AND8463/D

11 Watt TRIAC Dimmable PAR30 LED Lamp Driver

Prepared by: Jim Young
ON Semiconductor

ON Semiconductor®

http://onsemi.com

APPLICATION NOTE

Parabolic Aluminized Reflector (PAR) lamps are one of the most popular bulb types for downlighting, retail, and spot light applications. They range in size from PAR16 to PAR64. The number indicates the diameter in 1/8" units so a PAR30 lamp would have a diameter of 3.75" (9 cm). Other variants of these directional lamps include R and BR styles. Given that the light pattern of these types of bulbs is directional in nature, they are ideal candidates for LED light sources. In addition, since PAR lamps are offered in various beam widths, changing secondary optics on the LEDs can result in a range of product types from spot to flood.

The US ENERGY STAR™ program has just completed their standard for Integral LED bulbs which will go into effect August 31, 2010. These specifications are comprehensive and include items such as minimum light output requirements, efficacy, acceptable correlated color temperatures, dimming considerations, and warrantee as well as electrical requirements for integrated driver within the bulb. One of the key requirements which applies to all bulbs that draw more than 5 watts of power is that the power factor be ≥0.70 and the driver must meet specific FCC EMI requirements.

While not mandated, dimming is a key end market requirement for many uses - and is one of the reasons that CFL bulbs have not had broader acceptance in this bulb style where halogen and traditional incandescent are the norm. The standard requires that for those bulbs that are line dimmable via a wall dimmer, either leading edge (TRIAC) or trailing edge (transistor based), that the vendor clearly label whether the bulb is dimmable or not and provide a list of compliant dimmers that work with the LED bulb. One other consideration, since LEDs require a heatsink to remove the heat from the LED, the driver should normally be galvanically isolated.

Figure 1. PAR30 LED and Incandescent Lamps

July, 2010 − Rev. 1

Publication Order Number:
AND8463/D

This Application Note details how the NCL30000 single stage power factor corrected isolated flyback controller can be used to implement a complete power conversion solution. This design shown in Figure 1 above is adapted from the ON Semiconductor NCL30000 LED driver demonstration board with a range of changes to optimize the design for a well defined LED load. A commercially available LED heatsink assembly and E27 Edison base housing were used. CREE's MPL-EZW LED module was selected as the light engine. The LED module electrical connections and mechanical securement are made with the Tyco Electronics TE solderless LED socket 2106946-2. This connector provides a clean and efficient interface to the LED. This multi-LED module has 24 LEDs arranged in 3 strings of 8. The LEDs are configured in a series-parallel arrangement with a nominal drive current of 450 mA (150 mA per string). Other LEDs can be used as well but the ultimate limitation to the PAR form factor is the thermal heatsinking of the housing and the expected end application environment.

The size of the PAR30 envelope is well defined and the primary objective in this design is to provide as much power as possible to the LEDs while achieving high energy conversion efficiency.

Initial Design

Space inside the housing is limited and the general solution presented in the NCL30000LED1GEVB demonstration board will be modified towards the specific requirements of an 11 watt TRIAC dimmable LED lamp. Details for a 115 and a 230 V ac input version are presented in this Application Note. Here are the design goals:

- 115 V Lamp Input Voltage: 90 – 135 V ac
  Power Factor: >0.9
  Input current THD: <20%
- 230 V Lamp Input Voltage: 180 - 265 V ac
  IEC 61000−3−2 Class C compliant
- LED power: 11 watts
- LED current: 450 mA
- LED current accuracy: +/- 5%
- LED voltage: 21 – 27 V dc
- Efficiency: >82%
- Compatible with TRIAC and Electronic Low Voltage Dimmers
- Compliance with FCC Class B conducted emissions

The circuit design, component selection, and layout of the reference board were based on general safety guidelines although the design has not been submitted to a safety ratings agency for formal review.

A printed circuit board outline extending from the bottom of the E27 base to the LED mounting plate was chosen. The irregular outline matches the interior space of the selected heatsink and base assembly. Component placement and circuit routing is critical to provide adequate voltage spacing. The PCB and lamp assembly is shown in Figures 2, 3, and 4 below:

