

LM3414HV

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



Literature Number: SNVA451B

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National Semiconductor
Application Note 2076
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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.

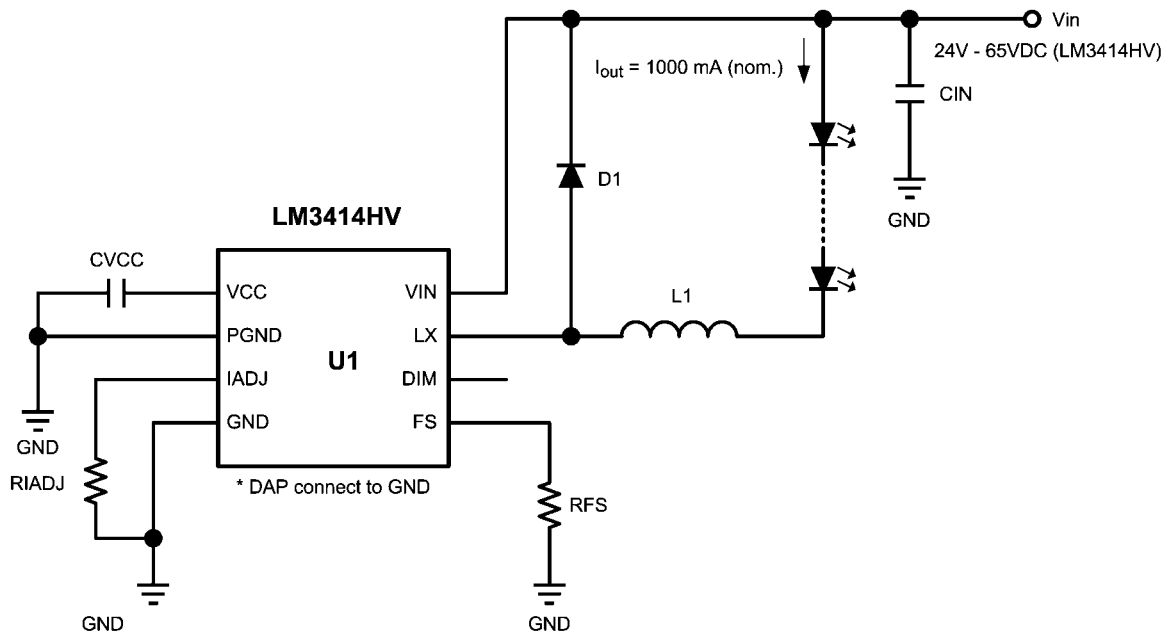
Standard Settings of the LM3414HV Evaluation Board

