AN3256
Application note

Low-cost LED driver for an A19 lamp

Introduction

This application note describes a prototype of a non-dimmable, non-isolated LED driver. The physical design is small enough to fit in the base of an A19 (screw bases 40 to 60 W equivalent) bulb outline. The coupled inductor has a stepdown winding to power the L6562A PFC driver.

The design goals:

- Input: 96-132VAC, 60 Hz, non-dimmable, TRIAC dimmer safe (no damage)
- Output: 370 mA into strings of 5 to 12 LEDs
- Topology: stepdown (buck) switching regulator
- Features: regulation of LED current, power factor acceptable for US market for residential use, excellent efficiency

ST devices:

- PFC controller: L6562A
- Switching FET: STD5NM50
- Flywheel diode: STTH1R04

Figure 1. Physical envelope

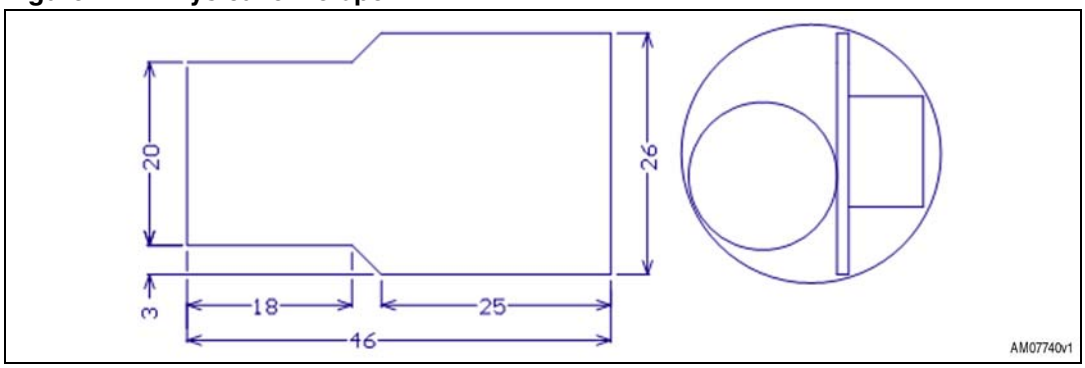

Figure 2. Image

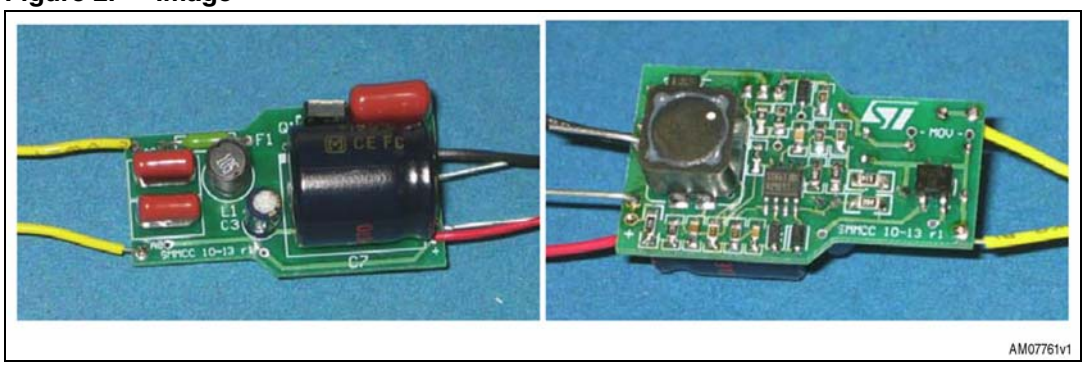

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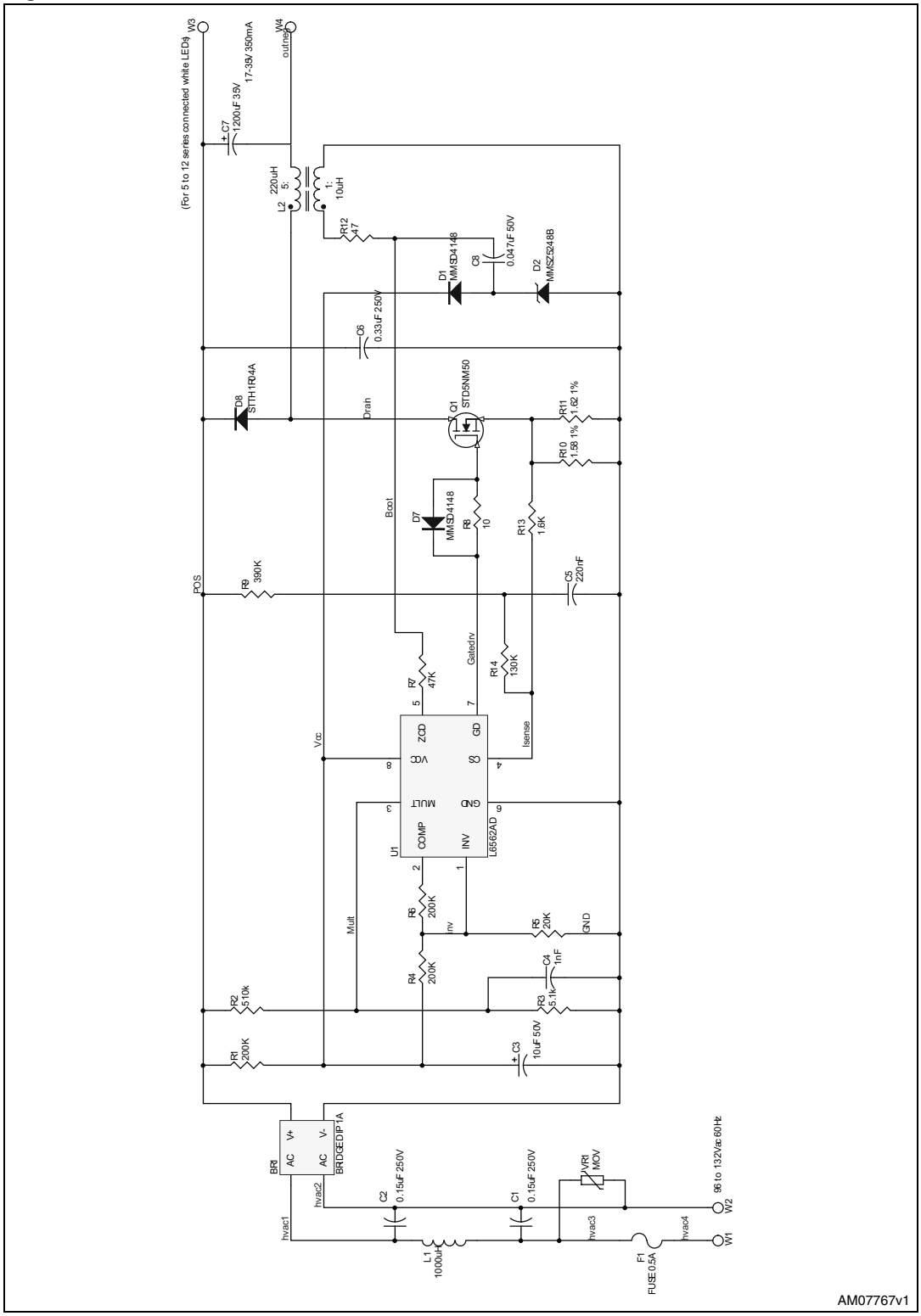
Figure 3. Schematic



