10-V to 55-V Input, 3.3-V Output, 4-A, Wide Input Range Synchronous Buck Converter Using the TPS40060

System Power

Contents

1 Introduction 1
2 Description 1
3 Performance Specifications 3
4 Schematic 4
5 Resistor Divider and Output Voltage 5
6 Test Setup 5
7 Power Up/Down Test Procedure 7
8 Performance Data and Characteristic Curves 8
9 Assembly Drawing and Layout 9
10 List of Materials 12

1 Introduction

The TPS40060EVM evaluation module (EVM) is a high efficiency, wide input range synchronous buck converter providing a fixed 3.3-V output at 4 A from a 10-V to 55-V input. The EVM is designed to start up from a single supply, so no additional bias voltage is required for start-up. The module uses the TPS40060 wide input range synchronous buck controller driving a P-channel high-side MOSFET.

2 Description

TPS40060EVM is a wide input range synchronous buck converter using the full input range of the TPS40060 to produce a regulated 3.3 V output at up to 4 A of load current. Using lossless $R_{DS(on)}$ current sense for short circuit protection and a high-side P-channel MOSFET simplifies the circuit design without sacrificing performance.

The evaluation module provides test points for input voltage, output voltage, key waveforms and a 50 Ω connection point in the feedback loop for non-invasive measurements of the feedback loop along with an oscilloscope jack for easy measurements of output ripple.

With the wide input range and voltage feed-forward capabilities of the TPS40060, many different sources are possible from a single converter, including 16 V, 24 V, 36 V and 42 V.

2.1 Applications

The TPS40060 has a non-isolated wide-input range from 10 V to 55 V for input systems requiring light current and low output voltage, including:

- DSP and logic Power
- General computing
- Point-of-load DC/DC conversion from unregulated or variable bus voltage

2.2 Features

- Up to 93% peak and 91% full load efficiency at 10 V input
- 10 V to 55 V input range
- 3.3 V fixed output, adjustable with single resistor
- 4 Adc output current
- 250 kHz operation
- Single main switch MOSFET and single synchronous rectifier MOSFET
- Compact size, surface mount design (2.0” x 2.2”)
- Voltage mode control
- Up to 20 kHz feedback loop bandwidth for fast transient response and high stability operation
- Double sided PCB with power stage and devices all on top side
- Convenient test points for probing critical waveforms and non-invasive loop response testing

3 Electrical Performance Specifications

PARAMETER	TEST CONDITIONS		V_{IN}	MIN	TYP	MAX	UNITS
INPUT CHARACTERISTICS							
Input voltage range				10		55	V
Maximum input current	10 V ≤ V_{IN} ≤ 55 V,	I_{OUT} = 4 A			1.5	1.8	A
No−load input current	10 V ≤ V_{IN} ≤ 55 V,	I_{OUT} = 0 A				15	mA
OUTPUT CHARACTERISTICS							
Output voltage set	10 V ≤ V_{IN} ≤ 55 V,	0A ≤ I_{OUT} ≤ 4 A		3.25	3.30	3.35	
Output voltage regulation	Line regulation, 10 V ≤ V_{IN} ≤ 55 V	I_{OUT} = 0 A,	All			1%	
	Load regulation,	V_{IN} = 32				1%	
Output voltage ripple	V_{IN} = 55,	I_{OUT} = 4 A			30		mVpp
Output load current			All				A
CONTROL LOOP CHARACTERISTICS							
Switching frequency			All	225	250	275	kHz
Control loop bandwidth				15		30	
Phase margin				60		90	°
EFFICIENCY							
Peak efficiency	V_{OUT} = 3.3 V,	2A ≤ I_{OUT} ≤ 3 A	10 V		93%		
			16 V		91%		
			24 V		89%		
			36 V		85%		
			42 V		84%		
			55 V		80%		
Full load efficiency	V_{OUT} = 3.3 V,	I_{OUT} = 4 A	10 V		91%		
			16 V		90%		
			24 V		88%		
			36 V		85%		
			42 V		84%		
			55 V		80%		