Vin range: 4.5V to 65V

No. of LEDs: 1 - 18

LED current: 1A

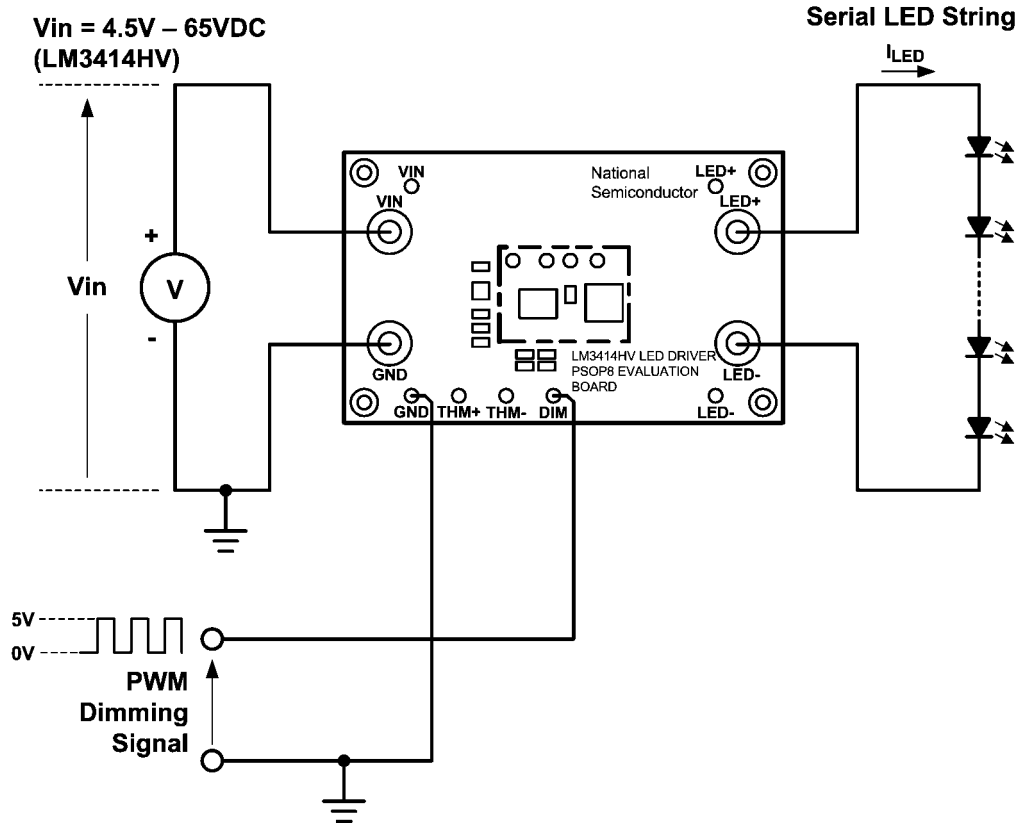
Switching frequency: 500 kHz



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FIGURE 1. Standard Schematic for the LM3414HV Evaluation Board

Board Connectors and Test Pins



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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 3.09k Ω , 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} (k Ω)
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 40k Ω 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} (k Ω)
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 inductor 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:

$$V_{f(60C)} @ 700\text{mA} = 3.0\text{V}$$

$$V_{f(25C)} @ 700\text{mA} = 3.2\text{V}$$

$$V_{f(-10C)} @ 700\text{mA} = 3.5\text{V}$$

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 $T_A = 25^\circ\text{C}$ and 3.5V at $T_A = -10^\circ\text{C}$ 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 $\pm 3\%$ output voltage variation can be used.

Step 2. Defining switching frequency f_{SW}

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):

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

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

In this example, because a 24V DC power supply with $\pm 3\%$ 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 $V_{IN(MAX)}=24.72\text{V}$ and $V_{f(MIN)}=18\text{V}$, 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):

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

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

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:

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

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.

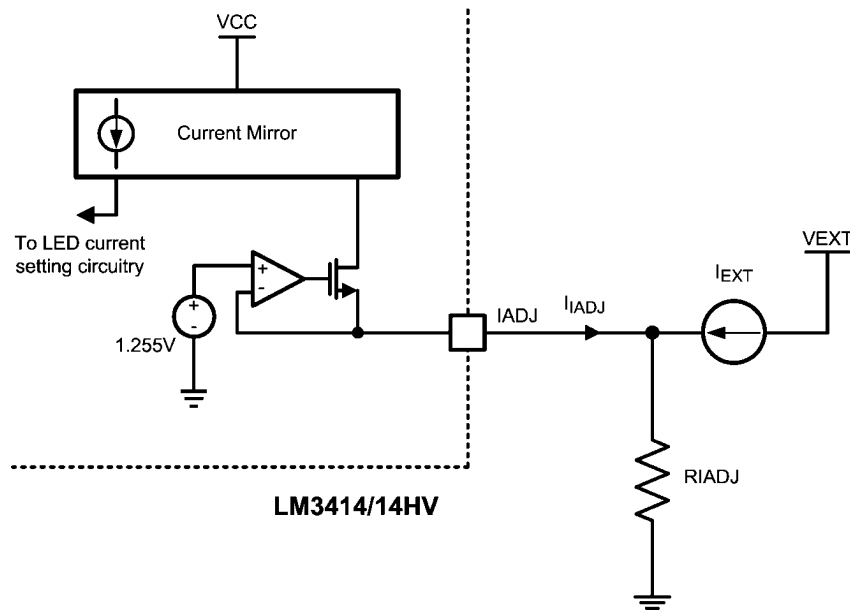


FIGURE 3. Reducing LED current with external current to the IADJ pin

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

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

Figure 4 shows a practical thermal foldback control circuit which reduces the LED current when the temperature of the LED string is exceeding certain preset threshold. Because the temperature threshold for thermal foldback control depends

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):

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

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).