2 Circuit description

C1, L1, and C2 provide filtering for conducted EMI. Bridge rectifier BRI feeds the stepdown switching regulator. The regulator appears inverted - the flywheel diode, D8, is connected to the positive rail instead of the negative. Q1 pulls the inductor input negative, rather than positive. Inductor L2 filters the output current, feeding C7 and the LED load.

The circuit starts up with a trickle of current into C3 thru R1. It takes about ¼ second to charge C1 to U1's startup voltage.

The startup timer in U1 starts the switching cycle by turning on Q1. Current in Q1 and L2 increases from zero to about 800 mA. This current appears on R10 and R11 which drop about 0.6 V. A filtered portion of the rectified AC line (from R9 and C5, added by R14 and R13) is added to this voltage, to compensate out the duty cycle shift due to line voltage. U1 turns off Q1 when it sees about 1 V at pin 4. The LED average current would increase with line voltage if not compensated, due to the decrease in FET ON time. R10 and R11 drop about 0.6V at the current peak. Line voltage compensation is added to this from divider R9-R14-R13. C6 filters the line voltage to DC to avoid further distortion of the line current".

L2's current continues to flow after Q1 turns off, instead flowing in D8. The current ramps toward zero, at which time D8 turns off. L2 and stray capacitance then ring the voltage at D8's anode down to about twice the LED voltage below the positive rail. When the ringing voltage turns up, U1 senses the end of the discharge and turns on Q1. The cycle then repeats. Current in L2's upper winding therefore ramps between zero and twice the load current. When Q1 turns on, D8 has already turned off, so Q1 does not see D8's reverse recovery spike.

Housekeeping power is supplied by the auxiliary (lower) winding on L2. This winding steps down the peak-to-peak voltage (the bulk input voltage) applied to the upper winding by 5:1. D1 and D2, with C8, peak detect the transitions on the auxiliary winding. D2 is a Zener diode, clamping the maximum voltage applied to C3 to slightly over 16 V. The 5:1 turns ratio is not optimum - about 7:1 would be better, wasting less power in D2 and R12.

Note: It should be noted that this circuit is not capable of providing output open circuit protection. Monitoring of the voltage on C3 no longer provides an indication of the output voltage.

The auxiliary winding also provides U1 with timing for the zero-current sensing function, through R7.

The current waveform at the circuit's AC input is not sinusoidal, but it is clean enough to give acceptable power factor for residential use in the U.S. Some improvement at the leading and trailing edges is provided by U1's multiplier input, which is allowed to affect the current limit only when the instantaneous line voltage is very low.

3 Performance with LED loads

The data in this section was taken with loads consisting of two parallel strings of LEDs. The driver acts as a current source, the LEDs determine the output voltage.

3.1 Strings of 4 series-connected 1 W white LEDs

Table 1. Performance overline voltage range with 4 LEDs per string

Parameter	20 % low line	10 % low line	Nominal line	10 % high line
Line voltage	95.5	107.7	119.7	132.3
Line current, mA	69.5	65.3	61.8	59.2
Input power, Watts	5.90	5.985	6.015	6.050
Power factor	0.888	0.851	0.815	0.769
Output voltage	12.52	12.53	12.52	12.51
Output current, Amps	0.394	0.398	0.398	0.395
Output power, Watts	4.933	4.987	4.983	4.941
Efficiency	83.6 %	83.3 %	82.8 %	81.7 %
Power loss	0.967	0.998	1.032	1.109
U1 Vcc	11.41	13.37	15.16	16.35

At low line input the circuit stops operating when housekeeping power fails to keep the converter running. The result is that the LEDs flash, at an annoying rate. The line voltage at which this occurs is noted below.

Dropout to flashing, 88 V (too close to the minimum spec line voltage, 96 V. Strings of 4 LEDs cannot be used without modifying the circuit. Strings of 5 LEDs give sufficient margin).

- Trace colors:
  - Yellow= line voltage, 50 V/div ref 0
  - Magenta= line current, 100 mA/div ref 0
  - Blue= LED voltage, 5 V/div ref -3 div
  - Green= LED current, 100 mA/div ref -3 div

Figure 4. 96 V input, 4 LED load

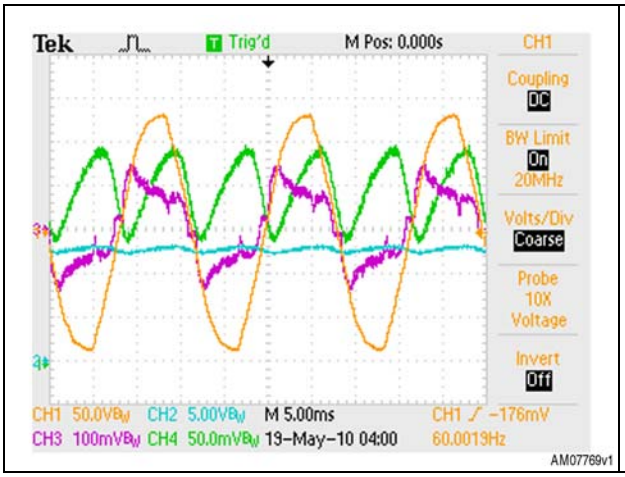
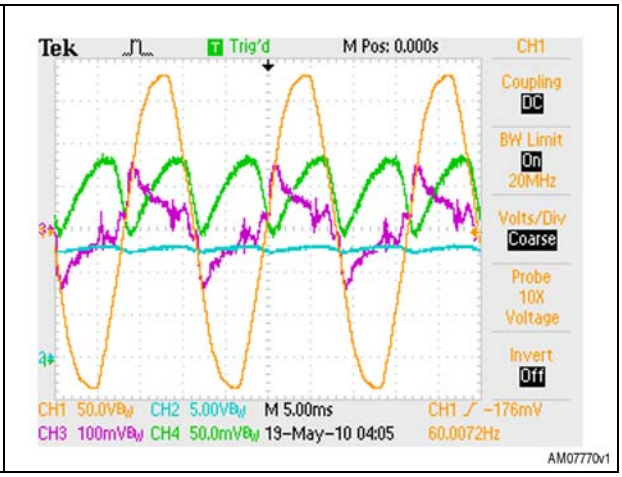


