TEXAS INSTRUMENTS

1-MHz, 3.3-V, High-Efficiency Synchronous Buck Converter With TPS43000 PWM Controller

User’s Guide

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It is important to operate this EVM within the input voltage range of 3.3 Vdc to 9.0 Vdc and the output of 3.3 V ± 5%.

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During normal operation, some circuit components may have case temperatures greater than 50°C. The EVM is designed to operate properly with certain components above 50°C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during operation, please be aware that these devices may be very warm to the touch.

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1-MHz, 3.3-V, High-Efficiency Synchronous Buck Converter With TPS43000 PWM Controller

Systems Power

Contents

1 Introduction

This full-featured controller is designed to drive a pair of external MOSFETs (N or P) and can be used with a wide range of output voltages and power levels. It can be widely used in networking equipment, servers, PDAs, cellular phones, and telecommunication applications. The datasheet describes the functionalities of the controller in more detail.

A schematic of this board is shown in Figure 1. Recommended parts list is provided in Table 1. The layout of the PCB board is shown in Figure 6.

The specification for this board is as follows:

- $4.5\ V \le V_{IN} \le 8.5\ V$
- $V_{OUT} = 3.3\ V$
- $50\ mA \le I_{OUT} \le 2\ A$, enters PFM at 200 mA, nominal current is 1 A
- Switching frequency, $f_S = 1\ MHz$
- Ripple = 1%
- Efficiency at nominal load > 90%

