AN1916
APPLICATION NOTE

VIPower: OFFLINE CONSTANT CURRENT LED DRIVER USING VIPer12/22A

1. Abstract

High brightness LEDs are becoming a prominent source of light and often have better efficiency and reliability when compared to that of conventional light sources. While LEDs can operate from an energy source as simple as a battery and resistor, most applications require an efficient energy source not only for the reduction of losses, but also for the lumen maintenance of the LED itself. Using integrated off line switching regulators like the VIPer12A and VIPer22A in a constant current configurations, a low cost, high efficient LED driver for multiple LEDs has been developed.

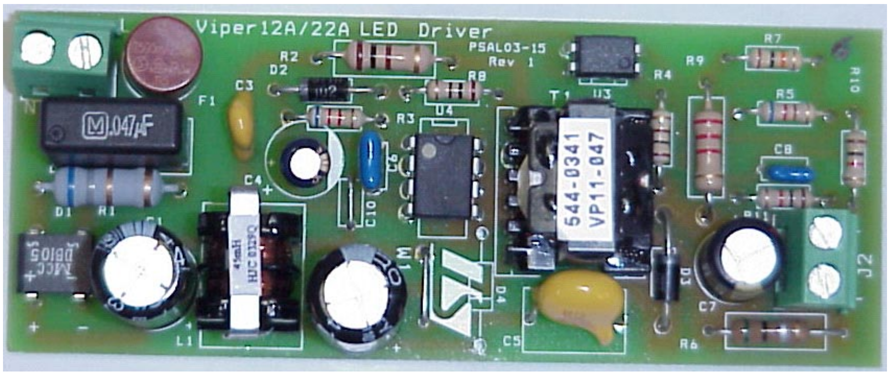
2. Introduction

This paper introduces the isolated and non-isolated offline constant current LED driver based on VIPerX2A family. All three LED driver configurations operate in the extended wide range input voltage, from 90 to 264Vac.

VIPer12A and VIPer22A are low cost monolithic smart power devices with integrated PWM controllers. Their internal control circuit offers benefit such as automatic burst mode in low load condition, overvoltage protection in hiccup mode, and large voltage range on the VDD pin.

An isolated VIPer12A constant current LED driver has been configured to drive 1 to 4 LEDs while the isolated VIPer22A configuration has been optimized for 2 to 8 LEDs.

Figure 1. VIPer12A Constant Current Led Driver Board Layout



3. LED Parameters

LED voltage drop tolerance varies by +/- 16.6% for the white LED, as shown in table 1.

Different colors will have different typical voltage drop. For this reason, it is recommended that the LEDs be connected in series rather than parallel. If the LEDs were connected in parallel, the current flowing in each LED would depend on each unit's individual voltage drop (VF) characteristic and not be matched to the other devices, resulting in different brightness for each LED. Below is the forward voltage drop spec from the Luxeon Star Technical Data Sheet DS23.

Table 1. Electrical Characteristics at 350mA, Junction Temperature T_J=25ºC

Color	Forward Voltage V_F (V) Min	Typ.	Max	Dynamic Resistance (Ω) R_D	Temperature Coefficient of Forward Voltage (mV/ºC) $\Delta V_F/\Delta T_J$
White	2.79	3.42	3.99	1.0	-2.0
Green	2.79	3.42	3.99	1.0	-2.0
Cyan	2.79	3.42	3.99	1.0	-2.0
Blue	2.79	3.42	3.99	1.0	-2.0
Royal Blue	2.79	3.42	3.99	1.0	-2.0
Red	2.31	2.85	3.27	2.4	-2.0
Amber	2.31	2.85	3.27	2.4	-2.0

4. Led Intensity

The intensity of the brightness also varies with different color as shown in the Luxeon data sheet.

Table 2. Flux Characteristics at 350mA, Junction Temperature T_J=25ºC

Color	Minimum Luminous Flux (lm) or Radiometric Power (MW) ϕ_V	Typical Luminous Flux (lm) or Radiometric Power (MW) ϕ_V
White	13.9	25
Green	13.9	30
Cyan	13.9	30
Blue	3.8	10
Royal Blue	55 mW	150 mW
Red	13.9	27
Amber	10.7	25

The brightness is directly related to the current driving the LED. A test was conducted in a closed box with a white LED mounted 12 inches away from the light meter. The results showed a linear relationship between current and light output as shown in figure 2. Figure 2 also shows the relation between current and forward drop of the LED.

