-1, sets a low impedance between the power lines from a CM standpoint – this means that a single inject capacitor is adequate for AEF current injection. Finally, connect a nominal 12-V bias supply from VDD to GND to power the AEF circuit.

Refer to the diagram of Figure 4-2 for an example of suitable component placement on the filter board. The EVM header J1 mounts directly to receptacle J2.

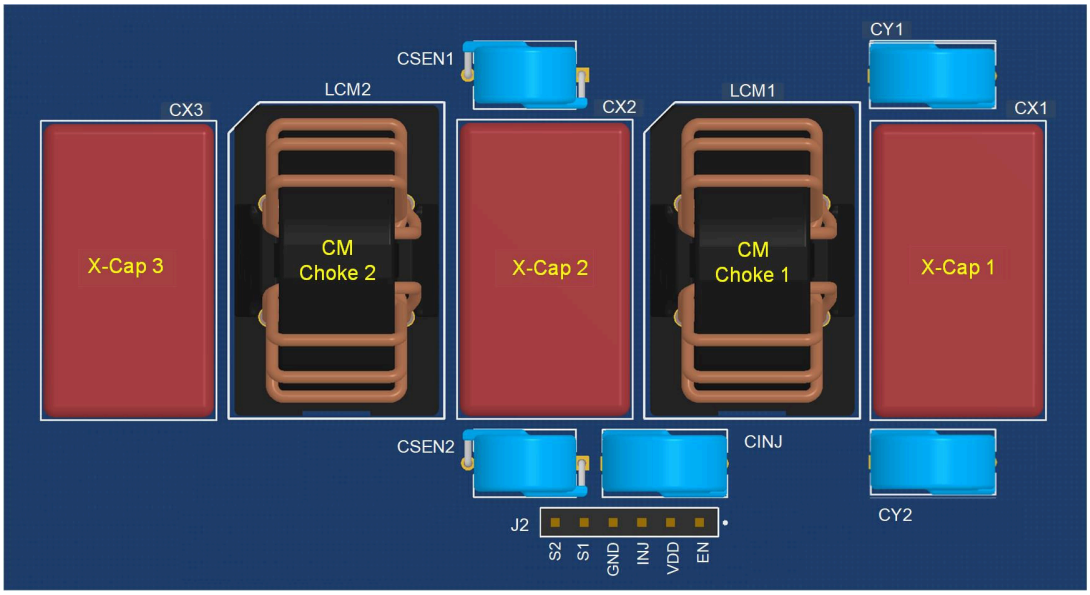

Figure 4-2. Filter Component and EVM Placement Example

4.3 EVM Performance Validation

1. Before plugging in the EVM to the EMI filter board, connect the bottom terminals of the sense and inject Y-caps to GND (Earth or chassis ground connection).
2. Turn the regulator ON. Perform measurements of the common-mode and total EMI to benchmark the existing passive filter solution.
3. Turn the regulator OFF. Wait for all high-voltage capacitors to fully discharge.
4. Plug in the EVM to the filter board (see receptacle J2 in Figure 4-2).
5. Apply a VDD bias supply voltage of 8 V to 16 V (nominal 12 V) with ripple voltage less than 50 mV peak-to-peak.
6. Probe the INJ pin of the EVM with respect to GND – it must be stable with a DC level of $V_{VDD}/2$. If the INJ pin voltage is oscillating, some of the passive components on the EVM must be modified.

7. If the INJ pin voltage is stable, turn the regulator ON. Repeat the measurements for the common-mode and total EMI.
8. Power down the regulator and EVM.
9. If the EMI measurement in step 5 is lower compared to the result in step 2, the AEF circuit functions correctly. Conversely, if the EMI measurement in step 5 is NOT lower than that from step 2, probe the INJ pin voltage while the regulator is operational. Ensure that the INJ pin voltage is not getting clipped near the positive or negative supply rails (within 2 V of each rail).
   - If the INJ pin voltage is getting clipped, one of the following must be increased:
     - Regulator-side Y-capacitance
     - Inject capacitance.

Note

The sense and inject capacitors are Y-rated components supplied by the user, and the EVM as provided is essentially a low-voltage design. Typical values for the sense and inject capacitances are 680 pF and 4.7 nF, respectively. Depending on the EMI filter implementation in the target application, the default damping and compensation component values installed on the EVM can require suitable modification by the user to achieve acceptable loop stability.

Refer to the *TPSF12C1-Q1 Standalone Active EMI Filter for Common-mode Noise Mitigation in Single-Phase AC Automotive Power Systems* data sheet and *TPSF12C1-Q1 quickstart calculator* for additional context pertaining to EVM component selection and optimization.

