UM10479

SSL2101 120 V 7.5 W GU10 flyback reference board

Rev. 1.1 — 19 August 2011 User manual

Document information

Info	Content
Keywords	SSL2101, flyback, convertor, dimmable, active bypass
Abstract	This document explains the operation and application of a 7.5 W 120 V dimmable LED driver featuring SSL2101. The demo board has a form factor that is compatible with the base of a GU10 LED lamp.

Revision history

Rev	Date	Description
v.1.1	20110819	second version
Modifications:		• Table 1 “Specification” on page 5: values changed. • Section 7 “Performance data (on Cree’s XPE LEDs)” on page 8: first paragraph added to.
v.1	20110707	first version

1. Introduction

WARNING

Lethal voltage and fire ignition hazard

The non-insulated high voltages that are present when operating this product, constitute a risk of electric shock, personal injury, death and/or ignition of fire.

This product is intended for evaluation purposes only. It shall be operated in a designated test area by personnel qualified according to local requirements and labor laws to work with non-insulated mains voltages and high-voltage circuits. This product shall never be operated unattended.

This document explains the operation and application of a 7.5 W 120 V dimmable LED driver featuring the SSL2101. The demo board has a form factor that is compatible with the base of a GU10 LED lamp. The board employs a flyback converter to provide an isolated solution for mains-dimmable LED recessed-light applications.

The board is available in two different versions, designed to support both a 5-LED and 7-LEDs load with an output power of approximately 7.5 W. The board operates at approximately 45 kHz and produces a regulated output current of 470 mA for the 5-LED load or 340 mA for the 7-LED load, with an efficiency of around 73 %. Both versions are fully compliant with EMC regulations. Key features of the board include:

- Deep dimming capability
- Wide dimming compatibility
- Small form factor tailored to fit a GU10 lamp
- Cost effectiveness

Dimensions of the board are shown in Figure 1. The board is shaped to fit in the base of a GU10 LED lamp. Board components are precisely placed on the board to allow for enough headroom when the board is inserted into the lamp base.

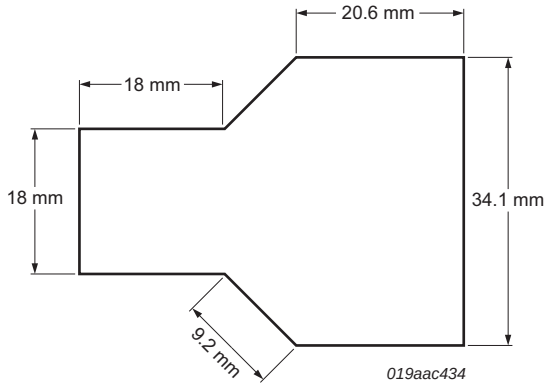

Fig 1. Board dimensions

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Fig 2. SSL2101 demo board (top view)

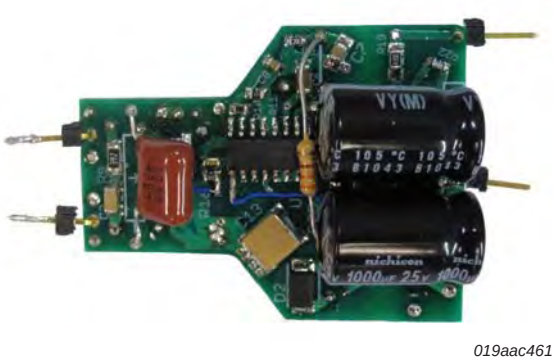

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Fig 3. SSL2101 demo board (bottom view)

2. Safety warning

The board needs to be connected to the mains voltage. Touching the board while it is connected to the mains voltage must be avoided at all times. An isolated housing is obligatory when used in uncontrolled, non laboratory environments. Galvanic isolation of the mains phase using a variable transformer is always recommended.

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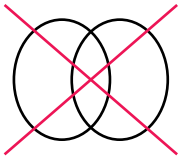
a. Isolated



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b. Not isolated

Fig 4. Variac isolation symbols

3. Specification

3.1 Demo board performance and specification

Table 1. Specification

Parameter	Value	Comment
AC line input voltage	108 V (AC) to 132 V (AC)	Nominal input 120 V, 60 Hz
Output voltage	16 V	5-LED string load
	22 V	7-LED string load
Output current	455 mA	5-LEDs; ± 3.5 %
	330 mA	7-LEDs; ± 3.5 %
Efficiency	73 %	
Power factor	0.93	5-LEDs
	0.945	7-LEDs
Output current ripple	30 %	5-LEDs
	22 %	7-LEDs
Switching frequency	45 kHz	
Output current regulation	±5 %	±10 % offset nominal line voltage

4. Functional description

The LED driver uses the SSL2101 control IC. The SSL2101 is a Switched Mode Power Supply (SMPS) controller with an integrated MOSFET. Detailed information about the operation of SSL2101 can be found in its data sheet, see Ref. 1.

The driver employs flyback converter topology with secondary current regulation. The converter operates in Discontinuous Conduction Mode (DCM), or a Boundary Conduction Mode (BCM), with valley switching detection. In BCM, valley switching detection is used to minimize magnetic component and switching losses while enhancing efficiency.

The demo board is triac dimmable. When dimmers are used, the circuit detects the rectified voltage change and reduces the switching duty cycle to reduce the output current. The SSL2101's own internal strong and weak bleeders are used to supplement the current in the circuit to provide for the hold and latch currents required by triac dimmers. The circuit is compatible with a broad range of dimmers as shown in Table 2

5. Dimmer compatibility

Several dimmers have been tested as different dimmers have different specifications, the dimming performance of the board may vary. Table 2 shows the range of mains dimmers tested for compatibility with the SSL2101 demo board.

