

# **TPS2549Q1EVM-729 Evaluation Module**

This User's Guide describes the evaluation module (EVM) for the TPS2549-Q1 (TPS2549Q1EVM-729). The TPS2549-Q1 is a USB charging port controller with an integrated power switch and USB 2.0 high-speed data line (DP/DM) switches.

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## **1 Introduction**

The TPS2549Q1EVM-729 allows reference circuit evaluation of the TI TPS2549-Q1 automotive USB charging port controller with integrated power switch and cable compensation. The TPS2549Q1EVM-729 provides the electrical signatures on DP\_IN and DM\_IN to support all current charging schemes. The TPS2549Q1EVM-729 incorporates USB cable voltage drop compensation by linearly sensing the port current and automatically adjusting the output voltage of the LM53603AQ to keep the cable end device voltage within the normal operating range.

## 1.1 Features

The TPS2549-Q1 features include:

- Built-in IEC 61000-4-2 protection on DP\_IN and DM\_IN pins
- Linear USB cable voltage-droop compensation
- Fully AEC Q100 qualified
- Built-in short to VBUS protection and notification on DP\_IN and DM\_IN pins
- LM53603AQ high performance 2.1-MHz automotive qualified DC/DC converter

## 1.2 Applications

The TPS2549-Q1 can be used in the following applications:

- Automotive infotainment system
- Automotive USB charging box

## 2 Description

The TPS2549Q1EVM-729 enables full evaluation of the TPS2549-Q1 device, refer to the schematic in [Figure 1](#). An automotive voltage range input is applied at the J3 connector. The input stage consists of an input switch (Q1), protection (D2), and an input filter (L1, C1, C2, C3, C5). The voltage at the 5VDC node is regulated by the LM53603AQ buck regulator (U1) and associated circuitry. This provides a nominal 5-V, 3-A output for the TPS2549-Q1 (U2).

The TPS2549-Q1 internal power switch connects the 5VDC node to VBUS at the downstream facing USB connector, J1. When the internal power switch is ON, the D5 LED (green) will illuminate. USB 2.0 data can be passed through the TPS2549Q1EVM-729 from J2 to J1 when the TPS2549-Q1 is configured for either SDP or CDP mode using the J6 header. TPS2549-Q1 status and fault conditions can be detected using the D4 (blue) and D3 (red) LEDs, respectively.

TPS2549-Q1 provides system-level ESD protection in accordance with IEC 61000-4-2 up to  $\pm 8$ -kV contact and  $\pm 15$ -kV air discharge at the DP\_IN and DM\_IN signals going to J1. These pins will also provide detection of shorts to VBUS by triggering the FAULT logic and illuminating D3.

The TPS2549-Q1 provides USB cable voltage-droop compensation at the load through the use of the CS pin. Sinking current into the CS pin mirrors the current through the TPS2549-Q1 power switch at a rate of 75  $\mu$ A/A. The CS pin current is summed with the LM53603AQ regulator feedback current through R8 causing the regulator output voltage to change with USB downstream load current. The voltage at the 5VDC node increases linearly as load current increases. This compensation will keep the load end voltage close to 5 V<sub>DC</sub>. The default compensation resistor values (R8 and R10) target a USB cable resistance of 200 m $\Omega$ . Three additional cable resistance examples are provided in the following list.

- For 300-m $\Omega$  CC: R8 = 5.11 k $\Omega$ , R10 = 17.8 k $\Omega$
- For 400-m $\Omega$  CC: R8 = 6.49 k $\Omega$ , R10 = 16.5 k $\Omega$
- For 500-m $\Omega$  CC: R8 = 7.68 k $\Omega$ , R10 = 15.4 k $\Omega$

Refer to the TPS2549-Q1 datasheet ([SLUSCE3](#)) for more information.

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**NOTE:** The values shown for R8 and R10 take into account the effects of the TPS2549Q1 power switch and J1 receptacle/plug resistances (approximately 0.1 ohms, total). The effects of R5 are also included. Designs which do not need to account for these losses can exclude these from the equations.

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### 3 Schematic

Figure 1 illustrates the EVM schematic.

