AL9910EV7

Triac Dimmable 120V_{AC} Evaluation Board

- Modification Guide -

Date: August 3, 2012

1. Standard Evaluation Board Schematic

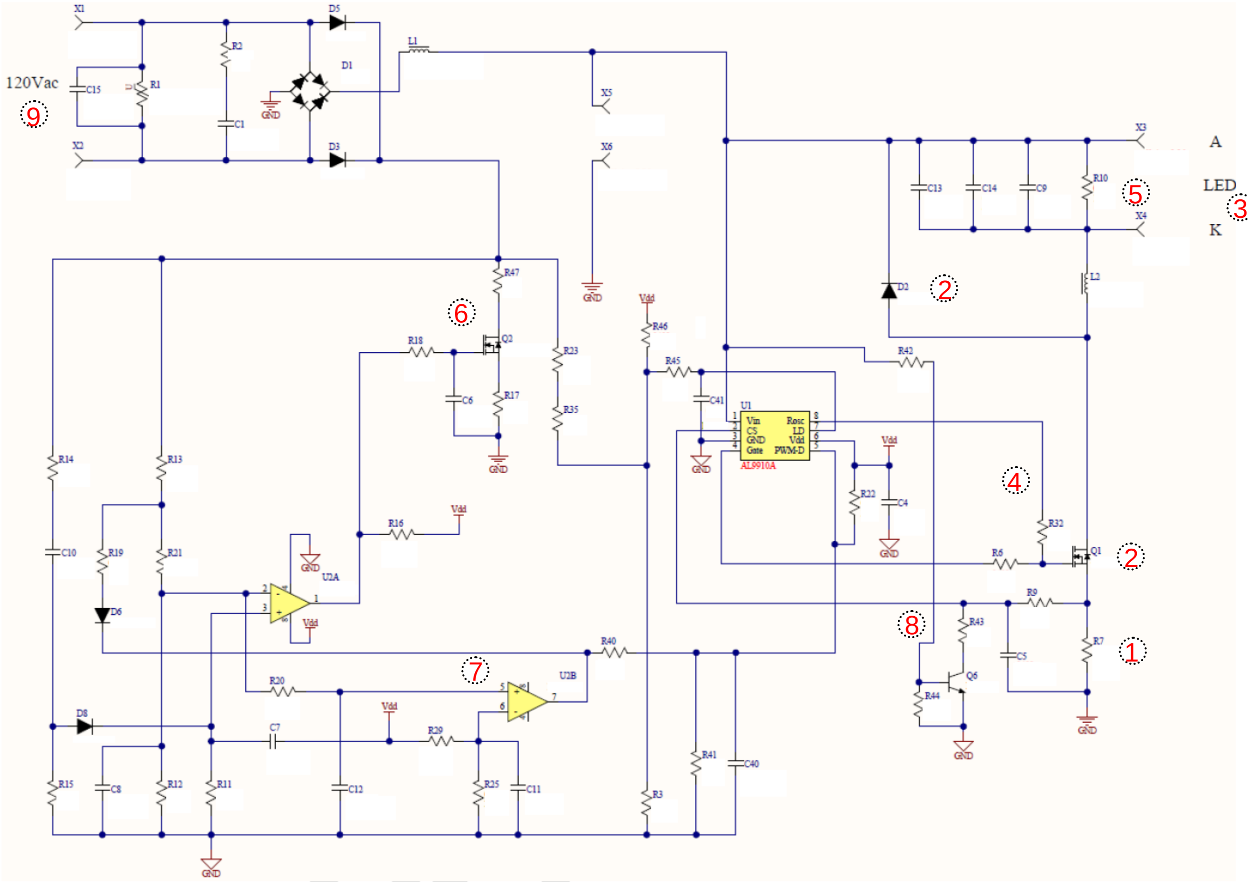


Figure 1: Standard Evaluation Board Schematic

2. Modification Summary

Based on the 8 LEDs configuration, we modified the following components to achieve higher efficiency:

1. Inductor (L2) – Coilcraft (MSS1278T-105KLB) with lower conduction and switching losses
2. MOSFET (Q1) – Alpha Omega (AOD4S60) with a low $R_{DS(on)}$ (0.9Ω) and low Qg (6nc)
3. Freewheeling Diode (D2) – Diodes (ES1G-13-F) with a faster recovery time of 25nSec
4. R_{OSC} resistor - Increase R32 to 440KΩ to lower the switching frequency
5. Gate drive resistor – Decrease R6 to 4.73Ω to turn on the MOSFET faster

We concluded the overall efficiency can be improved higher using the standard EVB to around 87%. In addition, we connected the 120V$_{AC}$ Lutron dimmer (P/N LG-603PG) at full brightness setting, the efficiency maintained at 80%.

3. Introduction

This report shows how to select components and change applications circuitry from the standard EVB to meet certain customer's requirement.

Customers have different requirement for their customized LED applications. We can modify our standard evaluation board to fulfill their needs and shorten the design-in time. Customers usually provide a set of test conditions such as input/output voltage, number of output LEDs, output LED current, output ripple current, power factor, and efficiency.

4. Modifications from Standard EVB

Here is a list of parameters that allows user to change the applications circuitry using our standard EVB to meet their customized LEDs requirements:

1. How to adjust output LED current (I_{LED})

User can change the R_{sense} resistor (R7) and Power Inductor (L2) to a different value to decrease or increase the output LED current.

Table below shows typical values for R7 and L2 selection to meet the I_{LED} requirement:

Rsense (Ω)	Power Inductor (mH)	I_{LED} (mA)
1.91	1.0	260
1.62	1.0	425
1.50	1.0	500
1.20	1.0	700

2. How to improve efficiency (Eff)

Efficiency varies with several parameters:

- **I_{LED}**
  LED current is direct proportional to the intensity of the light. The higher I_{LED} will increase the efficiency based on the power equation, Pout = Vout * I_{LED}. However, user needs to know the current limit of the types of LEDs and not to exceed this limit.

- **Numbers of LEDs**
  Typical LED voltage is 3.3V, the numbers of LEDs determine the Vout and based on the power equation, Pout = Vout * I_{LED}. When the numbers of LEDs increase, Vout will increase accordingly and affects the efficiency.

- **MOSFET selection**
  Power MOSFET is acting as a switch to regulate the voltage across the output of the LED. In conjunction with the current feedback loop circuitry, when the I_{LED} exceeded the limit, MOSFET will turn off to protect the LEDs.
  Two main parameters for MOSFETs selection to enhance the efficiency are:
  Low $R_{DS(on)}$ will reduce the conduction loss and Low Qg will reduce the switching loss.

- **MOSFET Gate Drive**
  Improve the gate drive by lowering R6 from 22Ω to 4.7Ω so the MOSFET will turn on faster and improve the efficiency.

- **Switching Inductor**
  With proper selection of the right inductance value, inductors can delivery system running under continue conduction mode to provide maximum efficiency performance.

  The following parameters are needed to be defined or calculate for inductance operating in continue conduction mode:

  - Maximum input voltage
  - Minimum input voltage
  - Maximum switching frequency
  - Maximum LED ripple current
  - Duty cycle

  Select a larger value inductance with +/-20% tolerance. Unfortunately, larger inductance requires more winding and tends to be higher DCR and cost.

  So the final inductor selection depends on four main design criteria: efficiency, electromagnetic interference (EMI), dimension, and cost. In handheld battery powered applications: high efficiency, low EMI, and smallest spacing are required. For retrofit LED lighting applications, the lowest cost solution is often employed for AC utility supply.

  Recommend to check each inductor "roll off" and frequency response beside parameters like Irms, Isat, and DCR. Refer to the data sheet for frequency response curves. For EV7 application, use the MSS1260T series high temperature power inductor from Coilcraft.