Table 2. Dimmer compatibility

Manufacturer	Model number	Voltage/type	Compatibility
LUTRON	S-600	120 V/incandescent	Yes
LUTRON	S-600P	120 V/incandescent	Yes
LUTRON	S600-H	120 V/incandescent	Yes
LUTRON	TG-600PH	120 V/incandescent	Yes
LUTRON	DVW-600PH	120 V/incandescent	Yes
LUTRON	DVW-603GH	120 V/incandescent	Yes
LUTRON	DVM-600PH	120 V/incandescent	Yes
LUTRON	DV-603PG	120 V/incandescent	Yes
LUTRON	DV-600P	120 V/incandescent	Yes
LUTRON	DV Beta Build	120 V/incandescent	Yes
LUTRON	CTCL-153PDH	120 V/incandescent	Yes
LUTRON	GL-600PH	120 V/incandescent	Yes
LUTRON	Credenza S31	120 V/incandescent (lamp)	Yes
LEVITON	6631	120 V/incandescent	Yes
LEVITON	6602	120 V/incandescent	Yes
LEVITON	6602-I	120 V/incandescent	Yes
LEVITON	RPI06	120 V/incandescent	Yes
Unknown	GL410A	120 V/incandescent (lamp)	Yes
GE	18021	120 V/incandescent	flicker
GE	52136	120 V/incandescent	flicker

6. Reference board connections and evaluation procedures

6.1 Connectivity

The GU10 LED driver board supplied by 120 V (AC) 60 Hz mains supply supports either a 5-LED or a 7-LED load. Setting up the board for evaluation is as shown in Figure 5, where input pins W1 and W2 must be connected to the AC input power (Line and Neutral), and an LED string in series with a current meter must be connected to the two output pins LED+ and LED−. Current comes out of pin LED+ and flows back to LED−. Therefore, the connection must be made so that the current enters the LED string from the anode of the first LED and exits from the cathode of the last LED. A voltage meter must be placed directly across the two LED+ and LED− pins for a more accurate reading.

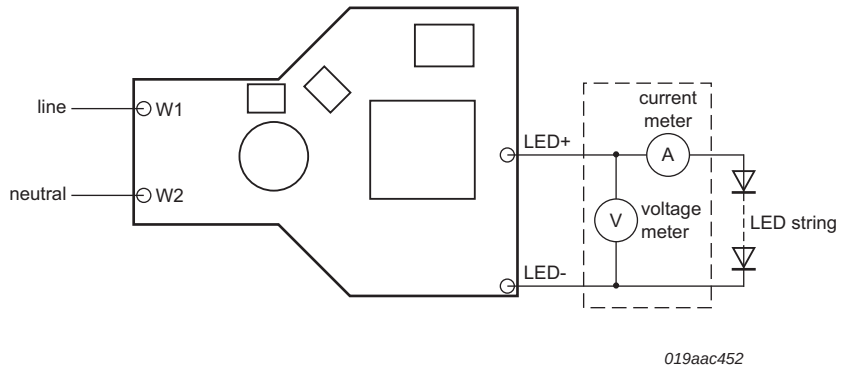


Fig 5. Board connections

Remark: All connections must be made with input power switched-off.

6.2 Evaluation

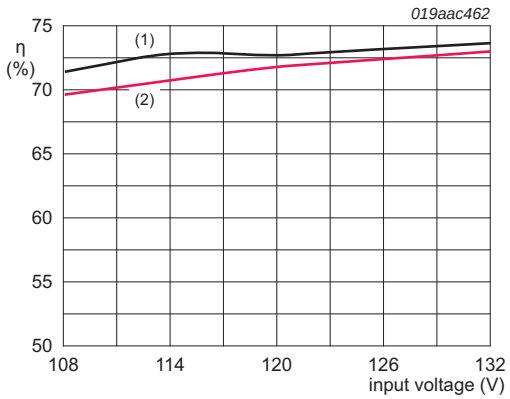
Set-up the board for testing and complete the following:

1. Switch-on the power supply
2. Check the LED current and voltage from the current and voltage meters. If there is no output, switch-off the power supply and check all connections. Once the correct voltage and current are established move to step 3.
3. Adjust the input voltage within the operating range. Now monitor the performance matrixes including, output current regulation, efficiency, current ripple, and power factor. See Figure 6 to Figure 10.
4. To test dimmer compatibility, switch-off the input power supply then connect a dimmer between input power supply and the input of the driver board. Now switch-on the power supply and adjust the dimmer and monitor the output current and LED light for a smooth, flicker-free dimming operation.

Remark: If the output current and voltage are correctly established, the current meter and voltage meter, as shown in Figure 5, can be removed and the LED string can be connected directly to the output pins LED+ and LED−.

7. Performance data (on Cree's XPE LEDs)

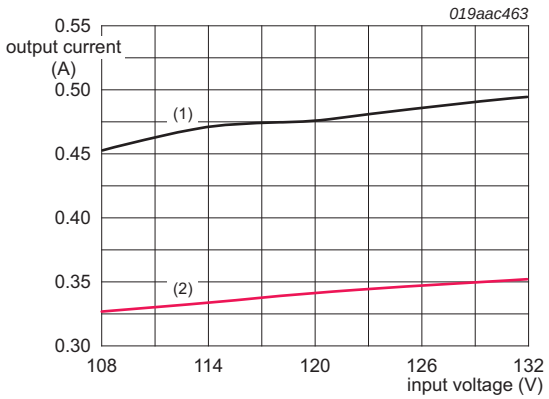
Figure 6 to Figure 10 provided detailed performance test results associated with the SSL2101 demo board. The results are based on a 470 mA output current for the 5-LED load and 340 mA for the 7-LED load. The output current can be adjusted within ± 10 % by changing the combined value of R21 and R23 (see Figure 11 and Figure 12).