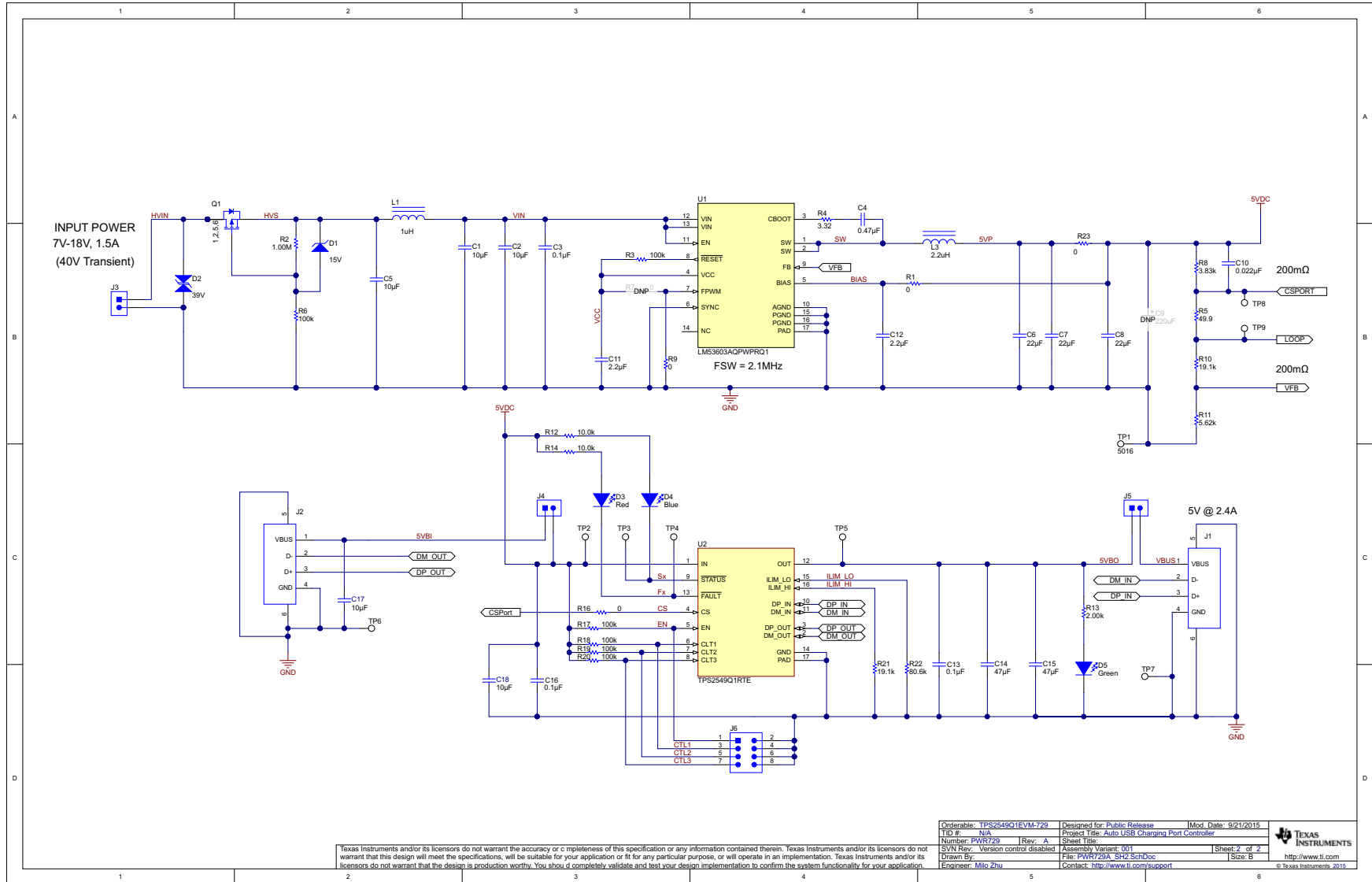


Figure 1. TPS2549Q1EVM-729 Schematic

## 4 General Configuration and Description

### 4.1 Physical Access

Table 1 lists the TPS2549Q1EVM-729 connector functionality, Table 2 describes the test point availability, and Table 3 describes the jumper functionality.

**Table 1. Connector Functionality**

Connector	Label	Description
J1	DOWNSTREAM	Downstream facing USB 2.0 connector. Connect to the USB 2.0 slave for data pass-through from J2. USB output power is provided to the slave when the J5 shunt is installed.
J2	UPSTREAM	Upstream facing USB 2.0 connector. Connect to the USB 2.0 host for data pass-through to J1. USB input power can also be provided by the host when the J4 shunt is installed.
J3	HVIN	Automotive input voltage range connector. Connect to a 7 V–18 V, 1.5-A voltage source according to the polarity marked on the EVM.
D3 (RED)	FAULT	TPS2549-Q1 FAULT output is triggered
D4 (BLUE)	STATUS	TPS2549-Q1 STATUS output is triggered
D5 (GREEN)	ON	TPS2549-Q1 output powered

**Table 2. Test Points**

Test Point	Color	Label	Description
TP1	SM-L	GND	Back side GND test point
TP2	SM-S	5VDC	TPS2549-Q1 power switch input from DC-DC converter
TP3	SM-S	STATx	TPS2549-Q1 STATUS pin output
TP4	SM-S	FLT <sub>x</sub>	TPS2549-Q1 FAULT pin output
TP5	SM-S	5VBO	TPS2549-Q1 power switch output
TP6	SM-L	GND	Top side GND test point near J2
TP7	SM-L	GND	Top side GND test point near J1
TP8	SM-S	CS	Loop injection point, use with TP9
TP9	SM-S	LOOP	Loop injection point, use with TP8

**Table 3. Jumpers**

Jumper	Label	Description
J4	5VDC	USB host furnished input voltage. Install to power TPS2549-Q1 with a USB host.
J5	5VBO	Install to connect TPS2549-Q1 power switch output to J1 VBUS
J6	J6	TPS2549-Q1 mode select jumper block. Install shunt at EN (1-2) to disable TPS2549-Q1. C1, C2, C3 positions select the charging mode for TPS2549-Q1. Refer to the datasheet for more information.

### 4.2 Test Setup

Figure 2 shows a typical test setup for TPS2549Q1EVM-729. Connect J3 to the 14-V power supply. The TPS2549-Q1 output load can be applied either between TP5 and TP7 or via the USB 2.0 cable plugged into J1.