  Total inductor loss comes from two factors: inductor core loss which is switching frequency related and DCR loss which is conduction resistance loss.

- **Free-Wheeling diode**
  Freewheeling diode is used to eliminate flyback, the sudden voltage spike across an inductive load and provide continuously current into the inductor when power MOSFET is suddenly switched OFF.

  Here are the selection criteria for the diode:
  - Peak forward current capacity (I_{PEAK}), reverse breakdown voltage (V_R), and average rectified output current (I_O)
  - Lower forward voltage drop (V_F) and faster reverse recovery time (t_{rr}) are recommended for better power efficiency.

3. How to reduce output ripple

User can add a Electrolytic Capacitor with proper voltage rating across LED+ (X3) and LED- (X4) to suppress the amplitude of the output waveform. Install the Electrolytic Capacitor carefully to make sure it will able to fit into the E27/A19 light bulbs housing.

Typical Electrolytic Capacitor values shown:

Electrolytic Capacitor (µF)	Output Ripple Suppressed
330 µF 50V	7%
470 µF 50V	26%
680 µF 50V	46%
1000 µF 50V	60%

4. How to adjust operating switching frequency

User can set AL9910 either on constant frequency or constant off time modes.

Constant switching frequency

Connect a resistor between Rosc pin and Ground pin.

Use tosc = (Rosc + 22)/ 25 µs

Switching frequency will impact efficiency. Be careful to have Duty cycle > 0.5 and min Ton >Tblank time (smaller number of LED and in low power mode < 3W) when use at constant frequency mode.

Constant Off time (Variable Frequency)

Connect Rosc between Rosc pin and Gate of external MOSFET. The switching frequency varies as either Vin or Vout changes. More suitable to be used for Triac

Dimming application circuitry that Vin and Vout are changing according to dimmer positions. Help to remove instability issue from Duty cycle > 50%.

5. **How to reduce harmonic distortion**

Harmonic is a measurement of amplitude and frequency of the input source. Harmonic distortion also depends on the numbers of LEDs and I_{LED}.

User can add capacitors both at input and output on the EVBs. However, adding components will impact BOM cost. The most economical way is to add just an output capacitor across LED+ (X3) and LED- (X4) and it will reduce the harmonic.

For the EV7 application, add a 220µF/50V 20% radial capacitor will be sufficient to reduce the harmonic.

6. **How to adjust holding current and dimmer compatibility**

The AL9910 triac dimming evaluation board includes a bleeder circuit to ensure proper triac operation by allowing current flow while the line voltage is low to enable proper firing of the triac since the existing triac dimmer requires a small amount of a few milliamps of current to hold them on throughout the AC line cycle. An external resistor (R17) needs to be placed on the source of Q2 to GND to perform this function. The R17 resistor can be adjusted independently. As the holding resistor R17 is increased, the overall efficiency will also increase.

7. **How to improve triac dimming range**

The AL9910EV7 evaluation board has been optimized with the dimming circuit for triac dimming controls. It is mainly used for both forward phase and reverse phase dimmers using a 120VAC input. In practice, a triac or electronic dimmer can be inserted in series to the hot line voltage after the AC power supply or AC wall power supply, which is then connected directly to the input of the LED driver board. As the AC power supply can be set at any voltage, normally at 120VAC for the AL9910EV7 evaluation board, the dimmer can be adjusted from maximum dimming range that provides full brightness of LEDs to minimum dimming range that provides the lowest brightness before it completely turns off at a cut-off threshold.

