# UM10509

## 230 V (AC) 17 W dimmable demo board using the SSL2103

**Rev. 1 — 16 January 2012**                                                                    **User manual**

**Document information**

| Info | Content |
|------|---------|
| **Keywords** | SSL2103, AC mains supply, dimmable LED driver, AC/DC conversion |
| **Abstract** | This user manual describes a demo board for evaluating an AC mains LED driver with a dimmer for 17 W, PAR38 LEDs using the SSL2103. It also describes key features and connections to aid the design of LED drivers for typical applications. |

**NXP**

**Revision history**

| Rev | Date | Description |
| --- | --- | --- |
| v.1 | 20120116 | first issue |

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# 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 user manual describes a demo board for evaluating an AC mains LED driver with a dimmer for 17 W, PAR38 LEDs using the SSL2103. It describes key features and connections to aid the design of LED drivers for typical applications.

The demo board operates from an AC mains voltage of 230 V (AC). The resulting design is a trade-off between high-power factor, efficiency and dimmer compatibility, combined with high output stability and ElectroMagnetic Compatibility (EMC) compliance.

# 2. Safety Warning

The demo board is powered by AC mains voltage. Avoid touching the board when power is applied. An isolated housing is obligatory when used in uncontrolled, non-laboratory environments. The secondary circuit with LED connection has galvanic isolation, however this isolation is not in accordance with any standard and has not been thoroughly tested. Always provide galvanic isolation of the mains phase using a variable transformer. The following symbols identify isolated and non-isolated devices.



*019aab173*          *019aab174*
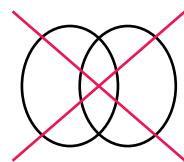
a. Isolated                b. Non-isolated

**Fig 1.    Isolated and non-isolated symbols**

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# 3. Specification

**Table 1. Demo board specification**

| Parameter | Value | Comment |
|---|---|---|
| AC line input voltage | 210 V (AC) to 250 V (AC), ±10 %, 50 Hz | 230 V (AC) model |
| Output voltage (LED voltage) | 17 V (DC) to 33 V (DC) | |
| Output voltage protection | 33 V (DC) | |
| Output current (LED current) | 500 mA typical | |
| Input voltage and load current dependency | −5 % to +5 %, between 210 V (AC) and 250 V (AC) | |
| Output voltage and load current dependency | −10 % to +10 %, between 19 V (DC) to 30 V (DC) | |
| Temperature stability | −3 % to +3 % from −20 °C to +100 °C | |
| Current ripple | ±15 % at 500 mA | typical value |
| Maximum output power (LED power) | 19 W | depends on load |
| Efficiency | 78 % to 82 % | |
| Power factor | >0.93 at 230 V (AC) | |
| Switching frequency | 40 kHz to 60 kHz | at 230 V (AC) input voltage |
| Dimming range | 100 % to 0 % | for triac dimmers |
| Board dimensions | 82 mm × 62 mm × 35 mm | L × B × H |
| Operating temperature | 0 °C to 105 °C | - |
| EMC Compliance | FCC15 and IEC 61000-3-2 pre-compliant | |
| | EN 55015 and IEC 61000-3-2 pre-compliant | |

