Design Note – DN05062/D

Compact 200-265 Vac Hi-PF Boost LED Driver

Device	Application	Input Voltage	Output Power	Topology	I/O Isolation
NCP1075 + NCP4328A	LED Driver	200 – 265 Vac	Up to 13 Watts	Boost	Non-isolated

Constant Current Output	30 mA
Nominal Voltage	393 Vdc
Maximum Voltage	440 Vdc
Minimum Voltage	380 Vdc

Typical Power Factor	0.96
Typical THDi	14%
Typical Efficiency	91.8%
Startup Time	<20 msec

Circuit Description

High voltage LEDs are becoming more popular and are now available from multiple LED manufacturers such as CREE and Philips-Lumileds, see figure 1. These package LEDs may have typical forward voltages ranging from 24 to >200 V.

Figure 1: Example High Voltage LED Products

The development of these types of LEDs has been driven in part by the desire to improve the power conversion from the AC mains voltage to the LED string voltage as well as simplifying the driver electronics. In fact in some cases they have been promoted as being 'driverless" since a diode bridge and linear regulator can implement a very simple circuit. There are several drawbacks to this approach. As the LEDs are off for a portion of every line cycle when the input voltage is below the LED forward voltage, more LEDs are needed to produce the desired lumen output. In addition, the LED lamp exhibits over 100% ripple at 100/120 Hz. The impact of low frequency ripple on human performance is not a new concern in the lighting world and there is work underway to study this effect and set acceptable guidelines for the amount of flicker in LED light sources which are more sensitive since there is no optical persistence as is found in filament lamps. Further information can be found at this website: (http://www.lrc.rpi.edu/programs/solidstate/assist/flicker.asp)

If the LED string can be configured such that the forward voltage V_F is greater than the peak AC voltage, this opens the door to use a boost topology to drive the LEDs. The output voltage must be higher than the peak of the applied ac input. This implies 265 Vac x$\sqrt{2}$ = 375 Vdc as the absolute minimum LED voltage suitable for this boost converter application.

A boost converter can provide high power factor and low THD, regulate accurate current regardless of LED forward voltage and line variation, and address the ripple issue eliminating the need to design with higher quantities of LEDs (or LED area) to achieve the desired lumen output. Note that many low power LEDs can also be arranged in long strings to achieve the required high voltage which is particularly attractive to distributed light applications such as linear tube replacements.

As with many high performance LED drivers, the proposed boost converter provides a constant output current compensating for input line voltage range and variation in LED voltage including temperature variation.

Shown below are the design guidelines for this driver:

- Input range: 200 – 265 V ac
- Output current: 30 mA typical
- Output voltage: 393 Vdc typical
- Efficiency: >88%
- Power Factor: >0.9
- Open Load Protection

This design is based on the ON Semiconductor NCP1075 switching regulator which integrates a 700 volt MOSFET with control functions in a space saving SOT-223 or PDIP-7 package. In addition to the many protection features, this monolithic solution provides an internal Dynamic Self-Supply (DSS) eliminating the need for external bias components. Since no bias winding is required, an off-the-shelf low cost magnetic can be used for the boost inductor.

Typically, a current mode control converter must utilize an analog multiplier to achieve high power factor. In this design example, a simple transistor follower is employed to force the converter to reduce current draw around the zero crossings of the ac mains. Combined with a small capacitor after the input diode bridge, this control method provides high power factor by programming the line current to follow the applied ac line voltage wave shape.

LED current regulation is controlled by modulating the on-time away from the zero crossings of the input sine wave. Since most of the power transfer in a high power factor converter occurs near the peaks of the sine wave, balancing the characteristic near the zero crossing with controlled switching near the peaks provides high power factor and tight LED current regulation.

Constant current control is implemented with a sense resistor in series with the LED load. The voltage across this resistor is processed by a combined Constant Voltage / Constant Current controller, the ON Semiconductor NCP4328A. An internal reference provides a nominal 62.5 mV level to the current control loop, and 1.250 V to the voltage control loop. These amplifiers are combined internally to provide a single output control pin in a compact 5 pin TSOP package.

The significance of this dual controller is the very low nominal supply current of 105 µA. At this low level, the DSS of the NCP1075 is able to provide bias power to the controller as well. Thus the bias network is as simple as a filter capacitor and a trace connecting the two devices.

