

#### **FEATURES**

- AC input, Dual DC output Transformerless Power Supply
  - Resistive
  - Capacitive
- Switching Element
  - SPDT Relay
  - TRIAC
  - SCR
- Zero-volt detection for phase angle firing of TRIAC/SCR
- BoosterPack for Texas Instruments' Launchpad platform
- Full- and Half-wave rectifier configurations
- Jumper-selectable VCC and relay coil voltage source from USB or AC power
- · Selectable pinout for switch control and zero volt detect
- Input and Output Voltage Surge Protection
- Meets IPC high voltage spacing up to 300V
- LED to display relay status

#### APPLICATIONS

- Appliances/White Goods
- Home Automation
- Heating Pads



ProtoPowerSwitch BoosterPack should be aware that the circuit exposes **dangerous high voltage**. Proper safeguards, high voltage training, and PPE is necessary to ensure safe operation. The ProtoPowerSwitch is intended to accelerate design efforts for OEMs that will unavoidably work with exposed high voltages during the course of product development. Always assume the circuit is unsafe to touch while powered.

Product developers using the



#### **General Description**

The ProtoPowerSwitch BoosterPack is a circuit board designed to make it easy to prototype electronic devices that control the flow of AC power to loads. The BoosterPack plugs directly into Texas Instruments' Launchpad devices, but may also be used with other microcontroller platforms through the use of jumper wires. The ProtoPowerSwitch BoosterPack can use a relay, TRIAC, or SCR to control power flow to loads. The ProtoPowerSwitch BoosterPack also incorporates a transformerless power supply that generates up to two low voltage DC outputs to power microcontrollers and relay coils.

The ProtoPowerSwitch can be ordered as a bare board or populated in custom configurations. Beyond the prototyping stage, Designer Circuits, LLC can support transition to production by designing and sourcing custom circuit boards for your specific application. Contact <u>info@designercircuits.com</u> to learn more.

#### Meet the ProtoPowerSwitch BoosterPack

The ProtoPowerSwitch BoosterPack can perform three distinct functions:

- Power switching via Relay, TRIAC, or SCR
- Generate low voltage DC via Transformerless AC Power Supply
- Detect zero voltage crossing of AC voltage

These functions are treated independently, and can be implemented individually or in combination with each other.

## ProtoPowerSwitch Functional Block Diagram





Figure 1 ProtoPowerSwitch Board, unpopulated



Figure 2 ProtoPowerSwitch Board, color coded to match Functional Block Diagram

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In a use case where all the capabilities are used in combination, the transformerless AC power supply generates power to run a microcontroller, and the zero volt crossing signal is used to schedule phase angle firing of a TRIAC for light dimming applications.

In another use case, the microcontroller and a relay (with a 5VDC coil) are both powered by the LaunchPad's USB 5VDC. The relay controls the flow of power (AC or DC) to loads. The AC transformerless power supply and zero volt detector can be left unused.

For applications such as white goods or appliances, the transformerless AC power supply may be used to generate power to run the microcontroller, which then controls a relay.

#### Why the ProtoPowerSwitch BoosterPack?

Many products which use wall-outlet AC power also require low voltage DC power to operate microcontrollers. The two common ways of generating these low voltages are to use a step-down transformer circuit or a transformerless power supply circuit.

- Transformer-based power supplies (e.g. "wall wart", power brick) are typically used in applications requiring more than about 30mA of current, or where isolation from the mains is required for safety reasons.
- Transformerless power supplies are more commonly used when only a small amount of current is needed (typically, 30mA or less but as much as 200mA), isolation from the mains is not required, and cost, size, and weight must be minimized.

White goods like washing machines and ovens, *appliances* like toasters and rice cookers, and *small consumer goods* like heating pads all use AC power to operate heaters, motors, and other electrical loads. For anything more than the simplest of devices, electronic controls are used to implement timers, measure temperatures, display information or perform a host of other functions. Low voltage DC-powered microcontrollers are typically employed to perform these sensing and control tasks because they are cost-effective and draw very little power while providing a relatively high degree of functionality. Texas Instruments offers several very low cost, very low power microcontrollers such as the MSP430<sup>™</sup> product line. To support development for these processors, TI provides Launchpad development boards which simplify programming and prototyping.