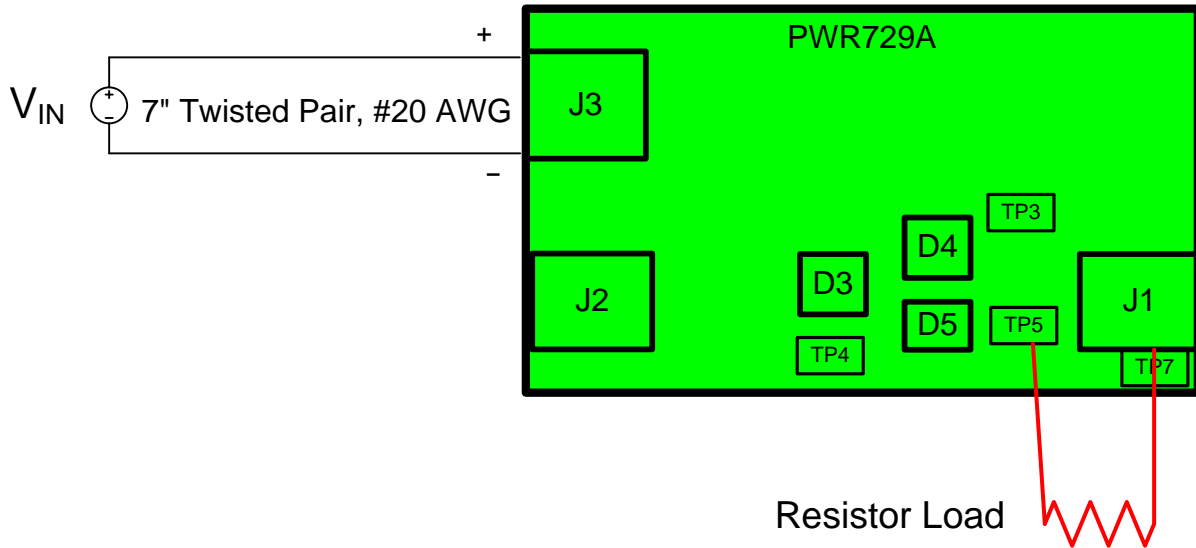


Figure 2. Typical TPS549Q1EVM-729 Test Setup

## 5 EVM Assembly Drawings and Layout Guidelines

### 5.1 PCB Drawings

