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LM3401 MR16 Reference Designs for Non-Dimming & Dimming LED Applications

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Revision 1.1

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MR16 Halogen/SSL Retro-Fit Analysis

Differences between Magnetic and Electronic Transformers

Magnetic Transformers

Magnetic transformers step down 120VAC line voltage to 12VAC. Magnetic transformers consist only of magnetic core, and copper wire, no electronics are used to step down the voltage from 120VAC to 12VAC. Due to the fact that the frequency of operation is 50Hz or 60Hz, the size of the Magnetic transformers is large and heavy. Magnetic transformers are primarily available in two types of construction; torroidal and laminated EI core.

With existing Halogen MR16 systems that require dimming, Magnetic Low Voltage Dimmers are required to be used.

Electronic Transformers

Electronic transformers also step down 120VAC line voltage to 12VAC. Electronic transformers are much smaller and more efficient than magnetic transformers. Electronic transformers are more common than magnetic transformers in existing Halogen MR16 system. Electronic Low Voltage Transformers (ELVT) consists of a small self resonant tank power supply. Electronic Low Voltage Dimmers (ELV dimmers) are used with ELVT for dimming systems.

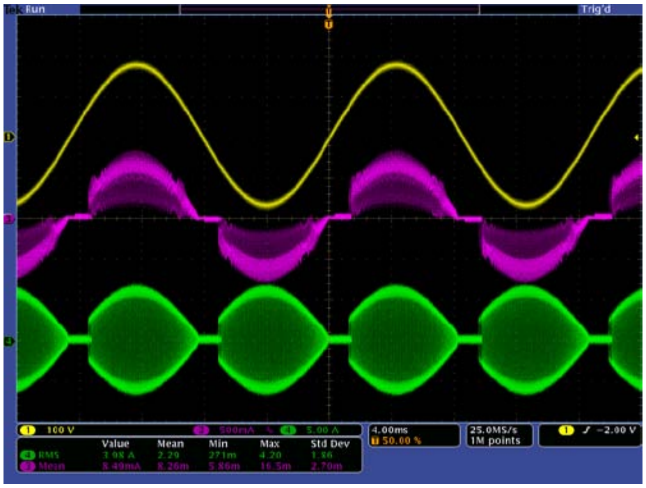
Although electronic transformers are more complex, with many more components, that their magnetic counterparts, electronic transformers are far less expensive and smaller. The shear amount of core material and copper within a magnetic transformer adds cost, and the weight of the product makes it expensive to manufacture, and ship.

SSL MR16 lamps compatibility concerns with ELVT and ELV dimmers (true retro-fit)

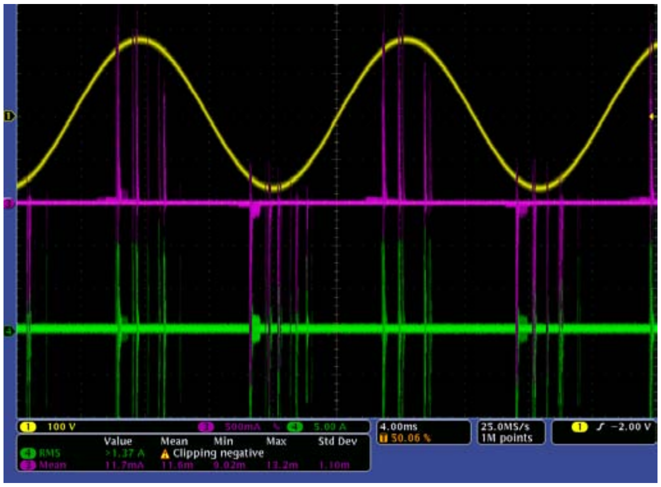
Electronic transformers modulate (PWM) the input AC voltage with a frequency of 35 kHz to150 kHz. This waveform is step-down from 120V or 230V (typical) to 12VAC with a transformer. The higher switching frequency allows for the smaller magnetic components, and the overall smaller design. As mentioned earlier, the electronic transformer is a self driven resonant half bridge topology. The self resonance half-bridge topology requires the converter to have a minimal load at all times to function properly. Common minimum loads for ELV dimmers are from 6W – 12W depending on manufacture, and maximum power rating of the ELVT. With traditional Halogen lamps, the minimal load is of no concern, common Halogen MR16 lamps use about 50W of power per lamp. These lamps are very inefficient, and 10W of Halogen power produces very little light.

With the current efficacy of the LEDs above 100 lumens per watt, 6W of SSL power is equivalent to about 40W to 50W of Halogen power. One can quickly see the compatibility issue of SSL MR16 lamps and the ELVT's. If the output power of the ELVT reduces below the minimum requirement, the ELV dimmer will stop operating. The turning on, and off of the ELVT will cause visible flicker from the SSL MR16 lamp, and could also cause reliability issues with the lamp or ELVT.

Halogen vs SSL MR16 waveforms



Halogen MR16 waveforms



Improper SSL MR16 operating waveform

- Channel - 1 (yellow trace) = Input line voltage
- Channel - 3 (purple trace) = Input line current
- Channel - 4 (green trace) = bulb current

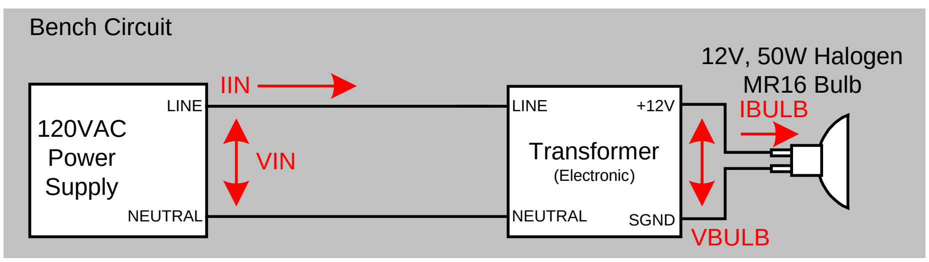
Issue #1 - The two scope captures above illustrate the SSL MR16 technical challenges. Figure one shows typical Halogen MR16 waveforms, and figure two is common MR16 replacement bulbs waveforms. The SSL replacement bulb looks capacitive to the ELVT; therefore large current spikes charge the energy storage device within the SSL MR16 bulb. The switching converter within the bulb then processes the input power from the energy storage element to the LED load. At this time the minimum load requirement of the ELVT is not satisfied, and the ELVT turns off. Once the energy is depleted within the MR16 converter, the ELVT will start up, and the process cycles. The turning off/on of the ELVT will manifest itself as visible flicker.

