

Compact 90-135 Vac Hi-PF Boost LED Driver



ON Semiconductor®

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DESIGN NOTE

Table 1. DEVICE DETAILS

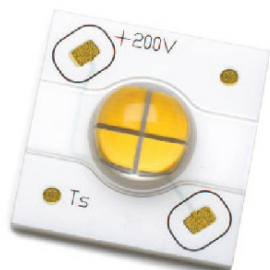
Device	Application	Input Voltage	Output Power	Topology	I/O Isolation
NCP1075 + NCP4328A	LED Driver	90 – 135 Vac	Up to 9 W	Boost	Non-isolated

Table 2. OTHER SPECIFICATIONS

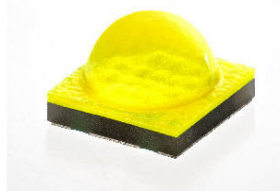
Constant Current Output	30 mA
Nominal Voltage	220 Vdc
Maximum Voltage	250 Vdc
Minimum Voltage	200 Vdc
Typical Power Factor	0.98
Typical THDi	11%
Typical Efficiency	90%
Startup Time	< 20 msec

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.



Philips Luxeon H



CREE XT-E

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 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 $135 \text{ Vac} \times \sqrt{2} = 191 \text{ Vdc}$ as the 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 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: 90–135 Vac
- Output Current: 30 mA Typical
- Output Voltage: 220 Vdc Typical
- Efficiency: > 88%
- Power Factor: > 0.95
- Open Load Protection

This design is based on the ON Semiconductor NCP1075 switching regulator which integrates a 700 V 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 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 line. 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 μ A. At this low level, the Dynamic Self-Supply of the NCP1075 is able to provide bias power to the controller as well. 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 9 W. The inductor determines the peak current as a function of applied voltage and on-time. In this case, 2.2 mH 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 may 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.

Maximum current for the NCP1075 occurs when the FB pin is about 3.2 V. 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. 280k meets these criteria by dissipating less than 100 mW. Note that a 1206 package is required due to voltage and power stress on this resistor. R5 is selected as 3.9 k Ω to satisfy the 3.2 V level with 135 Vac applied to the converter input.

This nominal 6.5 watt solution will support a range of LED voltages provided the current is adjusted to maintain the target power level. A nominal LED string voltage of 218 volts is used; therefore the output current is 30 mA nominal.

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

$$\begin{aligned} R7 &= V_{ref} / I_{out} \\ &= 0.0625 / 0.030 \\ &= 2.08 \Omega, \text{ or use } 2 \Omega \end{aligned}$$

A 10 μ F 315 volt output filter capacitor was selected to maintain small component size and good filtering. Derating maximum voltage stress to 80% prolongs the useful life of the capacitor, netting 252 volts maximum. Selecting a capacitor rated 105°C with long operating life also enhances reliability.

A resistor divider is used to monitor the output voltage, and in order to minimize dissipation, the upper resistor, R9, is selected at 2 M Ω . Given the voltage control loop has a reference of 1.250 volts, this means the lower divider resistor, R10, follows the equation:

$$\begin{aligned} R10 &= (V_{ref} \times R9) / (V_{out} - V_{ref}) \\ &= (1.250 \times 2 \text{ M}\Omega) / (252 - 1.250) \\ &= 9.97 \text{ k}\Omega, \text{ or use } 10 \text{ k}\Omega \end{aligned}$$

A capacitor is required after the diode bridge, providing a 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 line voltage 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 emission requirements.

A miniature axial fuse keeps the design compact and the 1 A rating helps in passing the surge current to the MOV transient suppressor without opening. The schematic is shown in Figure 3.

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 the 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 (24 mm by 35 mm).