4 Schematic

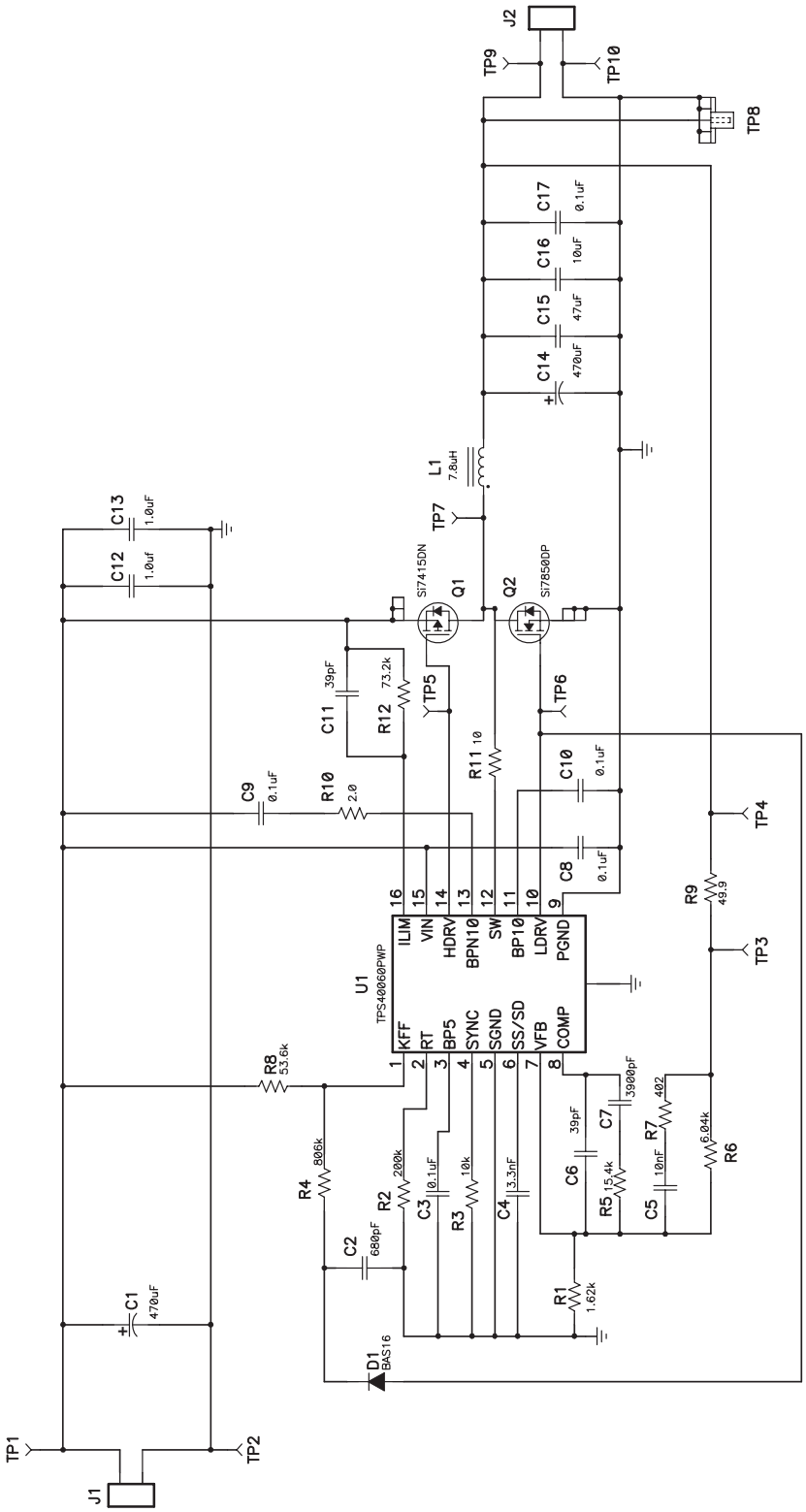

Figure 1. TPS40060EVM Schematic

5 Resistor Divider and Output Voltage

The regulated output voltage can be adjusted within a limited range by changing the ground resistor in the feedback resistor divider (R1). The output voltage is given by V_{REF} = 0.7 V, R6 = 6.04 kΩ and R1 by the formula in equation (1).

$$V_{OUT} = V_{REF} \times \left(1 + \frac{R6}{R1}\right) \quad (1)$$

Table 2 contains several values for R1 to generate several different popular output voltages. TPS40060EVM is stable through these output voltages and while the efficiency is very poor at high line and full load, the module is capable of delivering a regulated output voltage at full load for each of these output voltage.

