

TPS40055-Based Design Converts 12-V Bus to 1.8 V at 15 A (HPA070)

User's Guide

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TPS40055-Based Design Converts 12-V Bus to 1.8 V at 15 A (HPA070)

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System Power

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1 Introduction

In many modern electronic applications there is a growing demand for circuits to convert a 12-V bus to digital voltages as low as, but not limited to 1.8 V. The current requirements can range from below 1 A to over 15 A. For high-efficiency and small circuit size the TPS40055 wide-input synchronous buck controller can be used to provide the necessary control and drive functions to implement these converters. The TPS40055EVM-001 operates at 300 kHz and delivers 1.8 V at 15 A with efficiency over 90% for much of the load range, and a full load efficiency of 88%.

The TPS40055 synchronous buck controller offers a variety of user programmable functions such as operating frequency, soft-start time, voltage feed-forward, high-side current limit, and external loop compensation. This controller also provides a regulated 10-V bias voltage which supplies onboard drivers for the N-channel switch and synchronous rectifier MOSFETs, utilizing adaptive gate drive logic to prevent cross conduction of the power MOSFETs.^[1]

2 Features

The specification of this design is as follows:

- 92% peak efficiency at 6 A
- 88% peak efficiency at 15 A
- 1.8V output at 15 A
- V_{IN} range from 10 V_{DC} to 14 V_{DC}
- Small circuit size 1.4" x 2.5" SMT design, components on single side
- Line/load regulation < 0.5%
- High-frequency 300-kHz operation
- Transient deviation 60 mV with 10-A load step

3 Schematic

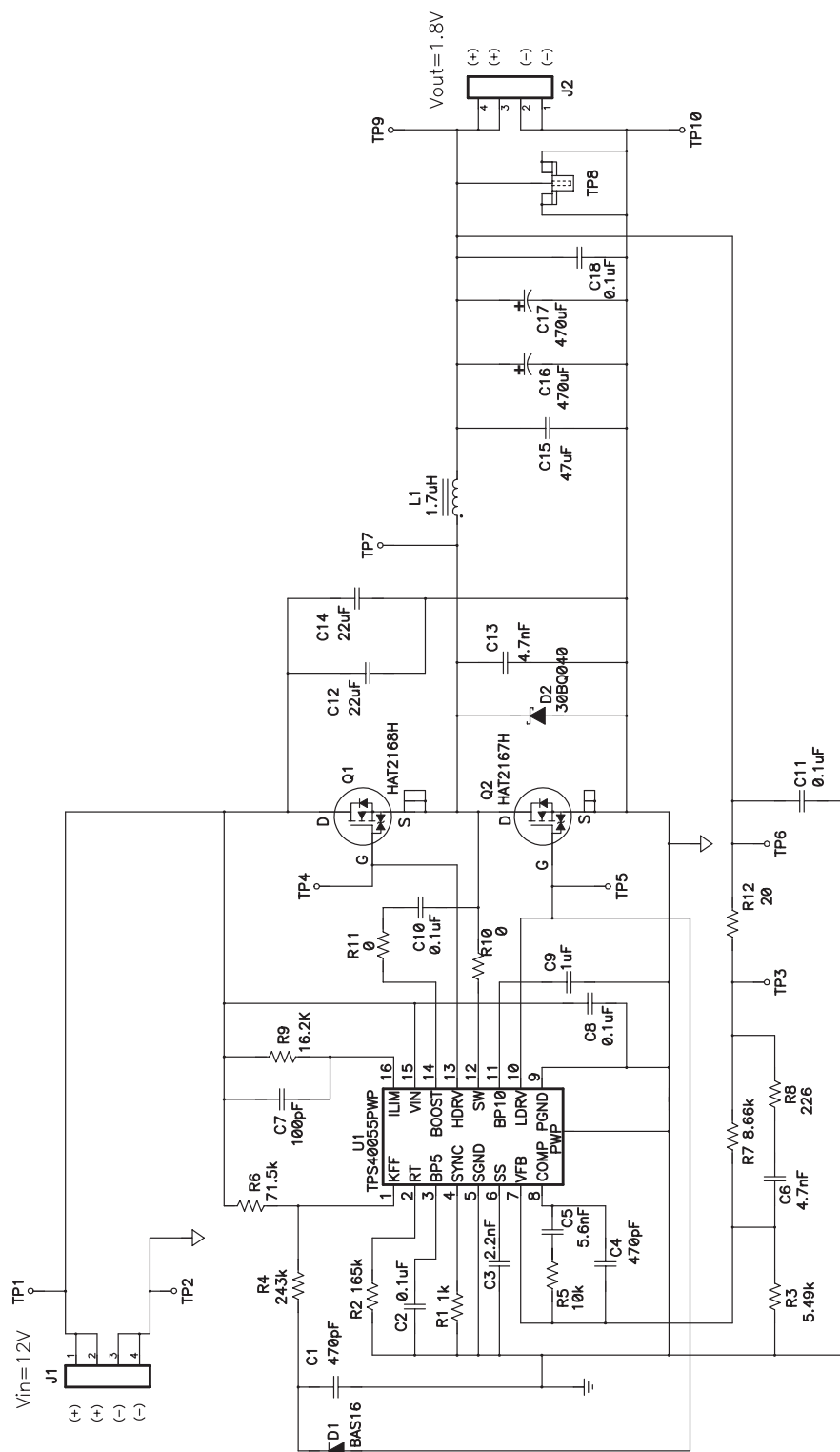


Figure 1. TPS40055EVM-001 (HPA070) Schematic

4 Component Selection

4.1 TPS40055 Device Selection

The TPS4005x family of parts offers a range of output current configurations including source only (TPS40054), source/sink (TPS40055), or source/sink with V_{OUT} prebias (TPS40057). In this converter the TPS40055 with source/sink capability is selected. This serves to maintain continuous inductor ripple current all the way to zero load to improve the small signal loop response by preventing the inductor current from transitioning to the discontinuous current mode.

