AN-2082 LM3444 -120VAC, 8W Isolated Flyback LED Driver

1 Introduction

This demonstration board highlights the performance of a LM3444 based Flyback LED driver solution that can be used to power a single LED string consisting of 4 to 8 series connected LEDs from an 90 V_{RMS} to 135 V_{RMS}, 60 Hz input power supply. The key performance characteristics under typical operating conditions are summarized in this application note.

This is a two-layer board using the bottom and top layer for component placement. The demonstration board can be modified to adjust the LED forward current, the number of series connected LEDs that are driven and the switching frequency. Refer to the *LM3444 AC-DC Offline LED Driver* (SNVS682) data sheet for detailed instructions.

A bill of materials is included that describes the parts used on this demonstration board. A schematic and layout have also been included along with measured performance characteristics.

2 Key Features

- Line injection circuitry enables PFC values greater than 0.99
- Adjustable LED current and switching frequency
- Flicker free operation

3 Applications

- Solid State Lighting
- Industrial and Commercial Lighting
- Residential Lighting

4 Performance Specifications

Based on an LED V_f = 3.57V

Symbol	Parameter	Min	Typ	Max
V_{IN}	Input voltage	90 V_{RMS}	120 V_{RMS}	135 V_{RMS}
V_{OUT}	LED string voltage	12 V	21.4 V	30 V
I_{LED}	LED string average current	-	350 mA	-
P_{OUT}	Output power	-	7.6 W	-
f_{sw}	Switching frequency	-	79 kHz	-

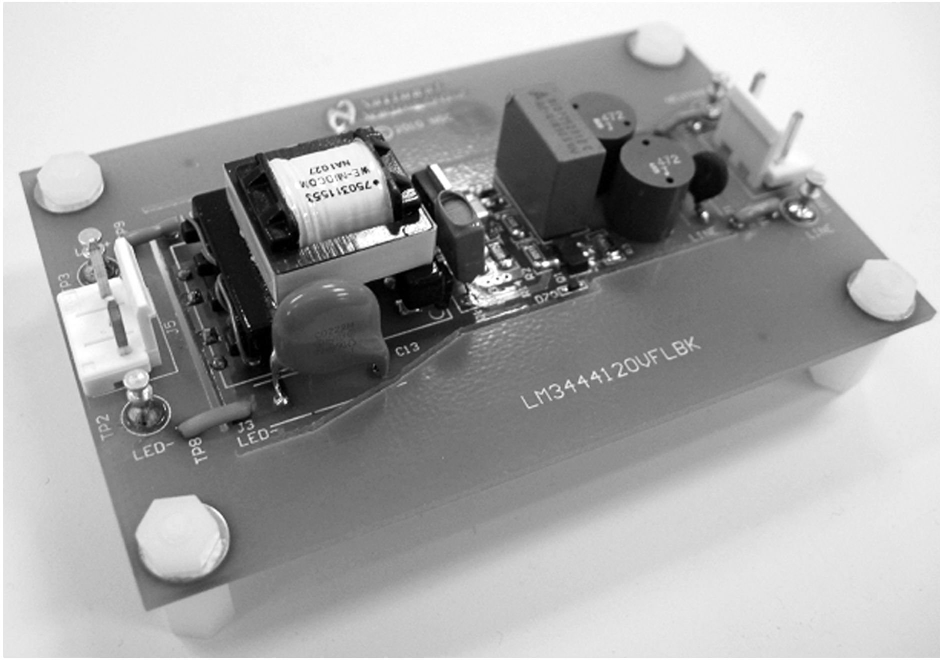
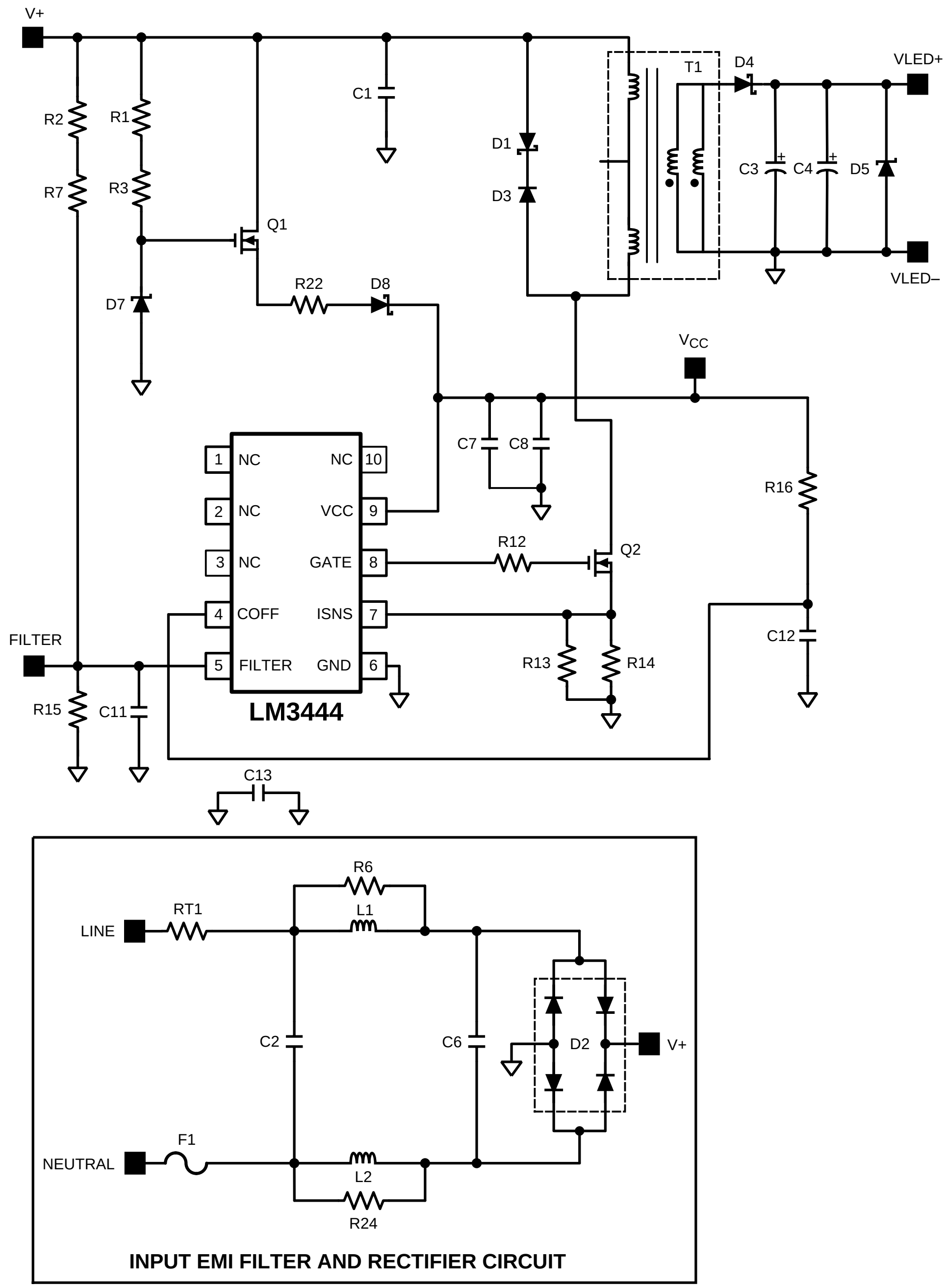


Figure 1. Demo Board

5 LM3444 120VAC, 8W Isolated Flyback LED Driver Demo Board Schematic



WARNING

The LM3444 evaluation board has exposed high voltage components that present a shock hazard. Caution must be taken when handling the evaluation board. Avoid touching the evaluation board and removing any cables while the evaluation board is operating. Isolating the evaluation board rather than the oscilloscope is highly recommended.