(1) 5-LED

(2) 7-LED

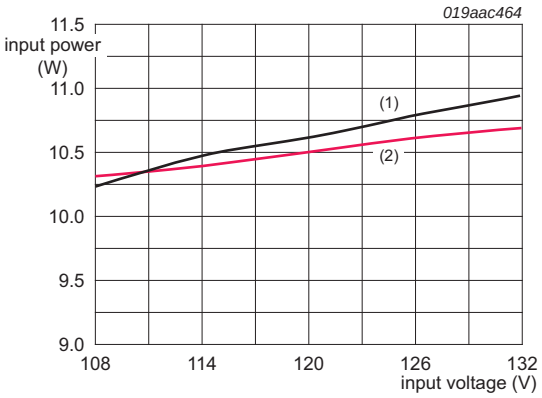
Fig 6. Efficiency



(1) 5-LED

(2) 7-LED

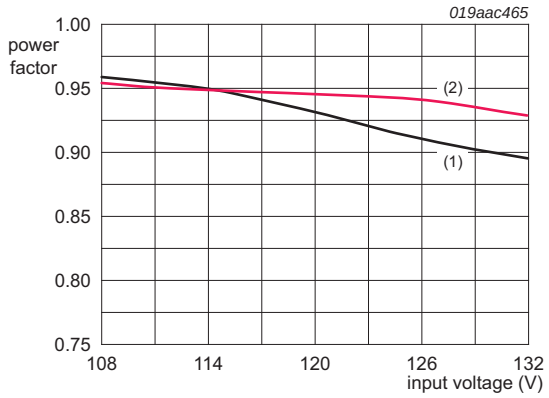
Fig 7. Output current



(1) 5-LED

(2) 7-LED

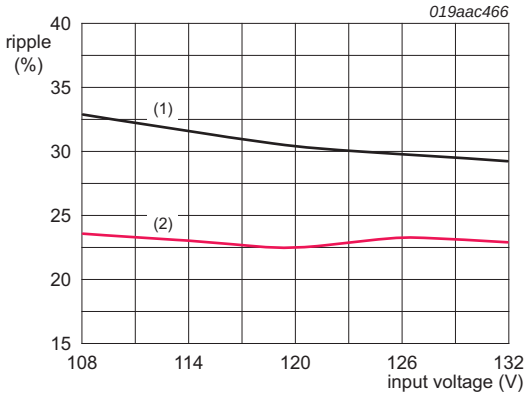
Fig 8. Input power



(1) 5-LED

(2) 7-LED

Fig 9. Power factor



(1) 5-LED

(2) 7-LED

Fig 10. Output current ripple

8. EMI

Both versions of the SSL2101 demo board are fully pre-compliant to EMC regulations.

