TEXAS INSTRUMENTS

Reference Design

Lighting Power Products
Longmont Design Center

LM3444 MR16 Buck Boost Reference Design for Non-Dimming & Dimming LED Applications

November10, 2011
Revision 1.0a

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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.

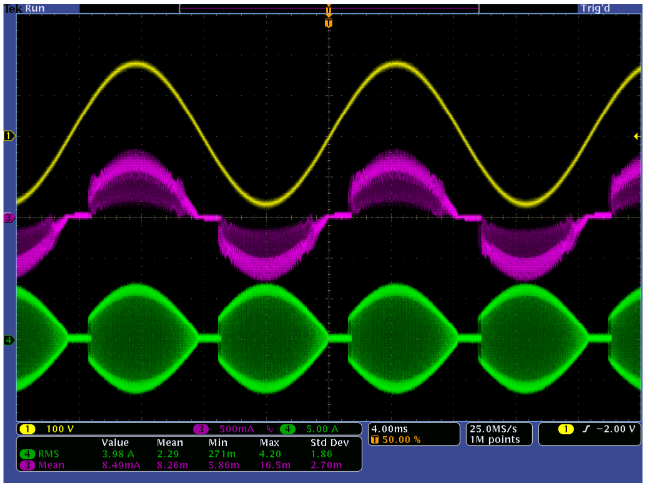
Although electronic transformers are more complex, with many more components, that their magnetic counterparts, electronic transformers are far less expensive and smaller. The shear amount of core material and copper within a magnetic transformer adds cost, and the weight of the product makes it expensive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

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

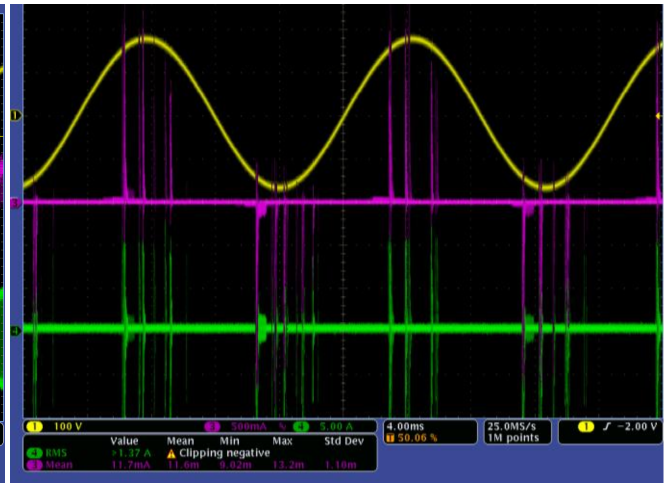
Electronic transformers modulate (PWM) the input AC voltage with a frequency of 35 kHz to150 kHz. This waveform is step-down from 120V or 230V (typical) to 12VAC with a transformer. The higher switching frequency allows for the smaller magnetic components, and the overall smaller design. As mentioned 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

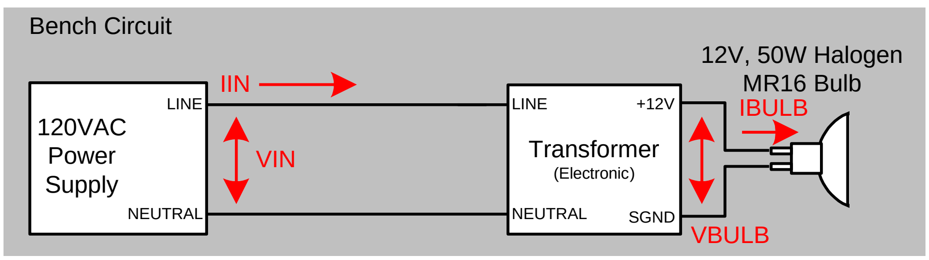
Issue #1 - The two scope captures above illustrate the SSL MR16 technical challenges. Figure one shows typical Halogen MR16 waveforms, and figure two is common MR16 replacement bulbs waveforms. The SSL replacement bulb looks capacitive to the ELVT; therefore large current spikes charge the energy storage 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.

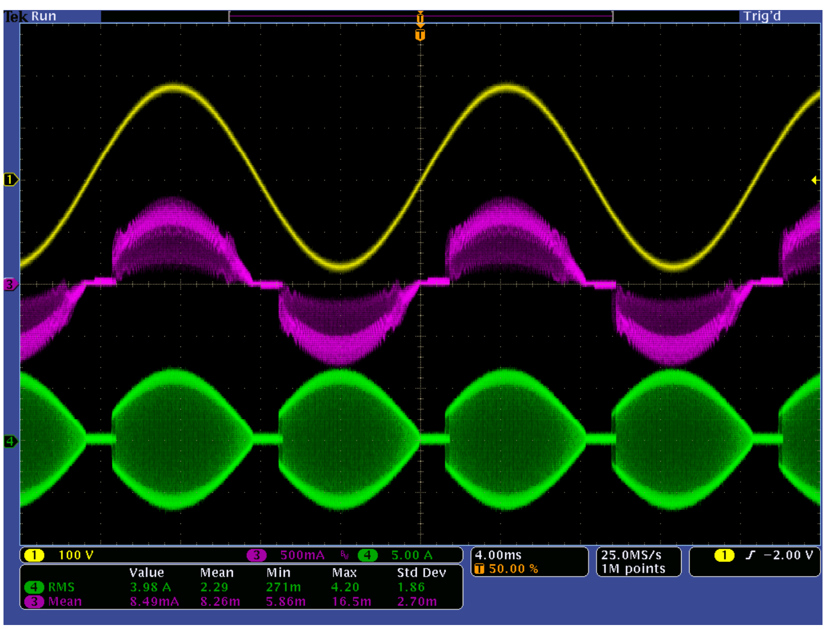
Issue #2 – The maximum input current to the Halogen bulb is approximately 4.25A. The maximum input current to the SSL bulb is approximately 12A. The large magnitude spike associated with charging the SSL MR16 input capacitor can cause premature failures within the SSL bulb, or even the ELVT.

