The TPS92070EVM-648 evaluation module (EVM) is a low power isolated flyback converter that provides 5 on-board LEDs with 370 mA of drive current from a nominal 230 VAC input. This EVM is designed to demonstrate the TPS92070 in a typical application where LEDs can be used for general illumination applications that require dimming.

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1 Description

This evaluation module uses the TPS92070 High Efficiency Integrated Dimming LED Lighting Driver Controller (TI Literature Number SLUSAN1) in a low power offline flyback converter to provide 370 mA to the on-board LED load. The input accepts a nominal 50 Hz, 230 VAC input voltage. The TPS92070EVM-648 is designed to be used with a leading edge triac dimmer switch in series with the input voltage to control the lumen output of the LEDs. The integrated dimming interface circuit on the TPS92070 provides exponentially controlled light output based on the external dimmer position.

This user's guide provides the schematic, component list, assembly drawing, and test set up necessary to evaluate the TPS92070 in an AC input LED lighting application. To use an input voltage greater than 240 VAC, it is recommended the user change the fuse to one rated for at least 300 V at 1 A.

1.1 Typical Applications

The TPS92070 is suited for use in low power lighting applications such as:

- LED light bulb replacement
- LED luminaires
- LED down-lights
- LED wall washers
1.2 Features
The TPS92070EVM-648 features include:
• 180 VAC to 240 VAC input range
• LED current regulation of 370 mA, nominal
• 6 W output at 16.5 V
• Advanced integrated dimming interface
• Exponential dimming profile
• Programmable minimum LED Current
• Valley switching and DCM operation
• Leading edge dimmer detection
• Valley fill power factor correction
• Cycle by cycle current limit protection

2 Electrical Performance Specifications

Table 1. TPS92070EVM-648 Electrical Performance Specifications

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
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<tr>
<td></td>
<td>INPUT CHARACTERISTICS</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>$V_{\text{IN}}$</td>
<td>Voltage range</td>
<td>180</td>
<td>230</td>
<td>265</td>
<td>VAC</td>
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<tr>
<td></td>
<td>$f_{\text{LINE}}$</td>
<td>Input frequency</td>
<td>50</td>
<td></td>
<td></td>
<td>Hz</td>
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<tr>
<td></td>
<td>$I_{\text{IN(MAX)}}$</td>
<td>Input current</td>
<td></td>
<td></td>
<td></td>
<td>mA</td>
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<tr>
<td></td>
<td>PF</td>
<td>Input power factor</td>
<td>$V_{\text{IN(MAX)}}, I_{\text{LED}} = \text{full load}^{(1)}$</td>
<td>0.80</td>
<td></td>
<td></td>
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<td></td>
<td>OUTPUT CHARACTERISTICS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_{\text{OUT}}$</td>
<td>Output voltage</td>
<td>$V_{\text{IN(MIN)}} \leq V_{\text{IN}} \leq V_{\text{IN(MAX)}}, I_{\text{LED}} = \text{full load}^{(1)}$</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$I_{\text{LED}}$</td>
<td>Output load current set point</td>
<td>$V_{\text{IN(MIN)}} \leq V_{\text{IN}} \leq V_{\text{IN(MAX)}}, I_{\text{LED}} = \text{full load}^{(1)}$</td>
<td>352</td>
<td>370</td>
<td>388</td>
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<tr>
<td></td>
<td></td>
<td>Output current regulation</td>
<td>$V_{\text{IN(MIN)}} \leq V_{\text{IN}} \leq V_{\text{IN(MAX)}}, I_{\text{LED}} = \text{full load}^{(1)}$</td>
<td>5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum LED current</td>
<td>$V_{\text{IN(MIN)}} \leq V_{\text{IN}} \leq V_{\text{IN(MAX)}}, I_{\text{LED}} = \text{full load}^{(1)}\text{ With dimmer capable of} 10% \text{ conduction angle}$</td>
<td>13</td>
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<td></td>
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<td></td>
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<td>Output voltage ripple</td>
<td>$V_{\text{IN(TYP)}}, I_{\text{LED}} = \text{full load}^{(1)}$</td>
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<td></td>
</tr>
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<td>SYSTEMS CHARACTERISTICS</td>
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<td></td>
<td>$f_{\text{SW}}$</td>
<td>Switching frequency</td>
<td></td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\eta$</td>
<td>Full load efficiency</td>
<td>$V_{\text{IN(TYP)}}, I_{\text{LED}} = \text{full load}^{(1)}$</td>
<td>83%</td>
<td></td>
<td></td>
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<td></td>
<td>$T_{\text{A}}$</td>
<td>Operating temperature</td>
<td></td>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) Full load is 5 on-board LEDs in series.

