Designing Safety and Reliability into Intelligent Power Outlets for Smart Homes

This article provides designers with recommendations for protection and low-power control components for power outlet design that both prevent overloads from damaging sensitive circuitry and maximize device efficiency.

Advances in wireless communications, the internet, and electronic circuitry have enabled the development of intelligent devices. Using Internet of Things (IoT) technology, non-intelligent devices are evolving into smart devices. Smart devices that provide power control, security, environmental control, and entertainment are becoming common in the home. Examples of non-intelligent power control devices that now have smart versions include light dimmers, power outlets, and ground-fault circuit interrupters (GFCIs)/arc-fault circuit interrupters (AFCIs).

While a non-intelligent device can be only manually controlled or always powered, smart devices have electronics and firmware which allow automated control and status feedback. The smart device, a constituent of the IoT domain, responds to control from a personal computer, tablet, smartphone, or virtual assistant. These products access the smart device using a wireless communication protocol such as cellular, Wi-Fi, or Bluetooth.

Designing for Safety and Reliability

The challenge for designers is to ensure that these new smart devices are safe and robust so that consumers can have high reliability without risk of an interruption in service. Therefore, the devices require overvoltage protection and overcurrent protection to maintain operation even when subjected to a wide range of environmental hazards such as a lightning surge, induced power surge, electrostatic discharge (ESD), and electrical fast transients. This article provides designers with recommendations for protection and low-power control components that both prevent overloads from damaging sensitive circuitry and maximize device efficiency.

Protecting Intelligent Light Dimmers and Power Outlets

Light dimmers and power outlets connect to the AC power line and are subject to both overcurrent and transient overvoltage conditions that can occur on an AC line. Transients such as lightning strikes, power line voltage variations due to load surges, inductive transients from motor turn-on or turn-off, and electrostatic discharge (ESD) can damage the electronic circuitry controlling a smart dimmer and a smart power outlet.

Figure 1 shows the protection and control components recommended for both protecting the electronic circuitry and efficiently controlling the light dimmer and a smart power outlet.

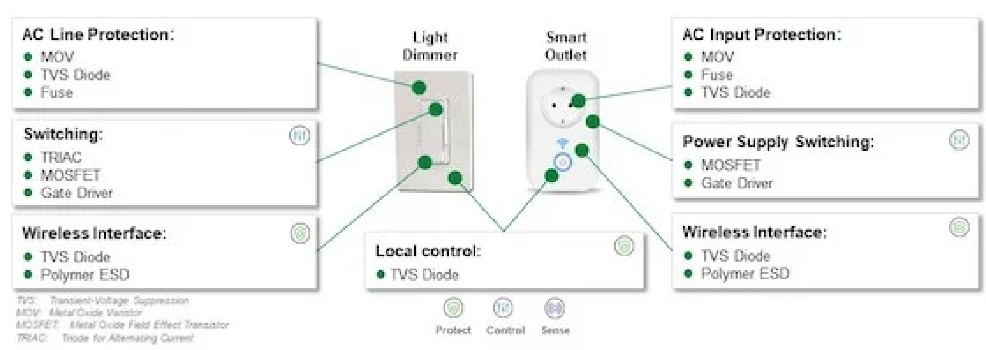


Figure 1. Recommended protection and control components for smart light dimmers and smart power outlets.

Protection and Control Components for a Smart Light Dimmer

Light dimmers are common items for controlling the illumination of a light fixture in the home. Smart dimmers allow precise remote control or timed control of a light fixture or a set of lights. Figure 2 shows a block diagram of an electronic dimmer switch and shows the specific circuit blocks in which the recommended protection and control components are used.

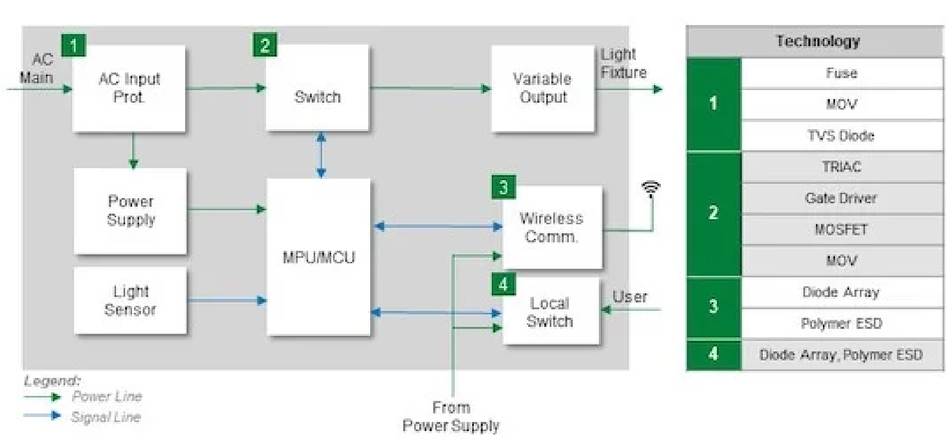


Figure 2. Block diagram of a smart light dimmer. The safety and control component options recommended for the circuit blocks are shown in the list adjacent to the block diagram.