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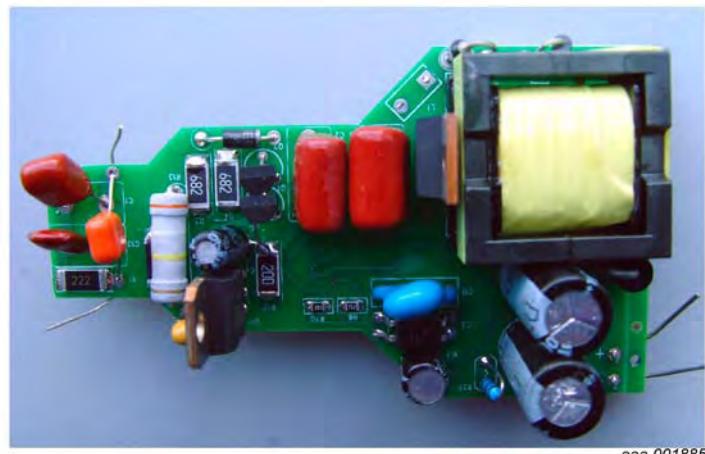
a. Top view.
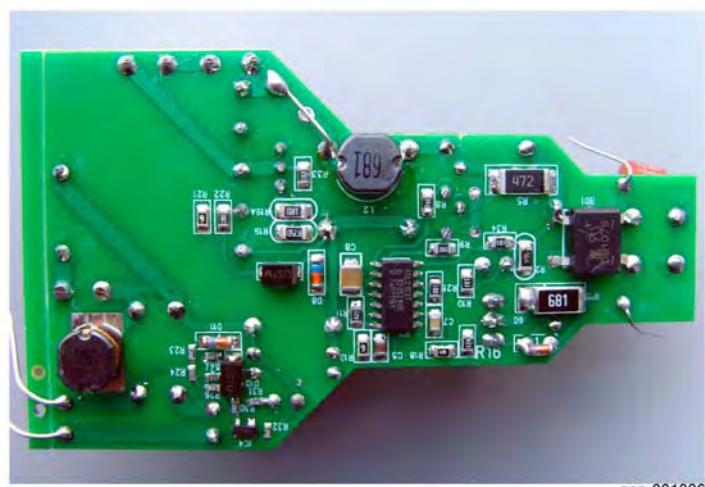


b. Bottom view.

**Fig 2.    17 W PAR38 LED demo board**

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## 4. Demo board connections

The demo board is optimized for an (AC) mains source of 230 V at 50 Hz. It is designed to work with multiple high-power LEDs having a total working voltage of between 18 V and 33 V. The output current is set to 600 mA at the typical load. The output voltage is limited to 33 V.

When attaching an LED load to the board (hot plugging), an inrush peak current occurs due to the discharge of output capacitors C9 and C10. Frequent discharges can damage or deteriorate the LEDs.

**Remark:** Mount the board in a shielded or isolated box for demonstration purposes.



**Fig 3.  Demo board connections**
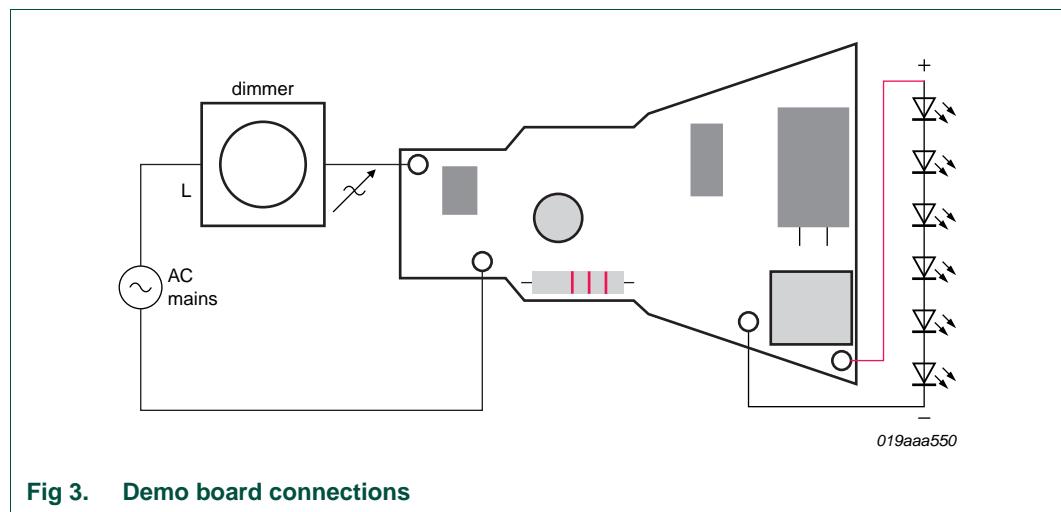
Place a galvanic isolated transformer between the AC source and the demo board, if one is used. Connect a series of between 5 and 10 LEDs to the output as shown in Figure 3.

## 5. Dimmers

NXP Semiconductors has tested the performance of several triac-based dimmers having different specifications. The range of dimmers which have been tested with the demo board are given in Table 2.

