

AN-2206 LM5114 Evaluation Board

1 Introduction

The LM5114 is a single low-side gate driver with 7.6A/1.3A peak sink/source drive current capability. It can be used to drive standard Si MOSFETs or enhancement mode GaN FETs in boost type configurations or to drive secondary synchronous FETs in isolated topologies. The LM5114 evaluation board is designed to provide the design engineer with a fully functional boost dc-dc converter to evaluate the LM5114. A 100V enhancement mode GaN FET (EPC2001) is used as the boost power switch. The control circuitry is implemented with the LM5020, a 100V current mode PWM controller.

The specifications of the evaluation board are as follows:

- Input Operating Voltage: 24V to 66V
- Output Voltage: 75V
- Output Current: 2A
- Measured Efficiency at 48V: 97% @ 2A
- Frequency of Operation: 500 kHz
- Line UVLO: 23.6V (Rising) /21.6V (Falling)
- Board size: 2.99 x 3.26 inches

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

2 LM5114 Features

- Independent source and sink outputs for controllable rise and fall times
- +4V to +12.6V single power supply
- 7.6A/1.3A peak sink/source drive current
- 0.23Ω open-drain pull-down sink output
- 2Ω open-drain pull-up source output
- Power-off pull-down clamping
- 12ns (Typ) propagation delay
- Matching delay time between inverting and non-inverting inputs
- Up to +14V logic inputs (Regardless of VDD voltage)
- -40°C to +125°C operating temperature range
- Pin-to-Pin compatible with MAX5048

3 Package

- SOT-23-6
- LLP-6 (3mm x 3mm)

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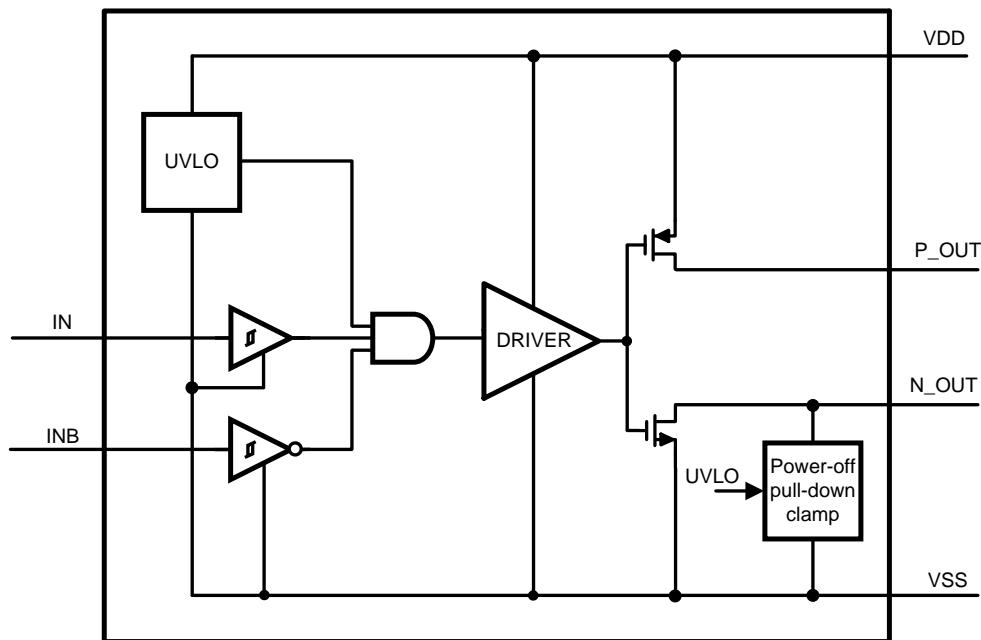


Figure 1. Simplified Block Diagram of LM5114

4 Powering and Loading Considerations

When applying power to the LM5114 evaluation board, certain precautions need to be followed. A misconnection can damage the assembly.

4.1 Proper Board Connection

Figure 2 depicts the typical evaluation setup. The source power is connected to VIN and GND1. The load is connected to VOUT and GND2. 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 will cause inaccurate measurements.

4.2 Source Power

To fully test the LM5114 evaluation board, a DC power supply capable of 66V and 7A is required. When a boost converter is powered up, a high inrush current may be generated due to the charge of the output capacitors. It is desirable to use a source power with a soft start-up to limit the inrush current.

The power supply and cabling must present low impedance to the evaluation board. Insufficient cabling or a high impedance power supply will droop during power supply application with the evaluation board inrush current. If large enough, this droop will cause 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.

4.3 Air Flow

To ensure a proper and reliable operation, sufficient cooling is required. Insufficient airflow can cause a catastrophic failure. A minimum airflow of 200CFM should always be provided.

4.4 Quick Start-up Procedure

1. Connect the source supply to VIN and GND1. Connect the load cable between VOUT and GND2.
2. Set the current limit of the source supply to provide about 1.5 times the anticipated output power.
3. Set the load current at 0A.

4. Set the input voltage at 24V and turn on the power supply. Check that the output voltage is 75V.
5. Slowly increase the input voltage and the load current while monitoring the output voltage.
6. A quick efficiency check is the best way to ensure the evaluation board is working properly.