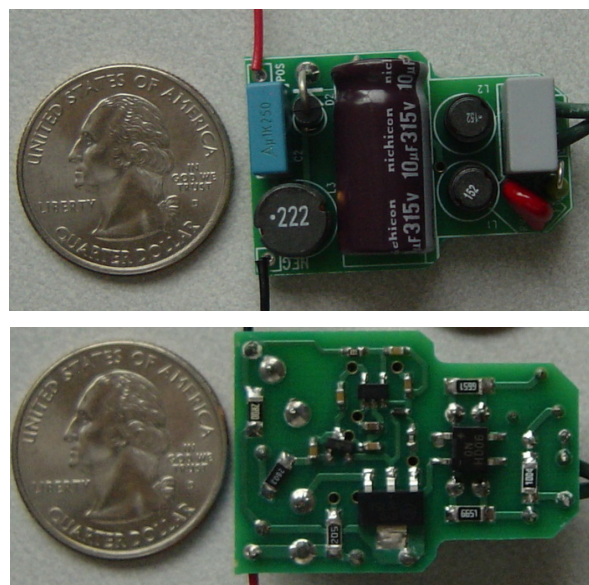


Figure 2. Demonstration Board

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

The conducted EMI profile meets the CISPR22 Class B limits. The signature is shown in Figure 6 and a Bill of Materials is shown in Table 3.

This example supports a 90–135 Vac input range but this design can be further optimized for the 100 Vac mains voltage found in Japan if need be and will meet the harmonic content requirements of JIS61000-3-2 Class C.