CAUTION
High voltage levels are present on the evaluation module whenever it is energized. Proper precautions must be taken when working with the EVM. Serious injury can occur if proper safety precautions are not followed.
Figure 1. TPS92070EVM-648 Schematic
4 Test Setup

4.1 Test Equipment

**Voltage Source:** The input voltage source shall be an isolated variable AC source capable of supplying between 180 VAC and 265 VAC at no less than 10W and connected as shown in Figure 2. (example. Hewlett Packard 6813B AC Power Source)

**Power meter:** For accurate efficiency calculations, a power meter should be inserted between the AC source and the EVM. For highest accuracy, connect the voltage terminals of the power meter directly across the Line and Neutral terminals of the EVM. (example: Voltech PM100 Single Phase Power Analyzer)

**Multimeters:** Two digital multimeters are used to measure the LED voltage (DMM $V_{LED}$) and load current (DMM $A_{LED}$). (example: Fluke 45 Digital Multimeter)

**Output Load:** By connecting a jumper wire from J2 pin 2 to J2 pin 3 (LED RTN) the 5 Cree™ MX series white LEDs that are on the EVM may be used as the load. The EVM can also be used to drive the user’s external LED load by connecting the jumper wire from J2 pin 1 (+LED) to the external 370mA, 3.2 V LEDs and return them to J2 pin 3 (LED RTN).

**Oscilloscope:** A 200 MHz digital oscilloscope with 4 isolated channels for differential mode measurements is recommended. Non-isolated probes may result in flickering. A high voltage probe and a current probe are also recommended. (examples: Tektronix TPS2024B Four Channel Digital Storage Oscilloscope, Tektronix P5205A High Voltage Differential Probe, Tektronix TCPA300 Amplifier AC/DC Current Probe)

**Dimmer:** A leading edge dimmer, rated for 230 VAC can be used for controlling to LED light output. (example: Busch 2250U)

**Fan:** Forced air cooling is not required.

**Recommended Wire Gauge:** A minimum of AWG 22 wire is recommended to connect the AC voltage source to the EVM at less than 3 feet long.
4.2 Recommended Test Setup

Figure 2. TPS92070EVM-648 Recommended Test Set Up

4.3 List of Test Points

Table 2. The Function of Each Test Point

<table>
<thead>
<tr>
<th>Test Point</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP1</td>
<td>+LED</td>
<td>LED output voltage, reference to TP15</td>
</tr>
<tr>
<td>TP2</td>
<td>Q2 drain</td>
<td>Phase detection circuit, reference to TP12</td>
</tr>
<tr>
<td>TP3</td>
<td>TDD</td>
<td>TRIAC dimmer detect, reference to TP14</td>
</tr>
<tr>
<td>TP4</td>
<td>Q2 gate</td>
<td>Phase detection circuit, reference to TP12</td>
</tr>
<tr>
<td>TP5</td>
<td>Q3 drain</td>
<td>High voltage switch drain, reference to TP14</td>
</tr>
<tr>
<td>TP6</td>
<td>DTS</td>
<td>Dimmer trigger control input, reference to TP14</td>
</tr>
<tr>
<td>TP7</td>
<td>BP</td>
<td>Bypass for internal 7 V regulator, reference to TP12</td>
</tr>
<tr>
<td>TP8</td>
<td>GATE</td>
<td>Q3 gate drive, reference to TP14</td>
</tr>
<tr>
<td>TP9</td>
<td>SRTN</td>
<td>Secondary side return</td>
</tr>
<tr>
<td>TP10</td>
<td>VDD</td>
<td>Bias pin, reference to TP12</td>
</tr>
<tr>
<td>TP11</td>
<td>Q3 source</td>
<td>Primary current sense access, reference to TP14</td>
</tr>
<tr>
<td>TP12</td>
<td>GND</td>
<td>Ground, reference for TP2, TP4, TP7, TP10, TP13, TP16, TP17, TP18, TP19, TP20</td>
</tr>
<tr>
<td>TP13</td>
<td>VD</td>
<td>Valley detect, reference to TP12</td>
</tr>
<tr>
<td>TP14</td>
<td>PGND</td>
<td>Power ground, reference for TP3, TP5, TP6, TP8, TP11</td>
</tr>
<tr>
<td>TP15</td>
<td>LED RTN</td>
<td>Return for LED load, reference for TP1</td>
</tr>
<tr>
<td>TP16</td>
<td>COMP</td>
<td>Loop compensation, reference to TP12</td>
</tr>
<tr>
<td>TP17</td>
<td>SEN</td>
<td>Dimmer sense input, reference to TP12</td>
</tr>
<tr>
<td>TP18</td>
<td>LP</td>
<td>Pole for DTC low pass filter, reference to TP12</td>
</tr>
<tr>
<td>TP19</td>
<td>ISO</td>
<td>Inverting input to LED current sense comparator, reference to TP12</td>
</tr>
<tr>
<td>TP20</td>
<td>CS</td>
<td>Non-inverting input to LED current sense comparator, reference to TP12</td>
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</table>
5 Test Procedure