The TPS4005x family is packaged in TI's PWP PowerPAD thermally enhanced package which should be soldered to the PCB using standard solder flow techniques. The PowerPAD™ technology uses a thermally conductive epoxy to attach the integrated circuit die to the leadframe die pad, which is exposed on the bottom of the completed package. The PWP PowerPAD package has a $\theta_{JC} = 2^{\circ}\text{C/W}$ which helps keep the junction temperature rise relatively low even with the power dissipation inherent in the onboard MOSFET drivers. This power loss is proportional to switching frequency, drive voltage, and the gate charge needed to enhance the N-channel MOSFETs. Effective heat removal allows the use of ultra-small packaging while maintaining high component reliability.

The technical brief, PowerPAD Thermally Enhanced Package^[2] contains more information on the PowerPAD package.

4.2 Frequency of Operation

The clock oscillator frequency for the TPS40055 is programmed with a single resistor from RT (pin 2) to signal ground. The following equation (1) from the datasheet allows selection of RT in k Ω for a given switching frequency in kHz.

$$R_T = R2 = \frac{1}{f_{SW} \times 17.82 \times 10^{-6}} - 23 \text{ (k}\Omega\text{)} \quad (1)$$

For 300-kHz operation, R2 is selected to be 165 k Ω .

For a particular operating frequency, the PWM ramp time must be programmed via the resistor R_{KFF} connected to V_{IN} . Also, the selection of R_{KFF} programs the V_{IN} voltage at which the circuit starts operation. This prevents the circuit from starting at low voltages, which can lead to current flow larger than desired. R_{KFF} is programmed using equation (2).

$$R_{KFF} = R6 = (V_{IN(min)} - 3.5) \times (58.14 \times R_T + 1340) \text{ (k}\Omega\text{)} \quad (2)$$

Where $V_{IN(min)}$ is the minimum startup input voltage, and R_T is in k Ω . Note that internal tolerances have been incorporated into this equation, so the actual $V_{IN(min)}$ of the input voltage should be used. For an oscillator frequency of 300-kHz, the R_{KFF} value of 71.5 k Ω is selected.

4.3 UVLO Circuitry

The user programmable UVLO built into the TPS4005x provides hysteresis for transients shorter than a total count of seven cycles. If the input voltage to the converter can be slowly rising around the minimum V_{IN} range, external hysteresis can be incorporated to prevent multiple on/off cycles during startup or shutdown. These on/off cycles are a result of line impedance external to the EVM causing V_{IN} to the module to drop when under load, which causes the programmable UVLO threshold to be crossed repetitively.

In this converter, C1 and D1 are added to form a peak detector from the lower gate drive which is only active when the converter is operating. This provides a bias source to deliver hysteresis current from the peak detector voltage to the lower KFF voltage of 3.5 V, enabling the designer to alter the programmable UVLO shutdown point. The bias is not present during startup, so the circuit starts as expected from the R_{KFF} calculation.

In this application, R4 is selected to provide a hysteresis current of 20% I_{KFF} . R4 can be calculated from equation (3).

$$R_{HYS} = R4 = \frac{R_{KFF} \times (V_{PD} - 3.5)}{0.2 \times (V_{IN(min)} - 3.5)} \quad (3)$$

where

- V_{PD} is the voltage on the peak detector
- $V_{IN(min)}$ is the desired start voltage used in the determination of R_{KFF}

In a typical case, $V_{PD} = 8V$, and R4 is found to be 247 k Ω , and a standard value of 243k Ω is selected. Testing shows the startup voltage to be 9.2 V, and the shutdown voltage to be 8.5 V.

4.4 Inductance Value

The output inductor L1 value used in the circuit of Figure 2 was selected from equation (4).

$$L = \frac{V_{OUT}}{f \times I_{RIPPLE}} \times 1 - \frac{V_{OUT}}{V_{IN(min)}} \quad (4)$$

in which I_{RIPPLE} is usually chosen to be in the range between 10% and 40% of I_{OUT} . With $I_{RIPPLE} = 20\%$ of $I_{OUT(max)}$ there is a ripple current of 3 A, and the inductance value is 1.7 μH .

4.5 Input capacitor selection

Bulk input capacitor selection is based on allowable input voltage ripple and required RMS current carrying capability. In typical buck converter applications, the converter is fed from an upstream power converter with its own output capacitance. In this converter, ceramic capacitors capable of meeting circuit requirements are provided onboard. For this power level, input voltage ripple of approximately 250 mV is reasonable, and the minimum capacitance is calculated in (5).

$$C_{IN} = \frac{I \times \Delta t}{\Delta V} = \frac{I \times V_O}{\Delta V \times V_{IN} \times f_S} = \frac{15 A \times 1.8 V}{0.25 V \times 10 V \times 300 kHz} = 36 \mu F \quad (5)$$

Also consider the RMS current rating required for the input capacitors (6).

$$i \cong I_{OUT} \times \sqrt{D} = I_{OUT} \times \sqrt{\frac{V_{OUT}}{V_{IN}}} = 15 \times \sqrt{\frac{1.8}{10}} = 6.4 A \quad (6)$$

To meet this requirement with the smallest cost and size two 22 μF , 16 V, X5R ceramic capacitors (C12, C14) are installed on the board. In the 1812 case, the parts are able to carry approximately 4 A_{RMS} each. These capacitors function as power bypass components and should be located close to the MOSFET packages to keep the high-frequency current flow in a small, tight loop.