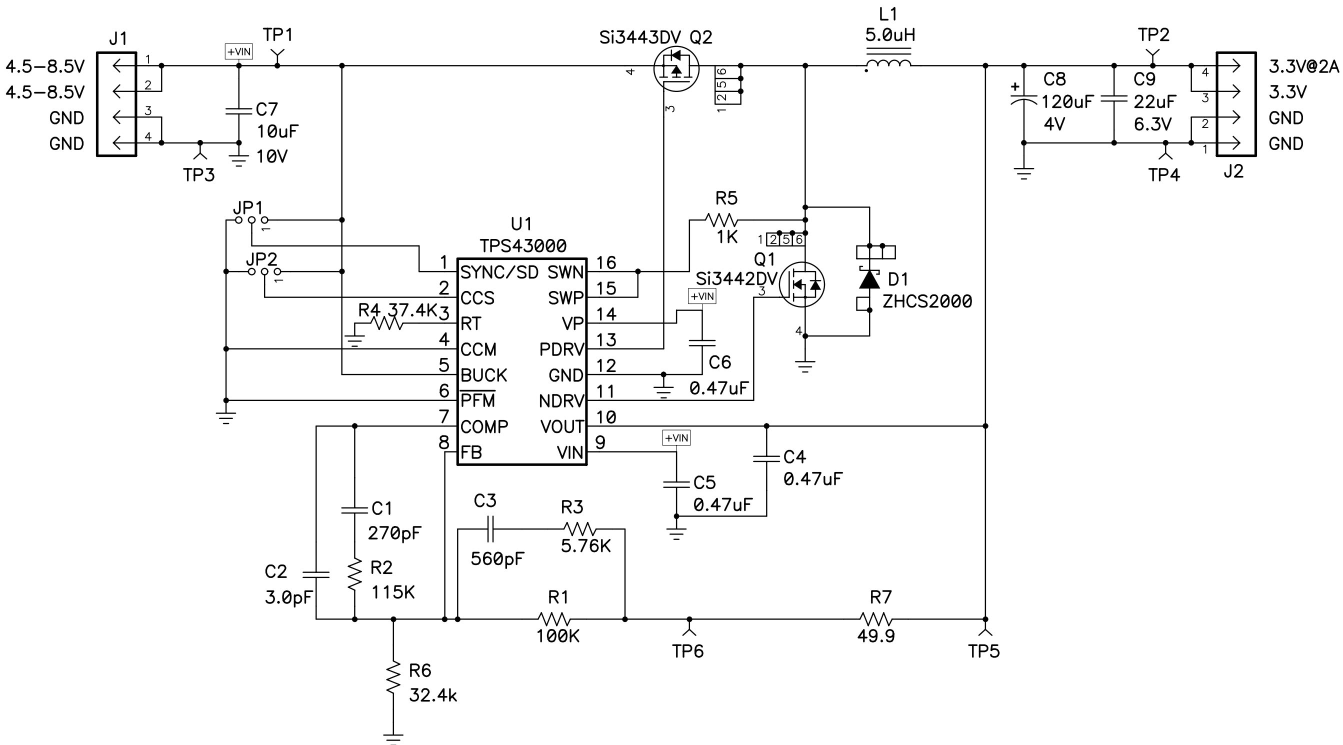

Figure 1. TPS43000–001EVM Schematic

2 Design Procedure

2.1 Frequency Setting

The TPS43000 can operate either in constant frequency, or in an automatic PFM mode. In the automatic PFM mode, the gate driver turns off when the inductor current goes discontinuous, and turns on when the output voltage has fallen by 2%. This pulse skipping can decrease gate-drive losses and significantly improve the efficiency at light load. (Refer to the TPS43000 Data Sheet, TI Literature No. SLUS489 for more information.)The converter is designed to operate at fixed 1 MHz above 0.2 A. The PFM mode is used when the load decreases to below 0.2 A.

A resistor, R4, connected from the RT pin to ground, programs the oscillator frequency. The approximate operating frequency is calculated in equation (1).

$$f\,(\text{MHz}) = \frac{38}{\text{R4 (k}\Omega\text{)}} \qquad (1)$$

R4 = 37.4 kΩ is chosen for 1-MHz operation.

2.2 Inductance Value

The inductance value can be calculated as shown in equation (2).

$$L_{(min)} = \frac{V_{OUT}}{f \times I_{RIPPLE}} \times \left(1 - \frac{V_{OUT}}{V_{IN(max)}}\right) \quad (2)$$

I_{RIPPLE} is the ripple current flowing through the inductor, which affects the output voltage ripple and core losses. According to the specification, the converter enters PFM mode at 200 mA, so the desired ripple current it 0.4 A. Based on this and the 1-MHz operating frequency, the inductance value is calculated at 5.0 µH.

2.3 Input and Output Capacitors

The output capacitance and required ESR can be calculated by equations (3) and (4).

$$C_{OUTPUT\ (min)} = \frac{I_{RIPPLE}}{8 \times f \times V_{RIPPLE}} \quad (3)$$

$$ESR_{OUT} = \frac{V_{RIPPLE}}{I_{RIPPLE}} \quad (4)$$

With 1% output voltage ripple, the capacitance required is at least 1.5 µF and its ESR should be less than 81.7 mΩ. A Panasonic 4-V, 120-µF capacitor is chosen with an ESR of 18 mΩ.

The required input capacitance is calculated in equation (5). The calculated value is approximately 10 µF. A 10-µF ceramic capacitor is used in order to handle the ripple current.

$$C_{IN\ (min)} = I_{OUT\ (max)} \times D_{max)} \times \frac{T_S}{V_{IN\ (ripple)}} \quad (5)$$

2.4 Compensation Design

The TPS43000 uses voltage-mode control. R1, R2, and R3 along with C1, C2 and C3, form a Type III compensator network. The L-C frequency of the power stage, f_C is approximately 6.5 kHz and the ESR zero is around 73.7 kHz, as shown in Figure 2. The overall crossover frequency, f_{0db} , is chosen at 50 kHz for reasonable transient response and stability. The two zeros, f_{Z1} and f_{Z2} from the compensator are set at 0.5 f_C and f_C separately. The two poles f_{P1} and f_{P2} are set at ESR zero and 0.5 f. The frequency of poles and zeros are defined by the following equations:

$$f_{Z1} = \frac{1}{2\pi \times R2 \times C1}$$

$$f_{Z2} \approx \frac{1}{2\pi \times R1 \times C3} \quad \text{assuming } R1 \gg R3$$

$$f_{P1} = \frac{1}{2\pi \times R3 \times C3}$$

$$f_{P2} \approx \frac{1}{2\pi \times R2 \times C2} \quad \text{assuming } C1 \gg C2$$