5.1 Line Regulation and Efficiency Measurement Procedure
1. With the dimmer removed from the test set up, set the AC voltage source to 180 VAC, 50 Hz.
2. The LEDs should be lit and the LED current should be within regulation per Table 1.
3. Adjust AC voltage up to 265 VAC.
4. LEDs should be lit and the current should remain within regulation per Table 1 with no flicker.
5. Efficiency data should be taken without the dimmer in circuit and input measurements taken from the power meter.
6. Turn off AC power. LEDs should turn off with no flashing or flicker.

5.2 Dimming
1. With dimmer in circuit, set the AC voltage source between 180 VAC and 265 VAC, 50 Hz.
2. Adjust the dimmer to control light output.

5.3 Equipment Shutdown
1. Turn off AC voltage source.

6 Performance Data and Typical Characteristic Curves

Figure 3 through Figure 17 present typical performance curves for the TPS92070EVM-648. Since actual performance data can be affected by measurement techniques and environmental variables, these curves are presented for reference and may differ from actual field measurements.

6.1 Efficiency

![Efficiency Graph](image)

Figure 3. TPS92070EVM-648 Efficiency with Respect to Line Voltage, no Dimmer
6.2  **LED Current Regulation**

![LED Current Regulation Graph](image1)

*Figure 4. TPS92070EVM-648 LED Current Regulation with Respect to Line Voltage, no Dimmer*

6.3  **Power Factor**

![Power Factor Graph](image2)

*Figure 5. TPS92070EVM-648 Power Factor with Respect to Line Voltage, no Dimmer*
6.4 Average Conduction

![Graph showing LED current with respect to average dimmer conduction]

Figure 6. LED Current with Respect to Average Dimmer Conduction

6.5 Turn On

![Graph showing turn on, full load, no dimmer]

Figure 7. Turn on, Full Load, no Dimmer, VIN = 230 VAC, CH1 = SEN, CH2 = VDD, CH3 = BP, CH4 = LINE
6.6 Output Voltage Ripple

Figure 8. LED Turn on, Full Load, no Dimmer, VIN = 230 VAC

Figure 9. LED Output Voltage Ripple, Full Load, no Dimmer, VIN = 230 VAC
6.7 **Output Current Ripple**

![Graph of LED Output Current Ripple](image)

Figure 10. LED Output Current Ripple, Full Load, no Dimmer, \( V_{IN} = 230 \text{ VAC} \), scale = 1 Amp per volt

6.8 **AC Input**

![Graph of Input AC Voltage and Current](image)

Notice the influence of the DTC circuit at the zero voltage crossings.

Figure 11. Input AC Voltage and Current, Full Load, no Dimmer, \( CH1 = I_{IN}, CH3 = V_{IN} \), scale = 1 Amp/V
6.9 Switching Waveform

Figure 12. Switching Waveforms, Full Load, no Dimmer,
VIN = 230 VAC, CH1 = Q3 drain, CH2 = GATE, CH3 = PCS, 328 mV

6.10 TDD, No Dimmer

Figure 13. TDD Signal Low When There is no Dimmer Detected on the Input, Valley Fill PFC is Enabled,
Full Load, VIN = 230 VAC, CH1 = TDD, CH2 = SEN, CH3 = VIN
6.11 **TDD, With Dimmer**

![Diagram showing TDD signal high when there is a dimmer detected on the input, Valley Fill PFC is disabled, full load, VIN = 230 VAC, CH1 = TDD, CH2 = SEN, CH3 = VIN.]