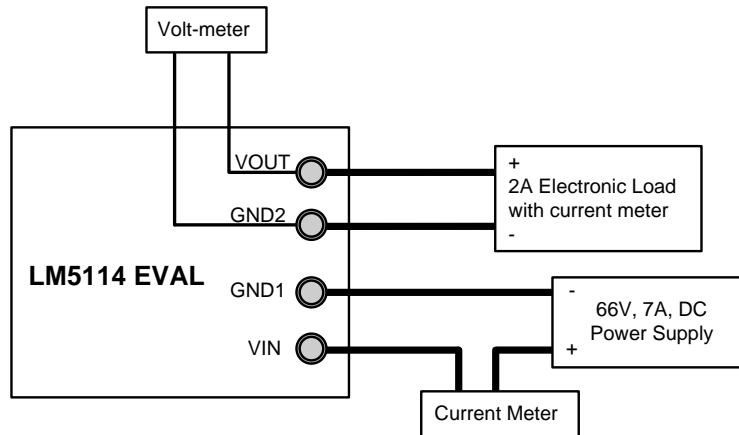


Figure 2. Typical Evaluation Setup

5 Applications Information

5.1 Operating Description

The LM5114 evaluation board operates in both Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM). For a given input voltage, the operation mode of the evaluation board is determined by the load current. [Figure 3](#) illustrates the operation mode for different input voltages and load currents. The control loop design of a boost converter is usually more challenging than that of a buck converter due to a right half-plane zero (RHZ) in conjunction with quadratic poles. Thanks to the use of a small inductor in DCM operation, RHZ and the pole associated with the inductor move to the higher frequency, which eases the control loop design.

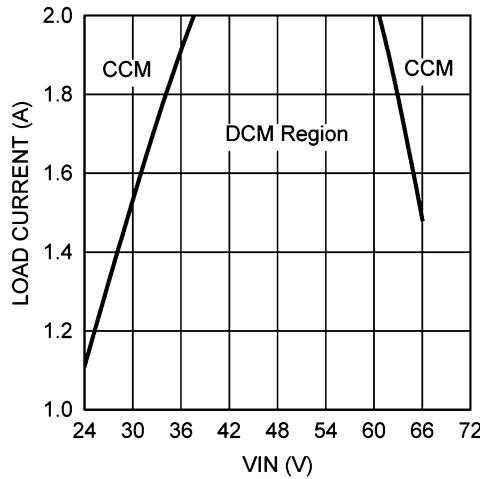


Figure 3. CCM and DCM Operation Boundary

5.2 Gate Drive

The enhancement mode GaN FETs have small gate capacitance and low threshold gate voltage. Therefore GaN FETs are prone to gate oscillations induced by PCB parasitic elements. It is necessary to place the driver as close to the GaN FET as possible to minimize the stray inductance. Gate resistors can be used to damp the oscillations and to adjust the switching speed. The LM5114 has split outputs, providing flexibility to adjust the turn-on and turn-off strength independently. In the evaluation board, 1.5Ω and 2.7Ω gate resistors are used in the turn-on and turn-off path respectively.

5.3 Bias Supply

The PWM controller LM5020 contains an internal high voltage startup regulator. When power is applied, the regulator generates 7.7 V output voltage with the output current limited to 15 mA. In addition, an auxiliary bias rail is also generated to reduce the power dissipation of the LM5020. As shown in [Figure 17](#), voltages across the boost inductor during respective turn-on and turn-off periods are sensed by an auxiliary winding, and then are stored in two capacitors. The auxiliary bias voltage is the combination of the two capacitor voltages and is proportional to the output voltage in steady state. The calculation of the auxiliary bias voltage is as follows.

$$V_{BIAS} = \frac{1}{N} [V_{in} + (V_0 - V_{in})] = \frac{1}{N} \cdot V_0 \quad (1)$$

Where N is the turns ratio and is equal to 6 in this case. The corresponding bias voltage is around 11 V. [Figure 4](#) compares the efficiency achieved with and without the auxiliary bias winding. As can be seen, with an auxiliary winding, the efficiency is improved by almost 2% at light load.

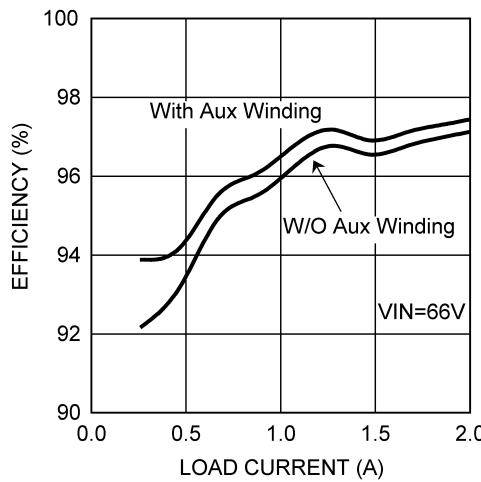


Figure 4. Efficiency Comparison Between With and Without the Auxiliary Bias Winding