The transfer function for the compensator is calculated as:

$$A(s) = \frac{(1 + s \times C1 \times R2) \times (1 + s \times C3 \times (R1 + R3))}{s \times R1 \times C1 \times \left(1 + \left(\frac{C2}{C1}\right) + s \times C2 \times R2\right) \times (1 + s \times C3 \times R3)}$$

The compensator values are calculated as:

C1 = 270 pF, C2 = 3.0 pF, C3 = 560 pF, R1 = 100 kΩ, R2 = 115 kΩ, and R3 = 5.76 kΩ.

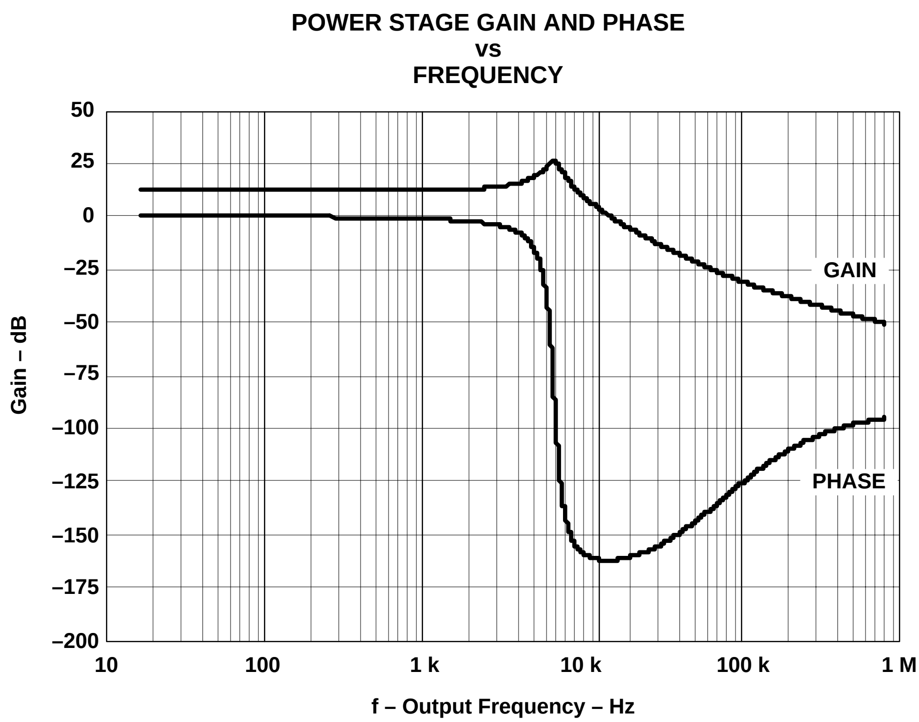

Figure 2.

2.5 MOSFETs and Diode

For a 3.3-V output voltage, the lower the $R_{DS(on)}$ of the MOSFET, the higher the efficiency. Also, considering the 1-MHz switching frequency, Si3442DV ($R_{DS(on)}$ = 65 mΩ) and Si3443DV ($R_{DS(on)}$ = 70 mΩ) are chosen for fast switching speed.

2.6 Current Limiting

Two types of current limiting can be selected from the controller. Detailed information is available in the datasheet (TI Literature No. SLUS489). A jumper, JP2, is used to choose different current limiting. By tying the CCS pin to VIN, the controller enters pulse-by-pulse current limiting and the current-limiting threshold is calculated by equation (6):

$$I_{MAX\,(p-p)} = \frac{150\ mV}{R_{DS(on)}} \tag{6}$$

in which $R_{DS(on)}$ is the on-resistance of Q2. In this design, the threshold is approximately 2.3 A. This value may change with temperature.

