LM3414HV

Application Note 2076 LM3414HV 1A 65V LED Driver Evaluation Board

TEXAS INSTRUMENTS

Literature Number: SNVA451B

LM3414HV 1A 65V LED Driver Evaluation Board

National Semiconductor
Application Note 2076
SH Wong
August 10, 2010

Introduction

The LM3414HV is a 65V floating buck LED driver that designed to drive up to 18 pieces of serial High Brightness LEDs (HBLEDs) with up to 1000mA LED forward current. With the incorporation of the proprietary Pulse-Level-Modulation (PLM) technology, the LM3414HV requires no external current sensing resistor to facilitate LED current regulation. The LM3414HV features a dimming control input (DIM pin) that allows PWM dimming control. The LM3414HV is available in LLP-8 (3mm x 3mm outline) and ePSOP8 to fulfil the requirements of small solution size and high thermal performance respectively. In order to demonstrate the performance of the LM3414 family, the LM3414HV is selected for the evaluation boards because of the wide input voltage range (4.5V to 65V) providing the best flexibility to fit the requirements of different applications. Two versions of evaluation board with identical schematic are available with the LM3414HV in either LLP-8 or PSOP-8 package. The board with LLP-8 package demonstrates the high power density of the device. The board with PSOP-8 package demonstrates the functionality of the LM3414HV with enhanced thermal performance. The schematic, bill of materials and PCB layout for the evaluation boards are provided in this document. The evaluation boards can be adapted to different application requirements by changing the values of a few components only. This evaluation board is also suitable for the LM3414 with maximum acceptable input voltage reduced to 42VDC.