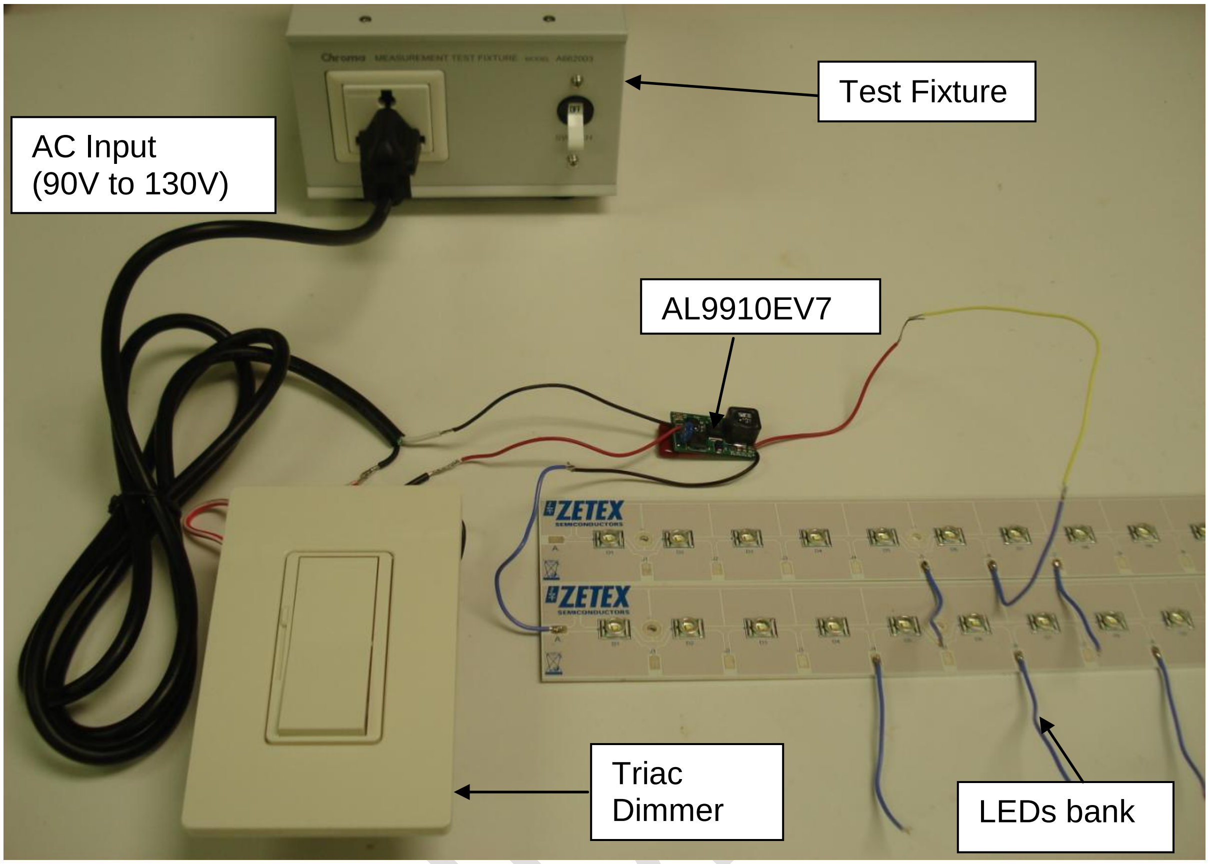
For design flexibility for different condition requirements, the value of resistance in the dimming circuit can be selected to provide wide maximum and minimum range of LED dimming.

Table below shows maximum and minimum LED dimming ranges:

Resistor	Comment
R25 (Refer to figure 2 – Standard EVB's schematic)	Lower R25 (20 KΩ) to an acceptable value if needed (based on the type of dimmers) to achieve lower LED dimming range
R2 (Refer to figure 2 – Standard EVB's schematic)	Lower R2 (10 KΩ) to an acceptable value if needed (based on the type of dimmers) to achieve higher LED dimming range

Here is a list of Triac dimmers which were tested in our lab:

Item #	Dimmer Type	Model Number	Voltage (VAC Input)
1	Lutron	LG-603PG	120
2		DV-603PG	120
3		DV-600P	120
4		CTCL-153PD	120
5		TGCL-153P	120
6	Copper	D106P	120
7		SLC03P	120
8		NOM426	120



8. **How to adjust Power Factor Correction (PFC)**

   EV7 power factor correction circuitry contains R42, R43, R44 and Q6. It works as a controlled voltage divider added into the current feedback loop to have the input current waveform matched with the voltage waveform will improve the power factor. But adjust R42 and R44 to have a high power factor may hurt LED current line rejection tolerance. Disable this circuitry to replace with valley-fill circuitry which is a passive power factor correction. It can maintain a stable LED current over line voltage variation and good power factor at a higher BOM cost trade off.