4.6 Output Capacitor Selection

Selection of the output capacitor is based on many application variables, including function, cost, size, and availability. The minimum allowable output capacitance is determined by the amount of inductor ripple current and the allowable output ripple, as given in equation (7).

$$C_{OUT(min)} = \frac{I_{RIPPLE}}{8 \times f \times V_{RIPPLE}} = \frac{3 \text{ A}}{8 \times 300 \text{ kHz} \times 15 \text{ mV}} = 83 \mu\text{F} \quad (7)$$

In this design, $C_{OUT(min)}$ is 83 μF with $V_{RIPPLE}=15 \text{ mV}$ to allow for some margin. However, this only affects the capacitive component of the ripple voltage, and the final value of capacitance is generally influenced by ESR and transient considerations. The voltage component due to the capacitor ESR.

$$C_{ESR} \leq \frac{V_{RIPPLE}}{I_{RIPPLE}} = \frac{15 \text{ mV}}{3 \text{ A}} = 5 \mu\Omega \quad (8)$$

An additional consideration in the selection of the output inductor and capacitance value can be derived from examining the transient voltage overshoot which can be initiated with a load step from full load to no load. By equating the inductive energy with the capacitive energy the equation (9) can be derived:

$$C_O \leq \frac{L \times I^2}{V^2} = \frac{L \times \left((I_{OH})^2 - (I_{OL})^2 \right)}{(V_f)^2 - (V_i)^2} = \frac{1.7 \mu\text{H} \times (15 \text{ A})^2}{((1.9 \text{ V})^2 - (1.8 \text{ V})^2)} = 1034 \mu\text{F} \quad (9)$$

where

- I_{OH} = full load current
- I_{OL} = no load current
- V_f = allowed transient voltage rise
- V_i = initial voltage

For compactness while maintaining transient response capability, two 470- μF POSCAP capacitors (C16, C17) are fitted in parallel. The total ESR of these capacitors is approximately 5 $\text{m}\Omega$. An additional 47- μF , 6.3-V ceramic capacitor C15 is placed in parallel with the POSCAPs to help suppress high frequency noise generated by the fast current transitions as the current switches between the input and output circuits during each switching cycle.

4.7 MOSFET selection

Proper MOSFET selection is essential to optimize circuit efficiency. To operate with high current it is important to choose a package which allows the generated heat to be removed from the package as easily as possible. Various MOSFETs with a package similar to the SO-8 footprint are considered for this application, and devices with reduced junction-case thermal impedance are selected.

For the upper switch Q1, a Hitachi HAT2168H MOSFET with low gate charge (typically 27 nC at 10 V) and with an $R_{DS(on)}$ of 6 $\text{m}\Omega$ is selected to keep the switching losses to a minimum. The low-side rectifier switch Q2 was chosen as a Hitachi HAT2167H, which has slightly more gate charge (43 nC at 10 V) but lower $R_{DS(on)} = 4.2 \text{ m}\Omega$ to minimize conduction losses. A schottky diode, D2, is placed across Q2 in this high current design to carry some of the high circulating current during short circuit conditions.

4.8 Short Circuit Protection

The TPS40055 implements short circuit protection by comparing the voltage across the topside MOSFET while it is ON to a voltage developed across R_{LIM} due to an internal current source of $10\ \mu\text{A}$ inside pin 16. Both of these voltages are negative with respect to V_{IN} . From the datasheet equation, R_{LIM} is defined as:

$$R_{LIM} = R9 = \frac{I_{OC} \times R_{DS(on) (max)}}{1.12 \times I_{SINK}} = \frac{V_{OS}}{I_{SINK}} = (\Omega) \quad (10)$$

where

- I_{OC} is the overcurrent set point equal to the DC output current plus one-half the inductor ripple current
- V_{OS} is the overcurrent comparator offset, and I_{SINK} is the current into ILIM (pin 16).

Using worst case tolerances the value of R_{LIM} should be maximized to ensure that the converter can deliver full rated current under all conditions. In a worst case condition, $R_{LIM}=R9$ and

$$R_{LIM} = \frac{(15\text{ A} + 1.5\text{ A}) \times (7.9\text{ m}\Omega \times 1.45)}{1.12 \times 8.65\ \mu\text{A}} + \frac{-30\text{ mV}}{8.65\ \mu\text{A}} = 16.0\text{ k}\Omega \quad (11)$$

The standard value of $16.2\text{ k}\Omega$ was selected. This ensures that we can deliver a minimum of 15 A before current limit is activated. There is also a small capacitor, C7, placed in parallel with R9 to filter the signal.

4.9 Snubber Component Selection

Initially, the junction of Q1, Q2, and L1 was ringing at a frequency near 100 MHz with a peak voltage near 30 V . This was due to the extremely fast switching speed of the MOSFETs and the lack of any cross-conduction. C13 was added to shunt the high-frequency ringing to ground and the peak voltage is now below 25 V .

4.10 Compensation Components

The TPS40055 uses voltage mode control with feed-forward in conjunction with a high-frequency error amplifier to implement closed loop control. The power circuit L-C double pole corner frequency f_C occurs at 3.8 kHz , and the output capacitor ESR zero is located at approximately 38 kHz . The feedback compensation network is implemented to provide two zeroes and three poles. The first pole is placed at the origin to improve DC regulation.

The first zero is placed at 2.8 kHz , just below the L-C corner frequency.

$$f_{Z1} = \frac{1}{2\pi \times R5 \times C5} \quad (12)$$

The second zero is selected to be coincident with the L-C corner frequency of 3.8 kHz ,

$$f_{Z2} = \frac{1}{2\pi \times (R7 + R8) \times C6} \quad (13)$$

The second pole is placed near the ESR zero frequency at 37 kHz .

$$f_{P1} = \frac{1}{2\pi \times R5 \times \left(\frac{C4 \times C5}{C4 + C5} \right)} \quad (14)$$

and the third pole is placed at 150 kHz , which is one-half the switching frequency.

$$f_{P2} = \frac{1}{2\pi \times R8 \times C6} \quad (15)$$

5 Test Setup

Figure 2 illustrates the basic test setup needed to evaluate the TPS40055EVM-001.