Halogen MR16

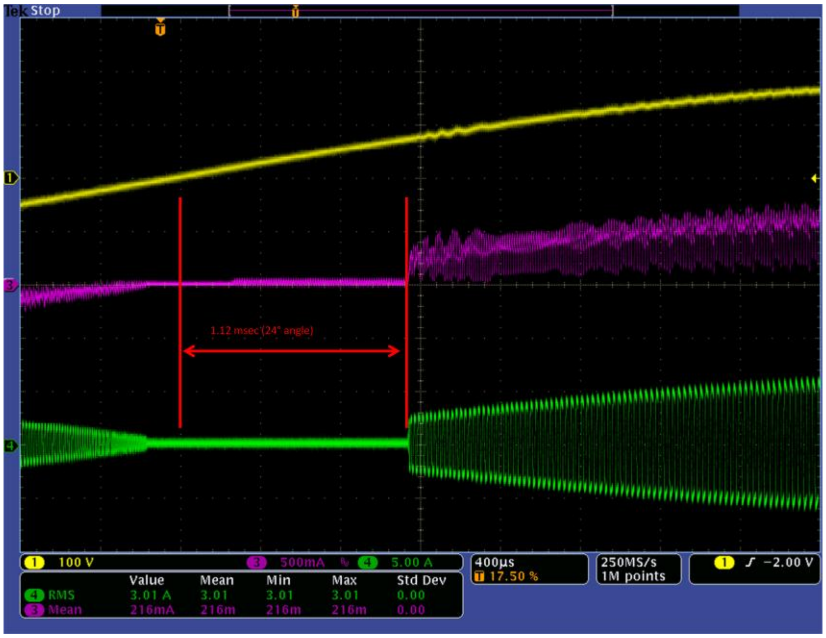
Summary: No flickering observed. There is a delay (1.12ms, 24° angle) from when the supply voltage starts ramping up from zero volts to when the electronic transformer starts to operate and the bulb turns on. This delay shows up on the LED MR16s as well although the magnitude of delay does vary from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

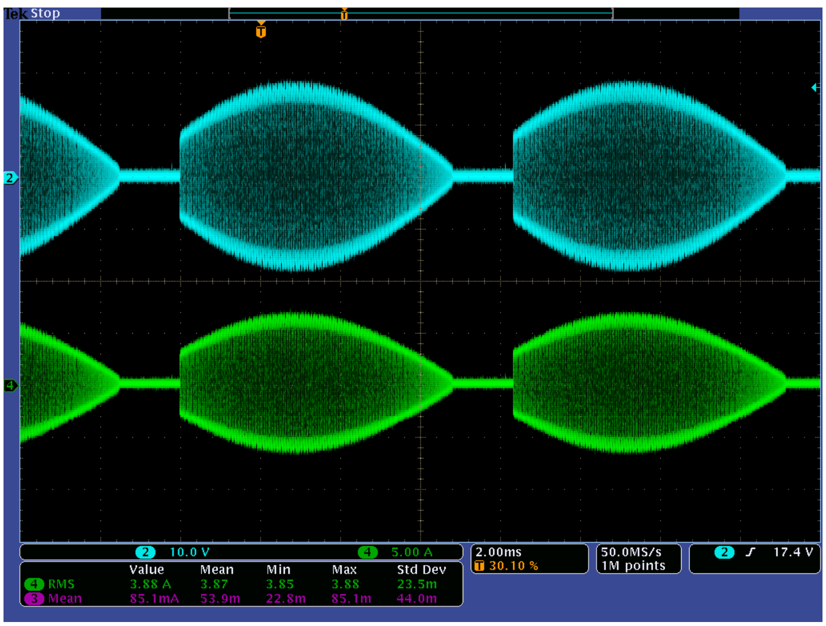




VIN (Yellow), IIN (Magenta), IBULB (Green)



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



VBULB (Blue), IBULB (Green)

LM3444 Buck Boost MR16 Reference Design

This reference design was based on the released LM3444 IC from National Semiconductor.

This design was developed to minimize the current spikes coming out of an electronic transformer to less than 6A, 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.

The circuit operates in a constant output power mode. The output power is fixed at about 5.5W.