5 Test Data and Performance Curves

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. Unless otherwise indicated, V_{VDD} = V_{EN} = 12 V.

5.1 EMI Performance

See the *Schematic* and *Bill of Materials* for details of the EVM components for this measurement.

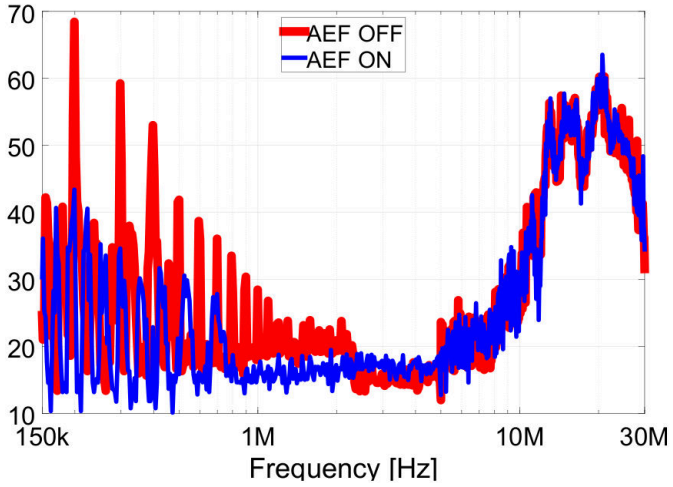

Figure 5-1. CM Conducted Emissions with AEF Enabled (Blue) and Disabled (Red)

5.2 Surge Immunity

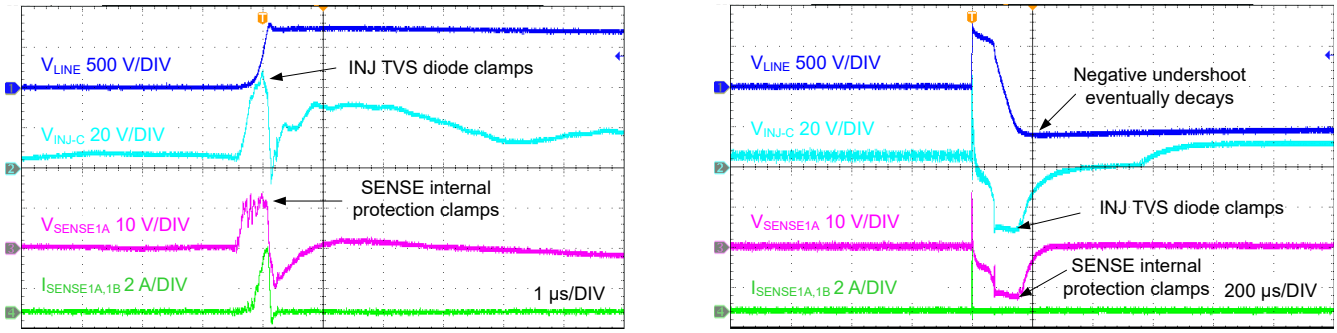

Figure 5-2. IEC 61000-4-5 Positive Surge, 5-kV Single Strike – 1 µs/div (a), 200 µs/div (b)

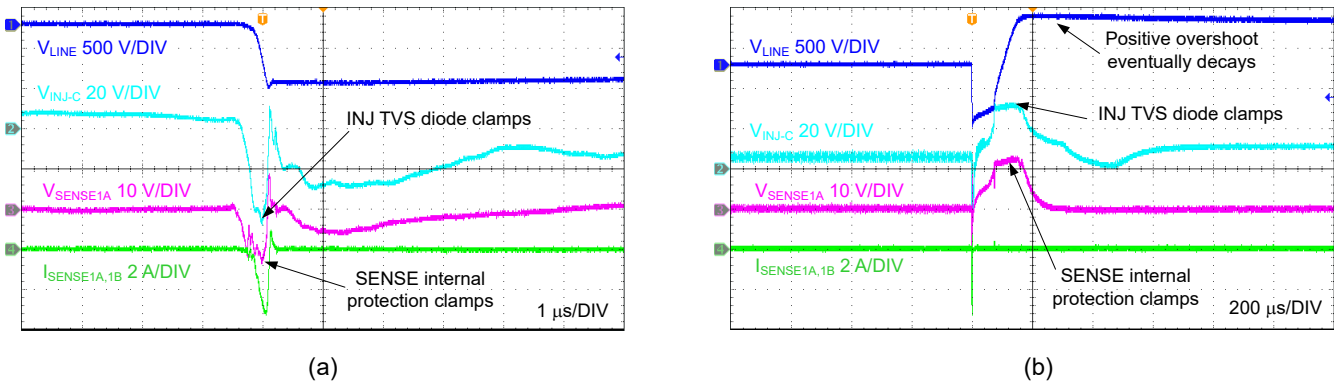

Figure 5-3. IEC 61000-4-5 Negative Surge, 5-kV Single Strike – 1 µs/div (a), 200 µs/div (b)

