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AND8470/D

A 25 to 55 V, 0.7 to 1.5 A, Single Stage Power Factor Corrected Constant Current Offline LED Driver with Flexible Dimming Options

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APPLICATION NOTE

Introduction

This application note describes a 40 to 90 W, off−line, single stage power factor correction (PFC), isolated constant current LED driver. There are a wide variety of medium power lighting applications that would benefit from replacing the traditional light source with an LED source including outdoor area lights, parking garages lights, wall washers, wall packs and architectural lighting. All these applications have high operating hours, challenging environmental conditions, and can benefit from advanced dimming control to further save energy. Moreover many of these applications have accessibility issues so long lifetime LED based solutions could significantly reduce maintenance costs.

This specific driver design is tailored to support LEDs such as the Cree XLamp™ XP−G and XM, OSRAM Golden DRAGON LED® Plus, and Philip−Lumileds Luxeon® Rebel that have maximum drive currents of 700 mA to 1500 mA. These example LEDs exhibit good efficacy's at higher drive currents, thus allowing fewer LEDs to be used to achieve the same light output. For example, a cool white Cree XP−G driven at 1 A can generate 280 − 320 lm typical at a junction temperature of 80°C with an efficacy in the range of 100 lm/W. If 14 of these were used in a wall pack, the source lumen output would be approximately 4200 lm excluding optical losses and the typical load power would be ~43 W.

This application note focuses on various options for dimming including PWM, analog and bi−level dimming. Intelligent dimming takes full advantage of the instant turn−on characteristics of LEDs and combines it with lighting controls to save significant energy without compromising lighting quality or user safety and comfort. In many cases, these techniques have not been used in the past as some traditional large area light sources are difficult to easily dim and may have long re−strike times. Additionally, LED lifetime improves when dimmed because the average operating junction temperature is reduced. PWM and analog dimming are traditional techniques for dimming. Bi−level or multi−level dimming involves establishing discrete drive current steps to support a range of light level. This method combined with sensors / controls (motion, occupancy, timer based, or remotely networked control) allows additional energy savings without compromising safety and convenience. This is especially useful in outdoor and underground lighting were bi−level control can reduce the light level based on time−of−day and occupancy to save power late at night when there is no activity, but still allows the light to return to standard light levels in the presence of activity. In fact the California Lighting Technology recently published a study where bi−level LED lighting saved 87% over conventional 70 W HID outdoor pathway bollards.

The power supply is designed around ON Semiconductor's NCL30001 single stage, continuous conduction mode (CCM) PFC controller and the NCS1002 secondary side constant voltage, constant current (CVCC) controller. Details of the operation of the NCL30001 are also discussed in AND8427 where the power stage design is discussed for a static (non−dimming) application.

Additional circuitry has been added to the CVCC control loop to support three types of dimming control: analog dimming with a 1 to 10 V programming signal; bi−level dimming with a simple logic level input signal; and PWM dimming using an onboard 800 Hz oscillator with variable pulse width. These three dimming functions are incorporated on an optional plug−in DIM card that can be wired into the NCL30001LEDGEVB evaluation board. The demo board already has a standard input which accepts a user provided logic level PWM input signal which can be varied from 350 Hz to several kilohertz.

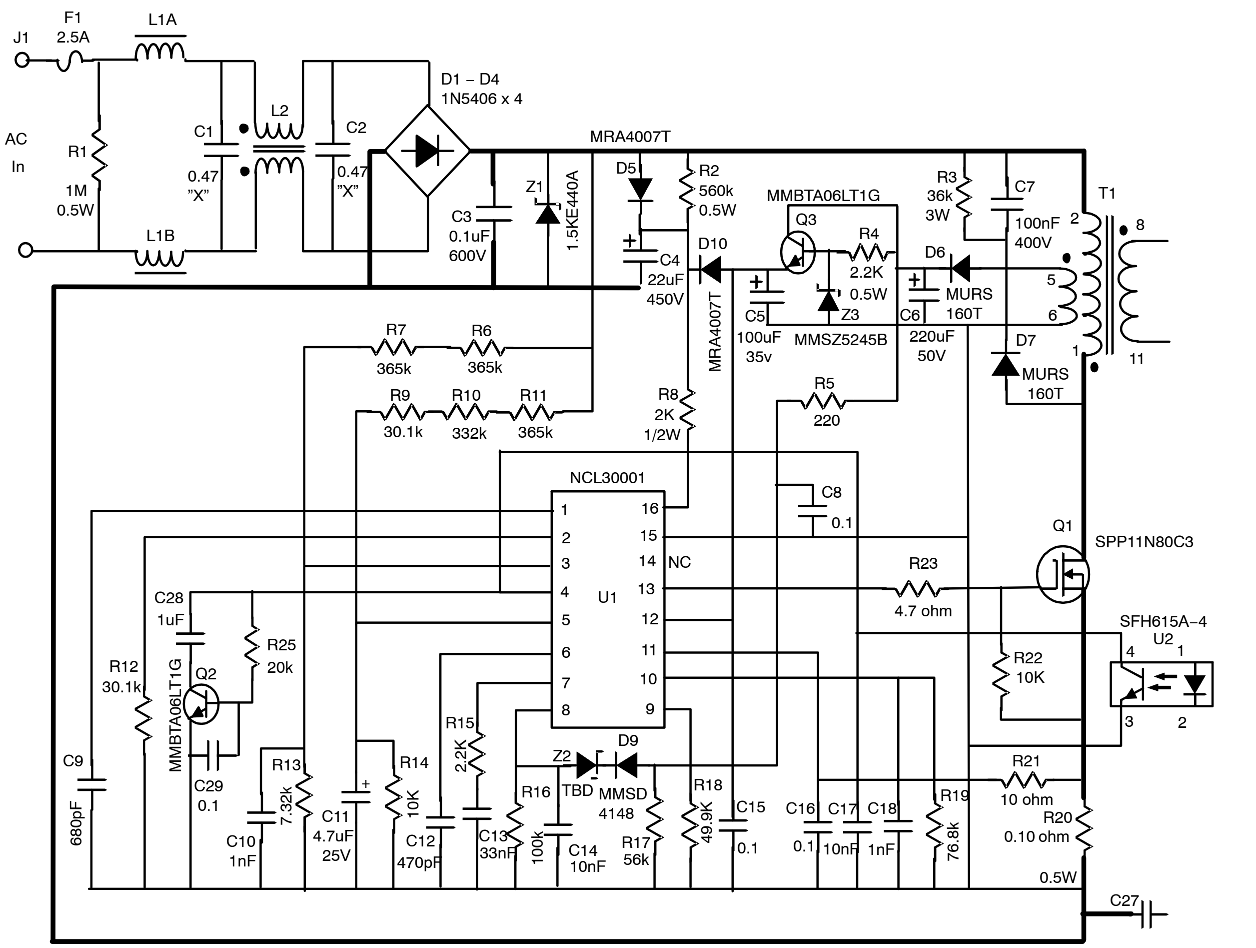
The basic specification of the demo board are listed below. The maximum output voltage can be adjusted via selection of a single resistor; and it is compliant enough to handle an output with a nominal 2:1 forward voltage range. This 2:1 range is dependent on the string series forward voltage and the drive current. The default output current is set at 1 A, but a maximum DC output current of 1.5 A is available by modifying a single resistor value. This power level of this design is targeted at applications operation below 60 Vdc maximum and below 100 VA to be under the maximum power requirements of IEC (EN) 60950−1 (UL1310 Class 2) power supplies. The demo board is illustrative of a typical operational schematic. If a higher voltage is required to drive a longer string of LEDs, then several secondary components would need to be changed and the transformer design would need to be modified.