WARNING

The ground connection on the evaluation board is NOT referenced to earth ground. If an oscilloscope ground lead is connected to the evaluation board ground test point for analysis and AC power is applied, the fuse (F1) will fail open. The oscilloscope should be powered via an isolation transformer before an oscilloscope ground lead is connected to the evaluation board.

WARNING

The LM3444 evaluation board should not be powered with an open load. For proper operation, ensure that the desired number of LEDs are connected at the output before applying power to the evaluation board.

6 LM3444 Device Pin-Out

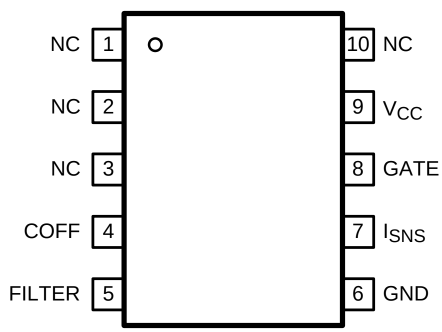


Table 1. Pin Description 10-Pin VSSOP

Pin #	Name	Description
1	NC	No internal connection.
2	NC	No internal connection.
3	NC	No internal connection.
4	COFF	OFF time setting pin. A user set current and capacitor connected from the output to this pin sets the constant OFF time of the switching controller.
5	FILTER	Filter input. A capacitor tied to this pin filters the error amplifier. Could also be used as an analog dimming input.
6	GND	Circuit ground connection.
7	ISNS	LED current sense pin. Connect a resistor from main switching MOSFET source, ISNS to GND to set the maximum LED current.
8	GATE	Power MOSFET driver pin. This output provides the gate drive for the power switching MOSFET of the buck controller.
9	V_{CC}	Input voltage pin. This pin provides the power for the internal control circuitry and gate driver.
10	NC	No internal connection.

7 Bill of Materials

Designator	Description	Manufacturer	Part Number
AA1	Printed Circuit Board	-	551600530-001A
C1	CAP .047UF 630V METAL POLYPRO	EPCOS Inc	B32559C6473K000
C2	CAP 10000PF X7R 250VAC X2 2220	Murata Electronics North America	GA355DR7GB103KY02L
C3, C4	CAP 330UF 35V ELECT PW	Nichicon	UPW1V331MPD6
C6	CAP .10UF 305VAC EMI SUPPRESSION	EPCOS	B32921C3104M
C7	CAP, CERM, 0.1µF, 16V, +/-10%, X7R, 0805	Kemet	C0805C104K4RACTU
C8	CAP CER 47UF 16V X5R 1210	MuRata	GRM32ER61C476ME15L
C11	CAP CER 2200PF 50V 10% X7R 0603	MuRata	GRM188R71H222KA01D
C12	CAP CER 330PF 50V 5% C0G 0603	MuRata	GRM1885C1H331JA01D
C13	CAP CER 2200PF 250VAC X1Y1 RAD	TDK Corporation	CD12-E2GA222MYNS
D1	DIODE TVS 150V 600W UNI 5% SMB	Littlefuse	SMAJ120A
D2	RECT BRIDGE GP 600V 0.5A MINIDIP	Diodes Inc.	RH06-T
D3	DIODE RECT GP 1A 1000V MINI-SMA	Comchip Technology	CGRM4007-G
D4	DIODE SCHOTTKY 100V 1A SMA	ST Microelectronics	STPS1H100A
D5	DIODE ZENER 30V 1.5W SMA	ON Semiconductor	1SMA5936BT3G
D7	DIODE ZENER 12V 200MW	Fairchild Semiconductor	MM5Z12V
D8	DIODE SWITCH 200V 200MW	Diode Inc	BAV20WS-7-F
F1	FUSE BRICK 1A 125V FAST 6125FA	Cooper/Bussmann	6125FA
J1, J2, J3, J4, TP8, TP9, TP10	16 GA WIRE HOLE, 18 GA WIRE HOLE	3M	923345-02-C
J5, J6	CONN HEADER .312 VERT 2POS TIN	Tyco Electronics	1-1318301-2
L1, L2	INDUCTOR 4700UH .13A RADIAL	TDK Corporation	TSL0808RA-472JR13-PF
Q1	MOSFET N-CH 600V 90MA SOT-89	Infineon Technologies	BSS225 L6327
Q2	MOSFET N-CH 600V 1.8A TO-251	Infineon Technology	SPU02N60S5
R1, R3	RES 200K OHM 1/4W 5% 1206 SMD	Vishay-Dale	CRCW1206200KJNEA
R2, R7	RES, 309k ohm, 1%, 0.25W, 1206	Vishay-Dale	CRCW1206309KFKEA
R6, R24	RES, 10.5k ohm, 1%, 0.125W, 0805	Vishay-Dale	CRCW080510K5FKEA
R12	RES 4.7 OHM 1/10W 5% 0603 SMD	Vishay-Dale	CRCW06034R70JNEA
R13	RES 10 OHM 1/8W 5% 0805 SMD	Vishay-Dale	CRCW080510R0JNEA
R14	RES 1.50 OHM 1/4W 1% 1206 SMD	Vishay-Dale	CRCW12061R50FNEA
R15	RES 3.48K OHM 1/10W 1% 0603 SMD	Vishay-Dale	CRCW06033K48FKEA
R16	RES 191K OHM 1/10W 1% 0603 SMD	Vishay-Dale	CRCW0603191KFKEA
R22	RES 40.2 OHM 1/8W 1% 0805 SMD	Vishay-Dale	CRCW080540R2FKEA
RT1	CURRENT LIMITOR INRUSH 60OHM 20%	Cantherm	MF72-060D5
T1	Transformer	Wurth Electronics	750311553 Rev. 01
TP2-TP5	Terminal, Turret, TH, Double	Keystone Electronics	1502-2
TP7	TEST POINT ICT	-	-
U1	Offline LED Driver, PowerWise™	Texas Instruments	LM3444

8 Demo Board Wiring Overview

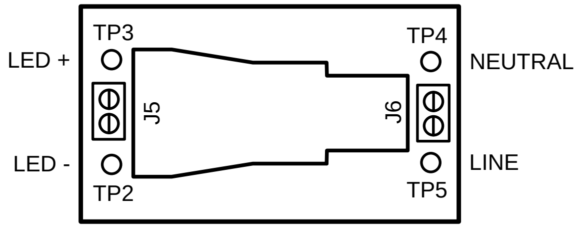


Figure 2. Wiring Connection Diagram

Test Point	Name	I/O	Description
TP3	LED +	Output	**LED Constant Current Supply** Supplies voltage and constant-current to anode of LED string.
TP2	LED -	Output	**LED Return Connection (not GND)** Connects to cathode of LED string. Do NOT connect to GND.
TP5	LINE	Input	**AC Line Voltage** Connects directly to AC line of a 120VAC system.
TP4	NEUTRAL	Input	**AC Neutral** Connects directly to AC neutral of a 120VAC system.