AC Input Protection Circuit

The AC input protection circuit block interfaces directly with the AC mains power line and requires both overcurrent and transient voltage protection. Designers should fuse the block to protect against overcurrent causing damage to the downstream circuit blocks. We recommend a slow blow fuse sized to avoid nuisance shutdown due to inrush currents such as from a switching power supply. The fuse should have a voltage rating that exceeds the nominal AC line voltage.

A critical parameter for a fuse is its interrupting rating. Make sure that the selected fuse will not melt or vaporize during a large overload. Estimate the maximum current capacity of the power line and select a fuse with an interrupting rating that exceeds your estimate of potentially available current. Fuses can have interrupting ratings that can be 10s of 100s of kiloamps (kA).

To protect the AC input protection circuit against transients on the AC line, we suggest using a metal oxide varistor (MOV). MOVs can withstand the maximum voltage from a transient and can absorb the current surge due to the transient voltage. We recommend you consider a MOV that absorbs as much as a 10,000 A current pulse and 400 J of energy from a transient. Good design practice is to place the MOV as close as possible to the input of the pc board to prevent transients from propagating into the circuit.

On the secondary side of the AC input protection circuit, use a transient voltage suppression diode (TVS) to protect the downstream secondary circuits. You can select either a uni-directional or a bi-directional diode depending on the likelihood that the circuit can be subject to both positive and negative transients. TVS diodes respond to transients extremely quickly, in under 1 ps. They can absorb peak pulse power of 1500 W and have low clamping voltages to protect low voltage electronic circuits.

Switch Circuit

The switch circuit controls the output to the light fixture. Minimizing power consumption maximizes the efficiency of the circuit and minimizes heat buildup in the dimmer. We recommend using a TRIAC (thyristor) with a low holding current.

TRIACs are available with holding currents under 10 mA. They can also operate safely at junction temperatures in excess of 100 °C. For further improvement in efficiency, consider MOSFETs to control the power to the TRIAC. Select power MOSFETs with low RDS(on) resistances of under 0.5 Ω and fast switching times to reduce power loss during device transitions and power consumption when the MOSFET is in its on-state.

You can simplify the management of driving MOSFETs with a single chip gate driver. Gate driver chips can contain two drive amplifiers to control high-side, low side power MOSFETs and maximize their switching speed. Select a gate drive with sufficient current capacity to drive the MOSFETs. Finally, protect this circuit from line voltage surges that have propagated into the switch circuit with a MOV which can withstand similar amounts as the MOV recommended for the AC input protection circuit.

Wireless Communication Circuit

The wireless communication circuit communicates with a PC, a tablet computer, or a smartphone using a wireless LAN (Wi-Fi) protocol for remote control of the dimmer. This circuit interfaces with the external environment and is subject to ESD, primarily induced by the user of the smart dimmer.

We recommend either a bi-directional TVS diode array (shown in Figure 3) or a polymer ESD protection device to protect the wireless communication circuit.

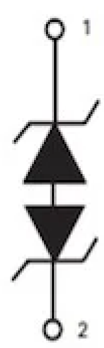


Figure 3. A bi-directional TVS diode array with two back-to-back diodes

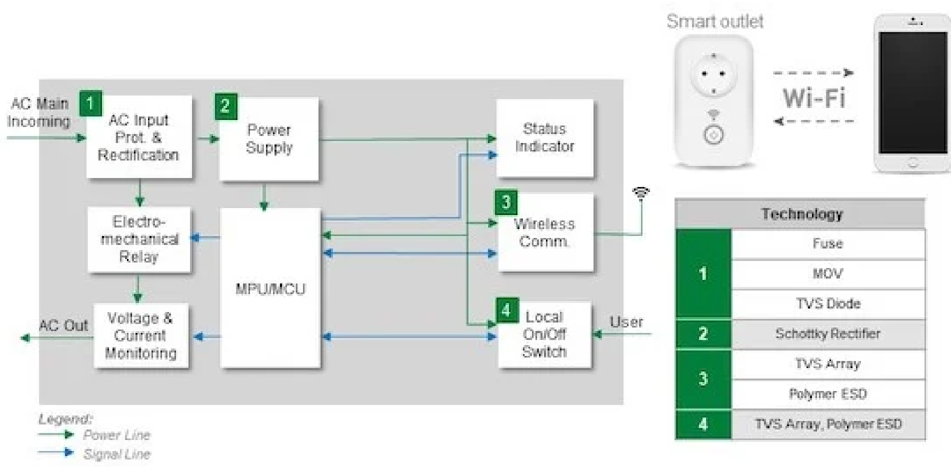
Both devices can protect I/O ports with minimal impact on circuit performance due to capacitances under 1 pF. Also, both components have surface-mount packaging to save limited pc board space. In addition, they draw leakage currents under 1 µA which reduces the power load of the circuit. Of most importance, either device will withstand a ±12 kV ESD strike in accordance with the IEC 61000-4-2 ESD standard.