Specifications

Extended Universal Input:	90 − 305 Vac (with proper X & Y cap ratings) – to support 277 Vac
Frequency	47 − 63 Hz
Power Factor:	> 0.9 (50−100% of Load)
Harmonic Content	EN61000−3−2 Class C Compliance
Efficiency	> 85% at 50 −100% of 50 W, I_{out} = 1 A / Vf = 50 V
Target	UL1310 Class 2 Dry/DA, isolated < 100 VA and < 60 V peak
V_{max} Range:	30 − 55 V (selectable by resistor divider)
Constant Current	
I_{out} Range:	0.7 − 1.5 A (selectable by resistor)
V_{out} Compliance	>50 to 100% of V_{out}
Voltage Ripple:	< 3 V_{pp} (dependent on C_{out})
Current Tolerance	± 3%
Cold Startup	< 1 sec typical to 50% of load
Pout Maximum:	90 W
Dimming:	Two Step Bi−level Analog Dimming
	PWM dimming input (350 Hz – 3 kHz) referenced to a secondary side signal ground)
	Dimming range > 10:1
	1−10 V analog voltage input dimming with a 100k potentiometer, 1 = minimum, 10 V is 100% on
Protection:	Short Circuit Protection
	Open Circuit Protection < 60 V peak
	Over Temperature – Latched (optional)
	Over Current Protection − Auto recovery (optional)
	Over voltage protection – Latched (optional)
	Over Temperature Foldback (optional)

Primary Side Circuitry

The primary side circuit schematic is shown in Figure 1. The primary circuitry is composed of the NCL30001 derived CCM flyback converter and associated control logic, input EMI filter, and V_{CC} “housekeeping” circuitry. It is similar to the primary circuitry shown in Figure 3 of AND8397 with the exception of the V_{CC} regulator circuit for the NCL30001 (U1) and a different EMI filter configuration. Components Q3, Z3, and R4 form a simple 15 V regulator to prevent V_{CC} overvoltage due to the potentially wide output compliance voltage that is reflected back to the auxiliary V_{CC} winding when driving LEDs. A complete description of the primary side circuit operation can be found in application note AND8397 and will not be presented here.



Notes:

1. Crossed schematic lines are not connected.
2. Heavy lines indicate power traces/planes.
3. Z2/D9 is for optional OVP (not used).
4. L1A/B are Coilcraft PCV−0−224−03L or equivalent.
5. L2 is Coilcraft P3220−AL or equivalent.
6. Q1 and D8 will require small heatsinks.

Figure 1. Primary Converter Circuit

Secondary Side Control Circuitry

The schematic of Figure 2 shows the secondary side circuitry responsible for the CVCC feedback control and the MOSFET switch (Q7) and associated circuitry that gates the output current for PWM dimming. Voltage and current regulation are achieved by utilizing ON Semiconductor's NCS1002 secondary side CVCC controller in an SOIC8 package. This chip contains two precision op−amps and an internal 2.5 V reference. The reference is internally connected to the non−inverting input of one of the op−amps. Referring to the schematic of Figure 2, this op−amp is used for voltage control (U3A). The power supply output is sensed through resistor divider R34 and R35 and presented to the inverting input of this op−amp section. The resistors are selected so as to provide 2.5 V to pin 3 when the output is at the desired maximum voltage (55 V in this case). Frequency compensation is provided by R30 and C26.

Since both amplifier outputs are "OR−ed" via diodes D11 and D12 to drive the optocoupler U2, the amplifier with the lowest output is dominant; hence CVCC control and mode transition is smooth with no interaction between the op−amps. Current control is achieved by sensing the output current through R26 and presenting this sense signal to U3B where it is compared to a scaled down value of the 2.5 V internal reference. Figure 2 also shows an interface (P1) to an optional dimming circuitry card. Details of this will be discussed in the next section.

Included on the NCL30001EVB board is a PWM input (J3) that can be connected to an external signal generator. A high (logic "1") will switch gating MOSFET Q7 off, so the default output current is maximum if no PWM signal is applied. In this mode, the external dimming card is not required and a jumper should be placed across pins 2 and 3 of P1. It should be noted that the main output terminals to the LEDs (J2) are "floating" and are not referenced to the logic common of any low level control or input signals.

Because the right hand side of current sense resistor R26 is connected to the secondary logic ground (or common), the sense node on the left hand side of the resistor will go negative with increasing current. The current sense divider network of R31 and R32 is biased up on the low side of R32 by the 2.5 V reference such that when pin 5 of U3B drops to zero, this amplifier section becomes dominant and controls the loop (note that the inverting input is grounded through signal MOSFET Q5 through R36.)

The output over−current threshold level is set by adjusting R31 and R32 such that the voltage level presented at pin 5 of U1 at no output load is exactly the voltage drop that will appear across R26 at maximum load. In this design example the maximum current is set at 1 A, so there must be 100 mV of bias at pin 5 under no output load.

The PWM signal from the DIM card is injected into Q6's base via R39 on the main board. This signal toggles Q6 which in turn switches Q7, the main output gating MOSFET on and off. Note that R37 pulls up the gate of Q7 such that the default position is on, and Q6 must turn on to turn Q7 off. One of the problems with interrupting the current through current sense resistor R26 is that current sense amp U3B will get a changing current sense signal during PWM operation which will corrupt the desired fixed peak level of the output current. This is overcome by adding sample and hold transistor Q5. When Q6 is on and Q7 is off, Q5 is also off and the current op−amp continues to see the voltage on capacitor C33 which is exactly what was across R26 when current was flowing during Q7's on period. In essence, Q5 and C33 form a sample and hold circuit which prevents pin 6 of U3B seeing a switched current level across R26. During the PWM "off−time" when no current is flowing through R26, the main inverter is still running and charging output capacitors C20, 21, and 22. As long as there is sufficient output capacity and the PWM gating frequency is high enough, the incremental voltage increase on the output capacitors is insufficient to cause any significant leading edge current spiking when Q7 switches back on to provide current to the LEDs.

Since the V_{CC} to run the secondary side circuitry is derived from the main output filter capacitors, this voltage can vary due to series LED diode Vf compliance, and with the nominal adjusted level of the output voltage. In order to keep the V_{CC} voltage for U3 and the associated circuitry stable, a simple linear regulator composed of Q4, Z4, and R27. This prevents the secondary V_{CC} from exceeding approximately 15 V.