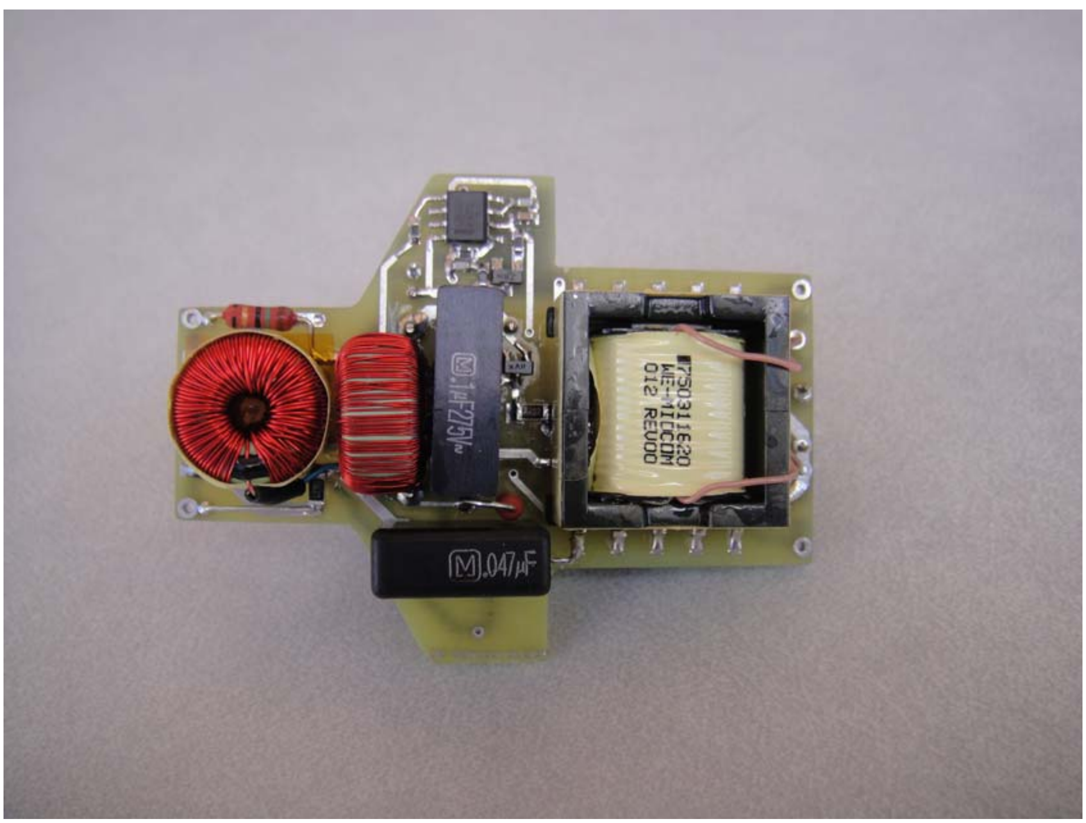

Figure 2.

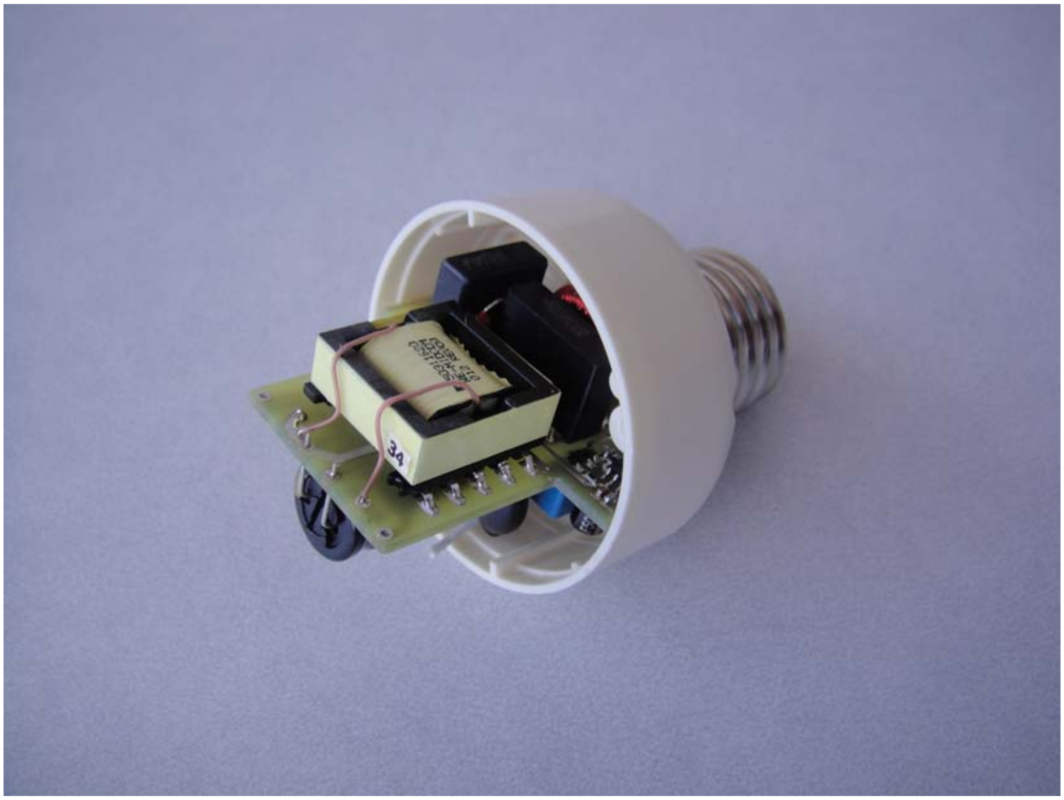

Figure 3.