Standard Settings of the LM3414HV Evaluation Board

Vin range: 4.5V to 65V

No. of LEDs: 1 - 18

LED current: 1A

Switching frequency: 500 kHz

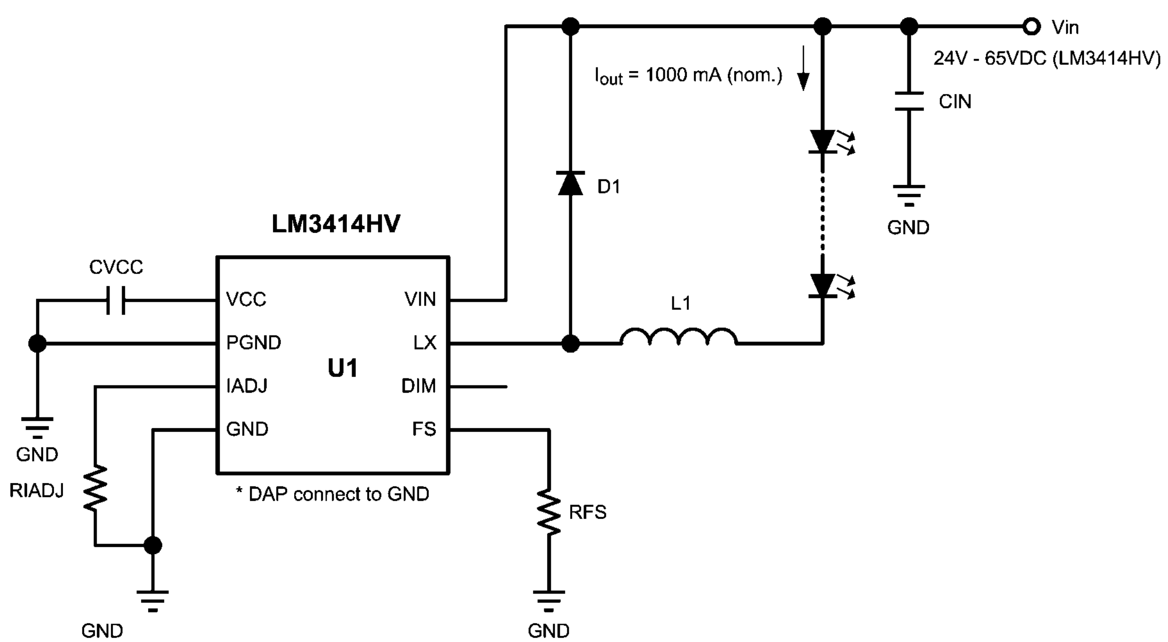


FIGURE 1. Standard Schematic for the LM3414HV Evaluation Board

Board Connectors and Test Pins

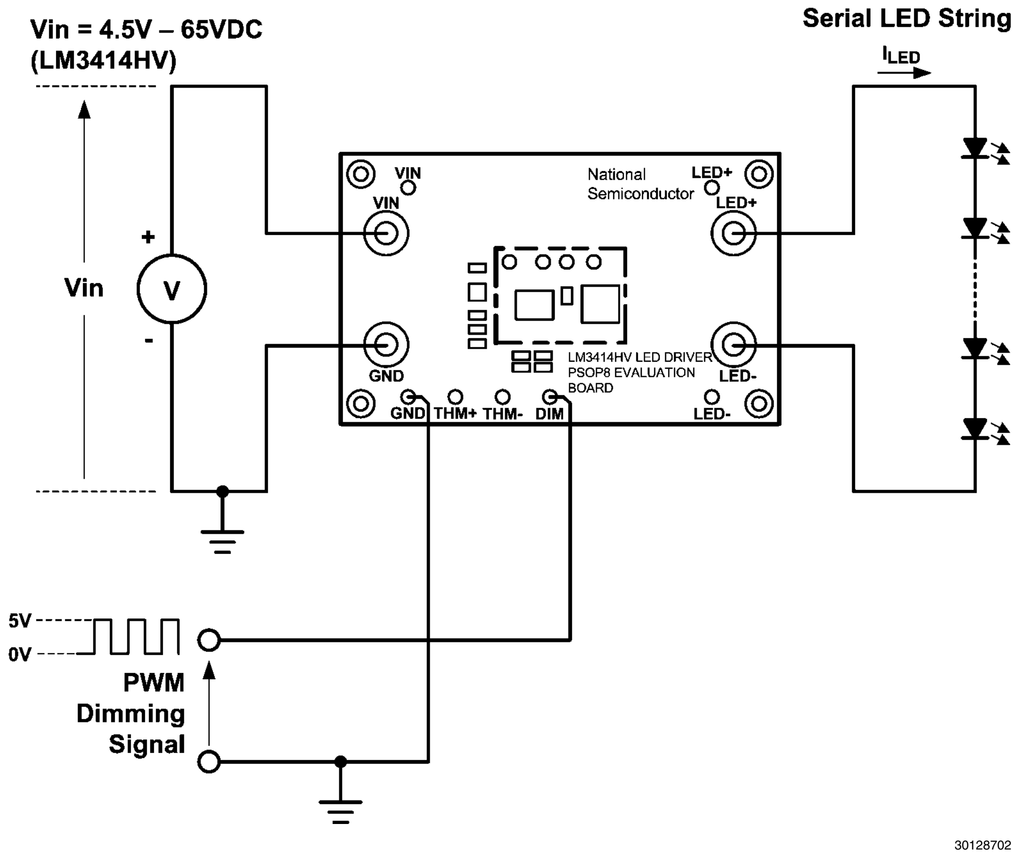


FIGURE 2. Connection Diagram

Terminal Designation	Description
VIN	Power supply positive (+ve) connection
GND	Power supply negative (-ve) connection
LED+	Connect to cathode of the serial LED string
LED-	Connect to anode of the serial LED string
DIM	PWM dimming signal input (TTL signal compatible)
THM+	Connect to PTC thermal sensor for thermal foldback control
THM-	Connect to PTC thermal sensor for thermal foldback control

Connecting to LEDs and Power Supply

The LM3414HV evaluation board can be powered by a DC voltage source in the range of 4.5V to 65V through the banana-plug type connectors (VIN and GND) on the board as shown in figure 2. This evaluation board is designed to provide 1A (I_{LED})output current to a LED string containing up to 18 pieces of serial HBLEDs. The anode and cathode of the LED string should connect to the LED+ and LED- banana-plug type connectors on the board respectively. By default, the LM3414HV on the evaluation board is enabled. The LEDs will light up as long as appropriate input voltage is applied to the evaluation board.

Adjusting the Output Current

The resistor RIADJ defines the output current of the LM3414HV evaluation board. The default value of RIADJ is 3.09kΩ, which sets the LED driving current to 1A. The LED current can be changed by adjusting the value of RIADJ with equation (1):

$$I_{LED} = \frac{3125 \times 10^3}{R_{IADJ}} \text{ mA} \quad (1)$$

Table 1 shows the suggested value of RIADJ for common output current settings:

I_{LED} (mA)	R_{IADJ} (kΩ)
350	8.93
400	7.81
500	6.25
600	5.21
700	4.46
800	3.91
900	3.47
1000	3.13

TABLE 1. Examples for RIADJ Setting

Adjusting the Switching Frequency

The resistor RFS defines the switching frequency of the LM3414HV evaluation board. The default value of the RIADJ is 40kΩ that sets the switching frequency to 500kHz. The LED current is adjustable by altering the resistance of RFS according to the equation (2):

$$f_{SW} = \frac{20 \times 10^6}{R_{FS}} \text{ kHz} \quad (2)$$

Table 2 shows the suggested value of RFS for different switching frequencies:

f_{SW} (kHz)	R_{FS} (kΩ)
250	8.93
500	7.81
1000	6.25

TABLE 2. Examples for RFS Setting

When setting the switching frequency, it is necessary to ensure the on time of the internal switch is no shorter than 400ns; otherwise the driving current to the LEDs will increase and may eventually damage the LEDs.

Design Example

Assuming a LED string containing six serial HBLEDs is being driven by the board with 700mA (I_{LED}). The forward voltages of one HBLED with 700mA driving current under different operation temperatures are:

$V_{f(60C)}$ @700mA = 3.0V
$V_{f(25C)}$ @700mA = 3.2V
$V_{f(-10C)}$ @700mA = 3.5V

Step 1. Defining input voltage range

Because the LM3414HV is a floating buck LED driver, the input voltage to the LED driver must be higher than the total forward voltage of the LEDs under all conditions. As the forward voltage of a common HBLED could increase as the driving current increases or the operation temperature decreases, it is essential to ensure the minimum supply voltage is at least 10% higher than the possible highest forward voltage of the LED string. For example, assuming the forward voltage of a HBLED is 3.2V at T_A = 25°C and 3.5V at T_A = -10°C at 700mA driving current. When 6 pieces of LED are connected in series, the total forward voltage of the LED string at 25°C and -10°C are 19.2V and 21V respectively. In order to secure current regulation under -10°C, the input voltage should not be lower than 23.1V. In this example, a standard 24V DC power supply with no more than +/– 3% output voltage variation can be used.

Step 2. Defining switching frequency fSW

When the maximum LED forward voltage and minimum input voltage are identified, the switching frequency of the LM3414HV can be defined. The switching frequency of the LM3414HV must be set in the range of 250kHz to 1MHz. Because the LM3414HV is designed to operate in continuous conduction mode (CCM) with 400ns minimum switch ON time limit, the maximum allowable switching frequency is restricted by the minimum input voltage, $V_{IN(MIN)}$ and maximum LED forward voltage, $V_{f(MAX)}$ according to equation (3):

$$f_{SW} \leq \frac{V_{f(MIN)}}{V_{IN(MAX)} \times 400 \times 10^{-6}} \text{ kHz}$$

$$\text{where} \quad 250 \text{ kHz} \leq f_{SW} \leq 1 \text{ MHz} \quad (3)$$

In this example, because a 24V DC power supply with +/- 3% output voltage variation is used, $V_{IN(MAX)}$ is 24.72V. The minimum forward voltage of the LED string $V_{f(MIN)}$ is 18V because the forward voltage of the LED string will be at the lowest level when the operation temperature rises to 60°C. According to equation (3), with $V_{IN(MAX)}$=24.72V and $V_{f(MIN)}$=18V, the switching frequency, f_{SW} should not set higher than 1.82MHz. However, because the switching frequency of the LM3414HV must set in the range of 250kHz to 1MHz, 1MHz switching frequency is selected.