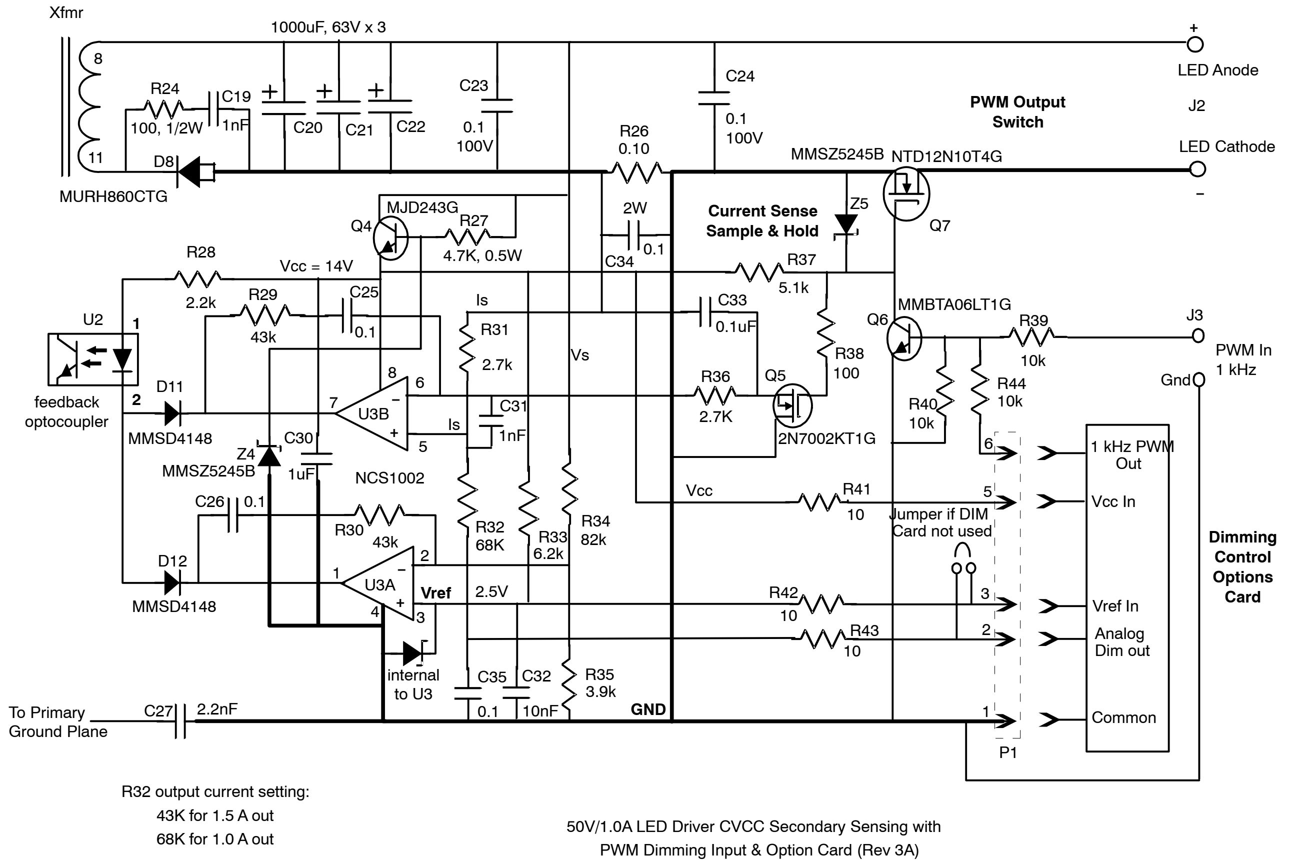


Figure 2. Secondary Sensing and PWM Control Schematic

Figure 3 is the schematic of the optional plug−in control card which supports dimming via three methods. These include analog dimming using a 1 to 10 V signal adjustable by a 15 turn potentiometer. An external, remote 100k potentiometer can be used by removing this potentiometer and wiring in the remote one with the PCB solder pads provided. The second dimming option is a bi−level mode which is typically used with an occupancy sensor, motion sensor, or microcontroller input to reduce the current level for reduced light output when there is no activity in an area. When activity is detected then the driver is switched to the standard higher drive current level. A simple logic level signal input is used for this control. The third method is PWM dimming where the output is switched on and off at an appropriate frequency by gating output MOSFET Q7. This dimming technique is preferred when the color point of the LED needs to be maintained regardless of brightness level. This is accomplished by modulating the desired peak LED current between on and off based on duty ratio thus changing the average LED current. An on−board 800 Hz oscillator circuit with potentiometer adjustable pulse width is incorporated on the DIM card to demonstrate this dimming method.

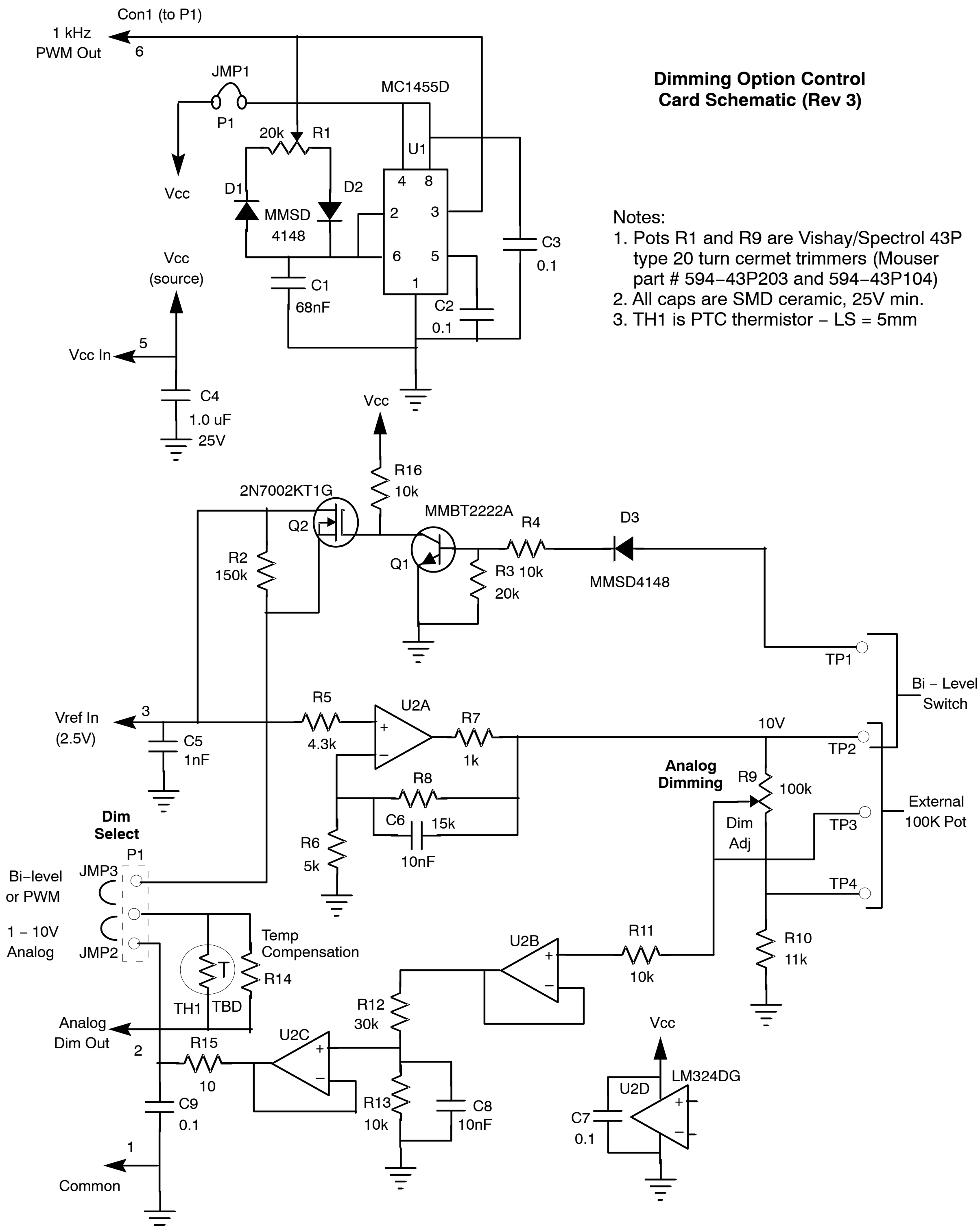


Figure 3. Optional DIM Card Schematic

For analog dimming using the DIM card, P1 should be jumpered via JMP2. In this case the reference level that biases up the lower side of R32 on the NCL30001EVB board is varied by the output signal from U2C on the DIM card. In this case the 2.5 V reference from the main board is DC amplified to a 10 V level by U2A on the DIM card and produces a stable reference for potentiometer R9. Due to the 1 V offset caused by R11, a 1 to 10 V signal is available for min to max dimming control. This signal is buffered by follower U2B and then divided again back to the 0 to 2.5 V level by R12 and R13. The output on U2C now re−injects this 0 to 2.5 V reference back to the main board to provide analog dimming capability. In the event that some type of temperature foldback or compensation is needed, TH1 and R14 are provided for temperature modification of the reference signal (normally jumpered out on the demo board).