Figure 5. 132 V input, 4 LED load



3.2 Strings of 6 series-connected 1 W white LEDs

Table 2. Performance overline voltage range with 6 LEDs per string

Parameter	20 % low line	10 % low line	Nominal line	10 % high line
Line voltage	95.7	107.9	120.2	132.3
Line current, mA	96.46	89.2	83.5	78.6
Input power, Watts	8.42	8.515	8.556	8.554
Power factor	0.912	0.880	0.853	0.823
Output voltage	18.84	18.83	18.81	18.79
Output current, Amps	0.389	0.393	0.392	0.389
Output power, Watts	7.329	7.400	7.374	7.309
Efficiency	87.0 %	86.9 %	86.2 %	85.4 %
Power loss, Watts	1.091	1.115	1.182	1.245
U1 Vcc	13.86	15.84	16.03	16.39

Dropout to flashing, 78 V.

- Trace colors:
  - Yellow = line voltage, 50 V/div ref 0
  - Magenta = line current, 100 mA/div ref 0
  - Blue = LED voltage, 5 V/div ref - 3 div
  - Green = LED current, 100 mA/div ref - 3 div

Figure 6. 96 V input, 6 LED load

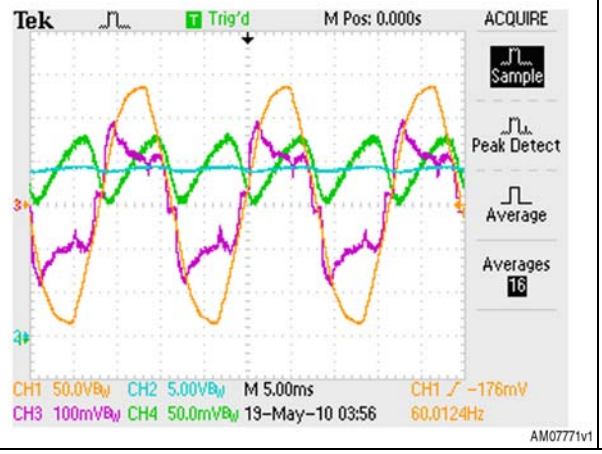
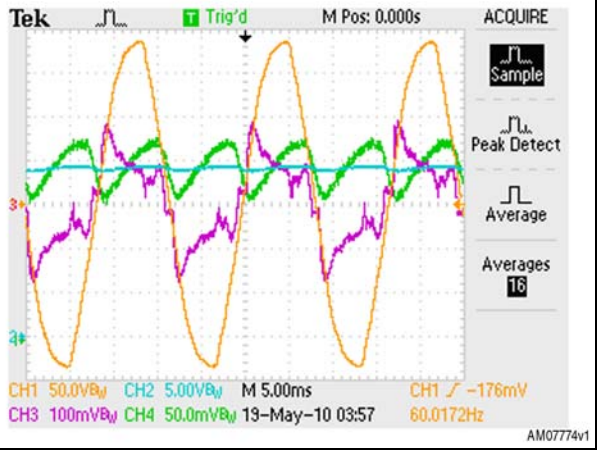


Figure 7. 132 V input, 6 LED load



3.3 Strings of 8 series-connected 1 W white LEDs

Table 3. Performance overline voltage range with 8 LEDs per string

Parameter	20 % low line	10 % low line	Nominal line	10 % high line
Line voltage	95.7	107.6	120.0	132.2
Line current, mA	123.2	113.2	104.9	97.9
Input power, Watts	10.80	10.93	11.00	10.98
Power factor	0.919	0.896	0.871	0.848
Output voltage	25.00	24.99	24.97	24.93
Output current, Amps	0.384	0.388	0.388	0.385
Output power, Watts	9.60	9.70	9.69	9.60
Efficiency	88.9 %	88.7 %	88.1 %	87.4 %
Power loss, Watts	1.20	1.23	1.31	1.38
U1 Vcc	14.62	16.2	16.58	16.90

Dropout to flashing, 73 V.

- Trace colors:
  - Yellow = line voltage, 50 V/div ref 0
  - Magenta = line current, 100 mA/div ref 0
  - Blue = LED voltage, 5 V/div ref - 3 div
  - Green = LED current, 100 mA/div ref -3 div

Figure 8. 96 V input, 8 LED load

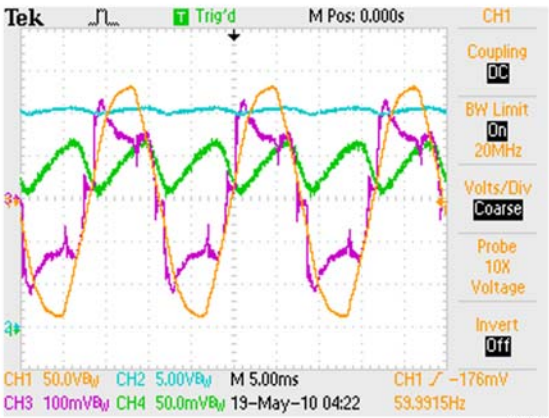
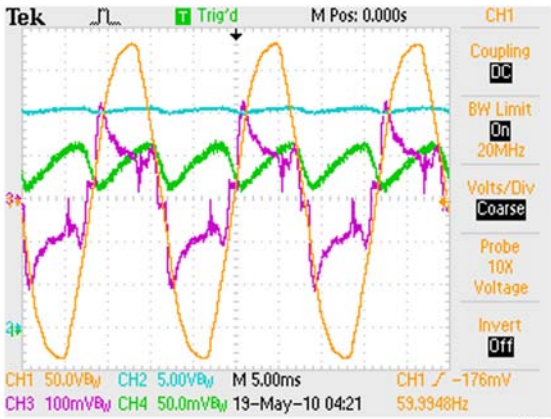