9. **How to improve Electromagnetic Interference (EMI)**

   Standard EV7 did not come with line EMI filter.
   EMI results may relate to customer's PCB layout, power source, loading conditions, LED lamp fixtures designs, components selection, switching frequency, and EMI filter design.
   User may consider using:

   - Common mode filter (ELF-11090E)
   - Differential mode inductor (MSS1260-105KL-KLB)
   - Choke RF Shielded inductor (RL875S)

for EMI enhancement. However, it will need a joined collaboration with sharing product information between customers and Diodes application supporting team to develop an optimize EMI solution.

5. Standard Evaluation Board Connections

Board Dimension (components included)**:**
WxLxH (in mm) = 20mm x 33mm x 19mm

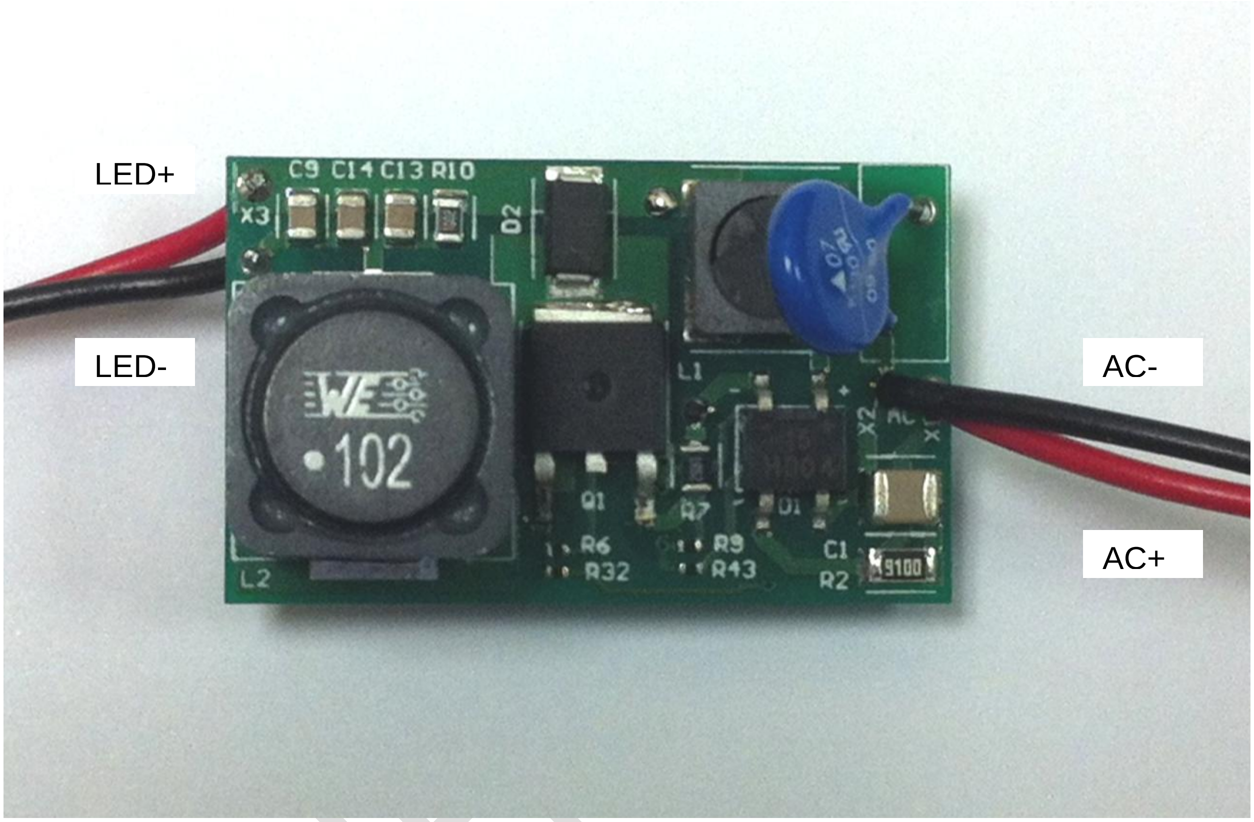


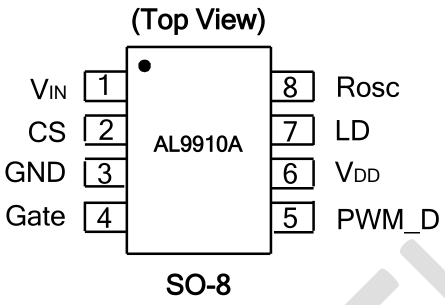
Figure 2: Top-View Board

Recommended Test conditions:
Input Voltage: 120VAC, 60Hz
LED Output Voltage: 24VDC
LED Output Current: 300mA
Efficiency: 87%.
Note: Use the MOSFET (Q1 - AOD4S60) and lower the gate drive resistor R6 to 4.7Ω.

Connection Instructions:
AC+ (X1) Input: Red – Hot
AC- (X2) Input: Black - Neutral
DC LED+ (X3) Output: LED+ (Red)
DC LED- (X4) Output: LED- (Black)

6. Standard AL9910A Pin Assignment and Description

AL9910A Pin Assignment



AL9910A Pin Description

Pin Name	Pin Number	Description
V_{IN}	1	Input voltage
CS	2	Senses LED string current
GND	3	Device ground
Gate	4	Drives the gate of the external MOSFET
PWM_D	5	Low Frequency PWM Dimming pin, also Enable input. Internal 100kΩ pull-down to GND
V_{DD}	6	Internally regulated supply voltage. 7.5V nominal for AL9910. Can supply up to 1mA for external circuitry. A sufficient storage capacitor is used to provide storage when the rectified AC input is near the zero crossings
LD	7	Linear Dimming by changing the current limit threshold at current sense comparator
R_{OSC}	8	Oscillator control. A resistor connected between this pin and ground sets the PWM frequency.