6 Performance Characteristics

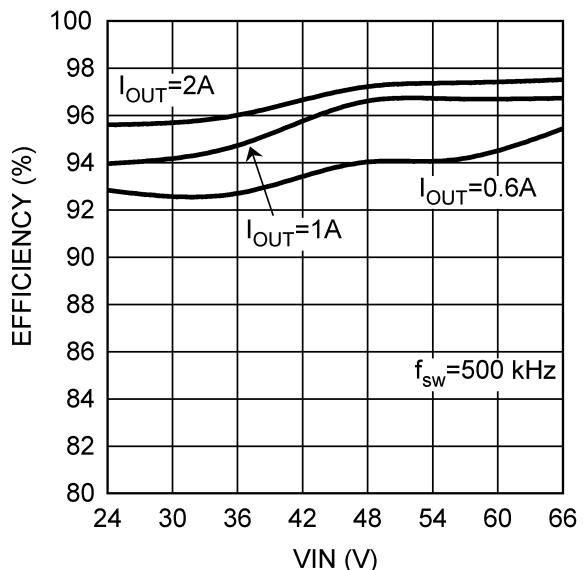
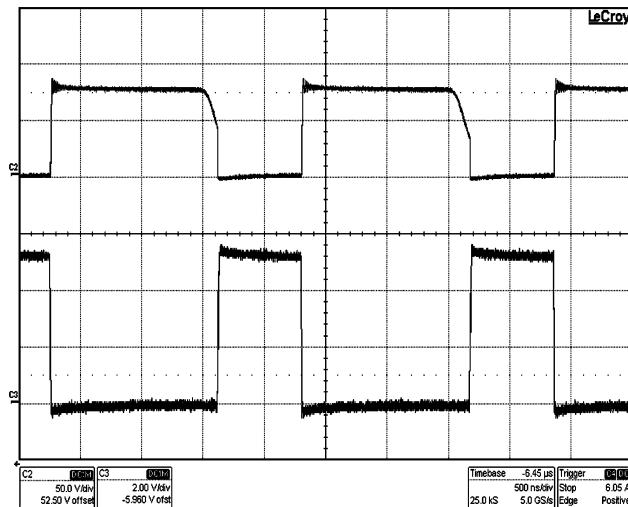


Figure 5. Evaluation Board Efficiency



Conditions: Input Voltage = 48 VDC, Load Current = 2 A
Traces: Top Trace: Switch-node voltage, Volt/div = 50 V
Bottom Trace: Gate-Source Voltage of GaN FET, Volt/div = 2 V Bandwidth Limit = 600 MHz Horizontal Resolution = 500 ns/div

Figure 6. Gate-Source Voltage

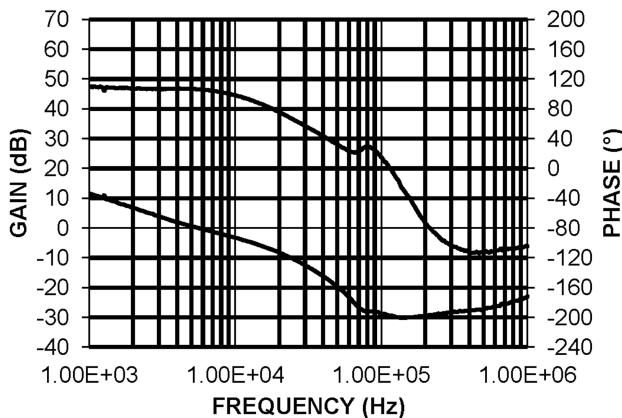
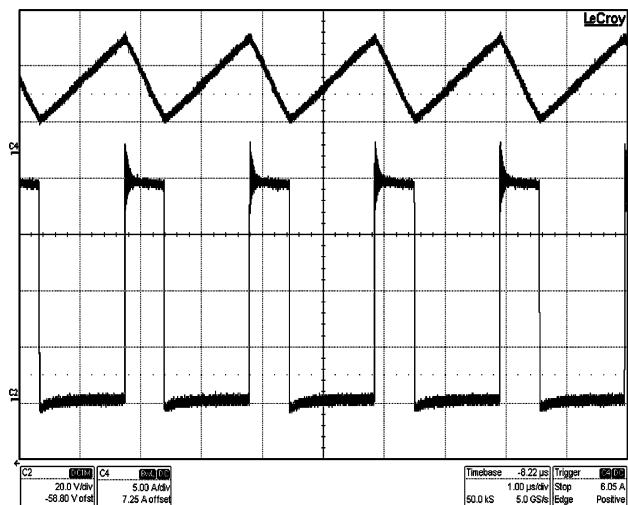
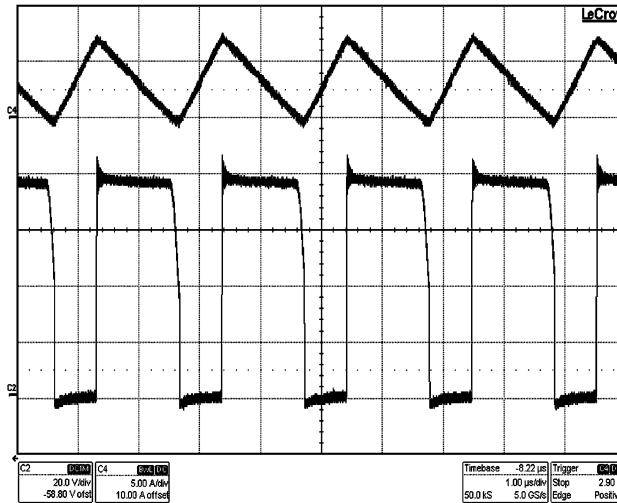