Step 3. Inductor Selection

The inductance of the inductor, L1 can be decided according to the switching frequency and output current settings determined in step 1 and step 2. The inductance must be adequate to maintain the LM3414HV to operate in CCM. The minimum inductance can be calculated by following equation (4):

$$L \geq \frac{(V_{IN(MAX)} - V_{f(MIN)}) \times V_{f(MIN)} \times 10^6}{I_{LED} \times V_{IN(MAX)} \times f_{SW} \times K} \mu H$$

$$\text{where } K = \frac{I_{RIP(P-P)}}{I_{LED}} \quad \Big| \quad 0 < K < 1.8 \qquad (4)$$

In equation (4), I_{LED} is the average output current of the LM3414HV circuit to drive the LED string. $I_{RIP(P-P)}$ is the peak-to-peak value of the inductor current ripple. Assuming that the required LED current is 700mA, 50% inductor current ripple and 1MHz switching frequency, the inductance should be no less than 14uH. Because common power inductor carries +/- 20% inductance tolerance, a standard 18uH inductor with +/-20% tolerance can be used.

Other than deciding a suitable inductance value, it is essential to ensure the peak inductor current is not exceeding the rated saturation current of the inductor. The peak inductor current is governed by the following equation:

$$I_{L(PEAK)} = \left[\frac{(V_{IN(MAX)} - V_{f(MIN)}) \times V_{f(MIN)}}{L_{(MIN)} \times V_{IN(MAX)} \times f_{SW} \times 2} + I_{LED}\right] A \qquad (5)$$

In equation (5), $I_{L(PEAK)}$ is the peak inductor current. As a 18uH with +/- 20% variation is used, the minimum inductance $L_{(MIN)}$ is 14.4uH. With 700mA LED current, the peak inductor current is 836mA, thus a standard 18uH power inductor with 1A saturation current (I_{SAT}) can be used.

PWM Dimming Control

The average LED current can be controlled by applying PWM dimming signal across the DIM and GND terminals of the LM3414HV evaluation board. The board accepts standard TTL level dimming signal. The output of the board is enabled when the DIM terminal is pulled high. The average LED current is adjustable according to the ON duty ratio of the PWM dimming signal by equation (6):

$$I_{LED(Avg)} = D_{DIM} \times \left(\frac{3125 \times 10^3}{R_{IADJ}}\right) mA \qquad (6)$$

In equation (6), $I_{LED(AVG)}$ is the average current flows through the LED string and D_{DIM} is the ON duty ratio of the PWM dimming signal being applied to the DIM pin of the LM3414HV.

Analog Dimming Control

As the output current of the LM3414HV is defined by the current being drawn to GND through RIADJ proportionally, analog dimming control (true output current control) can be accommodated by applying external current to RIADJ of the LM3414HV evaluation board. Figure 3 shows an example circuit for analog dimming control. With analog dimming control. Injecting additional current through the RIADJ to GND can effectively reduce the LED current (I_{LED}). The relationship of I_{LED} and I_{EXT} is governed by equation (7).

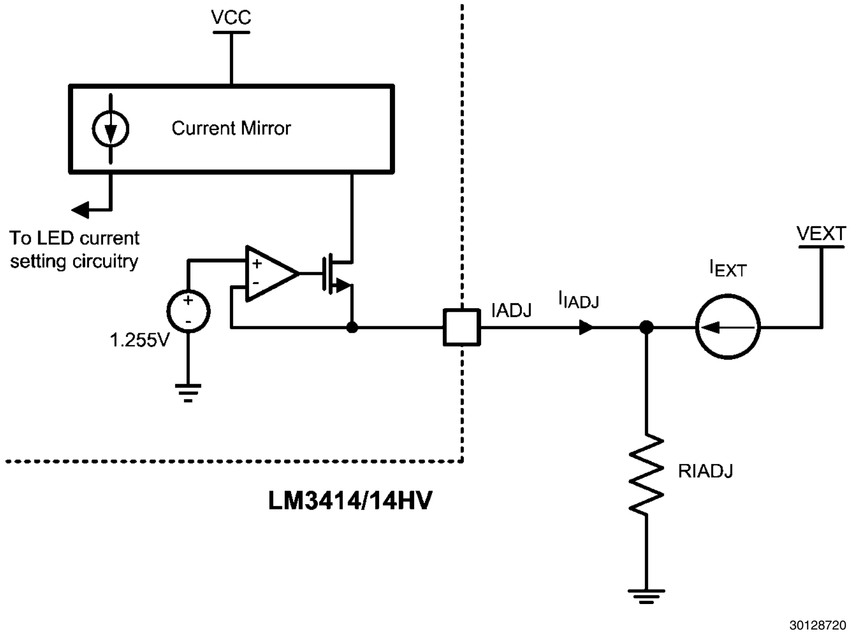
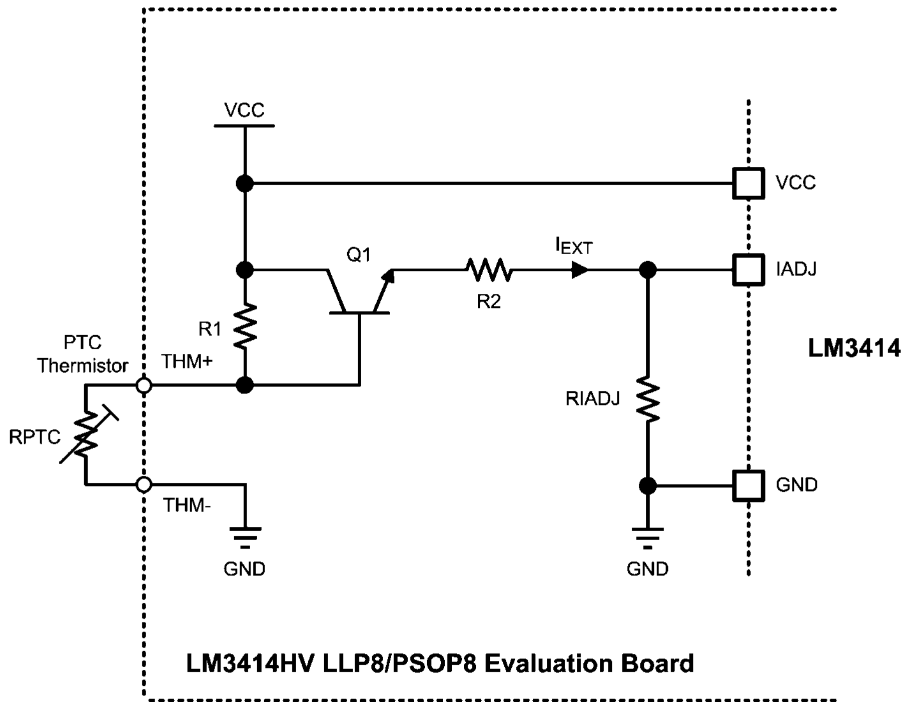


