EVM User's Guide: LM5113LLPEVB

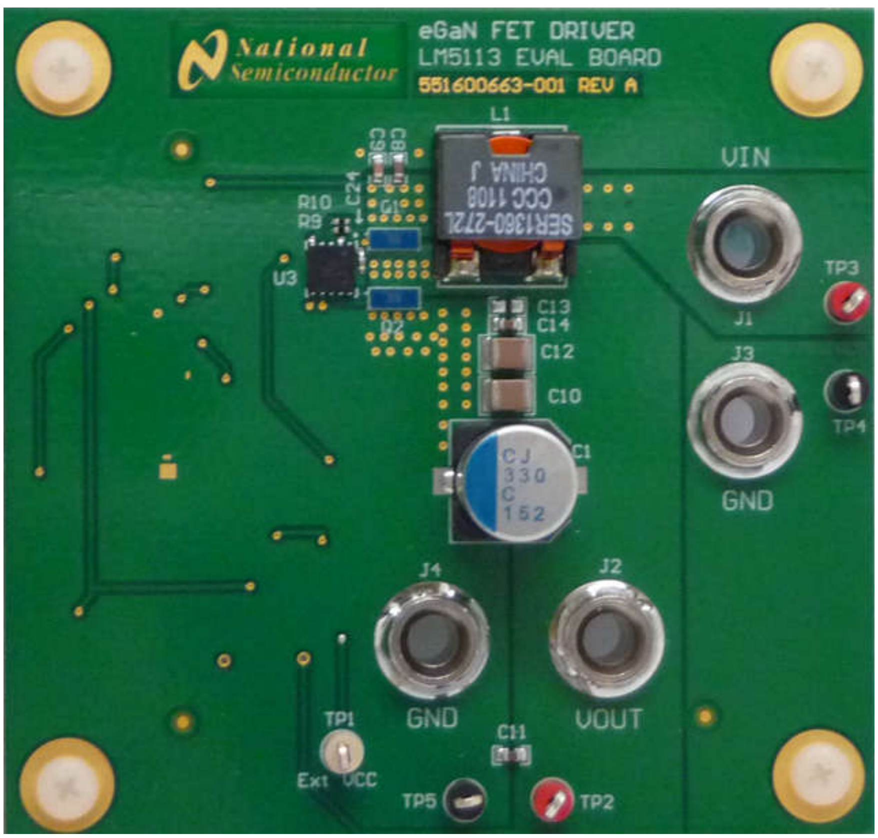
AN-2149 LM5113 Evaluation Board

Description

The LM5113 evaluation board is designed to provide the design engineers with a synchronous buck converter to evaluate the LM5113, a 100V half-bridge enhancement mode Gallium Nitride (GaN) FET driver. The active clamping voltage mode controller LM5025 is used to generate the PWM signals of the buck switch and the synchronous switch.

IC Features

- Independent high-side and low-side TTL logic inputs
- 1.2A/5A peak source/sink current
- High-side floating bias voltage rail operates up to 100VDC
- Internal bootstrap supply voltage clamping
- Split outputs for adjustable turn-on/turn-off strength
- 0.6Ω/2.1Ω pull-down/pull-up resistance
- Fast propagation times (28ns typical)
- Excellent propagation delay matching (1.5ns typical)
- Supply rail under-voltage lockout
- Low power consumption



1 Evaluation Module Overview

1.1 Introduction

The specifications of the evaluation board are as follows:

- Input Operating Voltage: 15V to 60V
- Output Voltage: 10V
- Output Current: 10A @ 48V, 7A @ 60V
- Measured Efficiency at 48V: 93.9% @ 10A
- Frequency of Operation: 800kHz
- Line UVLO: 13.8V (Rising) /10.8V (Falling)
- Board size: 3.00 x 2.83 inches

The printed circuit board (PCB) consists of 2 layers of 2 ounce copper on FR4 material, with a thickness of 0.050 inches.

This document contains the schematic of the evaluation board, Bill of Materials (BOM) and a quick setup procedure. The evaluation board can be reconfigured for different switching frequency, dead time, and the output voltage from the specifications above. An example of 48V to 3.3V conversion is given in Section 4. For more complete information, see the *LM5113 5A, 100V Half-Bridge Gate Driver for Enhancement Mode GaN FETs Data Sheet* (SNVS725).

1.2 Kit Contents

- Assembled LM5113 Evaluation Board
- LM5113 Application Note 2149

2 Hardware

2.1 Powering and Loading Considerations

Certain precautions need to be followed when applying power to the LM5113 evaluation board. A disconnection can damage the assembly.

2.1.1 Proper Board Connection

Figure 2-2 depicts the typical evaluation setup. The source power is connected to the J1 (VIN) and the J3 (GND). The load is connected to the J2 (VOUT) and the J4 (GND). Be sure to choose the correct connector and wire size. The input and output voltage must be monitored directly at the terminals of the board. The voltage drop across the connection wires causes inaccurate measurements.

