

LITTELFUSE SPECIAL ISSUE

APPLIANCE & HVAC

REPORT Reaching Design Engineers at the OEM Level

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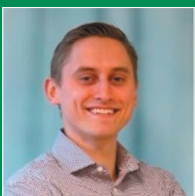
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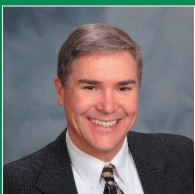
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Empowering Next-Generation Appliance, Power Tool, HVAC, and Building Automation Designs

By Paulius Juskevicius and Barry Brents

At Littelfuse, we believe that the best engineering solutions start with a clear understanding of the challenges you face—not just the products you need. From concept to production, our mission is to help design engineers create appliances, power tools, HVAC systems, and home and building automation solutions that are safer, smarter, and more efficient.

The pace of change in these markets is relentless. Devices must connect seamlessly to IoT platforms, operate reliably in increasingly compact form factors, and meet ever-tighter energy efficiency and safety regulations. Meanwhile, consumers expect intuitive controls, extended battery life, and long-term durability—even in demanding environments. These pressures can complicate every stage of product development, from component selection to certification.

Our approach is both customer-centric and solutions-oriented. Rather than simply supplying parts, we collaborate with you to understand the specific performance targets, environmental stresses, and regulatory requirements of your application. We combine decades of expertise in circuit protection, power control, sensing, and switching, with a deep knowledge of real-world use cases, helping you address technical challenges before they become costly redesigns.

This special Appliance & HVAC Report issue reflects that philosophy. Each featured article is designed to give you actionable insights you can apply to your projects.

For appliance and power tool engineers, we explore strategies for integrating IoT functionality into major and small appliances, ensuring these devices can communicate reliably and deliver valuable data to end-users. We also examine how to design robotic appliances that maintain safety and reliability, and how to create cordless power tools that balance high performance with efficiency and durability. A real-world case study shows how a compact, sealed tactile switch solved a battery indicator challenge in a cordless power tool design—illustrating how component choice can solve both environmental and ergonomic constraints.

For building automation and HVAC designers, we offer practical guidance for improving smart thermostats, designing resilient smart meters, and protecting critical life-safety systems like smoke and heat detectors. Additional features address smart water heater design and intelligent circuit protection and sensing for smart home locks and access controls—applications where reliability, safety, and user confidence are paramount.

Across all sectors, the fundamentals of circuit protection and sensing are crucial. This issue includes in-depth discussions on selecting the optimal overcurrent protection for modern electronics, enhancing surge protective devices for home and building applications, and asking the right questions before selecting sensors. These articles reflect our belief that the right questions lead to the best solutions—and that careful component selection is key to long-term product performance and reliability.

Whether you're developing the next generation of connected home appliances, refining industrial-grade HVAC controls, or improving safety in building automation systems, Littelfuse is here to help. Our global engineering resources, extensive portfolio, and collaborative design approach ensure you have the tools, knowledge, and support to bring your ideas to life—safely, efficiently, and on time.



Dear Reader,

Welcome to this special edition of The Appliance & HVAC Report, proudly sponsored by Littelfuse.

Every successful publication must evolve to meet the changing needs of its audience—and over the past six years, we've done just that. We've expanded our reach, launched bi-monthly eNewsletters, hosted webinars, grown our presence on social media, and now—entered the world of what we like to call *engineering book publishing*.

This 48-page volume is not a traditional book you'd find at your local library. Instead, it's a focused, high-value resource built around a single, trusted voice—Littelfuse. Every article featured here has been previously published in our regular issues, but for the first time, they're compiled in one place for convenient reference and deeper insight.

Here's a preview of the technical content you'll find inside, grouped into TWO themes:

Appliances & Power Tools

- How to Design Smart Major Appliances for IoT Homes
- Designing Smart Small Appliances for IoT Homes
- How to Design Safe and Reliable Robotic Appliances
- Tips for Designing Robust and Efficient Cordless Power Tools
- Case Study: Sealed Tactile Switch Solves Battery Indicator Challenges in a European Power Tool Design

Building Automation & HVAC

- Improving Smart Thermostats for Efficient Environmental Control
- How to Design Smart Meters that Outsmart Electrical Hazards
- Smoke and Heat Detector Design Best Practices
- Smart Water Heater Design: Three Important Technologies You Shouldn't Forget to Use
- Intelligent Circuit Protection and Sensing for Smart Locks & Access Controls

Whether you're designing smart appliances, HVAC systems, or embedded sensing and protection electronics, this collection offers practical, relevant guidance you can use today.