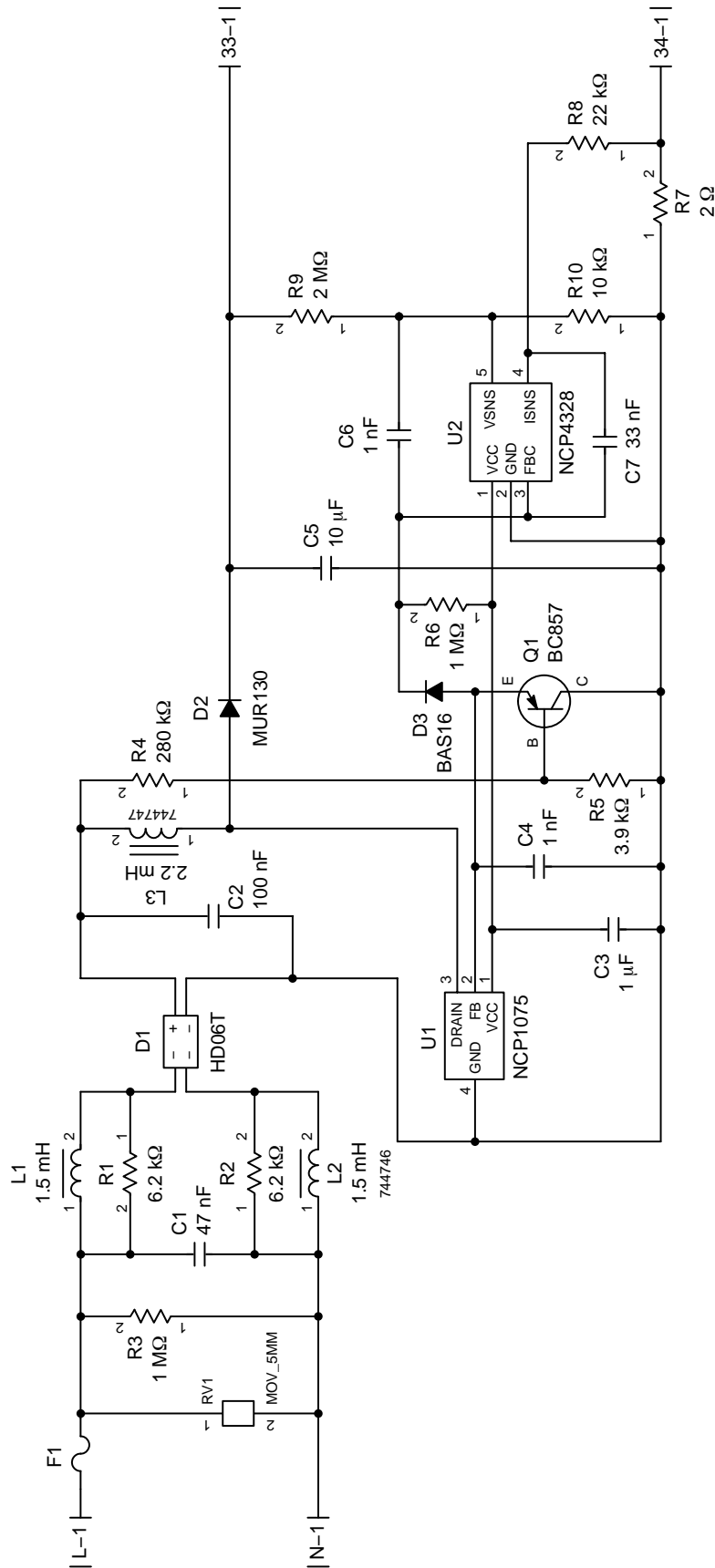


Figure 3. Schematic

DN05055/D

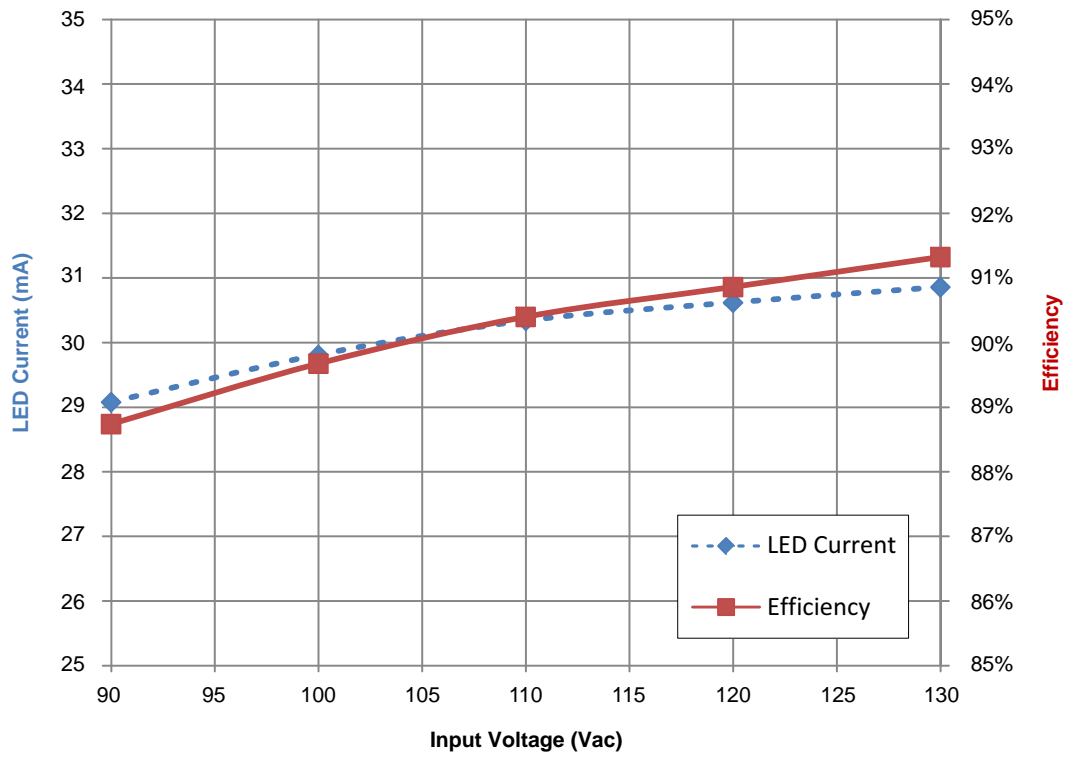


Figure 4. Current Regulation and Efficiency

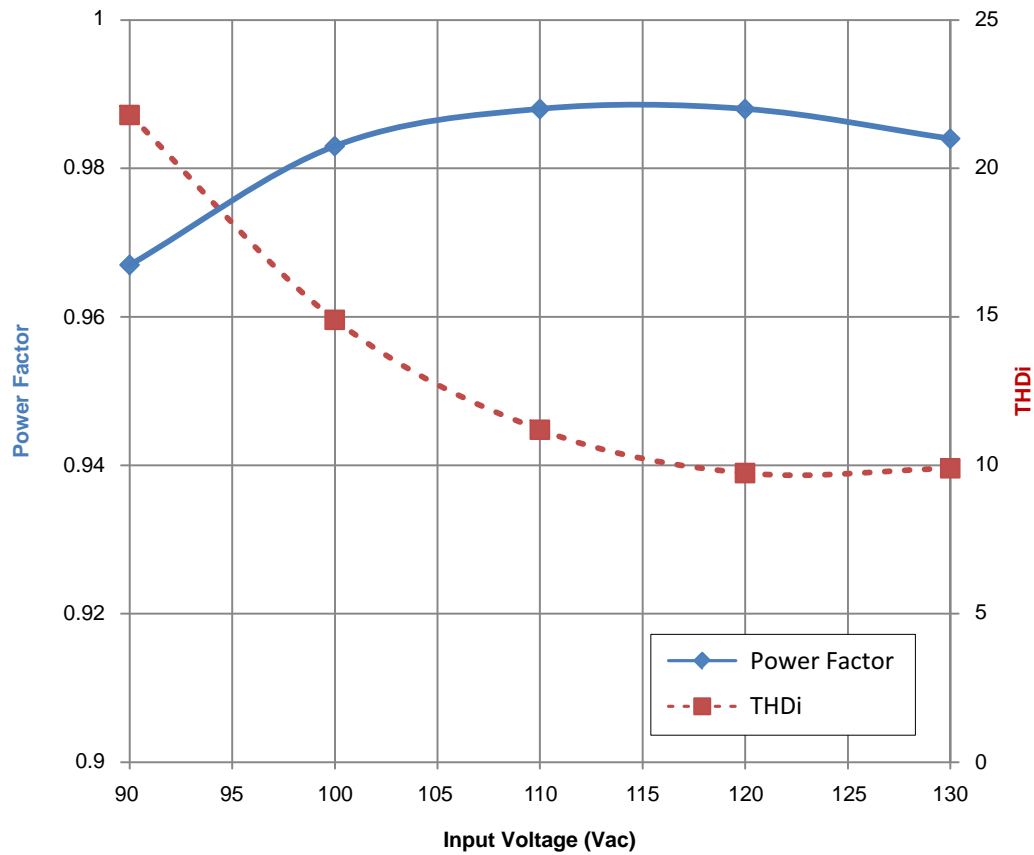


Figure 5. Power Factor and THD

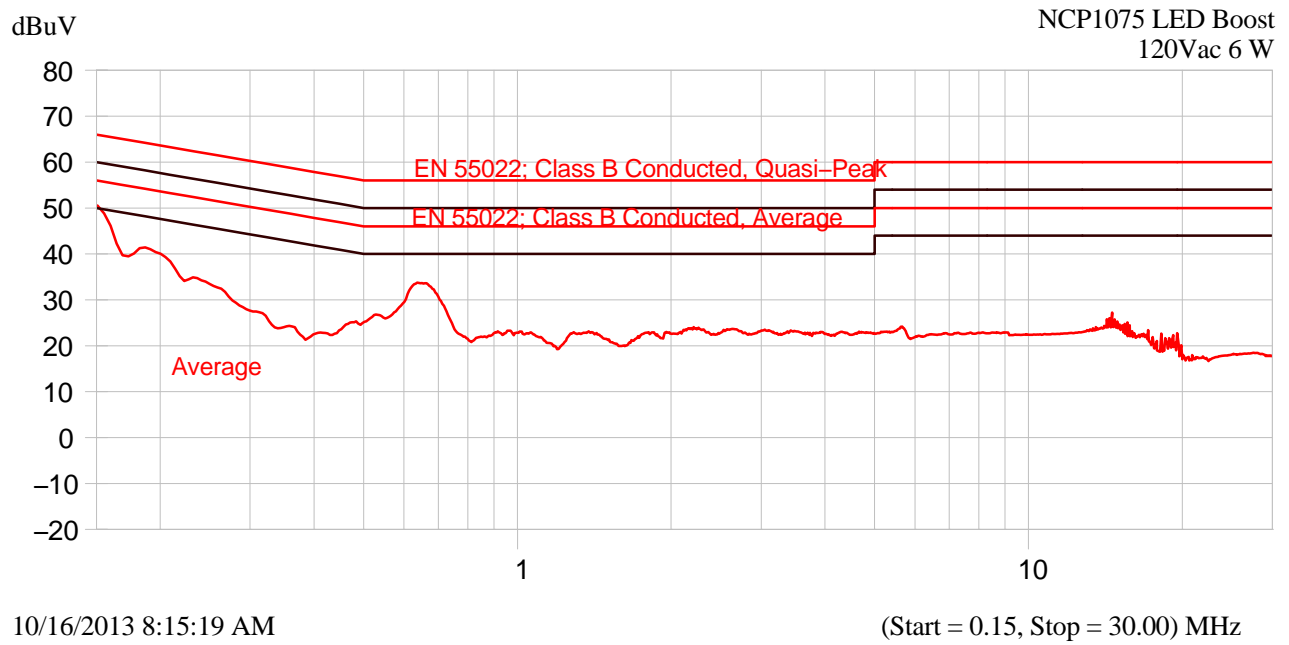



Figure 6. EMI Signature

Table 3. BILL OF MATERIALS

Ref	Qty	Type	Value	Description	Tolerance	Footprint	Manufacturer	Part Number
C1	1	Capacitor	47 nF	310 Vac Metallized Polyester	±5%	Box	Vishay	BFC233820473
C2	1	Capacitor	100 nF	250 Vdc Metallized Polyester	±10%	Box	Epcos	B32520C3104K
C3	1	Capacitor	1 µF	16 V Ceramic X7R	±10%	0603 SMD	TKD	C1608X7R1C105K080AC
C4, C6	2	Capacitor	1 nF	50 V Ceramic NPO	±10%	0603 SMD	TKD	C1608C0G1H102K080AA