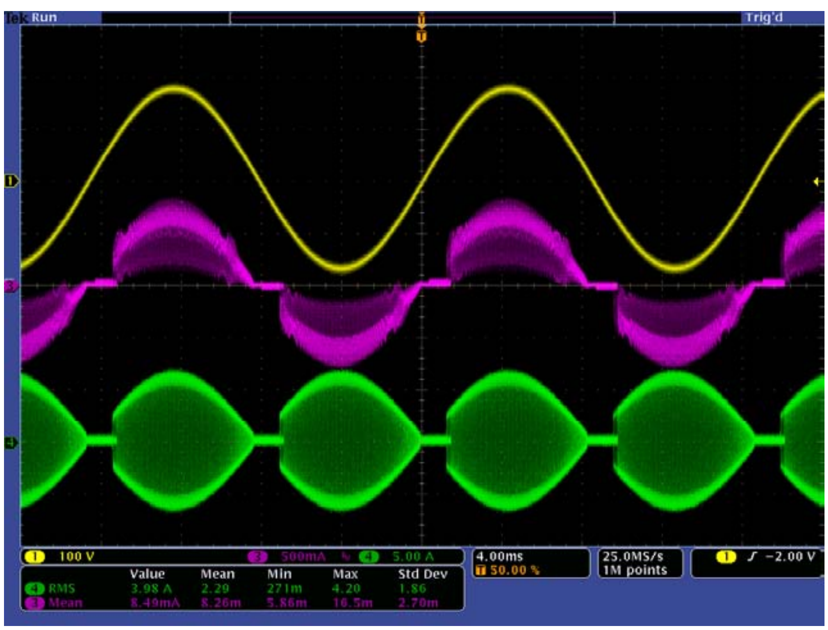
Issue #2 – The maximum input current to the Halogen bulb is approximately 4.25A. The maximum input current to the SSL bulb is approximately 12A. The large magnitude spike associated with charging the SSL MR16 input capacitor can cause premature failures within the SSL bulb, or even the ELVT.

Halogen MR16

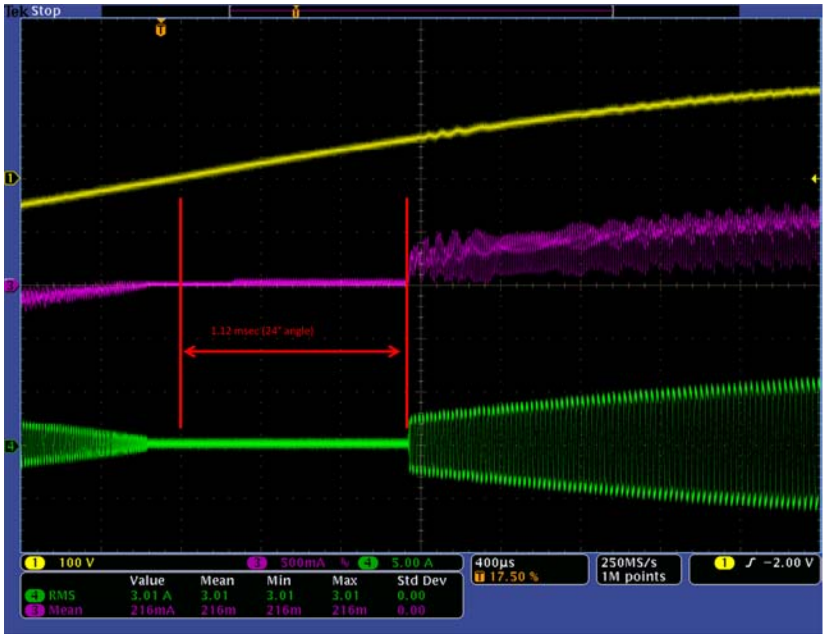
Summary: No flickering observed. There is a delay (1.12ms, 24° angle) from when the supply voltage starts ramping up from zero volts to when the electronic transformer starts to operate and the bulb turns on. This delay shows up on the LED MR16s as well although the magnitude of delay does vary from bulb to bulb. No current spikes observed out of the transformer.

The bench set-up diagram below was used in the evaluation of the halogen MR16 bulb. The following scope plots show voltage and current waveforms designated by the labels indicated in the bench set-up diagram. The electronic transformer used was the Lightech LET-75.

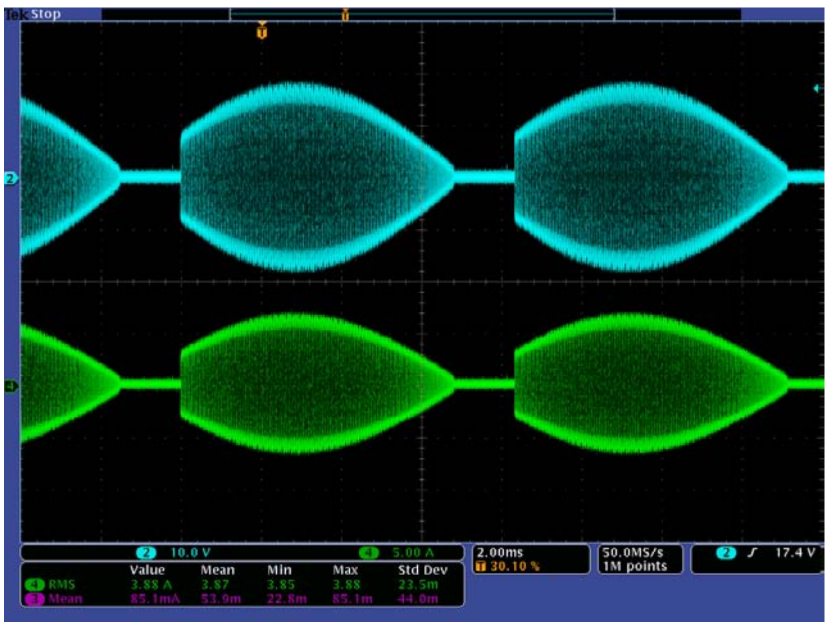




VIN (Yellow), IIN (Magenta), IBULB (Green)



VIN (Yellow), IIN (Magenta), IBULB (Green)



VBULB (Blue), IBULB (Green)

LM3401 Standard Reference Design

This reference design was based on the released LM3401 IC from National Semiconductor. A common LM3401 reference board is available today: http://www.national.com/pf/LM/LM3401.html#Overview

A MR16 specific evaluation PCB is currently being manufactured for customers, please contact your National Semiconductor representative.