5. Design Consideration

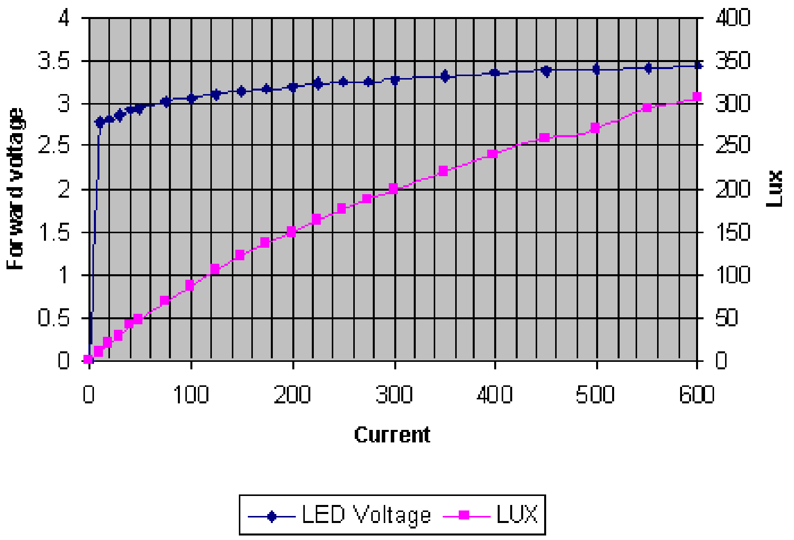
The main consideration in designing this constant current power supply is the transformer. Since one to four LEDs can be operated, and each LED is 3.5 volts nominal, the output can vary from 3.5V to 14 volts. The output voltage will be reflected back across the transformer and will in turn change the Vdd voltage to the control circuit and the peak Vds voltage across the MOSFET. The transformer must be designed with three limiting factors in mind.

1) Vdd, which has a range of 9 volts for under voltage to 38 volts for the over voltage threshold.

2) Wattage, specified at 8 watts for the VIPer12A and 12 watts for the VIPer22A.

3) Reflected voltage across the drain of the MOSFET which is the turn ratio of (Np/Ns)*Vout, added to the input voltage and must be below 730 volts

Figure 2. Current Vs. Lux and Vf



In order to keep the reflected voltage manageable, the transformer is designed for a turn's ratio of primary to secondary output voltage for the maximum number of LEDs. Using these criteria, as the number of LEDs is reduced, so is the reflected voltage. If the transformer were based on one LED then the reflected voltage would quadruple with 4 LEDs and may exceed the rating of the Viper. The turn's ratio between secondary to the Vdd winding is set for an output voltage of one LED to the minimum Vdd voltage, of 9 volts. As more LEDs are added, the Vdd voltage increases proportionally until it reaches the overvoltage shutdown point of 42 volts nominal. With this starting point a table can be derived as shown in table 3 for the VIPer12 and table 4 for VIPer22A. The yellow squares indicate parameters that are approaching the limit for that parameter. The following table shows the results of the parameters that should be considered for the proper design.

Table 3. 1 to 4 LEDs System at 350 mA

# of LED	Output voltage at 350 mA (1)	Vdd	Output Wattage	V reflected	Vds not including spike at 375Vdc	Turns ratio Ns/Np
1	3.57	10.05	1.25	30.51282	405.5128	0.117
2	6.99	18.33	2.45	59.74359	434.7436	Nvdd/Ns
3	10.41	26.60	3.64	88.97436	463.9744	2.419
4	13.83	34.87	4.84	118.2051	493.2051	
5	17.25	43.15	6.04	147.4359	522.4359	

(1) The output voltage includes 0.175 volt drop in the current sense resistor.

In the case of table 3, the Vdd would be the limiting factor reaching the over voltage shut down point.
In the case of table 4, the Vdd would be the limiting factor reaching the overvoltage shutdown point. The turn ratio of primary to secondary is based on the highest output voltage for 8 LEDs. The VIPer12A and VIPer22A are ideal for this application because of the wide range of Vdd. This ranges from 8 to 42 volts typical. The overvoltage kicks in at 42 volts, preventing the addition of LEDs driving the output voltage, the voltage across the drain to source, and the wattage, from being exceeded.

Table 4. 2 to 8 LEDs System at 350mA

# of LED	Output voltage at 350 mA (2)	Vdd	Output Wattage	V reflected	Vds not including spike at 375Vdc	Turns ratio
2	6.99	10.63	2.45	33.12796	408.128	0.211
3	10.41	15.67	3.64	49.33649	424.3365	Nvdd/Ns
4	13.83	20.71	4.84	65.54502	440.545	1.474
5	17.25	25.75	6.04	81.75355	456.7536	
6	20.67	30.79	7.23	97.96209	472.9621	
7	24.09	35.84	8.43	114.1706	489.1706	
8	27.51	40.88	9.63	130.3791	505.3791	
9	30.93	45.92	10.83	146.5877	521.5877	

(2) The output voltage includes 0.175V drop in the current sense resistor.

The circuit shown in figure 4 can drive from 1 to 4 LEDs. The circuit shown in figure 5 can drive from 2 to 8 LEDs. Table 3 and 4 are based on the nominal voltage drop for a white LED as stated in the LED data sheet of table 1. Because of the Vf spread, the maximum number of LEDs can be limited to 3 LEDs for the VIPer12A and 6 LEDs for the VIPer22A demo board. Worse case parameters must be considered for a robust design. If the design calls for a fixed number of LEDs, than the only limiting factor is the VIPer maximum output power capability which can increase the number of LEDs.