C5	1	Capacitor	10 µF	315 V Electrolytic, 5000Hrs	±10%	Radial	Nichicon	UPW2F100MPD
C7	1	Capacitor	33 nF	50 V Ceramic X7R	±10%	0603 SMD	TKD	C1608X7R1H333K080AA
D1	1	Diode	HD06-T	Rectifier bridge, 600 V, 0.8 A	–	SMD	Diodes Inc.	HD06-T
D2	1	Diode	MUR130	300 V, 1 A	–	SMA	ON Semiconductor	MUR130RLG
D3	1	Diode	BAS16	100 V, 200 mA	–	SOD-523	ON Semiconductor	BAS16XV2T1G
F1	1	Fuse	1 A	PICO, FAST, 125 Vac	–	Axial	Littelfuse	0251001.MXL
L1, L2	2	Inductor	1.5 mH	Drum Inductor, 0.19 A	±10%	Radial	Würth	7447462152
L3	1	Inductor	2.2 mH	Drum Inductor, 0.32 A	10%	Radial	Würth	7447471222
Q1	1	Transistor	PNP	65 V, 100 mA	–	SOT-23	ON Semiconductor	BC857BLT1G
R1, R2	2	Resistor	6.2 kΩ	1/4 W	5%	1206 SMD	Panasonic	ERJ-8GEYJ622V
R3	1	Resistor	1 MΩ	1/4 W	5%	1206 SMD	Panasonic	ERJ-8GEYJ105V