7. Standard Evaluation Board BOM List

Item	Comment	Description	Size	Qty	Manufacturer	Part Number
C1	C1206 - 0.047u 630V	Multilayer Ceramic Capacitors (1206) 0.047µF 630V 10%	C1206	1	Murata	C3216X7T2J473M/SOFT
C4,	C0603 - 4.7u 16V	Multilayer Ceramic Capacitors (0603) 4.7µF 16V 10%	C0603	1	TDK	C1608X5R1C475M
C6, C41	C0603 - 1u 16V	Multilayer Ceramic Capacitors (0603) 1.0µF 16V 10%	C0603	2	TDK	C1608X7R1C105K
C5	C0402 - 220p 50V	Multilayer Ceramic Capacitors (0402) 220pF 50V 5%	C0402	1	Murata	GRM155R71H221JA01J
C7, C8, C12	C0603 - 0.1u 16V	Multilayer Ceramic Capacitors (0603) 0.1µF 16V 10%	C0603	3	Murata	GCM188R71C104KA37D
C9, C13, C14	C0805 – 4.7u 50V	Multilayer Ceramic Capacitors (0805) 4.7µF 50V 10%	C0805	3	TDK	C2012X5R1H475K
C10	C1206 – 1n 500V	Multilayer Ceramic Capacitors (1206) 1nF 500V 10%	C1206	1	Vishay/Vitramon	VJ1206Y102KXEAT5Z
C11	C0603 – 4.7u 10V	Multilayer Ceramic Capacitors (0603) 4.7µF 10V 10%	C0603	1	AVX	0603ZD475KAT2A
C15	C0805 - 0.022u 450V	Multilayer Ceramic Capacitors (0805) 0.022µF 450V 10%	C0805	1	TDK	C2012X7T2W223K
C40	C0603 – 2.2u 16V	Multilayer Ceramic Capacitors (0603) 2.2µF 16V 10%	C0603	1	TDK	C1608X5R1C225KT
C42	C1206 – 0.22u 250V	Multilayer Ceramic Capacitors (1206) 0.22µF 250V 10%	C1206	1	TDK	C3216X7T2E224K
X5-X6	C0.22µF, 250V	Polyester Film Capacitor	WxLxH (mm) 5.5 x 10.3 x 15.5	1	Panasonic	ECQ-E2224JB
D1	HD06	Bridge Rectifiers 0.8A, 600V	MiniDip	1	Diodes Inc	HD06-T
D2	MURS160	Super-Fast Rectifiers 1.0A, 600V	SMB	1	Diodes Inc	MURS160-13-F
D3, D5, D8	SM4005PL-TP	Diode SIL 1.0A, 600V	Power lite 123	3	Micro Commercial Co	SM4005PL-TP
D6	1N4148WT	Fast Switching Diode 100V	SOD-523	1	Diodes Inc	1N4148WT-7
L1	SRR6028-681Y	Power Inductors 680µH 220mA	L6028	1	Bourns	SRR6028-681Y

L2	7447709102	Power Inductors 0.9A, 1mH	L12.5 x 12.5 x 10	1	Wurth Electronics	7447709102
Q1	STD7NM60N	MOSFET Power N-Chan 600V, 5 Amp	D-PAK	1	ST Microelectronics	STD7NM60N
Q2	SPD01N60C3	MOSFET Power COOL MOS N-CH 650V, 0.8A	D-PAK	1	Infineon	SPD01N60C3