Figure 14. TDD Signal High When There is a Dimmer Detected on the Input, Valley Fill PFC is Disabled, Full Load, VIN = 230 VAC, CH1 = TDD, CH2 = SEN, CH3 = VIN

6.12 **Valley Detect**

![Diagram showing Valley detect, full load, no dimmer, VIN = 230 VAC, CH1 = VD, CH2 = GATE, CH3 = PCS.]

Figure 15. Valley Detect, Full Load, no Dimmer, VIN = 230 VAC, CH1 = VD, CH2 = GATE, CH3 = PCS
6.13 Turn Off

Figure 16. Turn off, Full Load, no Dimmer, VIN = 230 VAC, CH1 = SEN, CH2 = VDD, CH3 = BP, CH4 = LINE

6.14 Dimmer Detection

Figure 17. Dimmer Detection, DTC Sinks Current During AC Zero Crossing to Keep TRIAC Triggered. CH1 = VIN, CH2 = DTC, CH3 = SEN
7 EVM Assembly Drawing and PCB layout

Figure 18. TPS92070EVM-648 Top View

Figure 19. TPS92070EVM-648 Top Layer Assembly Drawing (Top View)
Figure 20. TPS92070EVM-648 Bottom View

Figure 21. TPS92070EVM-648 Bottom Assembly Drawing (Bottom view)
Figure 22. TPS92070EVM-648 Top Copper (Top View)

Figure 23. TPS92070EVM-648 Internal Layer 1 (Top View)

Figure 24. TPS92070EVM-648 Internal Layer 2 (Top View)
### Bill of Materials

The bill of materials table lists the components according to the schematic shown in Figure 1.

#### Table 3. Bill of Materials

<table>
<thead>
<tr>
<th>Count</th>
<th>RefDes</th>
<th>Description</th>
<th>Part Number</th>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>C1</td>
<td>Capacitor, Aluminum Electrolytic, 4.7 µF, 400V, –40 to 105°C, ±20%, 10.00 mm Dia</td>
<td>EKM401ELL4R7MU16S</td>
<td>United Chemi-Con</td>
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<td>1</td>
<td>C2</td>
<td>Capacitor, Ceramic, 68 pF, 1000V, U2J, ±5%, 1206</td>
<td>GRM31ATU3A680JW31D</td>
<td>Murata Electronics</td>
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<td>C3</td>
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<td>GRM31BR72J103K0W01L</td>
<td>Murata Electronics</td>
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<td>C4</td>
<td>Capacitor, Ceramic, 47 nF, 630V, X7R, ±10%, 1210</td>
<td>C3225X7R2J47K</td>
<td>TDK Corporation</td>
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<td>C5</td>
<td>Capacitor, Metallized Polypropylene Film, 10 nF, 305VAC, X2, ±20%, 0.157 x 0.512 inch</td>
<td>B32921C3103M</td>
<td>Epcos Inc</td>
</tr>
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<td>C6</td>
<td>Capacitor, Aluminum Electrolytic, 4.7 µF, 200V, -40 to +105°C, ±20%, 8.00 mm Dia</td>
<td>EKM4021ELL4R7MU65D</td>
<td>United Chemi-Con</td>
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<td>Murata Electronics</td>
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<td>Capacitor, Ceramic Disc, 330 0pF, 500VAC, X1Y1, ±20%, 15 mm Dia</td>
<td>VY1332MSY5UF63V0</td>
<td>Vishay/BC Components</td>
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<td>Std</td>
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<td>Std</td>
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<td>D1, D3</td>
<td>Diode, Rectifier, 1A, 60 0V, SMA</td>
<td>S1J-13-F</td>
<td>Diodes, Inc</td>
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<td>D2, D4, D7, D8, D10</td>
<td>LED, Xlamp, 1A Max, White, 5.0 x 6.0 mm</td>
<td>MX6AWT-A1-0000-000AE7 or MX3AWT-A1-0000-000BE7</td>
<td>Cree</td>
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<td>D5, D9</td>
<td>Diode, Bridge Rectifier, 0.5A, 600V, SO-4</td>
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<td>Fairchild Semiconductor</td>
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<td>On Semiconductor</td>
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<td>D12</td>
<td>Diode, Zener, 5.12V, 250 mW, SOT-23</td>
<td>BZX84-C5V121S</td>
<td>NXP Semiconductors</td>
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<tr>
<td>1</td>
<td>F1</td>
<td>Fuse, Slow Blow, 1A, 250V, 0.335 inch</td>
<td>3B211000410</td>
<td>Littelfuse / Wickmann</td>
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<tr>
<td>3</td>
<td>L1, L2, L3</td>
<td>Inductor, Filter Choke, 1mH, ±10%, 6 mm Dia</td>
<td>7447462102V</td>
<td>Wurth Middom</td>
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<td>1</td>
<td>Q1</td>
<td>MOSFET, N-ch, 200V, 650mA, 2.2 Ohms, TSOP-6</td>
<td>IRF5801TRPBF</td>
<td>International Rectifier</td>
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<td>Q2</td>
<td>MOSFET, N-ch, 600V, 0.3A, 11.5 Ohms, TO-92</td>
<td>FQN1N60CTA</td>
<td>Fairchild Semiconductor</td>
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<td>Q3</td>
<td>MOSFET, N-ch, 800V, 2.5A, 4.5 Ohms, DPAK</td>
<td>ST3NK80ZT4</td>
<td>STMicroelectronics</td>
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<td>Std</td>
</tr>
</tbody>
</table>
### Table 3. Bill of Materials (continued)