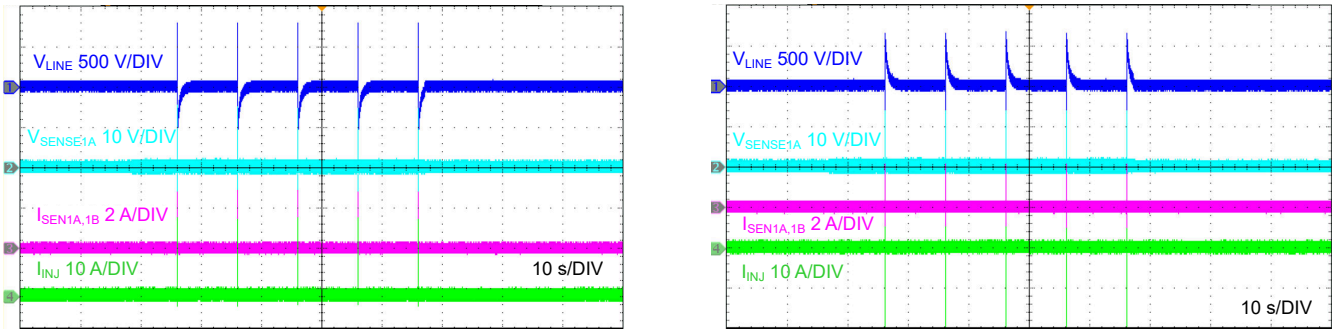

Figure 5-4. IEC 61000-4-5 Surge, 5-kV Repetitive Strike at 10-Second Intervals – Positive (a), Negative (b)

6 EVM Documentation

6.1 Schematic

Figure 6-1 provides the EVM schematic.