This design was developed to minimize the current spikes coming out of an electronic transformer to less than 5A, which is a typical transformer rating, when driving an LED MR16 circuit. The off the shelf LED MR16 solutions exhibit spikes that significantly exceed a transformer's maximum rated output current which will degrade the reliability of the transformer and reduce its operating lifetime.

This design also generates a constant LED current over most of the power cycle when an electronic transformer is on versus the short bursts of current applied to an LED stack from the off the shelf LED MR16 bulbs. This results in better power factor and more stable circuit operation.

Operating Specifications

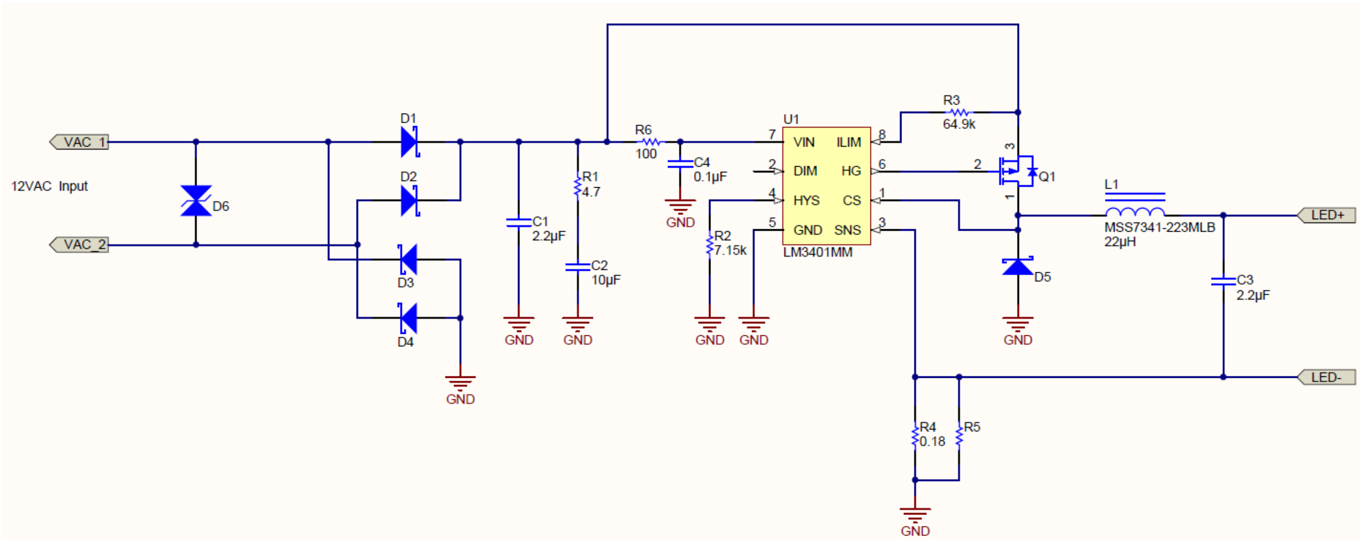
NOTE: The following specifications are typical values based on the LED driver being powered directly by a 12VAC supply (i.e. no electronic or magnetic step-down transformer).

Input Voltage, V_{IN}: .... 12 VAC
Output Voltage, V_{OUT}: .... 6.2V (Single string of 2 LEDs)
Input Current, I_{IN} 650mA
LED Output Current, I_{LED} .... 1.0 A

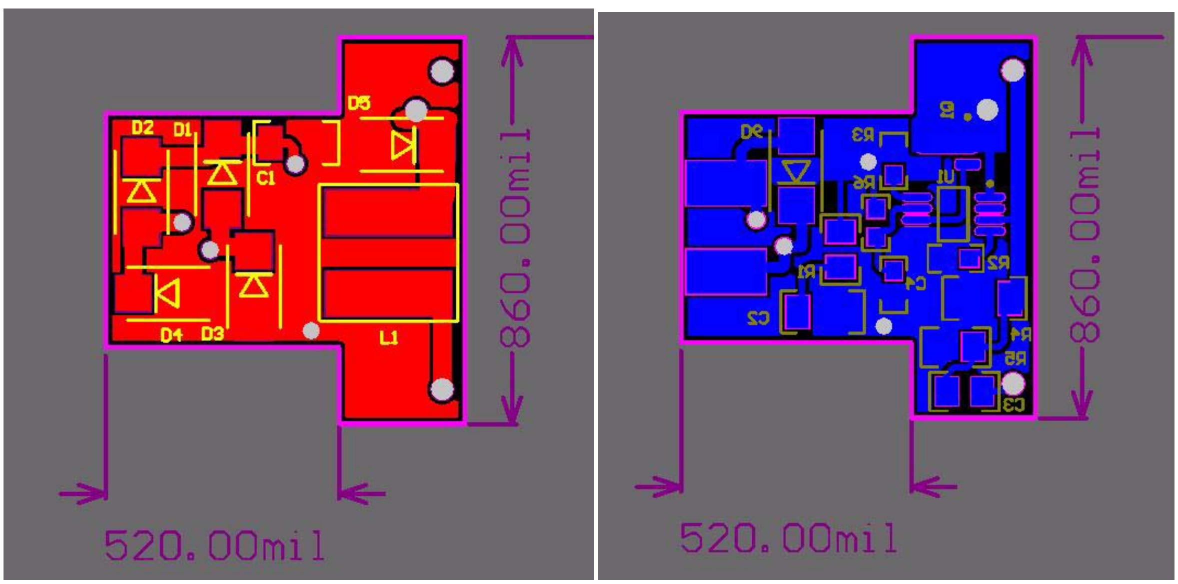
Input Power, P_{IN} .... ~ 7.7W
Output Power, P_{OUT} .... ~ 6.2W
Efficiency .... ~ 81 %
Power Factor 0.85