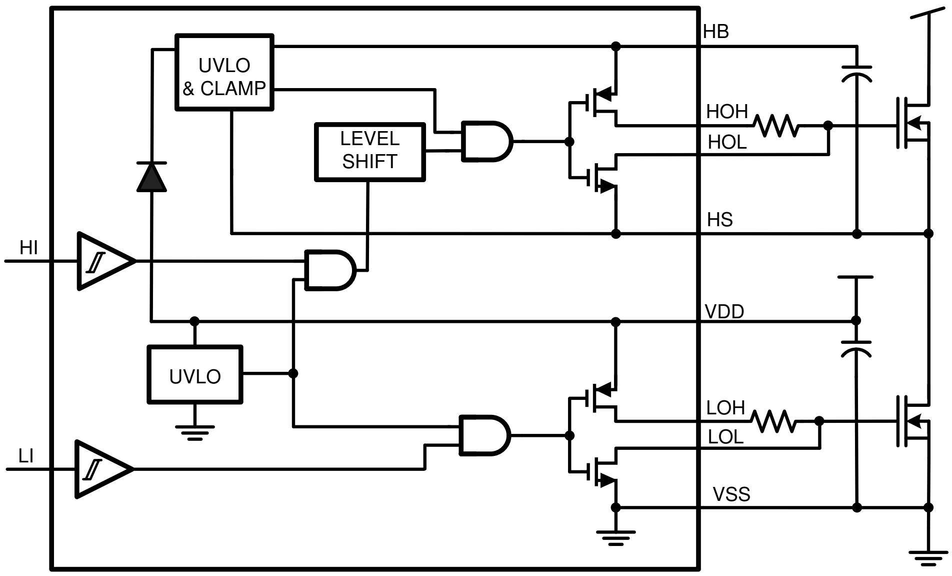


Figure 2-1. Simplified Block Diagram of LM5113

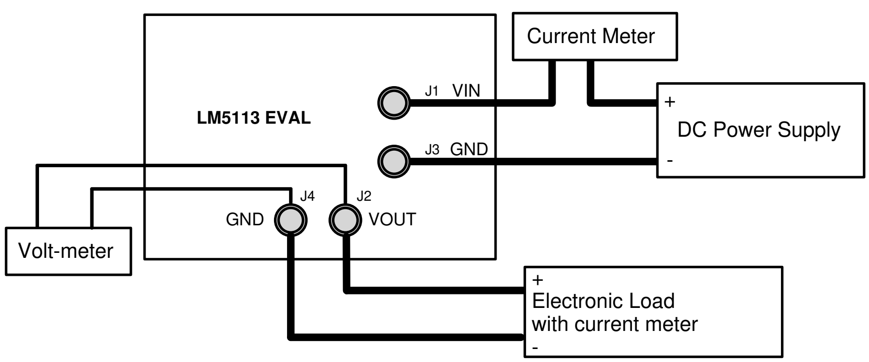


Figure 2-2. Typical Evaluation Setup

2.1.2 Source Power

To fully test the LM5113 evaluation board, a DC power supply capable of 60V and 8A is required. The power supply and cabling must present low impedance to the evaluation board. Insufficient cabling or a high impedance power supply droop during power supply application with the evaluation board inrush current. If large enough, then this droop causes a chattering condition upon power up. This chattering condition is an interaction with the evaluation board under voltage lockout, the cabling impedance and the inrush current.

2.1.3 Output Current Derating

The LM5113 evaluation board is designed to operate with a maximum load current of 10A for input voltages ranging from 15V to 48V. With further increases of the input voltage, the maximum allowable load current gradually decreases to 7A, to verify reliable prolonged operation. Figure 2-3 illustrates the derating curve of the output current at room temperature with airflow of 200CFM. To further reduce the maximum load current at higher ambient temperature can be necessary.

Note that the LM5113 evaluation board does not have over current protection. Certain precautions must be taken to prevent the load current from exceeding the derating curve shown in Figure 2-3, otherwise a catastrophic failure can result.

2.1.4 Air Flow

Sufficient cooling is required to verify a proper and reliable operation. Especially at high line input and full load, most of the power losses are dissipated in the buck switch. Insufficient airflow can cause overheating of the GaN FETs. A minimum airflow of 200CFM must always be provided.

2.1.5 Quick Start-Up Procedure

1. Set the current limit of the source supply to provide about 1.5 times the anticipated output power. Connect the source supply to J1 and J3.
2. Connect the load cable between J2 and J4. Disable the load.
3. Set the input voltage and turn on the power supply without load current. Check that the output voltage is 10V.
4. Slowly increase the load current while monitoring the output voltage.

When the evaluation board is powered off, wait for 30 seconds before powering on the evaluation board again to allow the full discharge of the soft start capacitor.

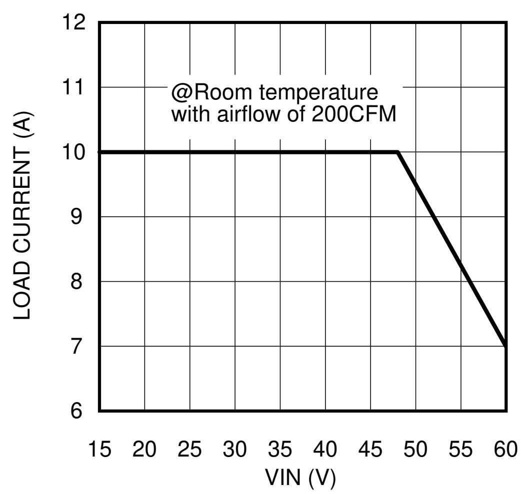


Figure 2-3. Load Current Derating Curve

3 Implementation Results

3.1 Performance Characteristics

Figure 3-1 shows the efficiency of the LM5113 evaluation board at different input voltage and the load current. 30ns dead time between HI and LI input of the LM5113 is selected to eliminate the shoot through while achieving high efficiency.