6. Transformer Specification

The transformer is designed and manufactured by Cramer Coil and Transformer Co. The electrical characteristics of the transformer in table 5 are shown.

Table 5. Electrical Characteristics of the Trasformer

Primary Inductance	3.25mH ±10%
Primary Leakage Inductance	39.9 µH typical
HIPOT (N1, N3, N4 to N2)	4000VAC, 1Sec
Turns Ratio (N1/N4:N2)	1:0.117
Turns Ratio (N1/N4:N3)	1:0.283

When the VIPerX2A (U4) is on, energy is stored in the primary winding of transformer (8-10), T1. This energy is transferred to the auxiliary winding (5-6), and to the output (1-2) when the VIPerX2A turns off.The auxiliary winding provides the bias voltage for the VIPerX2A at pin 4 (Vdd).

Figure 3. Mechanical Characteristics of the Trasformer

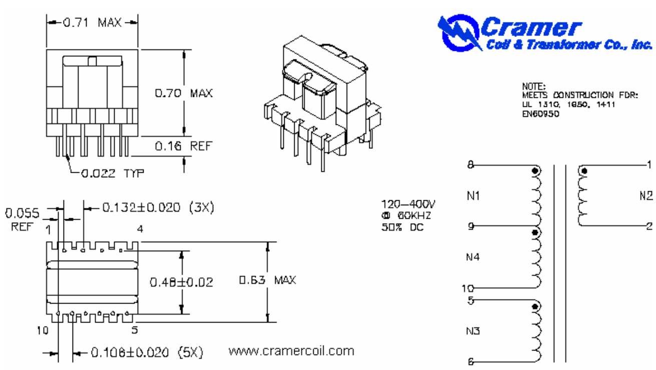


Figure 4: VIPer12A Constant Current Led Driver Schematic

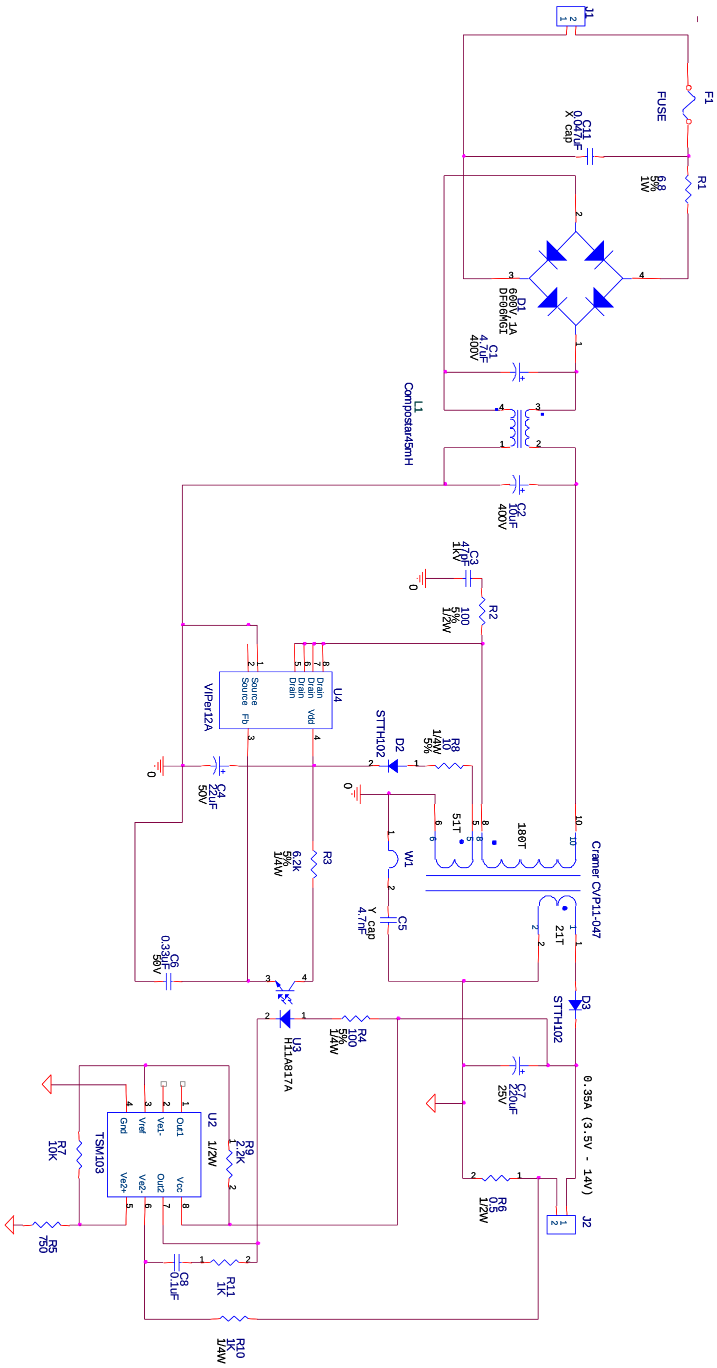
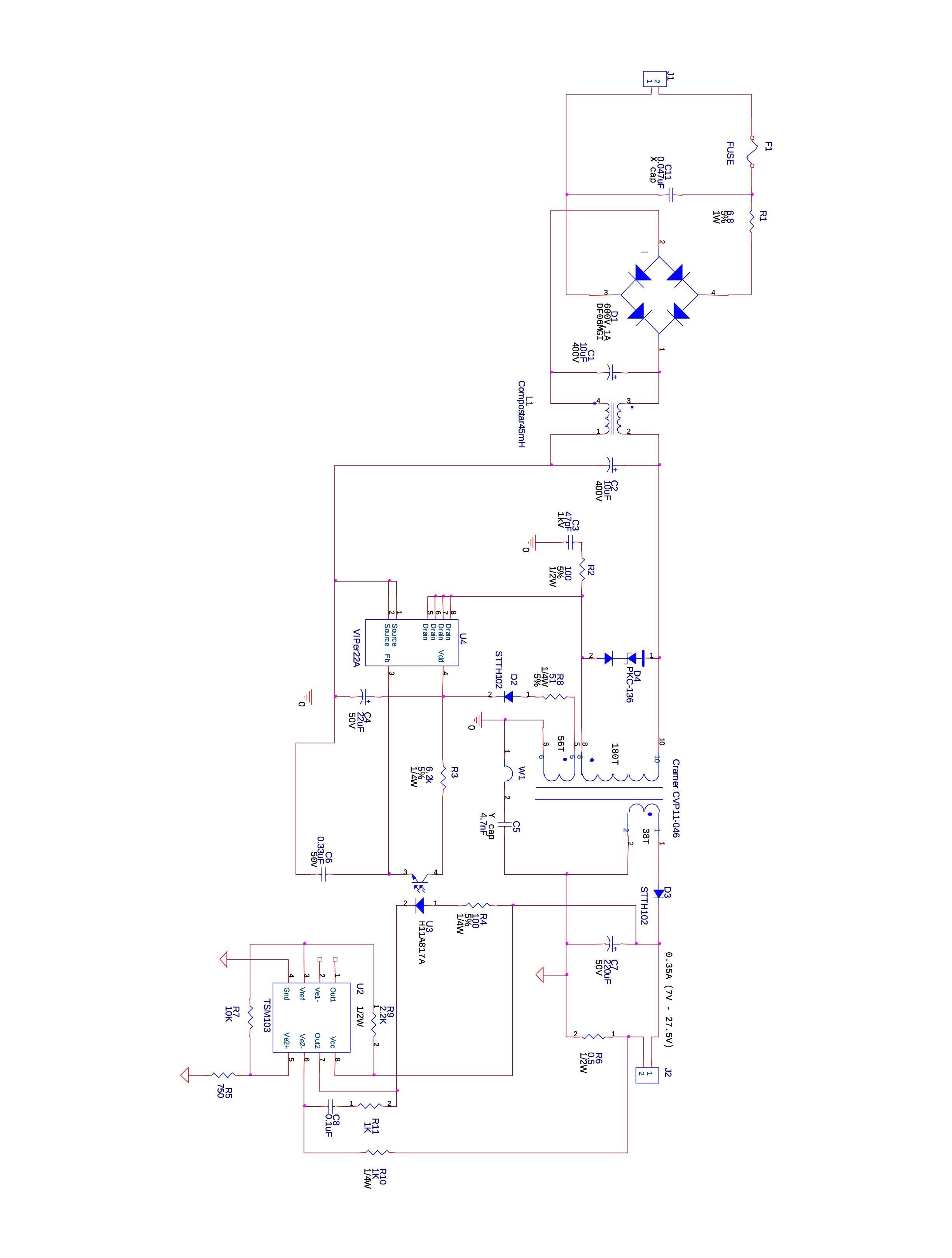


Figure 5: VIPer22A Constant Current Led Driver Schematic