SMPS Topology .... Buck

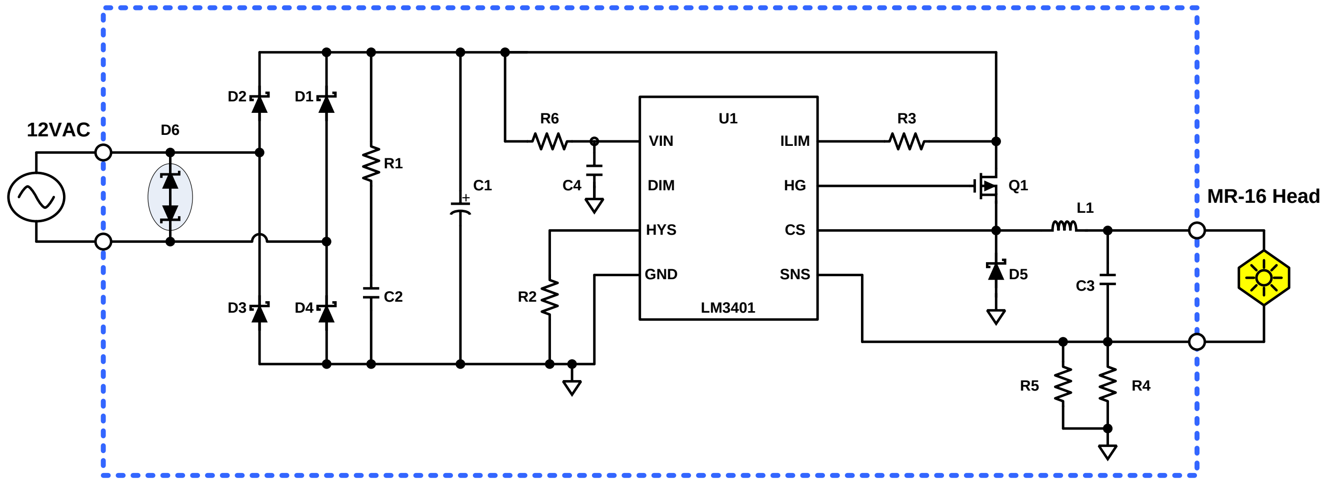
Final PCB Schematic



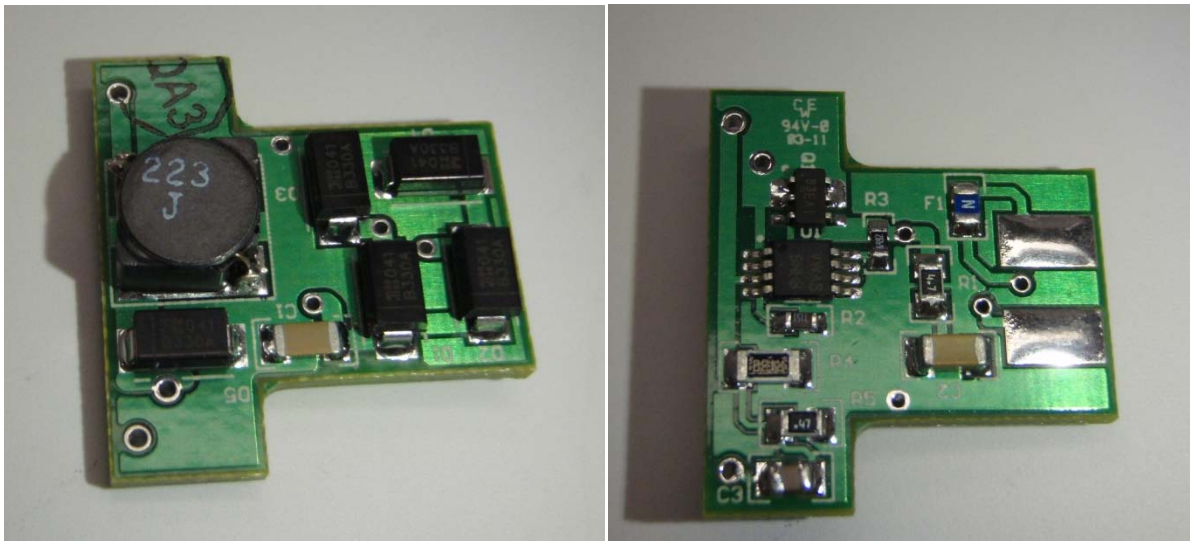
PCB Layout



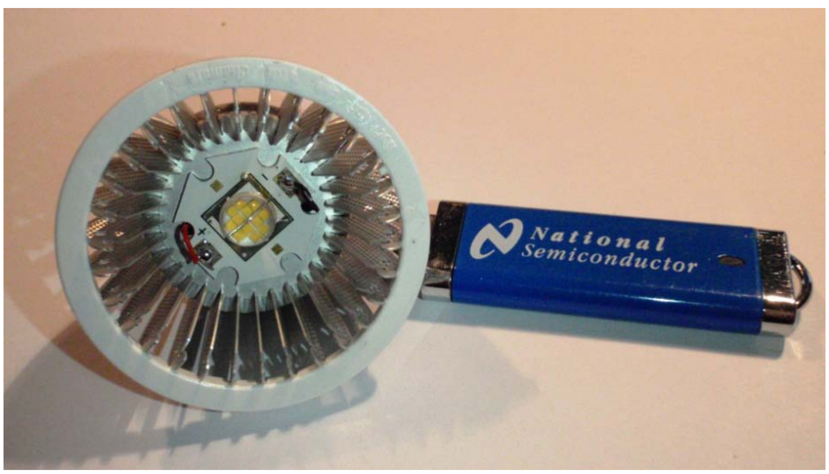
LM3401 Standard Schematic



Standard LM3401 PCB Photo (top/bottom)