For bi−level or PWM dimming, the jumper (JMP3) for P1 must be in the position such that MOSFET switch Q2 on the DIM card now controls the pin 2 output from the card. For the bi−level dimming option, no signal into the DIM card logic input will cause Q1 to be off and Q2 to be on, which will by pass resistor R2 and the power supply output current will be maximum. With a logic “1”, Q2 will turn off adding R2 in series with R32 back on the main board. This will modify the current amplifier reference to a lower, fixed level such that the output current will be about 30% of maximum.

For PWM dimming, U1 on the DIM card generates an 800 Hz square wave signal that is PWM adjustable via potentiometer R1. To activate this oscillator circuit, P1 should be jumpered (via JMP1) and P2 should be jumpered for the PWM/Bi−Level position (JMP3).

DIMMING OPTIONS CONFIGURATION

Dimming Configuration	Modifications; Jumper Configurations
External PWM dimming input	Omit DIM card; short pins 2 and 3 of connector P1,
	Inject PWM signal into J3
On board PWM dimming	Add DIM card with JMP1 added to P1 on DIM card; Add JMP3 to P2 on DIM card. Adjust pot R1 to vary pulse width
Bi−Level Dimming	Add DIM card with JMP1 (P1) removed; Add JMP3 to P2 on card; Connect switch from TP1 And TP2. Closed switch gives low dim level.
Analog Dimming, On board Adjust	Add DIM card with JMP1 (P1) removed: Add
	JMP2 to P2; Adjust pot R9 for LED brightness.
Analog Dimming, Ext. Potentiometer	Add DIM card with JMP1 (P1) removed. Add
	JMP2 to P2. Remove pot R9 and wire in external 100k potentiometer to TPs 2, 3 and 4. TP3 is the pot wiper. Adjust external pot for LED brightness.

Test Results and Plots

Data was taken using a string of 1 A white LEDs arranged for a typical Vf range of series LEDs. This LED configuration falls within the 50 V to approximately 20 V output compliance range of the power supply and provides typical operational load characteristics for the circuitry.

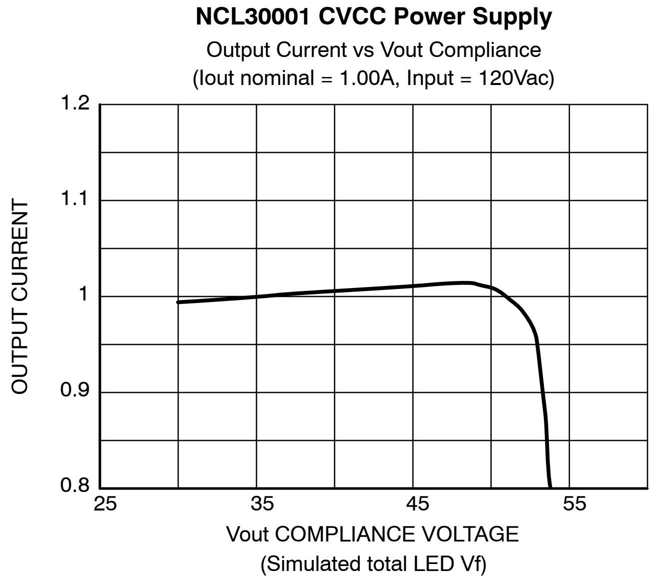


Figure 4. Current Regulation versus LED String V_f (# of series LEDs); I_{out} set to 1 A

PWM DIMMING – Minimum I_{out} and PF vs LED String Vf

# LEDs	String Vf	Duty Ratio	PWM I_{min}	Power Factor
14	49 Vdc	0.09	90 mA	0.96
11	40 Vdc	0.11	110 mA	0.96
9	31 Vdc	0.15	150 mA	0.95
7	22 Vdc	0.24	240 mA	0.95

NOTE: Measurements taken at 100 Vac input (worst case), PWM frequency 800 Hz. I_{max} at 100% Duty Ratio = 1.0 A.

In the case of Analog Dimming as shown in the table below, when the LED current is reduced, the forward voltage of the LED drops. The data below represents the range of dimming achievable with various numbers of series LEDs.

ANALOG DIMMING (1 – 10 Vdc signal input)

# LEDs	String Vf	Duty Ratio	PWM I_{min}	Power Factor
14	32 Vdc	0.10	100 mA	0.93
11	27 Vdc	0.14	140 mA	0.93
9	22 Vdc	0.19	190 mA	0.94
7	20 Vdc	0.72	720 mA	0.98

Dimming Limitations

Note that at 100 Vac input, the analog dimming mode is limited in the minimum amount of current possible as the LED string Vf becomes lower for the given transformer design. This is due to depletion of the circuit V_{CC} and operating voltages necessary for stable circuit operation. It is important to keep the LED Vf range as closely matched to the transformer design and its V_{out} max design parameter (secondary turns). The PWM dimming minimum level does not degrade the circuit V_{CC} in the same manner as analog dimming does when the LED string voltage is lowered for a given transformer Vf max output design. At increased line voltage the minimum level of current also declines somewhat in the analog dimming mode.

It is important to note that in this demo board, the transformer has been optimized to achieve widest range of operation at maximum load V_f = 55 V/I_{out} = 1.5 A. To address a different string length and drive current, the transformer turns ratio should be optimized for that specific operating condition or V_f range to achieve the widest range or analog or dimming performance. Using a transformer with excessive maximum voltage capability will limit the lower level of PWM and analog dimming capability as shown by the table above for low LED string Vf values.

EFFICIENCY AND POWER FACTOR VERSUS DIODE STRING Vf (Measured at I_{out} = 1 A)

Vf @ 1 A	# LEDs	Efficiency	PF −120 Vac	PF −230 Vac
49 Vdc	14	86.5%	0.99	0.97
40 Vdc	11	86%	0.99	0.97
31 Vdc	9	85.3%	0.99	0.95
22.5 Vdc	7	85%	0.98	0.91

POWER FACTOR VERSUS DUTY RATIO WITH PWM DIMMING MODE (D = 1.0 > 1 A out)

D (PWM)	I_{out}	120 Vac PF	230 Vac PF
1.0	1.0 A	0.99	0.97
0.75	0.75 A	0.99	0.96
0.50	0.50 A	0.99	0.93
0.25	0.25 A	0.98	0.82
0.10	0.10 A	0.95	0.62

In specific regions, electronic lighting components connected to the AC mains must comply with IEC61000−3−2 Class C. Below are the test results for this evaluation board at a 50 W load and a V_{in} of 230 Vac.

