AN2811
Application note

3.5 W non-isolated offline constant-current LED driver based on VIPER17

Introduction

High brightness LEDs are becoming a prominent source of lighting. Compared to conventional incandescent bulbs, high brightness LEDs (light emitting diodes) have advantages in higher light efficacy, much longer life and faster reaction time in a smaller profile. Since LEDs cannot sustain high voltage stress directly from an AC source, providing a reliable constant-current source to drive LEDs becomes fundamental. This solution provides even luminosity, reliability, the highest efficacy and the longest operating life for LEDs.

This application note describes the non-isolated offline constant-current driver based on the VIPER17HN (high frequency version). This solution operates with an AC line input range from 176 V to 264 VAC and provides 500 mA constant current from a 7 VDC source. It can illuminate two LEDs in series.

This device is an offline converter with an 800 V rugged power section, a PWM control, twice the level of overcurrent protection, overvoltage and overload protections, hysteretic thermal protection, soft-start and also safe auto-restart after any fault condition removal. The embedded brownout function protects this switch mode power supply in case the main input voltage falls below the specified minimum level for this system.

Figure 1. STEVAL-ILL017V1 demonstration board

AM00611v1

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1 Safety instructions

Warning: The demonstration board must be used in a suitable laboratory by only qualified personnel who are familiar with the installation, use, and maintenance of electrical systems.

Intended use

The demonstration board is a component designed for demonstration purposes only, and shall be used neither for domestic installation nor for industrial installation. The technical data as well as the information concerning the power supply and working conditions shall be taken from the documentation included with the demonstration board and strictly observed.

Installation

The installation of the demonstration board shall be taken from the present document and strictly observed. The components must be protected against excessive strain. In particular, no components are to be bent, or isolating distances altered during the transportation, handling or usage. The demonstration board contains electro-statically sensitive components that are prone to damage through improper use. Electrical components must not be mechanically damaged or destroyed (to avoid potential risks and health injury).

Electrical connection

Applicable national accident prevention rules must be followed when working on the mains power supply. The electrical installation shall be completed in accordance with the appropriate requirements (e.g. cross-sectional areas of conductors, fusing, and PE connections).

Board operation

A system architecture which supplies power to the demonstration board shall be equipped with additional control and protective devices in accordance with the applicable safety requirements (e.g. compliance with technical equipment and accident prevention rules).

2 Design considerations

2.1 Selected topology

This is a 500 mA constant-current source conversion from 176 VAC ~ 264 VAC line input. The specifications shown in *Table 1* are for refrigerator lighting usage.

Table 1. Specifications

Parameter	Value
AC input	220 VAC ± 20%
Output current	500 mA
Output voltage	7 V max
Dimensions	30 mm x 30 mm
Isolation	Not required
Topology	Constant-current source

According to the specifications the maximum operating power is 3.5 watts. No power factor correction circuit is required. Therefore, both buck and flyback topologies are suitable for this application. *Figure 2* shows the conventional buck converter while *Figure 4* illustrates the flyback converter. To convert high voltage to low voltage, a conventional buck converter just requires a few components. Output current ripple is small due to Vout obtained from inherent filter L1 and C1, thus the voltage and current stresses on these power components are small. In order to properly drive the MOSFET (Q1), a controller and an additional transformer are required. Additional winding with L1 to bias Q1 as well as a feedback current to manage output in constant-current mode are needed.

Figure 2. Conventional buck converter

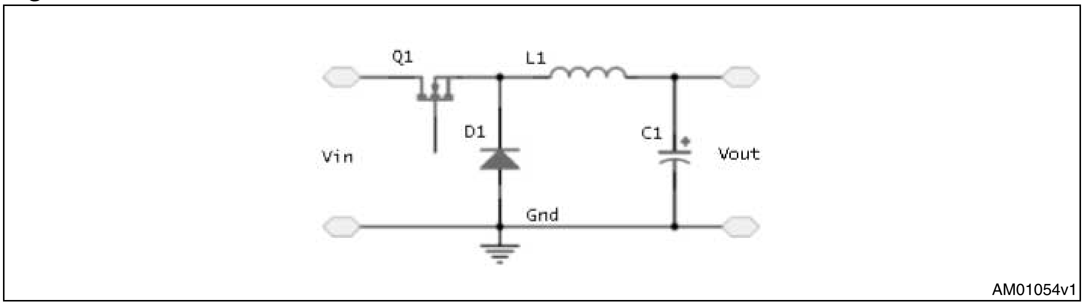
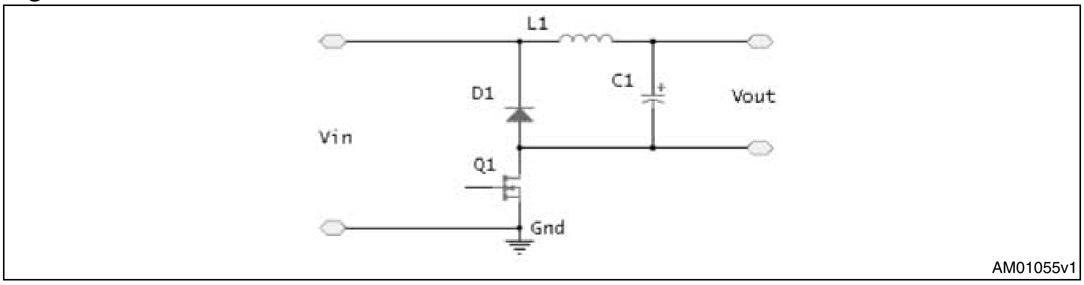
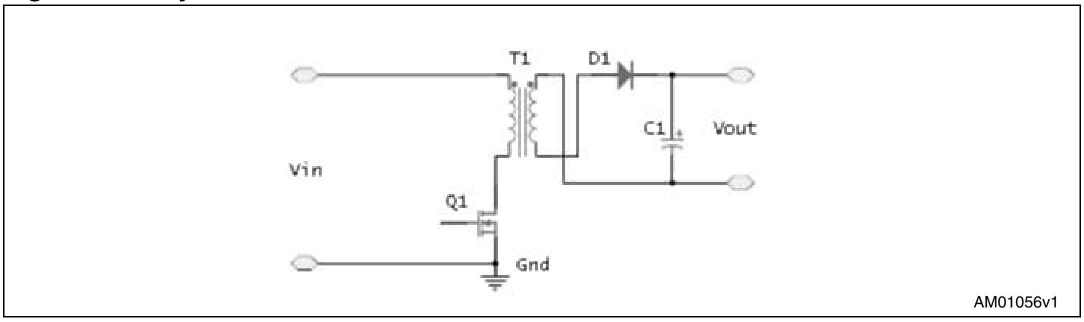