Figure 9. 132 V input, 8 LED load



3.4 Strings of 10 series-connected 1 W white LEDs

Table 4. Performance overline voltage range with 10 LEDs per string

Parameter	20 % low line	10 % low line	Nominal line	10 % high line
Line voltage	95.2	108.3	120.1	132.6
Line current, mA	148	135.3	125.5	116.2
Input power, Watts	13.01	13.20	13.28	13.28
Power factor	0.923	0.901	0.882	0.861
Output voltage	31.11	31.09	31.07	31.03
Output current, Amps	0.377	0.381	0.382	0.379
Output power, Watts	11.73	11.85	11.87	11.76
Efficiency	90.1 %	89.7 %	89.4 %	88.6 %
Power loss, Watts	1.28	1.35	1.41	1.44
U1 Vcc	15.14	16.39	16.74	17.01

Dropout to flashing, 71.5 V.

- Trace colors:
  - Yellow = line voltage, 50 V/div ref 0
  - Magenta = line current, 100 mA/div ref 0
  - Blue = LED voltage, 5 V/div ref - 3 div
  - Green = LED current, 100 mA/div ref -3 div

Figure 10. 96 V input, 10 LED load

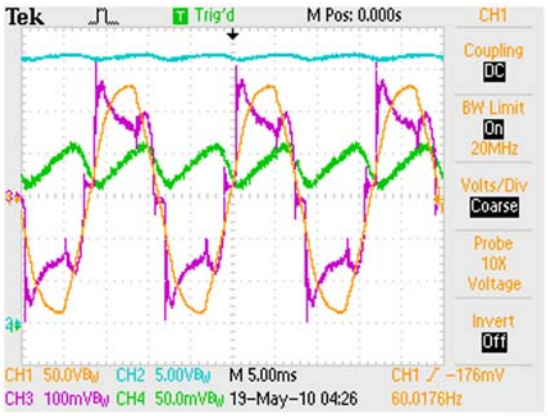
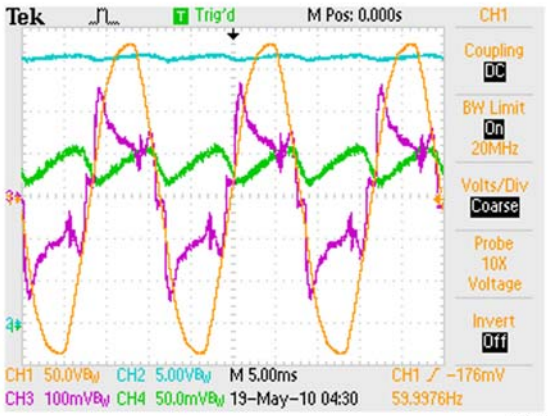


Figure 11. 132 V input, 10 LED load



3.5 Strings of 12 series-connected 1 W white LEDs

Table 5. Performance overline voltage range with 12 LEDs per string

Parameter	20 % low line	10 % low line	Nominal line	10 % high line
Line voltage	95.7	107.8	120.2	132.5
Line current, mA	170.3	157.1	144.8	134.6
Input power, Watts	15.09	15.32	15.44	15.46
Power factor	0.923	0.905	0.886	0.868
Output voltage	37.17	37.14	37.13	37.10
Output current, Amps	0.369	0.374	0.375	0.373
Output power, Watts	13.716	13.89	13.92	13.84
Efficiency	90.9 %	90.7 %	90.2 %	89.5 %
Power loss, Watts	1.374	1.430	1.520	1.620
U1 Vcc	15.74	16.48	16.86	17.14

Dropout to flashing, 70 V.

- Trace colors:
  - Yellow = line voltage, 50 V/div ref 0
  - Magenta = line current, 200 mA/div ref 0
  - Blue = LED voltage, 10 V/div ref - 3 div
  - Green = LED current, 100 mA/div ref -3 div

Figure 12. 96 V input, 12 LED load

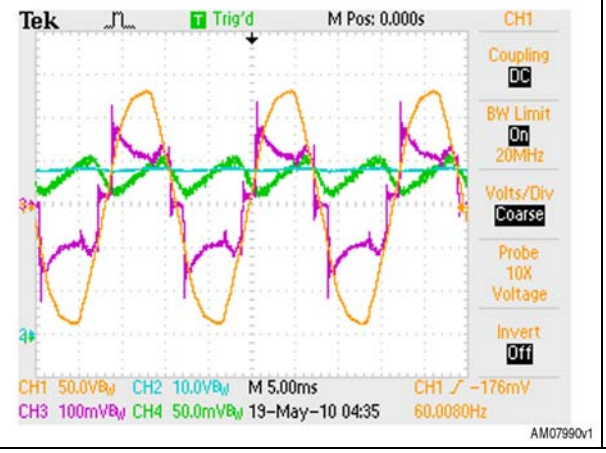
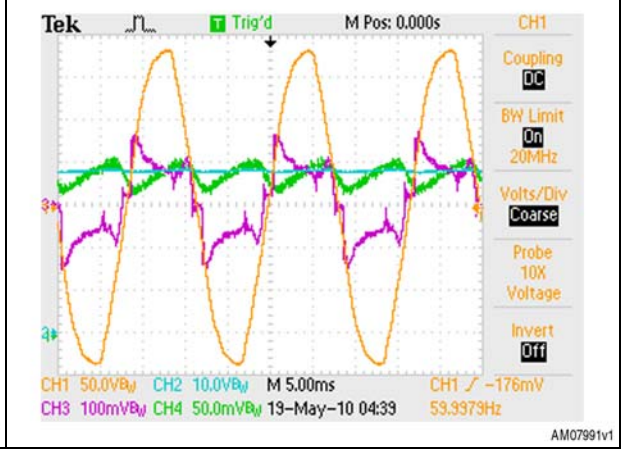
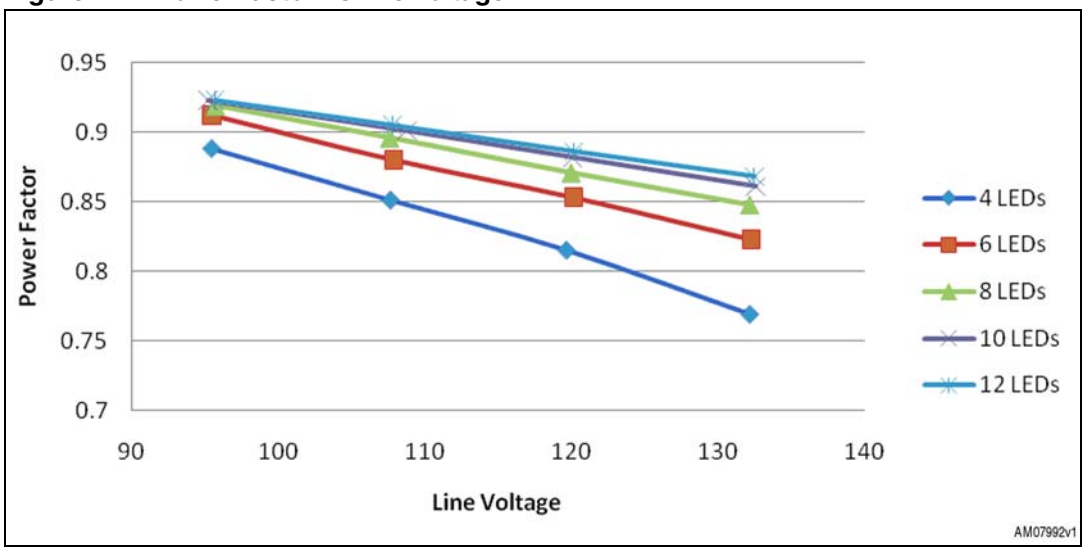