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 composed of R1 and RPTC. When the temperature of the LEDs rises, the volt-

age 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} .

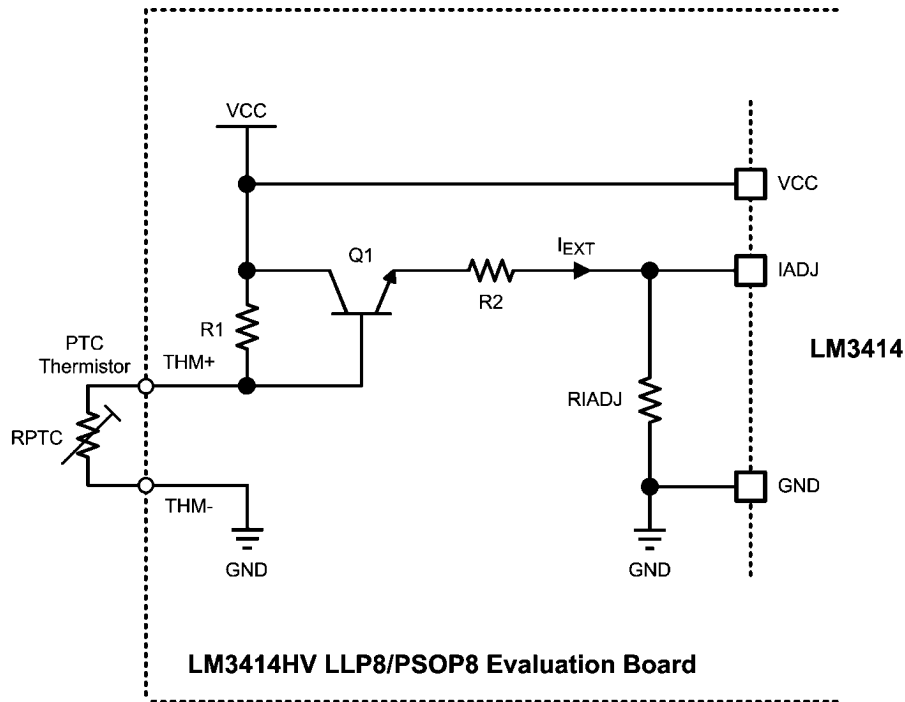


FIGURE 4. Thermal Foldback Control with PTC thermistor

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.

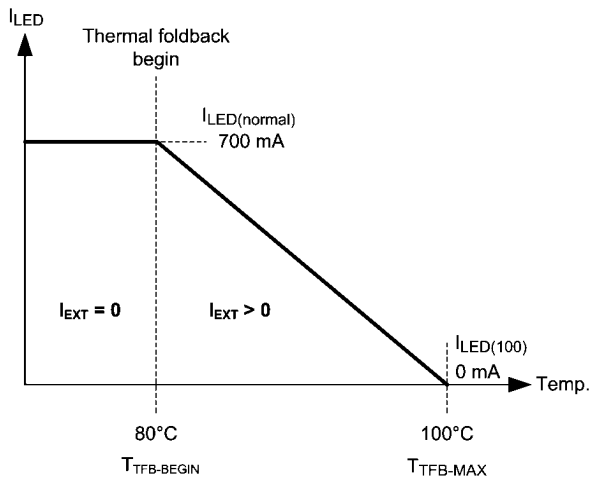


FIGURE 5. Reduction of LED current with thermal foldback control

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

$$R_{PTC(25C)} = 330\Omega$$

$$R_{PTC(80C)} = 1.2k\Omega$$

$$R_{PTC(100C)} = 10k\Omega$$

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 80°C 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:

$$\therefore I_{R2} = 0A$$

$$\therefore V_E = V_{IADJ} = 1.255V$$

$$\begin{aligned} V_{PTC} &= V_E + V_{BE} \\ &= 1.255V + 0.7V \\ &= 1.955V \end{aligned}$$

$$\begin{aligned} V_{PTC} &= V_{CC} \times \frac{R_{PTC(80C)}}{R1 + R_{PTC(80C)}} \\ &= 5.4V \times \frac{1.2k\Omega}{R1 + 1.2k\Omega} \end{aligned}$$

$$R1 = 11.08k\Omega \quad (8)$$

At 100°C:

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

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

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

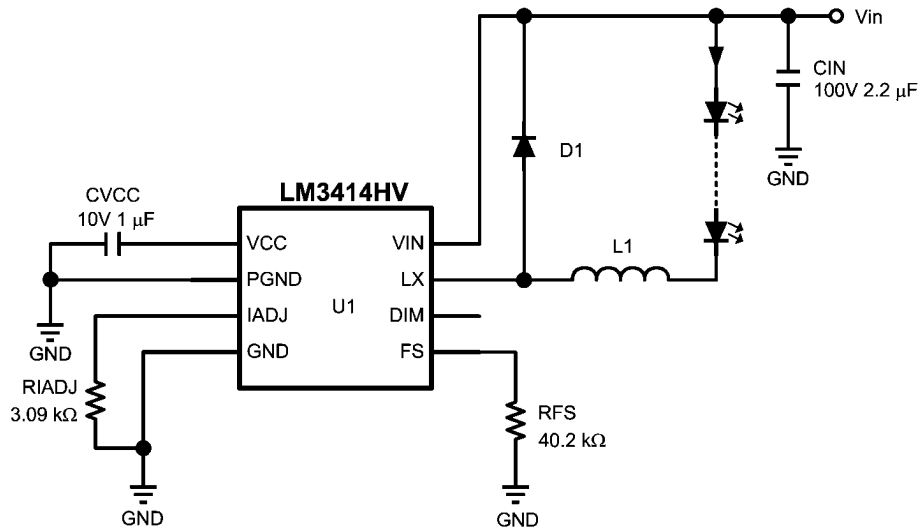
$$= \frac{1}{R2} \times \left[\frac{5.4V \times 10 k\Omega}{11.06 k\Omega + 10 k\Omega} - (0.7V + 1.255V) \right] A$$

$$R_2 = 2.17 k\Omega$$

(9)

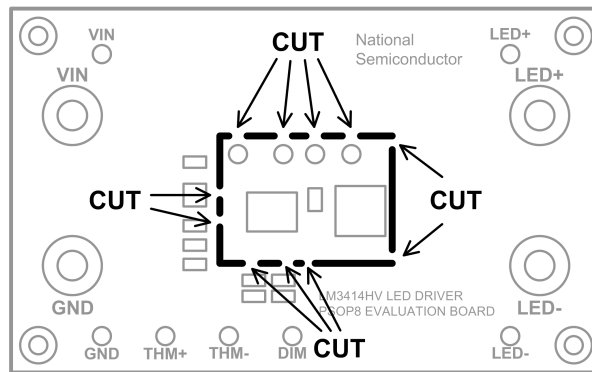
Tiny Board Outline

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.



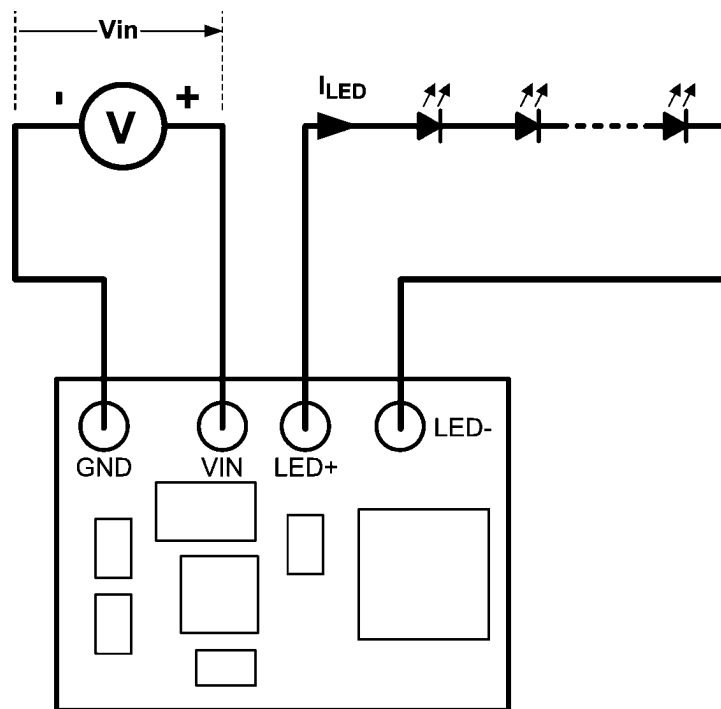
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FIGURE 6. Core Circuitry of the LM3414HV Evaluation Boards