Depending on the application, either an isolated power supply or a transformerless power supply may be used to generate low voltage DC needed to power the microcontroller The primary benefit of a transformerless power supply is low cost in production, but other benefits include reduced size, reduced parts count, and fewer failure modes.

These benefits can generally only be enjoyed for systems intentionally designed to isolate the end user from potential

#### ProtoPowerSwitch BoosterPack

shock hazards. This can be achieved through the use of appropriate plastic housings or non-user-serviceable equipment in a grounded metal chassis.

The ProtoPowerSwitch BoosterPack, in combination with a Launchpad or other microcontroller platform, provides much of the capability necessary to create prototype electronics for new products. Product developers can reduce design time and increase cost savings by leveraging the implementation flexibility of the ProtoPowerSwitch BoosterPack. This User Guide describes the ProtoPowerSwitch BoosterPack in detail.

#### **Circuit Capabilities**

The ProtoPowerSwitch BoosterPack provides a high degree of versatility. Some applications may simply require a relay board capable of handling high voltage with adequate isolation for the microcontroller and USB connection. Others may need to drive an SCR directly from the pins of the microcontroller (no isolation) while using the AC power to generate the low voltage DC for the microcontroller. Still others may simply want to use the transformerless AC power supply but have no need for relays, TRIACs, or SCRs. Whatever the intended use, it is likely the ProtoPowerSwitch circuit can support it. Many of the options provided by the board are outlined below:

- Power Source
  - 5V USB
    - > External power supplies
    - AC Transformerless Power Supply (non-isolated from mains)
      - Resistive
      - Capacitive (X2 film capacitor) with 15mm, 22.5mm, 27.5mm lead spacing
- Power switching device
  - Relay
  - ➤ TRIAC
  - SCR
- Switching element footprint
  - Standard SPDT Relay with NO and NC outputs
  - ➤ TO220
  - ➤ TO92

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- Optional Transient Suppression (MOVs) for
  - Input voltage
  - Normally Open (NO) output
  - Normally Closed (NC) relay output
  - Relay coil control via
  - Optoisolator
  - Transistor
  - TRIAC/SCR gate current source
  - > Optotriac
  - Microcontroller pin (under certain conditions)
  - Relay coil voltage supply
  - 5V from USB
  - 24V transformerless power supply
  - Any externally applied voltage

- Grounding
  - Shared ground between relay coil drive voltage and microcontroller supply voltage (needed for USBpowered option)
  - Separate ground between relay coil drive voltage and microcontroller supply voltage (needed for transformerless power supply option)
- AC transformerless power supply current rating
  - Standard, half wave (neutral tied to microcontroller GND)
  - Extra current, full wave (neutral **not** tied microcontroller GND)
  - Through hole or surface mount options for
    - LEDs
      - Transformerless power supply Zener diodes

#### **Application Information**

# Transformerless Power Supply

For detailed information about designing transformerless power supplies, please refer to DesignNote001a.

### Input Stage

Figure 3 highlights the area of the ProtoPowerSwitch board used for the the input stage of the transformerless power supply.



#### Figure 3 Transformerless Supply Input Stage

To enable the transformerless power supply option, either a resistor or an X2-class capacitor (rated for use across the

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mains) can be installed in location C1. For capacitors, the board supports the standard 15mm, 22.5mm, and 27.5mm lead spacing. Be aware that capacitor height may interfere with additional Boosterpack stacking. For a resistive power supply, multiple input resistors may be paralleled to overcome limitations caused by the resistor power rating.

If a capacitive power supply is employed, for safety reasons, a resistor, R18, should be placed in parallel with the capacitor. This resistor dissipates energy that may be stored in the capacitor after the device is unplugged from the mains. A 1M $\Omega$  resistor for R18 is typically sufficient to discharge the capacitor to safe levels in a reasonable amount of time.