By tying the CCS pin to ground, the controller enters hiccup-mode overcurrent limiting . The current-limiting threshold is calculated in equation (7). The threshold in this case is approximately 3.8 A. This value may change with temperature.

$$I_{MAX\,(hu)} = \frac{250\ mV}{R_{DS(on)}} \tag{7}$$

2.7 Voltage Sense Resistor

R1 and R6 operate as the output voltage divider. The internal reference voltage is 0.8 V. The relationship between the output voltage and divider is described in equation (8).

$$\frac{V_{REF}}{R6} = \frac{V_{OUT}}{R1 + R6} \tag{8}$$

With an R1 value of 100 kΩ and 3.3-V voltage regulation, R6 is calculated at 32.4 kΩ.

3 Test Results

3.1 Efficiency Curves

Efficiency tested at different loads and input voltages is shown in Figure 4. The maximum efficiency is as high as 94% at 0.5 A output. The light-load efficiency is improved due to the PFM operation mode.

3.2 Typical Operation Waveform

Typical operating waveforms are shown in Figure 5 with V_{IN} = 4.5 V and I_{OUT} = 2 A.

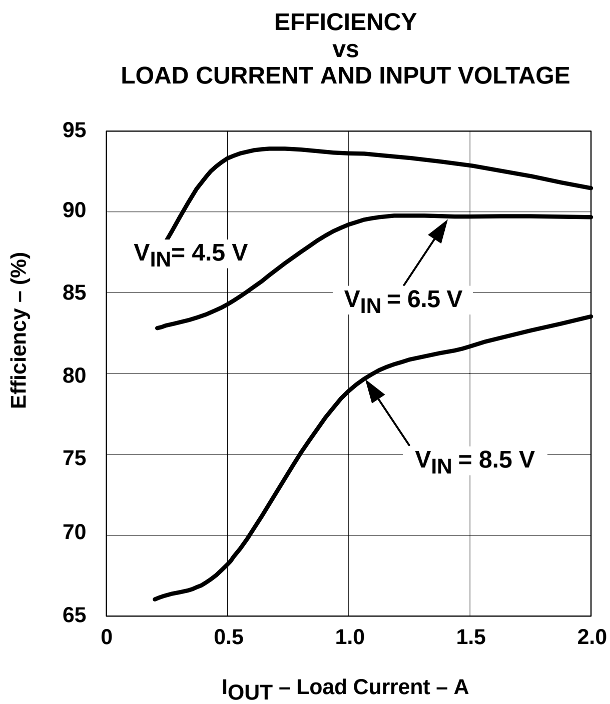

Figure 3.

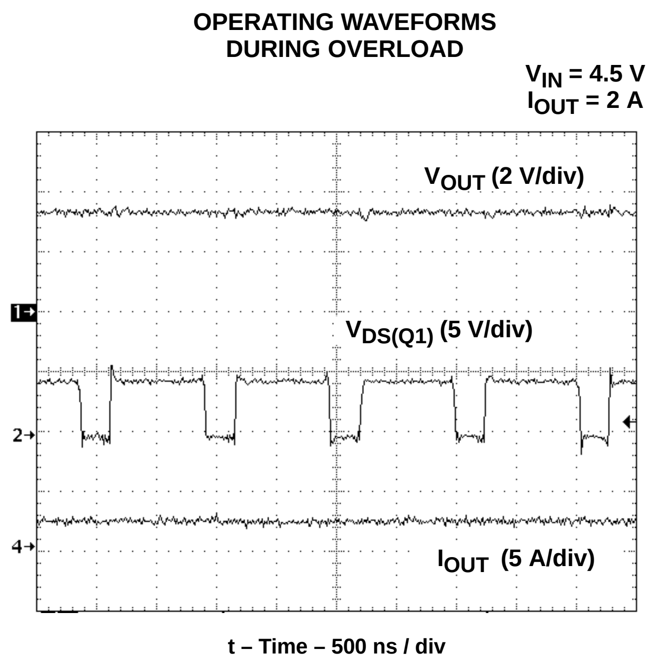

Figure 4.