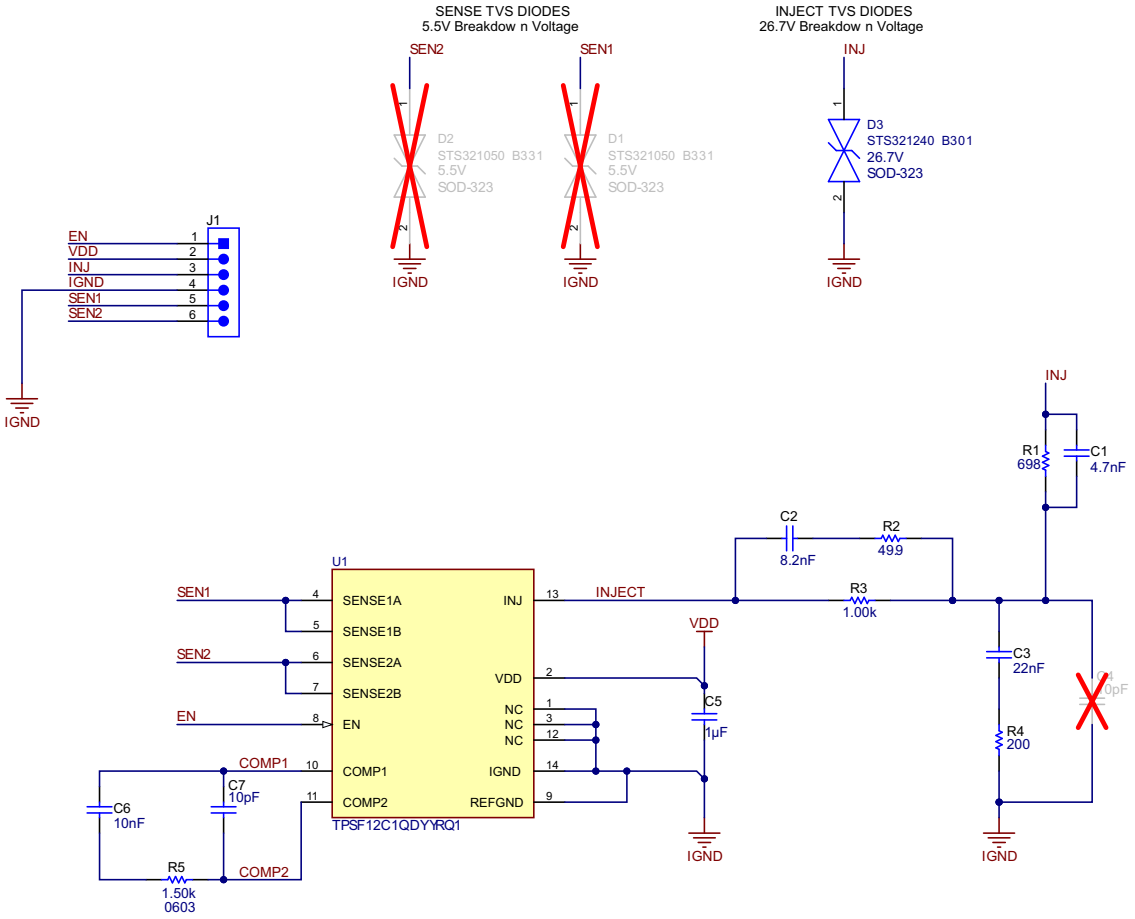

Figure 6-1. EVM Schematic

6.2 Bill of Materials

Table 6-1. EVM Component BOM

REF DES	QTY	VALUE	DESCRIPTION	PACKAGE	PART NUMBER	MANUFACTURER
C1	1	4.7 nF	CAP, CERM, 4.7 nF, 50 V, X7R	0603	C0603C472J5RACTU	Kemet
C2	1	8.2 nF	CAP, CERM, 8.2 nF, 50 V, X7R	0603	GRM188R71H822KA01D	MuRata
C3	1	22 nF	CAP, CERM, 22 nF, 50 V, X7R	0603	C0603C223K5RACTU	Kemet
C5	1	1 µF	CAP, CERM, 1 µF, 25 V, X7R	0603	CGA3E1X7R1E105K080AC	TDK
C6	1	10 nF	CAP, CERM, 10 nF, 50 V, X7R	0603	C0603X103K5RACTU	Kemet
C7	1	10 pF	CAP, CERM, 10 pF, 50 V, C0G/NP0	0603	CGA3E2C0G1H100D080AA	TDK
D3	1	24 V	TVS diode ESD suppressor, 50 V at 8 A	SOD-323	STS321240B301	Eaton
J1	1	–	Header, 100 mil, 6 × 1, Gold, R/A, TH	–	TSW-106-08-G-S-RA	Samtec
J2	1	–	Receptacle, 6 × 1, 2.54 mm, Gold, TH	–	SSW-106-01-G-S	Samtec
R1	1	698 Ω	RES, 698 Ω, 1%, 0.1 W	0603	CRCW0603698RFKEA	Vishay-Dale
R2	1	49.9 Ω	RES, 49.9 Ω, 1%, 0.1 W	0603	CRCW060349R9FKEA	Vishay-Dale
R3	1	1 kΩ	RES, 1 kΩ, 1%, 0.1 W	0603	CRCW06031K00FKEA	Vishay-Dale
R4	1	200 Ω	RES, 200 Ω, 1%, 0.1 W	0402	CRCW0603200RFKEA	Vishay-Dale
R5	1	1.5 kΩ	RES, 1.5 kΩ, 1%, 0.1 W	0402	CRCW06031K50FKEA	Vishay-Dale
U1	1	–	TPSF12C1-Q1 common-mode AEF IC	TSOT23-14	TPSF12C1QDYYRQ1	Texas Instruments

Table 6-2. Sense and Inject Capacitors (Not Supplied)

REF DES	QTY	VALUE	DESCRIPTION	PACKAGE	PART NUMBER	MANUFACTURER
C_{SEN1}, C_{SEN2}	2	680 pF	CAP, CERM, 680 pF, 300 VAC, Y2	Disc	DE2B3SA681KN3AX02F	MuRata
C_{INJ}	1	4.7 nF	CAP, CERM, 4.7 nF, 300 VAC, Y2	Disc	DE2E3SA472MA3BX02F	MuRata

6.3 PCB Layout

Figure 6-2 through Figure 6-7 show the PCB layout images, including 3D views, copper layers, assembly drawings, and layer stackup diagram. The PCB is 62-mils standard thickness with 1-oz copper on all layers.