R17 is the inrush current limiting resistor. It is used to limit the current that would otherwise charge up the input capacitor at the moment the device is plugged in. If the AC voltage is instantaneously near peak voltage and C1 is fully dischared, there is risk of arcing or tripping circuit breakers upon plugging the device into an outlet.

### **Rectification Stage**

Figure 6 highlights the area of the ProtoPowerSwitch board used to rectify the input voltage.



#### Figure 4 Transformerless Supply Rectification Stage

This stage is generally used only for pre-Zener rectification. The component footprint supports a full wave bridge rectifier such as the G3SBA20L-E3/51. Half wave rectification also supported through a discrete diode and shorting wire, as indicated in Figure 5. If all rectification occurs post-Zener, then the diode in Figure 5 should also be replaced with a shorting wire.





Figure 5 Transformerless Supply Rectification Stage wired for Half-wave rectification pre-zener

### VCC Supply, Voltage Regulation Stage 1

Figure 6 highlights the area of the ProtoPowerSwitch board used to generate and regulate low voltage DC which powers the microcontroller.



#### Figure 6 Transformerless Supply Voltage Regulation Stage 1

The Zener diode that generates the VCC output voltage voltage is installed at D5. The footprint is designed to accept either a through hole or DO-214AC surface mount package

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Zener diode. Surface mount diodes are recommended for improved thermal management.

C2 and C3 are parallel capacitors which filter the VCC output voltage. These are typically electrolytic capacitors, and can be either through hole or surface mount (4mm diameter). If an unusually large capacitor is desired, a through hole capacitor can span C2 and C3, using one hole from each footprint.

D7 provides rectification for post-Zener transformerless power supply. Refer to DesignNote1a for more information on the role of this diode and whether or not it is needed for your application. To summarize, is *required* to be present in the Resistive and Capacitive Half-Wave Rectified (Post-Zener) versions of the transformerless power supply, and is optional for the other three versions (for the optional versions, if the diode is not installed, a jumper wire should be used in its place).

U5 enables additional regulation of the output voltage. The zener-generated voltage will exhibit ripple at the input AC frequency. To address this, the Zener voltage may be set slightly above the desired output voltage and an LDO (in TO-92 package) can be installed in U5 to provide a well-regulated output (such as the 3.3V required by the Tiva-C Launchpad). From left to right in the picture above, the through holes are input, ground, and output. If LDO regulation is not needed, the input hole should simply be shorted to the output hole.

Transformerless power supplies are generally only effective at producing tens of milliamps of output current. If additional current is needed from VCC, then one technique to achieve this is to generate a much higher output voltage (e.g. 30V) and then use a DC-DC switching power supply to generate a low, regulated output voltage (e.g. 3.3V). This provides a multiplier effect for the output current beyond traditional transformerless supply limits, easily enabling applications which consume upwards of 100mA. To facilitate this capability, the U5 footprint is pin-compatible with Pololu step-down converters (such as D24V3F3). Figure 7 shows a board which uses a Pololu converter for U5. Note that the Pololu board can be installed in either a vertical or horizontal orientation (to facilitate either larger-than-usual capacitors or board stacking, as needed)



# Figure 7 Pololu step down converter used for high current applications

J24 and J25 are jumpers which connect the VCC and ground of the transformerless power supply to the VCC and Ground pins of the Launchpad. If the ProtoPowerSwitch is used as a transformerless power supply, jumpers J24 and J25 should be installed. If VCC power is instead provided by the Launchpad USB (or any source other than the ProtoPowerSwitch transformerless supply), then jumpers J24 and J25 should be removed.

### Relay Coil Supply, Voltage Regulation Stage 2

If relays are used on the Boosterpack, they need a voltage source to drive their input coils. This source can be 5V from the LaunchPad's USB connection, 24V (or other) from the transformerless power supply, or any other voltage provided by an external power supply through the through-holes of D6.

**To use USB 5V as the relay coil drive voltage**, R22 and R23 should be shorted with jumpers or jumper wires. When connecting to 40 pin LaunchPads, 5V will be available through position 1 (the square pad) of the connector J8 on the PPS. In 20 pin LaunchPads (such as the MSP430 Launchpad), this connection must be made separately by installing jumper wires from J8 position 1 on the Boosterpack to TP1 of the Launchpad. If J8 needs to remain either unused or populated with a standard header connection, and jumper-wire-based compatibility with a 20-pin Launchpad is still desired, the jumper wire may instead be connected to the top hole of R22.