Figure 3. **Modified buck converter**



For ease in driving Q1 using a conventional buck converter, a modified buck converter has been introduced as shown in *Figure 3*. Such topology is widely used to drive LEDs. With this modified solution, the MOSFET is no longer floating. In this case the output (Vout) is not connected to ground, and it becomes quite difficult to sense the output current in the output stage directly. Compared to a buck converter, the flyback converter may be the better choice. *Figure 4* shows the typical circuit of a flyback converter.

Figure 4. **Flyback converter**



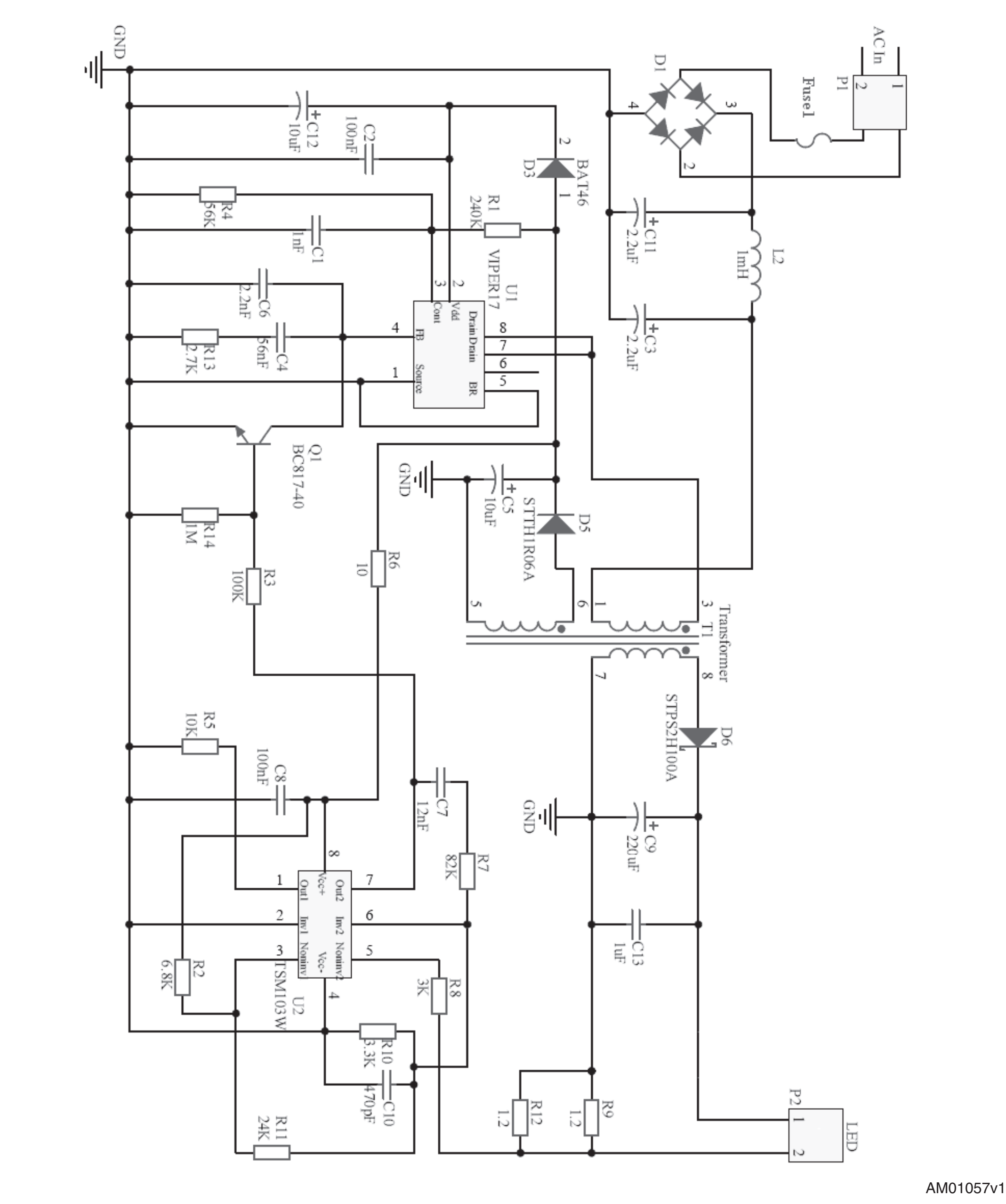
The auxiliary winding can be added to the transformer (T1) to provide bias for Q1. Unlike the buck converter, T1 provides isolation between Vin and Vout. Since such isolation is not required for this application, a current sense resistor can be placed across the primary ground and negative polarity of Vout. Thus, Vout shares the same primary ground. In this topology, the MOSFET is not floating. Thanks to VIPer17 the board is built with a high-performance low-voltage controller chip with an 800 V avalanche rugged power MOSFET. Designed with VIPer17, only a few external components are required which allows a smaller profile in the design.

3 General circuit description

3.1 Schematic diagram

Figure 5 shows the complete schematic diagram of the demonstration board. It consists of an input full-bridge rectifier with filtering circuit, flyback converter and output stage.