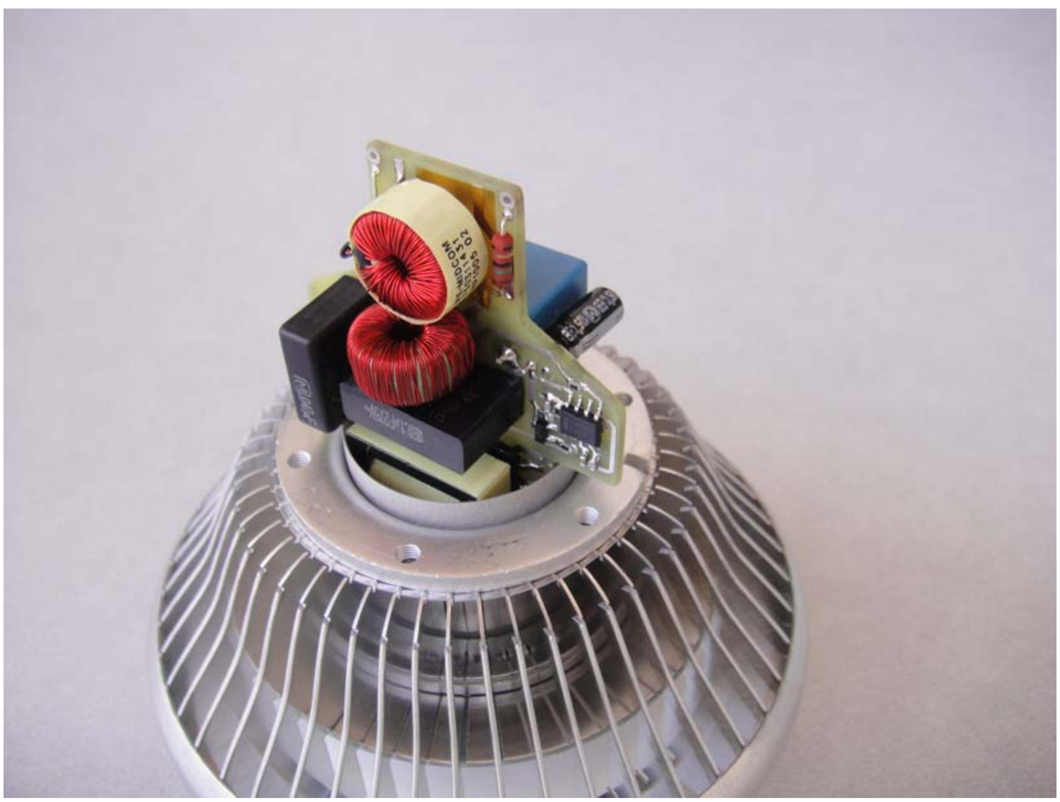

Figure 4.

Detailed Design

Complete design details for the NCL30000 are presented in Application Notes AND8451 and AND8448. The 11 watt power level is close to the 15 watt operation of the demonstration board. As such, a similar EMI filter will be used for this PAR30 design. The MOV surge limiter is relocated across the input line for better circuit board placement and to limit energy dissipated in the input resistors R1 and R10. These input resistors are included for TRIAC compatibility along with R4 and C3. The component values depend on the input voltage range.

Designing for a narrow output voltage range allows some simplifications to the original schematic, in particular, the biasing networks. For dimming, the input waveform will be chopped and the bias capacitor must store energy during the active input periods and deliver bias power to the NCL30000 during periods when the input is not present. The narrow LED operating range allows elimination of electrolytic capacitor C6. C8 is required for energy storage and Q2 is needed to improve efficiency of regulator zener diode D9.

Biasing for optocoupler U2 is provided by D8 and R14 without affecting the low current start up energy provided by R7 and R13. Turn on time is controlled by R7 and R13. Reducing the value of these resistors will speed turn on delay but will adversely affect efficiency. Setting the resistance too high will result in insufficient current for the base of Q2 and will limit bias power at low dimming settings. Selecting R7 and R13 as 47K ohms provides turn on delay of 240 msec for the 115 V lamp and 150K ohms provides 290 msec for the 230 V lamp and performs well when dimming.

An EFD20 transformer core is used which fits the limited volume inside the housing. The NCL30000 Design Spreadsheet is used to establish transformer parameters. The process begins with entering the input voltage range and LED output parameters. A 500 V FET is sufficient for 115 V applications whereas the 230 V application requires an 800 V FET. Likewise, a 100 V Schottky rectifier is appropriate for 115 V applications and a 200 V device was chosen for 230 V lamps.

A turns ratio of 5.3 to 1 will function well with both input ranges. The minimum operating frequency will change depending on the input voltage. Frequency is sufficiently low for the EMI filter to accommodate either range. Safety isolation requires triple insulated wire where 21 turns of #26 wire fills one layer. Splitting the primary in two equal series-connected segments with the secondary positioned in between will provide low leakage inductance. In this case, 56 turns per primary section are used.