R21 should be left *open* only if USB power is used for both VCC and 5V for the relay coil voltage.

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Or, jumper wire for 5V USB from 20-pin LaunchPad can be tied into either indicated location. If tied into J8 pin 1, R22 must have a jumper across it.



# Figure 8 Wiring to provide relay coil power from an external source or USB 5V

To use the transformerless power supply to generate the relay coil drive voltage, R22 and R23 should be left open. The relay coil voltage can be generated by the transformerless power supply even if VCC for the microcontroller is provided via USB (instead of via transformerless power supply). The circuit which provides regulation of the relay coil voltage is very similar to the method used in the previous section for VCC generation, aside from built-in support for additional regulation via LDO or step-down converter. The portion of the ProtoPowerSwitch board used for generating the relay coil voltage transformerlessly is highlighted in Figure 9.





#### Figure 9 Transformerless Supply Voltage Regulation Stage 2

If both VCC and the relay coil voltage are generated transformerlessly, it should be noted that the voltages do not operate with the same reference potential (note: isolation provided by optocoupler U1 permits relay control across this difference in potential). The "ground" of the relay coil voltage is at the same/similar potential as the microcontroller VCC. Because these two output stages are connected in series, they will have the same maximum output current limit. As any unused current (below the maximum rating) is dissipated as heat in the Zener diodes, caution should be exercised with higher voltage Zener diodes with regards to heat dissipation and thermal limits.

For relay coil drive applications, selection of a 24V coil voltage is recommended to minimize the current consumption. Relay coils need a minimum amount of power to actuate. Low voltage coils draw high currents, whereas high voltage coils draw low currents; these coil voltage options within a product family typically use the same pinouts and packaging. Thus 24VDC or 27V Zener diode is typically recommended for D6, as a 24V relay coils can operate with less than 20mA.

Similar to the VCC regulation stage in the previous section, C4 and C5 are the output hold-up capacitors, and D8 is used for transformerless supplies with Post-Zener Rectification (and short circuited otherwise). In configurations which use transformerless power supplies, R21 should be shorted. If the ProtoPowerSwitch board is used only to generate VCC, both R21 and D6 should be shorted.

### Zero Volt Detection

The zero volt detector signals to the microcontroller when the AC voltage is instantaneously near zero. Figure 10 highlights the area of the ProtoPowerSwitch board used for zero volt detection.

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Figure 10 Zero Volt Detection

The detector does not wait to signal until the voltage is exactly zero, because the AC voltage is only truly zero for an infinitesimally small slice of time. Recognizing this, the signal should change state in some voltage window around 0V. For the purposes of timing for triggering an SCR or TRIAC, the smaller this window is and the closer to zero volts the detection occurs, the more accurate the triggering time will be.

The zero volt detector uses an AC-input optoisolator and current-limiting resistor to detect voltage levels. If the instantaneous voltage is high enough, it will generate current through the resistor (and optoisolator input). This current is then scaled either up or down by the optoisolator currenttransfer ratio (CTR). This acts as a current limit on the output of the optoisolator. If the current becomes large enough, it will overcome the pull-down resistor across the output and generate a voltage near VCC on the output of the optoisolator.

The specific component values will vary depending on the desired precision of the detector, but for a 120VAC input voltage with the LTV-814 optoisolator installed in U6, an input current limiting resistor of 100kohms for R19 and output pull down resistor of about 40kohms for R20 appears to give good results. Keep in mind that the CTR of an optoisolator will degrade (decrease) over the life of the component, so some margin should be applied when selecting resistors.

Note that an AC-input optoisolator will operate for both positive and negative input voltages, so for sinusoidal AC input, the resulting output pulse will be centered around the zero volt point, unless capacitive filtering is added which can generate a phase shift (delay) in the received signal. Capacitive filtering can help stabilize the received signal if the AC waveform is particularly noisy. If desired, the capacitor can be installed at C6 as either a through hole or surface mount 1210.