Figure 5. Schematic diagram of demonstration board



Referring to the schematic diagram in *Figure 5*, fuse1 is the input fuse to prevent hazards if the system current exceeds the fuse rating. D1 is the bridge rectifier to convert AC to DC. The filter is formed by C11, L2 and C3 that are used to attenuate the high frequency harmonic interference. T1 is the flyback transformer and U1 is formed by the PWM controller and output MOSFET. The auxiliary winding (pin 5 and 6) and diode D5 provide bias supply for each control circuit. The output stage includes D6, C9 and C13. R9 and R12 are the output current sense resistors providing current sense signal. These are connected in parallel to share the power dissipation.

The constant-current control circuit consists of U2, Q1, U1 and some passive components. The output current sense signal feeds to OP amp in U2. R7 and C7 consist of the compensation network for the output signal of U2 in order to properly drive Q1. The 0.3 V reference voltage on pin 6 of U2 is obtained by voltage divider R11 and R10. The collector junction of Q1 is connected to the feedback pin of U1 and completes the feedback loop.

The output voltage is indirectly monitored by the auxiliary winding (pin 5 and 6 of T1) and feedback to pin 3 of U1 through R1 and R4. Once the voltage at pin 3 of U1 exceeds 3 V, U1 shuts down, then enters the auto-restart mode. Thanks to U1, which includes an overload protection function, if the LED is absent in the application (no load), this solution provides a safeguard. The LED and the application board are both fully protected.

3.2 Bill of material

Table 2. Bill of material

Name	Value	Rated	Type
C1	1 nF	25 V	Ceramic cap [0603]
C2, C8	100 nF	25 V	Ceramic cap [0603]
C3, C11	2.2 µF	400 V	Al elcap CAPPR3.5-8X12
C4	56 nF	25 V	Ceramic cap [0603]
C5, C12	10 µF	25 V	Al elcap CAPPR2-5X11
C6	2.2 nF	25 V	Ceramic cap [0603]
C7	12 nF	25 V	Ceramic cap [0603]
C9	220 µF	16 V	Al elcap CAPPR3.5-8X11.5
C10	470 pF	25 V	Ceramic cap [0603]
C13	1 µF	25 V	Ceramic cap [0805]
D1	MB6S PKG30 E3	1 A 600 V bridge rectifier	Vishay
D3	BAT46JFILM	Small signal Schottky diode	STMicroelectronics [SOD323]
D5	STTH1R06A	1 A 600 V ultrafast rectifier	STMicroelectronics [SMA]
D6	STPS2H100A	2 A 100 V Schottky rectifier	STMicroelectronics [SMA]
Fuse1	500 mA 250 V	Fuse_5_8.5*8_Bel	
L2	LPS3314-105ML	1 mH, 0.1 A	Inductor, Coilcraft L_LP3314
Q1	BC817-40	NPN general-purpose transistor	[SOT-23]
R1	240 kΩ	1%	Resistor [0603]

Table 2. Bill of material (continued)

Name	Value	Rated	Type
R2	6.8 kΩ	1%	Resistor [0603]
R3	100 kΩ	1%	Resistor [0603]
R4	56 kΩ	1%	Resistor [0603]
R5	10 kΩ	1%	Resistor [0603]
R6	10 Ω	1%	Resistor [0603]
R7	82 kΩ	1%	Resistor [0603]
R8	3 kΩ	1%	Resistor [0603]
R9, R12	1.2 Ω	1%	Resistor [1206]
R10	3.3 kΩ	1%	Resistor [0603]
R11	24 kΩ	1%	Resistor [0603]
R13	2.7 kΩ	1%	Resistor [0603]
R14	1 MΩ	1%	Resistor [0603]
T1 (1)	T_EE10/11_TDK	1 mH	TDK flyback transformer
U1	VIPER17HN	Offline high voltage converter	STMicroelectronics [DIP-7]
U2	TSM103W	Dual OP and voltage reference	STMicroelectronics [SO-8]

1. T1, the transformer design, is shown in *Section 3.4 on page 11*. *Table 3* gives the basic electrical characteristics, *Figure 8* shows the winding structure, and *Figure 9* illustrates the bobbin outline.

3.3 PCB layout view

The PCB views are shown in *Figure 6* and *Figure 7*.

Figure 6. Top view

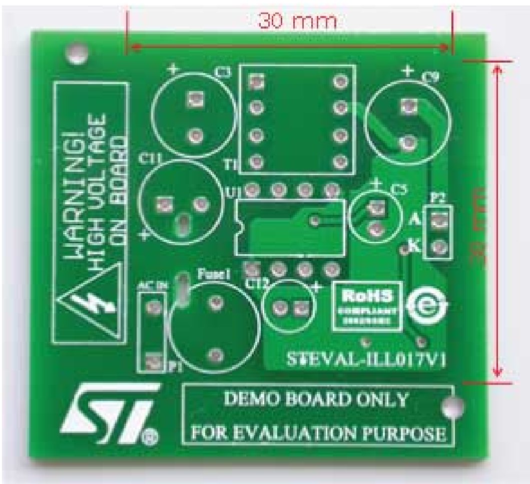


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Figure 7. Bottom view with SMD parts

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3.4 Transformer design

Table 3. Basic electrical characteristics of flyback transformer (T1)

Name	Value
Core type	EE10/11-PC40
Bobbin type	BE10-118CPSFR
Primary inductance	1 mH +/- 10%
Leakage inductance	10 µH typical

Figure 8. Winding structure

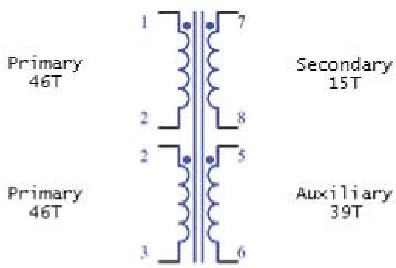

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Figure 9. Bobbin outline

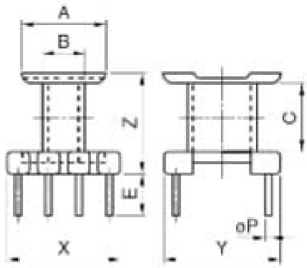

Table 4. Bobbin dimensions

Dimension	Value
A	7.2 mm
B	3.5 mm
C	6.6 mm
E	3.85 mm
X	10.2 mm
Y	10.2 mm
Z	9 mm
P	0.5 mm

4 Test results and waveforms

Figure 10 shows the overall efficiency versus a range of AC line voltage loads with one LED and two LEDs. Under both load conditions, we can observe that the efficiency drops when input voltage increases. The maximum efficiency occurs at minimum AC line input (176 VAC). Comparing a load condition of one LED with a load condition of two LEDs in series, the efficiency increases by 7%. The efficiency with 1 LED is close to 75%.