5.1 DC Input Source

The input voltage source should be capable of supplying between 10 V_{DC} and 14 V_{DC} and rated for at least 4 A of current. For best results the input leads should be made with a wire of 18AWG or larger.

5.2 Output Load

The output load can be either an electronic load or a resistive load configured to draw between 0 A and 15 A. The output leads should be made with a wire of 16AWG or larger diameter wire. Monitor the output voltage on the PCB by connecting a voltmeter to TP9 and TP10 to prevent voltage drops through PCB traces and the output terminal block which can lead to substantial measurement errors.

5.3 Oscilloscope Probe Test Jacks

An oscilloscope probe test jack (TP8) has been included to allow monitoring the output voltage ripple.

5.4 Fan

There is no cover to prevent the user from probing the internal circuit nodes. There are components that can get hot to the touch (above 60°C) in normal operation. A small fan delivering more than 15 cfm should be used when operating at and near full load.

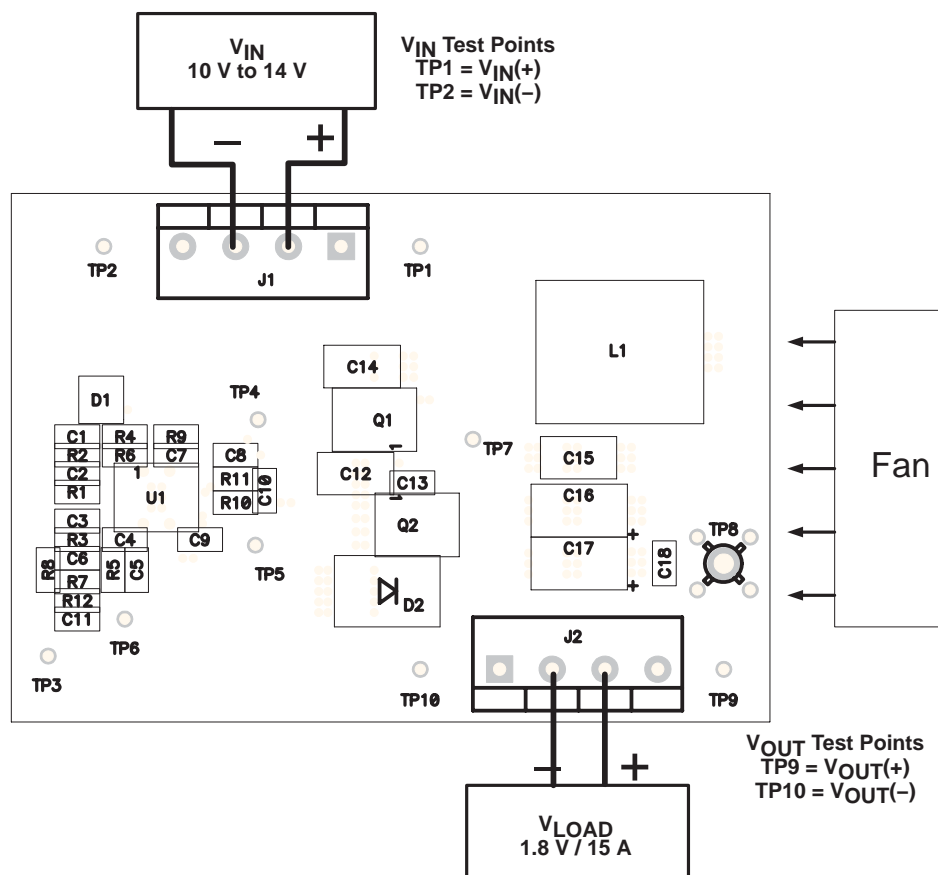


Figure 2. Test Setup

6 Test Results / Performance Data

6.1 Efficiency and Power Loss

Figure 3 shows the efficiency as the load is varied from 1 A to over 15 A. The typical efficiency remains over 90% as the load ranges from 3 A to 12 A.