FIGURE 3. Reducing LED current with external current to the IADJ pin

$$I_{LED} = \left[\left(\frac{1.255}{R_{IADJ}} - I_{EXT}\right) \times 2490 \times 10^3\right] mA \qquad (7)$$

In equation (7), I_{EXT} is the external current being injected into RIADJ. As I_{EXT} increases, ILED decreases.

Figure 4 shows a practical thermal foldback control circuit which reduces the LED current when the temperature of the LED sting is exceeding certain preset threshold. Because the temperature threshold for thermal foldback control depends on end application, the components required in this thermal foldback control circuitry are not included in the LM3414HV evaluation board. Physical pads and connections for R1, R2 and Q1 have been reserved on the board for component mounting. In order to detect the temperature of the LED string, a Positive Temperature Coefficient (PTC) thermistor, RPTC should be connected across the THM+ and THM- terminals of the LM3414HV evaluation board. In figure 4, the bipolar transistor, Q1 is biased by a potential divider composes of R1 and RPTC. When the temperature of the LEDs rises, the voltage drop across RPTC increases as the resistance of RPTC increases. As the emitter voltage of Q1 reaches 1.255V, thermal foldback control is activated and the LED current reduces according to I_{EXT}.

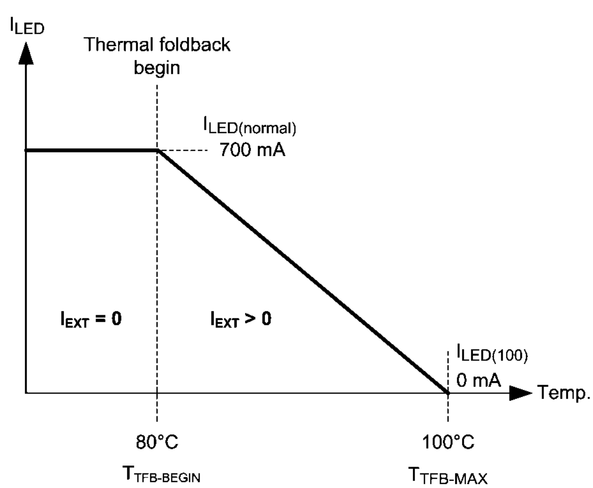


30128721

FIGURE 4. Thermal Foldback Control with PTC thermistor

Design Example

The LM3414HV evaluation board is used to drive a LED string at 700mA and thermal foldback control is needed to take place when the temperature of the LED strings exceeds 80°C as presented in Figure 5.



30128722

FIGURE 5. Reduction of LED current with thermal foldback control

Assume the resistance of the PTC thermistor under 25°C, 80°C and 100°C are:

$RPTC_{(25C)} = 330\Omega$
$RPTC_{(80C)} = 1.2k\Omega$
$RPTC_{(100C)} = 10k\Omega$

In Figure 5, the LED current with the LED temperature below 80°C ($I_{LED(normal)}$) is 700mA. As the temperature of the LED goes up to 80°C, thermal foldback begins and reduces the LED driving current with respect to the increase of resistance of RPTC. As the temperature of the LEDs reaches 100°C, the LED current reduces to zero. Provided that the resistance of the thermistor RPTC under 80C and 100°C are 1.2kΩ and 10kΩ respectively, the values of R1 and R2 can be calculated following the steps listed below.

At 80°C:

$$\because\ I_{R2} = 0A$$
$$\therefore\ V_E = V_{IADJ} = 1.255V$$
$$V_{PTC} = V_E + V_{BE} = 1.255V + 0.7V = 1.955V$$
$$V_{PTC} = V_{CC} \times \frac{R_{PTC(80°C)}}{R1 + R_{PTC(80°C)}} = 5.4V \times \frac{1.2\ k\Omega}{R1 + 1.2\ k\Omega}$$
$$R_1 = 11.08\ k\Omega \quad (8)$$

At 100°C:

$$\because\ I_{LED} = 0A$$

$$\therefore\ I_{EXT} = \frac{1.255V}{RIADJ} = 281\ \mu A$$

$$= \frac{1}{R2} \times \left[\frac{V_{CC} \times R_{PTC(100°C)}}{R1 + R_{PTC(100°C)}} - (V_{BE} + V_{IADJ}) \right] A$$

$$= \frac{1}{R2} \times \left[\frac{5.4V \times 10\ k\Omega}{11.06\ k\Omega + 10\ k\Omega} - (0.7V + 1.255V) \right] A$$

$$R_2 = 2.17\ k\Omega \tag{9}$$

Tiny Board Outline

The tiny packages of the LM3414 family are exceptionally suitable for the applications that require high output power in limited space. In order to demonstrate the high power density of the LM3414HV, the core circuitry of this evaluation boards are completed in compact form factors: 22mm x 19mm for LLP-8 package, 26mm x 19mm for PSOP-8 package. The schematic of the core circuitry is as shown in Figure 6. The core circuitry can be extracted by cutting out from the PCB frame of the board as shown in Figure 7.