9 Demo Board Assembly

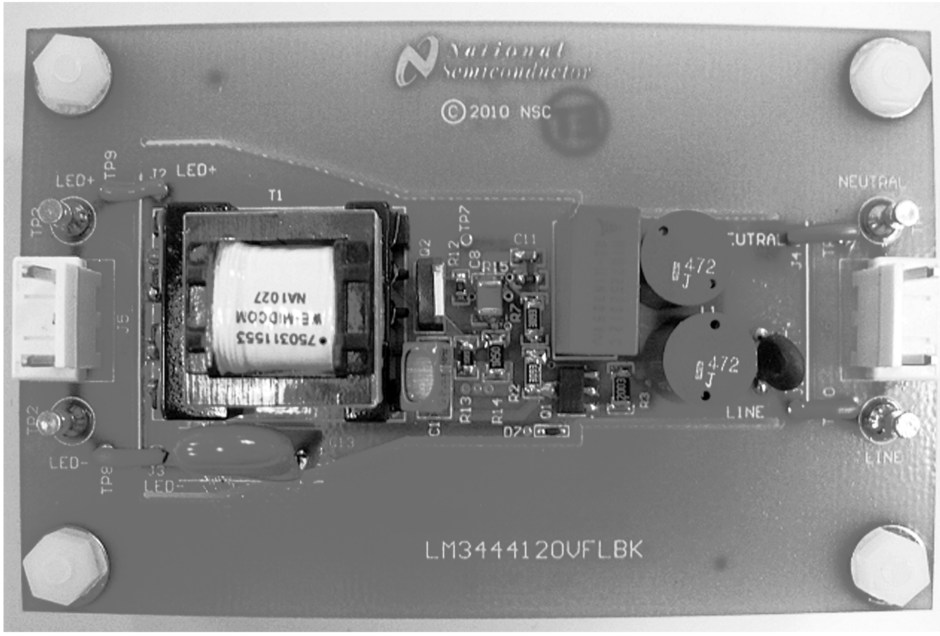


Figure 3. Top View

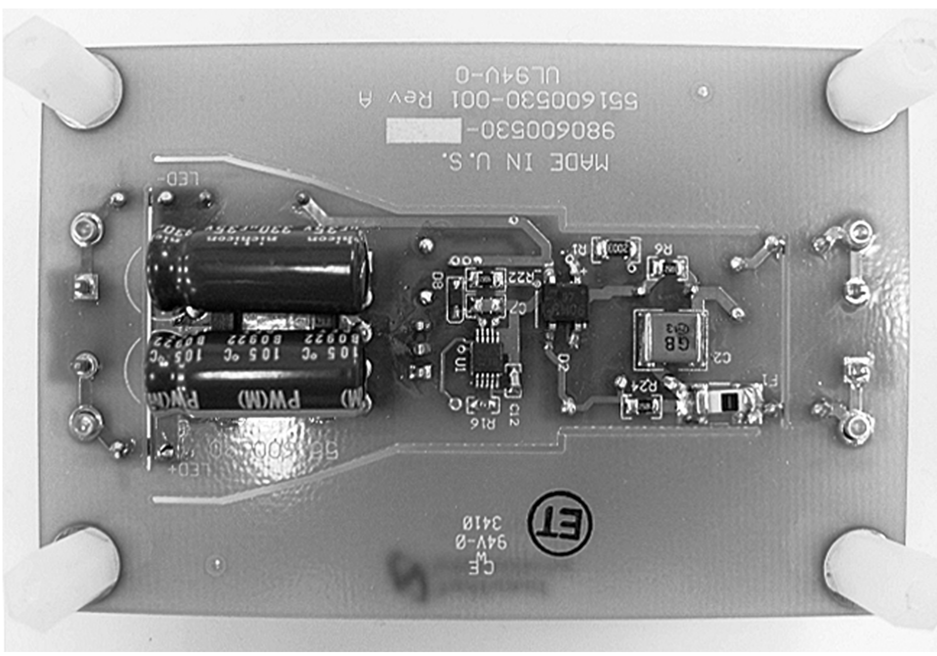


Figure 4. Bottom View

10 Typical Performance Characteristics

Original Circuit: R14 = 1.50Ω; Modification A: R14 = 1.21Ω; Modification B: R14 = 1.00Ω; Modification C: R14 = 0.75Ω