The bias winding must provide sufficient power to maintain operation when connected to a phase cut dimmer. Empirical testing shows 17 to 20 volts minimum works well. A bias winding of 16 turns ensures adequate voltage. The transformer primary inductance is 1.9 mH.

Secondary bias can be simplified due to the lower LED forward voltage. In this case, the regulator transistor can be eliminated utilizing resistor R21 and zener D11 to establish bias voltage. Further reduction in parts is possible in this dimming application compared to a non-dimming application. Since the load is well defined and the line voltage is restricted, the maximum on-time capacitor limits the peak power delivered such that the 'fast' current control loop utilized on the NCL30000LED evaluation board can be eliminated.

The NCS1002 dual op-amp plus reference replaces the dual op amp and separate reference. The op-amp connected directly to the reference provides open load protection and the second op-amp is the LED current regulator. The 0.2 ohm sense resistor keeps sensing losses to a minimum.

The schematic for the 115 V driver is shown in Figure 5 below. A complete bill of material is shown in Appendix A at the end of this Application Note.

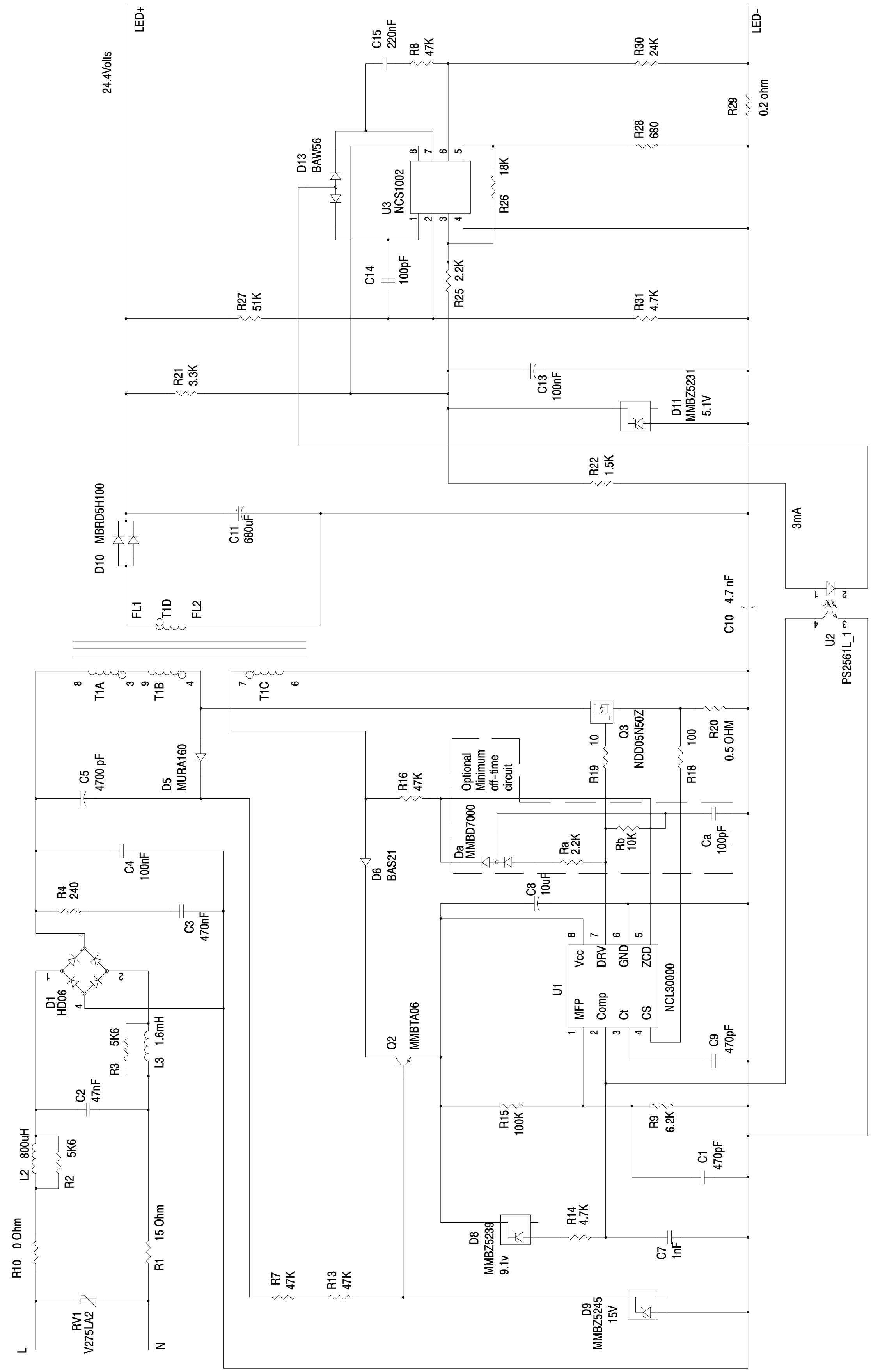

Figure 5. 115V Lamp Schematic

Performance Results

Data shown below in Table 1 was collected from each version of PAR30 lamp. The damper network comprised of R4 and C3 improves performance when a TRIAC dimmer is used. This network dissipates energy and introduces some phase displacement on input current. If dimming is not required, the damper network can be eliminated. Performance for each configuration is shown below:

Table 1. Performance of PAR30 Lamps

Lamp Version	RC Damper Present	Input Power (W)	PF	%THD	Output Current (mA)	Output Volts (Vdc)	Output Power (W)	Efficiency (%)
115	Yes	12.91	0.98	10.2	452	23.61	10.67	82.7
	No	12.72	0.99	6.5	452	23.60	10.67	83.9
230	Yes	13.00	0.87	23.4	453	23.60	10.69	82.2
	No	12.59	0.97	11.2	453	23.44	10.62	84.4

As with any high power factor single stage converter output ripple is filtered by the secondary side capacitor. LEDs display a constant voltage characteristic and current ripple is sensitive to the driver's output ripple voltage where higher capacitance minimizes ripple. Space is limited in this application and a 680 μF capacitor was selected as the output filter. Ripple current is shown in Figures 6 and 7 below. Scale factor is 167 mA/division:

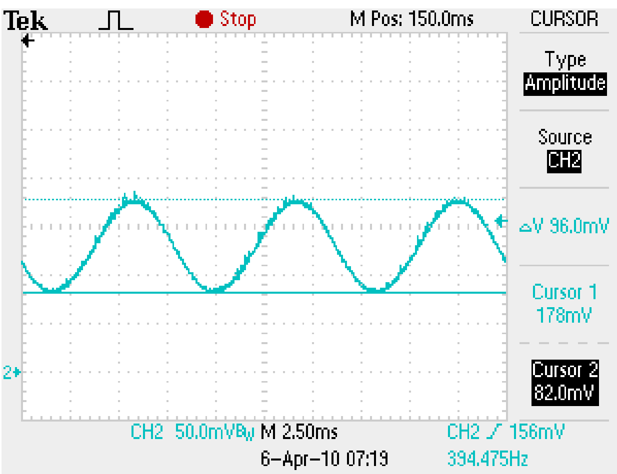

Figure 6. 320 mA pk-pk ripple current for 115V Lamp

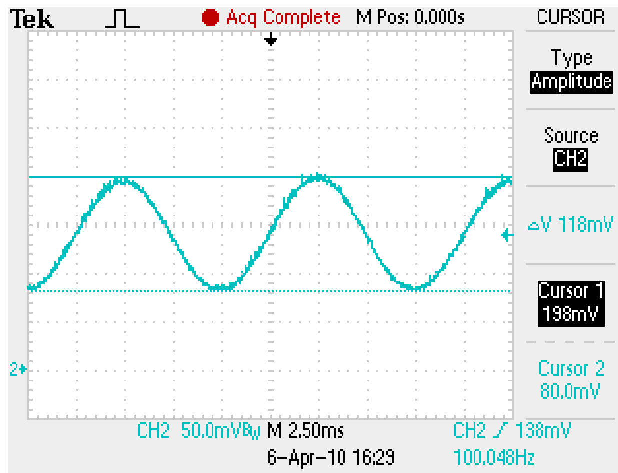

Figure 7. 393 mA pk-pk ripple current for 230V Lamp

The peak of the ripple current is maintained below the maximum operating current of the LEDs selected.

Thermocouples were affixed to critical components and the driver was enclosed in the lamp housing with the heatsink attached in its expected configuration. LED temperature was monitored on the aluminum base plate adjacent to the LED module. The lamp was operated until thermal equilibrium was achieved. Results are shown in Table 2 below:

Table 2. Thermal Test Results

Ambient	LEDs	Q3 FET	D10 Output Rectifier	Transformer	C11 output capacitor
17.8°C	56.9°C	75.2°C	82.0°C	72.4°C	57.8°C
Temp Rise	39.1°C	57.4°C	64.2°C	54.6°C	40.0°C

In a production integral LED lamp it is common to have the power supply assembly encapsulated in a potting compound. Potting will improve thermal transfer and reduces hot spot temperatures.

IEC61000-3-2 Current Harmonics

The design passes Class C current harmonic requirements for both 115 V and 230 V versions. Test results are shown below in Table 3. Note these lamps also pass the more stringent requirements for inputs equal to or greater than 25 watts.