Operating Specifications

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

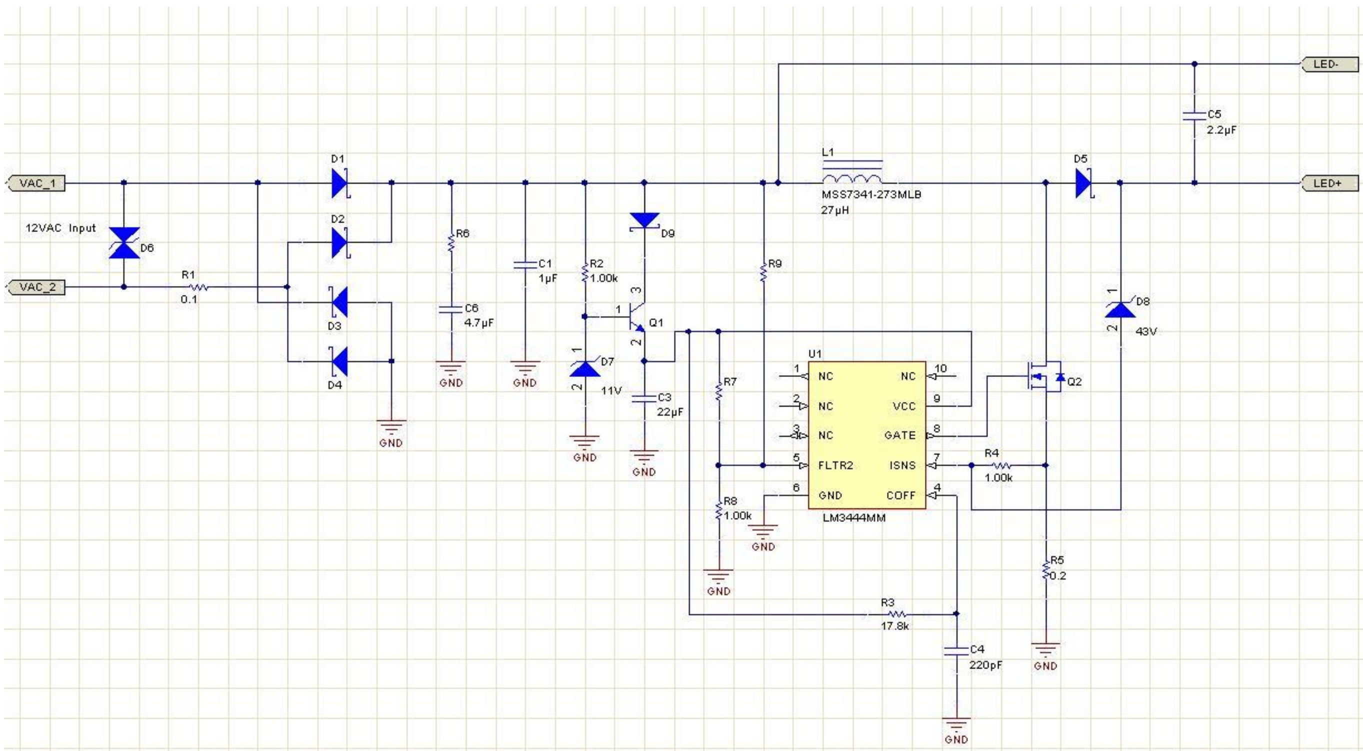
Input Voltage, V_{IN}: .... 12 VAC
Output Voltage, V_{OUT}: .... 10.6V (Single string of 3 LEDs)
Input Current, I_{IN} 600mA
LED Output Current, I_{LED} 485mA
Input Power, P_{IN} .... ~ 6.6W
Output Power, P_{OUT} .... ~ 5.2W
Efficiency .... ~ 78 %
Power Factor .... ~ 0.92

Input Voltage, V_{IN}: .... 12 VAC
Output Voltage, V_{OUT}: .... 13.5V (Single string of 4 LEDs)
Input Current, I_{IN} 640mA
LED Output Current, I_{LED} 415mA
Input Power, P_{IN} .... ~ 7.1W
Output Power, P_{OUT} .... ~ 5.6W
Efficiency .... ~ 79 %
Power Factor .... ~ 0.93

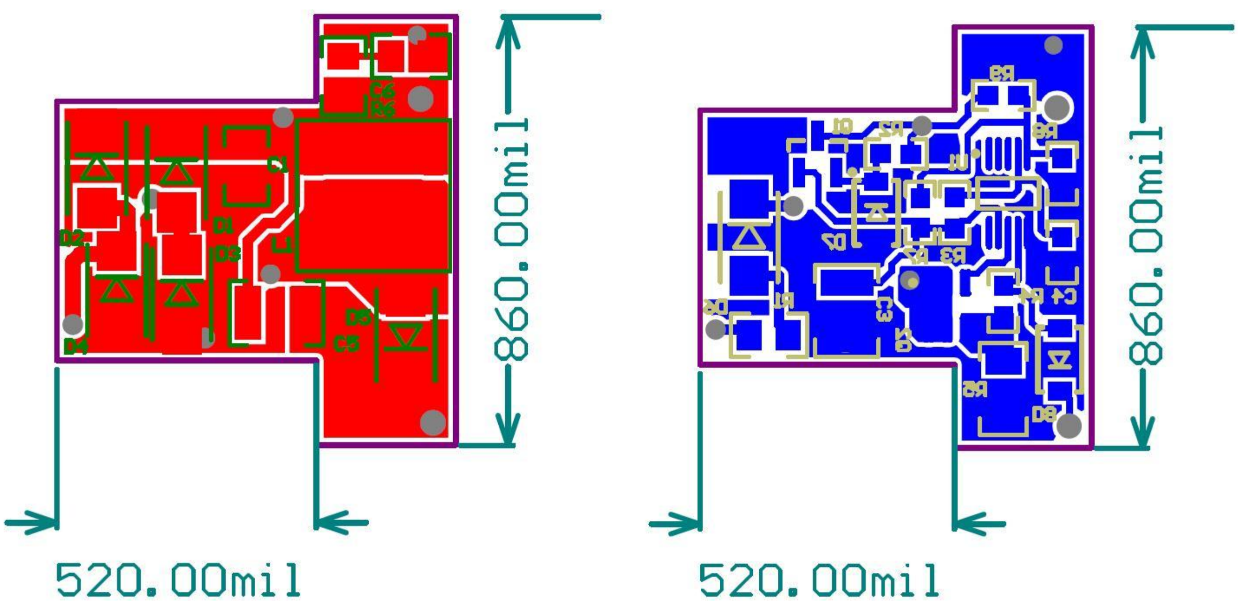
Input Voltage, V_{IN}: .... 12 VAC
Output Voltage, V_{OUT}: .... 16.7V (Single string of 5 LEDs)
Input Current, I_{IN} 660mA
LED Output Current, I_{LED} 350mA
Input Power, P_{IN} .... ~ 7.4W
Output Power, P_{OUT} .... ~ 5.9W
Efficiency .... ~ 80 %
Power Factor .... ~ 0.93