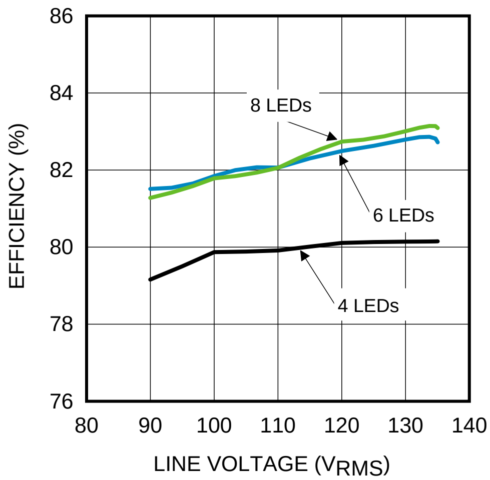


Figure 5. Efficiency vs Line Voltage Original Circuit

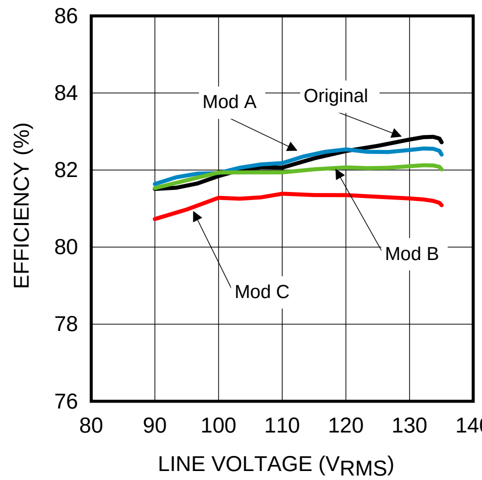


Figure 6. Efficiency vs. Line Voltage Modified Circuits

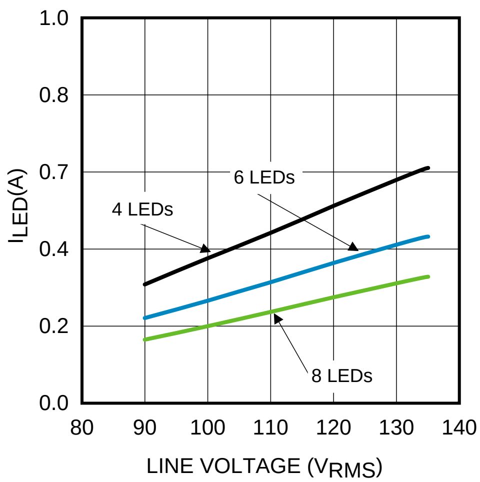


Figure 7. LED Current vs. Line Voltage Original Circuit

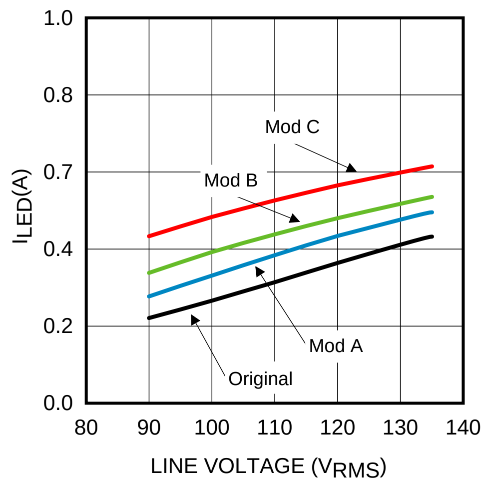


Figure 8. LED Current vs. Line Voltage Modified Circuits

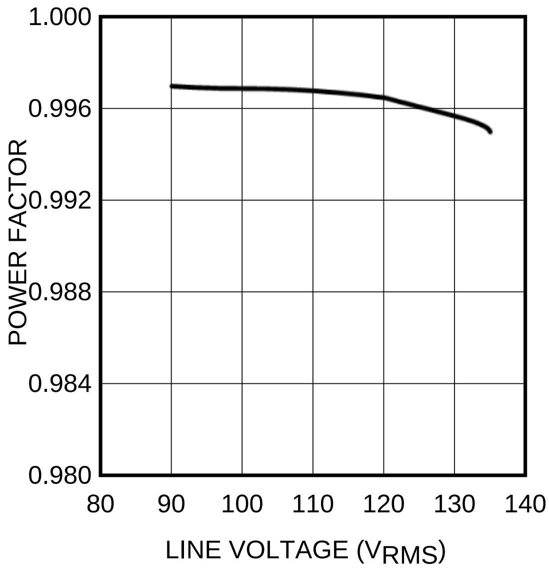


Figure 9. Power Factor vs. Line Voltage Original Circuit

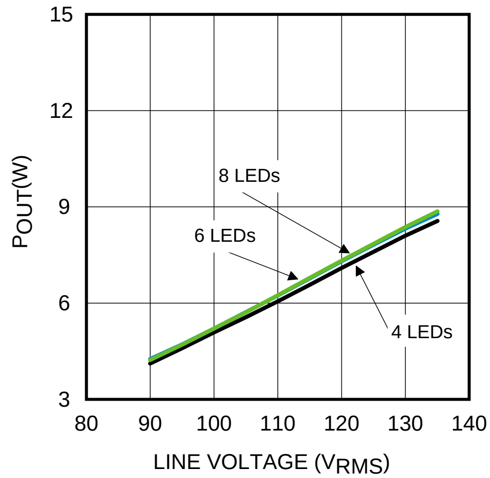


Figure 10. Output Power vs. Line Voltage Original Circuit

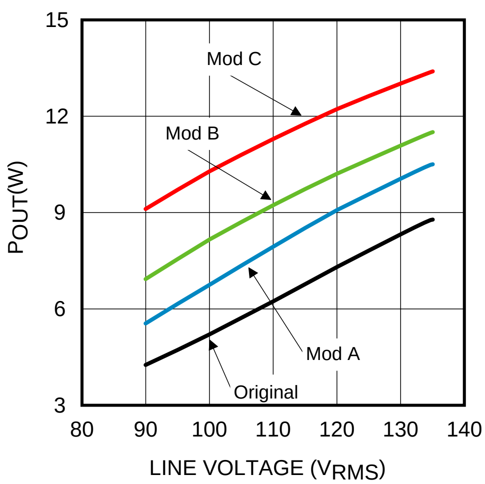


Figure 11. Output Power vs.Line Voltage Modified Circuits

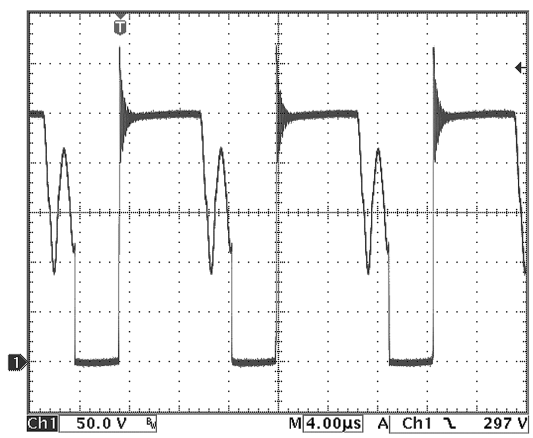


Figure 12. Power MOSFET Drain Voltage Waveform (V_{IN} = 120V_{RMS}, 6 LEDs, I_{LED} = 350mA)

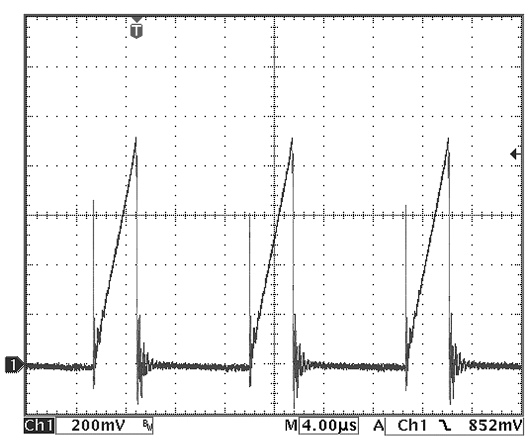


Figure 13. Current Sense Waveform (V_{IN} = 120V_{RMS}, 6 LEDs, I_{LED} = 350mA)

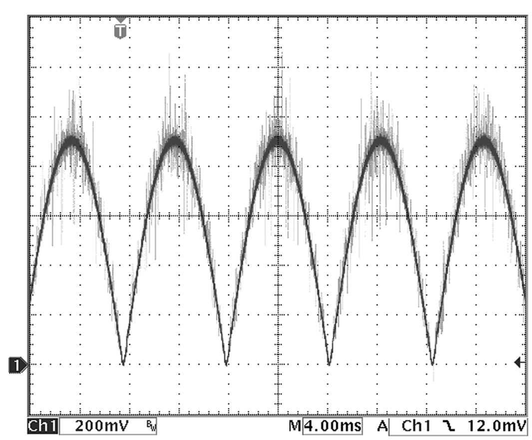


Figure 14. FILTER Waveform (V_{IN} = 120V_{RMS}, 6 LEDs, I_{LED} = 350mA)