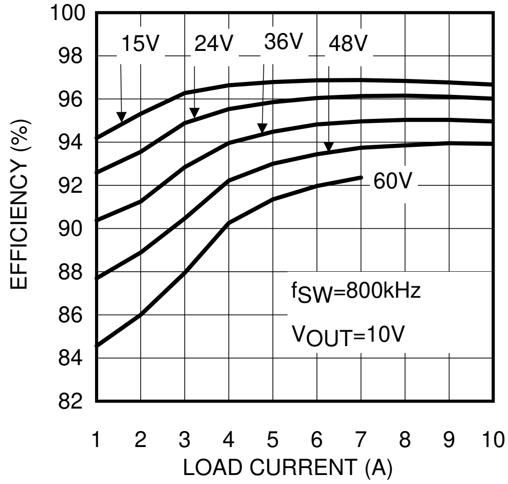


Figure 3-1. Evaluation Board Efficiency vs. Load Current

During the dead time, the HS pin voltage can be pulled down below -0.7V and results in an excessive bootstrap voltage. The LM5113 has an internal clamping circuitry that prevents the bootstrap voltage from exceeding 5.25V typically. Figure 3-2 shows the average of the bootstrap voltage with the different load current. As can be seen, the bootstrap voltage is well regulated.

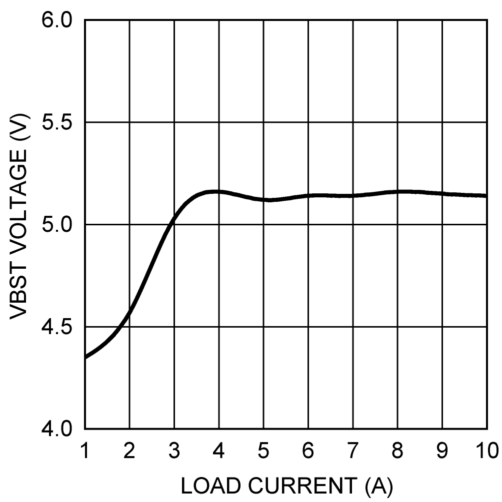
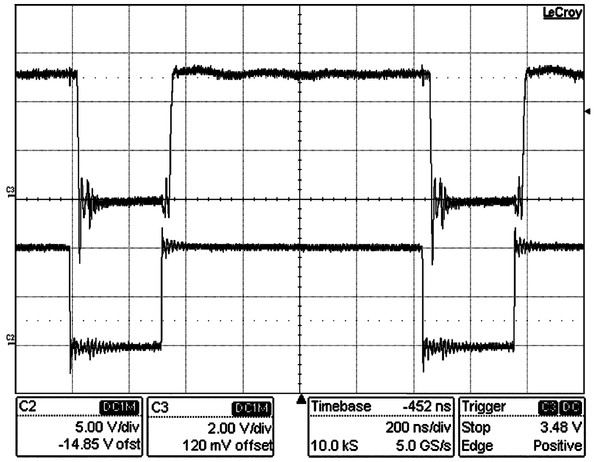


Figure 3-2. Bootstrap Voltage Regulation vs. Load Current

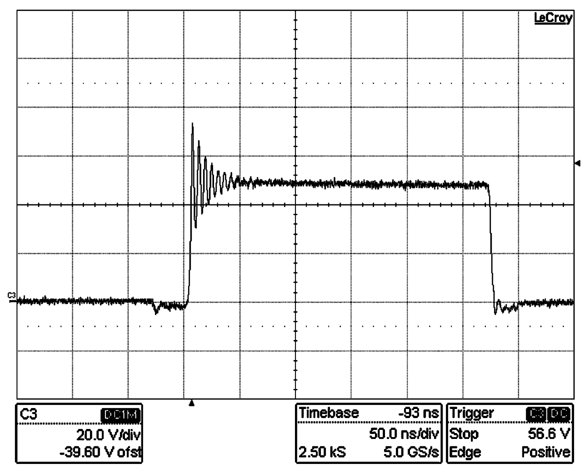
Figure 3-3 compares the input and the output of the low-side driver.



Conditions: Input Voltage = 48V DC, Load Current = 5A **Traces**: Top Trace: Gate of Low-Side eGaN FET, Volt/div = 2V Bottom Trace: LI of LM5113, Volt/div = 5V Bandwidth Limit = 600MHz Horizontal Resolution = 0.2µs/div

Figure 3-3. Low-Side Driver Input and Output

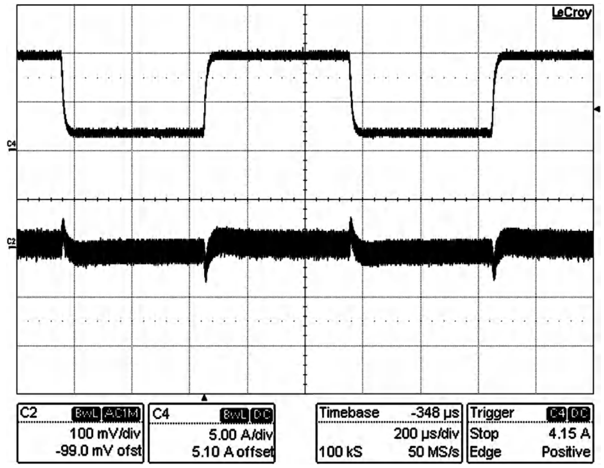
Figure 3-4 shows the switch node voltage that is also the drain voltage of the low-side FET. The ringing on the switch node voltage can be reduced by the HOH gate resistor. 2Ω HOH gate resistance is selected to achieve a drain-source voltage margin of 12V for a 60V input.