Figure 7. Close Loop Gain Measurement, $V_{IN} = 48$ V, Load Current = 2 A



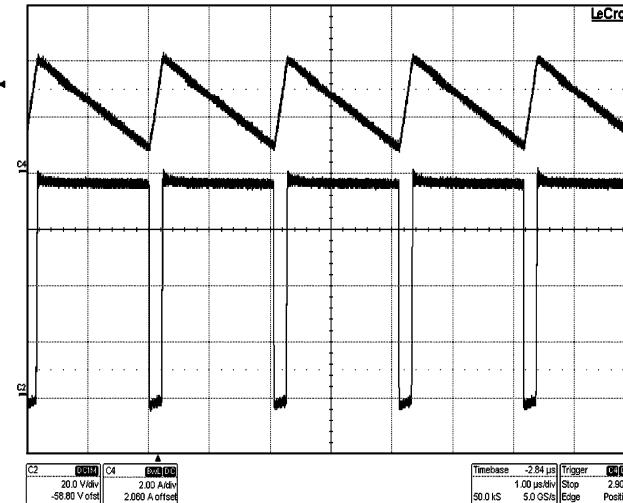
Conditions: Input Voltage = 24 VDC, Load Current = 2 A
Traces: Top Trace: Inductor Current, Amp/div = 5 A Bottom Trace: Switch-Node Voltage, Volt/div = 20 V Bandwidth Limit = 600 MHz Horizontal Resolution = 1 us/div

Figure 8. Switching Node Voltage $V_{IN} = 24$ V, Load Current = 2 A



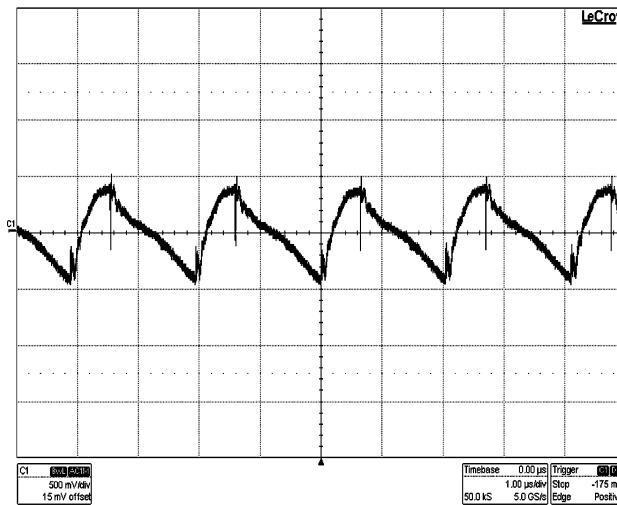
Conditions: Input Voltage = 48 VDC Load Current = 2 A
Traces: Top Trace: Inductor Current, Amps/div = 5 A Bottom Trace: Switch-Node Voltage, Volt/div = 20 V Bandwidth Limit = 600 MHz Horizontal Resolution = 1 us/div

Figure 9. Switching Node Voltage $V_{IN} = 48$ V, Load Current = 2 A



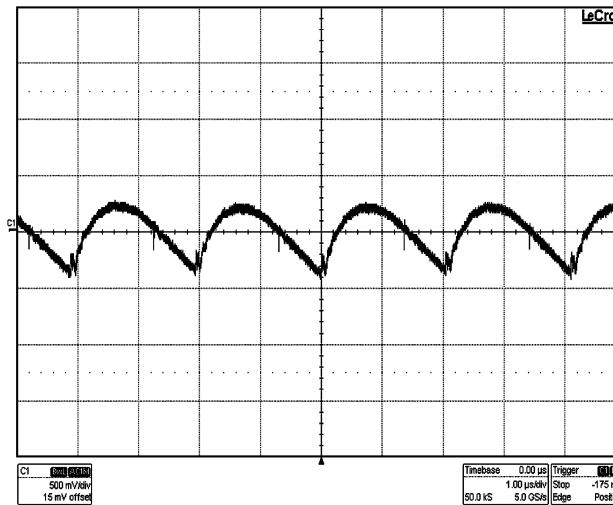
Conditions: Input Voltage = 66 VDC Load Current = 2 A
Traces: Top Trace: Inductor Current, Amp/div = 5 A Bottom Trace: Switch-Node Voltage, Volt/div = 20 V Bandwidth Limit = 600 MHz Horizontal Resolution = 1 us/div