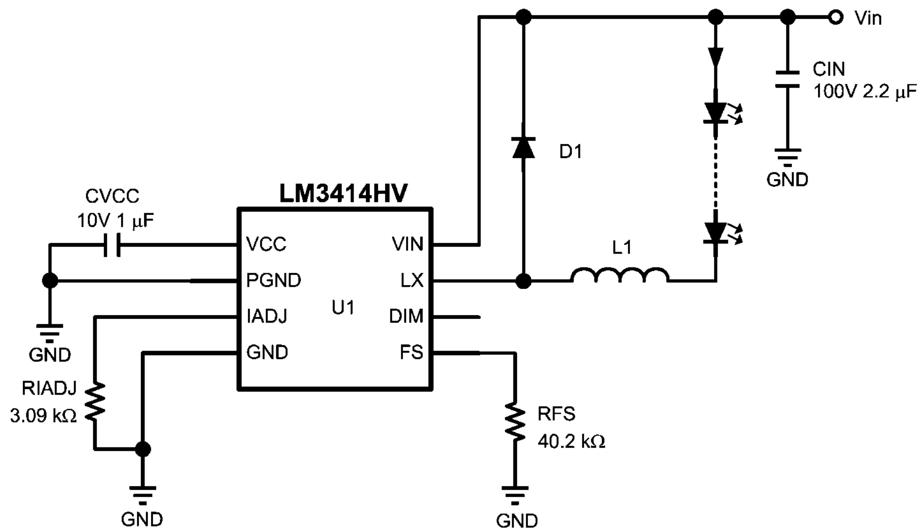


FIGURE 6. Core Circuitry of the LM3414HV Evaluation Boards

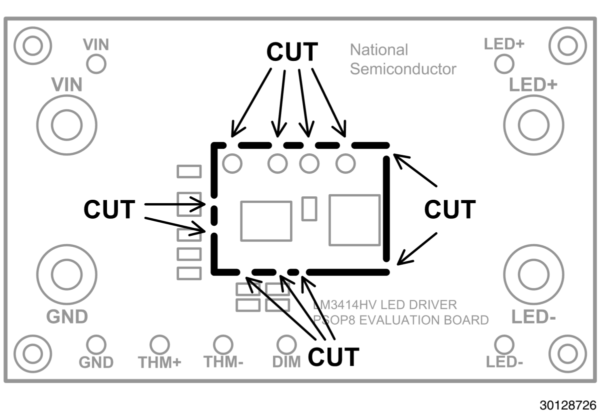


FIGURE 7. Extracting the core circuitry from the LM3414HV evaluation boards

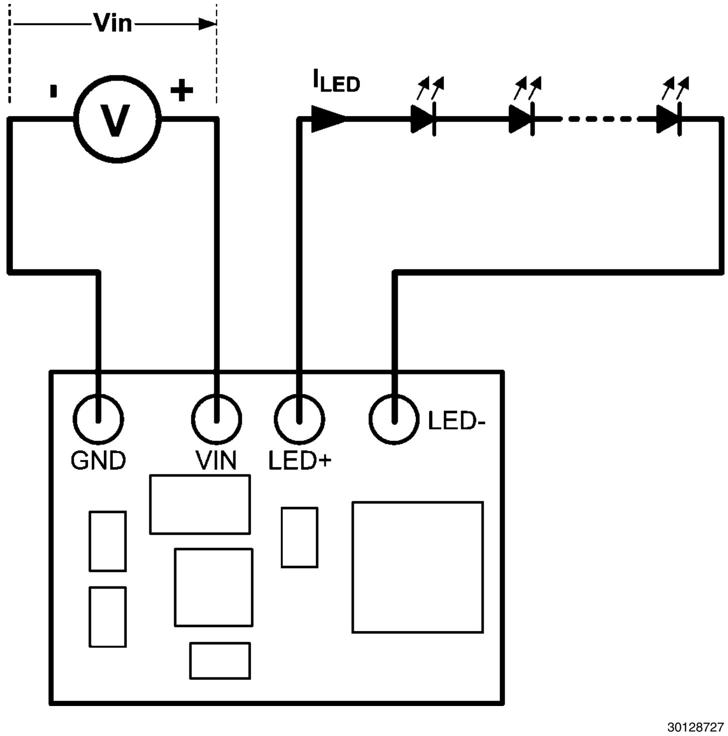


FIGURE 8. Connecting to the core circuitry

The board of the core circuitry features four connection pads for connections to DC power supply and LED string, as shown in Figure 8. To ensure thermal performance of the board, a heatsink attaches to the bottom layer of the board may be required depending on actual operation environment.