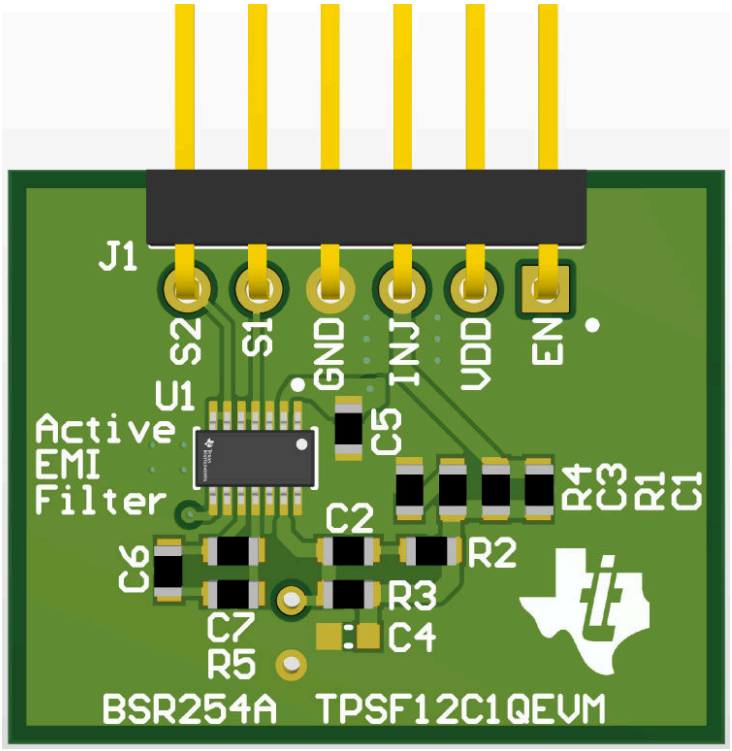

Figure 6-2. 3D Top View

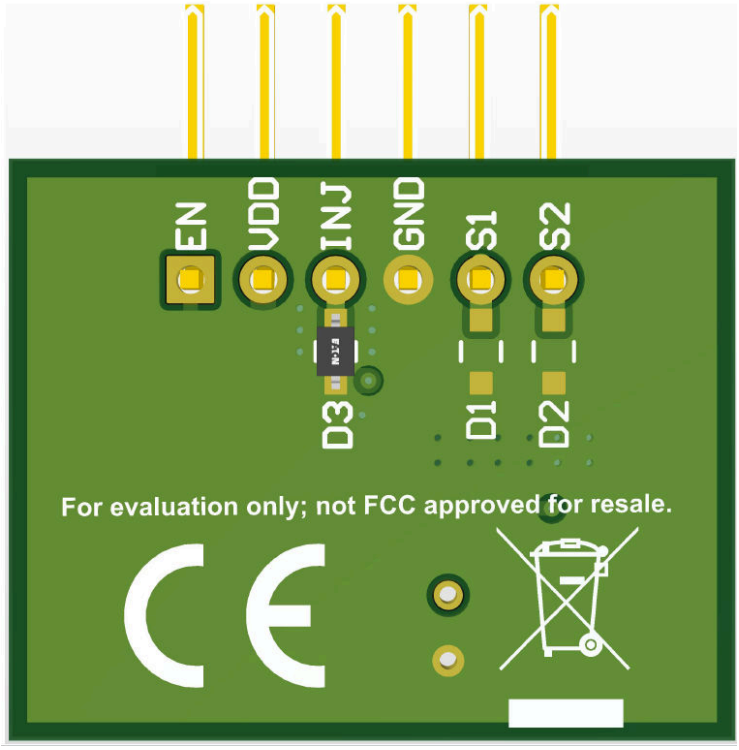

Figure 6-3. 3D Bottom View

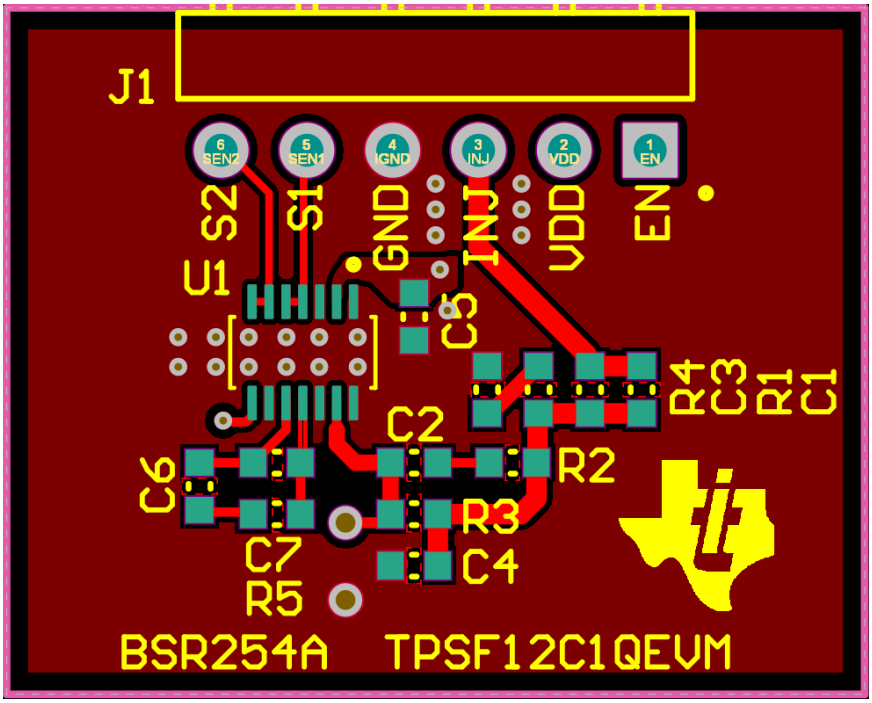