**Table 2.    Tested dimmers**

| Manufacturer | Part |
|---|---|
| **Leading-edge dimmers** | |
| Berker | 2819 |
| Berker | 2873 |
| Gira | 030000/I01 |
| Busch-Jaeger Elektro | 2250U |
| Busch-Jaeger Elektro | 2200 |
| Clipsal | E2032v |
| Legrand | V004 |
| Flexalite | FL630D |
| Kiny | DF-300P-2w |
| **Trailing edge dimmers** | |
| Berker | 286710 |
| Berker | 2874 |
| Gira | 030700/I02 |
| Busch-Jaeger Elektro | 6513 U102 |
| Richmond lighting | DG09007 |
| Richmond lighting | DG07093 |
| Jung licht management | 243E4 |
| Jung licht management | 22570E |

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# 6. Functional description

Refer to Figure 4 "Demo board 230 V (AC) schematic" on page 12 for more information.

The AC mains LED driver IC SSL2103 controls and drives a flyback converter circuit and ensures correct dimmer operation. The IC has three integrated high-voltage switches, one of which, located between pins DRAIN and SOURCE, controls flyback input power. When the switch opens, current flows and is stored as energy in transformer TX1. The current is interrupted when either:

- the duty factor exceeds the 75 % maximum level set using the PWMLIMIT pin
- the voltage on the SOURCE pin exceeds 0.5 V

In the next cycle, the energy stored in the transformer discharges via D6 to output capacitors C9 and C10. The load absorbs the energy. The external RC components connected to pins RC and RC2 control the internal oscillator timing. These external components set the flyback converter frequency. The upper and lower frequency values are set using the BRIGHTNESS pin. The ratio between R11 and R12 sets flyback converter frequency range.

The two other switches in the IC are called weak-bleeder (pin WB_DRV) and strong-bleeder (pin SB_DRV). When the voltage on these pins is below a certain value, typically 52 V, the strong-bleeder switches on. A path is provided for the load current to the dimmer during zero voltage crossing. The dimmer timer is reset. When the voltage on the pins is above 52 V and the voltage on pin ISENSE > −100 mV, transistor Q3 switches the weak-bleeder on. The weak-bleeder supplies a boosted (hold) current to the dimmer to maintain stable latching when the flyback converter draws insufficient current.

Figure 4 shows the bleeder voltage against time in dimmed and undimmed modes.

The demo board is optimized to work at a power factor above 0.9. The flyback converter operates during the MOSFET on-time. Capacitors C9 and C10 buffer the flyback converter output power. This configuration gives the circuit a resistive input current behavior in undimmed mode; see curve $I_I$ in Figure 4.

In dimmed mode, the dimmer latch and hold current must be maintained. In addition, add a damper to reduce the inrush current and dissipate the electric power stored in the dimmer LC filter.

A serial resistor is used as a damper at power ranges of less than 10 W. However, a serial resistor is inefficient at higher power ranges. The inefficiency is due to the significant voltage drop and dissipation that occurs from the supply current to the flyback converter.

The Darlington transistor Q4 provides the necessary high gain. Q4 is saturated while its base voltage is higher than the emitter voltage plus the base-emitter voltage ($V_{BE}$). The voltage across emitter resistor R14 increases with the current. When the emitter voltage rises above the threshold, Q4 stops saturation, turns off and R15 limits the current. Choose the values of D9 and R13 with care to ensure consistent operation. A Darlington transistor provides the necessary high current gain. This modification changes the specifications of efficiency and power factor.

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A combination of serial resistance and a parallel damper is chosen. The serial resistance comprises R14, R15 and R17. The parallel group damper comprises C1, C13 and R1 in parallel with C8 and R7 for optional fine-tuning. To improve efficiency, the major serial damping is activated only when there is a peak inrush current (active inrush current limiter). In normal operation, the Darlington transistor Q4 conducts, bypassing R15 and lowering ohmic losses. When a high inrush current is detected, Q4 starts to clip at its maximum current of 500 mA.