Local Switch

The local switch allows a user to manually control the dimmer's output power. Like the wireless communication circuit, this circuit interfaces with the external environment and has a high likelihood of being subjected to an ESD strike. This circuit needs the same protection components as the wireless communication circuit. Again, select either a diode array or a polymer ESD protection device.

Protection and Control Components for a Smart Outlet

Figure 4 illustrates the circuit blocks in a smart outlet and the recommended components that provide protection and efficient control. Like the smart dimmer switch, the smart outlet has AC input blocks, an AC-DC conversion supply block, a wireless communication circuit, and a manual switch control circuit.



	Technology
1	Fuse
	MOV
	TVS Diode
2	Schottky Rectifier
3	TVS Array
	Polymer ESD
4	TVS Array, Polymer ESD

Figure 4. Smart outlet block diagram showing where protection and control components are required. The table lists the recommended component options.

AC Input Protection and Rectification

The AC input and protection circuit connects to the AC mains line and, like the dimmer switch's AC input protection block, is subject to large overcurrent surges and high overvoltage transients that can be induced and propagated on the power line. The smart outlet circuit's AC input, therefore, requires a fuse, an MOV, and a TVS diode with characteristics identical to those recommended for the light dimmer input circuit.

Power Supply

Space and efficiency considerations in a smart outlet suggest that a switching power supply be used to generate the DC voltage needed for the control circuitry. We recommend maximizing efficiency with a high-frequency design. Consider using Schottky rectifier diodes in the circuit. These devices have low forward voltage drops that are typically under 0.5 V, and they can operate at high switching frequencies enabling a small, space-saving design operating at high efficiency.

Wireless Communication and the Local On/Off Switch

Like the smart dimmer switch, the wireless communication and the local on/off switch circuits are exposed to the external environment and subject to ESD strikes. Protect those circuits from ESD with either a TVS diode array or a polymer ESD suppressor.

Protecting GFCI, AFCI outlets, and USB Power Outlets

GFCI outlets have been in use since the 1970s for protecting individuals from moist environments. The National Electric Code and the Canadian Electrical Code have required AFCIs in new construction of residential facilities and homes since 2014 and 2015, respectively. The GFCI senses when the load current delivered on the hot line does not return on the neutral line.

If the current imbalance exceeds a pre-determined trip level, the GFCI removes power from the outlet to prevent an electric shock hazard. The AFCI detects an arc condition and removes power from the outlet to prevent a fire. Figure 5 shows the recommended protection and control components for a GFCI, an AFCI, and a power outlet with a USB charging port.

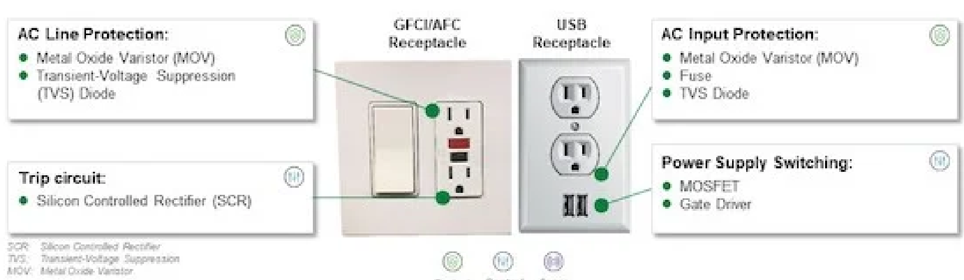


Figure 5. Recommended protection and control components for GFCIs, AFCIs, and USB charging outlets.

Figure 6 shows the circuit blocks in a GFCI and an AFCI. The GFCI has a current imbalance detection circuit while an AFCI has an arc detection circuit. As with the smart dimmer and the smart outlet, these two devices connect to the AC mains line and require overcurrent and transient voltage protection.