Figure 13. 132 V input, 12 LED load



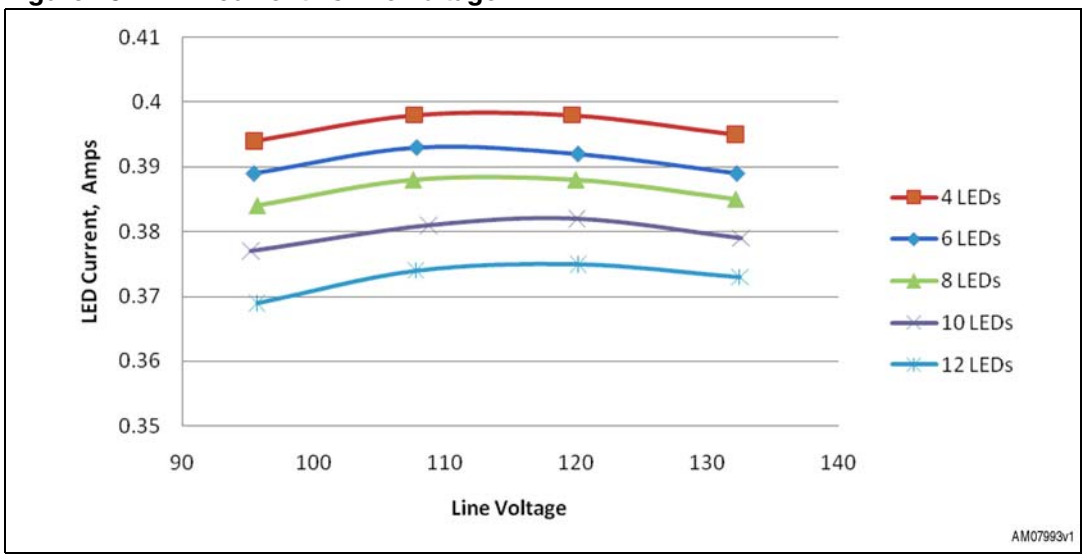
4 Graphical data

Figure 14. Power factor vs line voltage



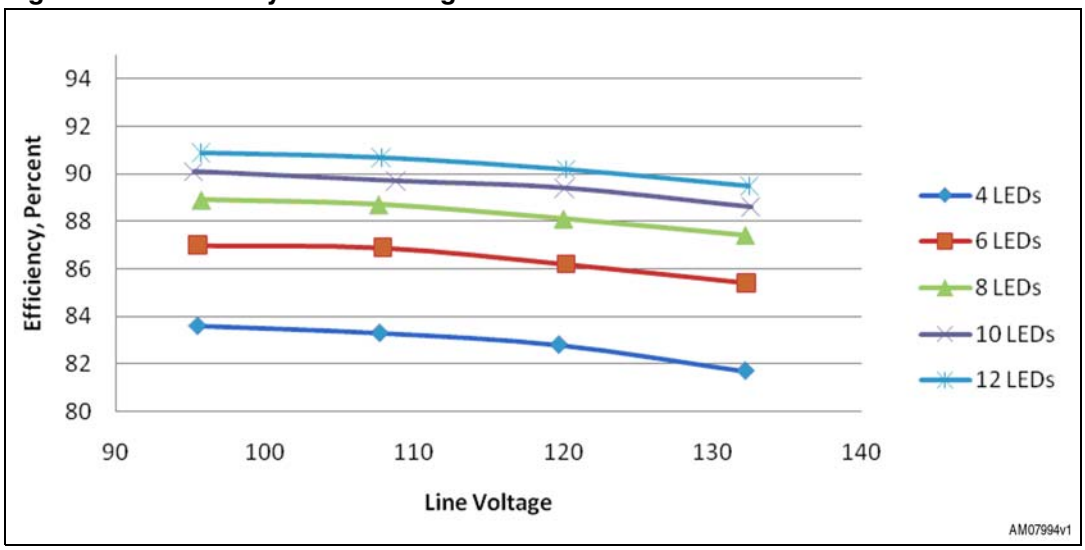
Power factor improves with more LEDs in the string, but is nearing the maximum. It is quite sensitive to line voltage, lowest at high line.