SMPS Topology .... Buck Boost

PCB Schematic



PCB Layout

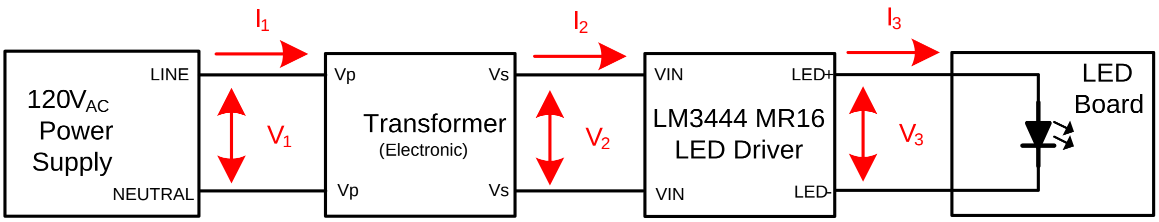


Bill of Materials

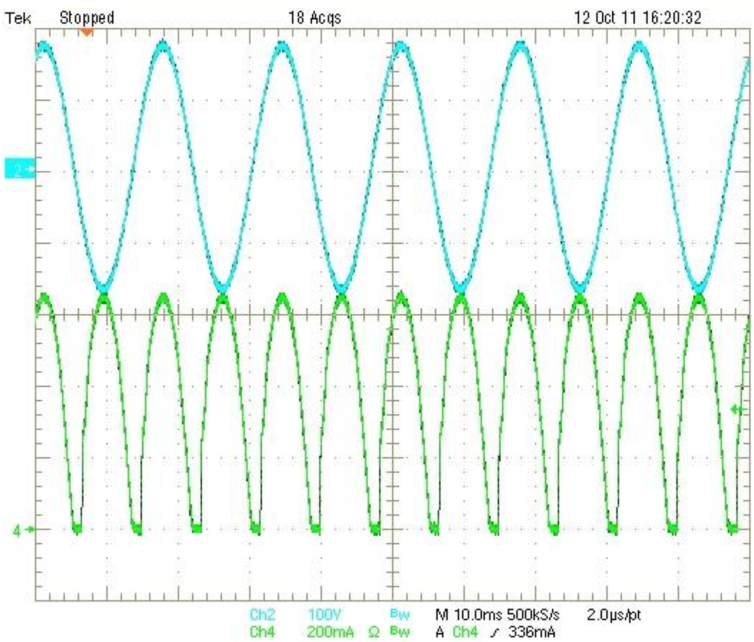
Designator	Description	MFG	Part Number
C1	CAP, CERM, 1.0uF, 25V, +/-10%, X5R, 0805	MuRata	GRM216R61E105KA12D
C3	CAP, CERM, 22uF, 25V, +/-10%, X5R, 1210	MuRata	GRM32ER61E226KE15L
C4	CAP, CERM, 220pF, 100V, +/-5%, X7R, 0603	AVX	06031C221JAT2A
C5	CAP, CERM, 22uF, 25V, +/-10%, X5R, 1210	MuRata	GRM32ER71H475KA882
C6	CAP, CERM, 4.7uF, 25V, +/-10%, X5R, 0805	MuRata	GRM21BR61E475KA12L
D1-D4	Diode, Schottky, 30V, 3A, SMA	Diodes Inc.	B330A-13-F
D5	Diode, Schottky, 60V, 3A, SMA	Central Semiconductor	CMSH3-60MA
D6	TVS BI-DIR 24V 400W SMA (Optional)	Diodes Inc	SMAJ24CA-13-F
D7	Diode, Zener, 11V, 500mW, SOD-123	Central Semiconductor	CMHZ4698
D8	Diode, Zener, 43V, 500mW, SOD-123	Diodes Inc.	BZT52C43-7-F
D9	Diode, Schottky, 75V, 150mA, SOD-323	Fairchild	1N4148WS
L1	Ind, Shielded Drum Core, Ferrite, 27uH, 1.22A, SMD	Coilcraft	MSS7341-273MLB
Q1	Transistor, NPN, 80V, 500mA, SOT-23	Central Semiconductor	CMPTA06
Q2	MOSFET, N-CH, 60V, 2.8A, SOT23-6	Diodes Inc.	ZXMN6A08E6TA
R1	RES, 0.1 ohm, 5%, 0.125W, 0805	Panasonic	ERJ-6RSJR10V
R2, R4, R8	RES, 1.00k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW06031K00FKEA
R3	RES, 17.8k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW060317k8FKEA
R5	RES, 0.2 ohm, 1%, 0.5W, 1206	Stackpole Electronics Inc	CSR1206FKR200
R6	RES, 4.7 ohm, 5%, 0.125W, 0805	Yageo	RC0805JR-074R7L
R7	RES, 54.9k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW060354k9FKEA
R9	RES, 150k ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW0603150kFKEA
U1	AC-DC Off Line LED Driver	National Semiconductor	LM3444MM