Conditions: Input Voltage = 48V DC Load Current = 10A **Traces:** Trace: Switch–Node Voltage, Volts/div = 20V Bandwidth Limit = 600MHz Horizontal Resolution = 50ns/div

Figure 3-4. Switch-Node Voltage

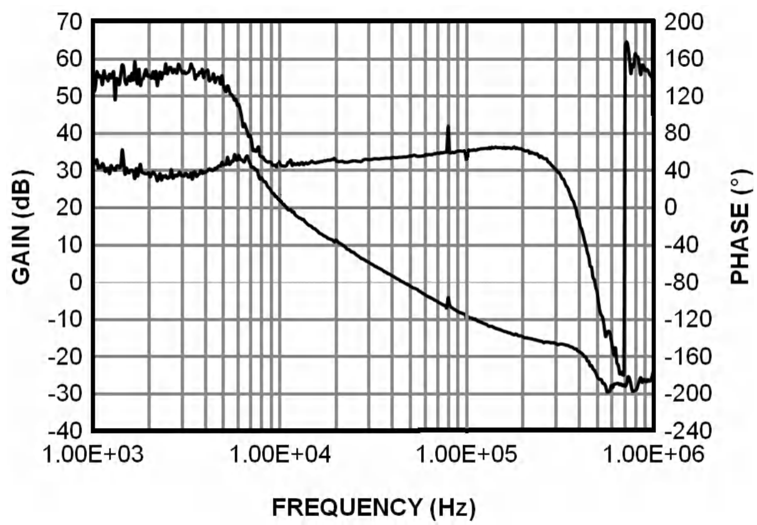
Figure 3-5 shows the load transient response. The load changes between 2A and 10A. 800kHz switching frequency allows the use of a small inductor of 2.7uH, which helps improve the large signal transient response.



Conditions: Input Voltage = 48V DC Output Current = 2A to 10A**Traces:** Top Trace: Load Current, Amp/div = 5A Bottom Trace: Output Voltage Volt/div = 100mV, AC coupled Bandwidth Limit = 20MHz Horizontal Resolution = 0.2ms/div

Figure 3-5. Load Transient Response

Figure 3-6 shows the measured overall loop response. The crossover frequency is 46kHz and the phase margin is around 55°.



Conditions: Input Voltage = 48V DC Output Current = 10A

Figure 3-6. Loop Gain and Phase

4 48V to 3.3V Conversion

The LM5113 evaluation board can also be reconfigured for different switching frequency, dead time and output voltage. By adjusting the resistor R17, the PWM controller LM5025 can operate up to 1MHz. The dead time can be adjusted with the resistor R15, and/or with RCD circuitry at the inputs of the LM5113. The output voltage can be adjusted with R16 as follows:

$$R16 = \frac{21 \times V_0}{20 - V_0} k\Omega \quad (1)$$

Note that the maximum output power can be derated to verify the safe operation of the GaN FETs when the evaluation board is configured for the switching frequency beyond the preceding specifications.

Figure 4-1 shows the design for a 48V to 3.3V conversion. The switching frequency is set at 500kHz. Note that the bias supply for the control circuitry is generated from the internal LDO of the LM5025. To aid thermal dissipation, sufficient cooling must be provided for the LM5025. Alternatively, an external 10V supply can be connected to the terminal TP1 EXT VCC to provide the bias voltage for the control circuitry.