The flyback converter input circuit must have a filter that is partially capacitive. C2, L2, C3, C13 and L1 form the filter that blocks most of the disturbance caused by the flyback converter input current. The drawback of this filter is a reduced power factor due to the capacitive load. A lower flyback converter power relative to the capacitive value of this filter/buffer reduces the power factor. With the 230 V (AC) design using 330 nF capacitors, a minimum power factor of 0.93 is achieved.

The demo board has a feedback loop to limit the output current. The feedback loop senses the LED current through sense resistor R25, and current mirror circuit with IC4. The current level can be set using R27 and R29. The same feedback loop is also used for overvoltage protection. If the LED voltage exceeds 33 V, a current starts to flow through R23 and D11. The current through the optocoupler IC3 forces pins PWMLIMIT and BRIGHTNESS LOW. At a value below 400 mV, the MOSFET on-time is zero.

The feedback loop has a proportional action only. The gain is critical because of phase shift caused by the flyback converter and C6.

The relationship between pin PWMLIMIT and the output current is quadratic in nature. The resulting output current spread is acceptable for most LED applications. If higher demands are placed on LED current spread, a secondary regulation circuit in combination with an added pure current action control is advisable.

The dimming range is detected by sensing the average rectified voltage. R2 and R10 form a voltage divider and C4 filters the resulting signal. The flyback converter sets its duty factor and converter frequency accordingly.

# 7. System optimization

The modifications described in this section can be applied to achieve customer application specifications.

## 7.1 Changing output voltage and LED current

One of the major advantages of a flyback converter over other topologies is its suitability for driving different output voltages. In essence, changing the winding ratio while maintaining the value of the primary inductance shifts the output working voltage accordingly. Part of the efficiency of the driver is linked to the output voltage. A lower output voltage increases the transformation ratio and cause higher secondary losses. In practice, mains dimmable flyback converters have an efficiency of:

- 85 % for higher output power and voltage such as 60 V
- 60 % for lower output power and voltage such as 1 W and 3 V

At lower voltages, synchronous rectification is advisable to reduce losses after high current is rectified. NXP Semiconductors TEA1761 and TEA1791 synchronous rectification controllers are ideal for this purpose. Calculations for transformer properties and peak current are described in detail in application note *AN10754, SSL2101 and SSL2103 dimmable mains LED driver*.

## 7.2 Changing the output ripple current

The LED voltage, the LED dynamic resistance and the output capacitor determine the output ripple current. While the values of C9 and C10 are chosen to optimize capacitor size with light output. A ripple of ±15 % results in an expected deterioration of LED brightness of less than 1 %[1].

The size of the buffer capacitor is determined using Equation 1.

$$\left( C10 + C9 = \frac{I_{led}}{\Delta I} \right) \times \frac{1}{6 \times f_{net} \times R_{dyn}} \tag{1}$$

**Example:**

A ±5 % ripple current, a 50 Hz AC mains frequency and a 0.6 Ω dynamic resistance, results in a combined C9 + C10 value of $\frac{20}{300 \times 0.6} = 111\ mF$.

A ripple current of 25 % and a dynamic resistance of 6 Ω, results in a value for C9 + C10 of $\frac{4}{(300 \times 6)} = 2200\ \mu F$.

Using a series of LEDs, the dynamic resistance of each LED can be added to the total dynamic resistance.

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1. M. Weiland 28-07-2006

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### 7.3 Adapting to high-power reverse phase transistor dimmers

Reverse phase (transistor) dimmers differ in two ways that can be beneficial:

- Due to the negative phase, there is no inrush current when the dimmer triggers. Using triac dimmers, there is a sudden voltage difference over the input, resulting in a steep charge of the input capacitors. The resulting peak current results in higher damper dissipation. Using transistor dimmers, the steep charge is missing. The input capacitors are less stressed and the input circuit is less prone to audible noise.

- Transistor dimmers contain active circuitry that requires a load charge while the dimmer is open. To avoid internal dimmer losses, the dimensioning of the internal supply voltage generation circuit is critical. This means that the remaining voltage drop across the lamp must be low enough to allow this charge to be reached. The minimum load to achieve such a low voltage drop results in inefficient operation at low output power levels. The cause of which is that most of the energy is wasted driving the dimmer instead of used to producing light.