7. Components List

Table 6: Bill of Materials for VIPer12A Solution

Qty	Reference	Description
1	D1	600V, 1A bridge
1	C1	4.7µF/400V electrolytic
1	C2	10µF/400V electrolytic
1	C3	47pF 1kV ceramic
1	C4	22µF/50V electrolytic
1	C5	4.7nF 250V Y cap
1	C6	0.33µF 50V ceramic
1	C7	220µF/25V electrolytic
1	C8	0.1µF 50V ceramic
1	C11	0.047µF 250V boxcap
2	D2, D3	**STMicroelectronics STTH102**
1	D4	Not used
1	F1	0.5A 250V fuse
2	J1, J2	Connectors
1	L1	Compostar 2 x 45mH inductor FUU10S-V24503-Q22650
1	R1	6.8Ω 5% 1W
1	R2	100Ω 5% 0.5W
1	R3	6.2KΩ 5% 0.25W
1	R4	100Ω 5% 0.25W
1	R5	750Ω 5% 0.25W
1	R6	0.5Ω 0.25W
1	R7	10KΩ 5% 0.25W
1	R8	10Ω 5% 0.25W
1	R9	2.2KΩ 5% 0.25W
2	R10, R11	1KΩ 5% 0.25W
1	T1	Cramer Coil transformer CVP11-047
1	U3	H11A817A or LTV817A
1	U4	**STMicroelectronics VIPer12A**
1	U5A	**STMicroelectronics TSM103**
2	W1, C10	Jumper wire

8. PCB Layout

The following components are changed for the VIPer22A constant current LED driver configuration.