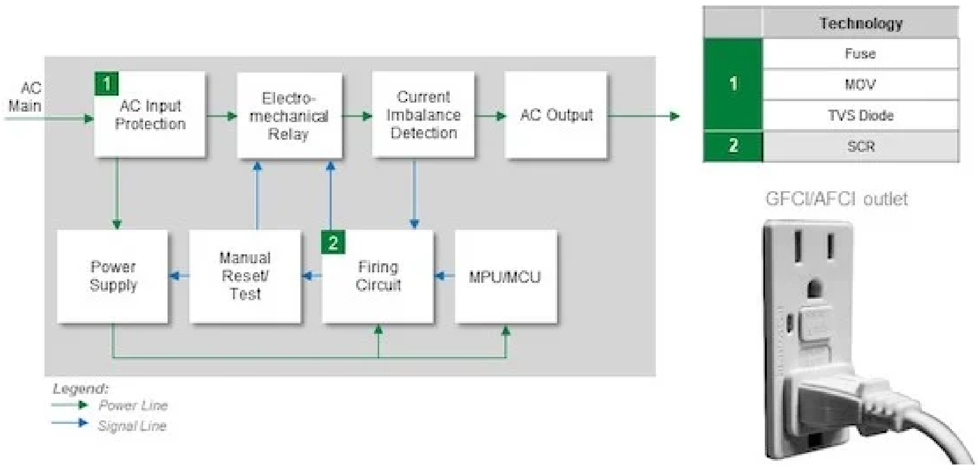


Figure 6. Block diagram of a GFCI or an AFCI. The adjacent table lists the recommended protection and control components.

Firing Circuit

Each of these devices needs a circuit to control the relay which can interrupt outlet power. That is the firing circuit. We recommend that you consider using an SCR to control the electromechanical relay. With an SCR, you can design a simple control circuit that is both efficient and compact. The SCR is a robust component that can withstand substantial current surges as high as 100 A and can support over 600 V. IF the relay coil has a low power draw, then you can use a surface-mount version of the component.

USB Outlet

The USB outlet offers the convenience of powering or re-charging a portable device with a USB cable. The user does not need a USB power adapter block since the outlet provides the DC charging current. The USB outlet requires the same fusing and transient voltage protection as the other intelligent devices that interface with the AC mains lines. Figure 7 illustrates a block diagram for a USB power outlet with a USB charging port.

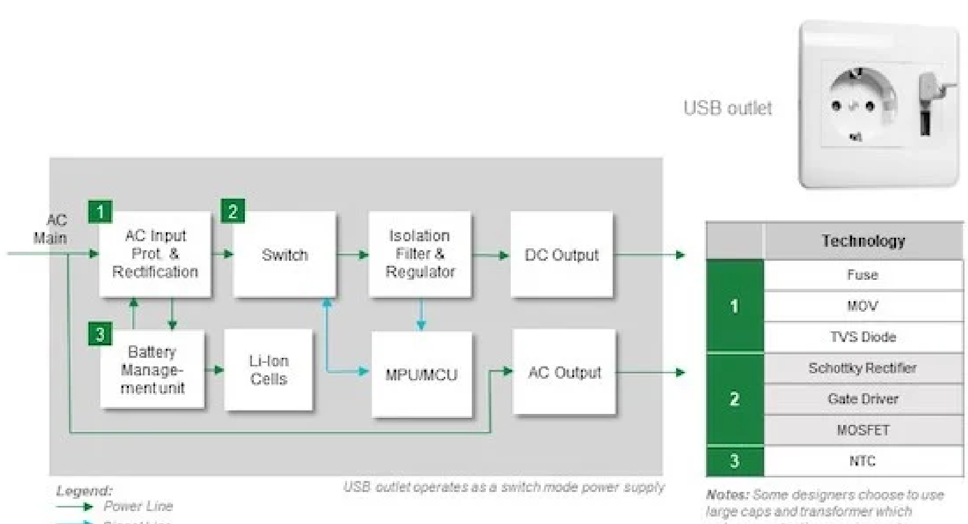


Figure 7. Block diagram of a USB outlet. The recommended protection and control components are shown in the adjacent list.

The switch circuit in the USB outlet provides the DC output for the outlet. You can maximize the efficiency of this circuit by using low forward voltage, Schottky diodes, and by using a high-frequency switcher design. In addition, consider using a power MOSFET and an integrated gate driver to further improve the efficiency of the DC power control circuitry.