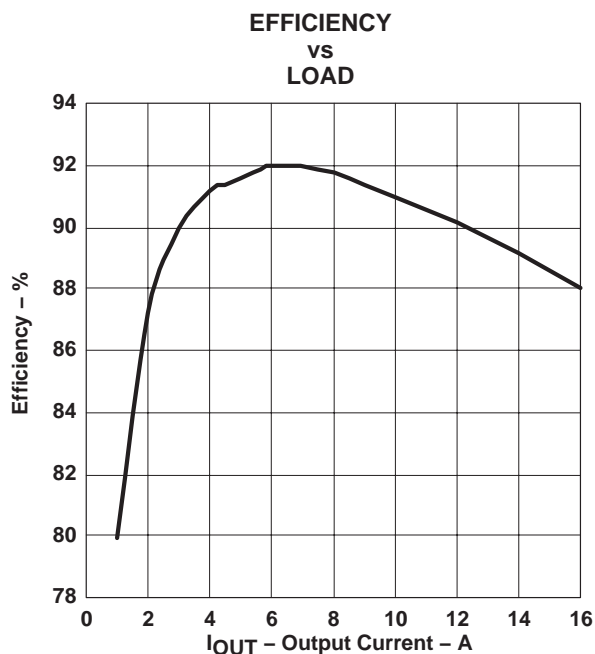


Figure 3

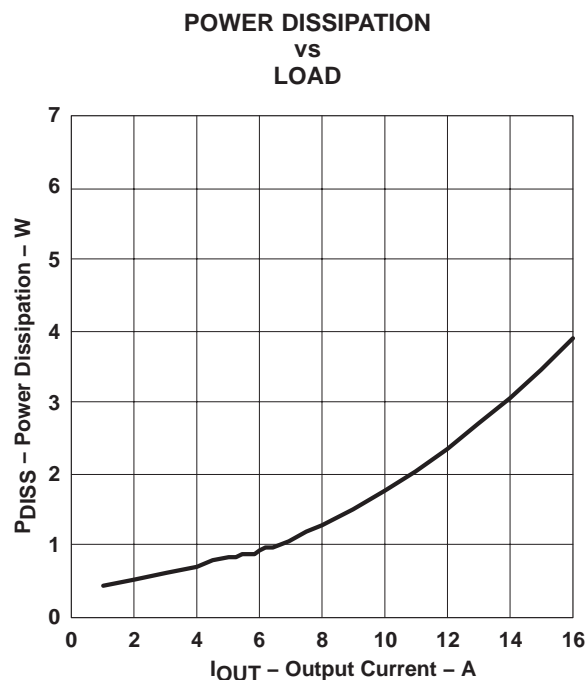


Figure 4

6.2 Closed Loop Performance

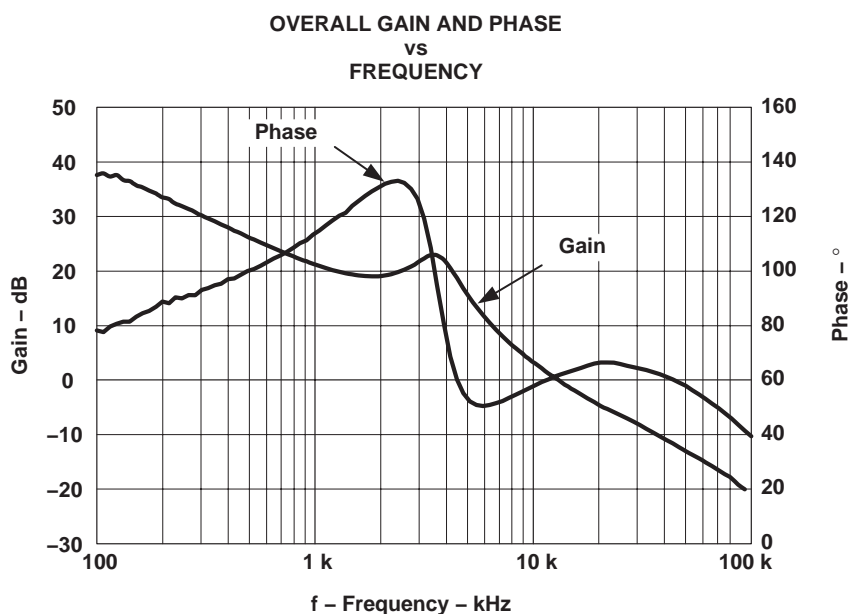


Figure 5.

6.3 Output Ripple and Transient Response

Figure 6 shows the typical output voltage ripple with $I_{OUT}=15\text{ A}$ to be less than 20 mVpp.

The transient response is shown in Figure 7 as the load is stepped from 5 A to 15 A. The voltage deviation is less than 60 mV.