9. Circuit diagrams

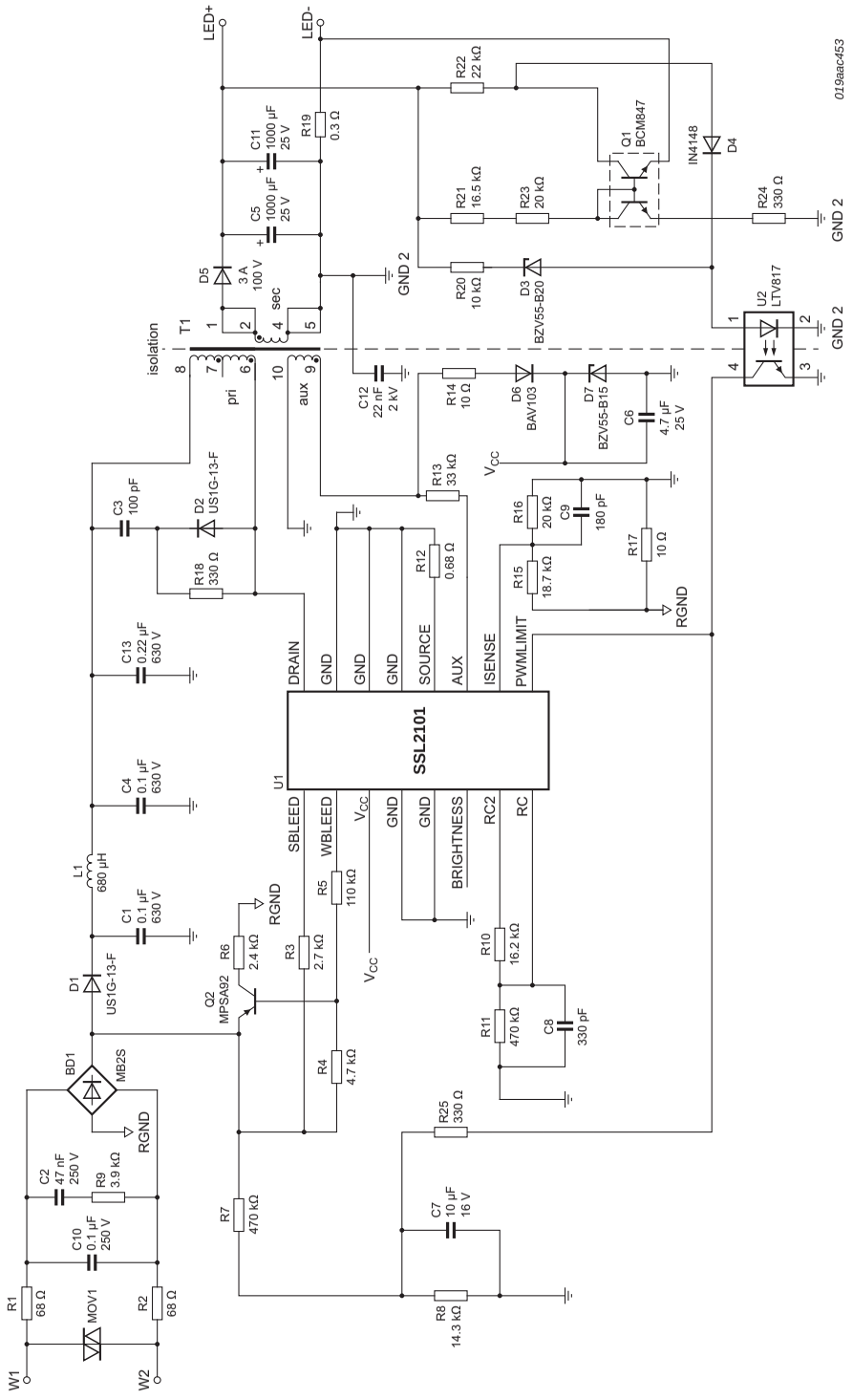


Fig 11. Demo board circuit diagram 5-LED load

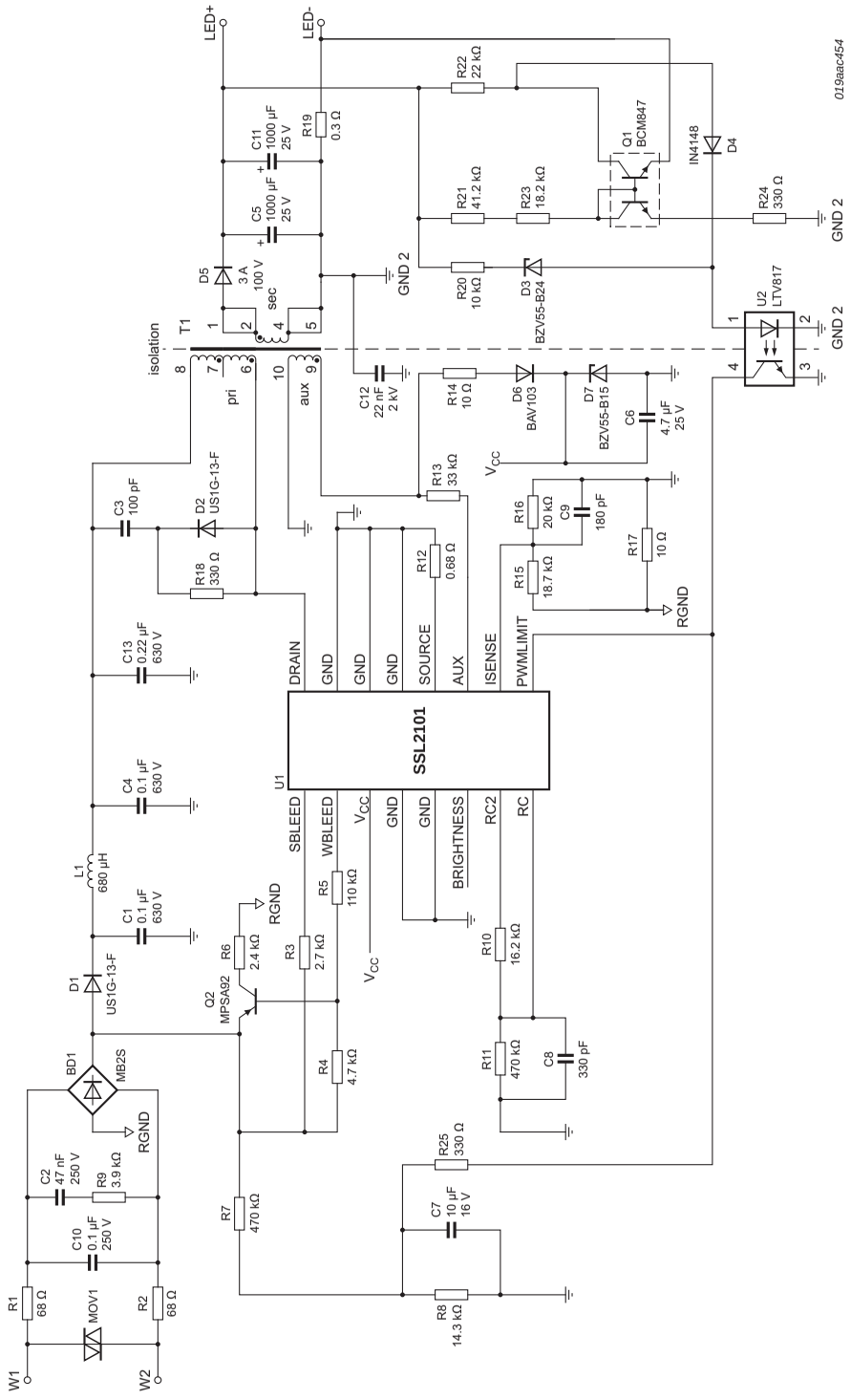


Fig 12. Demo board circuit diagram 7-LED load

10. Bill Of Materials (BOM)

Table 3 and Table 4 provides detailed component information for the SSL2101 (120 V) 5-LED and 7-LED load demo board versions. There are three component changes between the 5-LED and 7-LED demo boards, i.e. D3, R21 and R23. Please check the Table 3 and Table 4 for details.