Table 1. Adjusting V_{OUT} Using R1

V_{OUT} (V)	R1 (kΩ)
3.3	1.62
2.5	2.32
2.2	2.74
2.0	3.24
1.8	3.83
1.5	5.23
1.2	8.45
0.9	21.0

6 Test Set-Up

Shown in Figure 2 is the basic test set up recommended to evaluate the TPS40060EVM. Please note that although the return for J1 is the same as the J2 return, the V_{IN} and LOAD1 connections should remain separate as shown below.

6.1 EVM Setup

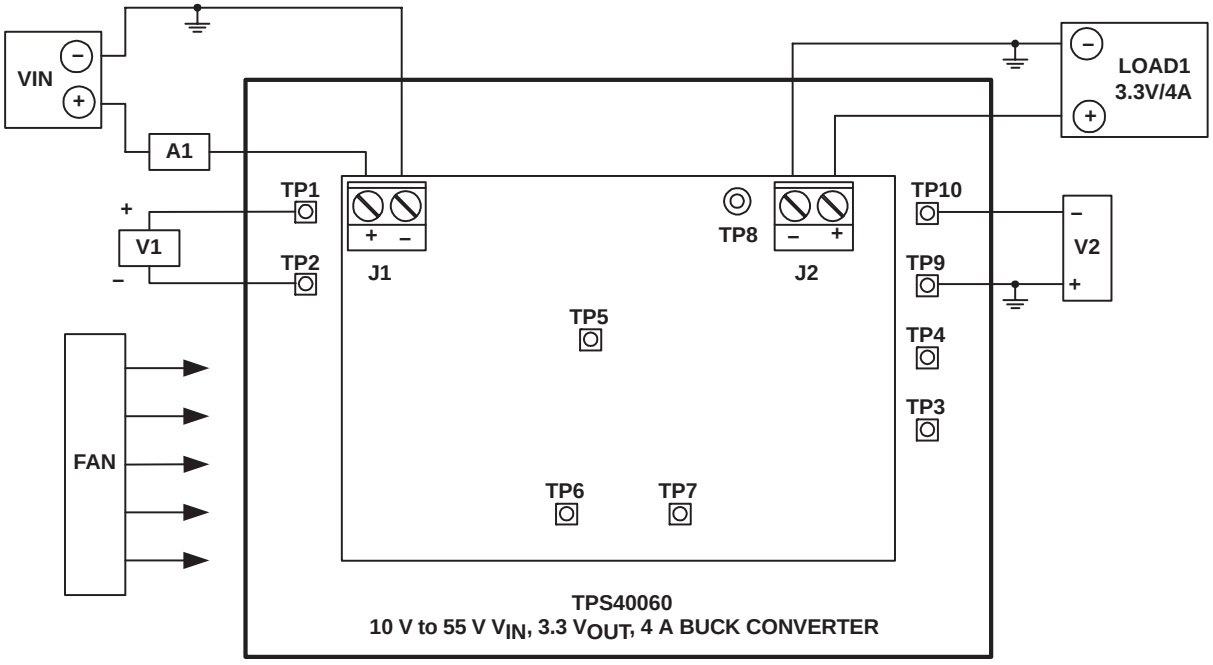

Figure 2. EVM Test Set-Up

6.2 Output Load (LOAD1)

For the output load to V_{OUT}, use a programmable electronic load set to constant current mode and capable of sinking between 0 Adc and 4Adc. Using a DC voltmeter, V2, it is also advised to make all output voltage measurements directly at TP10 and TP9 terminals. Measuring V_{OUT} at LOAD1 or J2 may result in some voltage measurement error, due to finite voltage drops across J2 and the wires between J2 and the electronic load.

6.3 DC Input Source (VIN)

The input voltage source shall be a variable DC source capable of supplying between 0 Vdc and 55 Vdc at no less than 2 Adc, and connected to J1 as shown in Figure 2. For fault protection to the EVM, good common practice is to limit the source current to no more than 2 Adc for a 10 V to 55 V input. A DC ammeter, A1 should also be inserted between VIN and J1 as shown in Figure 2 for input current measurements. A DC voltmeter, V1 should be connected to TP1 and TP2 for V_{IN} measurements.