Q6	BC847C	NPN Surface Small Signal Transistor 100mA, 45V	SOT-23	1	Diodes Inc	BC847C-7-F
R1	S07K300	Varistors 300Vrms 7MM Radial	Disc 7mm	1	EPCOS	S07K300
R2	R1206 – 10k	Chip Resistor (1206) 10kΩ 1/10W 1%	R1206	1	Panasonic - ECG	ERJ-P8J103V
R3	R0402 - 2k	Chip Resistor (0402) 2kΩ 1/10W 1%	R0402	1	Panasonic - ECG	ERJ-2RKF2001X
R6, R40	R0402 - 22	Chip Resistor (0402) 22Ω 1/10W 1%	R0402	2	Panasonic - ECG	ERJ-2RKF22R0X
R7	R0805 - 1.62	Chip Resistor (0805) 1.62Ω 1/8W 1%	R0805	1	Vishay	CRCW08051R62FKEA
R9	R0402 - 1k	Chip Resistor (0402) 1kΩ 1/10W 1%	R0402	1	Panasonic - ECG	ERJ-2RKF1001X
R10	R0805 - 10k	Chip Resistor (0805) 10kΩ 1/8W 1%	R0805	1	Panasonic - ECG	ERJ-6ENF1002V
R11	R0402 - 2.2M	Chip Resistor (0402) 2.2MΩ 1/10W 5%	R0402	1	Panasonic - ECG	ERJ-2GEJ225X
R12	R0402 - 200k	Chip Resistor (0402) 200kΩ 1/10W 1%	R0402	1	Panasonic - ECG	ERJ-2RKF2003X
R13	R1206 – 4.7M	Chip Resistor (1206) 4.7MΩ 1/4W 5%	R1206	1	Rohm Semiconductor	MCR18EZHJ475
R14	R1206 - 348k	Chip Resistor (1206) 348kΩ 1/4W 1%	R0805	1	Vishay/Dale	CRCW1206348KFKEA
R15	R0402 - 4.3k	Chip Resistor (0402) 4.3kΩ 1/10W 1%	R0402	1	Panasonic - ECG	ERJ-2RKF4301X
R16	R0402 - 120k	Chip Resistor (0402) 120kΩ 1/10W 1%	R0402	1	Panasonic - ECG	ERJ-2RKF1203X
R17	R1206 – 249	Chip Resistor (1206) 249Ω 1/4W 1%	R1206	1	Rohm Semiconductor	MCR18EZHF2490
R47	R1206 – 200	Chip Resistor (1206) 200Ω 1/4W 1%	R1206	1	Panasonic - ECG	ERJ-8ENF2000V
R18, R20	R0805 - 1M	Chip Resistor (0805) 1MΩ 1/8W 1%	R0805	2	Panasonic - ECG	ERJ-6ENF1004V
R19	R0402 - 1.2M	Chip Resistor (0402) 1.2MΩ 1/10W 5%	R0402	1	Panasonic - ECG	ERJ-2GEJ125X
R21	R0805 - 510k	Chip Resistor (0805) 510kΩ 1/8W 1%	R0805	1	Panasonic - ECG	ERJ-6ENF5103V
R22	R0402 - 300k	Chip Resistor (0402) 300kΩ 1/10W 1%	R0402	1	Panasonic - ECG	ERJ-2RKF3003X
R23	R1206 - 750k	Chip Resistor (1206) 750kΩ 1/3W 5%	R1206	1	Panasonic - ECG	ERJ-P08J754V
R35	R0805 - 750k	Chip Resistor (0805) 750kΩ 1/4W 5%	R0805	1	Panasonic - ECG	ERJ-P06J754V