Table 7. BOM Change for VIPer22A Solution

Qty	Reference	Description
1	C1	10uF/400V electrolytic
1	C7	220uF/50V electrolytic
1	R8	51Ω 5% 0.25W
1	D4	**STMicroelectronics PKC-136**
1	T1	Cramer Coil transformer CVP11-046
1	U4	**STMicroelectronics VIPer22A**

Figure 6. Board Top Legend (not in scale)

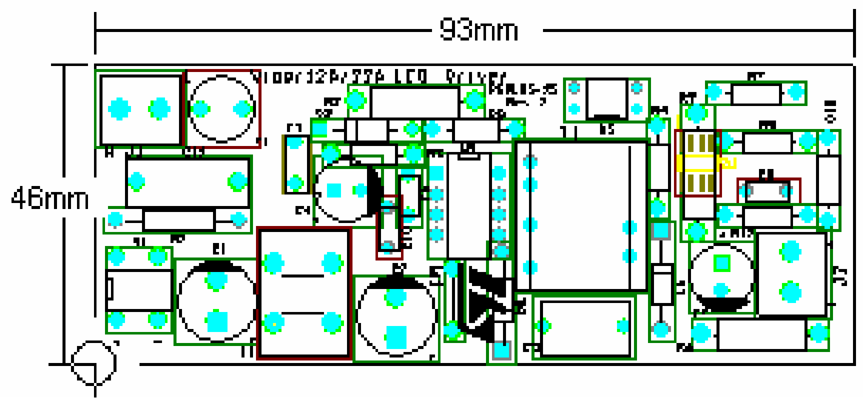
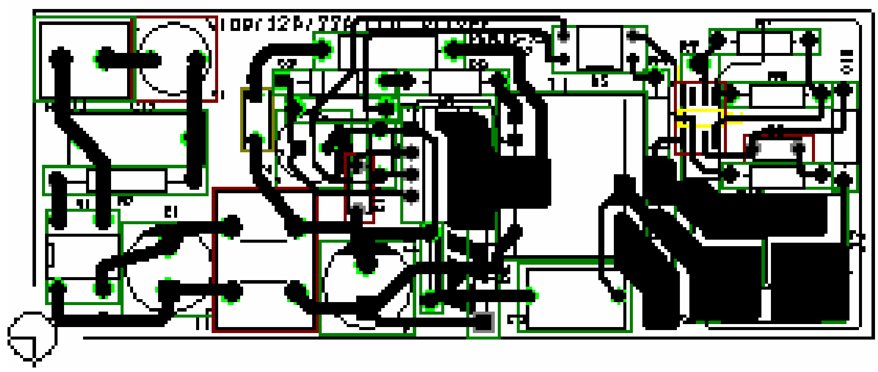


Figure 7. Board Bottom Foil Viewed From Top Side (not in scale)



9. General Circuit Description

The designs operate from 90 to 264Vac input. The AC input is rectified and filtered by the bridge BR1 to generate the high voltage DC bus that is applied to the primary winding of the transformer, CVP11-04X. C1, L1, C2, and C11 provide EMI filtering for the circuit.

A snubber circuit that consists of R2 and C3 reduces the leakage spike and voltage ringing on the drain pin of VIPerX2A, thereby provides additional EMI filtering. A transil, PKC-136, is used to clamp the drain voltage at a safe level for the VIPer22A constant current LED driver configuration because of the extra power level.

The current is controlled by monitoring the voltage drop across the sense resistor, R6. The non-inverting input of the operational amplifier inside TSM103 is set to 175mV through the resistors divider, R5 and R7. This operational amplifier will then regulate the inverting input to 175mV by adjusting its output by changing the current going through the optocoupler, H11A817A (U3). The gain of the transistor inside the optocoupler then controls the feedback loop of VIPerX2A.

The LED drive current is given by the equation:

$$I_{out} = 0.175V/R6$$

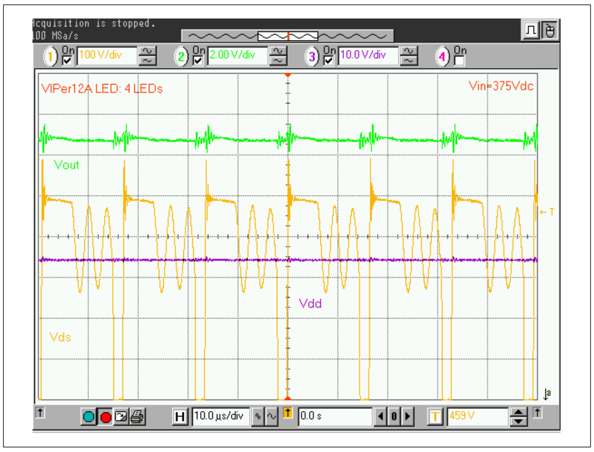
C6, C8, and R11 are utilized to ensure the stability of the circuit. C7 reduces the ripple current.