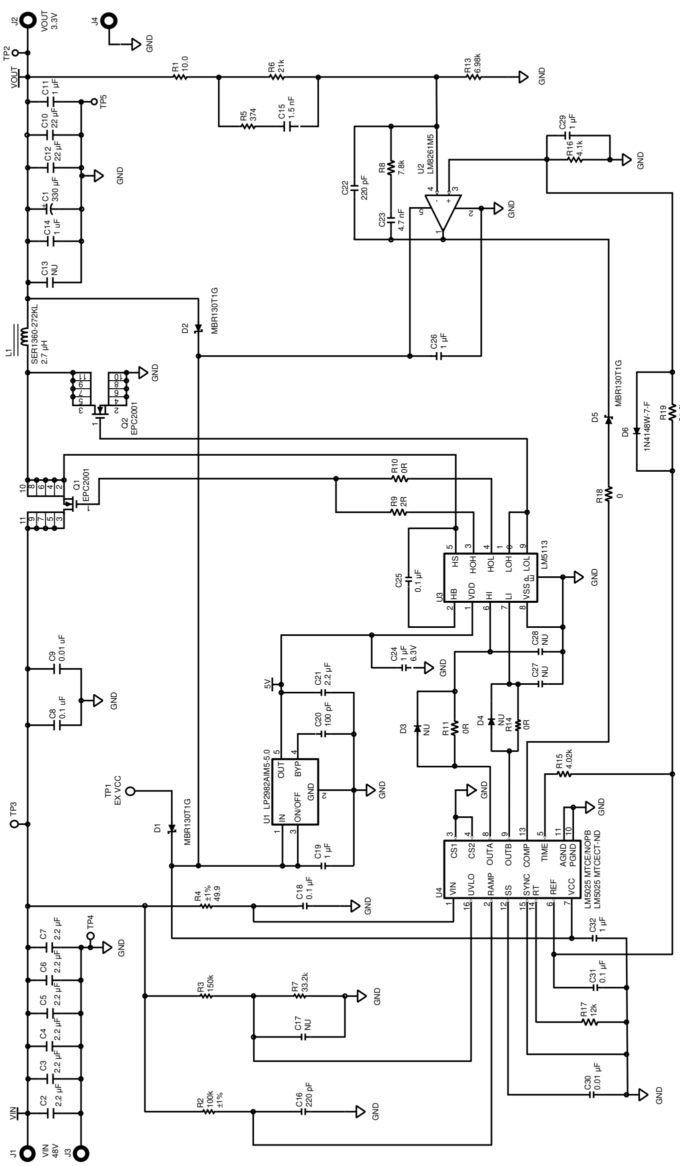


Figure 4-1. Application Circuit: Input 48V, Output 3.3V, 10A, 500kHz

5 Hardware Design Files

5.1 Evaluation Board Schematic

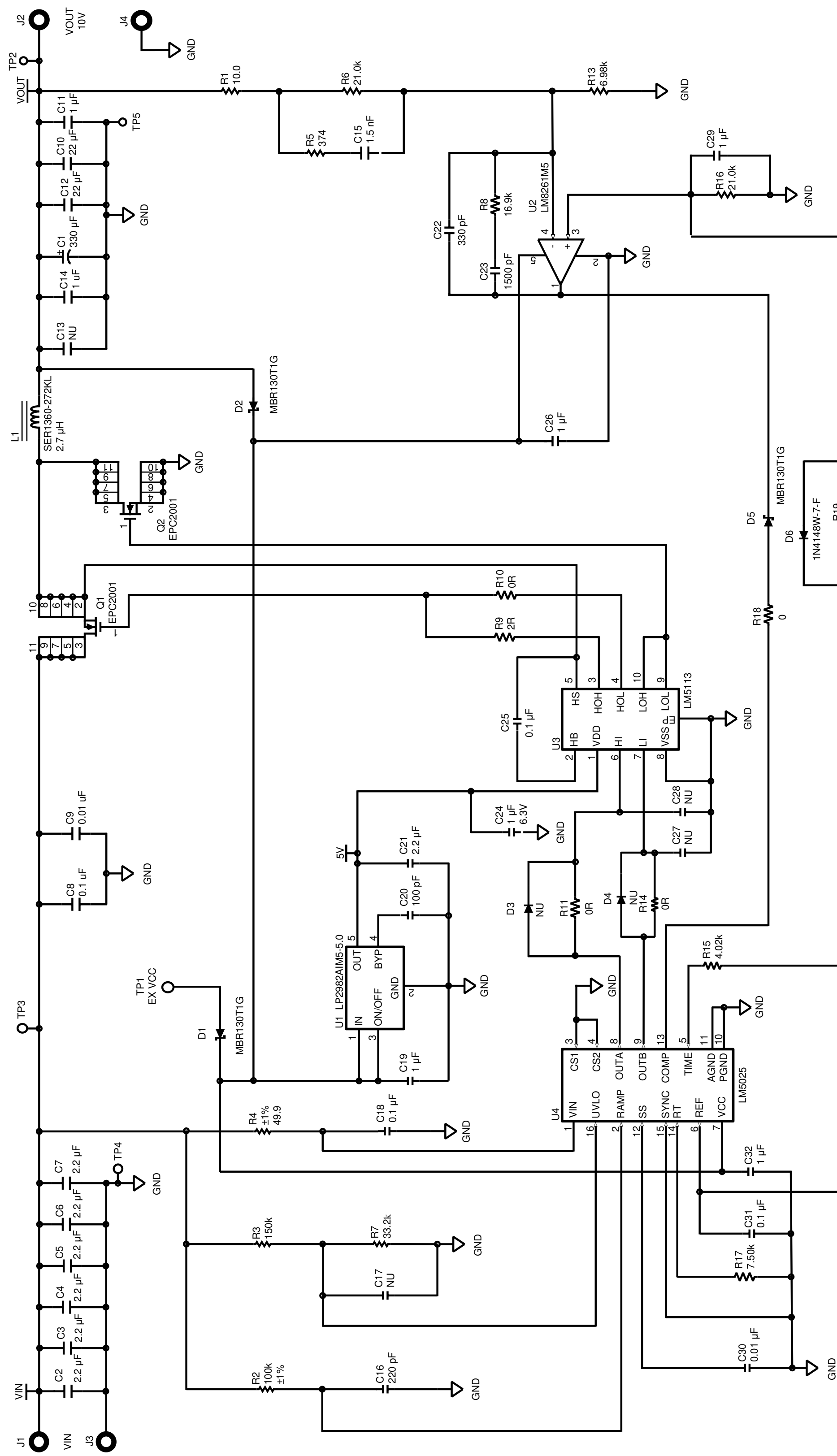


Figure 5-1. Application Circuit: Input 15V to 60V, Output 10V, 800kHz

5.2 PCB Layouts

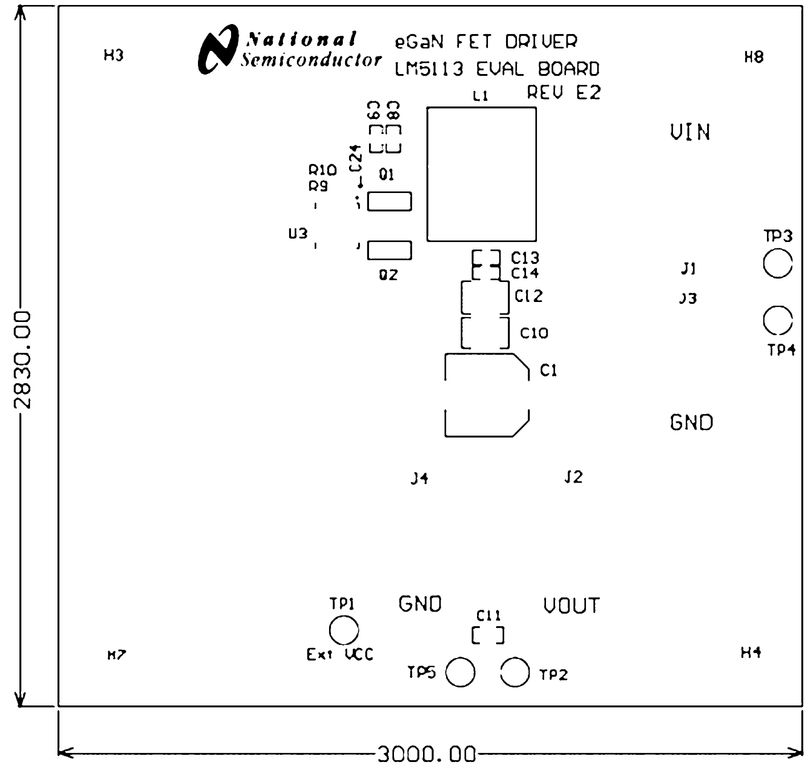


Figure 5-2. Top Side Silk Screen

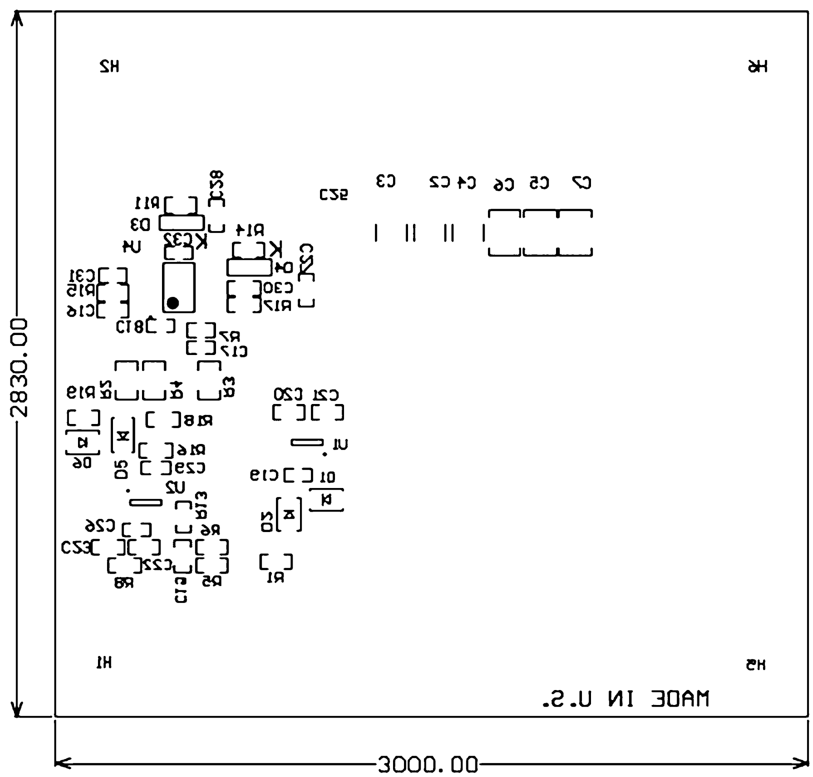


Figure 5-3. Bottom Side Silk Screen

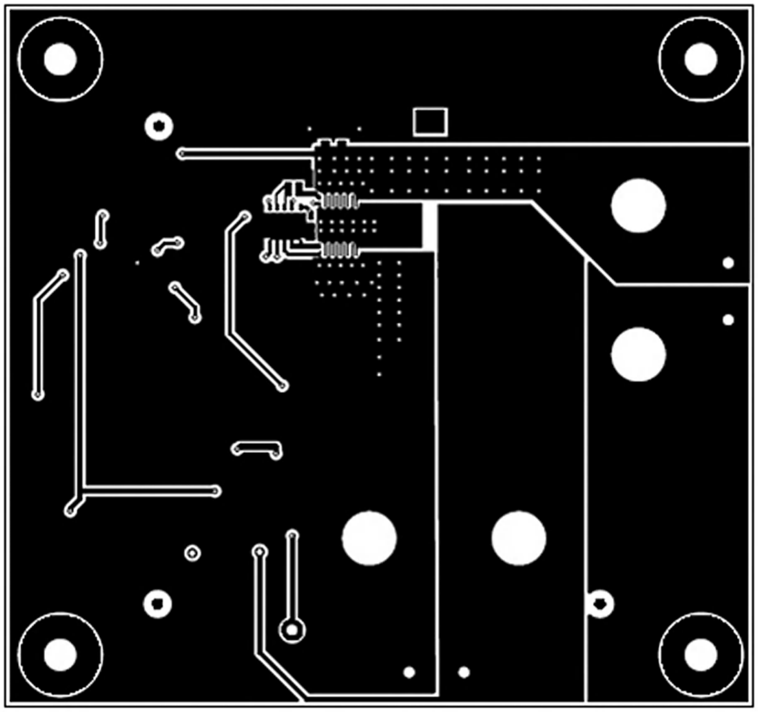


Figure 5-4. Top Layer

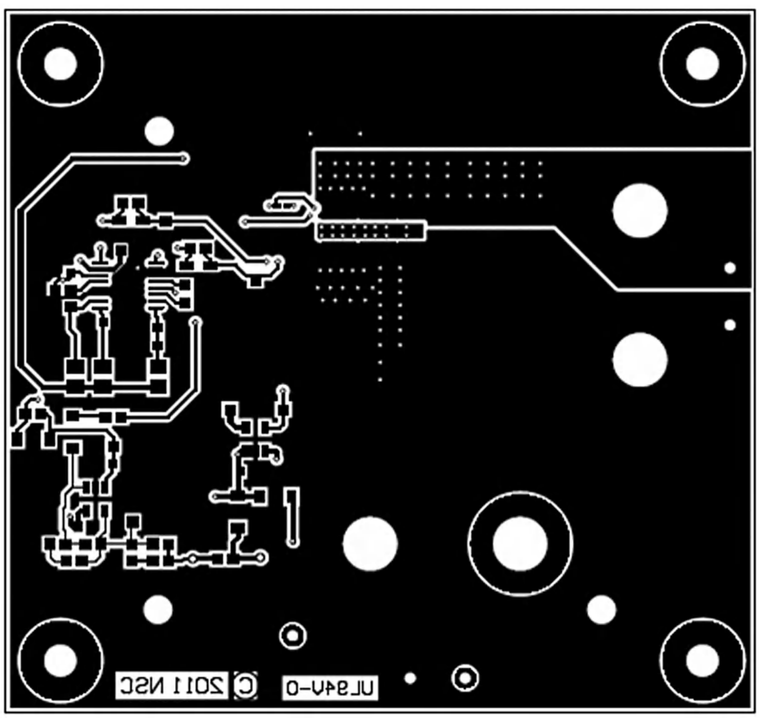


Figure 5-5. Bottom Layer

5.3 Bill of Materials (BOM)

Table 5-1. Bill of Materials (BOM)

Item	Part	Value	Package	Part Number	Manufacturer
1	C1	CAP, 330uF, 16V, 16mΩ	10mm x 10mm	PCJ1C331MCL1GS	Nippon Chemi-Con
2	C2, C3, C4	CAP, CERM, 2.2uF, 100V, X7R,	1812	C4532X7R2A225M	TDK