Figure 6-4. Top Layer Copper

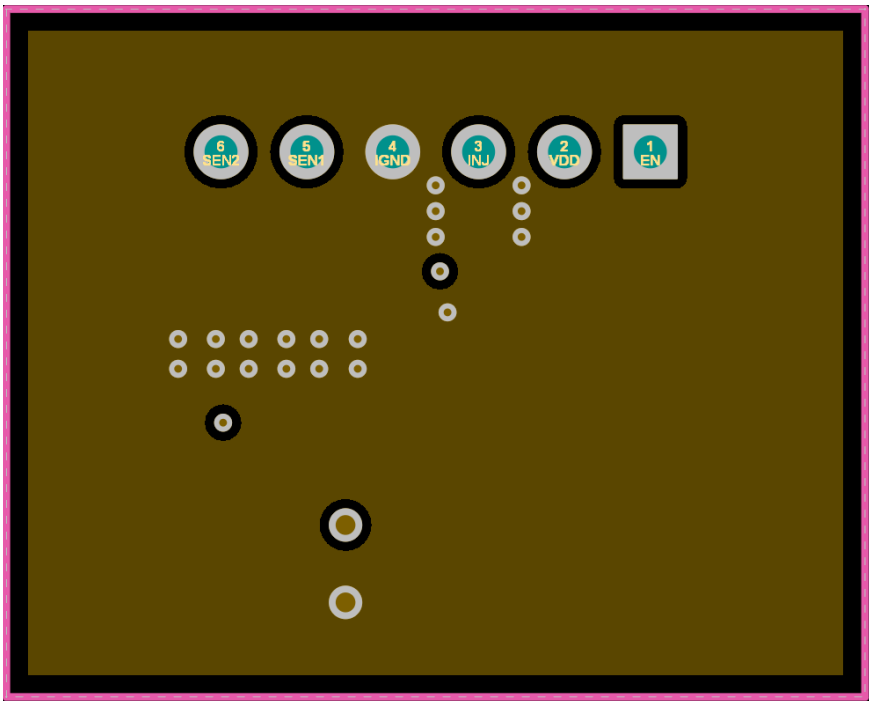

Figure 6-5. Layer 2 Copper

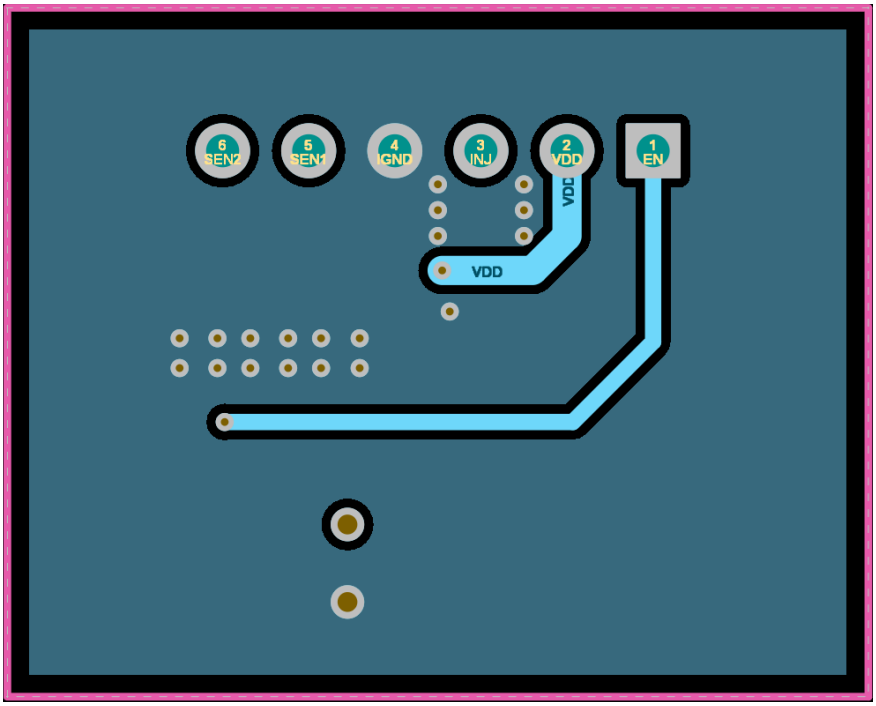

Figure 6-6. Layer 3 Copper