Figure 10. Efficiency versus input voltage

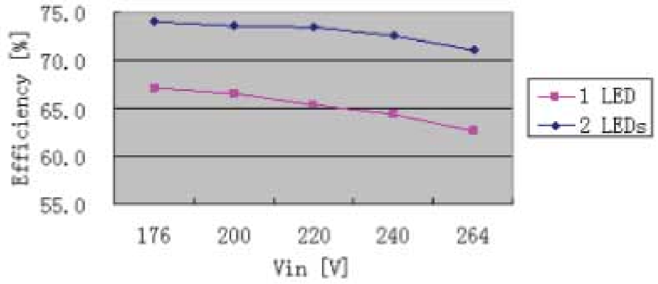

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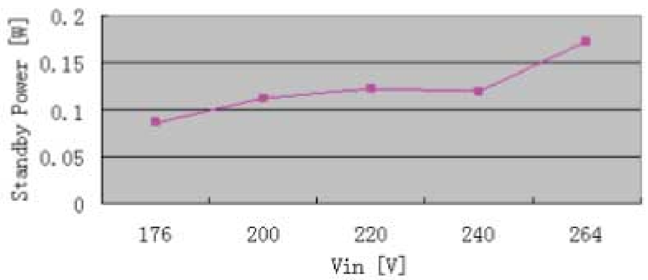
Figure 11 shows us the standby power which is measured when the LED is disconnected. Standby does not mean burst mode under light load. In standby, the overvoltage protection works. Under various AC line inputs, the maximum standby power is 0.18 W at 264 V input.

Figure 11. Standby power versus input voltage

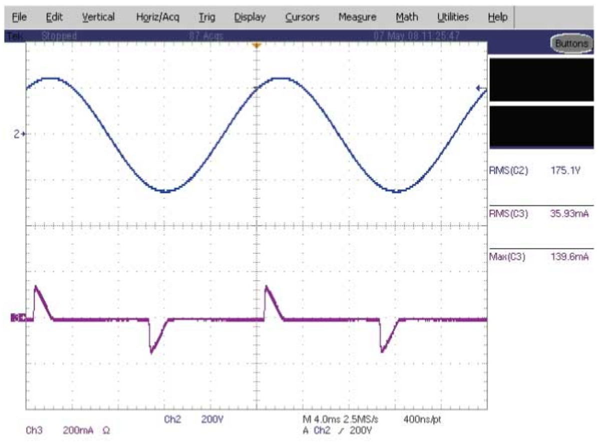


AM01063v1

With the aid of the filter formed by C11, L2 and C3, no high-frequency interference can be observed at the input current which definitely helps in meeting the conducted EMI standard. In *Figure 12* and *Figure 13* the waveform is captured at 176 VAC. In *Figure 14* and *Figure 15* the waveform is captured at 264 VAC.

To choose the proper rating of the fuse, we always refer to the inrush current. There are two inrush current plots at the AC line input 220 V: *Figure 16* with one LED and *Figure 17* with two LEDs.

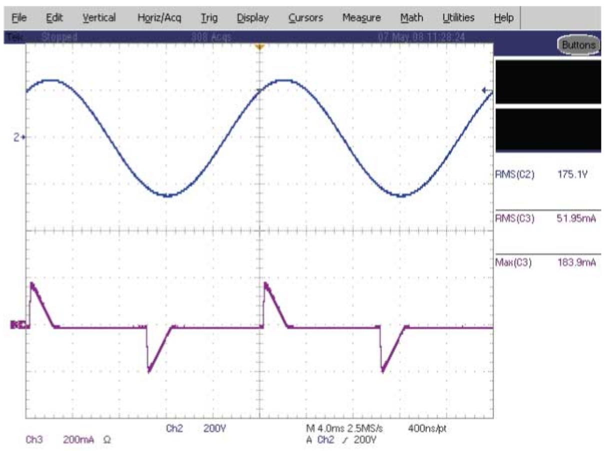
Figure 12. Vin and Iin at 176 VAC, one LED



AM01064v1

Top trace: Vin (200 V/div)
Bottom trace: Iin (200 mA/div)
Time: 4 ms/div

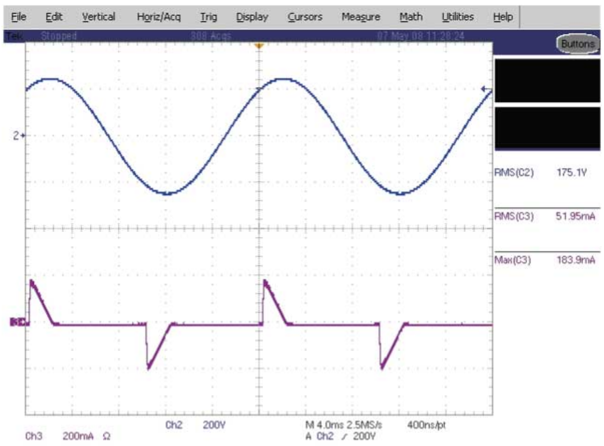
Figure 13. Vin and Iin at 176 VAC, two LEDs