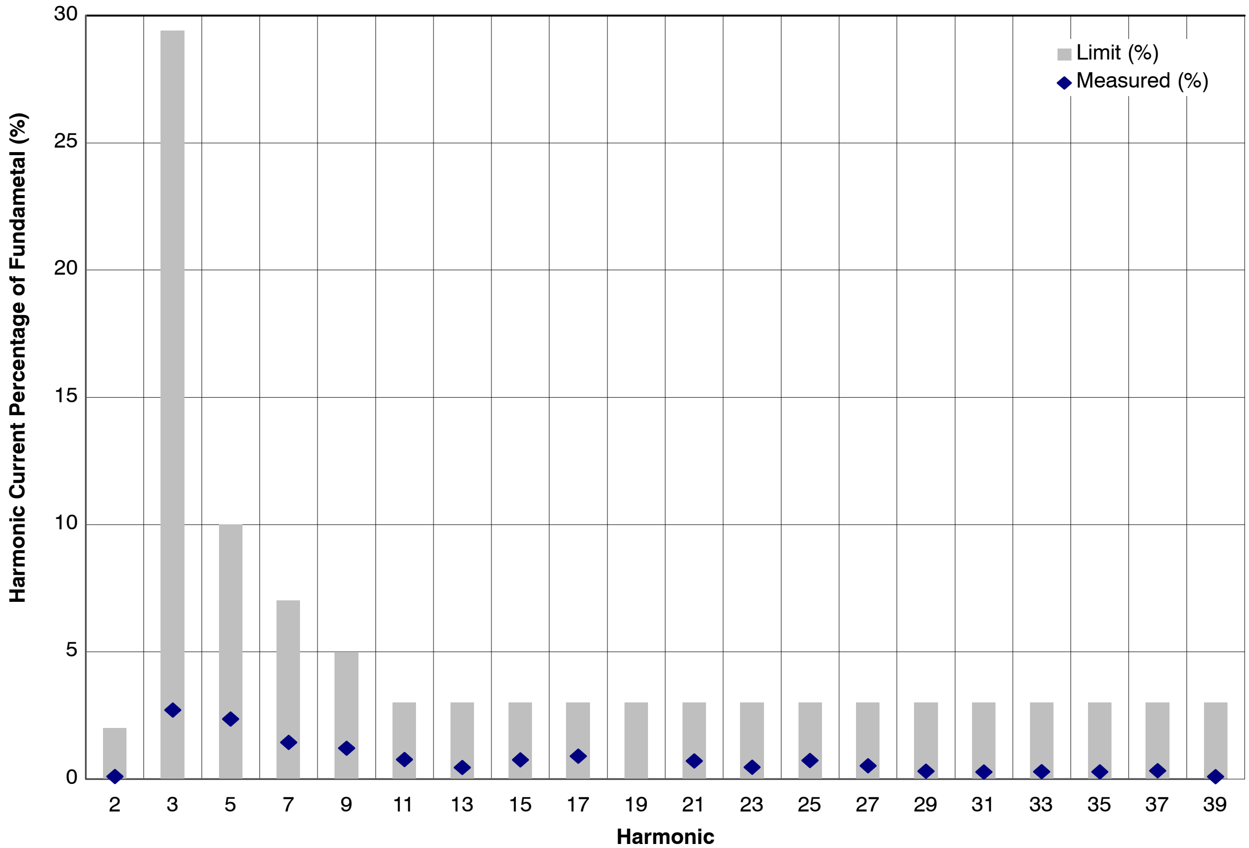


Figure 5. Harmonic Distortion Graph

WAVEFORMS PLOTS

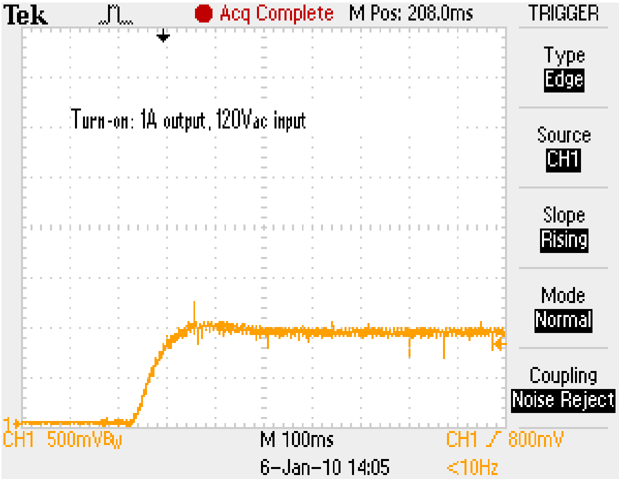


Figure 6. Output Current Turn−on Profile; 1 A output; 500 mA/Division

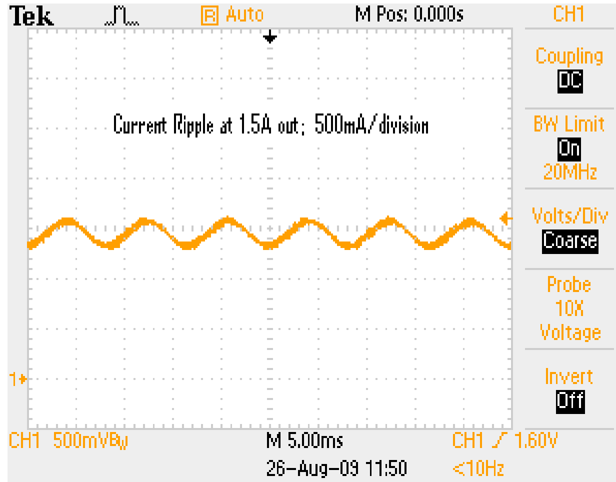


Figure 8. Output Current Ripple: 1.5 A Output (500 mA/division)

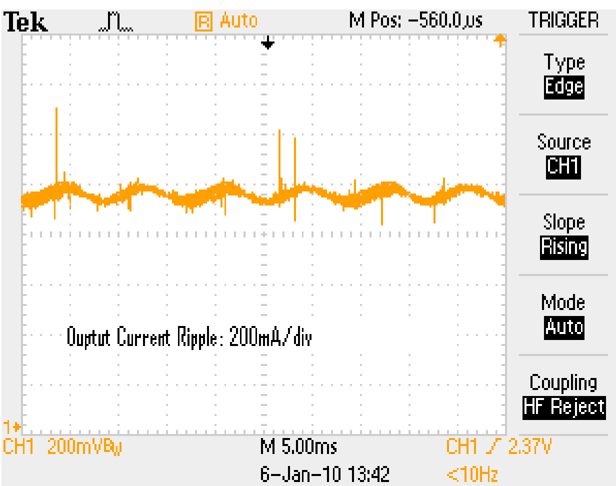


Figure 7. Output Current Ripple: 1 A Output (200 mA/division)