3.3 Output Ripple Voltage and Transient Response

The output ripple is approximately 28.8 mV peak-to-peak with a 1.5 A output and is shown in Figure 4. Figure 5 shows load changes from 0.5 A to 1.5 A, where the overshooting voltage is approximately 10 mV.

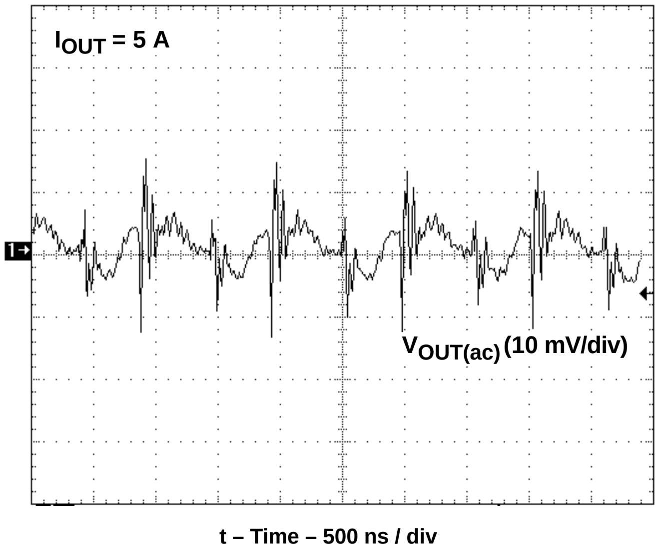

Figure 5. Output Ripple

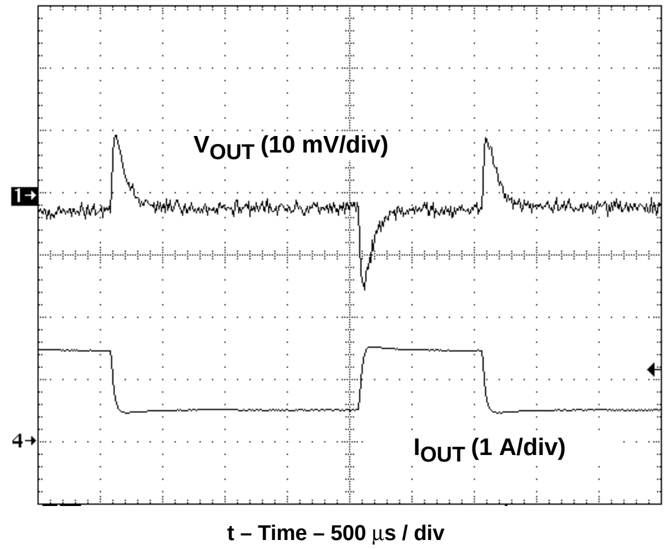

Figure 6. Transient Response

4 PCB Layout

Figures 7 through 9 show the PCB layout . All components are on the top side of the board. The bottom side of the board is the ground plane.