Figure 10. Switching Node Voltage $V_{IN} = 66$ V, Load Current = 2 A



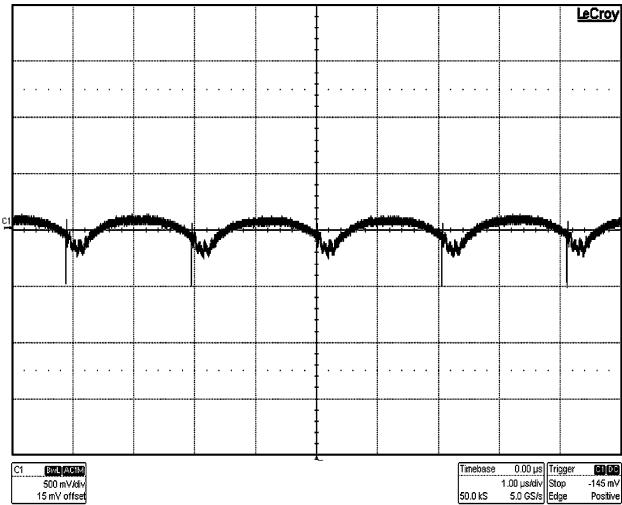
Conditions: Input Voltage = 24 VDC Load Current = 2 A
Traces: Trace: Output voltage ripple, Volt/div = 500 mV, AC coupled Bandwidth Limit = 20 MHz Horizontal Resolution = 1 us/div

Figure 11. Output Ripple $V_{IN} = 24$ V, Load Current = 2 A



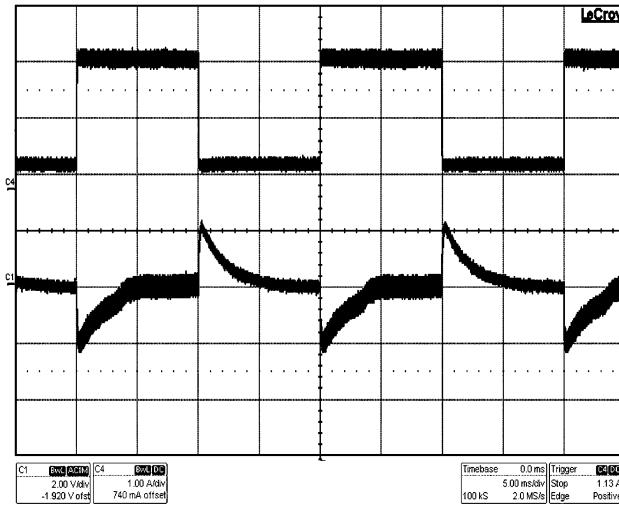
Conditions: Input Voltage = 48 VDC Load Current = 2 A
Traces: Trace: Output voltage ripple, Volt/div = 500 mV, AC coupled Bandwidth Limit = 20 MHz Horizontal Resolution = 1 us/div

Figure 12. Output Ripple, $V_{IN} = 48$ V, Load Current = 2 A



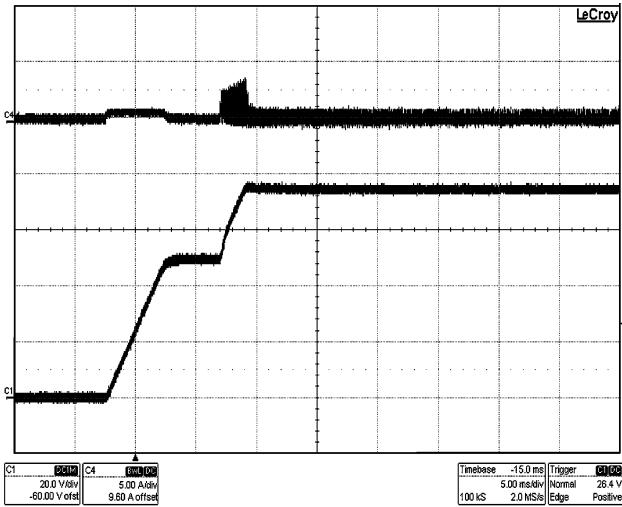
Conditions: Input Voltage = 66 VDC, Load Current = 2 A
Traces: Trace: Output voltage ripple, Volt/div = 500 mV, AC coupled Bandwidth Limit = 20 MHz Horizontal Resolution = 1 us/div

Figure 13. Output Ripple, $V_{IN} = 66$ V, Load Current = 2 A



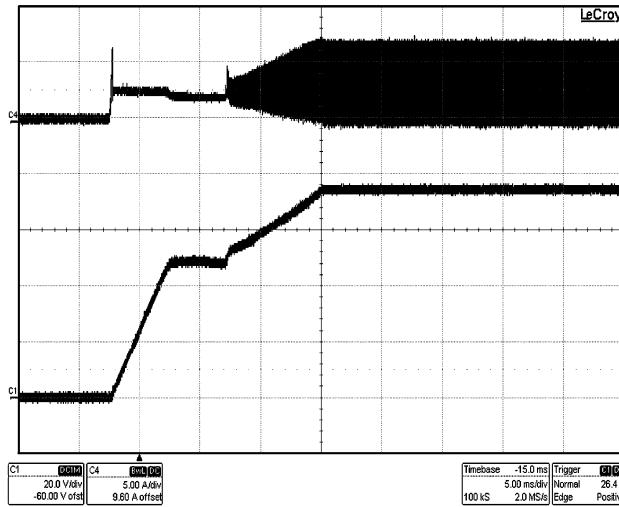
Conditions: Input Voltage = 48 VDC Load Current = 0.1 A to 2 A Traces: Top Trace: Load Current, Amp/div = 1 A Bottom Trace: Output Voltage Volt/div = 2 V, AC coupled Bandwidth Limit = 20 MHz Horizontal Resolution = 5 ms/div