10. Waveforms

Figure 8 shows VDD, Vout, and VDS at 375Vdc with one LED at the output for the VIPer12A constant current LED driver configuration while figure 9 shows likewise with four LEDs at the output.

Figure 8. VIPer12A with 1 LED at Output

Figure 9. VIPer12A with 4 LEDs at Output



The drain to source voltage, VDD, and Vout waveforms are shown in figure 12 and figure 13, taken at 375Vdc for two and eight LEDs at the output respectively. It can be seen at worse case condition, the voltages across the device are not exceeded.

Figure 10. VIPer12A EMI

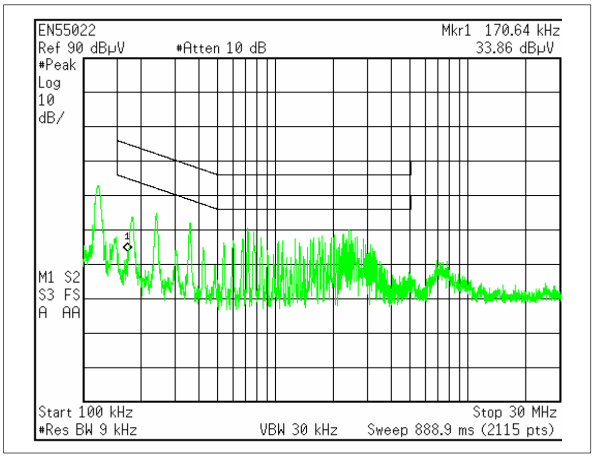


Figure 11. VIPer22A EMI

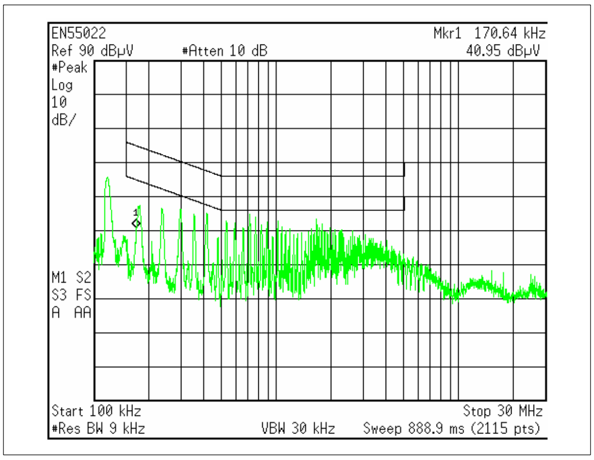
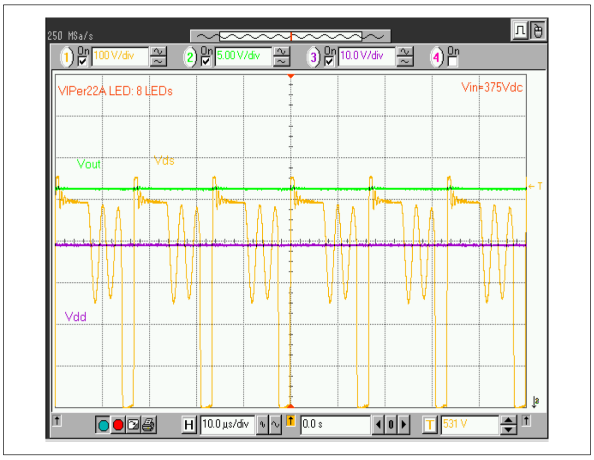


Figure 12. VIPer22A with 2 LEDs at Output

Figure 13. VIPer22A with 8 LEDs at Output



11. EMI Results

Both VIPer12A and VIPer22A constant current LED driver configurations were designed to pass EN55022 Class B EMI at 120Vac input. Peak EMI is met with a comfortable margin.

12. Current Regulation

The VIPer12A and the VIPer22A have excellent regulation as shown in figures 14 and 15.