Compliance with Safety Standards

Since each of these smart outlets connects to the AC power line, they must comply with the applicable national and international safety standards promulgated by Underwriters Laboratories (UL) and the International Electrotechnical Commission (IEC). The standards applicable to the various smart outlets are shown in Figure 8 and described in Table 1.

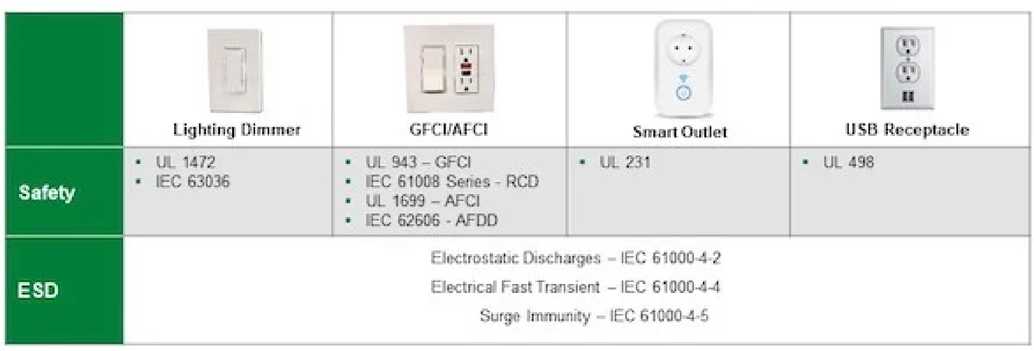


Figure 8. The safety and ESD standards applicable to light dimmers and power outlets.

Table 1. List of Applicable National and International Standards and Compliances for Power Outlets

Standard	Title	General Scope	Region
UL 1472	Solid State Dimming Control	Covers dimmers (non-touch) rated <600 vs touch rated <120 volts ac and electric s/ws minimum power rating of 300 watts incandescent or 300 volt-amp	North America
IEC 63036	Standard for Automatic Electric Controls for household	Specifies the electrical interface and test procedures for the control by mains voltage phase-cut dimming	Global
UL 943	Standard for Safety for GFCI	Class A, single and three-phase GFCI intended for personnel protection	North America
IEC 61008	RCCB without integral overcurrent protection for household	Protection against safety hazard (RCCB rated <440V, 125A)	Global
UL 1699	Standard for Safety for Arc-Fault Circuit-Interrupters	Covers AFCIs maximum rating of 20A and are intended for use in 120-Vac, 60-HZ circuits; cord AFCIs are rated up to 30A	North America
IEC 62606	General requirements for arc fault detection devices	Applies to arc fault detection devices (AFDD) for household and similar uses in AC circuits	Global
UL 231	Standard for Power Outlets	Cover power outlets, with or without integral mounting posts or pedestals	North America
UL 498	Standard for Attachment Plugs and Receptacles	Covers attachment plugs, receptacles, cord connectors, inlets, current taps provided with wiring terminals for flexible cord, and flatiron and appliance plugs	North America
UL 1310	Standard for Class II Power Units	Safety requirements covering indoor and outdoor use Class II power supplies and battery chargers	North America
UL 916	Standard for Energy Management Equipment	Covers energy management equipment and associated sensing devices rated 600V	North America
IEC 61000-4-2	Testing – Electrostatic Discharge (ESD)	Checks capability of the equipment to survive repetitive electrical fast transients and bursts	Global
IEC 61000-4-4	Electrical fast transient/burst immunity test	Evaluating the immunity of equipment when subjected to electrical fast transient/bursts on supply, signal, control, and earth ports	Global
IEC 61000-4-5	Fast Transient Surge Test	Evaluate the immunity of equipment when subjected to surges	Global

We recommend that the requirements for these standards be included in the product definition so that protection components can be cost-effectively designed in during the design project. Select UL-recognized protection components that are in the AC power line path. The combination of designing and testing based on standard requirements and using UL-recognized components both reduces certification time and avoids certification failures.

The Value of Protection and Control Components

Advances in IoT technology are incorporated in new products such as smart outlets which give the home more security, environmental control, and convenience. To ensure the successful adoption of these intelligent products, they need to be robust, reliable, and safe. Designers can ensure robust and safe products by ensuring their designs have overcurrent protection, overvoltage protection, and low power-consuming control components.

Designers can also save significant time and effort by taking advantage of the application expertise of manufacturers of these components such as Littelfuse who can assist designers with recommendations on circuit configurations, knowledge of safety standards, and component selection. Your effort will result in a product that gains a reputation for reliability, safety, and revenue growth.

Additional Resources

For more information on Littelfuse circuit protection solutions, refer to the following documents:

Or contact Littelfuse for design assistance from application specialists.