AM01065v1

Top trace: Vin (200 V/div)
Bottom trace: Iin (200 mA/div)
Time: 4 ms/div

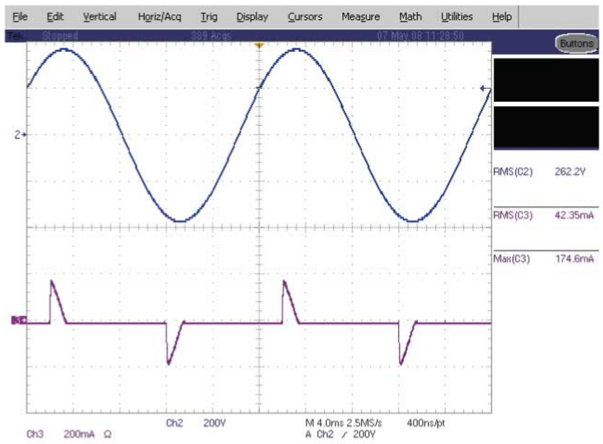
Figure 14. Vin and Iin at 264 VAC, one LED



AM01066v1

Top trace: Vin (200 V/div)
Bottom trace: Iin (200 mA/div)
Time: 4 ms/div

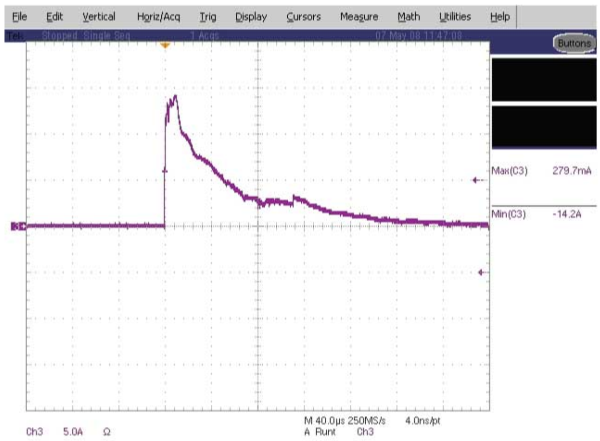
Figure 15. Vin and Iin at 264 VAC, two LEDs



AM01067v1

Top trace: Vin (200 V/div)
Bottom trace: Iin (200 mA/div)
Time: 4 ms/div

Figure 16. Inrush current at LINE IN, one LED

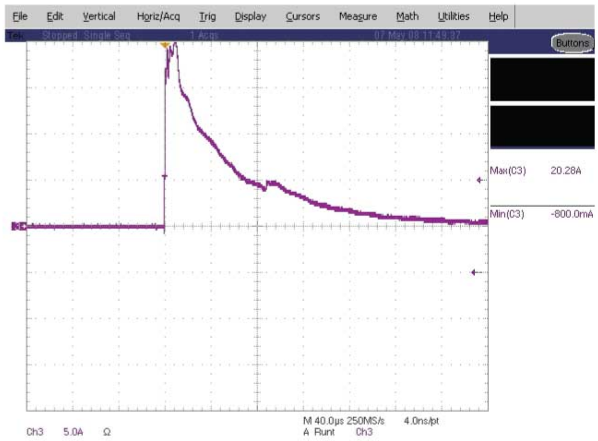


AM01068v1

Iin: 5 A/div, 40 us/div

Max. value: 14.2 A

Figure 17. Inrush current at LINE IN, two LEDs



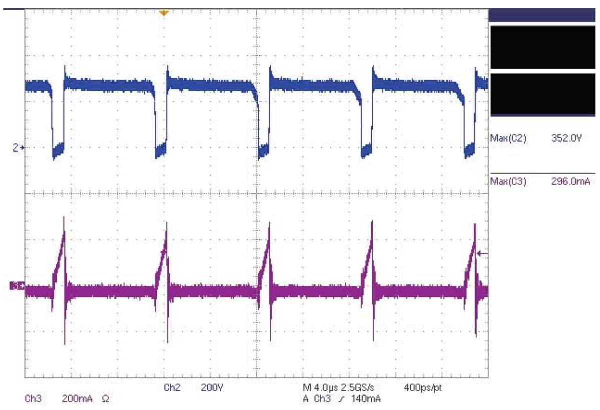
AM01069v1

Iin: 5 A/div, 40 us/div

Max. value: 20.28 A

The VIPer17 integrates one 800 V MOSFET and the drain current is limited at 0.6 A. The drain-source voltage and drain current waveforms are shown in *Figure 18* through *21*. In *Figure 18* and *Figure 19* the waveform is captured at 176 VAC. In *Figure 20* and *Figure 21* the waveform is captured at 264 VAC. The peak drain voltage, 496 V, is obtained at 264 V load with two LEDs (see *Figure 21*). Under the same condition, the peak drain current is 384 mA.

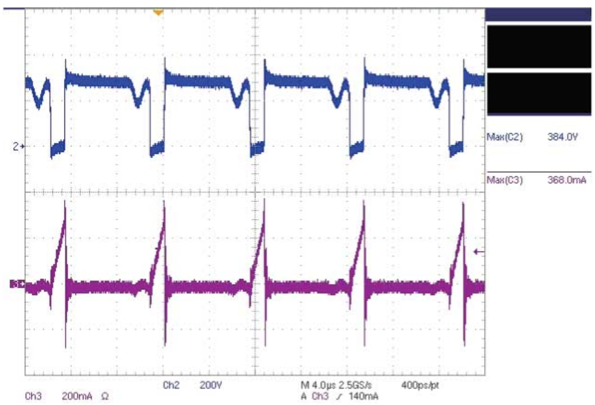
Figure 18. Vds and Id at 176 VAC, one LED



AM01070v1

Top trace: Vin (200 V/div)
Bottom trace: Iin (200 mA/div)
Time: 4 us/div

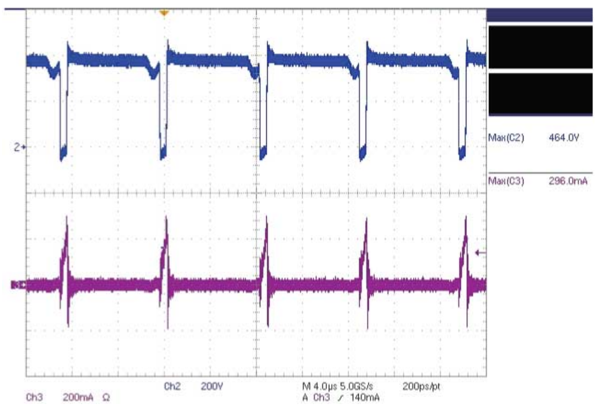
Figure 19. Vds and Id at 176 VAC, two LEDs