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



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FIGURE 8. Connecting to the core circuitry

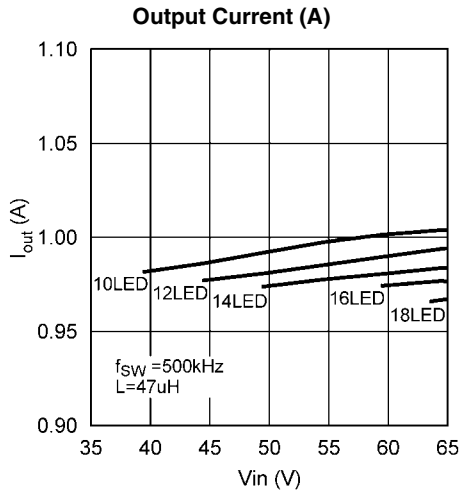
The board of the core circuitry features four connection pads for connections to DC power supply and LED string, as shown in Figure 8. To ensure thermal performance of the board, a heatsink attaches to the bottom layer of the board may be required depending on actual operation environment.

Bill of Materials

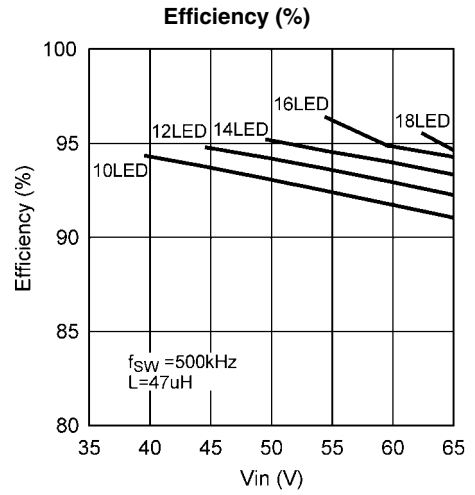
Designation	Description	Package	Manufacturer Part #	Vendor
U1	LED Driver IC, LM3414HV	LLP8 / PSOP8	LM3414MH	NSC
D1	Schottky Diode 100V 2A		SS2PH10-M3/84A	Vishay
L1	Power Inductor 47 μ H		MMD-08EZ-470M-S1	MAG.Layers
CIN	Cap MLCC 100V 2.2 μ F X7R 1210	1210	GRM32ER72A225KA35L	Murata
CVCC	Cap MLCC 10V 1 μ F X5R 0603	603	GRM185R61A105KE36D	Murata
RIADJ	Chip Resistor 3.09 k Ω 1% 0603	603	CRCW06033K09FKEA	Vishay
RFS	Chip Resistor 40.2 k Ω 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

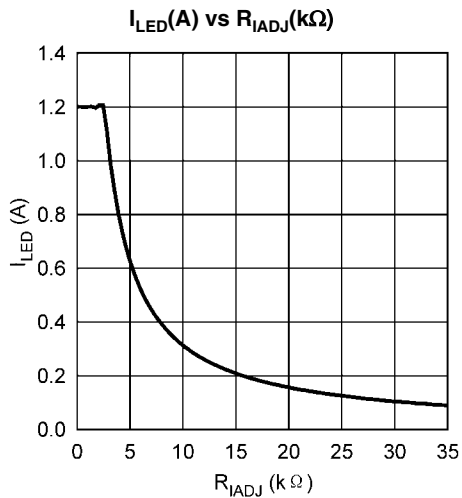
All curves taken at $V_{IN} = 48V$ with configuration in typical application for driving twelve power LEDs with four output channels active and output current per channel = 350 mA. $T_A = 25^\circ C$, unless otherwise specified.