Figure 14. VIPer12A Current Regulation

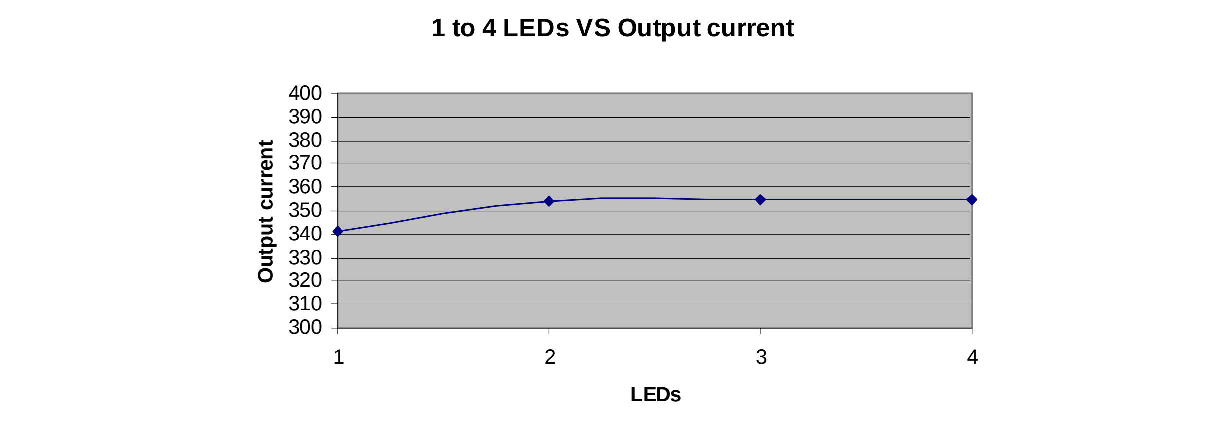


Figure 15. VIPer22A Current Regulation

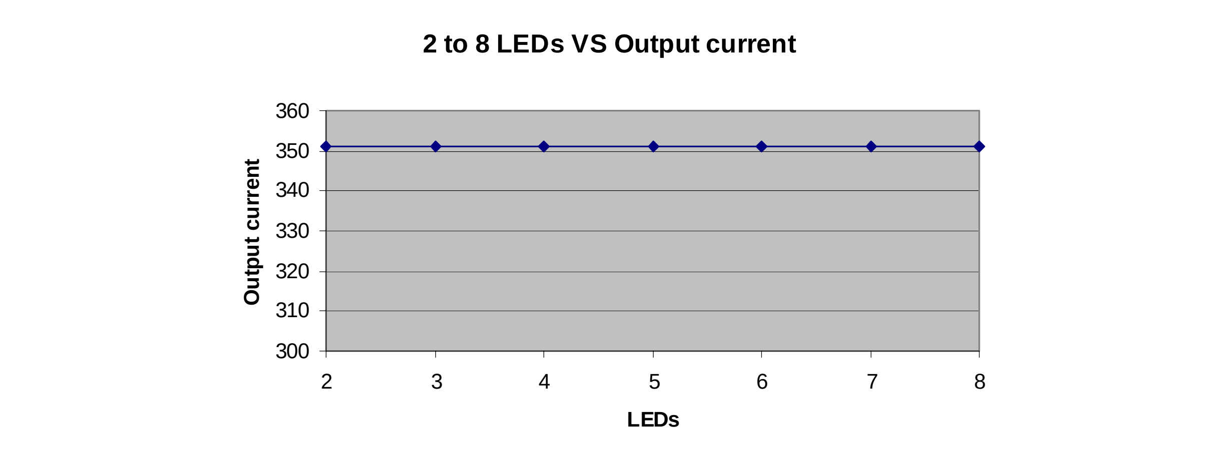


Figure 16. Ripple at 264Vac (VIPer12A)

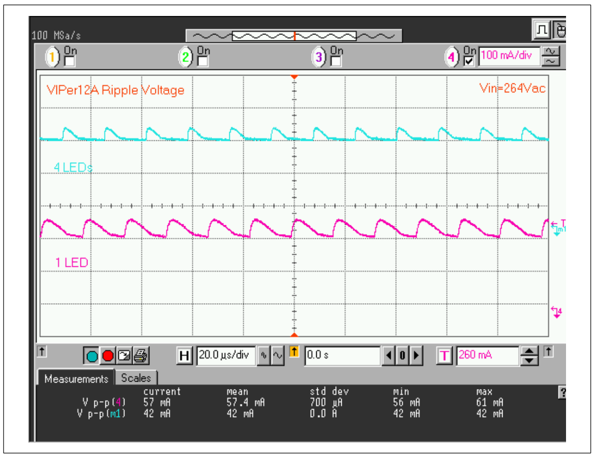
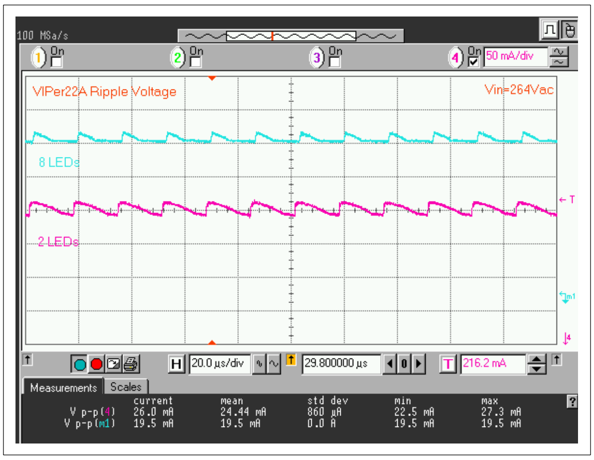


Figure 17. Ripple at 264Vac (VIPer22A)