11 PCB Layout

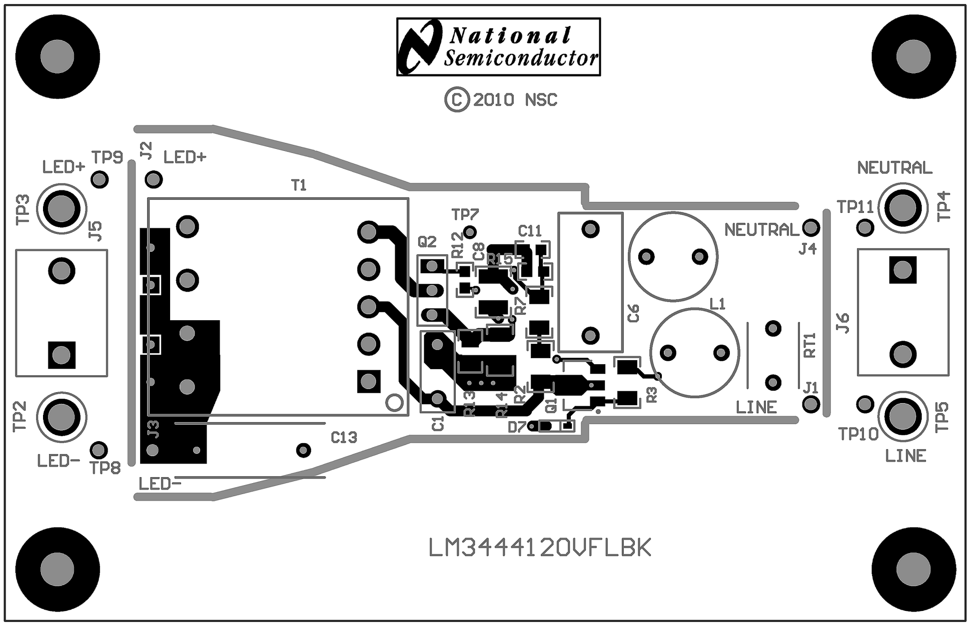


Figure 15. Top Layer

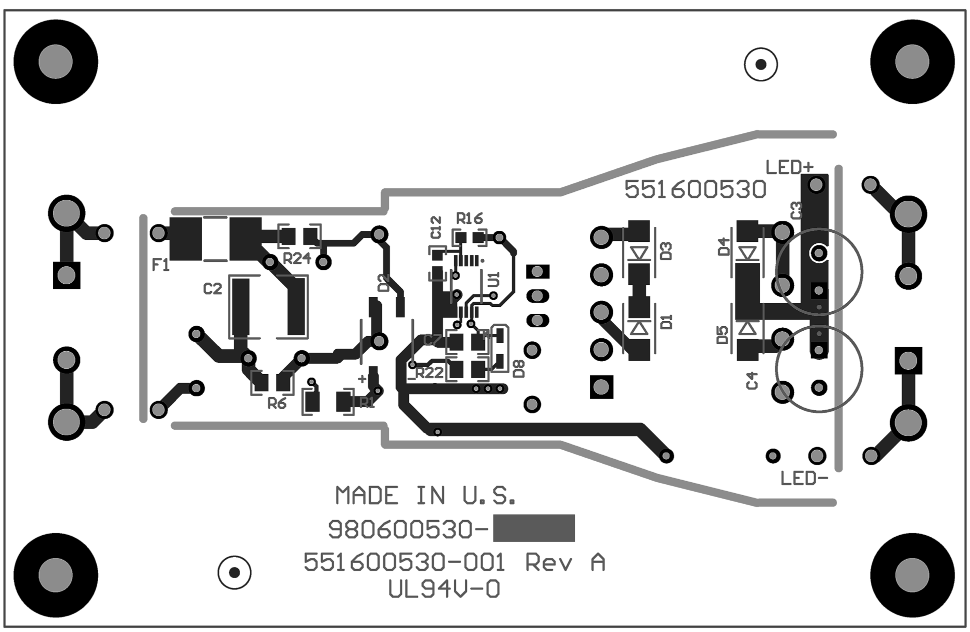
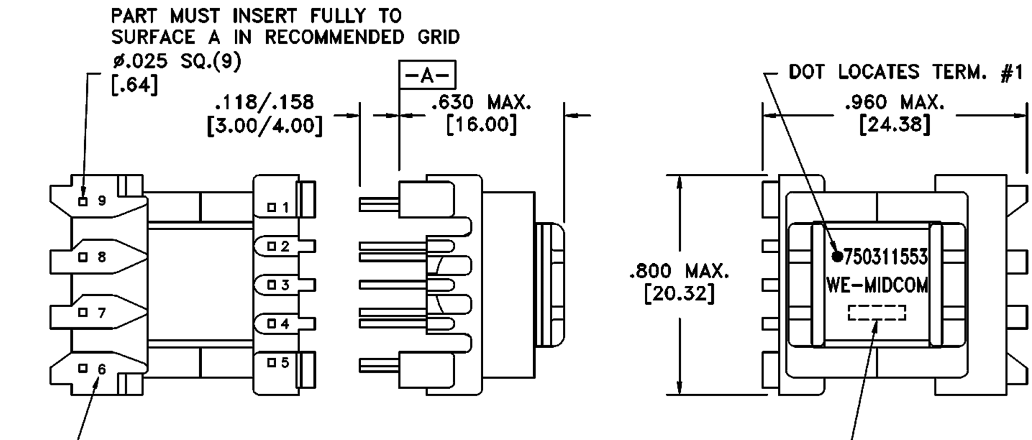
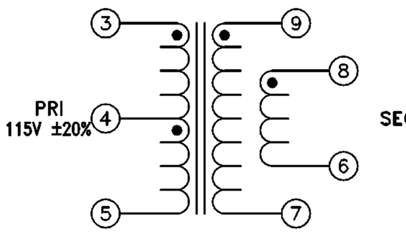


Figure 16. Bottom Layer

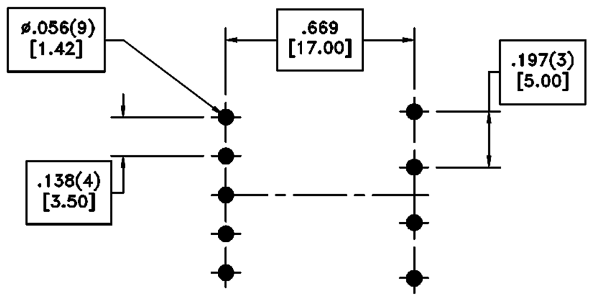
12 Transformer Design

Mfg: Wurth Electronics, Part #: 750311553 Rev. 01





Customer to tie terminals 9+8 and 7+6 internally on PCB.



RECOMMENDED
P.C. PATTERN, COMPONENT SIDE

ELECTRICAL SPECIFICATIONS @ 25°C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	3–5	@20°C	1.35 ohms max.
D.C. RESISTANCE	8–6	@20°C	0.284 ohms max.
D.C. RESISTANCE	9–7	@20°C	0.284 ohms max.
INDUCTANCE	3–5	100kHz, 100mVAC, Ls	803.5uH ±10%
INDUCTANCE	9–7	100kHz, 100mVAC, Ls	50.2uH ±10%
INDUCTANCE	8–6	100kHz, 100mVAC, Ls	50.2uH ±10%
LEAKAGE INDUCTANCE	3–5	tie(9+8+7+6), 100kHz, 100mVAC, Ls	5.50uH typ., 7.0uH max.
DIELECTRIC	3–9	tie(9+8), 4500VAC, 1 second	4500VAC, 1 minute
TURNS RATIO		(3–5):(9–7)	4:1, ±2%
TURNS RATIO		(3–5):(8–6)	4:1, ±2%

GENERAL SPECIFICATIONS:
OPERATING TEMPERATURE RANGE: −40°C to +125°C including temp rise.

Designed to comply with the following requirements as defined by IEC61558−2−17:
− Reinforced insulation for a primary circuit at a working voltage of 400VDC.

13 Experimental Results

The LED driver is designed to accurately emulate an incandescent light bulb and therefore behave as an emulated resistor. The resistor value is determined based on the LED string configuration and the desired output power. The circuit then operates in open-loop, with a fixed duty cycle based on a constant on-time and constant off-time that is set by selecting appropriate circuit components.

13.1 Performance

In steady state, the LED string voltage is measured to be 21.38 V and the average LED current is measured as 357 mA. The 120 Hz current ripple flowing through the LED string was measured to be 170 $mA_{pk\text{-}pk}$ at full load. The magnitude of the ripple is a function of the value of energy storage capacitors connected across the output port. The ripple current can be reduced by increasing the value of energy storage capacitor or by increasing the LED string voltage.

The LED driver switching frequency is measured to be close to the specified 79 kHz. The circuit operates with a constant duty cycle of 0.28 and consumes 9.25 W of input power. The driver steady state performance for an LED string consisting of 6 series LEDs is summarized in the following table.