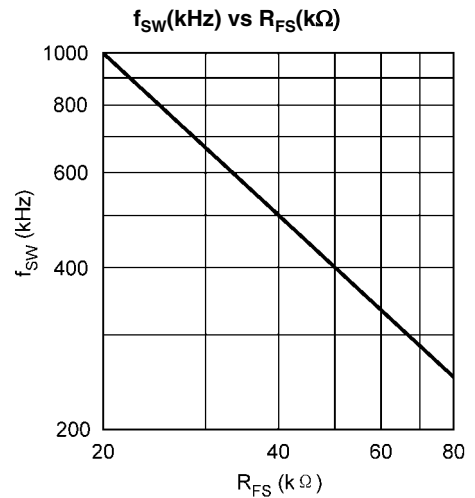
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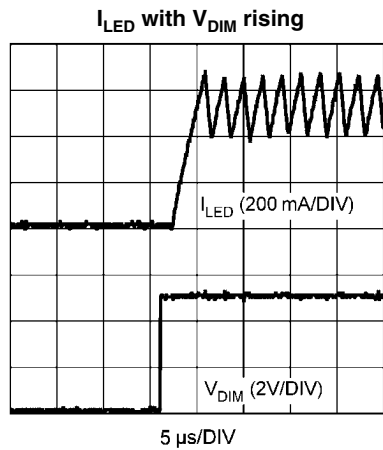
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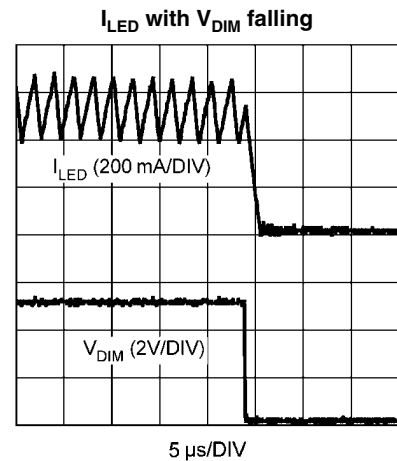
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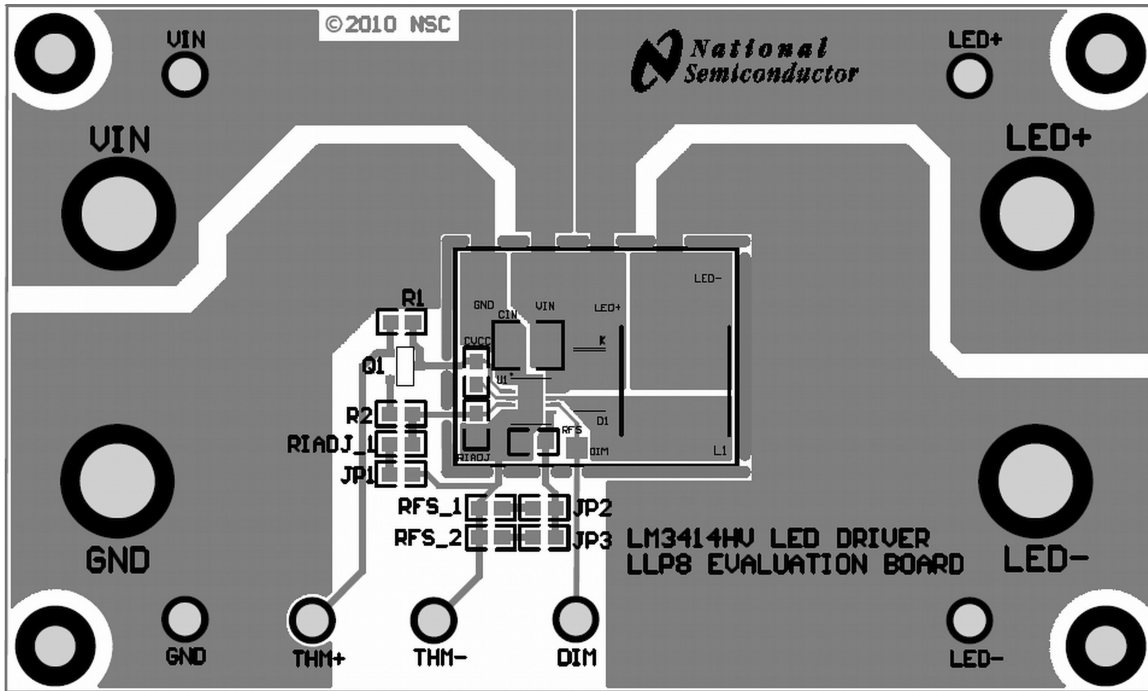