AM01071v1

Top trace: Vin (200 V/div)
Bottom trace: Iin (200 mA/div)
Time: 4 us/div

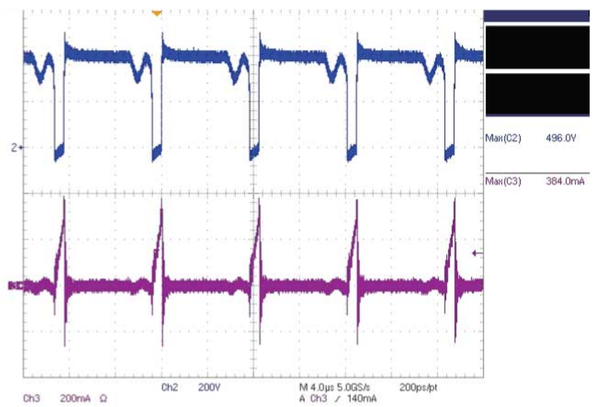
Figure 20. Vds and Id at 264 VAC, one LED



AM01072v1

Top trace: Vds (200 V/div)
Bottom trace: Id (200 mA/div)
Time: 4 us/div

Figure 21. Vds and Id at 264 VAC, two LEDs

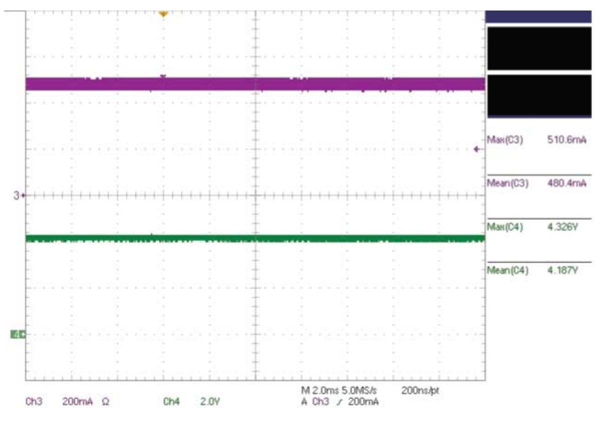


AM01073v1

Top trace: Vin (200 V/div)
Bottom trace: Iin (200 mA/div)
Time: 4 us/div

The current sense circuit (R9 and R12 in *Figure 5*) is one portion of output voltage. The additional voltage drop is 300 mV. The following figures show the output voltage and current waveforms for the load (one LED vs. two LEDs). In *Figure 22* and *Figure 23* the waveform is captured at 176 VAC. In *Figure 24* and *Figure 25* the waveform is captured at 264 VAC. We can observe that the output ripple current always less than 30 mA. Independent of the load condition, the output current is regulated at precisely 500 mA.

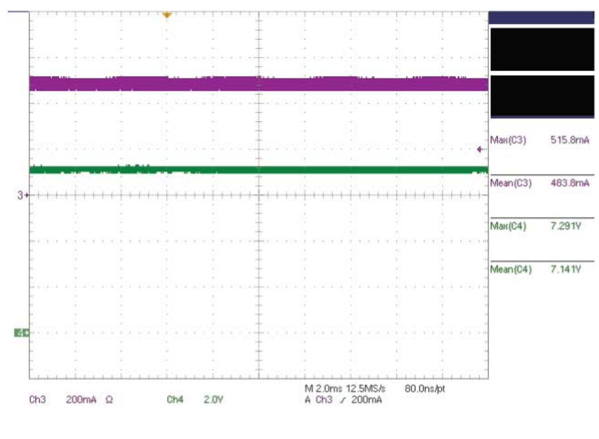
Figure 22. Vo and Io at 176 VAC, one LED



AM01074v1

Top trace: Io (200 mA/div)
Bottom trace: Vo (2 V/div)
Time: 2 ms/div

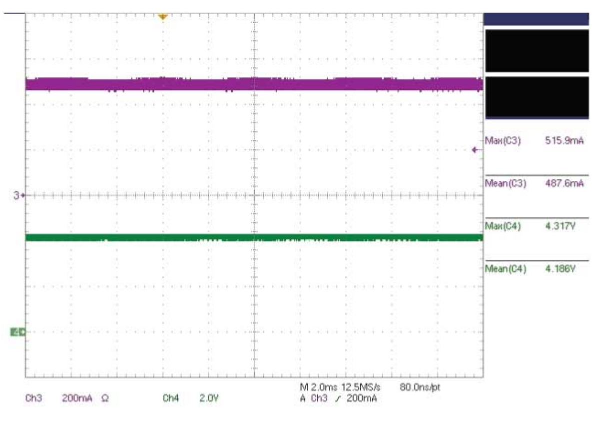
Figure 23. Vo and Io at 176 VAC, two LEDs



AM01075v1

Top trace: Io (200 mA/div)
Bottom trace: Vo (2 V/div)
Time: 2 ms/div

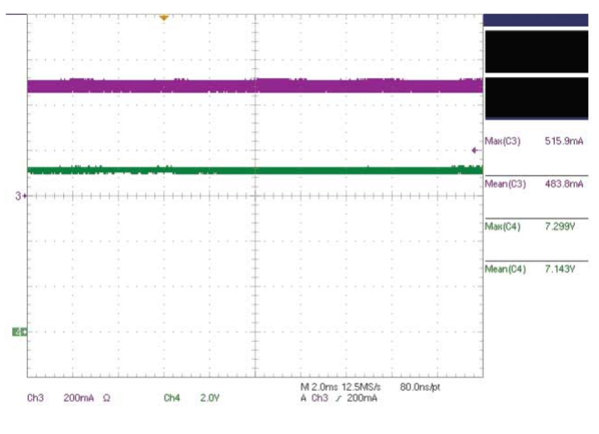
Figure 24. Vo and Io at 264 VAC, one LED