There will be timing particularities when difficulties when detecting signals from a modified sine wave produced by a low-cost inverter. The AC voltage essentially takes the form of a square wave with long periods at zero volts, so time-based triggering of an SCR or TRIAC will yield unexpected and

possibly undesirable results unless specifically accounted for. However, the unusual characteristics of such a waveform (with longer-than-normal durations near zero volts) can provide an opportunity to identify the waveform type and account for the behavior in the microcontroller software.

### **Designer-Selectable Pinout**

Aside from VCC and Ground, there are only two Launchpad I/O for the ProtoPowerSwitch board. The only input is the zero volt detection signal and the only output voltage is the signal to control of the switch element. The limited I/O enables the use of a simple pin selector that allows the user to choose which pin on the microcontroller performs which function. Any of the pins of the 20-pin Launchpad version (and the outer pins of 40-pin Launchpads) can be tied to the ProtoPowerSwitch signals via jumper. The selector is a 3x10 matrix of pins, wherein the center column of pins are all tied together and used for the particular function on the ProtoPowerSwitch, and the left and right sets of pins map to the 10 pins each on the left and right side of the Launchpad. The red lines in Figure 11 illustrate the connectivity map between the Launchpad pins and the jumper/selector pins.



#### Figure 11 Connectivity map for jumper-based pin selection (right side is mapped similarly)

Figure 12 shows part of a fully assembled board with a jumper on J2. That jumper maps the switch control signal to the third pin down on the right side of the Launchpad (XOUT/P2.7 for the MSP430 Launchpad).



Jumper ties switch control signal to this pin

#### Figure 12 Example jumper placement to select pin used for switch control

# Switch Control

Figure 13 highlights the area of the ProtoPowerSwitch board which holds the switch control, which enables the microcontroller to drive a relay coil or the gate of a TRIAC or SCR.



**Figure 13 Switch Control** 

In general, R1 limit current from the microcontroller, U1 translates microcontroller signals to the voltage and/or current levels required to drive the switching element, and R3 limits the current provided to the switching element.

### Driving a Relay

If the switch element is a relay, U1 is either an TO-92 style NPN transistor or a 4-pin DIP optoisolator (LTV-815 recommended, installed in the four leftmost pins of U1). If the relay has a 5V **coil**, and both the relay coil and microcontroller are powered by USB (as opposed to by transformerless power supply), then U1 should be a transistor (2N5551BU works well). The high

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current required by a 5V coil works better with the higher DC gain ( $h_{fe}$ ) of a transistor than the lower current transfer ratio (CTR) of an optoisolator. **If the relay coil power and the microcontroller power have separate grounds** such as when either is powered transformerlessly, then an optoisolator should be used for U1. In all cases where a relay installed, R2 should be permanently shorted (0 ohms), and D9 should be left unpopulated.

Two common relay configuration BOMs are detailed below.

Relay with 5V coil, powered via USB from Launchpad:	
U1	2N5551BU
R1	680 ohm
R2	0 ohm
R3	Do Not Populate
D9	Do Not Populate

Relay with 24V coil, powered transformrelessly via Voltage	
Regulation Stage 2:	
U1	LTV-815
R1	330 ohm
R2	0 ohm
R3	Do Not Populate
D9	Do Not Populate

If the switching element is a TRIAC or SCR, then U1 will usually be a 6-pin DIP optotriac (MOC3023 recommended). The optotriac operates much like a traditional optoisolator except that the output will conduct in both directions, and when off, the output can withstand higher voltages. Use of an optoisolator, along with

### Driving a TRIAC or SCR

When driving a TRIAC or SCR, there is usually no need to populate components for Voltage Regulation Stage 2 because the AC mains are used to trigger the gate of the device. A resistor is placed in series with the output of the optotriac at R3, which limits the current applied to the gate. For an SCR, a diode is installed in D9 to avoid reverse biasing the gate.