Figure 14. Step Load Response



Conditions: Input Voltage = 48 VDC Load Current = 0A
Traces: Top Trace: Inductor Current, Amp/div = 5 A Bottom Trace: Output Voltage, Volt/div = 20 V Bandwidth Limit = 600 MHz Horizontal Resolution = 5 ms/div

Figure 15. Start-Up at No Load



Conditions: Input Voltage = 48 VDC, Load Current = 2 A
Traces: Top Trace: Inductor Current, Amp/div = 5 A Bottom Trace: Output Voltage, Volt/div = 20 V Bandwidth Limit = 600 MHz Horizontal Resolution = 5 ms/div

Figure 16. Start-Up at Full Load

7 Evaluation Board Schematic

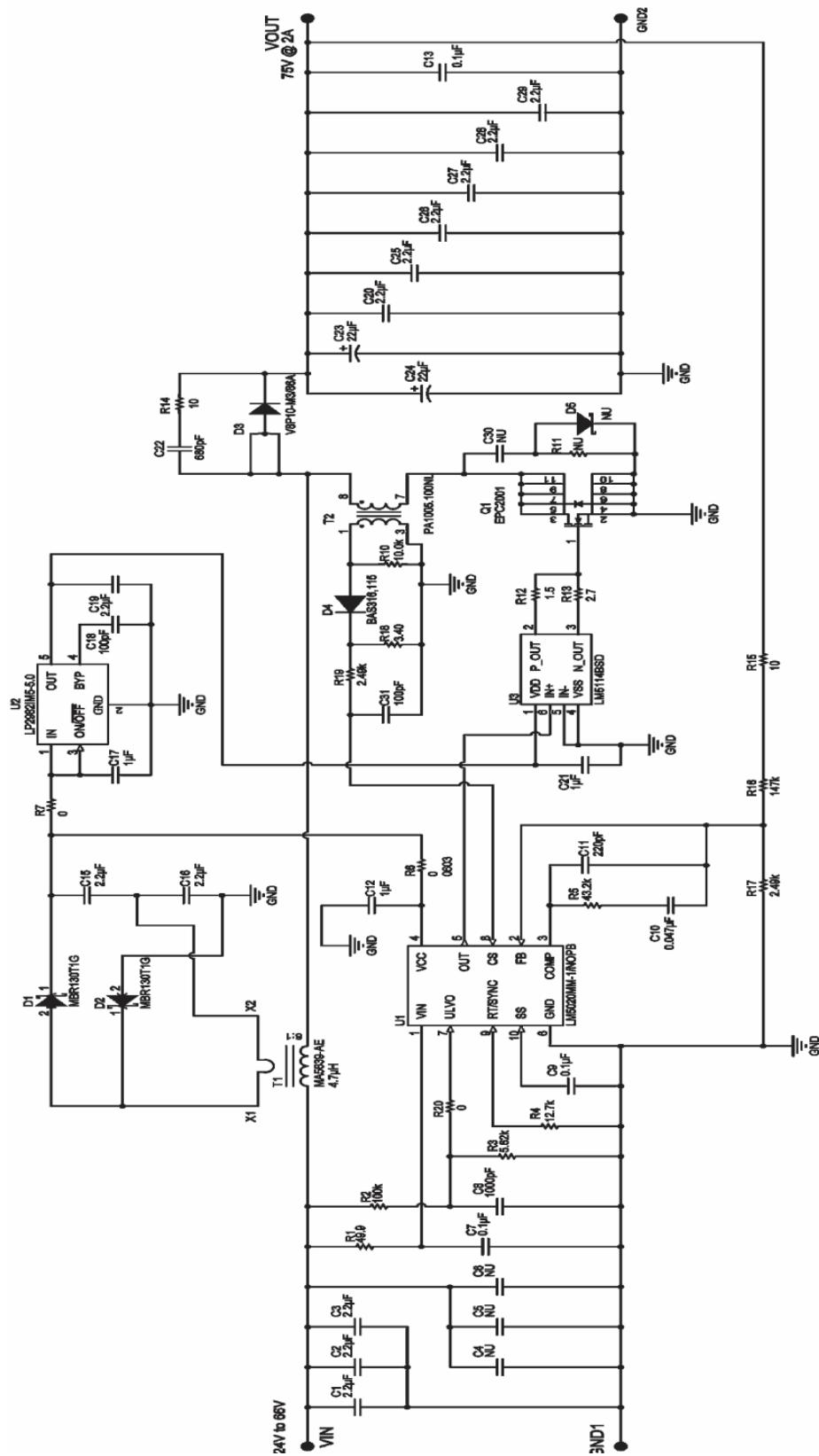


Figure 17. Application Circuit: Input 24 V to 66 V, Output 75 V, 2 A, 500 kHz

8 Bill of Materials

Part	Value	Package	Part Number	Manufacturer
C1, C2, C3, C20, C25, C26, C27, C28, C29	CAP, CERM, 2.2 uF, 100 V, +/-10%, X7R	1210	GRM32ER72A225KA35L	MuRata
C4, C5, C6	NU			
C7, C13	CAP, CERM, 0.1 uF, 100 V, +/-10%, X7R	0805	C0805C104K1RACTU	Kemet
C8	CAP, CERM, 1000 pF, 100 V, +/-5%, C0G/NP0	0603	GRM1885C2A102JA01D	MuRata
C9	CAP, CERM, 0.1 uF, 16 V, +/-10%, X7R	0603	C0603C104K4RACTU	Kemet
C10	CAP, CERM, 0.047 uF, 50 V, +/-10%, X7R	0603	GRM188R71H473KA61D	MuRata
C11	CAP, CERM, 220 pF, 50 V, +/-5%, C0G/NP0	0603	C0603C221K5GACTU	Kemet
C12, C17	CAP, CERM, 1 uF, 16 V, +/-10%, X5R	0603	C0603C105K4PACTU	Kemet
C15, C16	CAP, CERM, 2.2 uF, 25 V, +/-10%, X7R	0805	GRM21BR71E225KA73L	MuRata
C18, C31	CAP, CERM, 100 pF, 50 V, +/-5%, C0G/NP0	0603	C1608C0G1H101J	TDK
C19	CAP, CERM, 2.2 uF, 10 V, +/-10%, X7R	0603	GRM188R71A225KE15D	MuRata
C21	CAP, CERM, 1 uF, 6.3 V, +/-20%, X5R	0402	C1005X5R0J105M	TDK
C22	CAP, CERM, 680 pF, 100 V, +/-10%, X7R	0805	08051C681KAT2A	AVX