The weak-bleeder resistor values of R3 and R4 are chosen to ensure that any losses are within acceptable limits. These losses only occur in dimmed mode at the end of the phase. The voltage drop in some transistor dimmers is not sufficient for full control of the dimming range. The SSL2103 senses the dimming range by taking the average rectified voltage as input. To compensate for the reduced voltage difference, the voltage detection can be made more sensitive by placing a Zener diode in series with R2. The dimming curve is steeper and shifted when using triac dimmers because of increased sensitivity.

### 7.4 Changing the output current

The output current can be set initially by varying the values of R29 and R27. The power section and transformer train can withstand output currents up to 500 mA, but losses increase at higher current levels. Resistors R19/R19A limit the primary peak current and consequently the maximum output power.

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## 8. Demo board schematic



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**Fig 4. Demo board 230 V (AC) schematic**
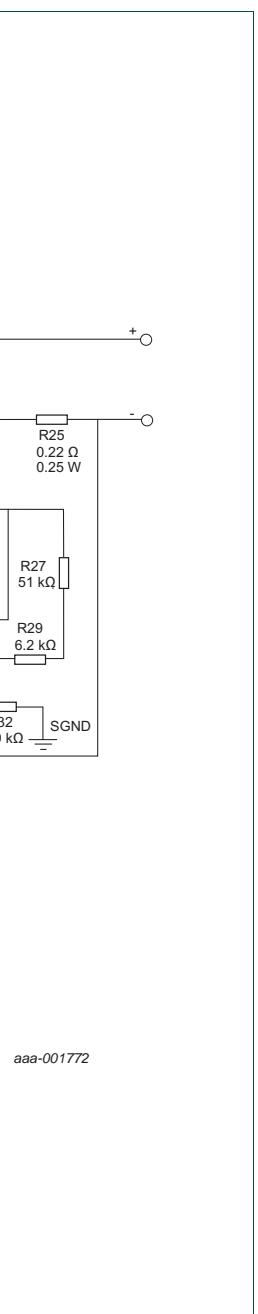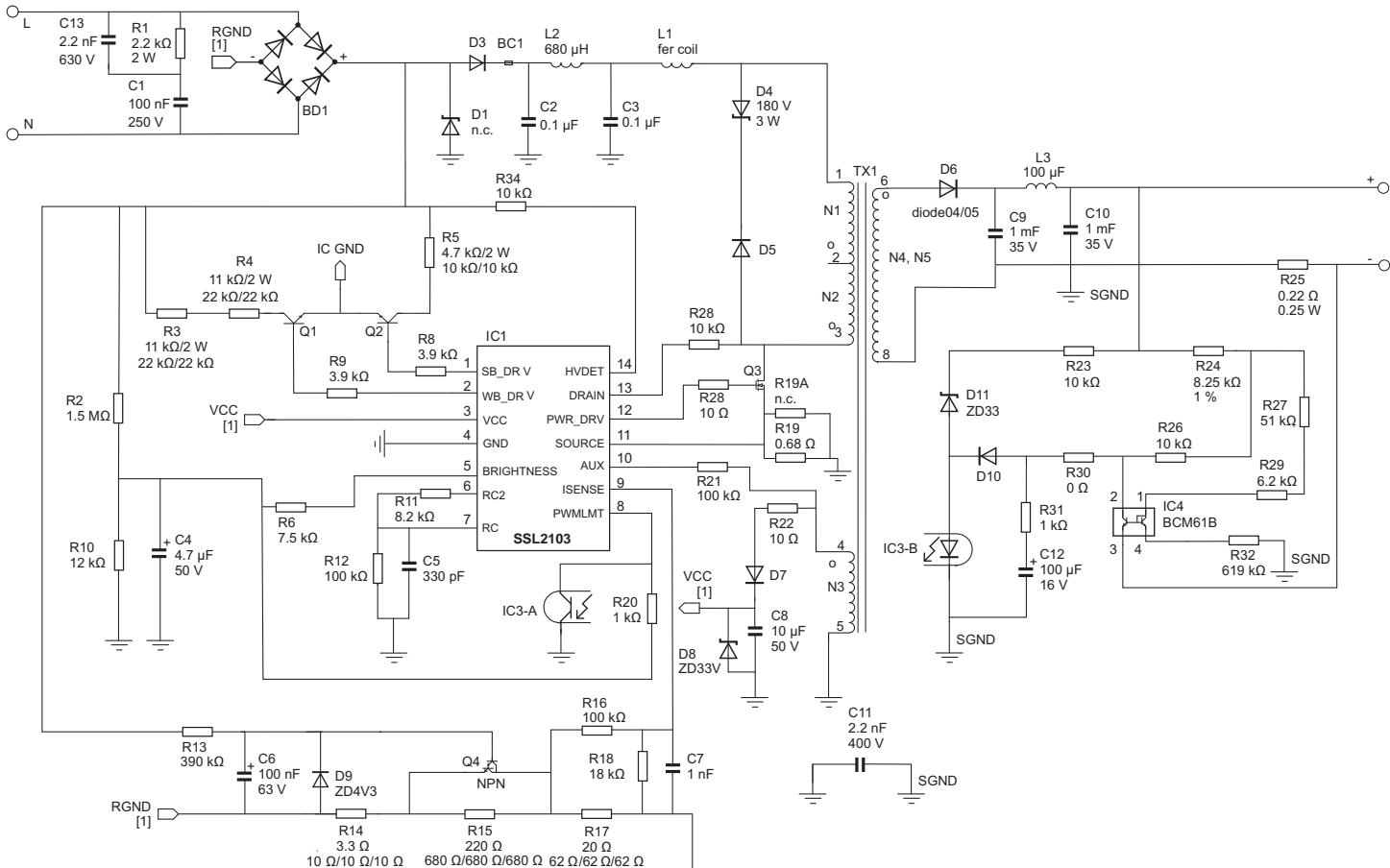
(1) Optional.