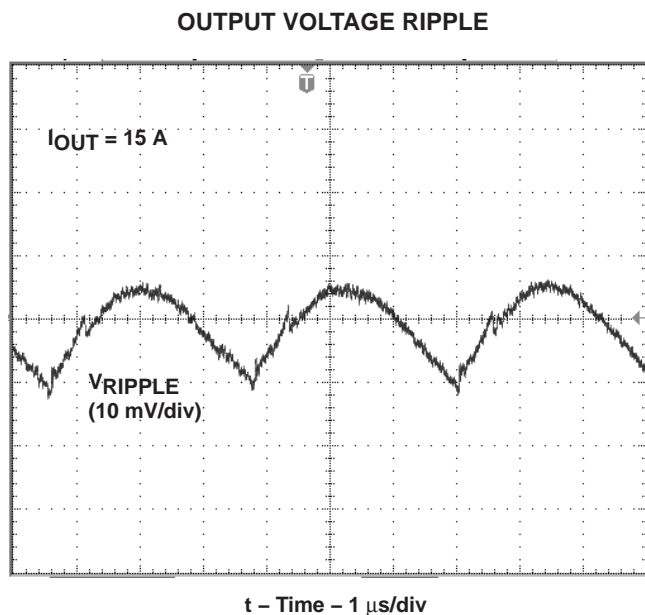


Figure 6

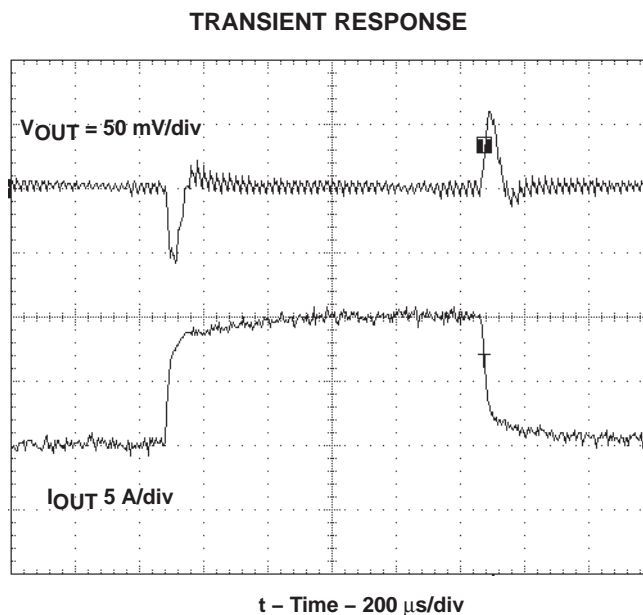


Figure 7

7 EVM Assembly Drawing and PCB Layout

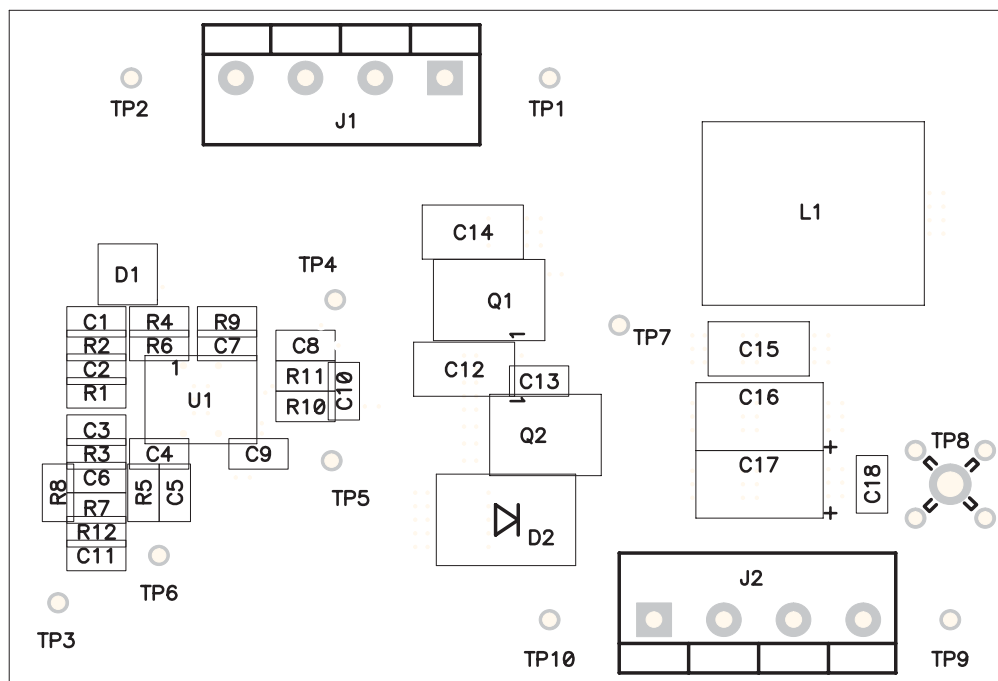


Figure 8. Top Side Component Assembly

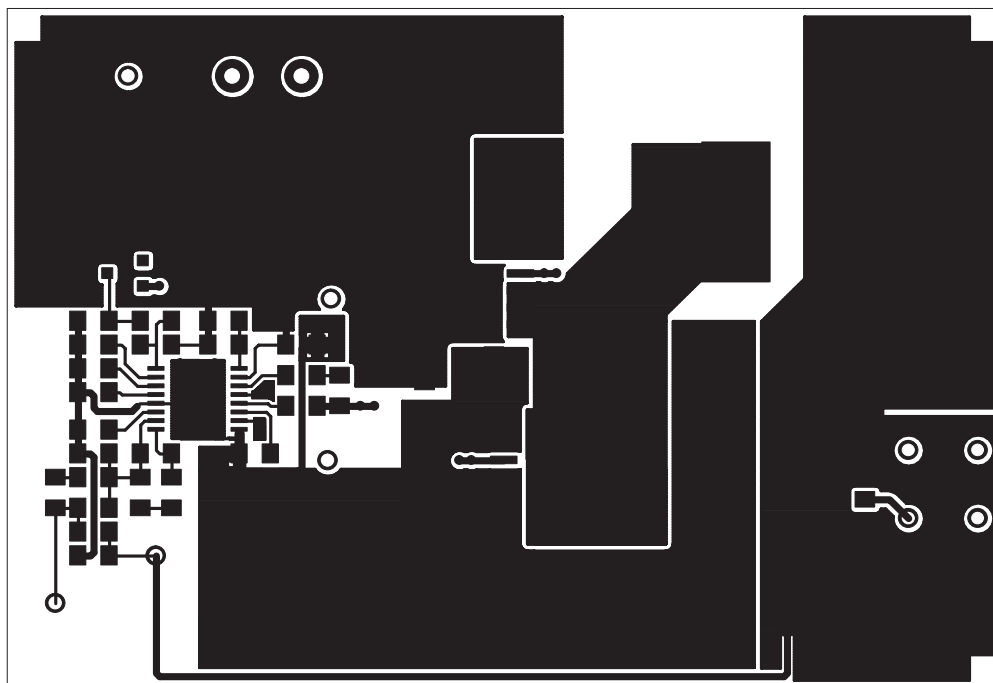


Figure 9. Top Side Copper

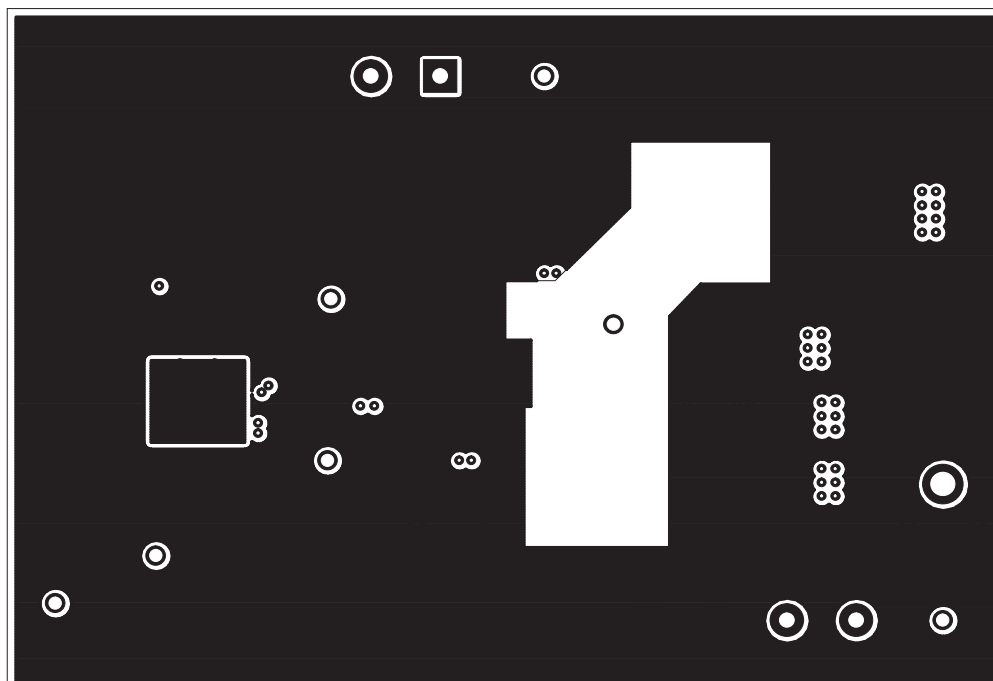