Figure 3 through Figure 8 show component placement and layout of the EVM.

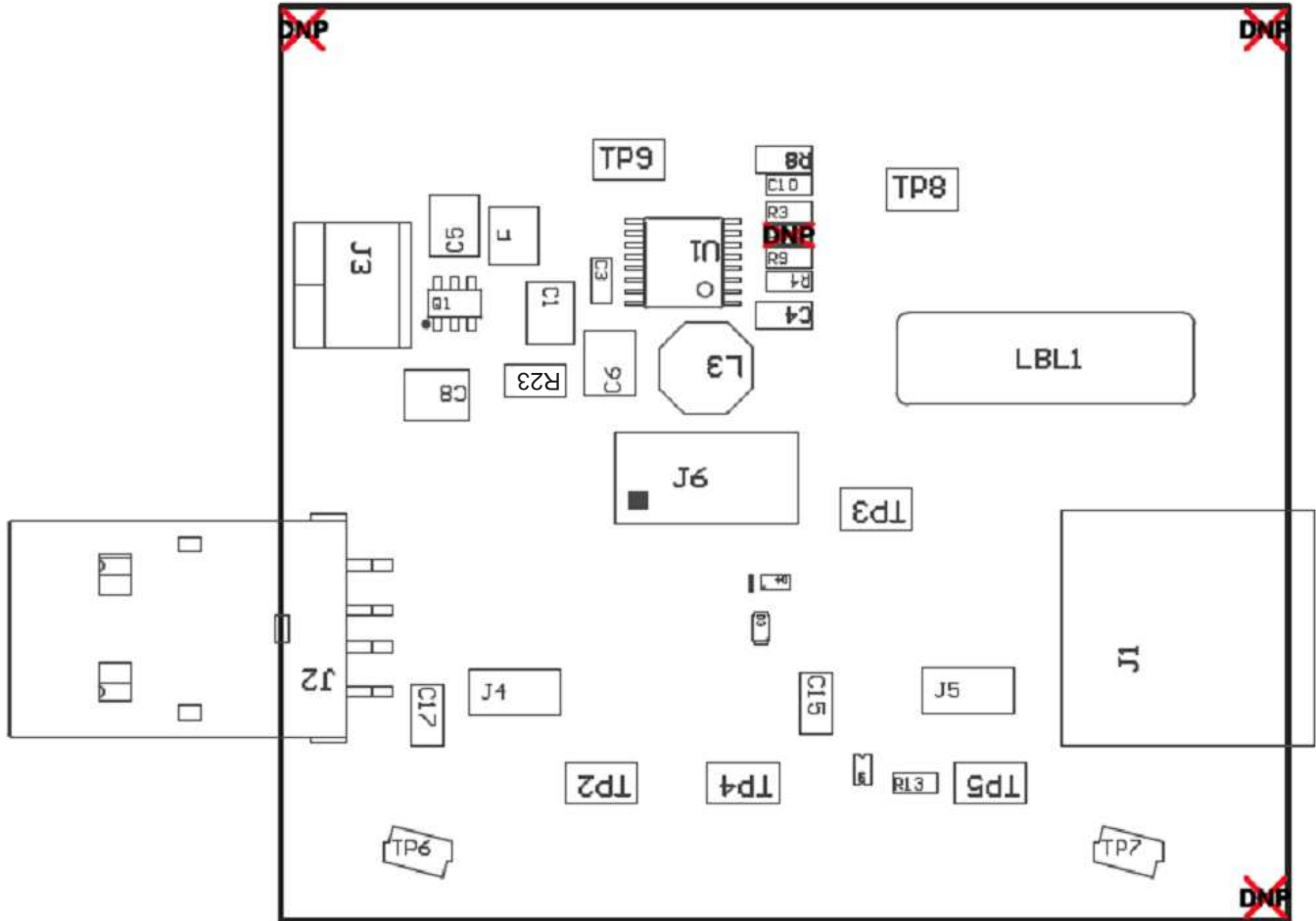
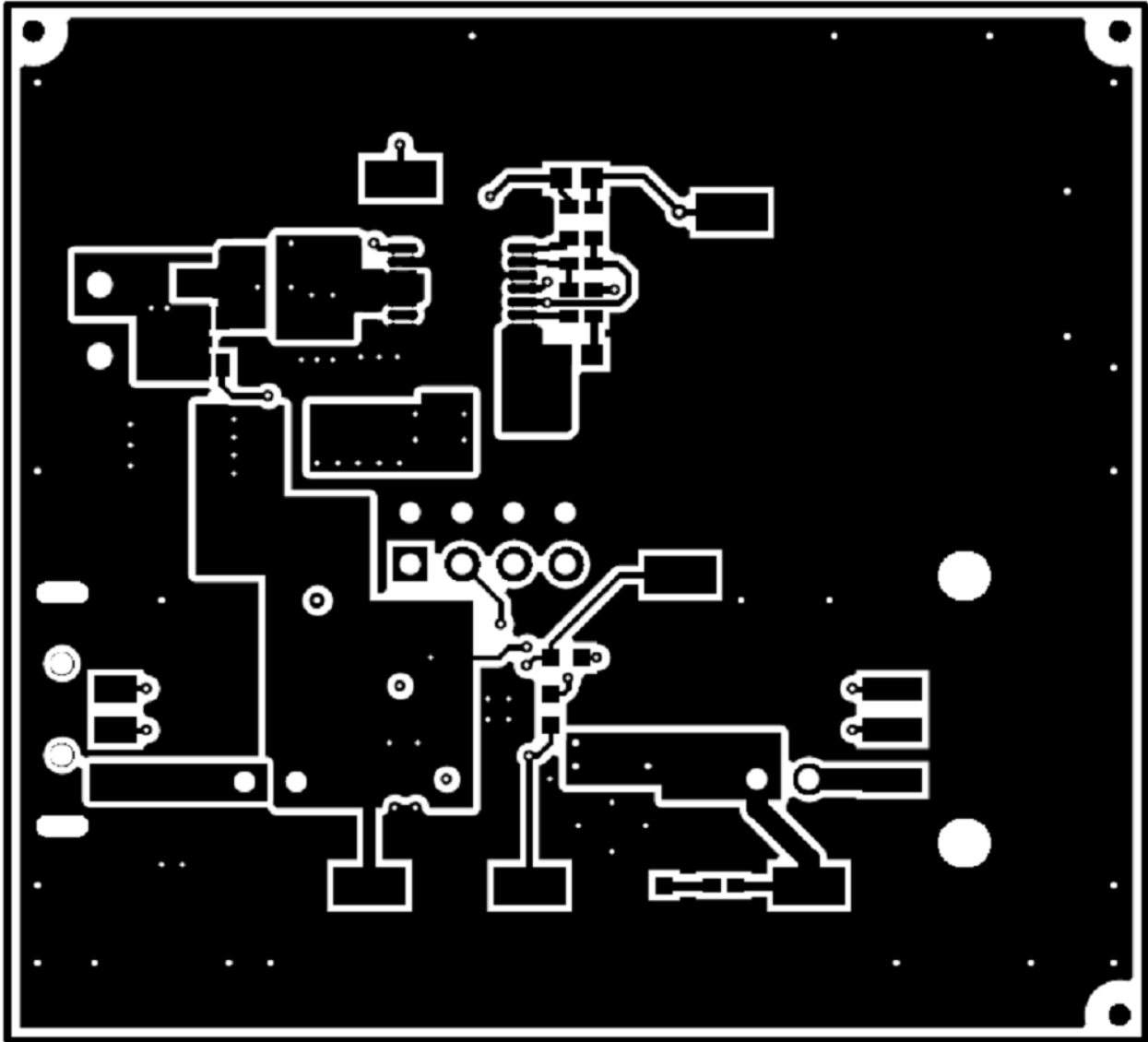