Typical Performance (Four series LEDs)

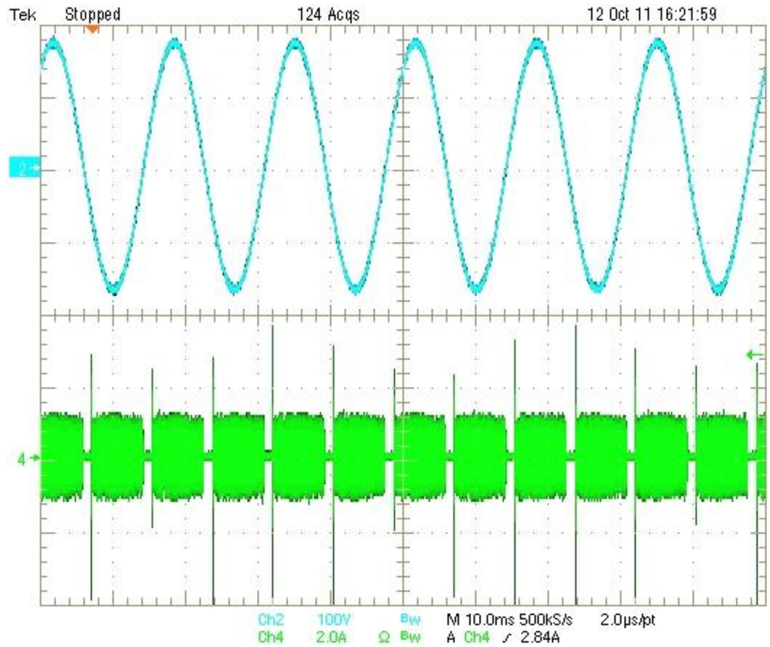
Bench Circuit



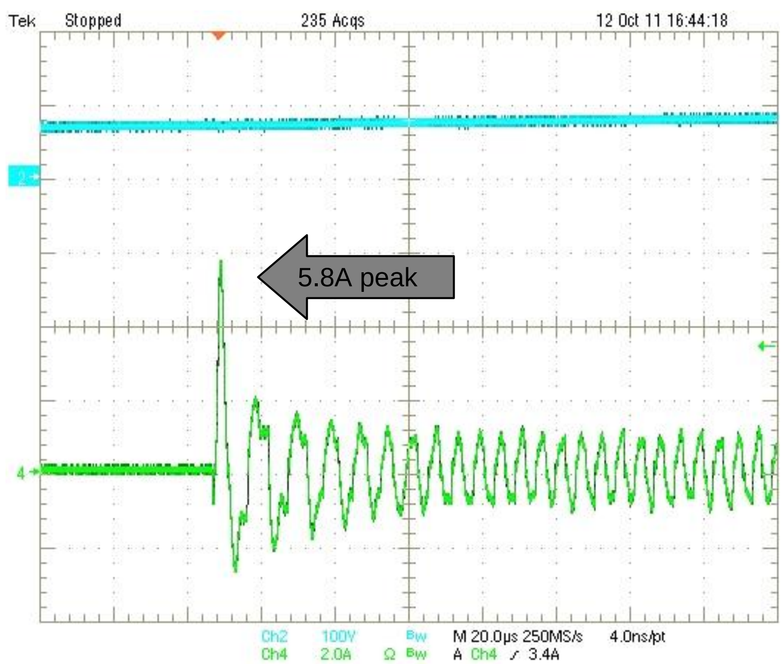
The following scope plots show voltage and current waveforms designated by the labels indicated in the following bench set-up diagram. The electronic transformer used was the Lightech LET-75.