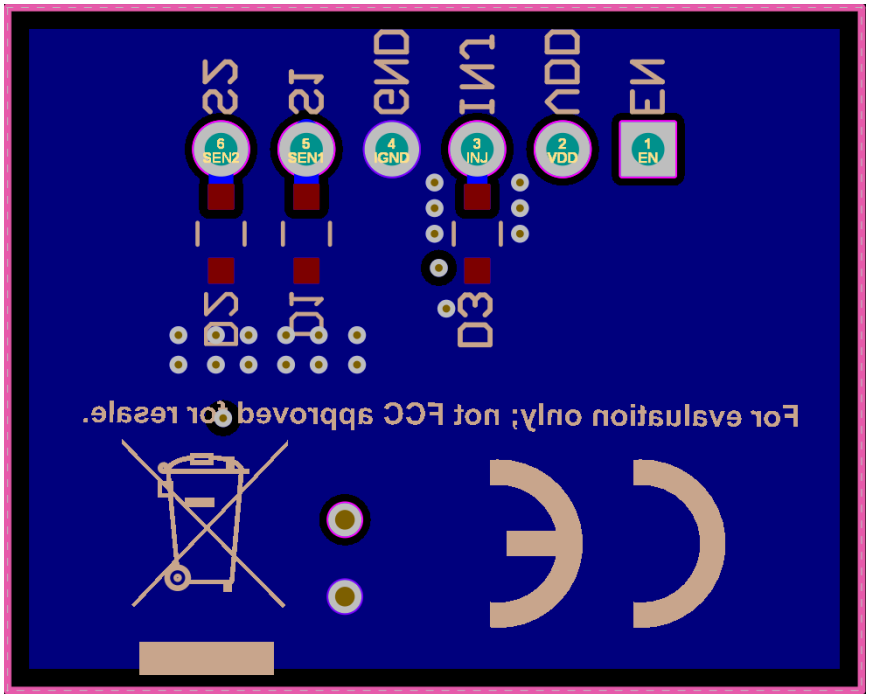

Figure 6-7. Bottom Layer Copper (Viewed From Top)

6.4 Assembly Drawings

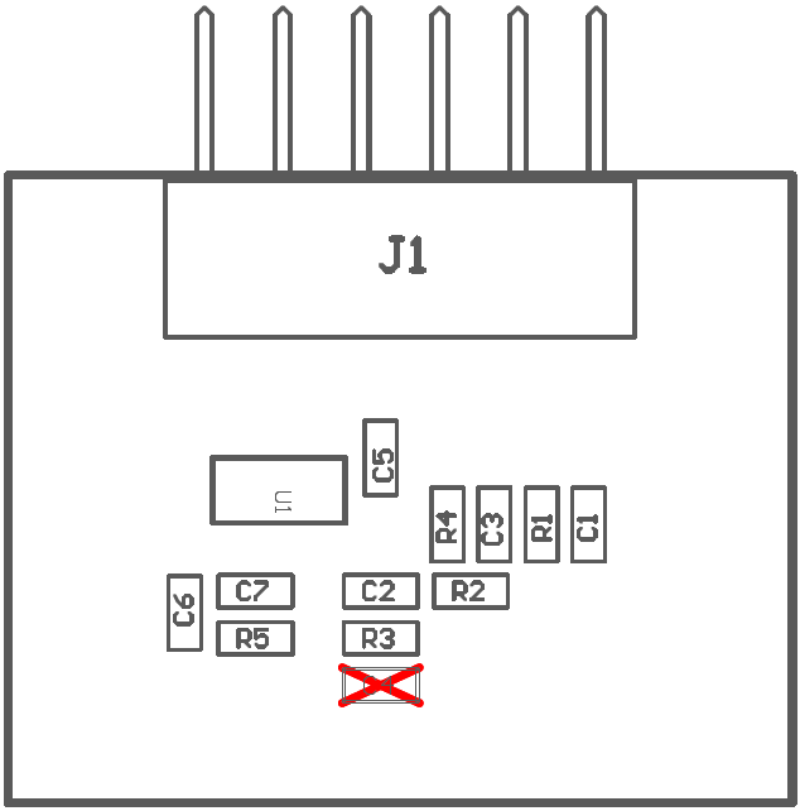

Figure 6-8. Top Assembly (Top View)