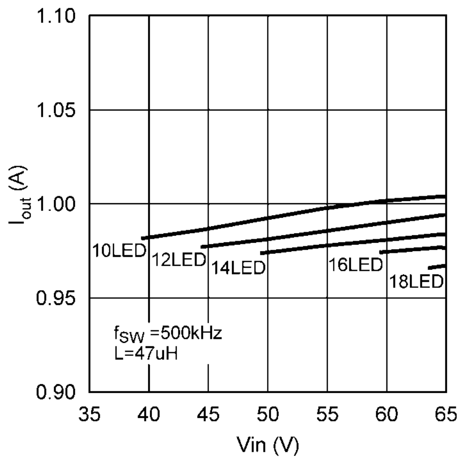
Bill of Materials

Designation	Description	Package	Manufacturer Part #	Vendor
U1	LED Driver IC, LM3414HV	LLP8 / PSOP8	LM3414MH	NSC
D1	Schottky Diode 100V 2A		SS2PH10-M3/84A	Vishay
L1	Power Inductor 47 µH		MMD-08EZ-470M-S1	MAG.Layers
CIN	Cap MLCC 100V 2.2 µF X7R 1210	1210	GRM32ER72A225KA35L	Murata
CVCC	Cap MLCC 10V 1 µF X5R 0603	603	GRM185R61A105KE36D	Murata
RIADJ	Chip Resistor 3.09 kΩ 1% 0603	603	CRCW06033K09FKEA	Vishay
RFS	Chip Resistor 40.2 kΩ 1% 0603	603	CRCW060340K2FKEA	Vishay
VIN, GND, LED+, LED-	Banana Jack 5.3(mm) Dia	5.3 (mm) Dia.	575-8	KEYSTONE
VIN, GND, LED+,LED-, THM+, THM-, DIM,	Turret 2.35(mm) Dia	2.35 (mm) Dia.	1502-2	KEYSTONE
PCB	LM3414EVAL PCB 85 X 54 (mm)	85 X 54 (mm)		NSC
Q1	NPN Bipolar Transistor	SOT23		
R1,R2,RFS_1, RFS_2,RIADJ_1	NA	603		
JP1,JP2,JP3	NA	603		

Typical Performance Characteristics

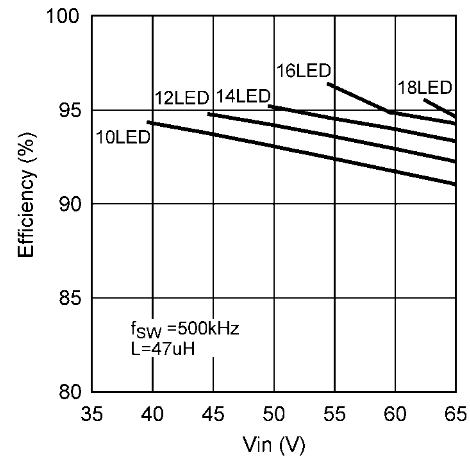
All curves taken at V_{IN} = 48V with configuration in typical application for driving twelve power LEDs with four output channels active and output current per channel = 350 mA. T_A = 25°C, unless otherwise specified.

Output Current (A)



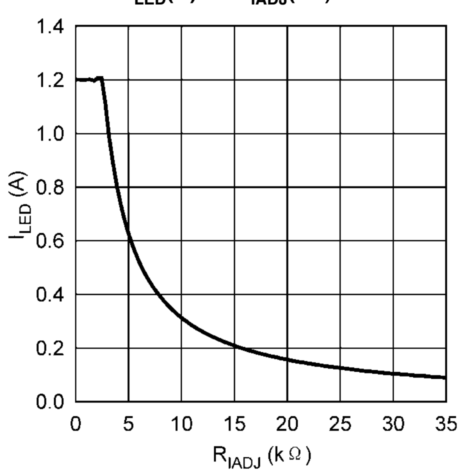
30128730

Efficiency (%)



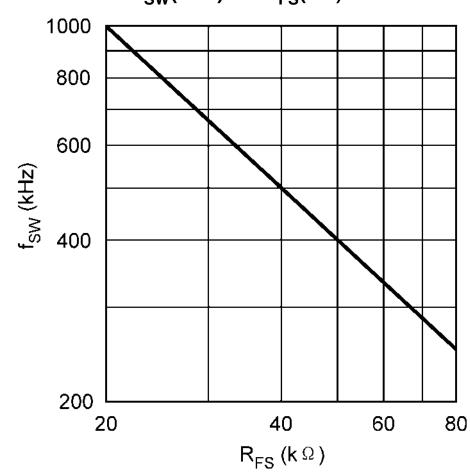
30128731

I_{LED}(A) vs R_{IADJ}(kΩ)



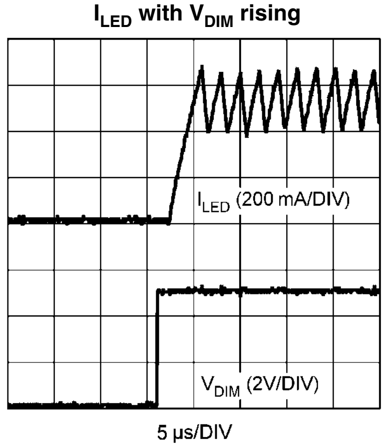
30128732

f_{SW}(kHz) vs R_{FS}(kΩ)