6.4 Network Analyzer

A network analyzer can be connected directly to TP3 and TP4 shown in Figure 2. The TPS40060EVM provides a 50 Ω resistor (R9) between the output and the voltage feedback to allow easy non−invasive measurement of the control to output loop response.

6.5 Recommended Wire Gauge

For the connection between the source voltage, VIN and J5 of the EVM the minimum recommended wire size is AWG #18 with the total length of wire less than 8 feet (4 feet input, 4 feet return). For the connection between J7 of the EVM and LOAD1 the minimum recommended wire size is AWG #12, with the total length of wire less than 8 feet (4 feet output, 4 feet return). Due to the low output voltage, and the limitations of an electronic load, larger wire with shorter total length may be required.

6.6 Test Points and Oscilloscope Test Jack

TP5, TP6, TP7 and TP8 are available to allow for convenient, non-invasive probing and measuring of high speed noise sensitive signals such as gate drive voltage, switch-node voltage and output voltage ripple without modification of the EVM design board

6.7 Fan

Most power converters include components that can get hot to the touch approaching temperatures of 60°C. Because this EVM is not enclosed to allow probing of circuit nodes, a small fan capable of between 200 and 400 LFM is recommended to reduce component temperatures during operation.

7 Power Up/Down Test Procedure

The following test procedure is recommended primarily for power up and shutting down the EVM. Whenever the EVM is running the fan should be turned on. Also, never walk away from a powered EVM for extended periods of time.

1. Working at an ESD workstation, make sure that any wrist straps, boot straps or mats are connected referencing the user to earth ground before power is applied to the EVM. Electrostatic smock and safety glasses should also be worn.
2. Prior to connecting the DC input source, V_{IN}, it is advisable to limit the source current from V_{IN} to 2-A maximum. Connect the ammeter A1 (0 Ato 2 A range) between V_{IN} and J1 as shown in Figure 2. Make sure V_{IN} is initially set to 0 V.
3. Connect LOAD1 to J2 as shown in Figure 2. Set LOAD1 to constant current mode to sink 0 Adc before V_{IN} is applied.
4. Connect the voltmeter, V2 to TP9 and TP10 as shown in Figure 2.
5. Increase V_{IN} from 0 V to 10 Vdc, while monitoring the output voltage on V2. V_{OUT} should be in regulation when V_{IN} > 10 V.
6. Turn on fan blowing air directly on the EVM
7. Vary LOAD1 anywhere between 0 A to 4 Adc.
8. Vary the input voltage between 10 V and 55 V.
9. Set LOAD1 to 0 A.
10. Set V_{IN} to 0 Vdc.
11. Shut down the electronic load.
12. Shut down V_{IN}.