Table 3. BOM for the SSL2101 120 V demo board 5-LED load

Reference	Component	Package	Quantity	Part number	Remarks
BD1	200 V 500 mA	TO-269AA	1	MB2S	Fairchild
C1,C4	0.1 μF; 630 V; 10 %	1812	2	C4532X7R2J104K	TDK
C2	47 nF; 250 V; 20 %	1206	1	C3216X7R2E473M	TDK
C3	100 pF; 250 V; 5 %	0603	1	C1608C0G2E101J	TDK
C5,C11	1000 μF; 25 V; 20 %	Radial	2	UVY1E102MPD-ND	Nichicon
C6	4.7 μF; 50 V; 10 %	1206	1	C3216X5R1H475K	TDK
C7	10 μF; 16 V; 10 %	0805	1	GRM21BR61C106KE15L	Murata
C8	330 pF; 25 V; 5 %	0603	1	06033A331JAT2A	AVX
C9	180 pF; 50 V; 5 %	0603	1	C1608C0G1H181J	TDK
C10	0.1 μF; 250 V; 10 %	Radial	1	ECQ-E2104KF	Panasonic-ECG
C12	2.2 nF; 2 KV; 10 %	Axial	1	DEBB33D222KA2B	Murata
C13	0.22 μF; 630 V; 10 %	2220	1	C5750X7R2J224K	TDK
D1,D2	fast recovery diode; 400 V 1 A	DO214AC	2	US1G-13-F	Diodes Inc
D3	20 V Zener; 2 %	SOD80C	1	BZV55-B20	NXP Semiconductors
D4	switching diode; 100 V 0.2 A	DO-35-V	1	1N4148,113	NXP Semiconductors
D5	fast recovery diode; 3 A 100 V	DO214AC	1	SK310A-TP	Micro Commercial Co
D6	switching diode; 200 V 0.25 A	SOD80C	1	BAV103,115	NXP Semiconductors
D7	15 V Zener; 15 V; 2 %	SOD80C	1	BZV55-B15	NXP Semiconductors
L1	680 μH; 0.28 A; 10 %	SMD	1	744775268A	Wurth
MOV1	surge absorber; 240 V	Axial	1	ERZ-V07D241	Panasonic-ECG
Q1	dual NPN; 45 V 0.1 A	SOT363	1	BCM847BS,115	NXP Semiconductors
Q2	PNP; 300 V 0.5 A	TO92	1	MPSA92	Fairchild
R1,R2	68 Ω; 0.25 W; 1 %	Axial	2	ERO-S2TJ680V	Panasonic-ECG
R3	2.7 kΩ; 0.25 W; 1 %	Axial	1	ERO-S2PHF2701	Panasonic-ECG
R4	4.7 kΩ; 0.10 W; 1 %	0603	1	ERJ-3EKF4701V	Panasonic-ECG
R5	110 kΩ; 0.25 W; 1 %	Axial	1	ERO-S2PHF1103	Panasonic-ECG
R6	2.4 kΩ; 1 W; 5 %	Axial	1	PR01000102401JR500	Vishay/BC Components
R7	470 kΩ; 0.25 W; 1 %	1206	1	RC1206FR-07470KL	Yageo
R8	14.3 kΩ; 0.10 W; 1 %	0603	1	RMCF0603FT14K3	Stackpole
R9	3.9 kΩ; 0.25 W; 5 %	1206	1	ERJ-8GEYJ392V	Panasonic-ECG
R10	16.2 kΩ; 0.10 W; 1 %	0603	1	ERJ-3EKF1622V	Panasonic-ECG
R11	470 kΩ; 0.10 W; 1 %	0603	1	RMCF0603FT470K	Stackpole
R12	0.68 Ω; 0.25 W; 1 %	1206	1	MCR18EZHFLR680	Rohm
R13	33 kΩ; 0.10 W; 5 %	0603	1	ERJ-3GEYJ333V	Panasonic-ECG
R14	10 Ω; 10 W; 5 %	0603	1	ERJ-3GEYJ100V	Panasonic-ECG

Table 3. BOM for the SSL2101 120 V demo board 5-LED load *…continued*

Reference	Component	Package	Quantity	Part number	Remarks
R15	18.7 kΩ; 0.10 W; 1 %	0603	1	ERJ-3EKF1872V	Panasonic-ECG
R16,R23	20 kΩ; 0.10 W; 5 %	0603	2	RC0603JR-0720KL	Yageo
R17	10 Ω; 0.125 W; 1 %	0805	1	ERJ-6ENF10R0V	Panasonic-ECG
R18	330 Ω; 0.25 W; 5 %	Axial	1	CFR-25JR-330R	Yageo
R19	0.3 Ω; 0.125 W; 1 %	0805	1	CSR0805FKR300	Stackpole
R20	10 kΩ; 0.10 W; 1 %	0603	1	RMCF0603FT10K0	Stackpole
R21	16.5 kΩ; 0.10 W; 1 %	0603	1	ERJ-3EKF1652V	Panasonic-ECG
R22	22 kΩ; 0.10 W; 1 %	0603	1	RMCF0603FT22K0	Stackpole
R24	330 Ω; 0.10 W; 1 %	0603	1	RC0603FR-07330RL	Yageo
R25	330 Ω; 0.25 W; 5 %	Axial	1	ERD-S2TJ331V	Panasonic-ECG
T1	1 mH primary; 650 mA	EE13	1	750311548	Wurth
U1	control IC; SSL2101	SO-16	1	SSL2101	NXP Semiconductors
U2	optocoupler; 35 V 50 mA	4-DIP	1	LTV-817	Lite-On Inc