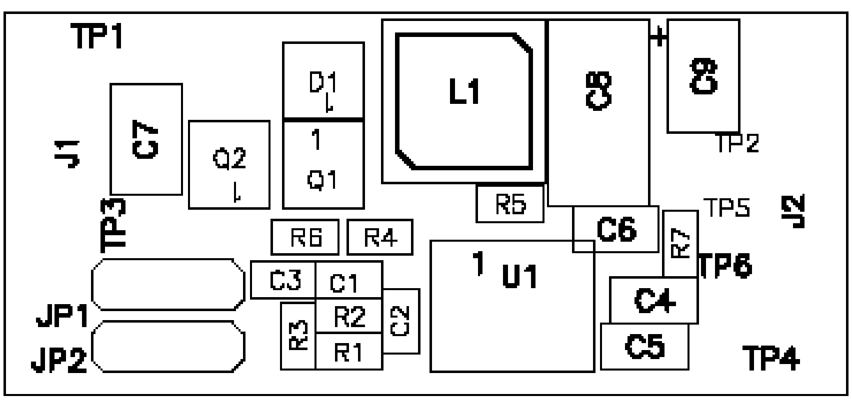

Figure 7. Parts Placement

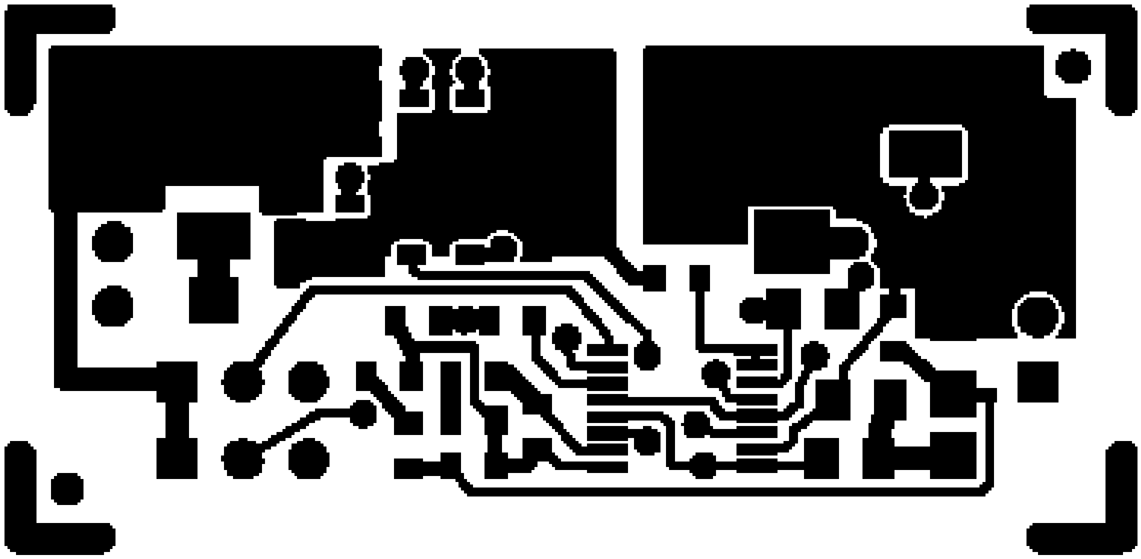

Figure 8. Top Layer

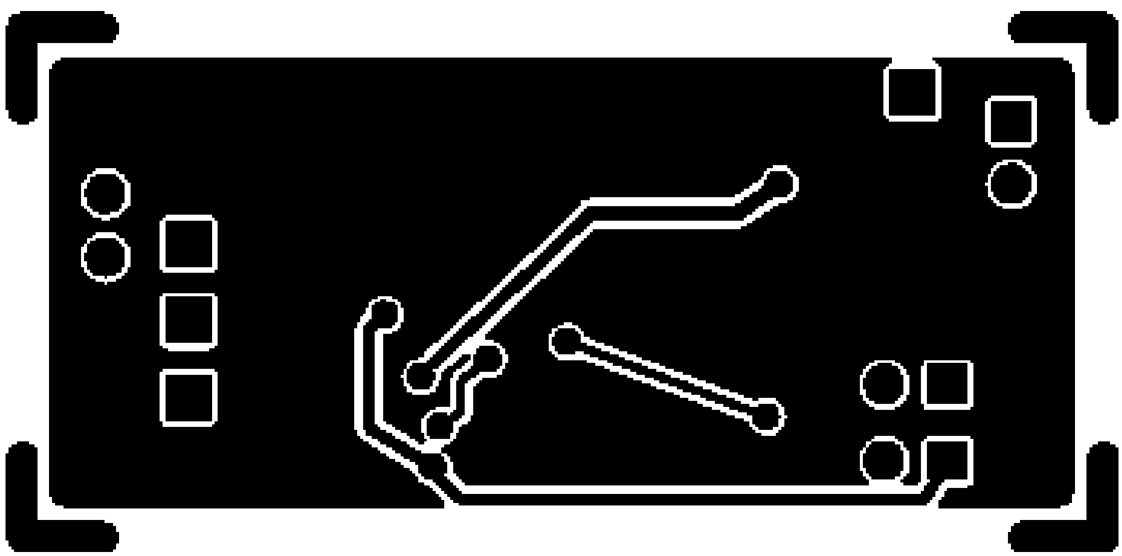

Figure 9. Bottom Layer

5 Bill of Materials

Table 1 lists the board components and their values, which can be modified to meet the application requirements.

. List of Materials

REFERENCE DESIGNATOR	QTY	PART NUMBER	DESCRIPTION	MFG	SIZE
C1	1	GRM1885C1H271J K	Capacitor, ceramic, 270 pF, 50 V, COG, 5%	Murata	603
C2	1	GRM1885C1H3R0J K	Capacitor, ceramic, 3 pF, 50 V, COG, 5%	Murata	603
C3	1	GRM188R71H561J K	Capacitor, ceramic, 560 pF, 50 V, 5%	Murata	603
C4,C5,C6	3	GRM219R71C474K K	Capacitor, ceramic, 0.47 µF, 16 V, X7R, 10%	Murata	805
C7	1	LMK325BJ106MN	Capacitor, ceramic, 10 µF, 10 V, 20%	Taiyo-Yuden	1210
C9	1	JMK325BJ226MM	Capacitor, ceramic, 22 µF, 6.3 V, 20%	Taiyo-Yuden	1210
C8	1	EEFUD0D121R	Capacitor, 120 µF, 4.0 V, 18 mΩ, 20%	Panasonic	7343 (D)
D1	1	ZHCS2000	Diode, schottky, 2 A, 40 V	Zetex	SOT23–6
J1,J2	2	PTC36SAAN	Header, 4-pin, 100 mil spacing, (36-pin strip)	Sullins	0.100 x 4”
L1	1	U2PB–3R3	Inductor, SMT, 5.0 µH, 2.9 A, 24 mΩ	Sumida	6.7 X 6.7 mm
R1	1	Std	Resistor, chip, 100 kΩ, 1/16-W, 1%	Std	603