Table 2. Measured Efficiency and Line Regulation (6 LEDs)

V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN}(W)	V_{OUT} (V)	I_{LED} (mA)	P_{OUT} (W)	Efficiency (%)	Power Factor
90	60	5.37	20.25	216	4.38	81.6	0.9970
95	63	5.95	20.47	238	4.87	81.8	0.9969
100	66	6.57	20.67	260	5.38	81.9	0.9969
105	69	7.23	20.86	285	5.94	82.1	0.9969
110	72	7.89	21.05	309	6.50	82.3	0.9968
115	75	8.59	21.23	334	7.09	82.5	0.9967
120	77	9.25	21.38	357	7.65	82.7	0.9965
125	80	9.94	21.53	382	8.23	82.8	0.9961
130	82	10.62	21.68	406	8.80	82.9	0.9957
135	84	11.26	21.80	428	9.34	83.0	0.9950

Table 3. LED Current, Output Power versus Number of LEDs for Various Circuit Modifications (V_{IN} = 120 V_{AC})

# of LEDs	Original Circuit [(1)]		Modification A [(1)]		Modification B [(1)]		Modification C [(1)]	
	I_{LED} (mA)	P_{OUT} (W)	I_{LED} (mA)	P_{OUT} (W)	I_{LED} (mA)	P_{OUT} (W)	I_{LED} (mA)	P_{OUT} (W)
4	508	7.57	624	9.55	710	11.05	835	13.24
6	357	7.65	440	9.58	500	11.02	590	13.35
8	277	7.69	337	9.59	382	11.00	445	13.00

(1) Original Circuit: R14 = 1.50Ω; Modification A: R14 = 1.21Ω; Modification B: R14 = 1.00Ω; Modification C: R14 = 0.75Ω

13.2 Power Factor Performance

The LED driver is able to achieve close to unity power factor (P.F. ~ 0.99) which meets Energy Star requirements. This design also exhibits low current harmonics as a percentage of the fundamental current (as shown in Figure 17) and therefore meets the requirements of the IEC 61000-3-2 Class-3 standard.

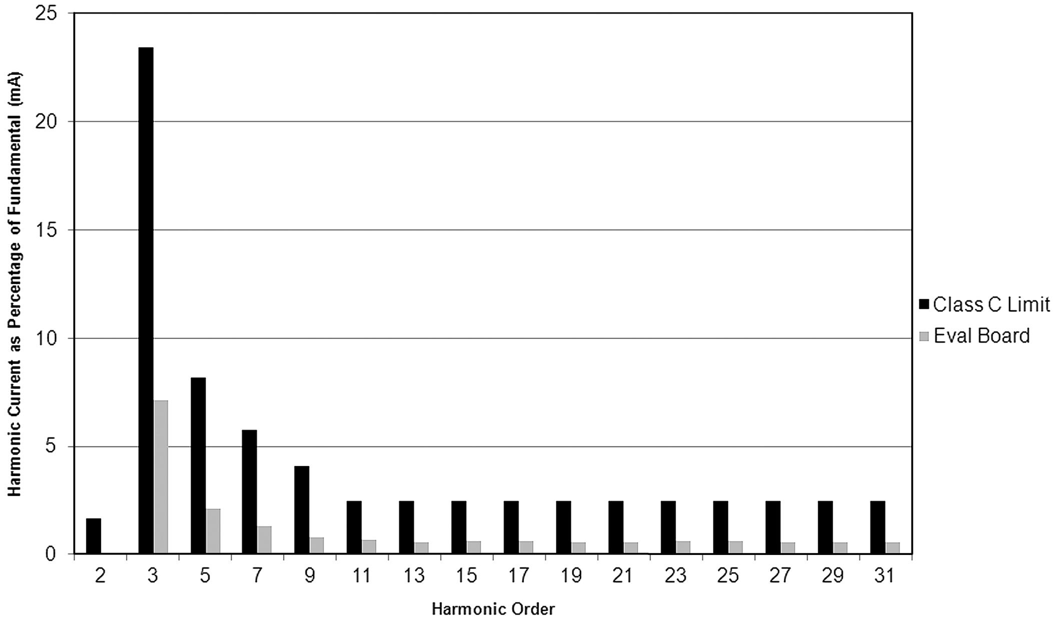


Figure 17. Current Harmonic Performance vs. EN/IEC61000-3-2 Class C Limits

14 Electromagnetic Interference (EMI)

The EMI input filter of this evaluation board is configured as shown in the following circuit diagram.

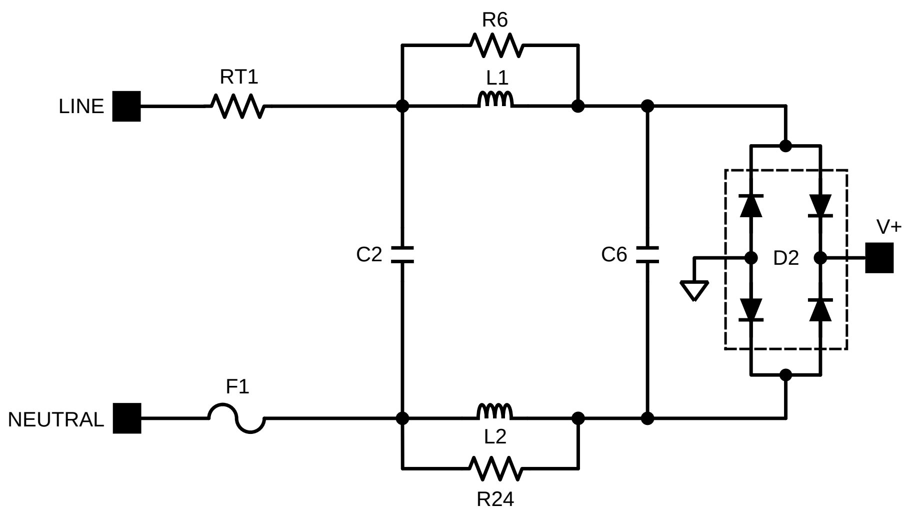


Figure 18. Input EMI Filter and Rectifier Circuit

In order to get a quick estimate of the EMI filter performance, only the PEAK conductive EMI scan was measured and the data was compared to the Class B conducted EMI limits published in FCC – 47, section 15.

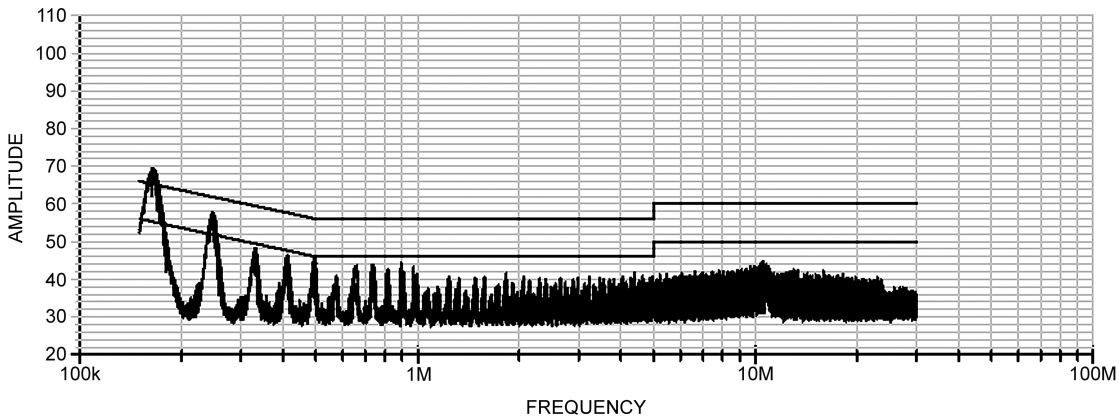


Figure 19. Peak Conductive EMI Scan per CISPR-22, Class B Limits

If an additional 33nF of input capacitance (C6) is utilized in the input filter, the EMI conductive performance is further improved as shown in Figure 20.