Table 4. BOM for the SSL2101 120 V demo board 7-LED load

Reference	Component	Package	Quantity	Part number	Remarks
BD1	200 V 500 mA	TO-269AA	1	MB2S	Fairchild
C1,C4	0.1 μF; 630 V; 10 %	1812	2	C4532X7R2J104K	TDK
C2	47 nF; 250 V; 20 %	1206	1	C3216X7R2E473M	TDK
C3	100 pF; 250 V; 5 %	0603	1	C1608C0G2E101J	TDK
C5,C11	1000 μF; 25 V; 20 %	Radial	2	UVY1E102MPD-ND	Nichicon
C6	4.7 μF; 50 V; 10 %	1206	1	C3216X5R1H475K	TDK
C7	10 μF; 16 V; 10 %	0805	1	GRM21BR61C106KE15L	Murata
C8	330 pF; 25 V; 5 %	0603	1	06033A331JAT2A	AVX
C9	180 pF; 50 V; 5 %	0603	1	C1608C0G1H181J	TDK
C10	0.1 μF; 250 V; 10 %	Radial	1	ECQ-E2104KF	Panasonic-ECG
C12	2.2 nF; 2 KV; 10 %	Axial	1	DEBB33D222KA2B	Murata
C13	0.22 μF; 630 V; 10 %	2220	1	C5750X7R2J224K	TDK
D1,D2	fast recovery diode; 400 V 1 A	DO214AC	2	US1G-13-F	Diodes Inc
D3	24 V Zener; 2 %	SOD80C	1	BZV55-B24	NXP Semiconductors
D4	switching diode; 100 V 0.2 A	DO-35-V	1	1N4148,113	NXP Semiconductors
D5	fast recovery diode; 3 A 100 V	DO214AC	1	SK310A-TP	Micro Commercial Co
D6	switching diode; 200 V 0.25 A	SOD80C	1	BAV103,115	NXP Semiconductors
D7	15 V Zener; 15 V; 2 %	SOD80C	1	BZV55-B15	NXP Semiconductors
L1	680 μH; 0.28 A; 10 %	SMD	1	744775268A	Wurth
MOV1	surge absorber; 240 V	Axial	1	ERZ-V07D241	Panasonic-ECG
Q1	dual NPN; 45 V 0.1 A	SOT363	1	BCM847BS,115	NXP Semiconductors
Q2	PNP; 300 V 0.5 A	TO92	1	MPSA92	Fairchild
R1,R2	68 Ω; 0.25 W; 1 %	Axial	2	ERO-S2TJ680V	Panasonic-ECG
R3	2.7 kΩ; 0.25 W; 1 %	Axial	1	ERO-S2PHF2701	Panasonic-ECG
R4	4.7 kΩ; 0.10 W; 1 %	0603	1	ERJ-3EKF4701V	Panasonic-ECG

Table 4. BOM for the SSL2101 120 V demo board 7-LED load *…continued*

Reference	Component	Package	Quantity	Part number	Remarks
R5	110 kΩ; 0.25 W; 1 %	Axial	1	ERO-S2PHF1103	Panasonic-ECG
R6	2.4 kΩ; 1 W; 5 %	Axial	1	PR01000102401JR500	Vishay/BC Components
R7	470 kΩ; 0.25 W; 1 %	1206	1	RC1206FR-07470KL	Yageo
R8	14.3 kΩ; 0.10 W; 1 %	0603	1	RMCF0603FT14K3	Stackpole
R9	3.9 kΩ; 0.25 W; 5 %	1206	1	ERJ-8GEYJ392V	Panasonic-ECG
R10	16.2 kΩ; 0.10 W; 1 %	0603	1	ERJ-3EKF1622V	Panasonic-ECG
R11	470 kΩ; 0.10 W; 1 %	0603	1	RMCF0603FT470K	Stackpole
R12	0.68 Ω; 0.25 W; 1 %	1206	1	MCR18EZHFLR680	Rohm
R13	33 kΩ; 0.10 W; 5 %	0603	1	ERJ-3GEYJ333V	Panasonic-ECG
R14	10 Ω; 10 W; 5 %	0603	1	ERJ-3GEYJ100V	Panasonic-ECG
R15	18.7 kΩ; 0.10 W; 1 %	0603	1	ERJ-3EKF1872V	Panasonic-ECG
R16	20 kΩ; 0.10 W; 5 %	0603	1	RC0603JR-0720KL	Yageo
R17	10 Ω; 0.125 W; 1 %	0805	1	ERJ-6ENF10R0V	Panasonic-ECG
R18	330 Ω; 0.25 W; 5 %	Axial	1	CFR-25JR-330R	Yageo
R19	0.3 Ω; 0.125 W; 1 %	0805	1	CSR0805FKR300	Stackpole
R20	10 kΩ; 0.10 W; 1 %	0603	1	RMCF0603FT10K0	Stackpole
R21	41.2 kΩ; 0.10 W; 1 %	0603	1	ERJ-3EKF4122V	Panasonic-ECG
R22	22 kΩ; 0.10 W; 1 %	0603	1	RMCF0603FT22K0	Stackpole
R23	19.6 kΩ; 0.10 W; 1 %	0603	1	ERJ-3EKF1962V	Panasonic-ECG
R24	330 Ω; 0.10 W; 1 %	0603	1	RC0603FR-07330RL	Yageo
R25	330 Ω; 0.25 W; 5 %	Axial	1	ERD-S2TJ331V	Panasonic-ECG
T1	1 mH primary; 650 mA	EE13	1	750311548	Wurth
U1	control IC; SSL2101	SO-16	1	SSL2101	NXP Semiconductors
U2	optocoupler; 35 V 50 mA	4-DIP	1	LTV-817	Lite-On Inc

11. Active bypass implementation

The efficiency of the demo board can be improved by reducing the resistance values of R1 and R2 (see Figure 13), if the requirement on dimmer compatibility is reduced. For example, by replacing R1 and R2 with 39 Ω resisters the board continues to provide flicker-free dimming for the majority (with 2 exceptions) of the dimmers listed in Table 2 with an efficiency of over 75 %. In addition, where the form allows the demo board efficiency can be further increased while still maintaining good dimmer compatibility by implementing active bypass as detailed below. Figure 13 shows a simple implementation of active bypass.

Damping resistor RD is connected in parallel with bypass PFET QB whose Gate-to-Source Voltage (Vgs), is decided by a resistive voltage divider (RB1 and RB2) connected between the line voltage and RGND. The resistance values of RB1 and RB2 are set so that Vgs is higher than the MOSFET's threshold voltage of most triac dimmers's switch-on point. Capacitor CB is placed across the gate and source of QB to provide a delay for the Vgs to ramp up. This allows the damping resistor to be present in the circuit for a short period of each line cycle immediately after the triac is switched on.

From this point, the inrush current spike at the beginning of each cycle can still be damped, however, the damping resistor will not be in the current path throughout the entire line cycle to contribute to conduction losses. CB can be adjusted to lengthen or shorten the amount of time in each cycle that QB is off and hence the damping resistor is not bypassed. Typical values for the components used are listed in Table 5.

Remark: As R1 and R2 are not used, it is not advisable to keep the EMI capacitor C10 in the circuit as it can cause flickering with triac dimmers when active bypass is used. If removing C10 results in a violation of EMC regulations, a common mode choke can be used to help solve the problem.