Figure 10. Internal Layer 1 Copper

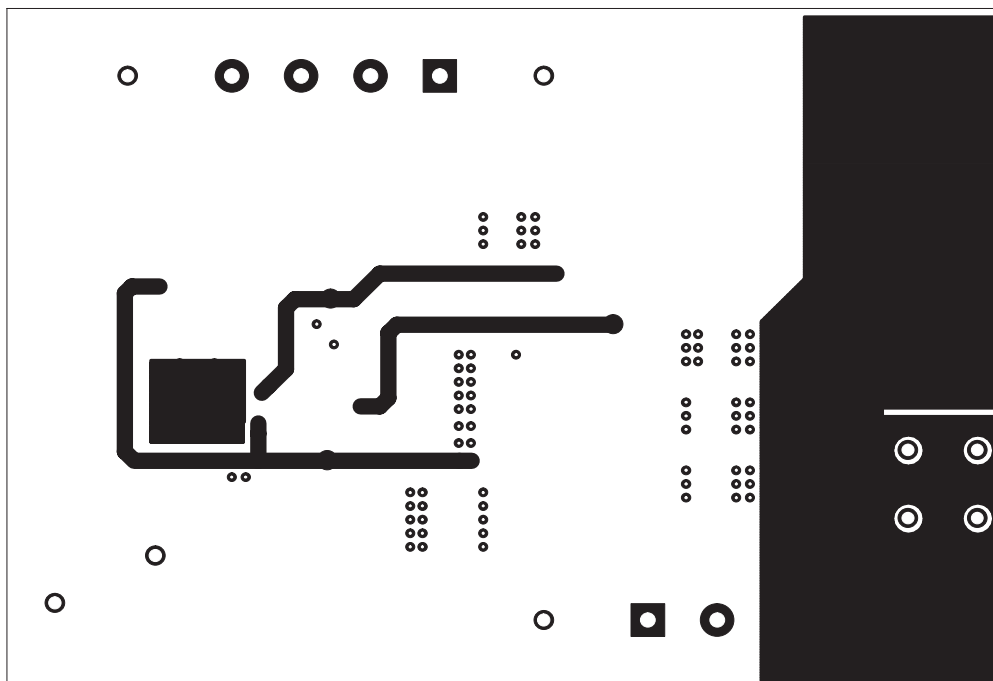


Figure 11. Internal Layer 2 Copper

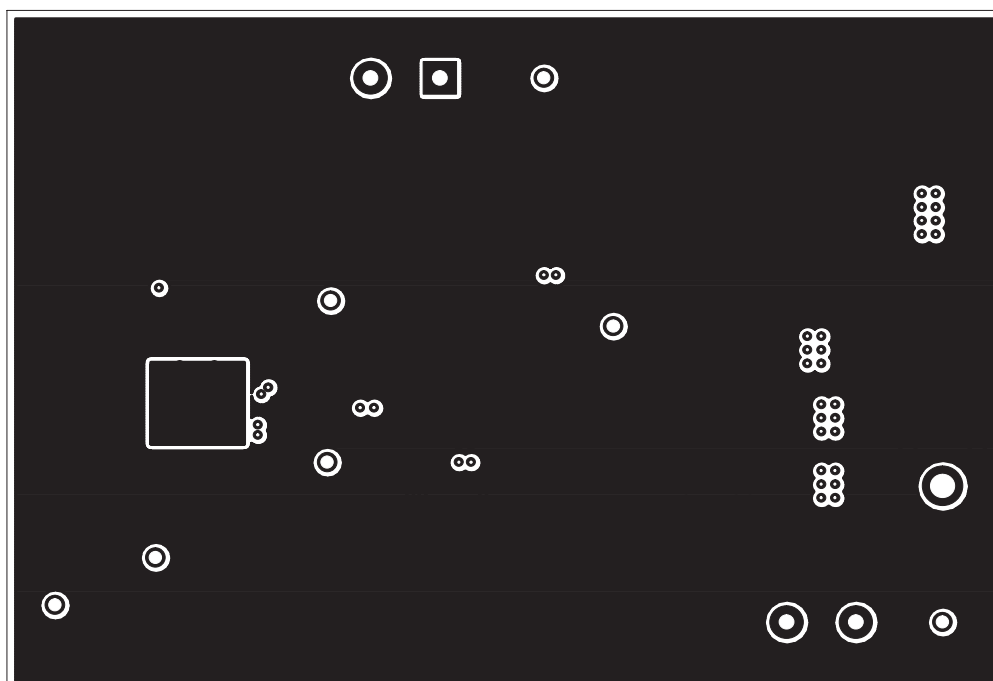


Figure 12. Bottom Layer Copper

8 List of Materials

Table 1 lists the parts values of the evaluation board. These values can be modified to meet the application requirements.