<table>
<thead>
<tr>
<th>Count</th>
<th>RefDes</th>
<th>Description</th>
<th>Part Number</th>
<th>Mfr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R4</td>
<td>Resistor, Metal Film, 475, 1/4 W, ±1%, 0.250 inch x 0.093 inch Dia</td>
<td>RNF14FTD475R</td>
<td>Stackpole Electronics Inc.</td>
</tr>
<tr>
<td>1</td>
<td>R7</td>
<td>Resistor, Chip, 205, 1/10W, ±1%, 0603</td>
<td>Std</td>
<td>Std</td>
</tr>
<tr>
<td>1</td>
<td>R9</td>
<td>Resistor, Thick Film, 0.27, 1/2 Watt, ±1%, 1206</td>
<td>RCWE1206R270FKEA</td>
<td>Vishay/Dale</td>
</tr>
<tr>
<td>1</td>
<td>R10</td>
<td>Resistor, Chip, 15.0, 1/10W, ±1%, 0603</td>
<td>Std</td>
<td>Std</td>
</tr>
<tr>
<td>2</td>
<td>R11, R16</td>
<td>Resistor, Chip, 162k, 1/10W, ±1%, 0603</td>
<td>Std</td>
<td>Std</td>
</tr>
<tr>
<td>1</td>
<td>R12</td>
<td>Resistor, Chip, 511, 1/10W, ±1%, 0603</td>
<td>Std</td>
<td>Std</td>
</tr>
<tr>
<td>1</td>
<td>R13</td>
<td>Resistor, Chip, 2.37, 1/10W, ±1%, 0603</td>
<td>Std</td>
<td>Std</td>
</tr>
<tr>
<td>1</td>
<td>R14</td>
<td>Resistor, Chip, 51.1k, 1/10W, ±1%, 0603</td>
<td>Std</td>
<td>Std</td>
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<tr>
<td>1</td>
<td>R15</td>
<td>Resistor, Chip, 68.1k, 1/10W, ±1%, 0603</td>
<td>Std</td>
<td>Std</td>
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<tr>
<td>1</td>
<td>T1</td>
<td>Transformer, 13.8 mH, ±10%, 20.3 x 24.38 mm</td>
<td>7508110410</td>
<td>Wurth Midcom</td>
</tr>
<tr>
<td>1</td>
<td>T2</td>
<td>Transformer, 450 µH, 1:1, 0.173 x 0.360 inch</td>
<td>750082157</td>
<td>Wurth Midcom</td>
</tr>
<tr>
<td>1</td>
<td>U1</td>
<td>IC, Dimmable Quasi-Resonant LED Lighting Controller, TSSOP</td>
<td>TPS92070PW</td>
<td>Texas Instruments</td>
</tr>
<tr>
<td>1</td>
<td>VAR1</td>
<td>Varistor, Disk, 300VAC, 5mm Radial, D Size</td>
<td>S05K300</td>
<td>Epcos Inc.</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Jumper Wire, U-Shape, 0.200 inch x 22 AWG</td>
<td>923345-02-C</td>
<td>3M</td>
</tr>
</tbody>
</table>
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