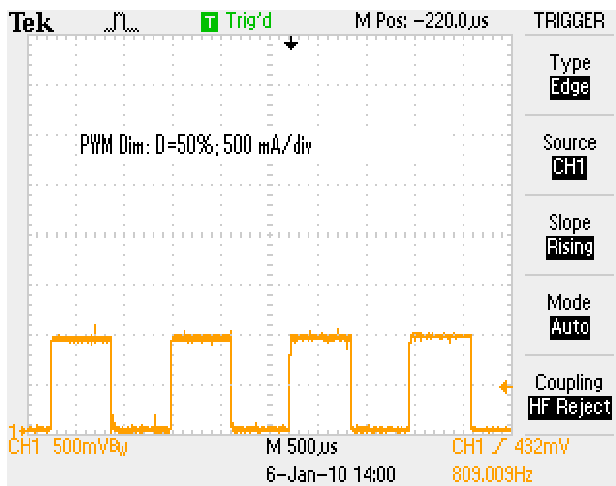


Figure 9. PWM Dimming Current Waveform Plots: D = 50%; I peak = 1 A

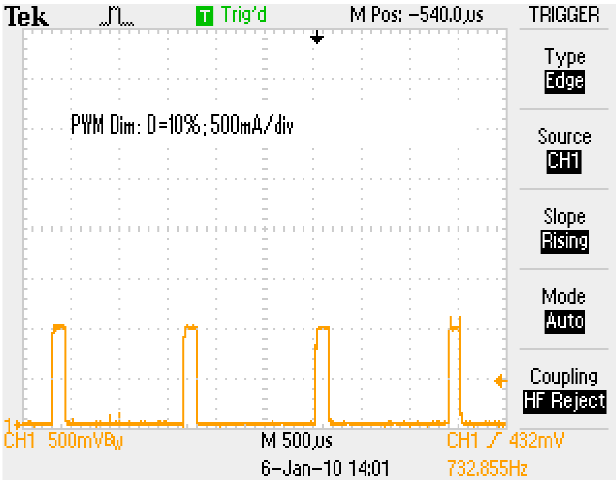


Figure 10. PWM Dimming Current: D = 10%; I peak = 1 A

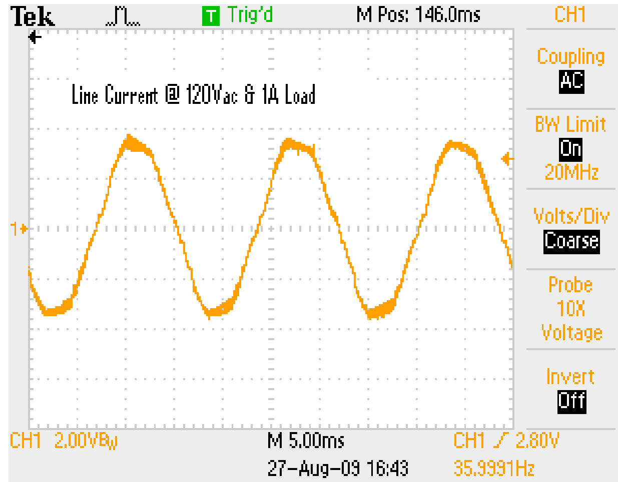


Figure 11. AC Input Current: 120 Vac, 48 Vdc, 1 A Output

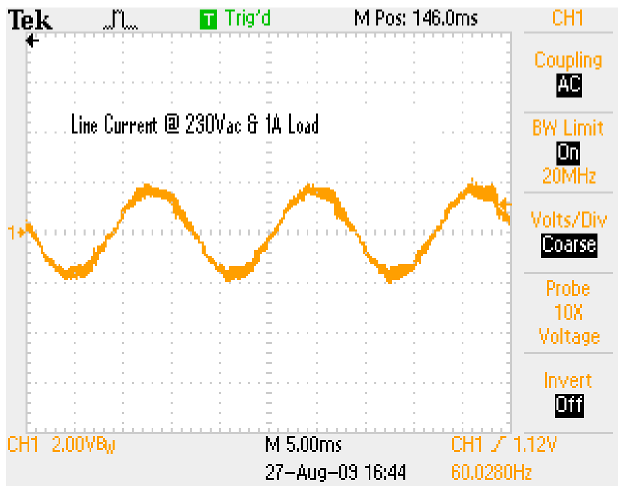


Figure 12. AC Input Current: 230 Vac, 48 Vdc, 1 A Output

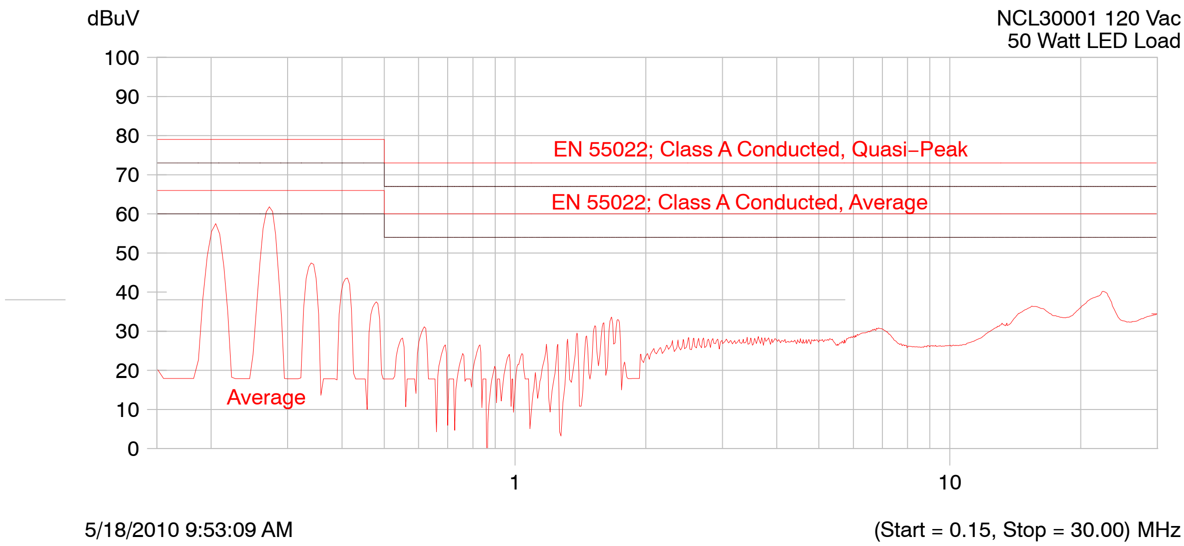


Figure 13. Conducted EMI Plot (50 W Output)

References:

1. NCL30001 Data Sheet
2. NCS1002 Data Sheet
3. California Lighting Technology Center Bi−Level Smart LED Bollard Study
4. AND8427

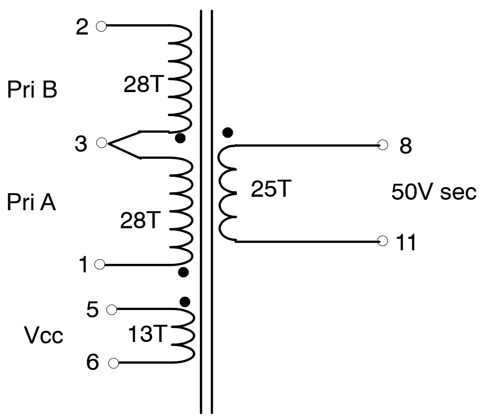
MAGNETICS DESIGN DATA SHEET

Project: NCL30001, 90 W, 50 Vout, isolated, single stage PFC LED driver
Part Description: CCM Flyback transformer, 70 kHz, 50 Vout
Schematic ID: T1
Core Type: PQ3230, 3C94 (Ferroxcube) or P material (Mag Inc.)
Core Gap: Gap core for 600 to 650 uH across pins 1 to 2.
Inductance: 625 uH nominal measured across primary (pins 1 to 2)
Bobbin Type: 12 pin pc mount (Mag Inc PC−B3230−12 or equivalent)

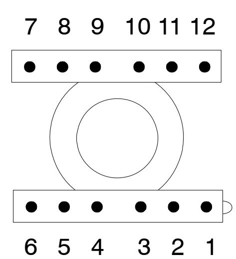
Windings (in order): Winding # / type	Turns / Material / Gauge / Insulation Data
Primary A: (1 − 3)	28 turns of #24HN over one layer (no margins). Self−leads to pins. Insulate for 3 kV to next winding.
50V Secondary (8 − 11)	25 turns of #24HN close wound over one layer and centered with 2 mm end margins. Insulate with tape for 3 kV to next winding.
Primary B: (3 − 2)	Same as primary A. Insulate for 1.5 kV to Vcc/Aux.
Vcc/Aux (5 − 6)	13 turns of #24HN spiral wound and centered with 8 mm end margins. Insulate with tape and terminate self−leads to pins.