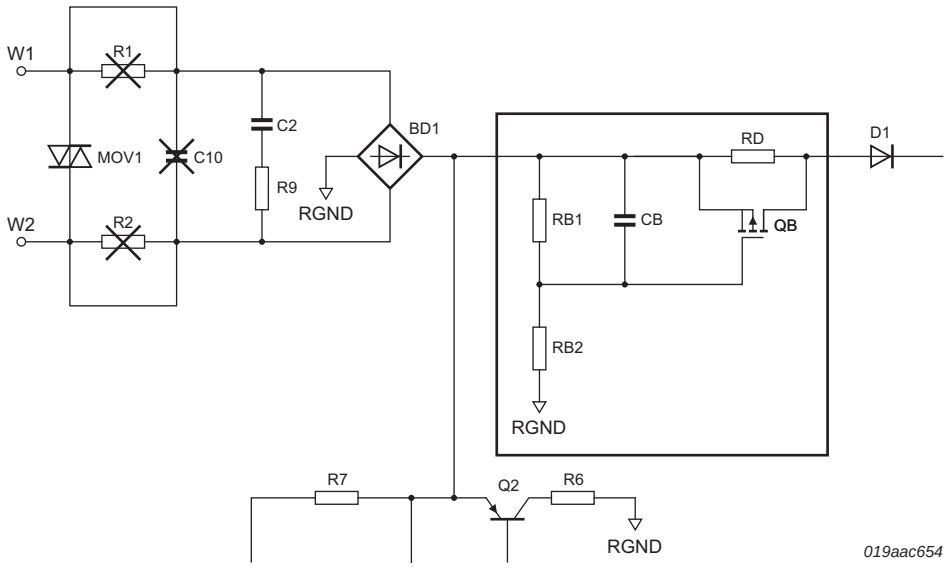


Fig 13. Active bypass implementation

Table 5. Components for active bypass

Reference	Component/Typical values
RB1	6.8 kΩ
RB2	120 kΩ
RD	200 Ω
CB	< 1 μF
QB	ZVP2120GTA

12. Demo board layout

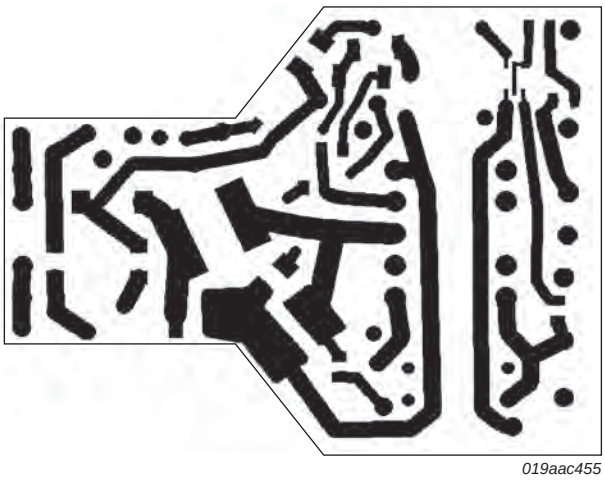


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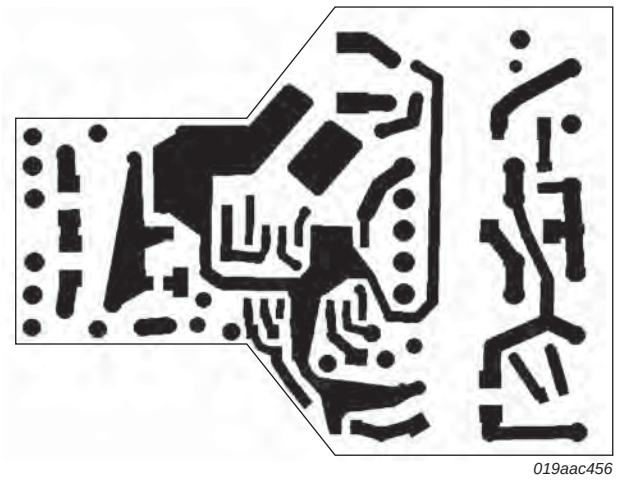
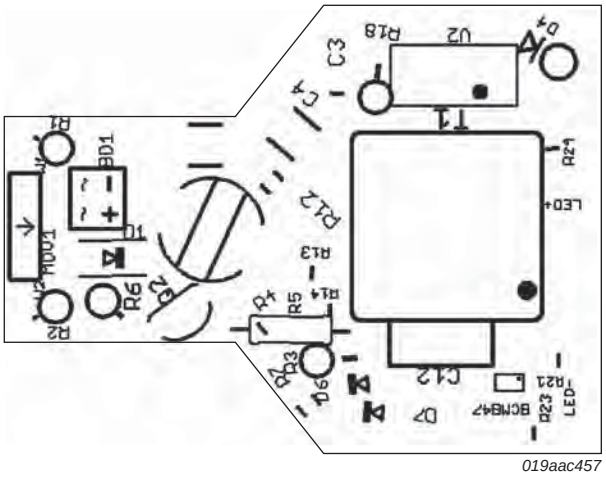
Fig 14. Top layer