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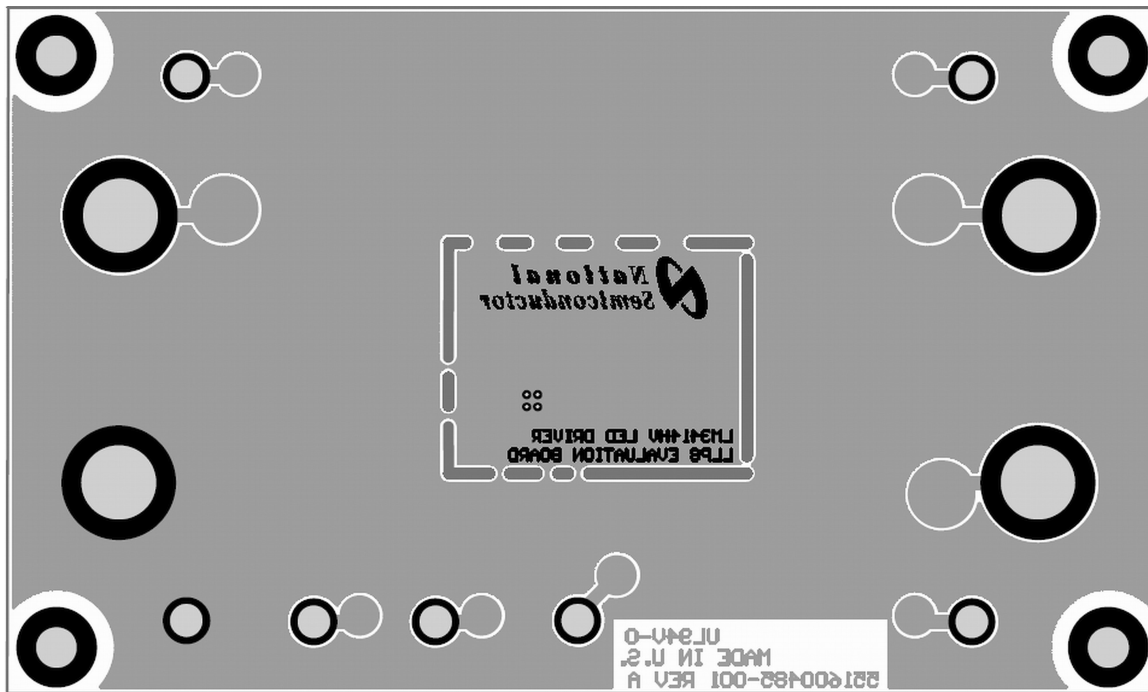
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Evaluation Board Layout (LLP-8 Package)



Top Layer and Top Overlay

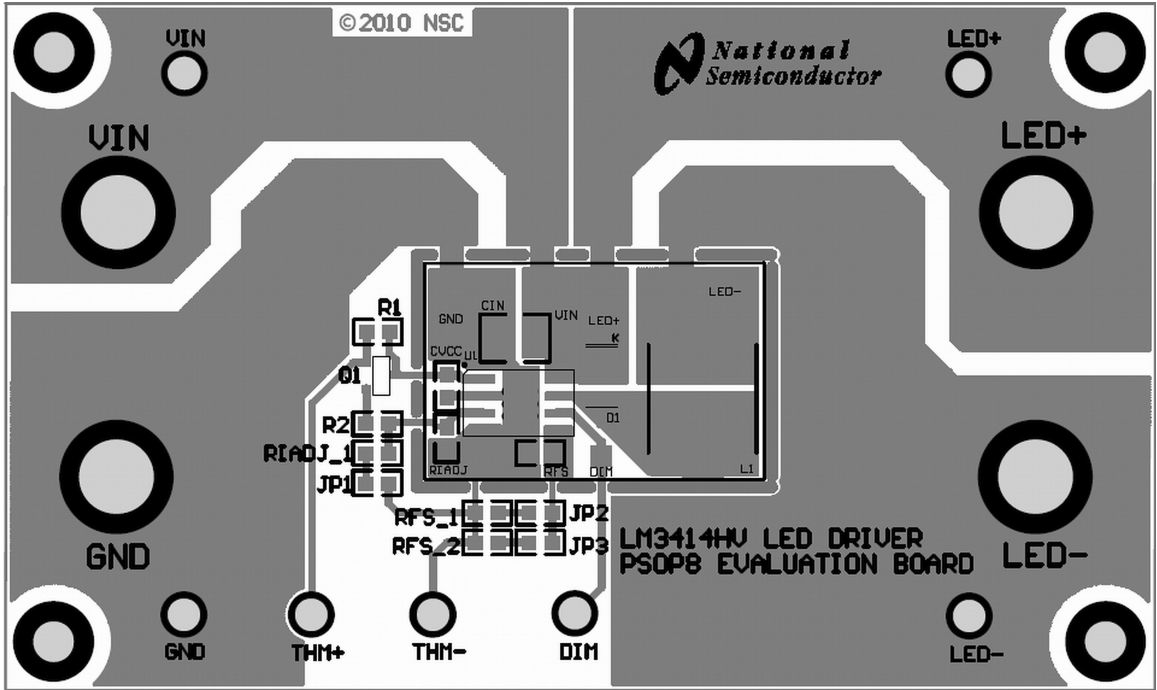
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Bottom Layer and Bottom Overlay