R2	1	Std	Resistor, chip, 115 kΩ, 1/16-W, 1%	Std	603
R3	1	Std	Resistor, chip, 5.76 kΩ, 1/16–W, 1%	Std	603
R4	1	Std	Resistor, chip, 37.4 kΩ, 1/16-W, 1%	Std	603
R5	1	Std	Resistor, chip, 1 kΩ, 1/16-W, 1%	Std	603
R6	1	Std	Resistor, chip, 32.4 kΩ, 1/16-W, 1%	Std	603
R7	1	Std	Resistor, chip, 49.9 kΩ, 1/16-W, 1%	Std	603
Q1†	1	Si3442DV	MOSFET, N–channel, 2.5-V_{GS}, 4 A, 70 mΩ	Siliconix	TSOP–6
Q2†	1	Si3443DV	MOSFET, P-channel, 2.5-V_{GS}, 4.4 A, 90 mΩ	Siliconix	TSOP–6
U1†	1	TPS43000PW	Multi–topology high-frequency PWM controller	Texas Instruments	TSSOP–16
TP1,TP2,TP5	3	240–333	Test point, red, 1 mm	Farnell	0.038”
TP3,TP4,TP6	3	240–333	Test point, black, 1 mm	Farnell	0.038”
N/A	1	SLVP217	Printed circuit board, FR4, 0.032, SMOBC	any	

† Components can not be substituted.

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- *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*

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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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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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