AM01076v1

Top trace: Io (200 mA/div)
Bottom trace: Vo (2 V/div)
Time: 2 ms/div

Figure 25. Vo and Io at 264 VAC, two LEDs

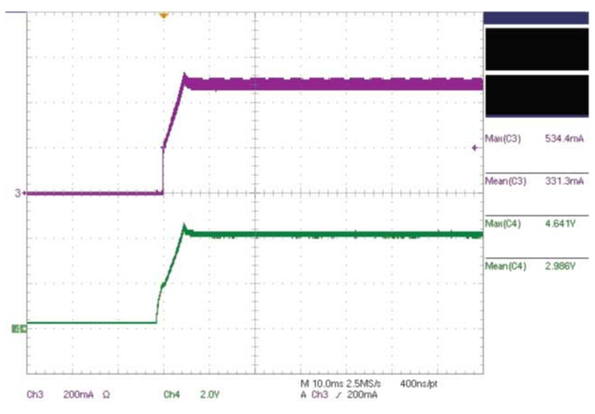


AM01077v1

Top trace: Io (200 mA/div)
Bottom trace: Vo (2 V/div)
Time: 2 ms/div

During the startup phase the output voltage response is optimized. No output voltage overshoot nor voltage spike has occurred thanks to the soft-start function and optimum regulation performance provided by the VIPer17. In *Figure 26* and *Figure 27* the waveform is captured at 176 VAC. In *Figure 28* and *Figure 29* the waveform is captured at 264 VAC.

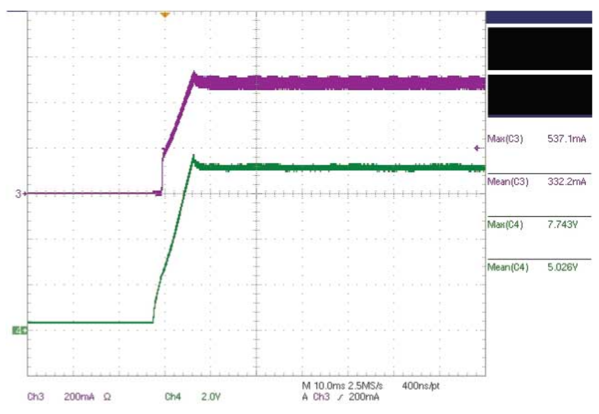
Figure 26. Startup of Vo and Io at 176 VAC, one LED



AM01078v1

Top trace: Io (200 mA/div)
Bottom trace: Vo (2 V/div)
Time: 10 ms/div

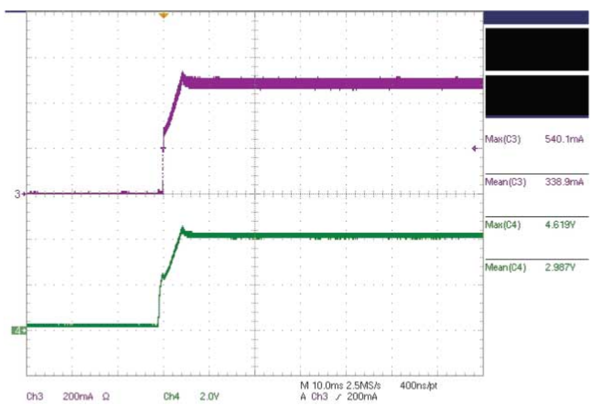
Figure 27. Startup of Vo and Io at 176 VAC, two LEDs



AM01079v1

Top trace: Io (200 mA/div)
Bottom trace: Vo (2 V/div)
Time: 10 ms/div

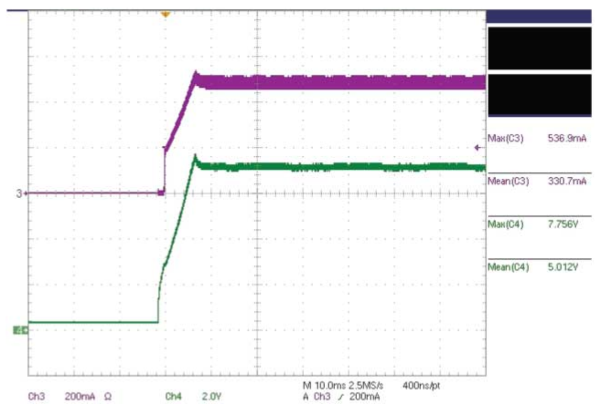
Figure 28. Startup of Vo and Io at 264 VAC, one LED



AM01080v1

Top trace: Io (200 mA/div)
Bottom trace: Vo (2 V/div)
Time: 10 ms/div

Figure 29. Startup of Vo and Io at 264 VAC, two LEDs

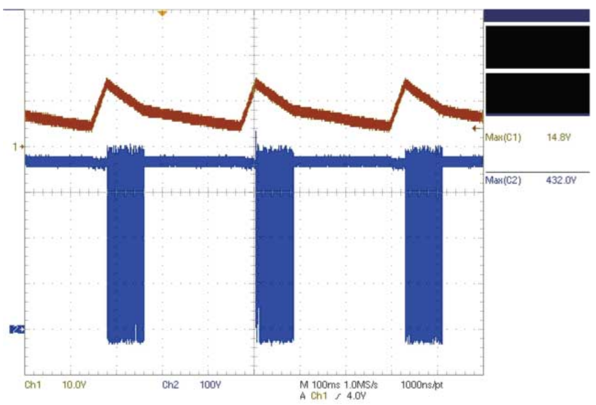


AM01081v1

Top trace: Io (200 mA/div)
Bottom trace: Vo (2 V/div)
Time: 10 ms/div

The load can be open-circuit (LED absent or wrong polarity at installation) or short-circuit due to the system undergoing installation or an operating anomaly. The LED lamp can be damaged due to overtemperature, for example. The system should be able to withstand damage until removal of the anomaly, thanks to the VIPer17 which provides full protection against output short-circuit as well as output open-circuit. In *Figure 30* and *Figure 31* the waveform from the short-circuit load condition is captured at the highest AC line input 264 V, which is the most hazardous condition to the system board. In *Figure 32* and *Figure 33* the waveforms are captured at the highest AC line input 264 V with the output load in open-circuit condition.