Figure 3. Top Side Placement



**Figure 4. Top Side Routing**

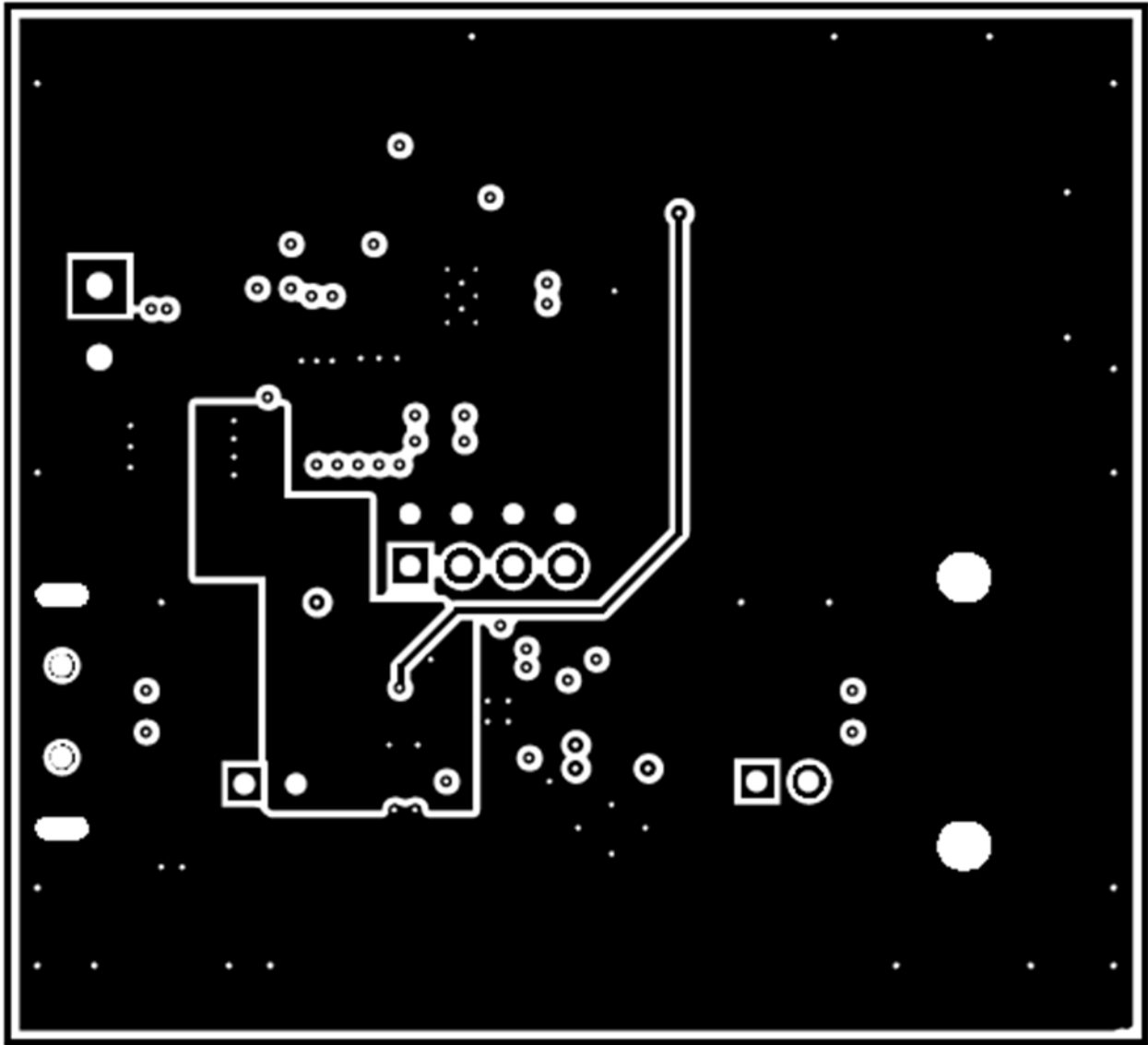
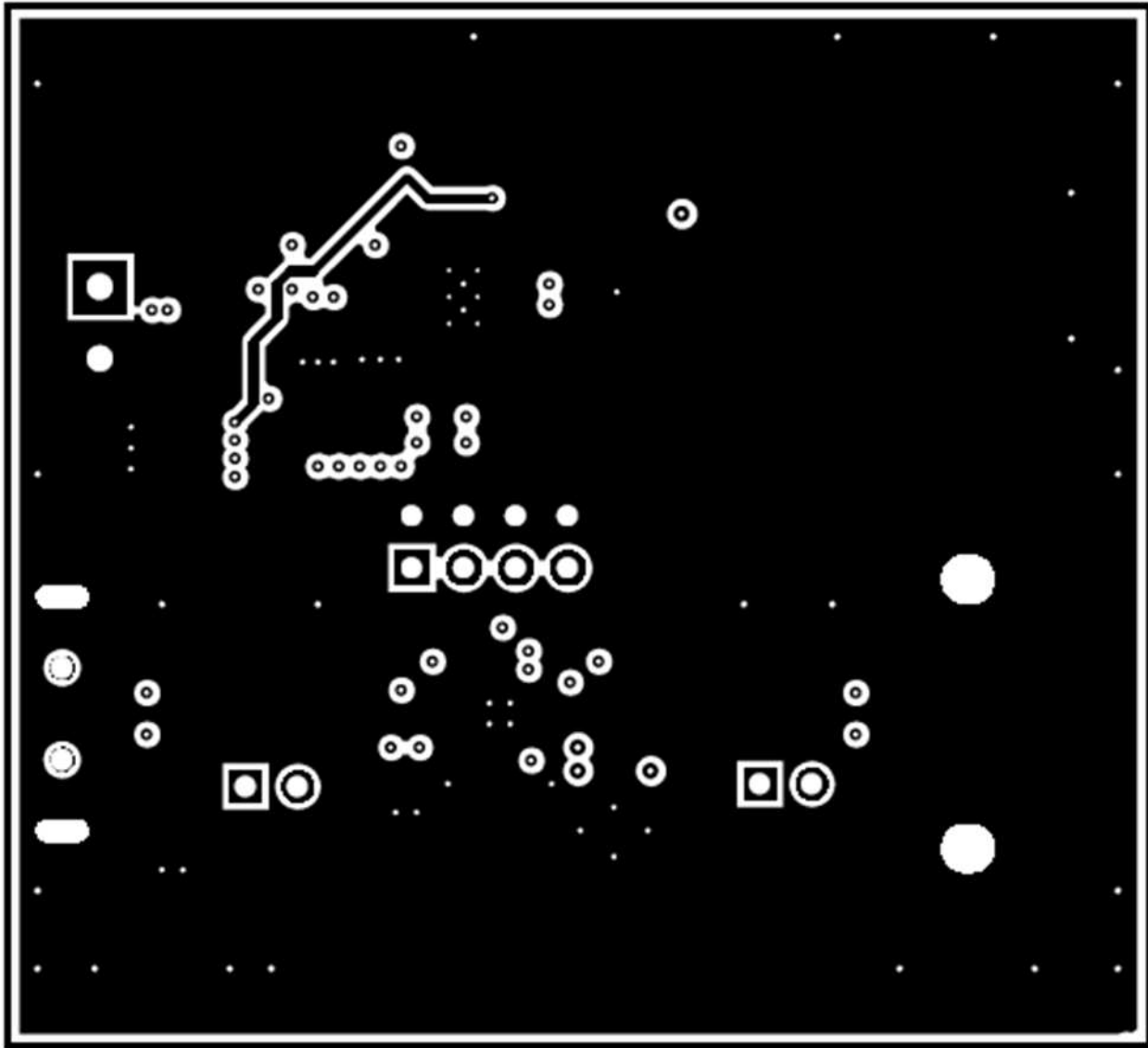