Table 1. TPS40055EVM–001 (HPA070) List of Materials

REFERENCE DESIGNATOR	QTY	DESCRIPTION	SIZE	MFR	PART NUMBER
C1, C4	2	Capacitor, ceramic, 470 pF, 50 V, X7R, 10%	805	Vishay	VJ0805Y471KXAAT
C12, C14	2	Capacitor, ceramic, 22 μ F, 16 V, X5R, 20%	1812	TDK	C4532X5R1C226MT
C15	1	Capacitor, ceramic, 47 μ F, 6.3 V, X5R, 20%	1812	TDK	C4532X5R0J476MT
C16, C17(1)	2	Capacitor, POSCAP, 470 μ F, 4 V, 10 m Ω , 20%	7343 (D)	Sanyo	4TPD470M
C2, C8, C10, C11, C18	5	Capacitor, ceramic, 0.1 μ F, 25 V, X7R, 10%	805	Vishay	VJ0805Y104KXXAT
C3	1	Capacitor, ceramic, 2.2 nF, 50 V, X7R, 10%	805	Vishay	VJ0805Y222KXAAT
C5	1	Capacitor, ceramic, 5.6 nF, 50 V, X7R, 10%	805	Vishay	VJ0805Y562KXAAT
C6,C13	2	Capacitor, ceramic, 4.7 nF, 50 V, X7R, 10%	805	Vishay	VJ0805Y472KXAAT
C7	1	Capacitor, ceramic, 100 pF, 50 V, NPO, 10%	805	Vishay	VJ0805A101KXAAT
C9	1	Capacitor, ceramic, 1 μ F, 16–V, X5R, 10%	805	TDK	C2012X5R1C105KT
D1	1	Diode, switching, 10 mA, 85 V, 350 mW	SOT23	Vishay–Liteon	BAS16
D2	1	Diode, schottky, 3 A, 40 V	SMC	IR	30BQ040
J1, J2	2	Terminal block, 4-pin, 15 A, 5.1 mm	0.80 x 0.35	OST	ED2227
L1(1)	1	Inductor, SMT, 1.7– μ H, 22.3 A, 1.8 m Ω	0.512 x 0.512	Coiltronics	HC1–1R7
Q1(1)	1	MOSFET, N–channel, V_{DS} 30 V, R_{DS} 6 m Ω , I_D 30 A	LFPAK	Hitachi	HAT2168H
Q2(1)	1	MOSFET, N–channel, V_{DS} 30 V, R_{DS} 4.2 m Ω , I_D 40 A	LFPAK	Hitachi	HAT2167H
R1	1	Resistor, chip, 1 k Ω , 1/10–W, 1%	805	Std	Std
R10	1	Resistor, chip, 0 Ω , 1/10–W, 5%	805	Std	Std
R11	1	Resistor, chip, 0 Ω , 1/10–W, yy%	805	Std	Std
R12	1	Resistor, chip, 20 Ω , 1/10–W, 5%	805	Std	Std
R2	1	Resistor, chip, 165 k Ω , 1/10–W, 1%	805	Std	Std
R3	1	Resistor, chip, 5.49 k Ω , 1/10–W, 1%	805	Std	Std
R4	1	Resistor, chip, 243 k Ω , 1/10–W, 1%	805	Std	Std
R5	1	Resistor, chip, 10 k Ω , 1/10–W, 1%	805	Std	Std
R6	1	Resistor, chip, 71.5 k Ω , 1/10–W, 1%	805	Std	Std
R7	1	Resistor, chip, 8.66 k Ω , 1/10–W, 1%	805	Std	Std
R8	1	Resistor, chip, 226 Ω , 1/10–W, 1%	805	Std	Std
R9	1	Resistor, chip, 16.2 k Ω , 1/10–W, 1%	805	Std	Std
TP1, TP4, TP5, TP7, TP9	5	JACK, test point, red		Farnell	240–345
TP2, TP3, TP6, TP10	4	JACK, test point, black		Farnell	240–333
TP8	1	Adaptor, 3.5 mm probe clip	0.2	Tektronix	131–4244–00 or 131–5031–00
U1	1	Wide input synchronous buck controller	PWP16	TI	TPS40055PWP
—	1	PCB, 2.85" x 2" x .062 In		Std	HPA070

9 References

1. Data Sheet, TPS40055 Wide-Input Synchronous Buck Controller (SLUS593).
2. Technical Brief, PowerPAD Thermally Enhanced Package (SLMA002).

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 - 2.3 TI's sole liability shall be at its option to repair or replace EVMs that fail to conform to the warranty set forth above, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.

WARNING

Evaluation Kits are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems.

User shall operate the Evaluation Kit within TI's recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI's recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI's instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGRADATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 Regulatory Notices:

3.1 United States

3.1.1 Notice applicable to EVMs not FCC-Approved:

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

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

CAUTION

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

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

FCC Interference Statement for Class A EVM devices

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

FCC Interference Statement for Class B EVM devices

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

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

3.2 Canada

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

Concerning EVMs Including Radio Transmitters:

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

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

Concernant les EVMs avec appareils radio:

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

Concerning EVMs Including Detachable Antennas:

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

Concernant les EVMs avec antennes détachables

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

3.3 Japan

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

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

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

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

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

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けていないものがあります。技術適合証明を受けていないもののご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
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東京都新宿区西新宿 6 丁目 2 4 番 1 号
西新宿三井ビル

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

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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, INDEMNITY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS, EXCEED THE TOTAL AMOUNT PAID TO TI BY USER FOR THE PARTICULAR EVM(S) AT ISSUE DURING THE PRIOR TWELVE (12) MONTHS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.
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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Last updated 10/2025