Figure 30. Vdd and Vds at 264 VAC, output in short-circuit



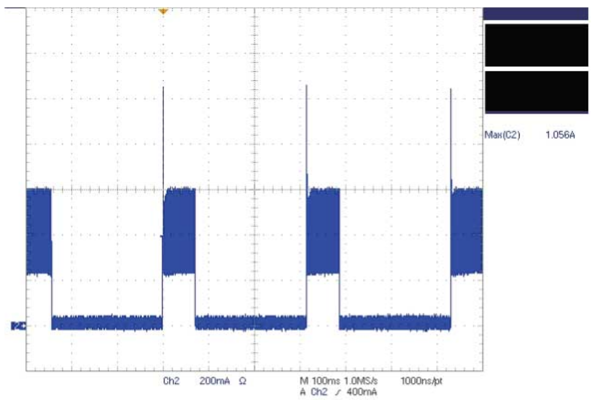
AM01082v1

Top trace: Vdd (10 V/div)

Bottom trace: Vds (100 V/div)

Time: 100 ms/div

Figure 31. Io at 264 VAC, output in short-circuit



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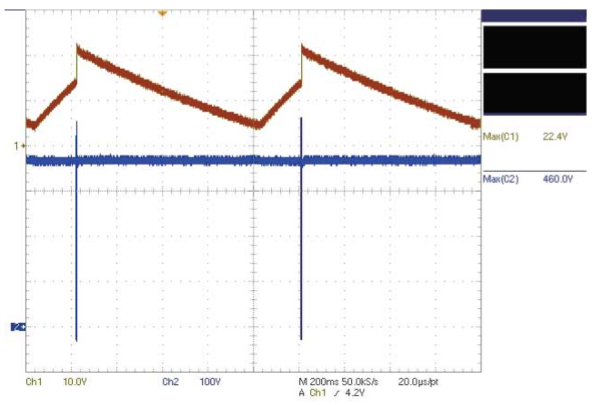
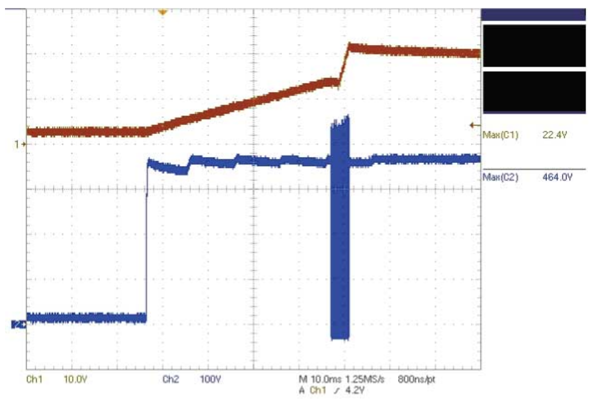
Io: 200 mA/div

Time: 100 ms/div

Figure 32. Vdd and Vds at 264 VAC, output in open-circuit	Figure 33. Startup of Vdd and Vds at 264 VAC, output in open-circuit
 AM01084v1	 AM01085v1
Top trace: Vdd (10 V/div) Bottom trace: Vds (100 V/div) Time: 200 ms/div	Top trace: Vdd (10 V/div) Bottom trace: Vds (100 V/div) Time: 10 ms/div

5 Connection of AC line and LED lamp to the demonstration board

Figure 34. Completed demonstration board connection

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Figure 35. Connection of AC line

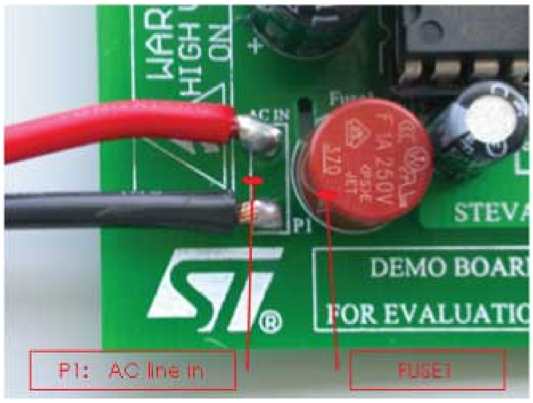

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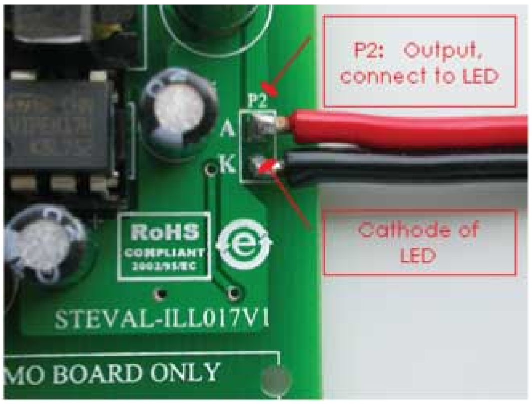
Figure 36. Connection of LED lamp



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6 Conclusion

This document introduces a non-isolated offline constant-current LED driver based on the VIPer17. The input range is 220 VAC +/- 20% and the device is capable of driving two 500 mA white light LEDs. The LED current is sensed and regulated through the TSM103W and attains a constant output current. By using resistors with 1% precision, the output current achieves a maximum tolerance less than 5%. The input fuse and input filter are built on a 30 mm x 30 mm PCB. Overtemperature protection, LED open-circuit and LED short-circuit protection are all integrated functions which enhance the reliability of the device.

7 References

- VIPer17, off-line high voltage converter (datasheet)
- TSM103W, dual operational amplifier and voltage reference (datasheet)
- STPS2H100A, power Schottky diode (datasheet)
- STTH1R06A, turbo 2 ultrafast high voltage rectifier (datasheet)
- BAT46JFILM, small signal Schottky diode (datasheet)

8 Revision history

Table 5. Document revision history

Date	Revision	Changes
16-Jun-2009	1	Initial release