MR16 with LM3401 driver board and CREE MT-G LED



LM3401 with CREE LED and MR16 assembly

Bill of Materials

Designator	Description	MFG	Part Number
C1	CAP, CERM, 2.2uF, 25V, +/-10%, X5R, 1206	MuRata	GRM316R61E225KA12D
C2	CAP, CERM, 10uF, 25V, +/-10%, X5R, 1206	MuRata	GRM31CR61E106KA12L
C3	CAP, CERM, 2.2uF, 16V, +/-10%, X7R, 0805	MuRata	GRM21BR71C225KA12L
C4	CAP, CERM, 0.1uF, 25V, +/-10%, X7R, 0603	MuRata	GRM188R71E104KA01D
D1-D5	Diode, Schottky, 30V, 3A, SMA	Diodes Inc.	B330A-13-F
D6	TVS BI-DIR 24V 400W SMA (Optional)	Diodes Inc	SMAJ24CA-13-F
F1	Fuse, SMD, 2A, 0805		MFU0805FF02000P100
L1	Ind, Shielded Core, Ferrite, 22uH, 1.42A, 0.082 ohm, SMD	Coilcraft	MSS7341-223MLB
Q1	MOSFET, P-CH, -30V, -4A, SOT-23-6	Fairchild	FDC658AP
R1	RES, 4.7 ohm, 5%, 0.125W, 0805	Panasonic	ERJ-6GEYJ4R7V
R2	RES, 7.15k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW06037K15FKED
R3	RES, 64.9k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW060364K9FKEA
R4	RES, 0.18 ohm, 1%, 0.25W, 1206		
R5	See variants below		
R6	RES, 100 ohm, 1%, 0.1W, 0603 (optional 0 ohm)	Vishay-Dale	CRCW0603100R
U1	Hysteretic PFET Controller for High Power LED Drive	National Semiconductor	LM3401MM

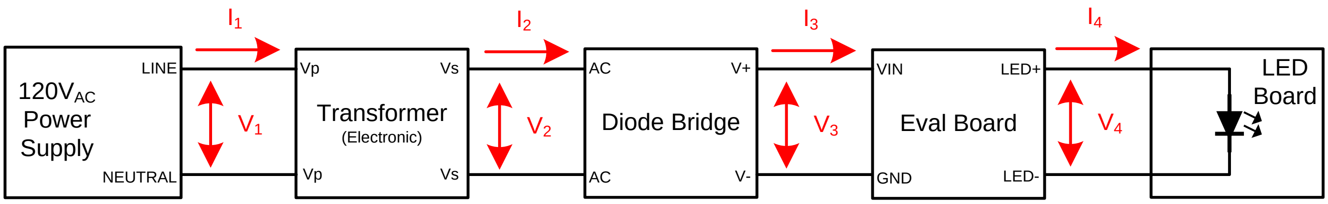
Current Sense Configuration Variants

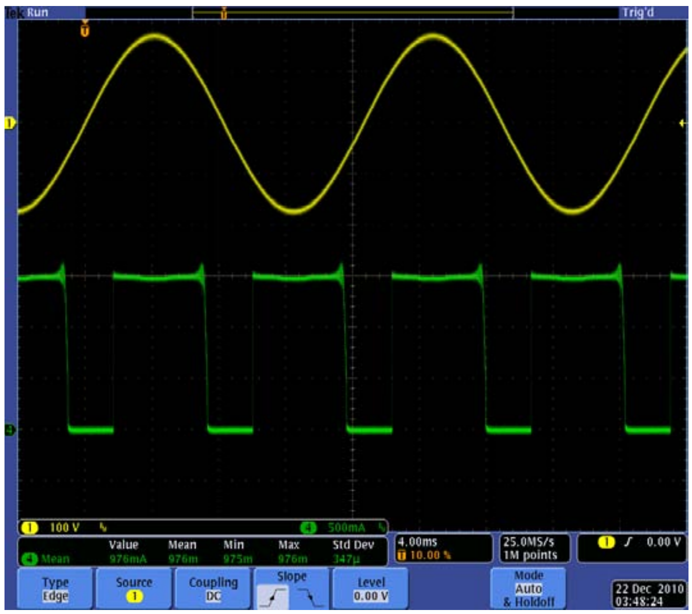
Series LEDs	V_{LED}	I_{LED}	R4	R5
2	~ 6V	1.0 A	0.18Ω	0.47Ω
3	~ 9V	700 mA	0.18Ω	open

Typical Performance (Two series LEDs @ 1.0A)

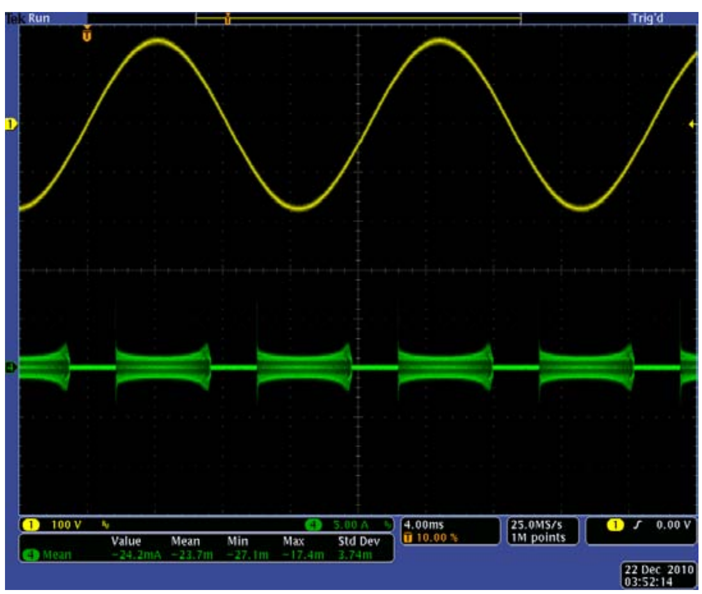
The following scope plots show voltage and current waveforms designated by the labels indicated in the following bench set-up diagram. This bench set-up was used in the evaluation of the LM3401 Standard MR16 design. The electronic transformer used was the Lightech LET-75.