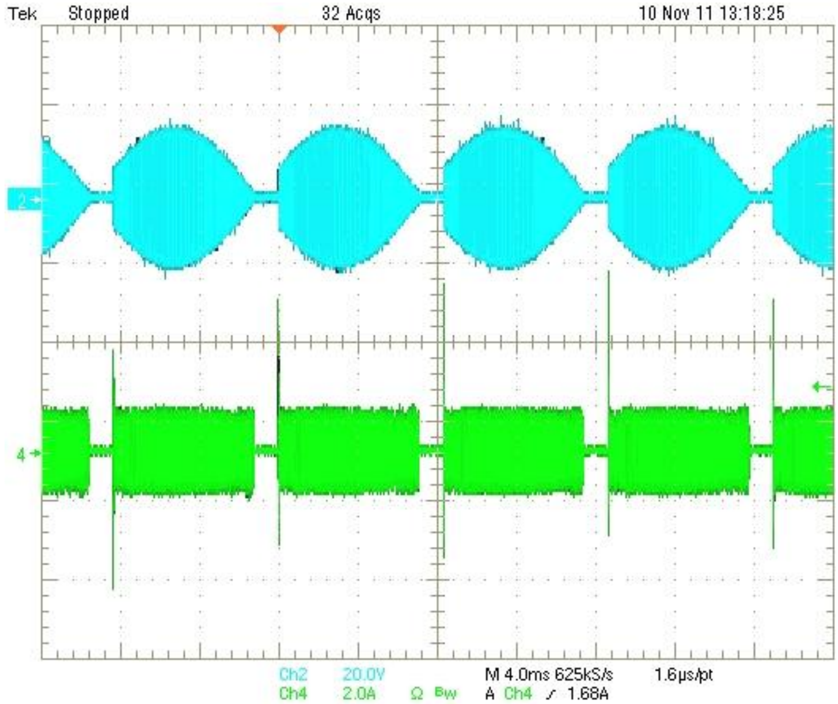
CH2 V1 Voltage, CH4 I3 Current



CH2 V1 Voltage, CH4 I2 Current

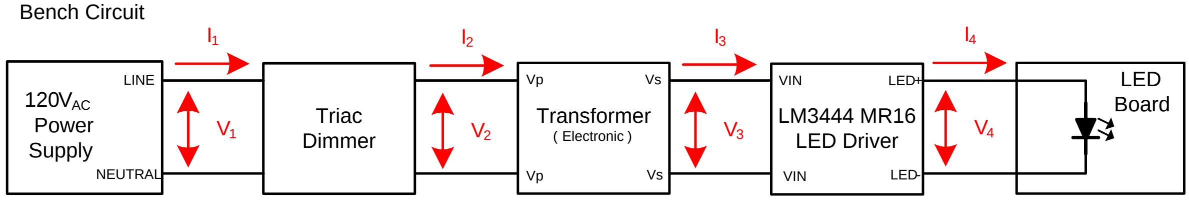


CH2 V1 Voltage, CH4 I2 Current



CH2 V2 Voltage, CH4 I2 Current

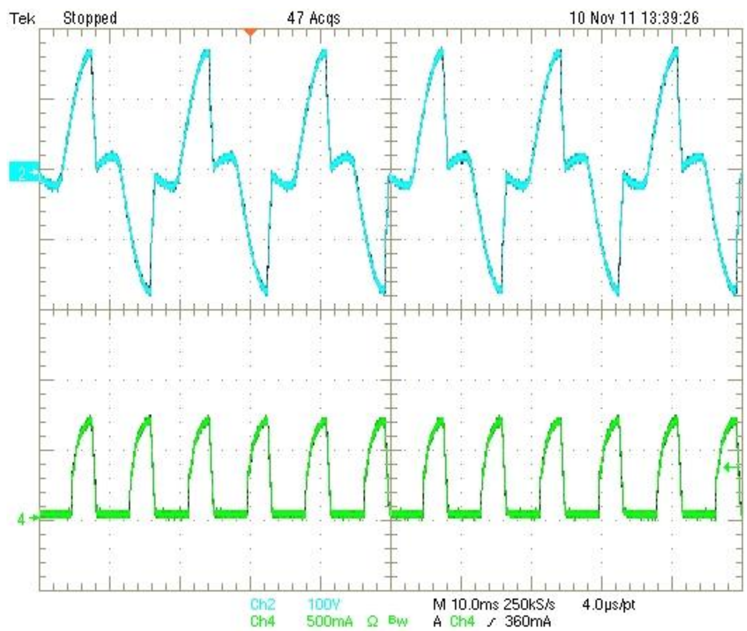
LM3444 MR16 Buck Boost evaluation board Dimming Waveforms



This LM3444 MR16 Buck Boost evaluation board is designed to operate (flicker-free) with common Electronic Low Voltage dimmers, and Electronic Transformers.

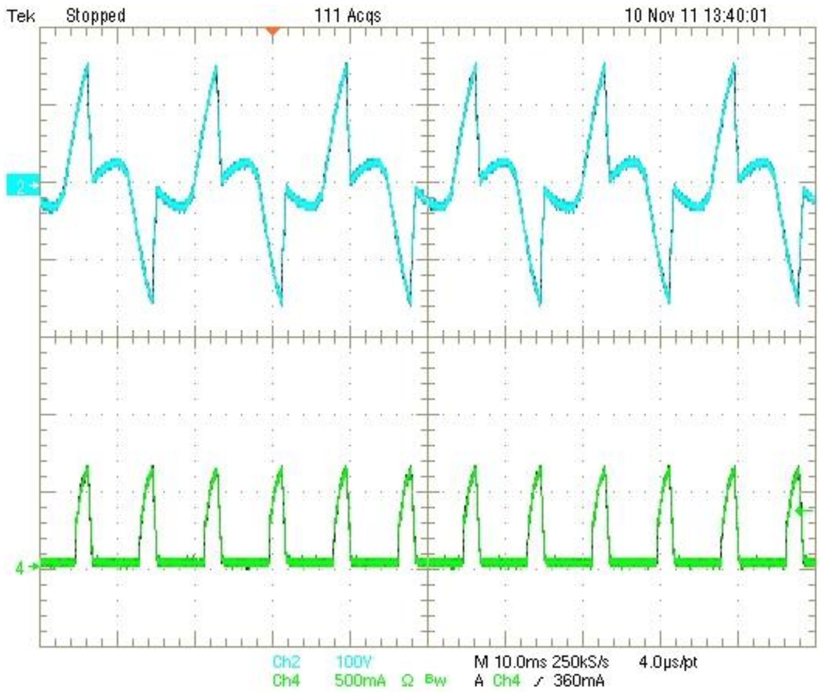
- Dimmer Used – Lutron SELV-300P-GR
- Electronic Transformer – Lightech LET75
- 20:1 dimming ratio