Hipot: 3 kV from primary/Vcc to 50V secondary winding.

Schematic



Lead Breakout / Pinout
(bottom view)



BILL OF MATERIALS FOR 50 V, 1 A NCL30001 CVCC LED DRIVER WITH PWM DIMMING

Designator	Qty	Description	Value	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed	Comment
D5, D10	2	Diode		SMA	ON Semiconductor	MRA4007T	No	
D1, D2, D3, D4	4	Diode		axial lead	ON Semiconductor	1N5406	No	
D6, D7	2	Ultrafast diode		SMB	ON Semiconductor	MURS160	No	
D9, 11, 12, 13	4	Signal diode		SOD123	ON Semiconductor	MMSD4148A	No	
D8	1	UFR diode		TO−220ABCT	ON Semiconductor	MURH860CTG	No	
Z1	1	TVS	Input transient option	axial lead		1.5KE440A	Yes	Not Inserted
Z3, 4, 5	3	Zener diode	15 V	SOD123	ON Semiconductor	MMSZ5245B	No	
Z2	–	Zener diode	Not Used (OVP option)	SOD123	ON Semiconductor	–	No	Not Inserted
Q5	1	Mosfet	40 V, 100 mA	SOT23	ON Semiconductor	2N7002KT1G	No	
Q7	1	Mosfet	100 V, A	DPak4	ON Semiconductor	NTD12N10T4G	No	
Q1	1	Mosfet	11 A, 800 V	TO−220	Infineon	SPP11N80C3	No	
Q2, Q3, Q6	3	BJT	60 V, 500 mA	SOT23	ON Semiconductor	MMBTA06LT1G	No	
Q4	1	BJT	100 V, 4 A	DPak4	ON Semiconductor	MJD243G	No	
U1	1	PFC controller		SOIC16	ON Semiconductor	NCL30001	No	
U2	1	Optocoupler		4 pin SMD	Vishay	H11A817 or SFH6156A−4	Yes	
U3	1	Dual amp + zener		SOIC−8	ON Semiconductor	NCS1002	No	
C1, C2	2	X caps	0.47 µF, 277 Vac	LS = 15mm	Evox Rifa/Kemet or EPCOS	PHE840MB6470MB16R1 7 or B32922C3474M	Yes	Digikey 495−2322−ND
C27	1	Y2 cap	2.2 nF, 1 kV	LS = 10 mm	Evox Rifa/Kemet	PME271Y422M or P271HE222M250A	Yes	Digikey 399-5410-ND
C3	1	Polyprop. Film	0.22 µF (630 V)	LS =24 mm	Vishay	2222 383 20224	Yes (must be polyprop)	Digikey P/N BC1858−ND
C7	1	Disc cap	68 to 100 nF, 400 V	LS = 10 mm	TDK	FK22X7R2J104K	high quality ceramic	Digikey P/N 445−2650−ND
C8, 15, 16, 25, C26, C29, C33	7	ceramic cap	0.1 µF, 50 V	1206	TDK	C3216X7R2A104K	Yes	Mouser P/N 445−1377−1−ND
C23, C24	2	ceramic cap	0.1 µF, 100 V	1206/1210	TDK	C3216X7R2A104K	Yes	Mouser
C28, C30	2	ceramic cap	1.0 µF, 25 V	1206	TDK	C3216X7R1H105K	Yes	Mouser P/N 810−C3216X7R1H105K
C19	1	ceramic disc cap	1 µF, 1 kV	LS = 8 mm	TDK	CK45−B3AD102KYNN	Yes	Mouser 810−CK45−B3AD102KYNN
C12	1	ceramic cap	470 pF, 50 V	1206	Vishay	VJ1206A471JXACW1BC	Yes	Mouser
C9	1	ceramic cap	680 pF, 50 V	1206	Kemet	C1206C681K5GACTU	Yes	Digikey 399−1216−1−ND
C10, C18, C31	3	ceramic cap	1 nF, 100 V	1206	Kemet	C1206C102K1RACTU	Yes	Digikey 399−1222−1−ND
C14, C17, C32	3	ceramic cap	10 nF, 50 V	1206	TDK	C3216COG2A103J	Yes	Digikey 445−2331−1−ND
C13	1	ceramic cap	33 nF, 50 V	1206	TDK	C3216COG1H333J	Yes	Digikey 445−2699−1−ND