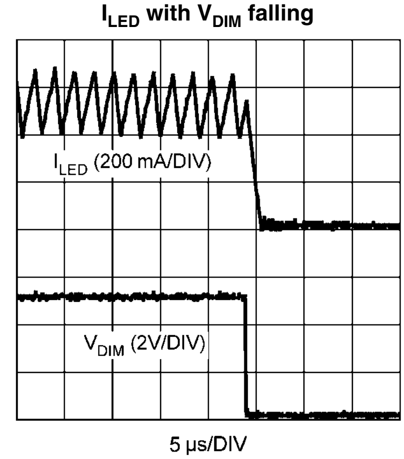
30128733

I_{LED} with V_{DIM} rising



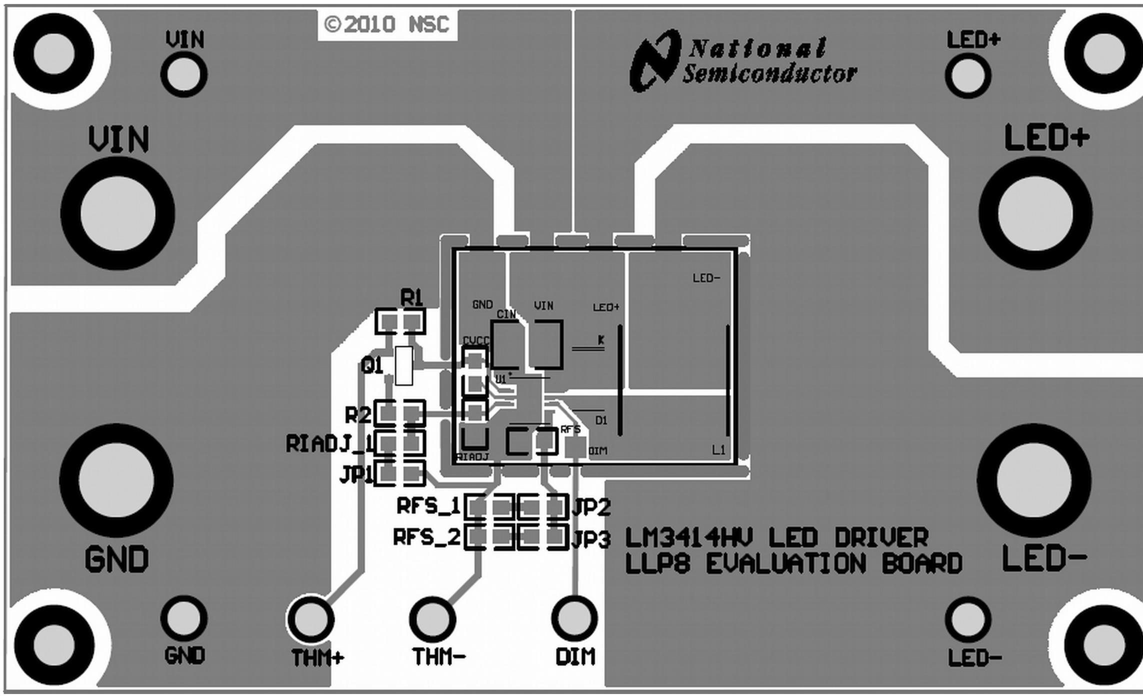
30128708

I_{LED} with V_{DIM} falling



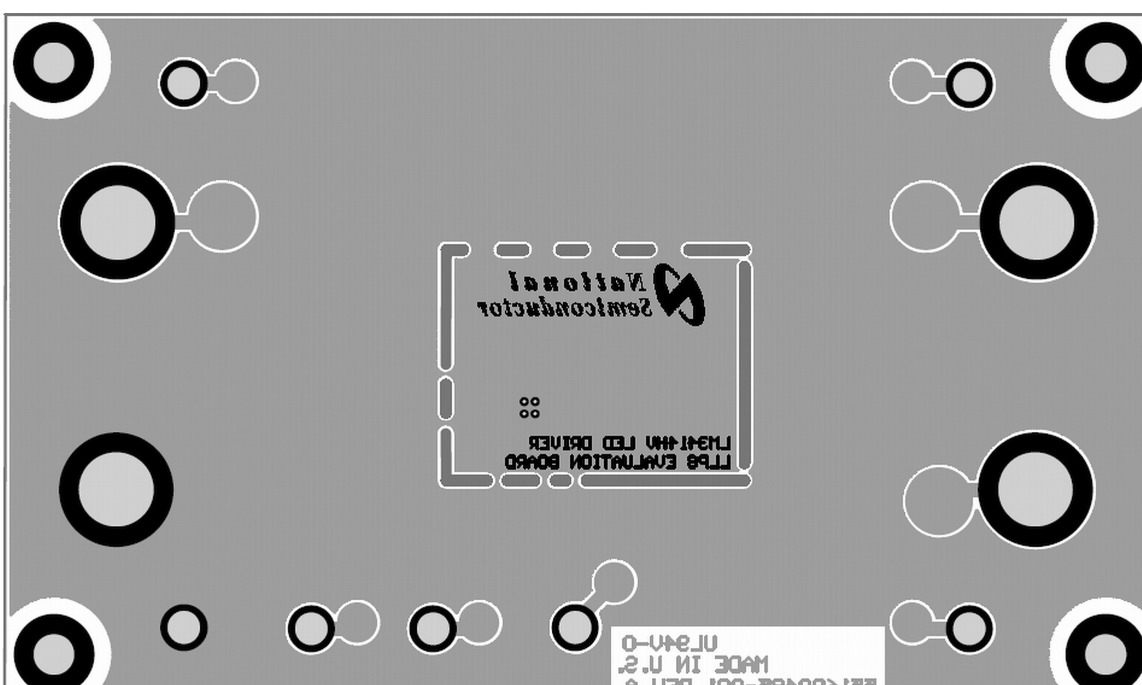
30128709

Evaluation Board Layout (LLP-8 Package)