Figure 15. LED current vs line voltage



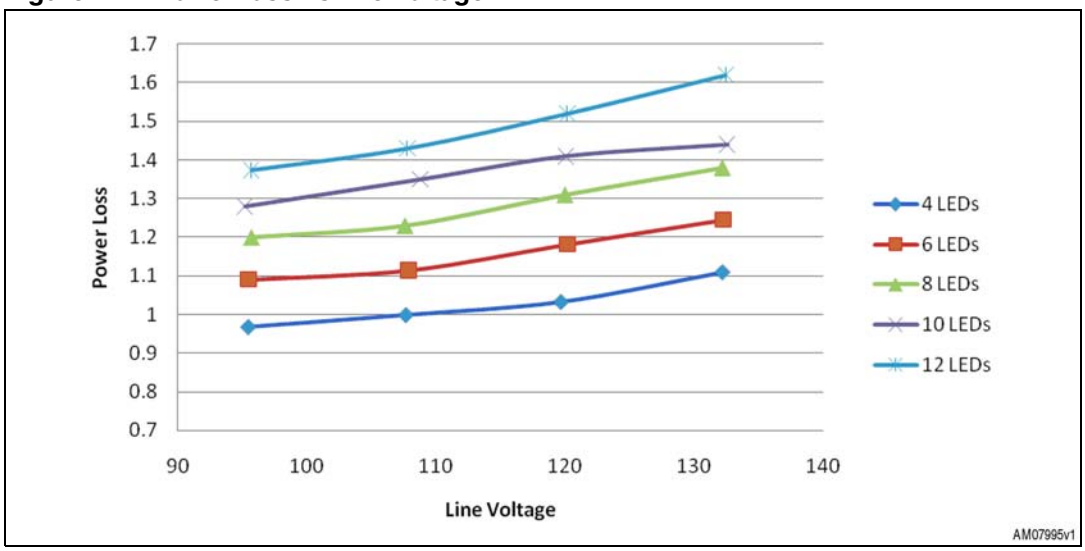
LED current is quite insensitive to line voltage, trimming may be needed depending on the number of LEDs in the load.

Figure 16. Efficiency vs line voltage



Efficiency improves with the number of LEDs. It is better at low line voltage.

Figure 17. Power loss vs line voltage



Power loss increases with both line voltage and number of LEDs in the load. This indicates a series loss - both the FET resistance and the input filter choke resistance could be contributing.

5 FET voltage and current stress

The images below were taken at the peak of the line voltage waveform, where stress on the parts is greatest.

- Yellow = FET voltage, 100 V/div
- Blue = FET current, appx. 0.24 A/div

Figure 18. 132 V input, 4 LED load

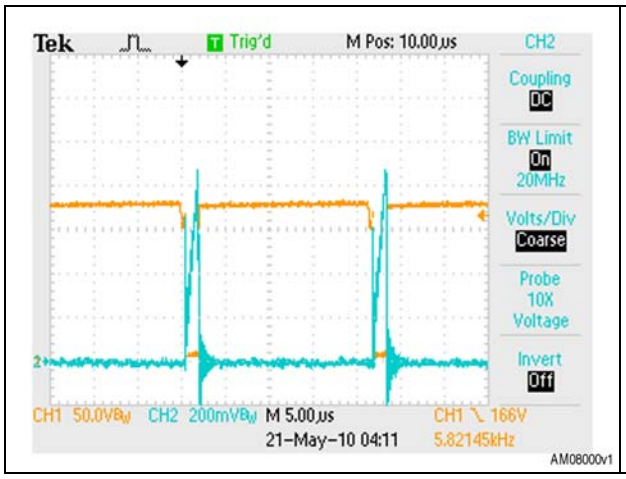


Figure 19. 132 V input, 4 LED load, single pulse

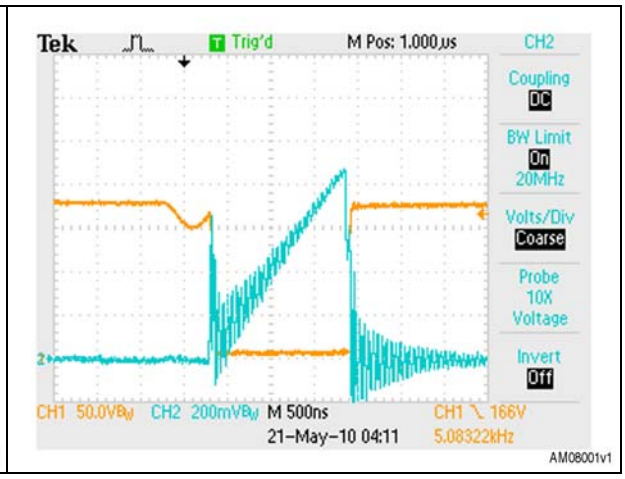


Figure 20. 132 V input, 12 LEDs

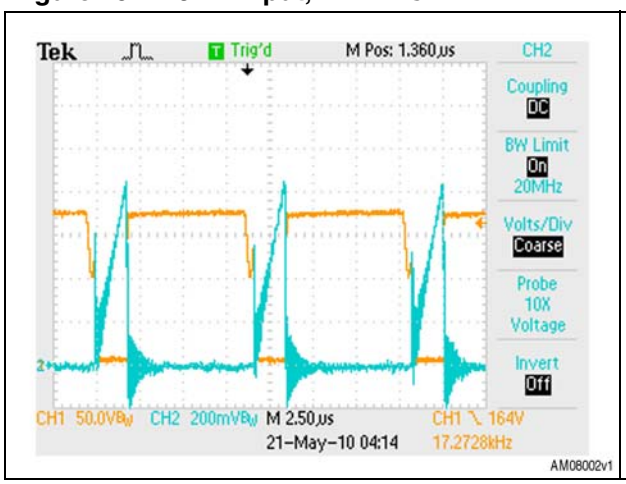
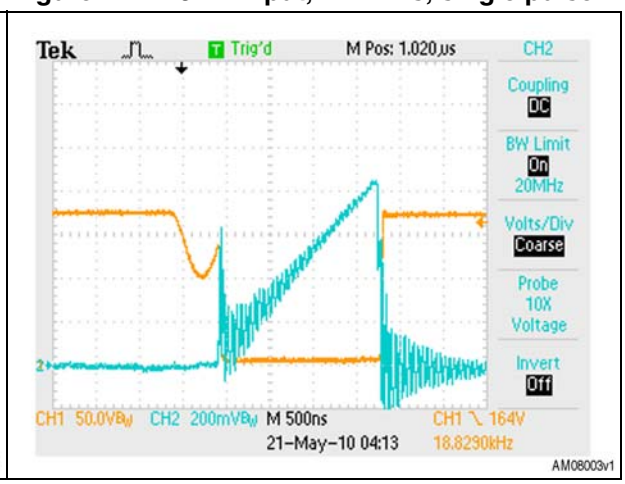


Figure 21. 132 V input, 12 LEDs, single pulse



The FET sees only the peak line voltage. The diode (D8) has turned off well before the FET turns on - there is no reverse recovery problem. The leading edge spike is small, and is due only to the FET discharging D8's and L2's capacitance, and includes the gate drive leading edge current.