C23, C24	CAP, AL, 22 uF, 100 V, +/-20%, 0.55 ohm	SMD	VEJ-220M2ATR-0810	Lelon
C30	NU			
D1, D2	Diode, Schottky, 30 V, 1 A	SOD-123	MBR130T1G	ON Semiconductor
D3	Diode Schottky 8 A 100 V	TO-277	V8P10-M3/86A	Vishay
D4	Diode SW 100 V 250 MA	SOD323	BAS316	NXP Semiconductors
D5	NU			
Q1	eGaN FET, 100 V, 25 A, 7 mΩ	4105um X 1632 um	EPC2001	EPC
R1	RES, 49.9 ohm, 1%, 0.1 W	0603	CRCW060349R9FKEA	Vishay-Dale
R2	RES, 100 k ohm, 1%, 0.1 W	0603	CRCW0603100KFKEA	Vishay-Dale
R3	RES, 5.62 k ohm, 1%, 0.1 W	0603	CRCW06035K62FKEA	Vishay-Dale
R4	RES, 12.7 k ohm, 1%, 0.1 W	0603	RC0603FR-0712K7L	Yageo America
R5	RES, 43.2 k ohm, 1%, 0.1 W	0603	RC0603FR-0743K2L	Yageo America
R6, R7	RES, 0 ohm, 5%, 0.1 W	0603	MCR03EZPJ000	Rohm
R10	RES, 10.0 k ohm, 1%, 0.1 W	0603	RC0603FR-0710KL	Yageo America
R11	NU			
R12	RES, 1.5 ohm, 5%, 0.063 W	0402	CRCW04021R50JNED	Vishay-Dale
R13	RES, 2.7 ohm, 5%, 0.063 W	0402	CRCW04022R70JNED	Vishay-Dale
R14	RES, 10.0 ohm, 1%, 3 W	2512	SCW-SC3LF-10R0-F	TT Electronics
R15	RES, 10 ohm, 5%, 0.1 W	0603	CRCW060310R0JNEA	Vishay-Dale

Part	Value	Package	Part Number	Manufacturer
R16	RES, 147 k ohm, 1%, 0.1 W	0603	CRCW0603147KFKEA	Vishay-Dale
R17, R19	RES, 2.49 k ohm, 1%, 0.1 W	0603	CRCW06032K49FKEA	Vishay-Dale
R18	RES, 3.40 ohm, 1%, 0.1 W	0603	CRCW06033R40FKEA	Vishay-Dale
R20	RES, 0 ohm, 5%, 0.1W	0603	ERJ-3GEY0R00V	Panasonic
T1	Inductor, 4.7 uH, with a single aux winding	SMD 12.6mmX12.7mm	MA5639-AE	Coilcraft
T2	Current Sensing Transformer 100:1	SMT	PA1005.100NL	Pulse Engineering
U1	100 V Current Mode PWM Controller	VSSOP-10	LM5020	Texas Instruments
U2	Micropower 50 mA Ultra Low-Dropout Regulator	5-pin SOT-23	LP2982	Texas Instruments
U3	7.6A Single Low-Side Driver	WQFN-6	LM5114	Texas Instruments