3	C5, C6, C7	CAP, CERM, 2.2uF, 100V, X7R	1210	HMK325B7225KN-T	Taiyo Yuden
4	C8	CAP CER .1UF 100V X7R 0603	0603	GRM188R72A104KA35D	Murata
5	C9	CAP CER 10000PF 100V X7R	0603	C1608X7R2A103K	TDK
6	C13	NU			
7	C18, C31	CAP, CERM, 0.1uF, 16V, X7R	0603	C1608X7R1C104K	TDK
8	C10, C12	CAP CER 22UF 16V X7R	1210	C3225X7R1C226K	TDK
9	C14, C11, C19, C26, C29, C32	CAP, CERM, 1uF, 16V, X7R	0603	C1608X7R1C105K	TDK
10	C15, C23	CAP, CERM, 1500pF, 25V, +/-5%, C0G/NP0	0603	GRM1885C1E152JA01D	MuRata
11	C16	CAP, CERM, 220pF, 100V, X7R	0603	06031C221KAT2A	AVX
12	C17	NU			
13	C20	CAP, CERM, 100pF, 25V, X7R	0603	06033C101KAT2A	AVX
14	C21	CAP, CERM, 2.2uF, 10V, X7R	0603	GRM188R71A225KE15D	Murata
15	C22	CAP, CERM, 330pF, 50V, +/-5%, C0G/NP0	0603	GRM1885C1H331JA01D	Murata
16	C24	CAP, CERM, 1uF, 6.3V, X5R	0402	C1005X5R0J105M	TDK