Table 3. Class C Current Harmonics

Lamp version	3rd Harmonic (Limit 86%)	5th Harmonic (Limit 61%)
115	5.94%	3.36%
230	16.6%	10.96%

Dimming Performance

The PAR30 LED lamp performs well with a variety of commercially available TRIAC and electronic phase cut dimmers. Dimming is continuous and predictable with many dimmers providing control down to zero light output. Table 4 below shows 115 V and Table 5 shows 230 V PAR30 lamp performance with various dimmers.

Table 4. 115 V Version Lamp Dimmer Performance

Manufacturer	Dimmer Model	Min Conduction Angle (degrees)	Current at Min Conduction Angle (mA)
Cooper	Aspire 9530AA	9.9	1
Ding Chung	DC-310	9.1	5
GE	Rotary DI 61	<10.4	<1
Kuei Lin	AC 110V 500W	<9.1	<1
Leviton	CFL Slide 6673-P	33.9	57
Leviton	Electronic 6615-POW	56.6	116
Leviton	Illumatech IPI06	16	11
Leviton	Rotary OC58L1	<11	<2
Leviton	Sureslide 6633-PLW	<11	<1
Lutron	Digital Fade MAW-600H	13.6	17
Lutron	Skylark S-600	<9.9	<1
Lutron	Toggler TG-600PH	25.5	22
Pass & Seymour	D703PLAV	8.6	<1
Pass & Seymour	LS603PLAV	8.2	<1
Pass & Seymour	LSLV603PWV	<6.7	<1
SCT	YM-2508A	<8	<1

Table 5. 230 V Version Lamp Dimmer Performance

Manufacturer	Dimmer Model	Min Conduction Angle (degrees)	Current at Min Conduction Angle (mA)
Alombard	741021	10	<1
Clipsal	KB31RD400	12.6	<1
Clipsal	32V500	14	<1
Legrande	999.58	50	110
Lutron	LLSM-502	9	3
MK	SX8501	18.4	11
SCT	Y-25082A	15	6

Conducted EMI

An input filter is necessary to meet Class B conducted EMI limits. The filter was carefully designed for compatibility with TRIAC dimmers since excessive current peaks when the TRIAC turns on will create oscillations in the filter. If this occurs, the resultant damped sinusoid input current can fall below the minimum TRIAC holding current forcing the TRIAC off prematurely. Depending on the TRIAC dimmer position and the line voltage the TRIAC could re-fire resulting in visible flicker and added component stress.

Minimizing 'across the line' or X-capacitance will reduce current peaks when the TRIAC turns on. Oscillations in the input filter will be reduced and TRIAC operation is more predictable. Adding resistance in series with the input (R1 and R10) and an R-C damper (R4 and C3) reduce the oscillations as well.

Figures 8 and 9 show the conducted EMI profiles for the 115 V and 230 V PAR30 lamps respectively.