Because resistor R3 will have a large voltage across it when the TRIAC/SCR is being driven on, it is important to limit the duration of the triggering pulse (20 microseconds is usually enough) and ensure that R3 is rated to handle the average power dissipated by the pulses. For a relay, this restriction does not exist; it can be held in the on state indefinitely.

In particularly cost-sensitive applications where the microcontroller is powered from a half-wave rectified transformerless supply (which ties the microcontroller ground to the AC neutral), it is possible to drive the TRIAC or SCR directly from the pin of a microcontroller without optoisolation. If zero volt detection is implemented, the device can be used in a phase-angle-controlled manner. However, direct driving from the microcontroller also enables continuous triggering of the gate (much like controlling a relay), due to the avoidance of relay R3.

# Switching Element

Figure 14 highlights the area of the ProtoPowerSwitch board which holds the switching element. The ProtoPowerSwitch board can support a relay, TRIAC, or SCR as the primary power switching element. To conserve space on the board, the footprint for each type of device overlaps on the board. The power switching element turns on and off power to an ACpowered load (like motors, lights, or heating coils) up to several amps (device-dependent).



#### **Figure 14 Switching Element**

### Relay

Relay switching elements provide the capability of switching AC or DC power to a load through electomechanical means. In steady state, the switch state will either be fully on or off, and there is a default unpowered state for the output pin(s), either normally open or normally closed. Two pins connect to the coil of the relay; when voltage is applied to these pins (in any polarity) the coil energizes and magnetically causes the internal contacts to move, toggling the state of the relay. The coil voltage required varies with each relay, but most configurations for the ProtoPowerSwitch will work best with either 5VDC (USB-powered) or 24VDC (transformerlessly powered). The relay coil is electrically isolated from the high voltage contacts

The relay coil has inductance which can generate damaging voltage spikes if a step change in current is applied to it. The

optocoupler which drives the relay provides a step change in current upon turnoff, so a small freewheeling diode D1 allows current to recirculate in the coil, safely dissipating the inductively stored energy through the relay coil resistance and the diode voltage drop.

The relay footprint used on the ProtoPowerSwitch board supports a general purpose relay that is common across many manufacturers. Compatible relay product families include:

American Zettler: AZ941/42 Aromat: JS Fujitsu: FBR161/163 GEI Relays: GP1 Hasco: KLT NTE: R46 OEG: ORW/SRU Omron: G5LE P&B: T72/N/T7C Song Chuan: 801/812/833/H Songle: SRD

The dimensions for the relay footprint itself are shown in Figure 15:



#### Figure 15 Supported relay footprint

While the ProtoPowerSwitch was designed to prototype ACpowered circuits, the relay version is capable of switching DC power to a load as well. However, due to the integrated connections on the board, the use of DC will preclude the use of any AC voltage on the board (including transformerless power supply or zero voltage detection).

#### TRIAC

TRIAC switching elements provide the capability of switching full-wave AC power to a load. In steady state, the TRIAC can appear to be fully on, fully off, or provide a reduced-RMS AC output voltage, such as those used in incandescent light dimmer circuits. The variable output is controlled by phaseangle firing, wherein the TRIAC turns on for only partway through each AC waveform (at a specific phase angle set by the microcontroller). This control is provided by triggering on only after measuring a time delay from the zero volt crossing Datasheet and User Guide

signal. The TRIAC can perform this function for both the positive and negative voltage within the AC waveform.

The TRIAC operates only as a normally-open device. Without an active trigger signal, there is no path which allows for current conduction.

Freewheeling diode D1 is only needed for relays and can be left unpopulated for a TRIAC.

The TRIAC packaging may be either TO220 or TO92. The silkscreen on the board indicates the orientation of the device. As a TO92 device, the center pin must be the gate pin, and as a TO220 device, an edge pin must be the gate pin. An as example, a compatible TO92 TRIAC is the Z00607MA from ST. An as example, a compatible TO220 TRIAC is the BTA06-600TRG, also from ST.

#### SCR

SCR switching elements provide the capability of switching half-wave AC power to a load. In steady state, the SCR can appear to be fully on, fully off, or provide a reduced-RMS rectified AC output voltage, such as those used in incandescent light dimmer circuits. Much like the TRIAC, the variable output is controlled by phase-angle firing. As the SCR only permits current to flow through it in one direction, it only can perform this function for both the positive voltages within the AC waveform.