6 Thermal stress

It is not likely that the layout is used as is by the customer. The temperatures below are for guidance only - measurements were taken after 30 minutes operation, in open air, on the workbench, in a 24.9 C ambient, 120 V input, 12 LED load.

Table 6. Component temperatures

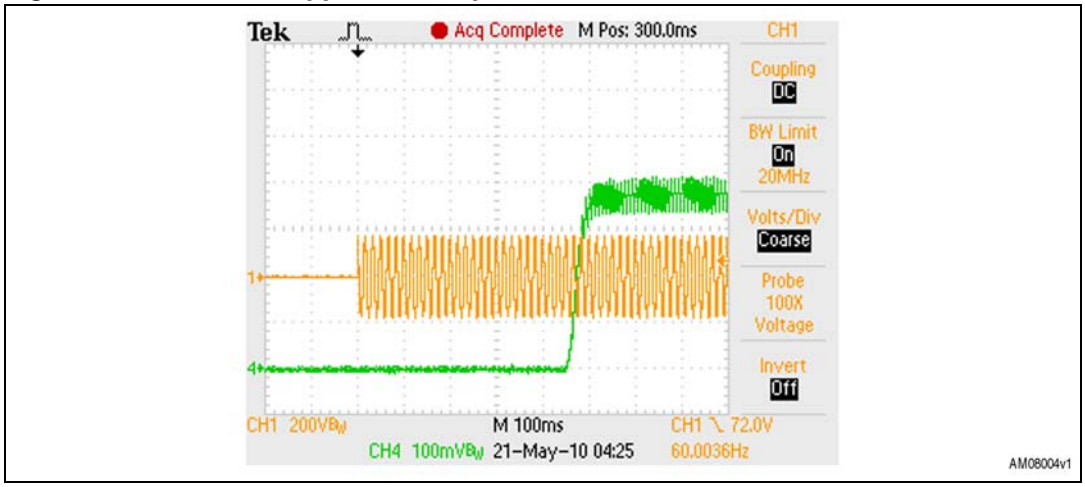
Component	Measured
L1	44.7
BR1	50.9
Q1	38.9
D8	59.8
L2	49.2

7 Startup

Cold start, everything discharged, 7 LEDs, 120 V in:

- Yellow = AC line, 200 V/div
- Green = LED current, 100 mA/div

Figure 22. Time from application of power to LED illumination



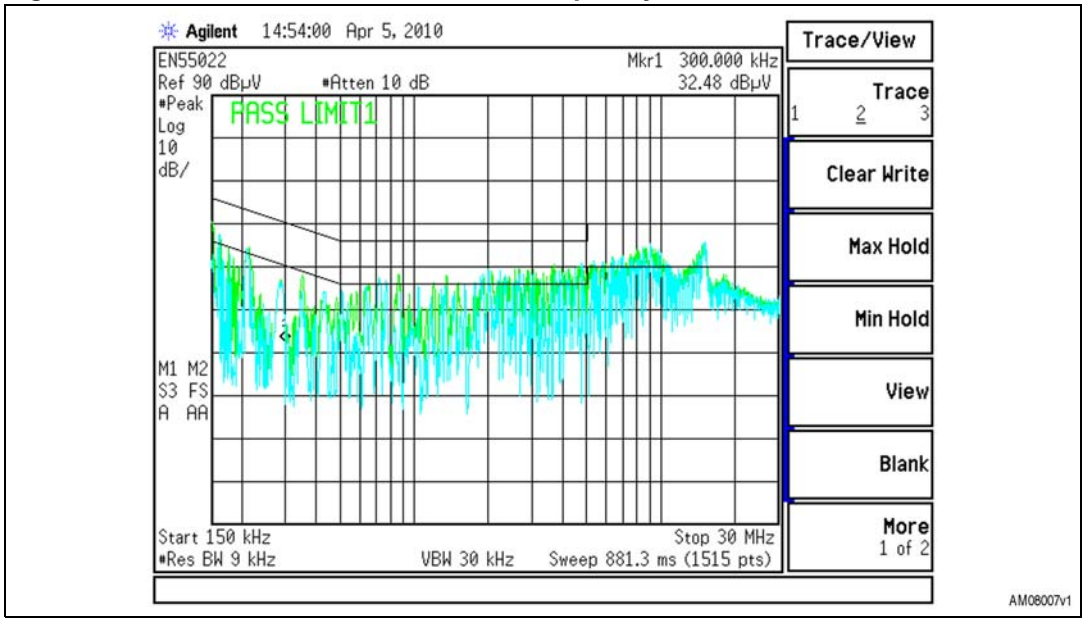
450 ms to light, 500 ms to full output.

8 Conducted EMI

Traces shown below are the maximum of 3 successive sweeps (max hold), peak values.

- Red = line 1
- Blue = line 2

Figure 23. Conducted EMI, dbµV versus frequency



Some work remains to be done. The input EMI choke L1 is too small. Damping resistors across the choke should help at its parallel self-resonance.