Some resistor values are shown with format x/x/x which represent the values required of resistors connected in parallel.

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## 9. PCB components

**Table 3.    Demo board 230 V (AC) components**

| Reference | Quantity | Description | Part/manufacturer | Comment |
|---|---|---|---|---|
| BD1 | 1 | BD_DB107S | - | - |
| C1 | 1 | 100 nF; 250 V | CM150-5_6X12 | - |
| C2; C3 | 2 | 0.1 $\mu$F; 0.1 $\mu$F; 400 V | CM150-5_6X18 | - |
| C4 | 1 | 4.7 $\mu$F; 50 V | CAL04/5 | - |
| C5 | 1 | 330 pF; 0805 | - | - |
| C6 | 1 | 100 nF; 63 V | CAL04/5 | - |
| C7 | 1 | 1 nF; 0805 | - | - |
| C8 | 1 | 10 $\mu$F; 50 V; 1206 | - | - |
| C9; C10 | 2 | 1 mF; 35 V; ECOUT | - | - |
| C11 | 1 | 2.2 nF; 400 V (AC); C-POLY | - | - |
| C12 | 1 | 100 $\mu$F; 16 V | CAL04/5 | - |
| C13 | 1 | 2.2 nF; 630 V | CM150-5_6X12 | - |
| D3 | 1 | ultra-fast diode 02/10; axial lead | - | - |
| D4 | 1 | diode; DIP; 180 V; 3 W | - | - |
| D5; D6 | 2 | switching diode; DIP-2 | - | - |
| D7 | 1 | switching diode; SO8; SMD | - | - |
| D8 | 1 | Zener diode; 33 V | ZD33V | - |
| D9 | 1 | Zener diode; 4.3 V; SOD80 | ZD/4V3 | - |
| D10 | 1 | diode; SOD80 | - | - |
| D11 | 1 | Zener diode; 33 V | ZD33V | - |
| IC1 | 1 | LED driver/dimmer IC | SSL2103; NXP Semiconductors | |
| IC3 | 1 | IC04-10/PC | LTV-817B; Lite-On | |
| IC4 | 1 | BCM61B | - | - |
| L1 | 1 | FERCHOCK; Ferrite Coil | - | - |
| L2 | 1 | L-DIP; 680 $\mu$H | - | - |
| L3 | 1 | WECHOCK-2; 100 $\mu$H | - | - |
| Q1; Q2 | 2 | NPN transistor; TO92 | - | - |
| Q3 | 1 | MOSFET; TO251 | - | - |
| Q4 | 1 | NPN transistor | ST901T | - |
| R1 | 1 | R-POWER; 2.2 k$\Omega$; 2 W | - | - |
| R2 | 1 | 1.5 M$\Omega$; 1206 | - | - |
| R3; R4 | 2 | R-POWER; 11 k$\Omega$; 2 W; 22 k$\Omega$/22 k$\Omega$ | - | - |
| R5 | 1 | R-POWER; 4.7 k$\Omega$; 2 W; 10 k$\Omega$/10 k$\Omega$ | - | - |
| R6 | 1 | 7.5 k$\Omega$; 0805 | - | - |
| R8; R9 | 2 | 3.9 k$\Omega$; 0805 | - | - |
| R10 | 1 | 12 k$\Omega$; 0805 | - | - |
| R11 | 1 | 8.2 k$\Omega$; 0805 | - | - |
| R12; R21 | 2 | 100 k$\Omega$; 0805 | - | - |