Figure 5. Layer Two Routing





**Figure 6. Layer Three Routing**

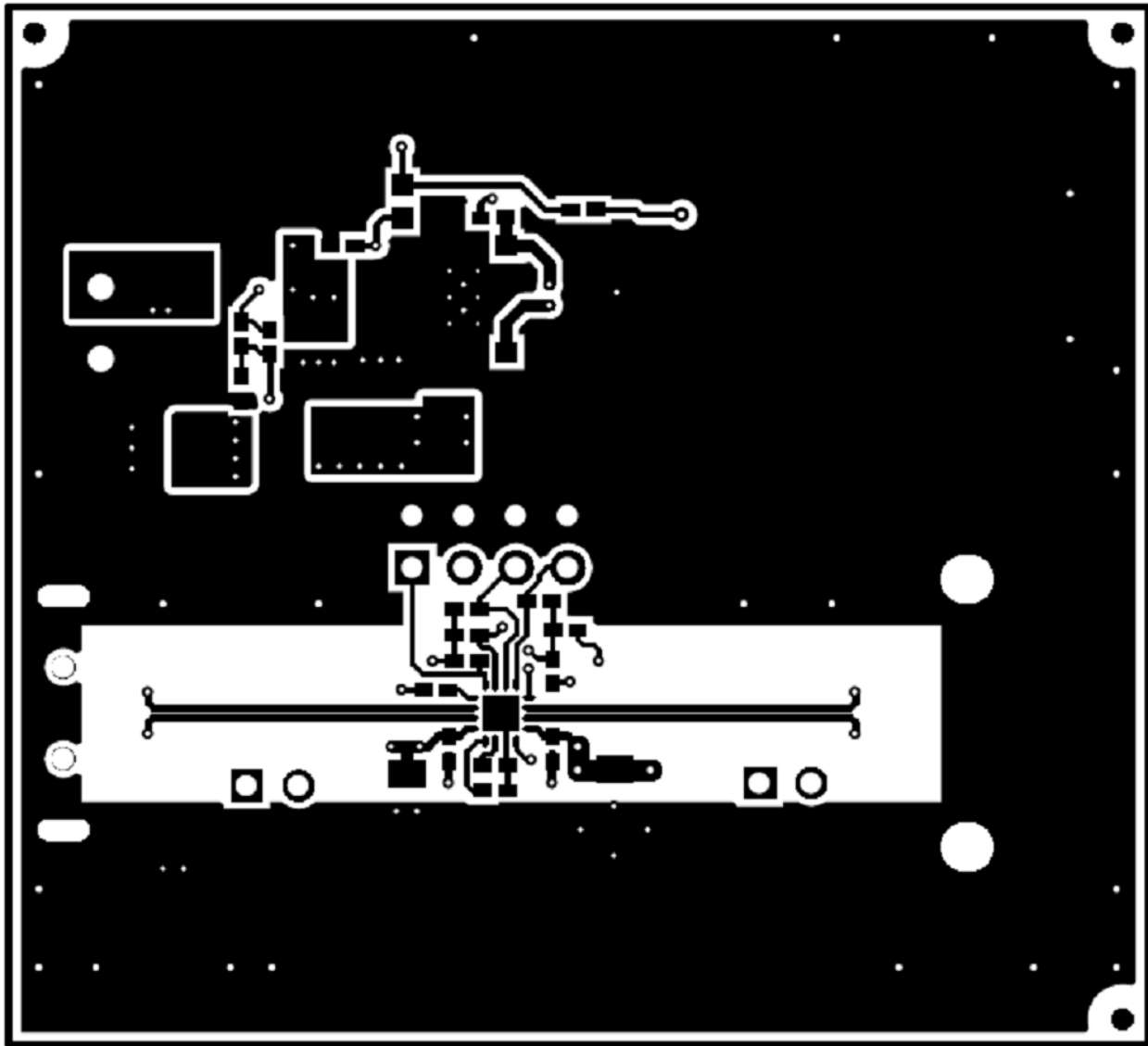


Figure 7. Bottom Side Routing

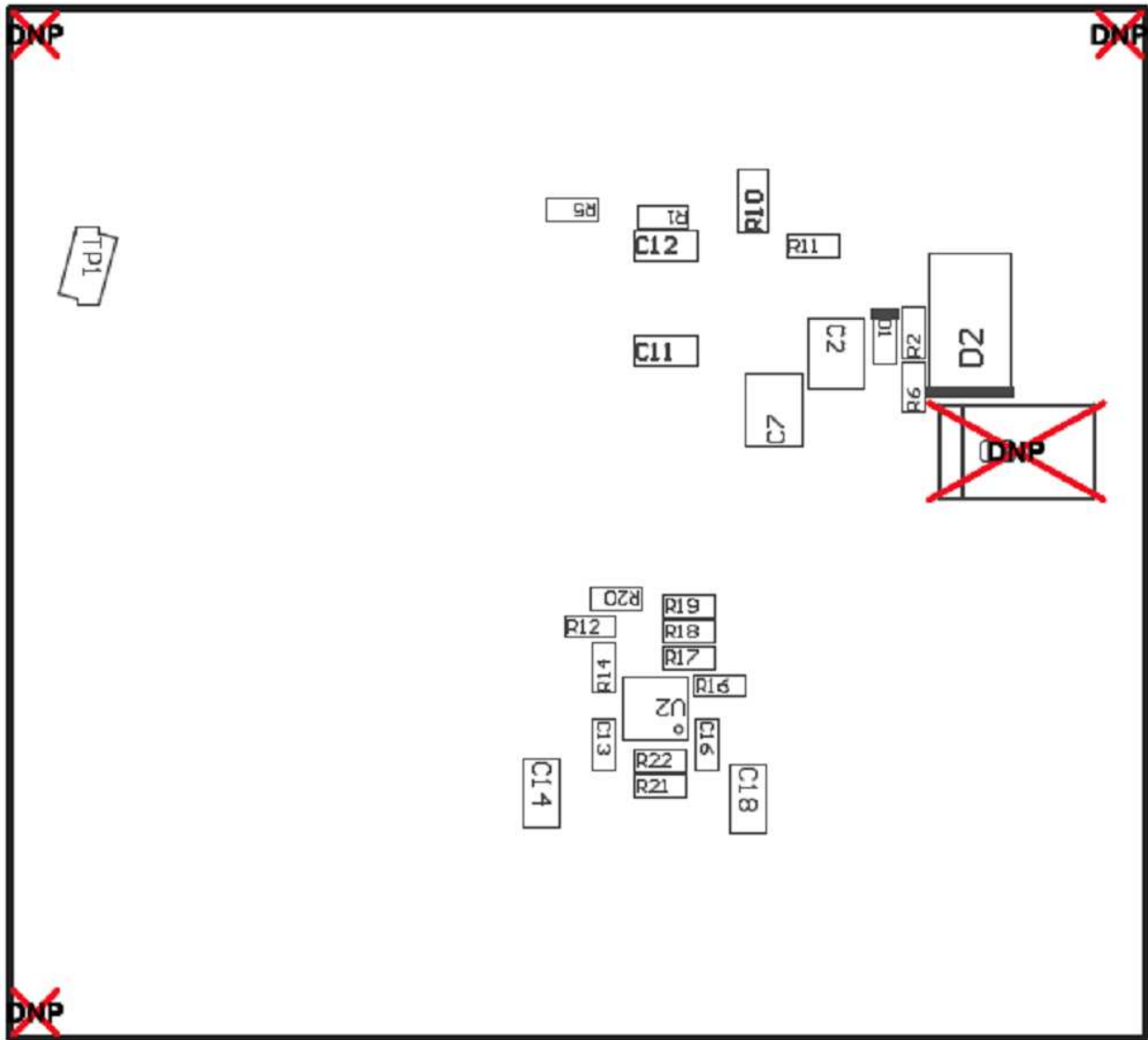


Figure 8. Bottom Side Placement

## 5.2 Layout Guidelines

This section contains the EVM layout guidelines:

- TPS2549-Q1 placement: Place the TPS2549-Q1 near the USB output connector and OUT pin filter capacitors. Connect the exposed pad to the GND pin and the system ground plane using an array of vias.
- IN pin bypass capacitance: Place the 0.1- $\mu$ F bypass capacitor near the IN pin and make the connection using a low inductance trace.
- DP-OUT/DM-OUT, DP-IN/DM-IN traces: Route these traces as controlled impedance differential pairs per the USB-2.0 specification. Minimize the use of vias in the high speed data lines. [Figure 7](#) provides a good signal routing example for the high-speed data traces. In this example, the data pairs are routed as edge-coupled microstrips with nominal differential impedance of 90  $\Omega$ . The reference plane is tied to GND and is shown in [Figure 6](#). Ensure that the reference plane is void of cuts or splits above the differential pairs to prevent impedance discontinuities.
- ILIM\_LO and ILIM\_HI Pin Connections: Current-limit, set-point accuracy can be compromised by stray current leakage from a higher voltage source to the ILIM\_LO or ILIM\_HI pins. Ensure that there is adequate spacing between IN pin copper/trace and ILIM\_LO pin trace to prevent contaminant buildup during the PCB assembly process.

## 5.3 EMI Containment

The following list describes EMI containment guidelines:

- Use compact loops for dv/dt and di/dt circuit paths (power loops and gate drives).
- Use minimal, yet thermally adequate, copper areas for heat sinking of components tied to switching nodes (minimize exposed radiating surface).
- Use copper ground planes (possible stitching) and top layer copper floods (surround circuitry with ground floods).
- Use 4-layer PCB, if economically feasible (for better grounding).
- Minimize the amount of copper area associated with input traces (to minimize radiated pickup).
- Maintain physical separation between input-related circuitry and power circuitry (use ferrite beads as boundary line).
- Possible use of common-mode inductors

## 6 Bill of Materials

Table 4 lists the EVM BOM.

**Table 4. TPS2549Q1EVM-729 Bill of Materials**

Designator	Qty	Value	Description	PackageReference	PartNumber	Manufacturer	Alternate Part Number	Alternate Manufacturer
!PCB	1		Printed Circuit Board		PWR729	Any		
C1, C2, C5	3	10uF	CAP, CERM, 10 µF, 50 V, +/- 10%, X7R, 1210	1210	GRM32ER71H106KA12L	Murata		