8 Performance Data and Characteristic Curves

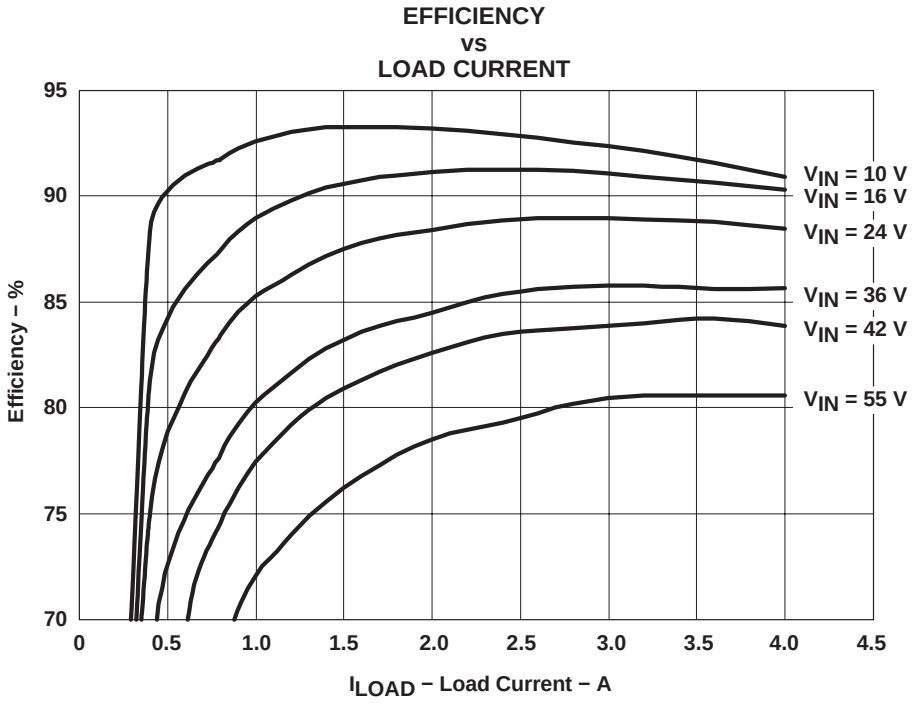

Figure 3.

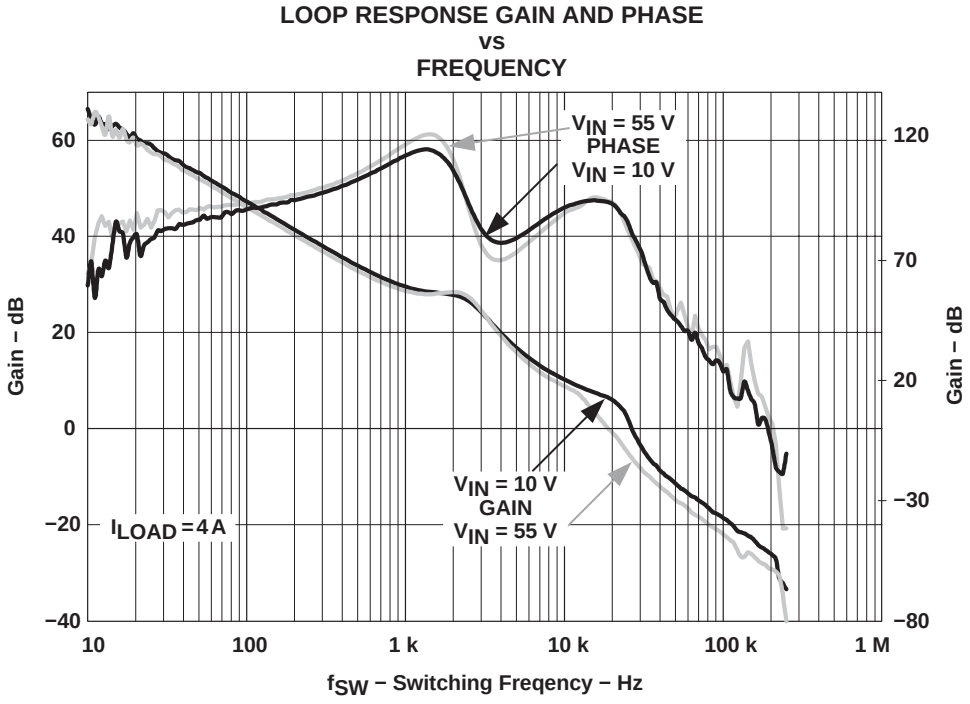

Figure 4.

9 EVM Assembly Drawing and PCB Layout

Figure 5 through 8 show the design of the TPS40060EVM printed circuit board. The EVM has been designed using an inexpensive two-sided, copper-clad circuit board 3.0” x 3.5” with all components and routing confined to a 2.0” x 2.2” area to allow the circuit design to be incorporated into almost any PCB design without needing to add additional internal layers, or as an external module.