Open load protection is provided by the second half of the NCP4328A controller. Precise regulation allows an LED operating voltage close to the maximum rating of the boost filter capacitor without typical tolerance concerns for less accurate protection methods.

Maximum output power for this specific NCP1075 design is limited by the peak current limit, switching frequency, and maximum on-time of the switcher to about 13 watts. The inductor determines the peak current as a function of applied voltage and on-time. In this case, 2.2mH satisfies the switcher limitations.

The selected inductor should support a peak current of 400 mA without saturating. Due to the low current, winding resistance is not a significant factor, but should be considered for maximum operating temperature. The close proximity of components on the small PCB means magnetic coupling is possible with the EMI filter magnetics which could introduce unwanted noise in the ac input. These magnetic components should be spaced as far as possible to avoid possible coupling. A magnetically shielded boost inductor like the part shown in the BOM can improve EMI performance.

Q1 modulates the FB control pin of the NCP1075 providing high power factor control. Q1 performs as a voltage follower based on the shape of the rectified ac input pulling the FB pin low at the ac zero crossings and consequently reducing the peak switching current.

Maximum current for the NCP1075 occurs when the FB pin is about 3.2 volts. The resistor divider formed by R4 and R5 sets the voltage at the base of Q1, and the emitter tied to FB pin is one diode drop higher. R4 is selected to provide a balance between low impedance to drive Q1 and minimal dissipation. 540k meets these criteria by dissipating about 125 mW. Note that two 1206 devices connected in series are required due to voltage and power stress on this resistor. R5 was empirically selected as 5.6k to optimize THD and PF at nominal 230 Vac input. A 10 nF capacitor provides some noise filtering at this node.

The LED current has been set at 30 mA, so with a typical LED voltage of 393 V, this equates to a nominal output power of 11.7 W.

Selecting the current sense resistor, R7, is as simple as dividing the reference voltage by the output current:

$$R7 = V_{ref} / I_{out}$$

$$= 0.0625 / 0.030$$

$$= \sim 2\ \Omega$$

A 6.8 µF 500 volt output filter capacitor was selected to maintain small component size and good filtering. Derating maximum voltage stress to 440 volts prolongs the useful life of the capacitor. Selecting a capacitor rated 105 ºC with long operating life also enhances reliability.

A resistor divider is used to monitor the output voltage, and in order to minimize dissipation and voltage stress, the upper resistor is realized with two 1206 devices in series. R9 and R9A are selected as 1.74 MΩ each for a total of 3.48 MΩ. Given the voltage control loop has a reference of 1.250 volts, this means the lower divider resistor, R10, follows the equation:

$$R10 = (V_{ref} \cdot R9) / (V_{out} - V_{ref})$$

$$= (1.250 \cdot 3.48\ M\Omega) / (440 - 1.250)$$

$$= 9.91\ k\Omega, \text{ or use } 10\ k\Omega$$

Noise filtering is provided by placing a 10 nF capacitor across R10.

A capacitor is required after the input diode bridge, providing low impedance at high frequency for the inductor charging current. Ideally, this capacitor will have minimal change in voltage as the inductor charges minimizing ripple which the EMI filter must attenuate. However, this capacitor must follow the rectified ac mains in order to provide high power factor. At this power level, 100 nF is a good balance between these factors.

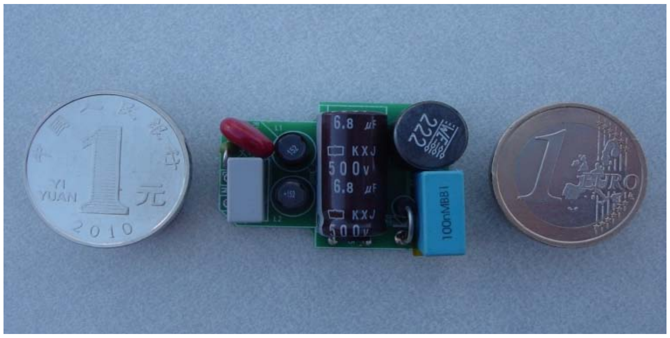
The design is complimented with an input filter comprised of two off-the-shelf compact drum inductors, an X-capacitor, transient voltage suppressor and a fuse. The X-capacitor and inductors should provide attenuation without excessive dissipation or reactive current which would degrade power factor. Two 1.5 mH inductors and a 47 nF capacitor were tested and found to meet conducted emission requirements.