Bench Circuit

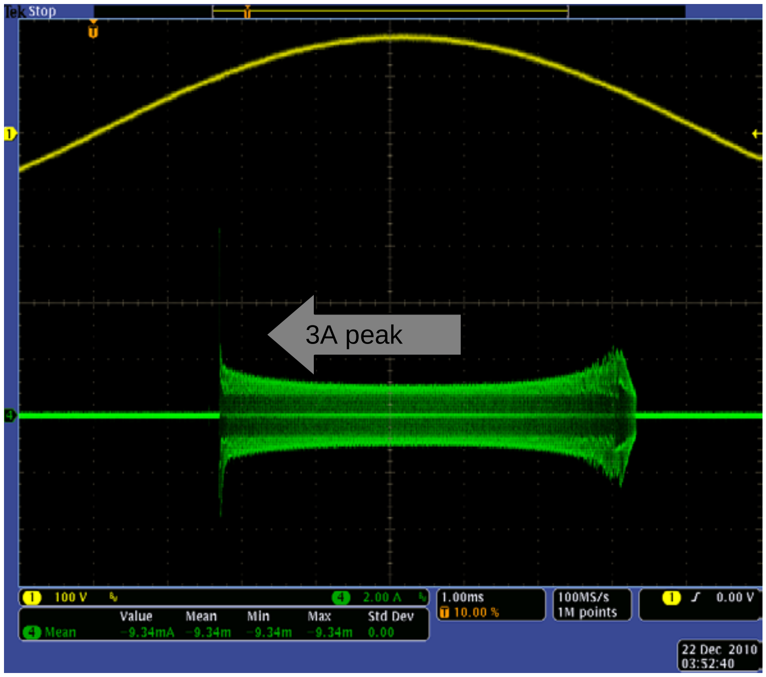




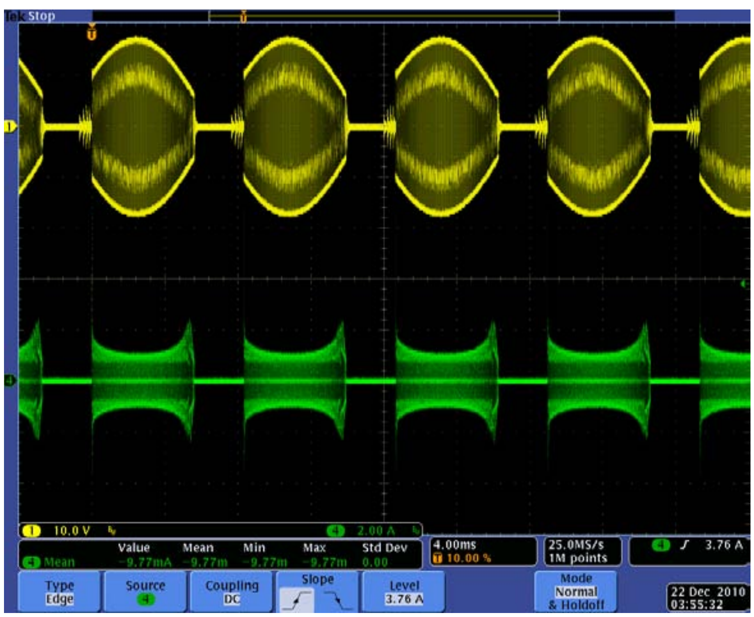
CH1 V1 Voltage, CH4 I4 Current



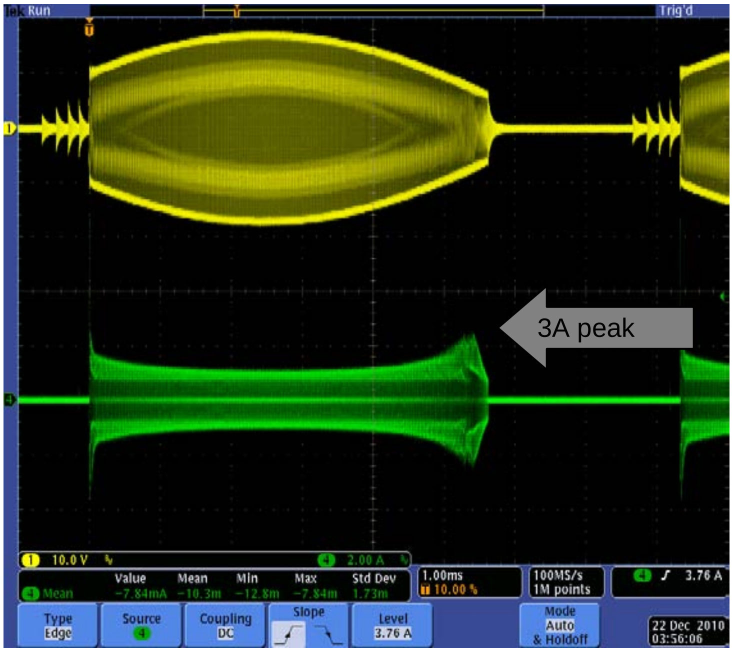
CH1 V1 Voltage, CH4 I2 Current



CH1 V1 Voltage, CH4 I2 Current



CH1 V2 Voltage, CH4 I2 Current



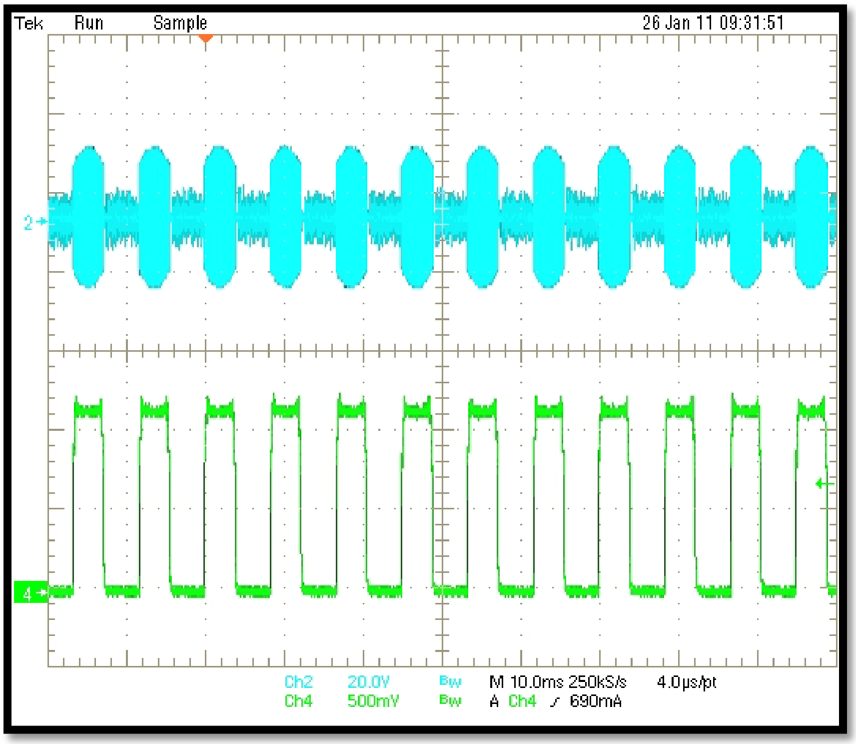
CH1 V2 Voltage, CH4 I2 Current

LM3401 Dimming Waveforms