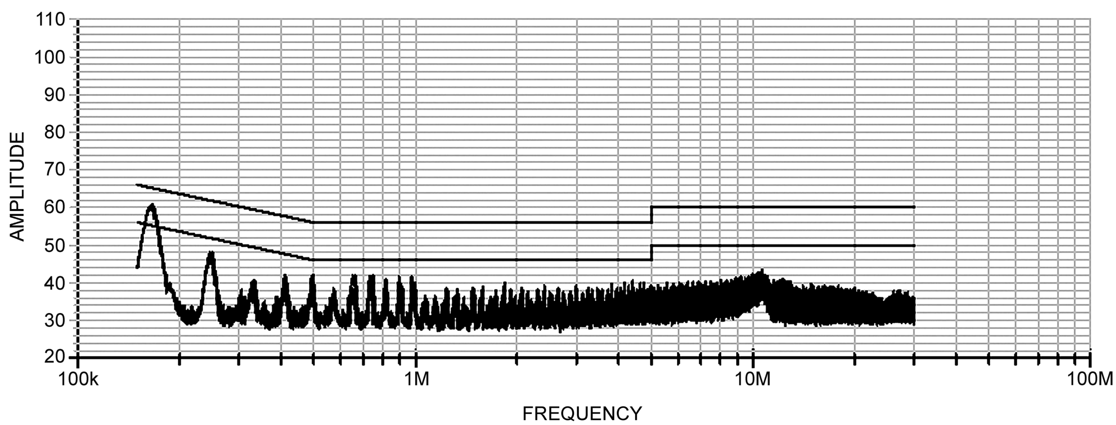


Figure 20. Peak Conductive EMI Scan With Additional 33nF of Input Capacitance

15 Thermal Analysis

The board temperature was measured using an IR camera (HIS-3000, Wahl) while running under the following conditions:

V_{IN} = 120 V_{RMS}

I_{LED} = 350 mA

# of LEDs = 6

P_{OUT} = 7.3 W

The results are shown in the following figures.