A miniature axial fuse keeps the design compact and the 1 amp rating helps in passing input ac line surge current to the MOV transient suppressor without opening.

A complete schematic is shown in Figure 3 and the bill of materials is shown in Figure 8.

A prototype unit was built targeting a small board outline designed to be compatible with popular lamp base enclosures. The narrow portion holding the EMI filter easily fits inside a GU10 bayonet or E27 screw base to utilize all available volume. The wider portion accommodates the high voltage output capacitor and boost inductor.

Figure 2 shows a photo of the PCB which measures 0.95 inches by 1.365 inches (24mm by 35mm).



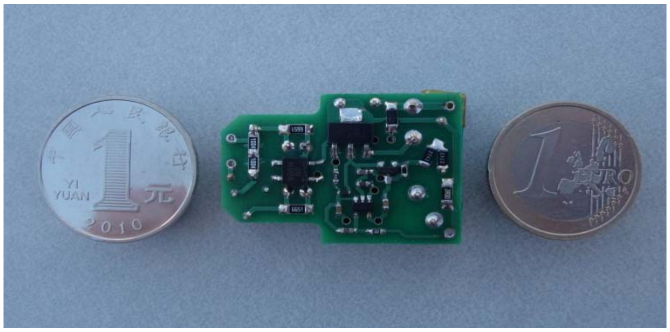


Figure 2: Demonstration Board

Performance is highlighted in Figures 4 and 5 showing current regulation, efficiency, Power Factor, and THD.

Input current harmonic limits for lighting are specified in IEC 61000-3-2 Class C and this design meets the more stringent requirements for applications over 25 W. Typical data is provided in the graph shown in Figure 6.

The conducted EMI profile meets the CISPR22 Class B limits with at least 6 dB margin. The signature is shown in Figure 7.

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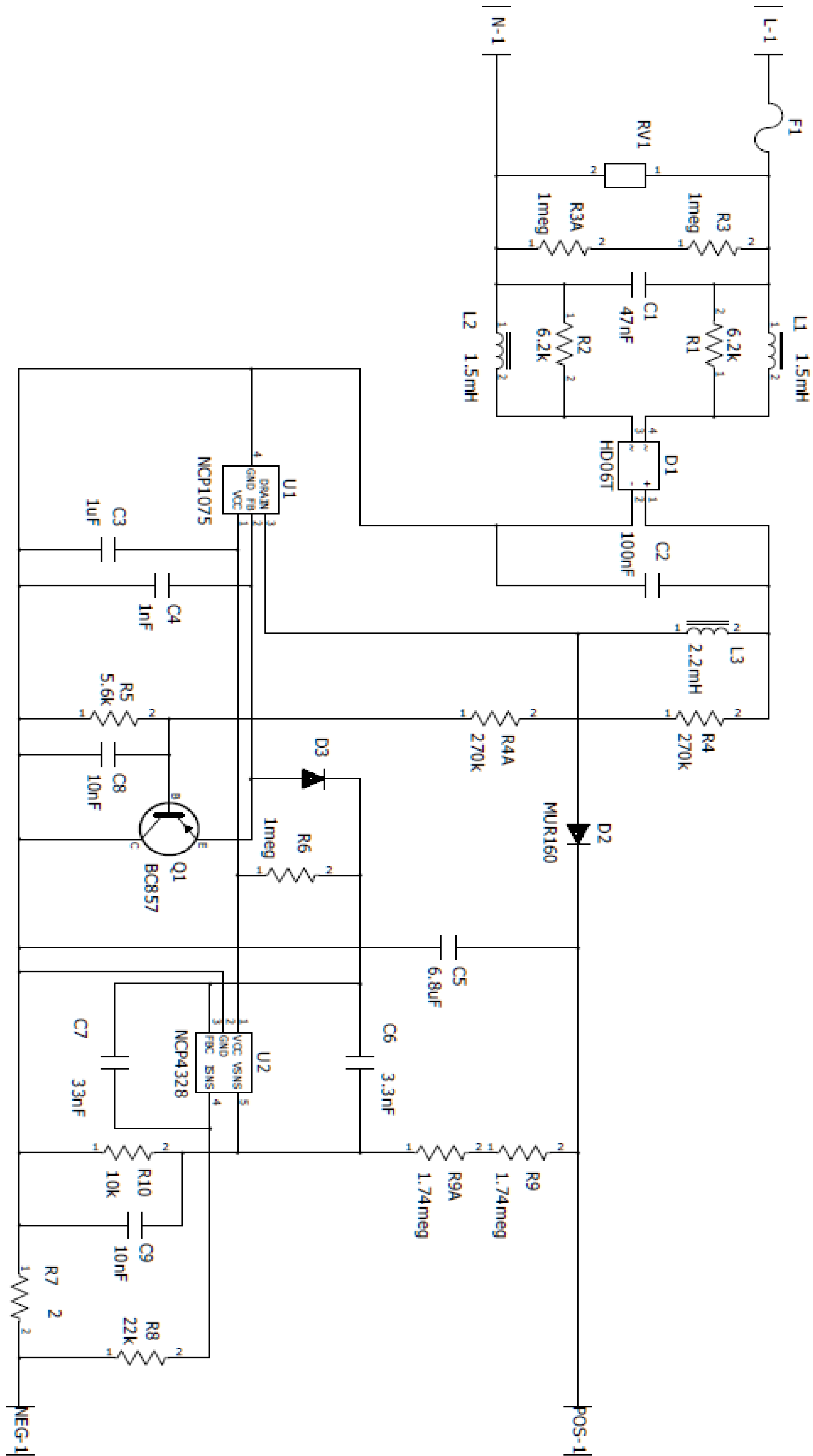