9 Layout

Figure 24. Top side layout and placement

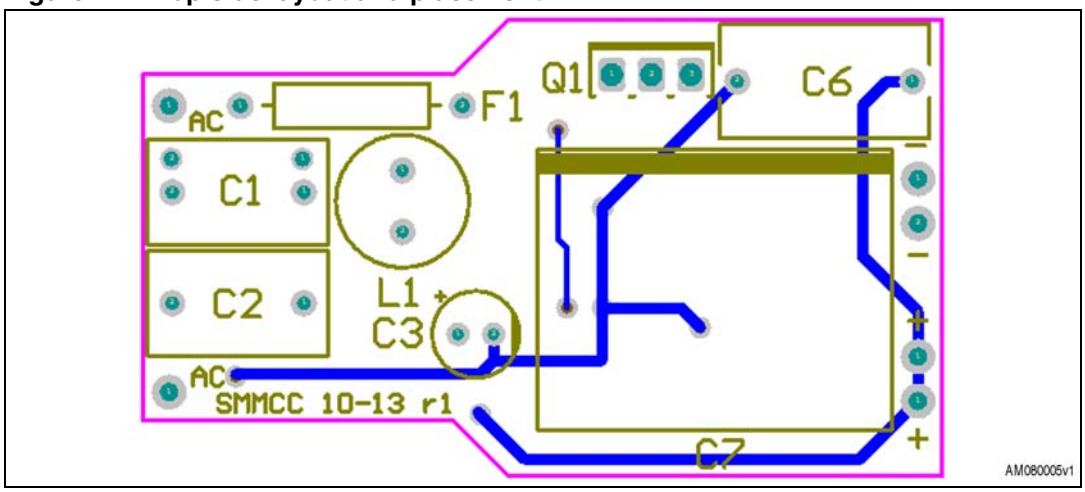


Figure 25. Bottom side layout

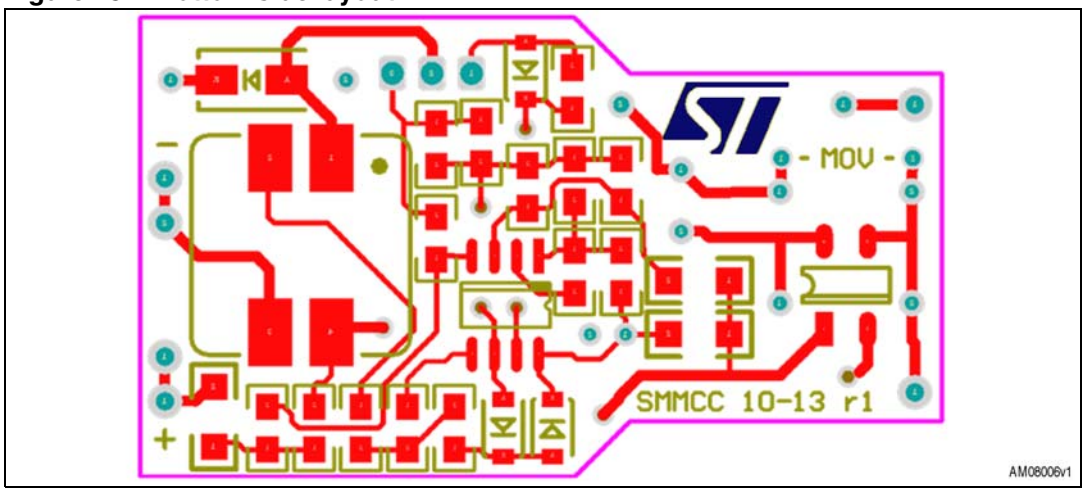
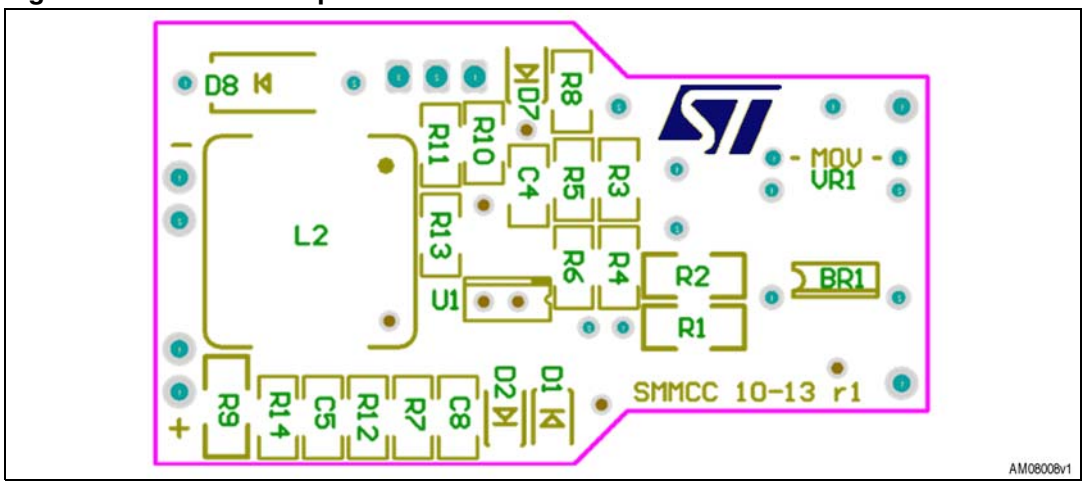


Figure 26. Bottom side placement



10 Bill of material

Table 7. BOM

Designator	Comment	Manufacturer	Comment
BR1	BRIDGE DIP 1 A	Diodes Inc HD06	
C1, C2	0.15 µF 250 V	Panasonic ECQ-E2154KF	
C3	10 µF 50 V	Panasonic EEU-FC1H100L	
C4	1 nF	X7R 0805	Generic
C5	220 nF	X7R 0805	Generic
C6	0.33 µF 250 V	Panasonic ECQ-E2334KF	
C7	1200 µF 35 V	Panasonic EEU-FM1V122S	
D1, D7	MMSD4148	Signal diode	
D2	MMSZ5248B	18 V ½ Watt Zener	
D8	STTH1R04A	ST STTH1R04A	STMicroelectronics
F1	FUSE 0.5 A	Littelfuse 0251.500MXL	
L1	1000 µH	Coilcraft DR0608-105L	
L2	220 µH	Wurth S09100111	5:1 stepdown
Q1	STD5NM50	ST STD5NM50	STMicroelectronics
R1	200 kΩ	5 % 1206	Generic
R2	510 kΩ	5 % 1206	Generic
R3	5.1 kΩ	5 % 0805	Generic
R4, R6	200 kΩ	5 % 0805	Generic
R5	20 kΩ	5 % 0805	Generic
R7	47 kΩ	5 % 1206	Generic
R8	10 Ω	5 % 0805	Generic
R9	390 kΩ	5 % 1206	Generic
R10	1.58 1 %	1 % 0805	Generic
R11	1.62 1 %	1 % 0805	Generic
R12	100 Ω	5 % 0805	Generic
R13	1.6 kΩ	5 % 0805	Generic
R14	130 kΩ	5 % 0805	Generic
U1	L6562AD	ST L6562AD	STMicroelectronics
VR1	MOV	TBD	

11 Reference

1. J. Shao, “Single Stage Offline LED Driver,” presented at Applied Power Electronics Conference and Exposition (APEC), Washington, DC, 2009.

12 Revision history

Table 8. Document revision history

Date	Revision	Changes
23-Sep-2010	1	Initial release.