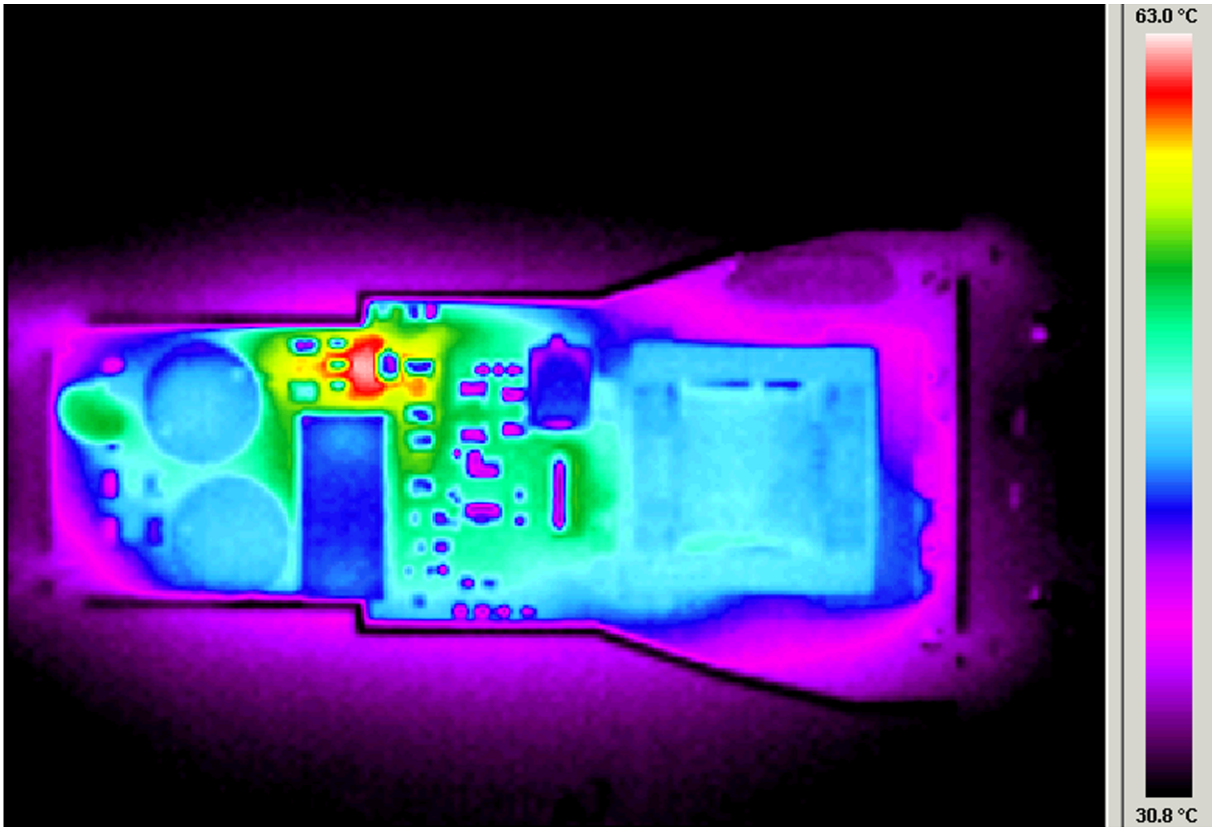


Figure 21. Top Side Thermal Scan

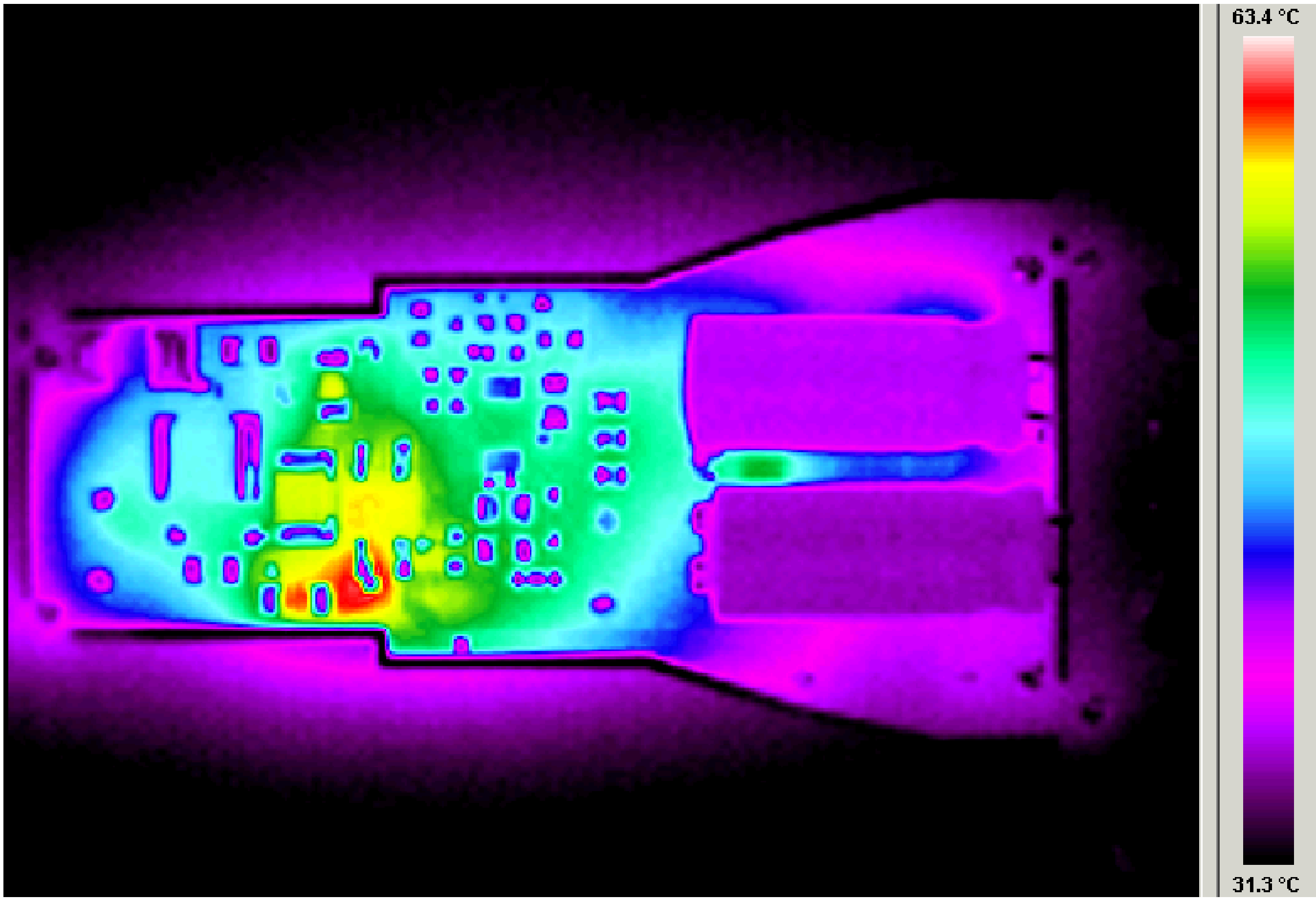


Figure 22. Bottom Side Thermal Scan

16 Circuit Analysis and Explanations

16.1 Injecting Line Voltage Into FILTER (Achieving PFC > 0.99)

If a small portion (750mV to 1.00V) of line voltage is injected at FILTER of the LM3444, the circuit is essentially turned into a constant power flyback, as shown in Figure 23.

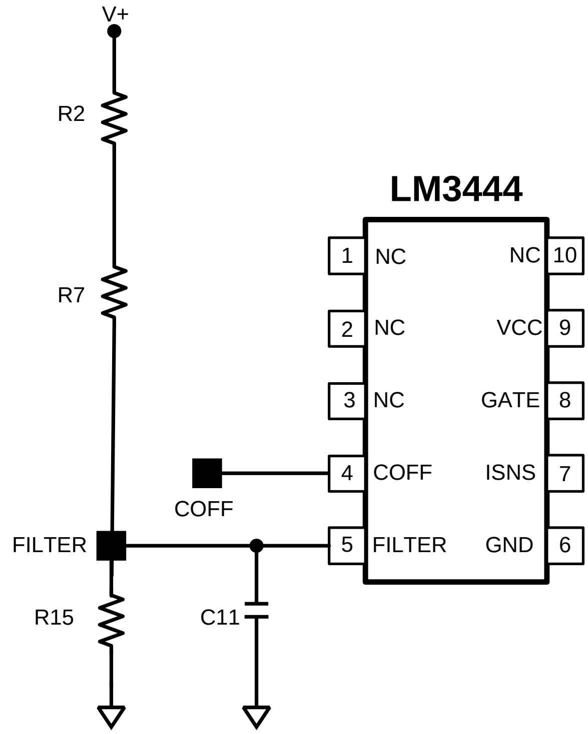


Figure 23. Line Voltage Injection Circuit

The LM3444 works as a constant off-time controller normally, but by injecting the 1.0V rectified AC voltage into the FILTER pin, the on-time can be made to be constant. With a DCM Flyback, Δi needs to increase as the input voltage line increases. Therefore a constant on-time (since inductor L is constant) can be obtained.

By using the line voltage injection technique, the FILTER pin has the voltage wave shape shown in Figure 24 on it. Voltage at V_{FILTER} peak should be kept below 1.25V. At 1.25V current limit is tripped. C11 is small enough not to distort the AC signal but adds a little filtering.

Although the on-time is probably never truly constant, it can be observed in Figure 25 how (by adding the rectified voltage) the on-time is adjusted.

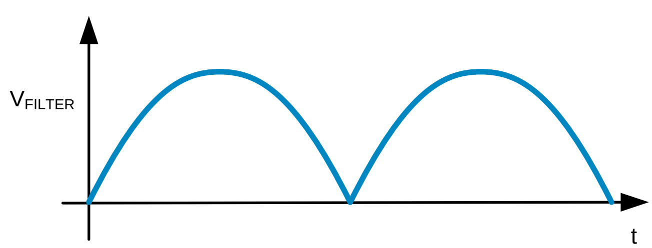


Figure 24. FILTER Waveform

For this evaluation board, the following resistor values are used:

R2 = R7 = 309kΩ

R15 = 3.48kΩ

Therefore the voltages observed on the FILTER pin will be as follows for listed input voltages:

For VIN = $90V_{RMS}$, V_{FILTER} = 0.71V

For VIN = $120V_{RMS}$, V_{FILTER} = 0.95V

For VIN = $135V_{RMS}$, V_{FILTER} = 1.07V

Using this technique, a power factor greater than 0.99 can be achieved without additional passive active power factor control (PFC) circuitry.

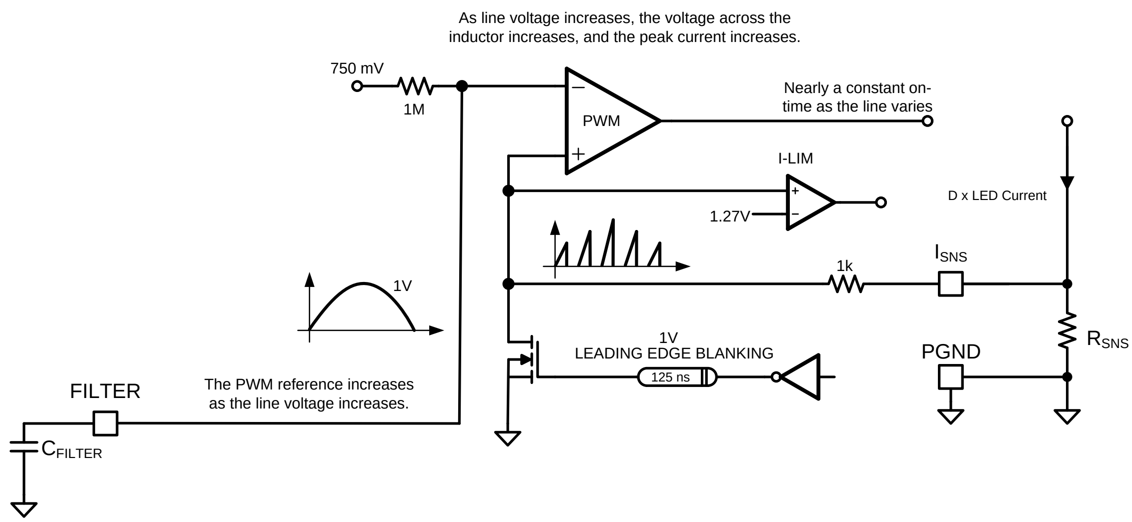


Figure 25. Typical Operation of FILTER Pin

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

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