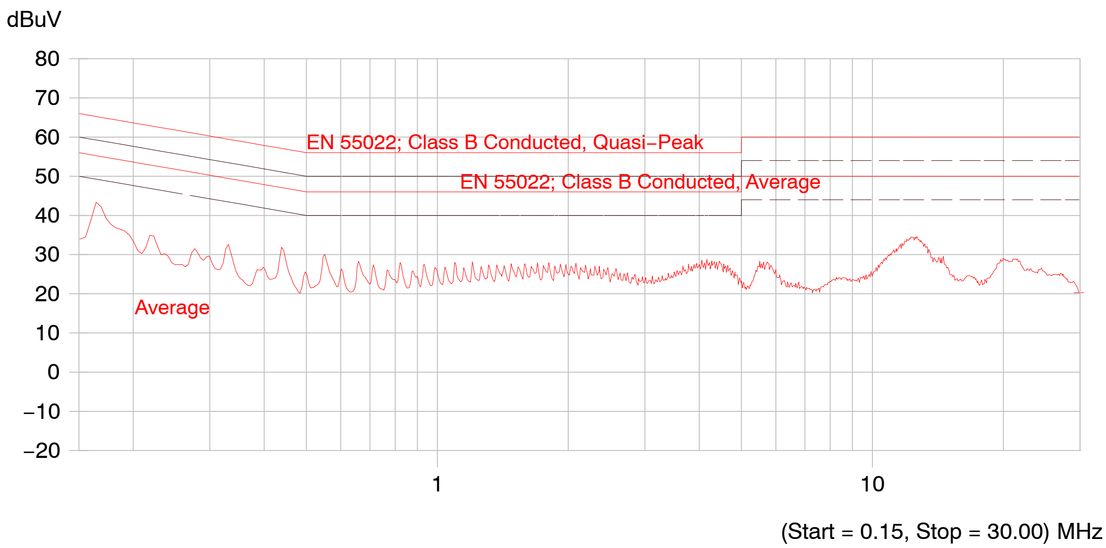

Figure 8. EMI Profile for 115 V Lamp

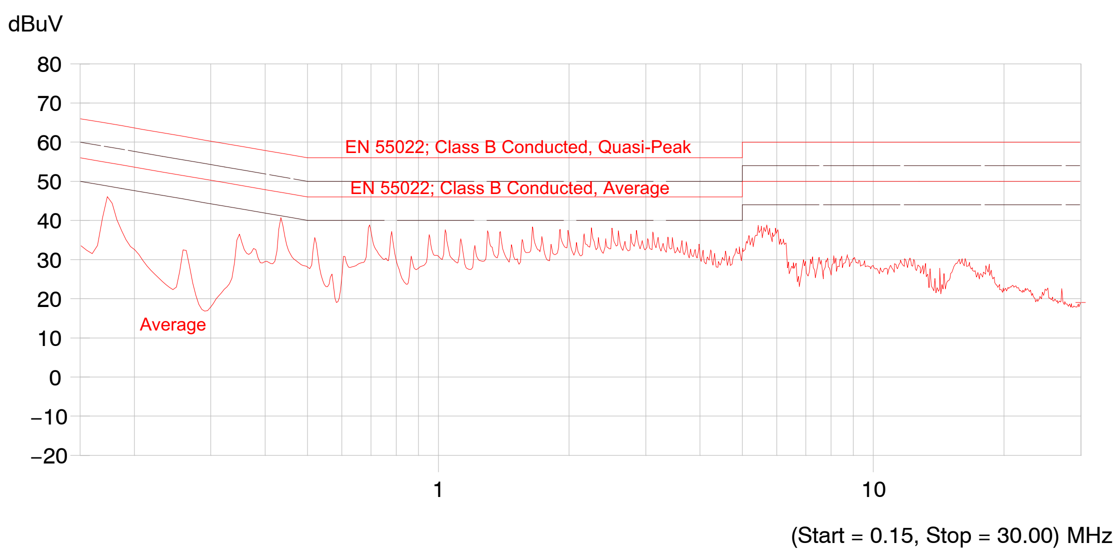

Figure 9. EMI Profile for 230 V Lamp

Conclusion

A practical PAR30 LED lamp design based on the NCL30000 LED controller is presented which meets the design objectives. This circuit can be tailored to match drive requirements for many different LED engines. The high efficiency allows the thermally limited PAR30 envelope to deliver more power to the LEDs and consume less power in the driver. The basic design can be scaled up for higher power to support PAR38 lamps.

APPENDIX A: Bill Of Materials

Bill of Materials for the NCL300000 PAR30 Driver					
Note: Parts specific to one version of Lamp are indicated as (115V) or (230V).					
Designator	**Value**	**Description**	**Footprint**	**Manufacturer**	**Manufacturer Part Number**
C1	470pF	50V Ceramic COG, NPO	0603 SMD	Panasonic	ECJ-1VC1H471J
C2	47nF	300 VAC Film X1 (LS = 12.5 mm)	Box	Panasonic	ECQ-U3A473MG
C3 (115V)	470nF	450 V Metal Polyester Film (LS = 15mm)	Box	EPCOS	B32522N6474J
C3 (230V)	330nF	250 VAC Metallized Polyester Film (LS=15 mm)	Box	Panasonic	ECQ-U2A334ML
C4	100nF	250 VAC X1 Metal Polyester Film (LS = 15 mm)	Box	Panasonic	ECQ-U2A104ML
C5	4700 pF	500V Ceramic X7R	1206 SMD	Vishay	VJ1206Y472KXEAT5Z
C7	1nF	50V Ceramic X7R	0603 SMD	Panasonic	ECJ-1VB1H102K
C8	10uF	50V Electrolytic, 5mm dia (LS = 2mm)	Radial	Panasonic	EEU-EB1H100S
C9 (115V)	470pF	50V Ceramic COG, NPO	0603 SMD	Panasonic	ECJ-1VC1H471J
C9 (230V)	180pF	50V Ceramic	0603 SMD	Panasonic	ECJ-1VC1H181J
C10	4.7 nF	250VAC Y5U X1Y1 (LS = 10mm)	Radial	Panasonic	CD16-E2GA472MYNS
C11	680uF	35V Aluminum Electrolytic	Radial	Panasonic	EEU-FM1V681
C13	100nF	25V Ceramic X7R	0603 SMD	Panasonic	ECJ-1VB1E104K
C14	100pF	50V Ceramic COG, NPO	0603 SMD	Panasonic	ECJ-1VC1H101J
C15	220nF	25V Ceramic X7R	0603 SMD	Panasonic	C1608XR1E224M
D1	HD06-T	Rectifier bridge, 600V, 0.8A	SMD	Diodes Inc.	HD06-T
D5	MURA160	600V, 1A	SMA	ON Semiconductor	MURA160T3
D6	BAS21	250V, 200mA	SOT23	ON Semiconductor	BAS21LT1G
D8	MMBZ5239	9.1V ZENER	SOT23	ON Semiconductor	MMBZ5239BLT1
D9	MMBZ5245	15V ZENER	SOT23	ON Semiconductor	MMBZ5245BLT1
D10 (115V)	MBRD5H100	Schottky, 100V, 5A	DPAK	ON Semiconductor	MBRD5H100T4G
D10 (230V)	MURD620	Rectifier, 200V, 6A	DPAK	ON Semiconductor	MURD620CT
D11	MMBZ5231	5.1V ZENER	SOT23	ON Semiconductor	MMBZ5231BLT1
D13	BAW56	70V, 200MA	SOT23	ON Semiconductor	BAW56LT1G
L2	800uH	Torroid	Through Hole	Wurth Midcom	750311431 Rev 6A
L3 (115V)	1.6mH	Torroid	Through Hole	Wurth Midcom	
L3 (230V)	800uH	Torroid	Through Hole	Wurth Midcom	750311431 Rev 6A
Q2	MMBTA06	NPN, 80V, 500mA	SOT23	ON Semiconductor	MMBTA06LT1G
Q3 (115V)	NDD05N50	N-Channel MOSFET 500V, 4.7A, 1.5R	DPAK	ON Semiconductor	NDD05N50ZT4G
Q3 (230V)	SPD02N80	N-Channel MOSFET 800V, 2A	DPAK	Infineon	SPD02N80C3
R1 (115V)	15	Fusible resistor, 1W	Axial	Vishay	NFR0100001509JR500
R1 (230V)	33R	Fusible resistor, 33R, 1W	Axial	Vishay	NFR0100003309JR500
R2 R3	5K6	1/10W	0603 SMD	Panasonic	ERJ-3GEYJ562V
R4 (115V)	240	Metal Film 1W	Axial	Vishay	PR01000102400JR500