17	C25	CAP CER .1UF 16V X7R	0402	GRM155R71C104KA88D	TDK
18	C27, C28	NU			
19	C30	CAP, CERM, 0.01uF, 50V, X7R	0603	GRM188R71H103KA01D	Murata
20	D1, D2, D5	Diode, Schottky, 30V, 1A	SOD-123	MBR130T1G	ON Semiconductor
21	D3, D4	NU	SOD-323		
22	D6	Diode, Ultrafast, 100V, 0.15A	SOD-123	1N4148W-7-F	Diodes Inc
23	L1	Inductor, Shielded E Core, Ferrite, 2.7uH, 12A	SMD 12.6mmX12.7mm	SER1360-272KLB	Coilcraft
24	Q1, Q2	eGaN FET, 100V, 25A, 7mΩ	4105um X 1632 um	EPC2001	EPC
25	R1	RES, 10.0 ohm, 1%, 0.1W	0603	RC0603FR-0710RL	Yageo America
26	R2	RES, 100k ohm, 1%, 0.125W	0805	CRCW0805100KFKEA	Vishay-Dale
27	R3	RES, 150k ohm, 1%, 0.125W	0805	CRCW0805150KFKEA	Vishay-Dale
28	R4	RES 49.9 OHM 1/8W 1%	0805	CRCW080549R9FKEA	Vishay-Dale
29	R5	RES, 374 ohm, 1%, 0.1W	0603	CRCW0603374RFKEA	Vishay-Dale