9 PCB Layouts

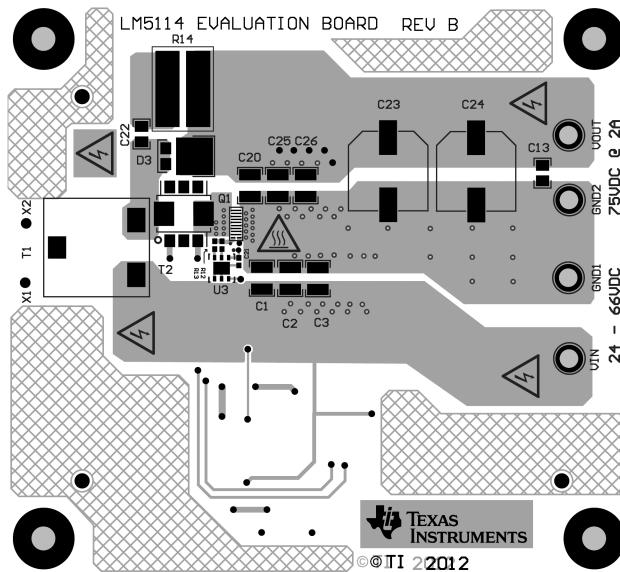


Figure 18. Top Layer Component View

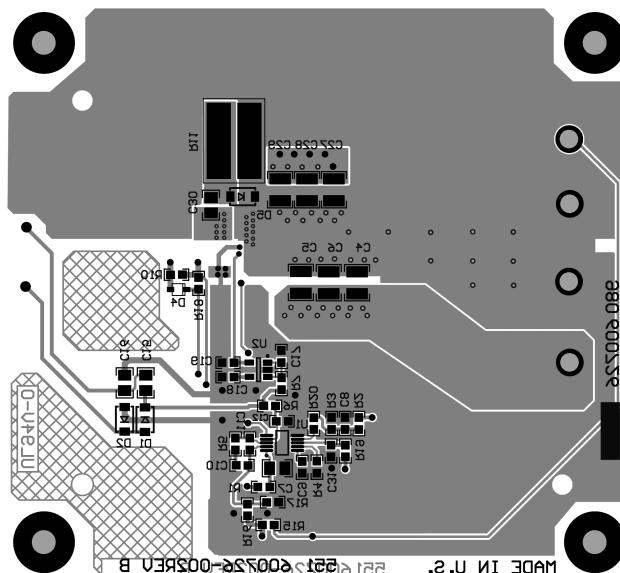


Figure 19. Bottom Layer Component View

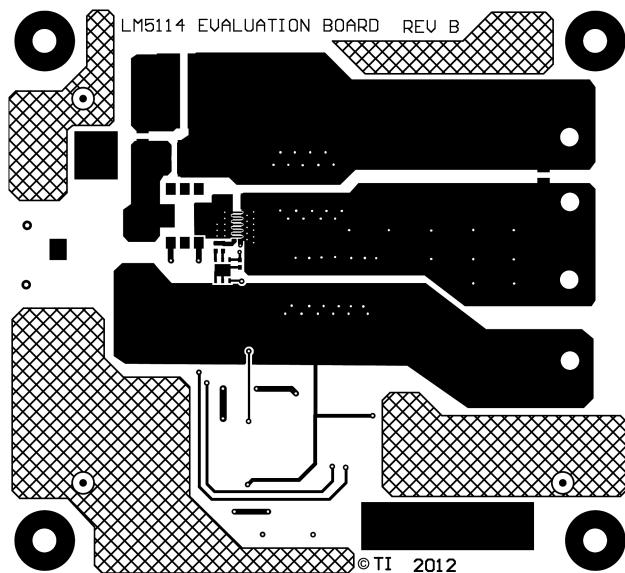


Figure 20. Top Layer

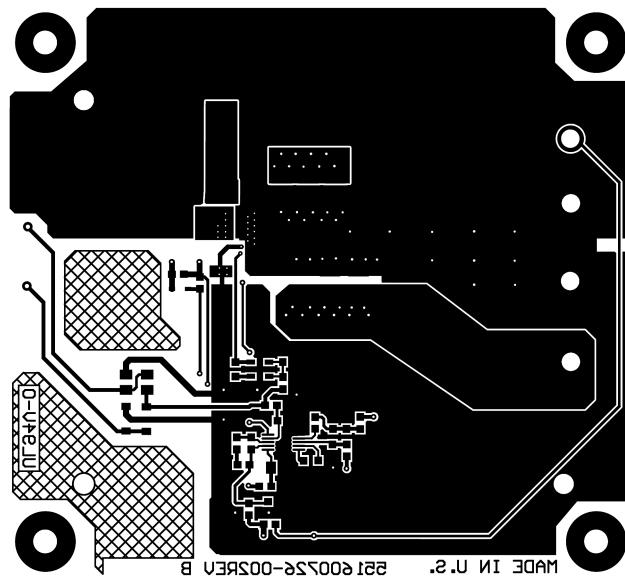


Figure 21. Bottom Layer

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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 isotope 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

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<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/lsts/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/LICENSENSORS 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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