Figure 3: Schematic

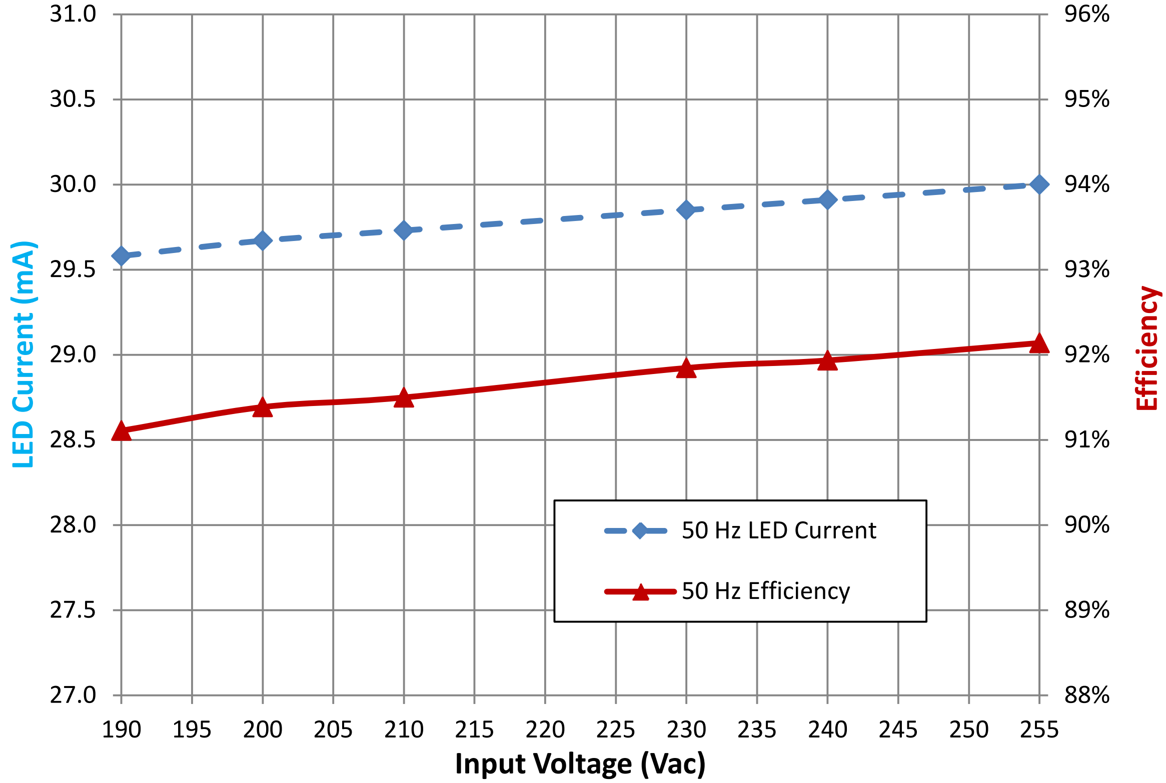

Figure 4: Current Regulation and Efficiency

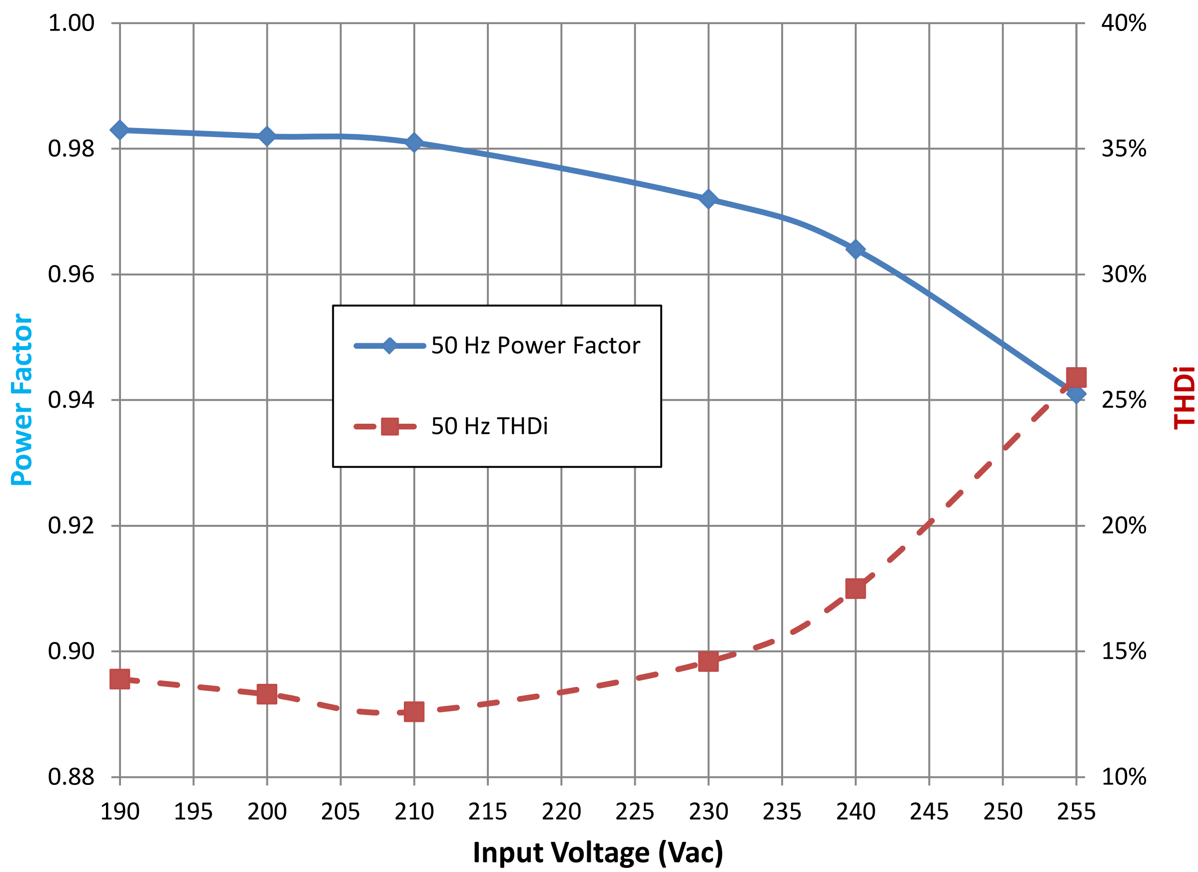

Figure 5: Power Factor and THD

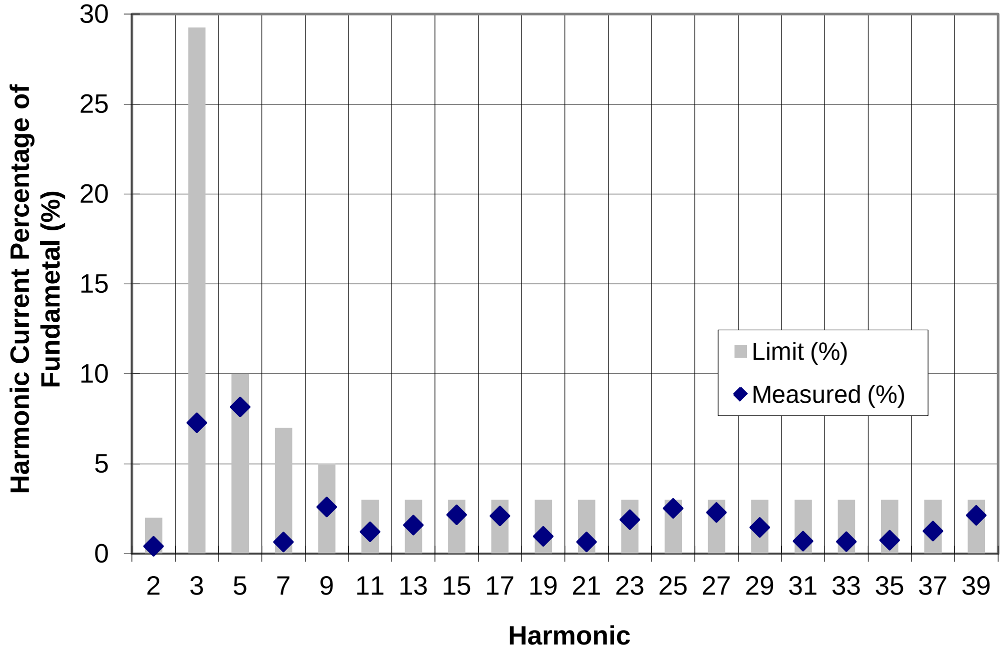

Figure 6: Class C Harmonics at 230 V ac, 50 Hz

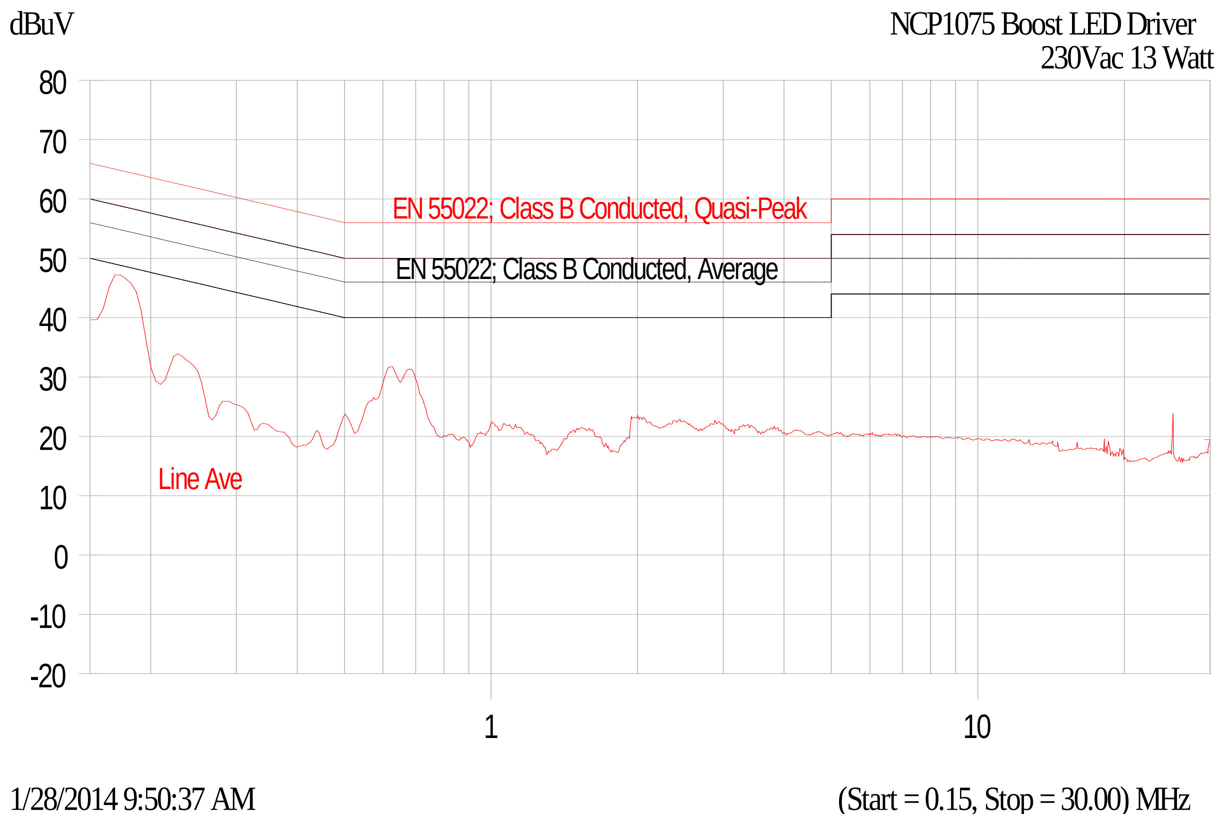

Figure 7: EMI Signature

Ref	Qty	Type	Value	Description	Tol (+/-)	Footprint	Manufacturer	Part Number
C1	1	Capacitor	47nF	310 Vac Metallized Polyester	20%	Box	Vishay	BFC233820473
C2	1	Capacitor	100nF	310 Vac Metallized Polyester	20%	Box	Vishay	BFC233820104