Table 5-1. Bill of Materials (BOM) (continued)

Item	Part	Value	Package	Part Number	Manufacturer
30	R6, R16, R19	RES, 21.0k ohm, 1%, 0.1W	0603	RC0603FR-0721KL	Yageo America
31	R7	RES, 33.2k ohm, 1%, 0.1W	0603	RC0603FR-0733K2L	Yageo America
32	R8	RES, 16.9k ohm, 1%, 0.1W	0603	RC0603FR-0716K9L	Yageo America
33	R9	RES, 2.00 ohm, 1%, 0.063W	0402	CRCW04022R00FKED	Vishay-Dale
34	R10	RES, 0.0 Ohm, 1/10W	0402	ERJ-2GE0R00X	Panasonic
35	R11, R14, R18	RES, 0 ohm, 5%, 0.1W	0603	ERJ-3GEY0R00V	Panasonic
36	R13	RES, 6.98k ohm, 1%, 0.1W	0603	RC0603FR-076K98L	Yageo America
37	R15	RES, 4.02k ohm, 1%, 0.1W	0603	RC0603FR-074K02L	Yageo America
38	R17	RES, 7.50k ohm, 1%, 0.1W	0603	CRCW06037K50FKEA	Vishay-Dale
39	U1	5.0V, 50mA LDO	SOT-23	LP2982	Texas Instruments
40	U2	Op Amp	SOT-23	LM8261	Texas Instruments
41	U3	5A, 100V, GaN FET Driver	WSON-10	LM5113-Q1	Texas Instruments
42	U4	Active clamp voltage mode PWM Controller	16–pin TSSOP	LM5025	Texas Instruments

6 Additional Information

6.1 Trademarks

All trademarks are the property of their respective owners.

7 Revision History

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

Changes from Revision A (May 2013) to Revision B (March 2024)	Page
• Changed the industrial version of the U3 from to the automotive version	12

STANDARD TERMS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, and/or documentation which may be provided together or separately (collectively, an “EVM” or “EVMs”) to the User (“User”) in accordance with the terms set forth herein. User's acceptance of the EVM is expressly subject to the following terms.

   1.1 EVMs are intended solely for product or software developers for use in a research and development setting to facilitate feasibility evaluation, experimentation, or scientific analysis of TI semiconductors products. EVMs have no direct function and are not finished products. EVMs shall not be directly or indirectly assembled as a part or subassembly in any finished product. For clarification, any software or software tools provided with the EVM (“Software”) shall not be subject to the terms and conditions set forth herein but rather shall be subject to the applicable terms that accompany such Software

   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

2 *Limited Warranty and Related Remedies/Disclaimers*:

   2.1 These terms do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for a nonconforming EVM if (a) the nonconformity was caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI, (b) the nonconformity resulted from User's design, specifications or instructions for such EVMs or improper system design, or (c) User has not paid on time. Testing and other quality control techniques are used to the extent TI deems necessary. TI does not test all parameters of each EVM. User's claims against TI under this Section 2 are void if User fails to notify TI of any apparent defects in the EVMs within ten (10) business days after delivery, or of any hidden defects with ten (10) business days after the defect has been detected.

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

WARNING

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

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

NOTE:

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

3 *Regulatory Notices:*

3.1 *United States*

3.1.1 *Notice applicable to EVMs not FCC-Approved:*

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

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

CAUTION

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

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

FCC Interference Statement for Class A EVM devices

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

FCC Interference Statement for Class B EVM devices

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

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

3.2 *Canada*

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

Concerning EVMs Including Radio Transmitters:

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

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

Concernant les EVMs avec appareils radio:

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

Concerning EVMs Including Detachable Antennas:

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

Concernant les EVMs avec antennes détachables

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

3.3 *Japan*

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

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。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。 日本テキサス･イ
ンスツルメンツ株式会社

東京都新宿区西新宿６丁目２４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/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.

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.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265