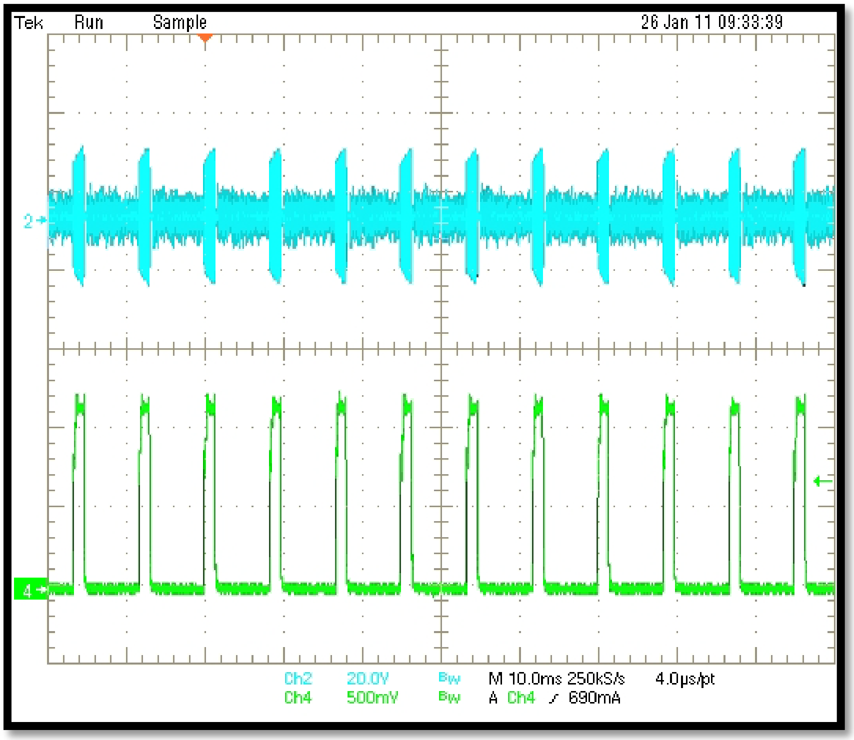
This LM3401 evaluation board is designed to operate (flicker-free) with common Electronic Low Voltage dimmers, and Electronic Transformers.

- Dimmer Used – Lutron SELV-300P-GR
- Electronic Transformer – Lightech LET75
- 12:1 contrast ratio

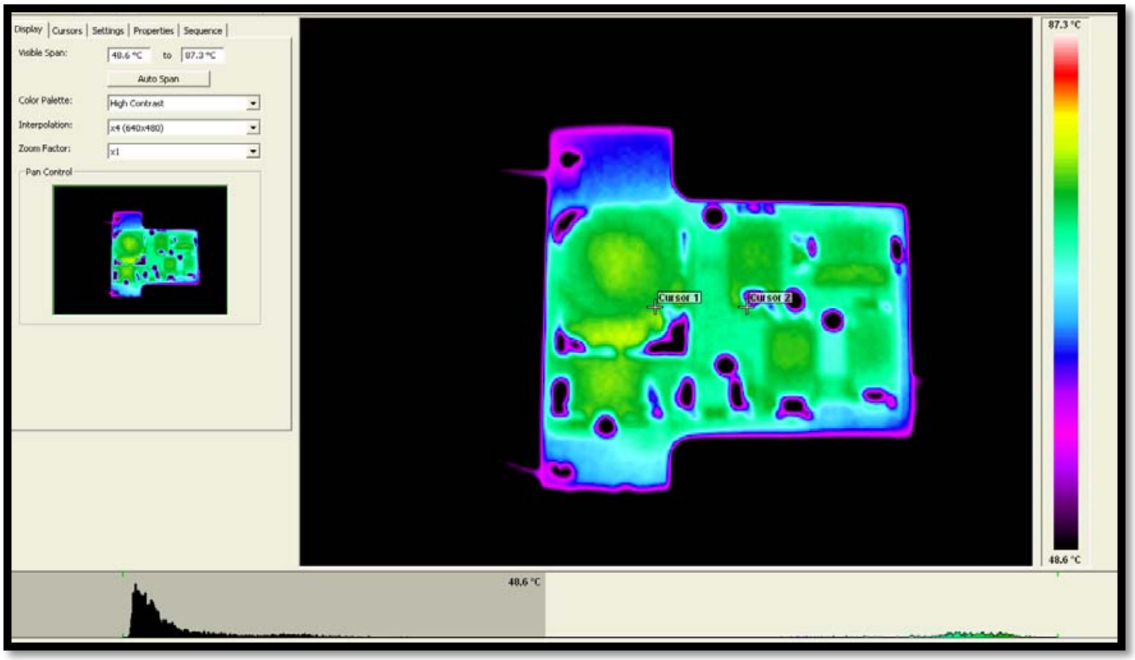
LM3401 Standard Buck - Two series connected LEDs at 1A (90° Conduction Angle)