30128712

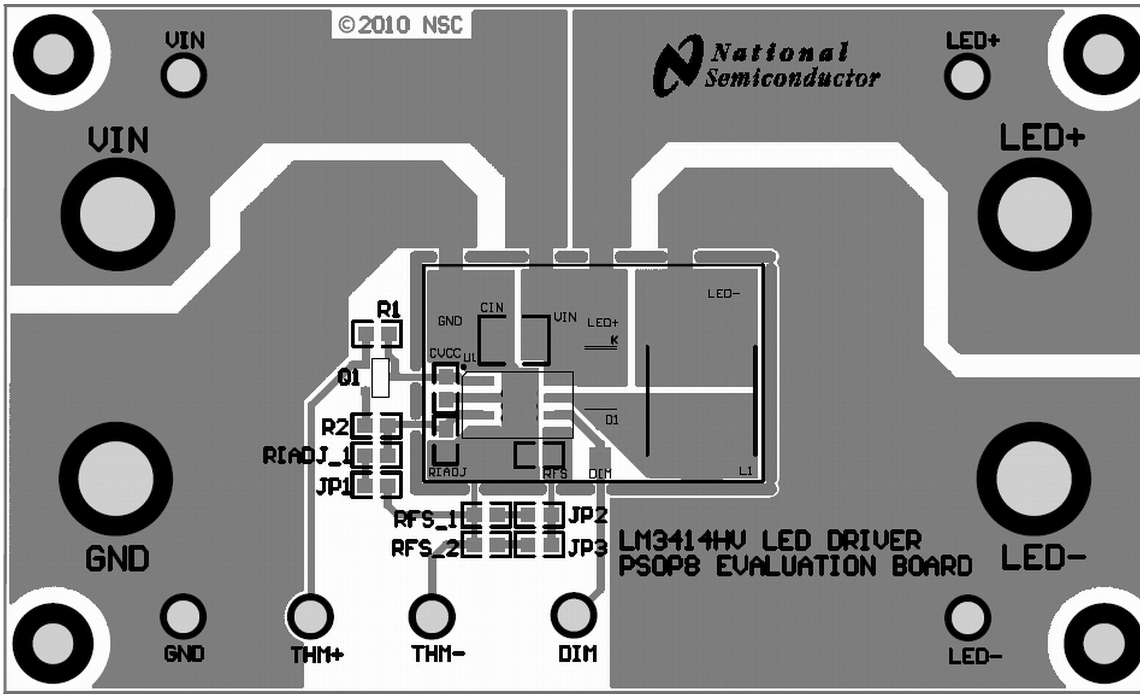
Top Layer and Top Overlay



30128713

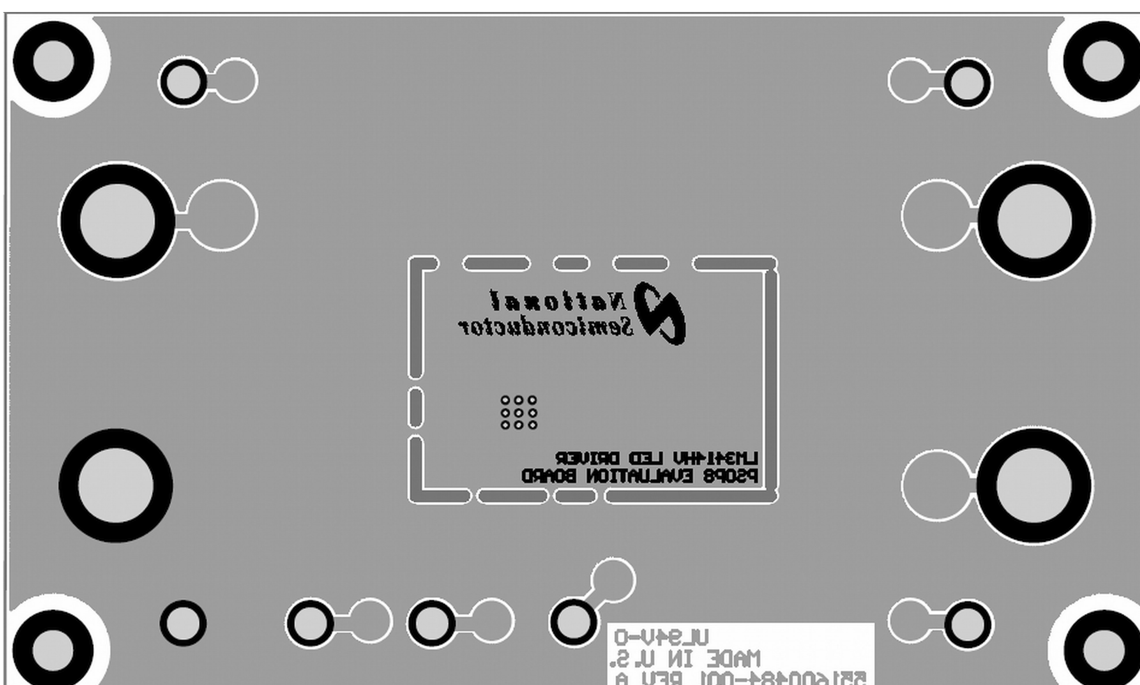
Bottom Layer and Bottom Overlay

Evaluation Board Layout (PSOP-8 Package)



30128714

Top Layer and Top Overlay



30128715

Bottom Layer and Bottom Overlay

Notes

Notes

For more National Semiconductor product information and proven design tools, visit the following Web sites at:
www.national.com

Products		Design Support	
Amplifiers	www.national.com/amplifiers	WEBENCH® Tools	www.national.com/webench
Audio	www.national.com/audio	App Notes	www.national.com/appnotes
Clock and Timing	www.national.com/timing	Reference Designs	www.national.com/refdesigns
Data Converters	www.national.com/adc	Samples	www.national.com/samples
Interface	www.national.com/interface	Eval Boards	www.national.com/evalboards
LVDS	www.national.com/lvds	Packaging	www.national.com/packaging
Power Management	www.national.com/power	Green Compliance	www.national.com/quality/green
Switching Regulators	www.national.com/switchers	Distributors	www.national.com/contacts
LDOs	www.national.com/ldo	Quality and Reliability	www.national.com/quality
LED Lighting	www.national.com/led	Feedback/Support	www.national.com/feedback
Voltage References	www.national.com/vref	Design Made Easy	www.national.com/easy
PowerWise® Solutions	www.national.com/powerwise	Applications & Markets	www.national.com/solutions
Serial Digital Interface (SDI)	www.national.com/sdi	Mil/Aero	www.national.com/milaero
Temperature Sensors	www.national.com/tempsensors	SolarMagic™	www.national.com/solarmagic
PLL/VCO	www.national.com/wireless	PowerWise® Design University	www.national.com/training

For the most current product information visit us at www.national.com

National Semiconductor Americas Technical Support Center
Email: support@nsc.com
Tel: 1-800-272-9959

National Semiconductor Europe Technical Support Center
Email: europe.support@nsc.com

National Semiconductor Asia Pacific Technical Support Center
Email: ap.support@nsc.com

National Semiconductor Japan Technical Support Center
Email: jpn.feedback@nsc.com

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

IMPORTANT NOTICE AND DISCLAIMER