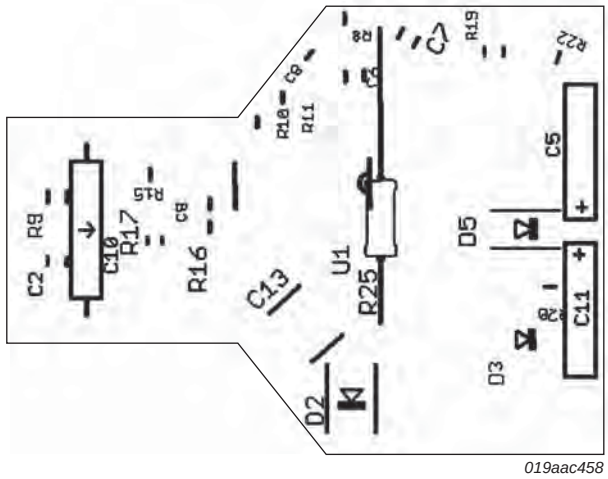
019aac456

Fig 15. Bottom layer



019aac457

Fig 16. Top silk



019aac458

Fig 17. Bottom silk

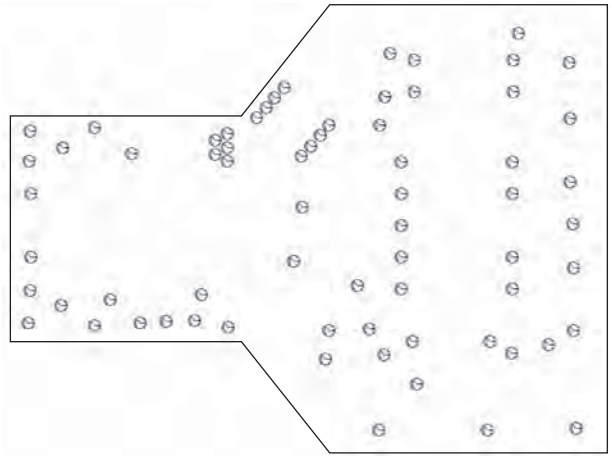


Fig 18. Drilled view

13. Transformer specification

Figure 19 below shows transformer marking, dimensions and winding information.

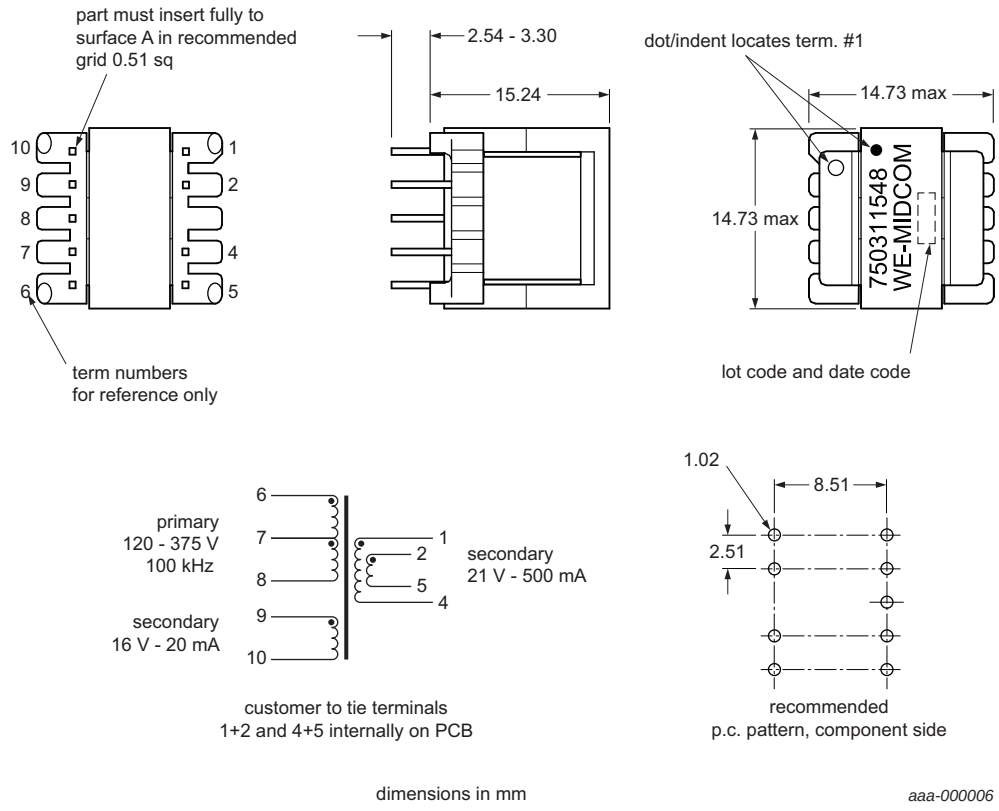


Fig 19. Demo board transformer specification

Transformer electrical specifications centered at 25 °C is as follows:

DC resistance:

- 1-5 (tie 1 + 2, 4 + 5), 0.095 Ω, ±10 %
- 6-8, 1.34 Ω, ±10 %
- 9-10, 0.440 Ω, ±10 %

Dielectric rating:

- 2000 V (AC), 1 minute tested by applying 2500 V (AC) for 1 second between pins 1-10 (tie 4 + 5, 8 + 9)
- 500 V (AC), 1 minute tested by applying 625 V (AC) for 1 second between pins 6-10.

Inductance:

- 1.00 mH ±10 % 10 kHz, 100 mV (AC), 0 mA (DC), 6-8, Ls

Saturation current:

- 650 mA saturation current that causes 20 % roll off from initial inductance.

Leakage inductance:

- 10 μH typ, 15 μH max, 100 kHz, 100 mV (AC), 6-8 (tie 1 + 2 + 4 + 5, 9 + 10), Ls

Turns ratio:

- (7-8):(6-7), (1):(1), ±1 %
- (6-8):(1-4), (5.5):(1), ±1 %
- (6-8):(2-5), (5.5):(1), ±1 %
- (6-8):(9-10), (7.333):(1), ±1 %

Operating temperature range:

- –40 °C to 125 °C including temperature rise.

14. Abbreviations

Table 6. Abbreviations

Acronym	Description
BCM	Boundary Conduction Mode
DCM	Discontinuous Conduction Mode
EMC	ElectroMagnetic Compatibility
EMI	ElectroMagnetic Interference
LED	Light Emitting Diode
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
PF	Power Factor

15. References

[1] **SSL2101 —** Data sheet: SMPS controller IC for dimmable LED lighting.

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