LM3444 MR16 Buck Boost - Four series connected LEDs at 200mA (90° Conduction Angle)



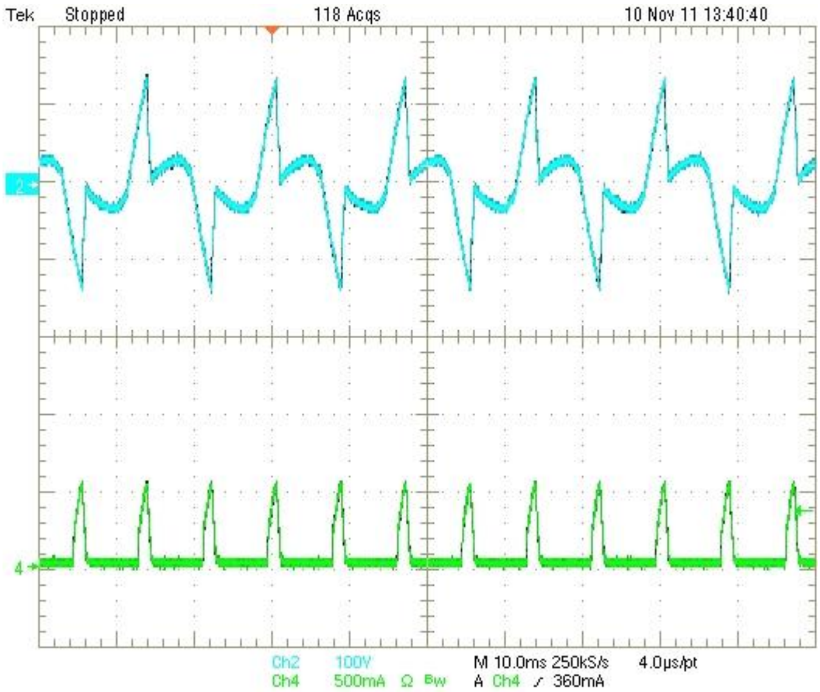
CH2 V2 Voltage, CH4 I4 Current

LM3444 MR16 Buck Boost - Four series connected LEDs at 100mA (45° Conduction Angle)