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**Table 3.** **Demo board 230 V (AC) components** *…continued*

| Reference | Quantity | Description | Part/manufacturer | Comment |
|---|---|---|---|---|
| R13 | 1 | RT3.5MM-2W20; 390 k$\Omega$ | - | - |
| R14 | 1 | R-POWER; 3.3 $\Omega$; 10 $\Omega$/10 $\Omega$/10 $\Omega$ | - | - |
| R15 | 1 | R-POWER, 220 $\Omega$; 680 $\Omega$/680 $\Omega$/680 $\Omega$ | - | - |
| R16 | 1 | 100 k$\Omega$; 0805 | - | - |
| R17 | 1 | R-POWER, 20 $\Omega$; 62 $\Omega$/62 $\Omega$/62 $\Omega$ | - | - |
| R18 | 1 | 18 k$\Omega$; 0805 | - | - |
| R19 | 1 | 0.68 $\Omega$; 1206 | - | - |
| R19A | 1 | NC; 1206 | - | - |
| R20 | 1 | 1 k$\Omega$; 0805 | - | - |
| R22 | 1 | 10 k$\Omega$; 0805 | - | tuned on LED/Aux voltage |
| R23; R26 | 2 | 10 k$\Omega$; 0603 | - | - |
| R24 | 1 | 8.25 k$\Omega$; 1 %; 0603 | - | - |
| R25 | 1 | RT3.5MM; 0.22 $\Omega$; 0.25 W | - | - |
| R27 | 1 | 51 k$\Omega$; 0603 | - | - |
| R28 | 1 | 10 $\Omega$; 0805 | - | - |
| R29 | 1 | 6.2 k$\Omega$; 0603 | - | - |
| R30 | 1 | 0 $\Omega$; 0603 | - | - |
| R31 | 1 | 1 k$\Omega$; 0603 | - | - |
| R32 | 1 | 619 $\Omega$ 1 %; 0603 | - | - |
| R33; R34 | 2 | 10 k$\Omega$; 0805 | - | - |
| TX1 | 1 | EFD25-DIP | - | - |

## 10. Test results

### 10.1 Input/output stability

**Table 4.    Input and output stability test results**

| Parameter | Conditions | | | | |
|---|---|---|---|---|---|
| $V_{IN}$ AC mains voltage | 220 | 230 | 240 | 250 | 260 |
| input power (W) | 16.176 | 17.703 | 18.135 | 18.28 | 18.419 |
| Power factor | 0.962 | 0.953 | 0.945 | 0.94 | 0.935 |
| $V_{LED}$ (V) | 29.57 | 29.81 | 29.828 | 29.82 | 29.83 |
| $I_{LED}$ (A) | 468.7 | 509 | 520.5 | 525.2 | 527.6 |
| $P_O$ (W) | 13.836 | 15.153 | 15.507 | 15.629 | 15.715 |
| $\eta$ (%) | 85.5 | 85.6 | 85.5 | 85.5 | 85.3 |

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