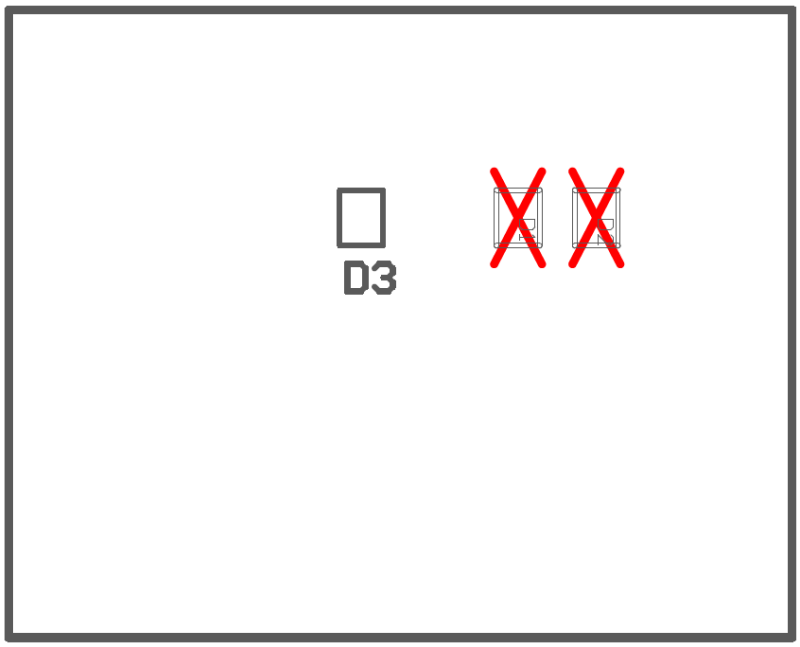

Figure 6-9. Bottom Assembly (Bottom View)

6.5 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		1oz	1.4mil	
	Dielectric 1	Prepreg	FR-4 High Tg		7mil	4.2
2	Signal Layer 1	Signal		1oz	1.4mil	
	Dielectric 2	Core	FR-4 High Tg		41mil	4.2
3	Signal Layer 2	Signal		1oz	1.4mil	
	Dielectric 3	Prepreg	FR-4 High Tg		7mil	4.2
4	Bottom Layer	Signal		1oz	1.4mil	
	Bottom Solder	Solder Mask	Solder Resist		0.4mil	3.5
	Bottom Overlay	Overlay				

Figure 6-10. Layer Stackup

7 Device and Documentation Support

7.1 Device Support

7.1.1 Development Support

For development support see the following:

- TPSF12C1-Q1 *Quickstart calculator*
- TPSF12C1-Q1 EVM *Altium layout source files*
- TPSF12C1-Q1 PSPICE for TI and SIMPLIS *simulation models*
- TPSF12C3-Q1 *EVM user's guide*
- For TI's reference design library, visit *TI Reference Design library*
- To design a low-EMI power supply, review TI's comprehensive *EMI Training Series*
- TI Reference Designs:
  - *Automotive wide V_{IN} front-end reference design for digital cockpit processing units*
- Technical Articles:
  - Texas Instruments, *How to reduce EMI and shrink power-supply size with an integrated active EMI filter*
  - Texas Instruments, *How device-level features and package options can help minimize EMI In automotive designs*
  - Texas Instruments, *How to use slew rate for EMI control*
- To view a related device of this product, see the TPSF12C3-Q1 three-phase active EMI filter for common-mode EMI mitigation

7.2 Documentation Support

7.2.1 Related Documentation

For related documentation, see the following:

- Texas Instruments, *An Engineer's Guide To EMI In DC/DC Regulators* e-book
- Texas Instruments, *Enhanced HotRod™ QFN Package: Achieving Low EMI Performance in Industry's Smallest 4-A Converter* application report
- Texas Instruments, *Designing High Performance, Low-EMI, Automotive Power Supplies* application report
- Texas Instruments, *EMI Filter Components And Their Nonidealities For Automotive DC/DC Regulators* technical brief
- Texas Instruments, *AN-2162 Simple Success With Conducted EMI From DC/DC Converters Application Report* application report
- Texas Instruments, *Simplify Low EMI Design with Power Modules* white paper

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。
http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page

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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東京都新宿区西新宿 6 丁目 2 4 番 1 号
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3.4 *European Union*

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

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

4 *EVM Use Restrictions and Warnings:*

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

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

4.3 *Safety-Related Warnings and Restrictions:*

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

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

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

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

6. *Disclaimers:*

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

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

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

8. *Limitations on Damages and Liability:*

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

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

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

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

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