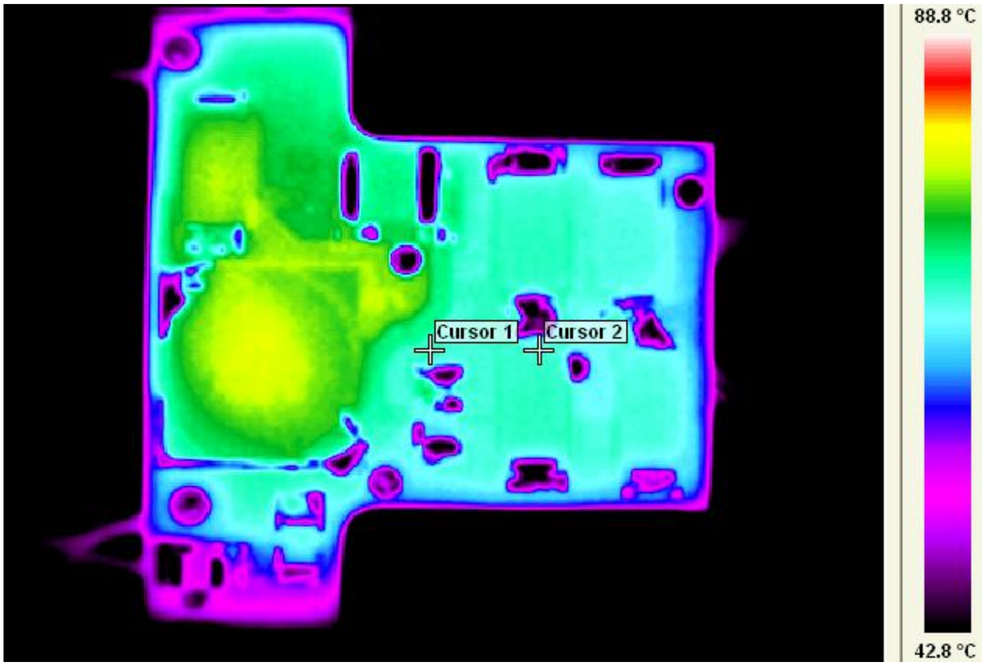
CH2 V2 Voltage, CH4 I4 Current

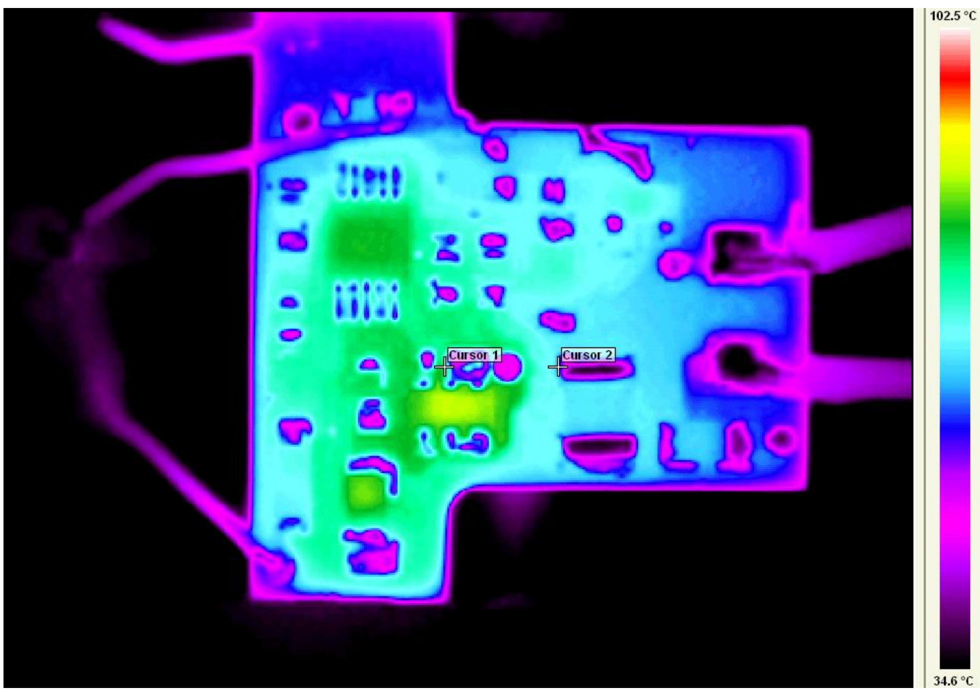
LM3444 MR16 Buck Boost - Four series connected LEDs at 10mA (minimum Conduction Angle)



CH2 V2 Voltage, CH4 I4 Current

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).

Electronic Transformers (120VAC to 12VAC):

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

Magnetic Transformers (120VAC to 12VAC):

Hatch, Model: LS1275EN, 75VA

Performance with 3 LEDs

Performance without transformer

The table below compares the performance of each reference design when powered directly by a 12VAC source

Specs	LM3441 BUCK BOOST 3 LEDs	Units
V_{IN}	12	VAC
I_{IN}	0.600	A
P_{IN}	6.63	W
V_{OUT} (1)	10.64	VDC
I_{LED} (1)	0.484	A
P_{OUT} (2)	5.15	W
Efficiency	77.7%	-
Power Factor	0.917	-

Performance with transformer

LET-75

Specs	LM3444 BUCK BOOST 3 LEDs	Units
V_{IN}	120	VAC
I_{IN}	0.064	A
P_{IN}	6.82	W
V_{OUT} (1)	10.16	VDC
I_{LED} (1)	0.472	A
P_{OUT} (2)	4.80	W
Efficiency	70.3%	-
Power Factor	0.885	-

HATCH RS12-80M

Specs	LM3444 BUCK BOOST 3 LEDs	Units
V_{IN}	120	VAC
I_{IN}	0.065	A
P_{IN}	6.65	W
V_{OUT}	10.15	VDC
I_{LED}	0.460	A
P_{OUT}	4.67	W
Efficiency	70.2%	-
Power Factor	0.845	-

Performance with 4 LEDs

Performance without transformer

The table below compares the performance of each reference design when powered directly by a 12VAC source

Specs	LM3441 BUCK BOOST 4 LEDs	Units
V_{IN}	12	VAC
I_{IN}	0.636	A
P_{IN}	7.08	W
V_{OUT} (1)	13.51	VDC
I_{LED} (1)	0.414	A
P_{OUT} (2)	5.59	W
Efficiency	79.0%	-
Power Factor	0.925	-

Performance with transformer

LET-75

Specs	LM3444 BUCK BOOST 4 LEDs	Units
V_{IN}	120	VAC
I_{IN}	0.068	A
P_{IN}	7.31	W
V_{OUT}	13.07	VDC
I_{LED}	0.403	A
P_{OUT}	5.27	W
Efficiency	72.0%	-
Power Factor	0.895	-

HATCH RS12-80M

Specs	LM3444 BUCK BOOST 4 LEDs	Units
V_{IN}	120	VAC
I_{IN}	0.069	A
P_{IN}	7.11	W
V_{OUT}	13.10	VDC
I_{LED}	0.391	A
P_{OUT}	5.12	W
Efficiency	72.0%	-
Power Factor	0.860	-

Performance with 5 LEDs

Performance without transformer

The table below compares the performance of each reference design when powered directly by a 12VAC source

Specs	LM3444 BUCK BOOST 5 LEDs	Units
V_{IN}	12	VAC
I_{IN}	0.659	A
P_{IN}	7.38	W
V_{OUT} (1)	16.71	VDC
I_{LED} (1)	0.353	A
P_{OUT} (2)	5.90	W
Efficiency	79.9%	-
Power Factor	0.933	-

Performance with transformer

LET-75

Specs	LM3444 BUCK BOOST 5 LEDs	Units
V_{IN}	120	VAC
I_{IN}	0.070	A
P_{IN}	7.65	W
V_{OUT}	16.22	VDC
I_{LED}	0.345	A
P_{OUT}	5.60	W
Efficiency	73.2%	-
Power Factor	0.902	-

HATCH RS12-80M

Specs	LM3444 BUCK BOOST 5 LEDs	Units
V_{IN}	120	VAC
I_{IN}	0.072	A
P_{IN}	7.50	W
V_{OUT}	16.09	VDC
I_{LED}	0.339	A
P_{OUT}	5.45	W
Efficiency	72.7%	-
Power Factor	0.872	-

Revision History

Date	Author	Revision	Description