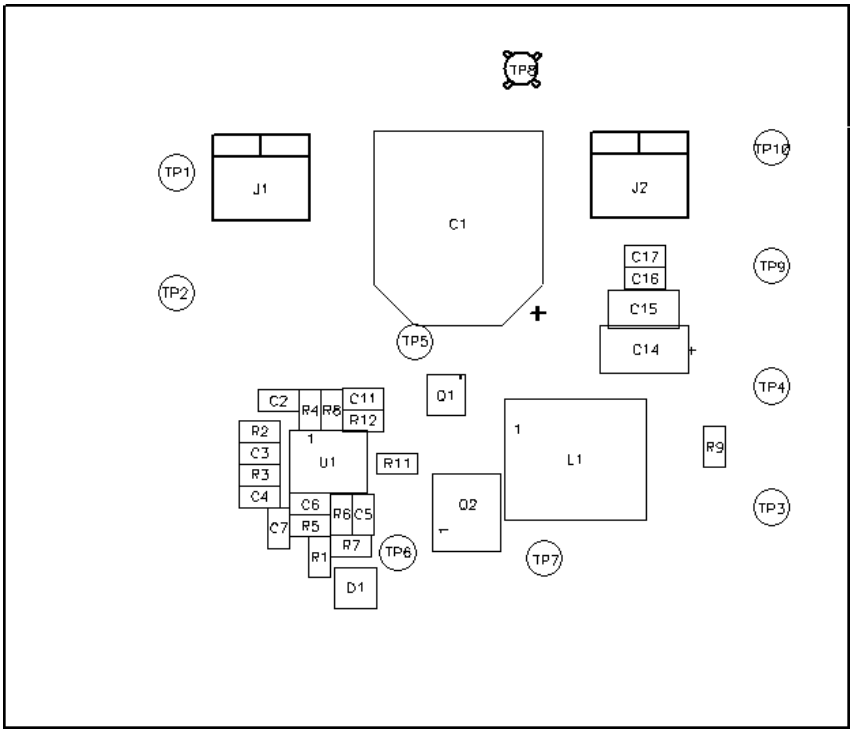

Figure 5. Top Side Component Assembly

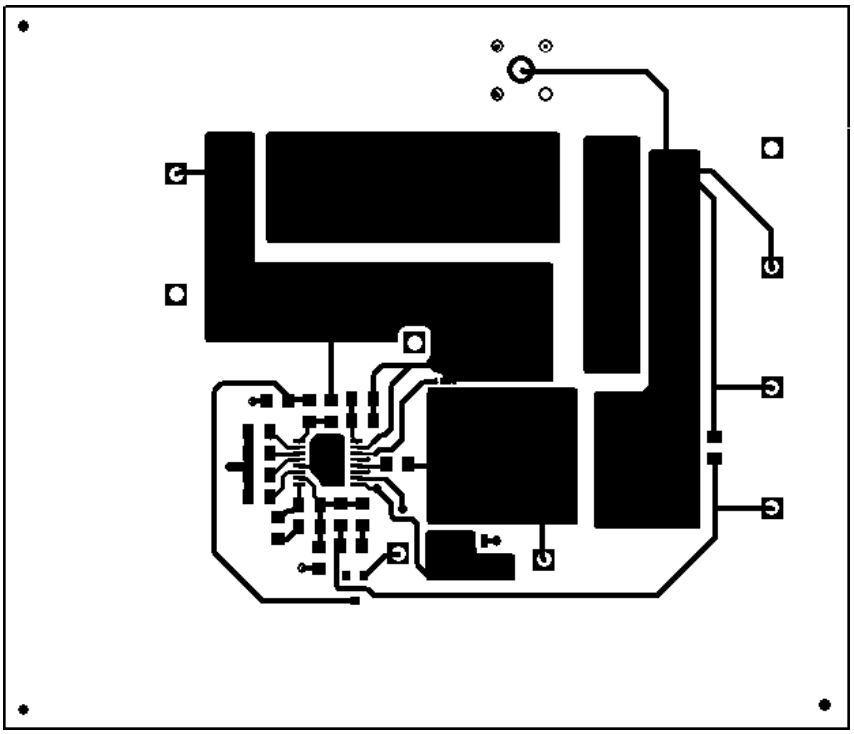

Figure 6. Top Side Copper Trace

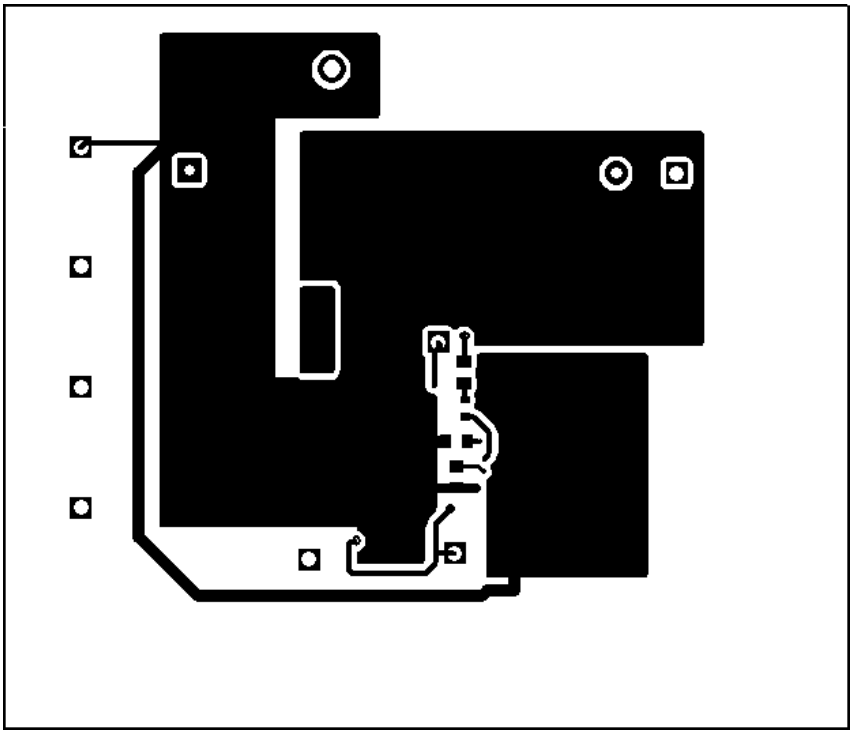

Figure 7. Bottom Side Copper Trace