Designator	Value	Description	Footprint	Manufacturer	Manufacturer Part Number
R4 (230V)	510	Metal Film 1W	Axial	Vishay	PR01000105100JR500
R7 R13 (115V)	47K	1/4W	1206 SMD	Panasonic	ERJ-8ENF4702V
R7 R13 (230V)	150K	1/4W	1206 SMD	Vishay	ERJ-8ENF1503V
R8	47K	1/10W	0603 SMD	Panasonic	ERJ-3EKF4702V
R9	6K2	1/10W	0603 SMD	Panasonic	ERJ-3EKF6201V
R10 (115V)	Zero	Jumper	-	-	-
R10 (230V)	33R	Fusible resistor, 33R, 1W	Axial	Vishay	NFR0100003309JR500
R14	4K7	1/10W	0603 SMD	Panasonic	ERJ-3EKF4701V
R15	100K	1/10W	0603 SMD	Panasonic	ERJ-3EKF1003V
R16	47K	1/10W	0603 SMD	Panasonic	ERJ-3EKF4702V
R18	100	1/10W	0603 SMD	Panasonic	ERJ-3EKF1000V
R19	10	1/10W	0603 SMD	Panasonic	ERJ-3EKF10R0V
R20	0.51	1/4W	1206 SMD	Rohm	MCR18EZHFLR510
R21	3.3K	1/4W	1206 SMD	Panasonic	ERJ-8ENF3301V
R22	1.5K	1/10W	0603 SMD	Panasonic	ERJ-3EKF1501V
R25	2.2K	1/10W	0603 SMD	Panasonic	ERJ-3EKF2201V
R26	18K	1/4W	1206 SMD	Panasonic	ERJ-8ENF1802V
R27	51K	1/4W	1206 SMD	Panasonic	ERJ-8ENF5102V
R28	680	1/10W	0603 SMD	Panasonic	ERJ-3GEYJ681V
R29	0.2	1/4W	1206 SMD	Rohm Semi	MCR18EZHFLR200
R30	24K	1/10W	0603 SMD	Panasonic	ERJ-3EKF2402V
R31	4K7	1/4W	1206 SMD	Panasonic	ERJ-8ENF4701V
RV1	V275LA2	275V 23 Joule (LS = 7mm)	Radial	Littelfuse	V275LA2P
U1	NCL30000	Single Stage PFC LED Driver	SOIC8	ON Semiconductor	NCL30000DR2G
U2	PS2561L_1	80V, 50mA	SMT4	NEC Electronics	PS2561L-1
U3	NCS1002	CV/CC Secondary Controller	SOIC8	ON Semiconductor	NCS1002DR2G
T1		EFD 20, 12 watt	SMD EFD20	Wurth Midcom	750311620

ENERGY STAR and the ENERGY STAR mark are registered U.S. marks.

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
P.O. Box 5163, Denver, Colorado 80217 USA
Phone: 303−675−2175 or 800−344−3860 Toll Free USA/Canada
Fax: 303−675−2176 or 800−344−3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800−282−9855 Toll Free USA/Canada
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910
Japan Customer Focus Center
Phone: 81−3−5773−3850

ON Semiconductor Website: **www.onsemi.com**

Order Literature: http://www.onsemi.com/orderlit

For additional information, please contact your local Sales Representative