C3, C13, C16	3	0.1uF	CAP, CERM, 0.1 µF, 50 V, +/- 10%, X7R, 0402	0402	C1005X7R1H104K050BB	TDK		
C4	1	0.47uF	CAP, CERM, 0.47 µF, 16 V, +/- 10%, X7R, 0603	0603	C0603C474K4RACTU	Kemet		
C6, C7, C8	3	22uF	CAP, CERM, 22 µF, 16 V, +/- 10%, X7R, 1210	1210	GCM32ER71C226KE19L	Murata		
C10	1	0.022uF	CAP, CERM, 0.022 µF, 16 V, +/- 10%, X7R, 0402	0402	GRM155R71C223KA01D	Murata		
C11, C12	2	2.2uF	CAP, CERM, 2.2 µF, 10 V, +/- 10%, X7R, 0603	0603	GRM188R71A225KE15D	Murata		
C14, C15	2	47uF	CAP, CERM, 47 µF, 16 V, +/- 15%, X5R, 1206	1206	C3216X5R1C476M160AB	TDK		
C17, C18	2	10uF	CAP, CERM, 10 µF, 16 V, +/- 10%, X7R, 1206	1206	GRM31CR71C106KAC7L	Murata		
D1	1	15V	Diode, Zener, 15 V, 300 mW, SOD-523	SOD-523	BZT52C15T-7	Diodes Inc.		
D2	1	39V	Diode, TVS, Bi, 39 V, 600 W, SMB	SMB	SM6T39CA	STMicroelectronics		
D3	1	Red	LED, Red, SMD	SMD, 2-Leads, Body 1.3x0.8mm	LS L29K-G1J2-1-Z	OSRAM		
D4	1	Blue	LED, Blue, SMD	BLUE 0603 LED	LB Q39G-L2N2-35-1	OSRAM		
D5	1	Green	LED, Green, SMD	0.8x1.6mm	HSMG-C190	Avago		
J1	1		Connector, Receptacle, USB TYPE A, R/A, Top Mount SMT	USB TYPE A CONNECTOR RECEPTACLE 4POS SMD	896-43-004-00-000000	Mill-Max		
J2	1		Connector, Plug, USB Type A, R/A, Top Mount SMT	USB Type A right angle	48037-1000	Molex		
J3	1		Terminal Block, 6A, 3.5mm Pitch, 2-Pos, TH	7.0x8.2x6.5mm	ED555/2DS	On-Shore Technology		
J4, J5	2		Header, 100mil, 2x1, Tin, TH	Header, 2 PIN, 100mil, Tin	PEC02SAAN	Sullins Connector Solutions		
J6	1		Header, 100mil, 4x2, Tin, TH	Header, 4x2, 100mil, Tin	PEC04DAAN	Sullins Connector Solutions		
L1	1	1uH	Inductor, Shielded, Ferrite, 1 µH, 2.15 A, 0.025 ohm, SMD	IND_3x1.5x3mm	VLF302515MT-1R0N	TDK		
L3	1	2.2uH	Inductor, Shielded, Ferrite, 2.2 µH, 3.2 A, 0.04 ohm, SMD	Inductor, 5x2.2x5mm	LTF5022T-2R2N3R2-LC	TDK		
LBL1	1		Thermal Transfer Printable Labels, 0.650" W x 0.200" H - 10,000 per roll	PCB Label 0.650"H x 0.200"W	THT-14-423-10	Brady		
Q1	1	60V	MOSFET, P-CH, 60 V, -3 A, SOT-23-6	SOT-23-6	FDC5614P	Fairchild Semiconductor		None
R1, R9, R16	3	0	RES, 0, 5%, 0.063 W, 0402	0402	RC0402JR-070RL	Yageo America		
R2	1	1.00Meg	RES, 1.00 M, 1%, 0.063 W, 0402	0402	CRCW04021M00FKED	Vishay-Dale		
R3, R6, R17, R18, R19, R20	6	100k	RES, 100 k, 1%, 0.063 W, 0402	0402	CRCW0402100KFKED	Vishay-Dale		
R4	1	3.32	RES, 3.32, 1%, 0.063 W, 0402	0402	CRCW04023R32FKED	Vishay-Dale		
R5	1	49.9	RES, 49.9, 1%, 0.063 W, 0402	0402	CRCW040249R9FKED	Vishay-Dale		
R8	1	3.83k	RES, 3.83 k, 1%, 0.1 W, 0603	0603	CRCW06033K83FKEA	Vishay-Dale		
R10	1	19.1k	RES, 19.1 k, 1%, 0.1 W, 0603	0603	CRCW060319K1FKEA	Vishay-Dale		
R11	1	5.62k	RES, 5.62 k, 1%, 0.063 W, 0402	0402	CRCW04025K62FKED	Vishay-Dale		
R12, R14	2	10.0k	RES, 10.0 k, 1%, 0.063 W, 0402	0402	CRCW040210K0FKED	Vishay-Dale		