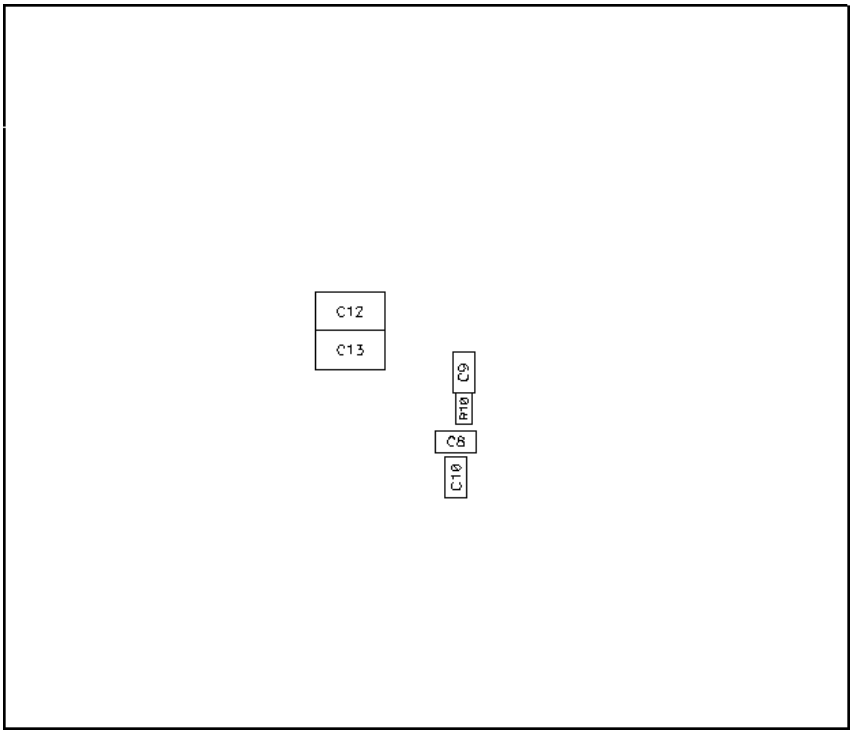

Figure 8. Bottom Side Component Assembly

10 List of Materials

Table 2 lists the EVM components as configured according to the schematic shown in Figure 1.