R25	R0402 - 20k	Chip Resistor (0402) 20kΩ 1/10W 1%	R0402	1	Rohm Semiconductor	TRR01MZPF2002
R29	R0603 - 180k	Chip Resistor (0603) 180kΩ 1/10W 1%	R0603	1	Panasonic - ECG	ERJ-3EKF1803V
R32	R0402 - 360k	Chip Resistor (0402) 360kΩ 1/10W 1%	R0402	1	Panasonic - ECG	ERJ-2RKF3603X
R41	R0402 - 750k	Chip Resistor (0402) 750kΩ 1/10W 1%	R0402	1	Panasonic - ECG	ERJ-2RKF7503X
R42	R1206 – 1.6M	Chip Resistor (1206) 1.6MΩ 1/4W 5%	R1206	1	Rohm Semiconductor	MCR18EZHJ165
R43	R0402 - 200	Chip Resistor (0402) 200Ω 1/10W 1%	R0402	1	Panasonic - ECG	ERJ-2RKF2000X
R44	R0402 - 4.7k	Chip Resistor (0402) 4.7kΩ 1/10W 1%	R0402	1	Panasonic - ECG	ERJ-2RKF4701X
R45	R0402 - 100k	Chip Resistor (0402) 100kΩ 1/10W 1%	R0402	1	Panasonic - ECG	ERJ-2RKF1003X
R46	R0402 - 150k	Chip Resistor (0402) 150kΩ 1/10W 1%	R0402	1	Panasonic - ECG	ERJ-2RKF1503X
R47	R1206 – 390	Chip Resistor (1206) 390Ω 1/3W 5%	R1206	1	Rohm Semiconductor	ESR18EZPJ391
R48	Thru-hole – 150	Through-hole - 150Ω 1/2W 5%	Axial	1	Panasonic - ECG	ERD-S1TJ151V
R49	R1206 – 15k	Chip Resistor (1206) 15kΩ 1/3W 5%	R1206	1	Rohm Semiconductor	ESR18EZPJ153
U1	AL9910ASP -13	LED Drivers - 10V LED Driver PWM 85 to 277VAC	SO-8EP	1	Diodes Inc	AL9910ASP-13
U2	LM2903	Comparator IC - Low Power Dual Voltage	SO-8	1	ST Microelectronics	LM2903DT

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