The SCR operates only as a normally-open device. Without an active trigger signal, there is no path which allows for current conduction.

Freewheeling diode D1 is only needed for relays and can be left unpopulated for a SCR.

The SCR packaging may be either TO220 or TO92. The silkscreen on the board indicates the orientation of the device. As a TO92 device, the center pin must be the gate pin, and as a TO220 device, an edge pin must be the gate pin. An as example, a compatible TO92 SCR is the MCR22-6G from ON Semiconductor. An as example, a compatible TO220 SCR is the BT168E,112 from NXP.

As mentioned in the switch control section, diode D9 should be installed for SCRs control.

### MOV usage

MOVs can be added across the output of any switching element to absorb potentially damaging inductive spikes that may occur when the switching device is toggled. The MOV in position VR1 is used for "normally open" connections, which are found on relays, TRIACs, and SCRs. The MOV in position VR2 is used for "normally closed" connections, which are found on form C relays.

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# **External Interfaces**

The ProtoPowerSwitch can work with either 120VAC or 240VAC. While some configurations can handle both voltage ranges, the tradeoffs in transformerless power supply design (particularly relating to losses, rated current, and cost) tend to result in configurations that are specific to one AC voltage range.

Power is brought into the board through J5, which holds screw terminals with 5mm spacing. VR0 supports the use of an input MOV, which can help protect against surges and/or lightning strikes. The VR0 MOV serves a different purpose than VR1 and VR2 which are meant to clamp voltage spikes from inductive loads. If it is known that all loads will have low inductance, then, there VR1 and VR2 may be unpopulated while VR1 is populated for protection from the mains. If the circuit is to be plugged into a dedicated surge suppressor, then VR1 can safely be unpopulated as well.

Power exits the board through J1, which also screw terminals with 5mm spacing. If a TRIAC, SCR, or "form A" relay (which only offers normally open contacts) is used, a smaller terminal may be used which only uses the center (Neutral) hole and the rightmost (Normally Open, NO) hole.

Both the transformerless power supply and zero volt detection capabilities require the neutral connection. If the application is only switching power on and off (e.g. using a relay powered by USB 5V), the neutral wire does not need to be connected.

An optional LED may be installed in LED1. This LED shows the state of the switch control pin. This may be useful for showing relay status, but is generally not useful for phase-angle controlled TRIACs or SCRs because the trigger pulse duration is too short to be visible.

# Usage and Safety

The ProtoPowerSwitch is intended for prototyping purposes only. It is not packaged as a final product in any form. It

exposes dangerous high voltages to the developer, and it can fail due to any number of test and development circumstances. For example:

- Shorting out components with misapplied multimeter probes. This can damage both components on the ProtoPowerSwitch board, as well as the microcontroller itself.
- Holding the gate of a TRIAC or SCR on too long, which can damage optoisolators or gate resistors. Note that this can easily happen on accident with an unfortunately-placed breakpoint while debugging code.
- Lack of vertical clearance between stacked Boosterpacks.

The ProtoPowerSwitch board intentionally uses screw terminals for input power rather than a common AC connector or power cord. To make an AC power connection, a **power cord** can be cut and insulation stripped; when plugged in, the **exposed wires** are clearly dangerous to handle. The **ProtoPowerSwitch board will be equally dangerous to handle** when the cord is plugged in and those wires are connected to the board. Caution should be used at all times when working with a board plugged into to AC power.

The exposed nature of the ProtoPowerSwitch means that it cannot meet UL approvals by design. However, the circuit has been designed with UL requirements in mind, even meeting IPC trace spacing requirements for high voltages (up to 300V).

The ProtoPowerSwitch was designed specifically to enable rapid prototyping of various transformerless power supplies and AC power controlling circuits. It is not optimized for volume production as-is. Please contact Designer Circuits, LLC if you are interested in a custom-assembled ProtoPowerSwitch board, or if you would like to initiate a custom circuit design intended for lower cost in production volumes.