Table 2. TPS40060EVM (HPA057A) List of Materials

REFERENCE DESIGNATOR	QTY	DESCRIPTION	SIZE	MFR	PART NUMBER
C1	1	Capacitor, aluminum, SM 470 µF, 63 V	0.67 x 0.75	Panasonic	EEVFK1J471M
C2	1	Capacitor, ceramic, 680 pF, 50 V, X7R, 20%	805	std	std
C3, C10, C17	3	Capacitor, ceramic, 0.1 µF, 50 V, X7R, 20%	805	std	std
C4	1	Capacitor, ceramic, 3.3 nF, 50 V, X7R, 20%	805	std	std
C5	1	Capacitor, ceramic, 10 nF, 50 V, X7R, 20%	805	std	std
C6,C11	2	Capacitor, ceramic, 39 pF, 50 V, X7R, 20%	805	std	std
C7	1	Capacitor, ceramic, 3900 pF, 50 V, X7R, 20%	805	std	std
C8, C9	2	Capacitor, ceramic, 0.1 µF, 100 V, X7R, 20%	805	std	std
C12, C13	2	Capacitor, ceramic, 1.0 µF, 100 V, X7R, 20%	1812	TDK	C4532X7R2A105M
C14	1	Capacitor, POSCAP, 470 µF, 6.3 V, 35 mΩ, 20%	D4	Sanyo	6TPB470M
C15	1	Capacitor, ceramic, 47 µF, 6.3 V, X5R, 20%	1812	TDK	C4532X5R0J476M
C16	1	Capacitor, ceramic, 10 µF, 6.3 V, X5R, 20%	805	TDK	C2012X5R0J106M
D1	1	Diode, switching, 10 mA, 85 V, 350 mW	SOT23	Vishay−Liteon	BAS16
J1, J2	2	Terminal block, 2-pin, 15 A, 5.1 mm	0.40 x 0.35	OST	ED1609
L1	1	Inductor, SMT, 7.8 µH, 8.2 A, 10.2 mΩ	0.325 x 0.318	TDK	RLF12560−7R8N8R2
Q1	1	MOSFET, P−channel, −60 V, 5.7 A, 0.065 mΩ	1212−8 single		Si7415DN
Q2	1	MOSFET, N−channel, 60 V, 10.3 A, 0.022 mΩ	PWRPAK SO−8		Si7850DP
R1	1	Resistor, chip, 1.62 kΩ, 1/10−W, 1%	805	Std	Std
R2	1	Resistor, chip, 200 kΩ, 1/10−W, 1%	805	Std	Std
R3	1	Resistor, chip, 10 kΩ, 1/10−W, 1%	805	Std	Std
R4	1	Resistor, chip, 806 kΩ, 1/10−W, 1%	805	Std	Std
R5	1	Resistor, chip, 15.4 kΩ, 1/10−W, 1%	805	Std	Std
R6	1	Resistor, chip, 6.04 kΩ, 1/10−W, 1%	805	Std	Std
R7	1	Resistor, chip, 402 Ω, 1/10−W, 1%	805	Std	Std
R8	1	Resistor, chip, 53.6 kΩ, 1/10−W, 1%	805	Std	Std
R9	1	Resistor, chip, 49.9 Ω, 1/10−W, 1%	805	Std	Std
R10	1	Resistor, chip, 2.0 Ω, 1/16−W, 5%	603	Std	Std
R11	1	Resistor, chip, 10 Ω, 1/10−W, 1%	805	Std	Std
R12	1	Resistor, chip, 73.2 kΩ, 1/10−W, 1%	805	Std	Std
TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP9, TP10	5	Test point, 0.050 hole,	0.050”	MILL−MAX	3103−1−00−15−00−00−0X−0
TP8	4	Adaptor, 3.5 mm probe clip (or 131−5031−00)	0.2	Tektronix	131−4244−00
U1	1	Wide input synchronous buck controller	PWP16	TI	TPS40060PWP
−−	1	PCB, 4-Layer FR4, 2.4” x 2.1” x 0.062”	2.4” x 2.1”	Any	HPA057A
−−	1	Bumpon, transparent	0.44” x 0.2”	3M	SJ5303

(1) Should not be substituted.

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NOTE:

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FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

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

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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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西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-for-power-line-communication.html

3.4 *European Union*

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

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

4 *EVM Use Restrictions and Warnings:*

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

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

4.3 *Safety-Related Warnings and Restrictions:*

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

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

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

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

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