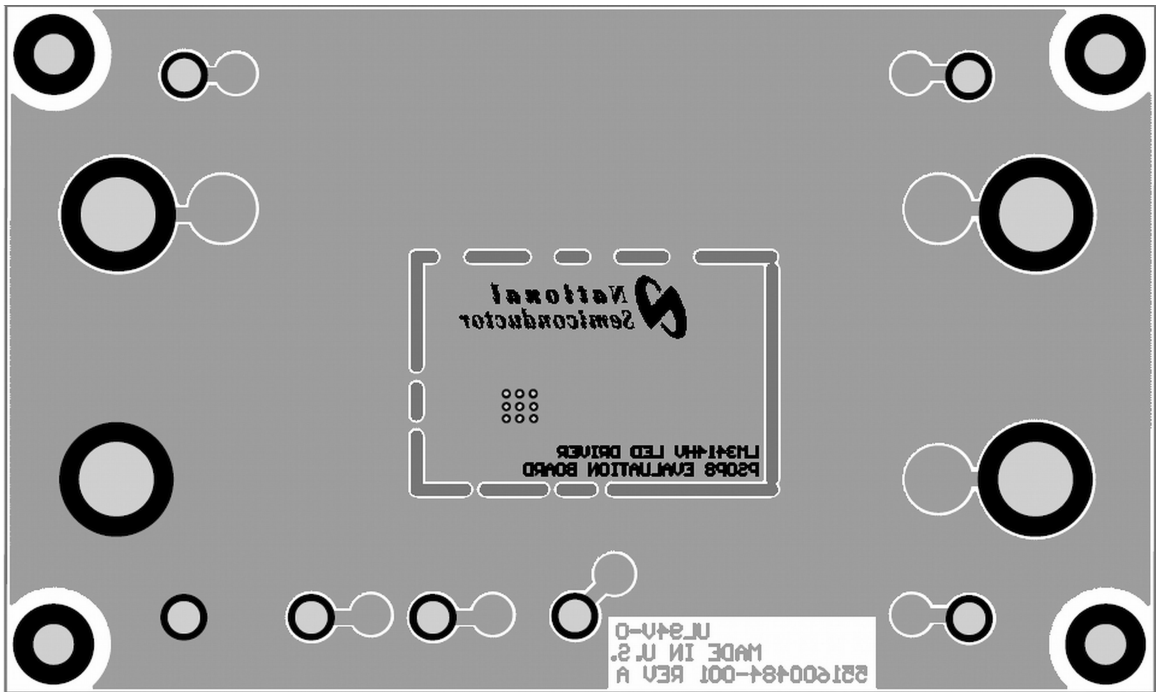
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Evaluation Board Layout (PSOP-8 Package)



Top Layer and Top Overlay

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Bottom Layer and Bottom Overlay

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Notes

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Notes

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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/tempensors	SolarMagic™	www.national.com/solarmagic
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Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Mobile Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

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