C3	1	Capacitor	1uF	16V Ceramic X7R	10%	0603 SMD	TDK	C1608X7R1C105K080AC
C4	1	Capacitor	1nF	50V Ceramic NPO	10%	0603 SMD	TDK	C1608C0G1H102K080AA
C5	1	Capacitor	6.8uF	500V Electrolytic, 8000Hrs	10%	Radial	UCC	EKXJ501ELL6R8MJ20S
C6	1	Capacitor	3.3nF	50V Ceramic X7R	10%	0603 SMD	TDK	CGA3E2X7R1H332K080AA
C7	1	Capacitor	33nF	50V Ceramic X7R	10%	0603 SMD	TDK	C1608X7R1H333K080AA
C8 C9	2	Capacitor	10nF	50V Ceramic X7R	10%	0603 SMD	TDK	C1608X7R1H103K080AA
D1	1	Diode	HD06-T	Rectifier bridge,600V,0.8A	-	SMD	Diodes Inc.	HD06-T
D2	1	Diode	MUR160	600V,1A	-	SMA	ON Semiconductor	MUR160RLG
D3	1	Diode	BAS16	100V,200mA	-	SOD-523	ON Semiconductor	BAS16XV2T1G
F1	1	Fuse	1A	PICO, FAST, 250Vac	-	Axial	Littelfuse	0263001.WRT1L
L1 L2	2	Inductor	1.5mH	Drum Inductor, 0.19A	10%	Radial	Wurth	7447462152
L3	1	Inductor	2.2mH	Shielded Inductor, 0.32A	10%	Radial	Wurth	7447471222
Q1	1	Transistor	PNP	65V, 100mA	-	SOT-23	ON Semiconductor	BC857BLT1G
R1 R2	2	Resistor	6k2	1/4W	5%	1206 SMD	Panasonic	ERJ-8GEYJ622V
R3 R3A	2	Resistor	1 Meg	1/4W	5%	1206 SMD	Panasonic	ERJ-8GEYJ105V
R4 R4A	2	Resistor	270k	1/4W	1%	1206 SMD	Panasonic	ERJ-8ENF2703V
R5	1	Resistor	5k6	1/10W	1%	0603 SMD	Panasonic	ERJ-3EKF5601V
R6	1	Resistor	1 Meg	1/10W	1%	0603 SMD	Panasonic	ERJ-3EKF1004V
R7	1	Resistor	2	1/4W	1%	1206 SMD	Vishay	CRCW12062R00FKEA
R8	1	Resistor	22k	1/10W	1%	0603 SMD	Panasonic	ERJ-3EKF2202V
R9 R9A	1	Resistor	1.74 Meg	1/4W	1%	1206 SMD	Vishay	CRCW12061M74FKEA
R10	1	Resistor	10k	1/10W	1%	0603 SMD	Panasonic	ERJ-3EKF1002V
RV1	1	MOV	495V	275Vac, 11J varistor	-	Disc	Littelfuse	V430ZA05P
U1	1	Controller	NCP1075	Switcher, 65kHz	-	SOT-223	ON Semiconductor	NCP1075STAT3G
U2	1	Controller	NCP4328	Sec Side CV/CC controller	-	TSOP5	ON Semiconductor	NCP4328ASNT1G

Figure 8: Bill of Materials

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