**Table 4. TPS2549Q1EVM-729 Bill of Materials (continued)**

Designator	Qty	Value	Description	PackageReference	PartNumber	Manufacturer	Alternate Part Number	Alternate Manufacturer
R13	1	2.00k	RES, 2.00 k, 1%, 0.063 W, 0402	0402	CRCW04022K00FKED	Vishay-Dale		
R21	1	19.1k	RES, 19.1 k, 1%, 0.063 W, 0402	0402	CRCW040219K1FKED	Vishay-Dale		
R22	1	80.6k	RES, 80.6 k, 1%, 0.063 W, 0402	0402	CRCW040280K6FKED	Vishay-Dale		
R23	1	0	RES, 0, 5%, 0.25 W, 1206	1206	CRCW12060000Z0EA	Vishay-Dales		
SH-J1, SH-J2	2	1x2	Shunt, 100mil, Gold plated, Black	Shunt	969102-0000-DA	3M	SNT-100-BK-G	Samtec
TP1, TP6, TP7	3	SMT	Test Point, Compact, SMT	Testpoint_Keystone_Compact	5016	Keystone		
TP2, TP3, TP4, TP5, TP8, TP9	6	SMT	Test Point, Miniature, SMT	Testpoint_Keystone_Miniature	5015	Keystone		
U1	1		5V/3.3V/ADJ, 3A, Buck Regulator For Automotive Applications, PWP0016H	PWP0016H	LM53603AQPWPRQ1	Texas Instruments	LM53603AQPWPTQ1	Texas Instruments
U2	1		Automotive USB Charging Port Controller with Integrated Power Switch & Cable Compensation, RTE0016C	RTE0016C	TPS2549Q1RTE	Texas Instruments		Texas Instruments
C9	0	220uF	CAP, TA, 220 $\mu$ F, 10 V, +/- 20%, 0.025 ohm, SMD	7.3x2.8x4.3mm	10TPE220ML	Panasonic		
FID1, FID2, FID3, FID4, FID5, FID6	0		Fiducial mark. There is nothing to buy or mount.	N/A	N/A	N/A		
R7	0	0	RES, 0, 5%, 0.063 W, 0402	0402	MCR01MZPJ000	Rohm		

## Revision History

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

Changes from Original (October 2015) to A Revision	Page
• Changed L2 50 ohm To: 0 in <a href="#">Figure 1</a> .....	3
• Changed item L2 To R23 in the <a href="#">Table 4</a> .....	14

## STANDARD TERMS AND CONDITIONS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including 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 and conditions set forth herein. Acceptance of the EVM is expressly subject to the following terms and conditions.
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  - 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 and conditions 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 any defects that are 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. Moreover, TI shall not be liable for any defects that result from User's design, specifications or instructions for such EVMs. Testing and other quality control techniques are used to the extent TI deems necessary or as mandated by government requirements. TI does not test all parameters of each EVM.
  - 2.3 If any EVM fails to conform to the warranty set forth above, TI's sole liability shall be at its option to repair or replace such EVM, 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.
3. *Regulatory Notices:*
  - 3.1 *United States*
    - 3.1.1 *Notice applicable to EVMs not FCC-Approved:*

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

#### Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSS standard(s). 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/llds/ti\\_ja/general/eStore/notice\\_01.page](http://www.tij.co.jp/llds/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/llds/ti\\_ja/general/eStore/notice\\_01.page](http://www.tij.co.jp/llds/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 by Radio Law of Japan to follow the instructions below with respect to EVMs:

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
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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.

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