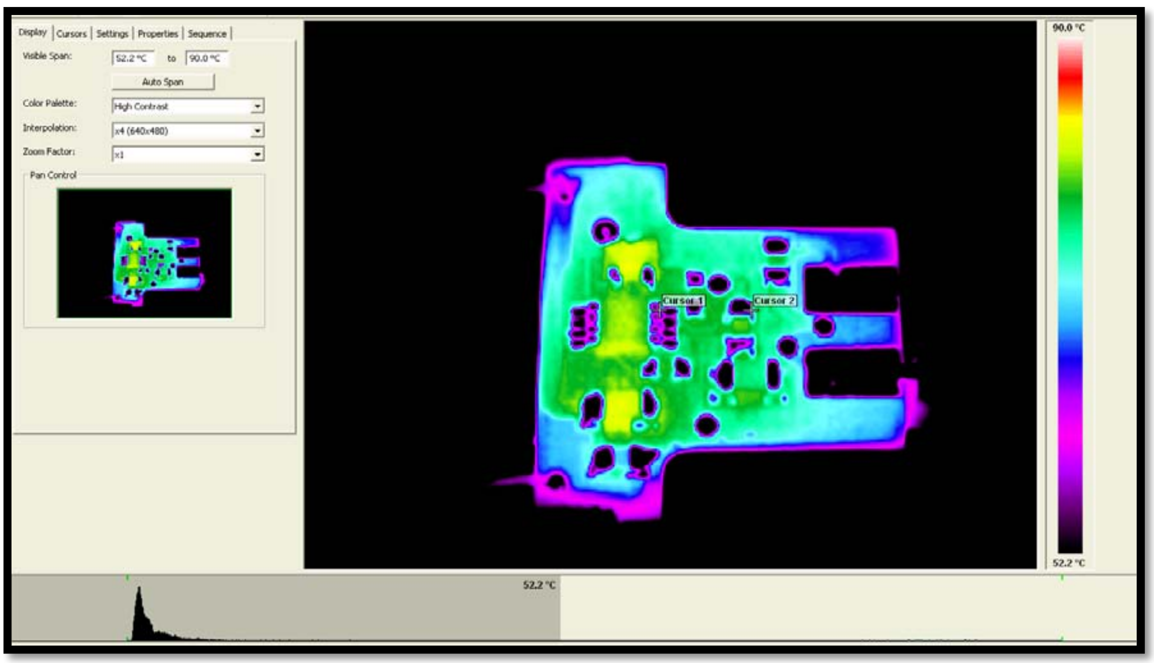


LM3401 Standard Buck - Two series connected LEDs at 1A (45° Conduction Angle)


Tek Run Sample
26 Jan 11 09:33:39
2
4
Ch2 20.0V BW
Ch4 500mV BW
M 10.0ms 250kS/s 4.0µs/pt
A Ch4 ⟋ 690mA

Thermal Analysis





Reference Design Transformer Compatibility

The following transformers were tested with the National LED driver designs described in this document. A compatibility matrix is shown below which describes which driver/transformer combinations are suitable (i.e. no flicker, stable operation).

<u>Electronic Transformers (120VAC to 12VAC):</u>

Lightech, Model: LET-60, 60W
Lightech, Model: LET-75, 75W
Lightech, Model: LET-60 LW, 60W
Hatch, Model: RS12-80M, 85W
Pony, Model: PET-120-12-60, 60W
Eurofase, Model: 0084 CLASS 2, 60W

<u>Magnetic Transformers (120VAC to 12VAC):</u>

Hatch, Model: LS1275EN, 75VA

LM3401 Standard Reference Design (Two Series Connected LEDs @ 1.0A)

Performance without transformer

The table below compares the performance of each reference design when powered directly by a 12VAC source (i.e. no step-down transformer used).

Specs	LM3401 STD CKT 2 LEDs @ 1A	Units
V_{IN}	12.09	VAC
I_{IN}	0.777	A
P_{IN}	8.25	W
V_{OUT} (1)	5.81	VDC
I_{LED} (1)	1.13	A
P_{OUT} (2)	6.94	W
Efficiency	84.1%	-
Power Factor	87.9	-

(1) This is the mean value as measured from oscilloscope waveform.
(2) This is the mean value of the instantaneous P_{OUT} waveform that was mathematically generated (i.e. V_{OUT}*I_{LED}) on the oscilloscope.

Performance with transformer

The table below compares the performance of each reference design when powered by a 120VAC source that is stepped down with an electronic transformer (i.e. Hatch, Model: RS12-80M). Since the transformer is not "on" during the full power cycle, power supplied to the LED driver is not constant but instead modulated "on and off" at a duty cycle that matches the "on-state" of the transformer. Operating specifications decrease compared to a system that doesn't use an electronic transformer.

LET-75

Specs	LM3401 STD CKT 2 LEDs @ 1A	Units
V_{IN}	120.04	VAC
I_{IN}	0.079	A
P_{IN}	7.97	W
V_{OUT} (1)	5.65	VDC (1)
I_{LED} (1)	1.010	A (1)
P_{OUT} (2)	6.23	W (2)
Efficiency	78.2%	-
Power Factor	84.3	-

HATCH

Specs	LM3401 STD CKT	Units
V_{IN}	120.04	VAC
I_{IN}	0.085	A
P_{IN}	8.44	W
V_{OUT} (1)	5.79	VDC (1)
I_{LED} (1)	1.080	A (1)
P_{OUT} (2)	6.71	W (2)
Efficiency	79.5%	-
Power Factor	82.5	-

(1) This is the mean value as measured from oscilloscope waveform.
(2) This is the mean value of the instantaneous P_{OUT} waveform that was mathematically generated (i.e. $V_{OUT}*I_{LED}$) on the oscilloscope.

LM3401 Standard Reference Design (Three Series Connected LEDs @ 600mA)

Performance without transformer

The table below compares the performance of each reference design when powered directly by a 12VAC source (i.e. no step-down transformer used).

Specs	LM3401 STD CKT 3 LEDs @ 0.7A	Units
V_{IN}	12.05	VAC
I_{IN}	0.659	A
P_{IN}	7.33	W
V_{OUT} (1)	8.43	VDC
I_{LED} (1)	0.700	A
P_{OUT} (2)	6.47	W
Efficiency	88.3%	-
Power Factor	0.924	-

(3) This is the mean value as measured from oscilloscope waveform.
(4) This is the mean value of the instantaneous P_{OUT} waveform that was mathematically generated (i.e. $V_{OUT}*I_{LED}$) on the oscilloscope.

Performance with transformer

The table below compares the performance of each reference design when powered by a 120VAC source that is stepped down with an electronic transformer (i.e. Hatch, Model: RS12-80M). Since the transformer is not "on" during the full power cycle, power supplied to the LED driver is not constant but instead modulated "on and off" at a duty cycle that matches the "on-state" of the transformer. Operating specifications decrease compared to a system that doesn't use an electronic transformer.

LET-60

Specs	LM3401 STD CKT 3 LEDs @ 0.7A	Units
V_{IN}	119.94	VAC
I_{IN}	0.069	A
P_{IN}	6.93	W
V_{OUT} (1)	8.19	VDC (1)
I_{LED} (1)	0.614	A (1)
P_{OUT} (2)	5.66	W (2)
Efficiency	81.7%	-
Power Factor	0.849	-

HATCH

Specs	LM3401 STD CKT 3 LEDs @ 0.7A	Units
V_{IN}	119.44	VAC
I_{IN}	0.072	A
P_{IN}	7.24	W
V_{OUT} (1)	8.44	VDC (1)
I_{LED} (1)	0.651	A (1)
P_{OUT} (2)	6.02	W (2)
Efficiency	83.1%	-
Power Factor	0.853	-

(3) This is the mean value as measured from oscilloscope waveform.
(4) This is the mean value of the instantaneous P_{OUT} waveform that was mathematically generated (i.e. $V_{OUT}*I_{LED}$) on the oscilloscope.

Revision History

Date	Author	Revision	Description

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