R4	1	Resistor	280 kΩ	1/4 W	1%	1206 SMD	Panasonic	ERJ-8ENF2803V
R5	1	Resistor	3.9 kΩ	1/10 W	1%	0603 SMD	Panasonic	ERJ-3EKF3901V
R6	1	Resistor	1 MΩ	1/10 W	1%	0603 SMD	Panasonic	ERJ-3EKF1004V
R7	1	Resistor	2 Ω	1/4 W	1%	1206 SMD	Vishay	CRCW12062R00FKEA
R8	1	Resistor	22 kΩ	1/10 W	1%	0603 SMD	Panasonic	ERJ-3EKF2202V
R9	1	Resistor	2 MΩ	1/4 W	1%	1206 SMD	Panasonic	ERJ-8ENF2004V
R10	1	Resistor	10 kΩ	1/10 W	1%	0603 SMD	Panasonic	ERJ-3EKF1002V
RV1	1	MOV	264 V	150 Vac, 7.0J Varistor	–	Disc	Littelfuse	V240ZA05P
U1	1	Controller	NCP1075	Switcher, 65 kHz	–	SOT-223	ON Semiconductor	NCP1075STAT3G
U2	1	Controller	NCP4328	Sec Side CV/CC Controller	–	TSOP6	ON Semiconductor	NCP4328ASNT1G

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