BILL OF MATERIALS FOR 50 V, 1 A NCL30001 CVCC LED DRIVER WITH PWM DIMMING

Designator	Qty	Description	Value	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed	Comment
C5	1	electrolytic cap	100 µF, 35 V	LS = 2.5 mm	UCC	ESMG350ELL101MF11D	Yes	Digikey 565–1082–ND
C11	1	electrolytic cap	4.7 µF, 25 V	LS = 2.5 mm	UCC	ESMG250ELL4R7ME11D	Yes	Digikey P/N 565–1054–ND
C6	1	electrolytic cap	220 µF, 50 V	LS = 5mm	UCC	ESMG500ELL221MJC5S	Yes	Digikey 565–1111–ND
C20, 21, 22	3	electrolytic cap	1000 µF, 63 V	LS = 8 mm	Nichicon	647–UVR1J102MHD	Recommended value	Mouser 647–UVR1J102MHD
C4	1	electrolytic cap	22 µF, 450 V	LS = 5 mm	Nichicon	647–UVY2W220MHD	Yes	Mouser 647–UVY2W220MHD
C34,C35	2	ceramic cap	0.1 µF, 50 V	1206	TDK	C3216X7R2A104K	Yes	Mouser P/N 445–1377–1–ND
R4	1	0.5 W resistor	2.2k	axial lead	Vishay	NFR25H0002201JR500	Yes	Digikey PPC2.2KBCT–ND
R1	1	0.5 W resistor	1M, 0.5 W	axial lead	Vishay	CMF601M0000FHEK	Yes	Newark
R8	1	0.5 W resistor	2k, 0.5 W	axial lead	Vishay	CMF552K0000FHEB	Yes	Digikey CMF2.00KHFCT–ND
R2	1	0.5 W resistor	560k	axial lead	Vishay	HVR3700005603JR500	Yes	Digiky PPCHJ560KCT–ND
R27	1	0.5 W resistor	4.7k – 5.0k	1210	Vishay	CRCW12104K70JNEA	Yes	Digikey
R24	1	0.5 W resistor	100 Ω	axial lead	Vishay	CMF50100R00FHEB	Yes	Digikey
R20, R26	2	0.5 W resistor	0.1 Ω	LS = 18 mm	Ohmite	WNCR10FET	Yes	Digikey WNCR10FECT–ND
R3	1	3 or 5 W resistor	36k to 39k	LS = 30 mm	Ohmite	PR03000203602JAC00	Yes	Digikey PPC36KW–3JCT–ND
R23	1	0.25 W resistor	4.7 Ω	1206	Vishay/Dale	CRCW12064R75F	Yes	
R5	1	0.25 W resistor	220 Ω	1206	Vishay/Dale	CRCW1206220RF	Yes	
R38	1	0.25 W resistor	100 Ω	1206	Vishay/Dale	CRCW1206100RF	Yes	
R21, 41, 42, 43	4	0.25 W resistor	10 Ω	1206	Vishay/Dale	CRCW120610R0F	Yes	
R15, R28	2	0.25 W resistor	2.2k	1206	Vishay/Dale	CRCW12062211F	Yes	
R31, R36	2	0.25 W resistor	2.7k	1206	Vishay/Dale	CRCW12062741F	Yes	
R29,R30	2	0.25 W resistor	43.2k	1206	Vishay/Dale		Yes	
R25	1	0.25 W resistor	20k	1206	Vishay/Dale	CRCW12062002F	Yes	
R32	1	0.25 W resistor	68k	1206	Vishay/Dale	CRCW12066812F	Yes	
R33	1	0.25 W resistor	6.2k	1206	Vishay/Dale	CRCW12066191F	Yes	
R37	1	0.25 W resistor	5.1k	1206	Vishay/Dale	CRCW12065111F	Yes	
R34	1	0.25 W resistor	82k	1206	Vishay/Dale	CRCW12068252F	Yes	
R35	1	0.25 W resistor	3.9k	1206	Vishay/Dale	CRCW12063921F	Yes	
R14, 22, 39, 40	4	0.25 W resistor	10k	1206	Vishay/Dale	CRCW12061002F	Yes	
R13	1	0.25 W resistor	7.32k	1206	Vishay/Dale	CRCW12064322F	Yes	
R9, R12	2	0.25 W resistor	30.1k	1206	Vishay/Dale	CRCW12063012F	Yes	
R17	1	0.25 W resistor	56k	1206	Vishay/Dale	CRCW12065622F	Yes	
R18	1	0.25 W resistor	49.9k	1206	Vishay/Dale	CRCW12064992F	Yes	

BILL OF MATERIALS FOR 50 V, 1 A NCL30001 CVCC LED DRIVER WITH PWM DIMMING

Designator	Qty	Description	Value	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed	Comment
R19	1	0.25 W resistor	76.8k	1206	Vishay/Dale	CRCW12067682F	Yes	
R16	1	0.25 W resistor	100k	1206	Vishay/Dale	CRCW12061003F	Yes	
R10	1	0.25 W resistor	332k	1206	Vishay/Dale	CRCW12063323F	Yes	
R6, 7, 11	3	0.25 W resistor	365k	1206	Vishay/Dale	CRCW12063653F	Yes	
F1	1	Fuse	2.5 A, 250 Vac	TR−5	Littlefuse	37212500411	Yes	Digikey WK4258BK−ND
L1A/B	2	EMI inductor	220 μH, 2 A	Slug core	Coilcraft	PCV−0224−03L	Yes	
L2	1	EMI inductor		Toroid	Coilcraft	P3220−AL	Yes	
T1	1	Flyback xfmr	55 V, 90 W CCM	custom	WE−Midcom (Wurth Electronics)	750311267, Rev 01	No	
J1, J2, J3	3	I/O connectors		LS = 5 mm	Weidmuller	1716020000	Yes	Digikey 281−1435−ND
(for Q1, D8)	2	Heatsink Q1, D8		LS = 25.4 mm	Aavid	531102B02500G (or similar)	Yes	
HD1	1	Header	CONN HEADER 2POS	0.100”	Molex	90120−0122	Yes	
JMP1	1	Shorting Jumper	0.1” Two Position Shorting Jumper	0.100”	Sullins Connector Solutions	SPC02SYAN	Yes	

OPTIONAL DIM DAUGHTER CARD BOM

Designator	Qty	Description	Value	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed	Comment
D1, D2, D3	3	Signal diode		SOD123	ON Semiconductor	MMSD4148A	No	
Q1	1	BJT	400 mA, 40 V	SOT23	ON Semiconductor	MMBT2222A	No	
Q2	1	Mosfet	40 V, 100 mA	SOT23	ON Semiconductor	2N7002KT1G	No	
U1	1	Timer IC	–	SOIC8	ON Semiconductor	MC1455D	No	
U2	1	Quad Opamp	–	SOIC14	ON Semiconductor	LM324DG	No	
C4	1	ceramic cap	1.0 μF, 25 V	1206	TDK	C3216X7R1H105K	Yes	Mouser 810−C3216X7R1H105K
C1	1	ceramic cap	68 nF, 50 V	1206	Vishay	VJ1206Y683KXAA	Yes	Mouser 77−VJ12Y50V683K
C2, 3, 7, 9	4	ceramic cap	0.1 μF, 50 V	1206	TDK	C3216X7R2A104K	Yes	Mouser 810−C3216X7R2A104K
C6, C8	2	ceramic cap	10 nF, 50 V	1206	TDK	C3216COG2A103J	Yes	
C5	1	ceramic cap	1 nF, 100 V	1206	Kemet	C1206C102K1RACTU	Yes	
R1	1	potentiometer	20k, 15 Turn	Thru hole	Vishay	T18203KT10	Yes	Mouser 72−T18−20K
R9	1	potentiometer	100k, 15 turn	Thru hole	Vishay	T18104KT10	Yes	Mouser 72−T18−100K
R4, 11, 13, 16	4	0.25 W resistor	10k	1206	Vishay/Dale	CRCW12061002F	Yes	
R2	1	0.25 W resistor	150k	1206	Vishay/Dale	CRCW12061503F	Yes	
R3	1	0.25 W resistor	20k	1206	Vishay/Dale	CRCW12062002F	Yes	
R5	1	0.25 W resistor	4.3k	1206	Vishay/Dale	CRCW12064321F	Yes	

OPTIONAL DIM DAUGHTER CARD BOM

Designator	Qty	Description	Value	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed	Comment
R6	1	0.25 W resistor	5k	1206	Vishay/Dale	CRCW12064991F	Yes	
R7	1	0.25 W resistor	1.0k	1206	Vishay/Dale	CRCW12061001F	Yes	
R8	1	0.25 W resistor	15k	1206	Vishay/Dale	CRCW12061502F	Yes	
R10	1	0.25 W resistor	11k	1206	Vishay/Dale	CRCW12061102F	Yes	
R12	1	0.25 W resistor	30k	1206	Vishay/Dale	CRCW12063012F	Yes	
R15	1	0.25 W resistor	10 Ω	1206	Vishay/Dale	CRCW120610R0F	Yes	
R14	1	0.25 W resistor	0 Ω	1206	Vishay/Dale	CRCW12060000Z	Yes	
TH1	1	PTC Thermistor	Not Used	Thru hole			Yes	
CON 1	1	right angle pins	0.1” 6 position	Thru hole	Molex or Tyco	Rt angle 6 pin connector, 0.1” pitch	Yes	

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