13. Ripple Current

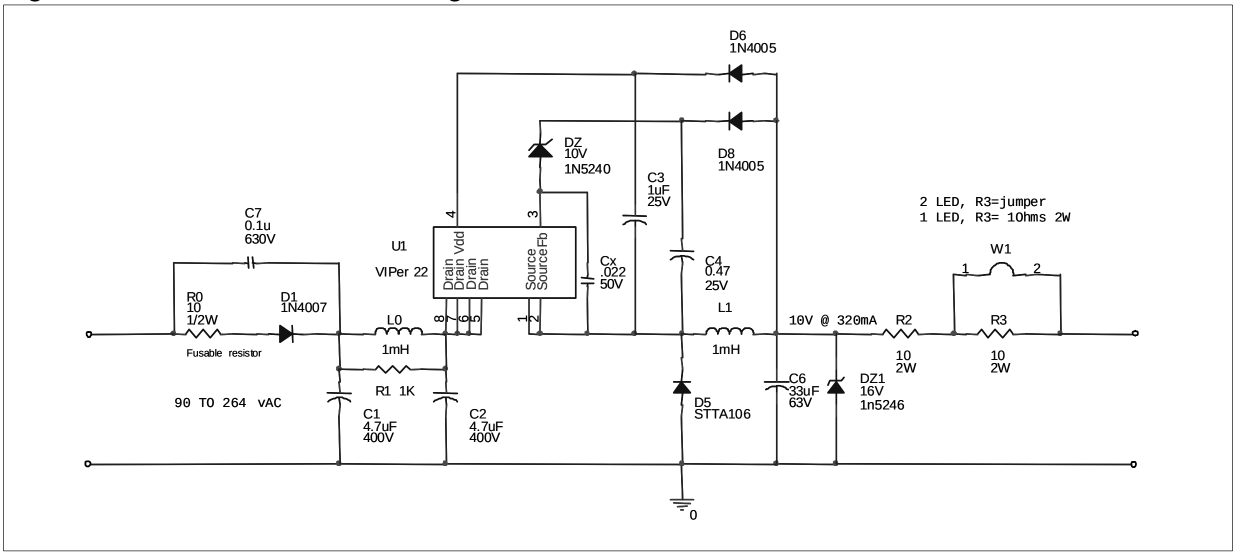
The ripple current measured at 90Vac with one LED at the output is 59mVpp and it is 57mVpp at 264Vac input for the VIPer12A (figure 16) constant current LED driver configuration. With four LEDs at the output the measured ripple current is 46mVpp at 90Vac input.

Figure 17 shows the ripple current measurements for the VIPer22A constant current LED driver configuration. Here, the measured ripple is 26mVpp at 264Vac input with 2 LEDs at the output while the ripple is 19.5mVpp for 8 LEDs at the output.

14. Low-cost Option

A lower cost alternative to the isolated VIPer12A power supply is to use the VIPer22A in a non-isolated Buck configuration as shown in figure 18. The circuit uses fewer and less expensive parts for systems that do not require safety isolation.

Figure 18. Non-Isolated Buck Configuration Schematic



C1, L0, and C2 form an EMI filter to meet emission standards. D6, C3 maintain voltage for Vdd. L1 and C6 form the output filter to average the DC output. The output is voltage regulated at 10 volts by the zener diode DZ1. R2 drops the voltage and sets the current to approximately 330mA. A different value resistor can be used to set the current to a value up to 370mA which is the limiting factor of L1, the output inductor. This unit will drive 2 LEDs or 1 LED by cutting one jumper before use. To drive 1 LED only, the jumper can be cut, placing a second resistor in series with the output to drop additional voltage. This is not as efficient as the previous design but simpler and less expensive.

The output is set to 10 volts because that is the minimum output voltage that will drive the VIPer22A with these minimum parts. With the addition of an inductor, 2 of 1N4005 and a small capacitor, a lower voltage can be designed to increase the efficiency.

Table 8: Bill of Material for Low-Cost Solution

Qty	Reference	Description
1	Cx	0.022µF/50V 1206SM
2	C1, C2	4.7µF/400V electrolytic
1	C3	1µF/25V electrolytic
1	C4	0.47µF/25V 1206SM
1	C6	33µF/63V low ESR
1	C7	0.1µF/630V poly
1	DZ	1N5240 (10V)
1	DZ1	1N5246 (16V)
1	D1	1N4007
1	D5	**STMicroelectronics STTA106**
2	D6, D8	1N4005
1	L0	1mH 160mA JW Miller 5300-37
1	L1	1mH 400mA Compostar Q3277
1	R0	10Ω 1/2W fusable resistor
1	R1	1kΩ 1/4W
2	R2, R3	10Ω 2W
1	U1	**STMicroelectronics VIPer22A**
1	W1	Jumper wire

15. PCB Layout

Below is a reference design of the VIPer22A-Buck LED driver above. The board measures 67mm by 26mm.

16. Conclusion

We have shown two isolated and one non-isolated off line power supplies to efficiently drive LEDs in series.

Figure 19. Low-cost Constant Current Led Driver Board Layout