You may have received this issue as part of our subscriber database, but it's also available via our website and will be promoted through our eNewsletters.

Special thanks to Littelfuse for partnering with us to make this resource possible.

As always, we welcome your feedback and look forward to continuing the conversation.

Best regards,

Brad Glazer

Founder & Publisher

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APPLIANCE & HVAC
REPORT Reaching Design Engineers at the OEM Level

Reaching
Design Engineers
at the
OEM Level

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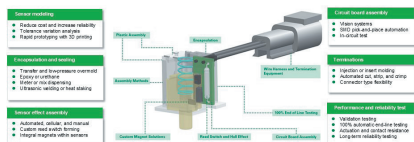
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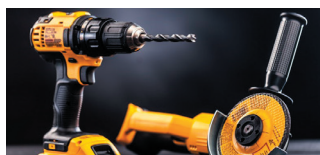
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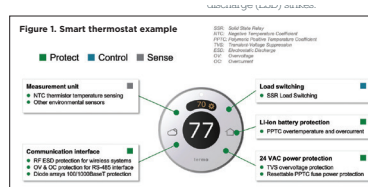
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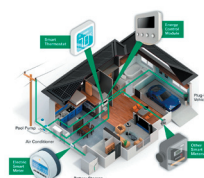
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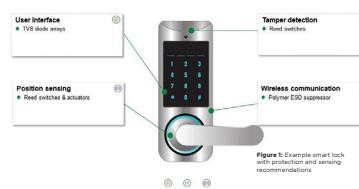
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How to Design Smart Major Appliances for IOT Homes

Essential factors to consider: Ensuring safe, efficient, and robust products

BY PAULIUS JUSKEVICIUS

Advanced electronic technologies and innovations appear in all electronic and electromechanical devices, including the common consumer appliance. IoT technology and advanced sensing technology are making appliances smart. They can operate under remote control and provide status indications on numerous parameters for diagnostic

information and predictive maintenance. These advances significantly increase the electronic circuitry in new appliances.

The designer's challenge is to develop a reliable appliance with the added complexity of the greater electronic content. That requires protecting the circuitry from overcurrent conditions, voltage transients, and electrostatic discharge (ESD). Also, the design needs efficient and robust sensing and control to minimize power consumption. Figure 1 displays a range of appliances, all of which require circuit protection and efficient control.

This article informs designers

about protecting their appliance circuitry from electrical hazards. It also provides recommendations for control and sensing for optimal appliance operation and introduces the designer to some unique components that will help reduce component count and simplify the task of ensuring circuit protection and efficient control.

Washing machine overview

The washing machine will serve as the major appliance example for presenting recommendations to ensure safe, reliable, and efficient operation. Figure 2 presents an overview of the components that enable a robust and efficient



Figure 1. Major appliances share common design principles with all appliance types



Figure 2.
Components recommended for safe and efficient operation of a smart washing machine

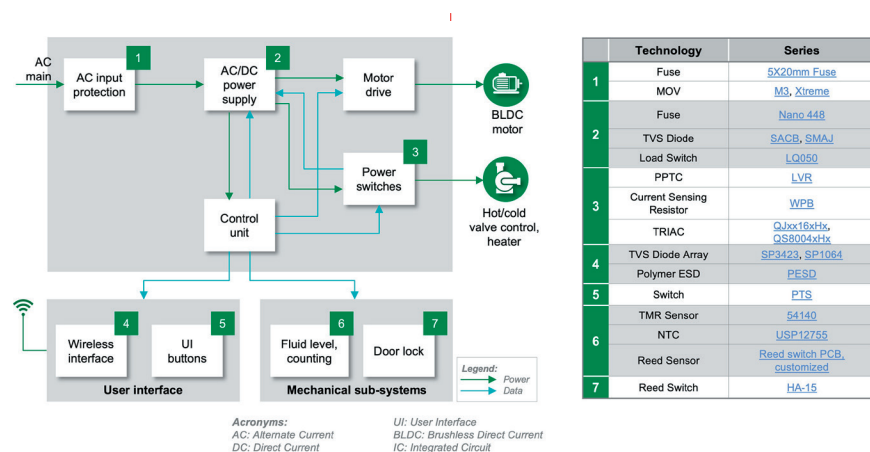


Figure 3. Smart washing machine block diagram with recommended components

Figure 3 details the circuit blocks in a smart washing machine. The table lists the recommended components and shows which circuits use them to ensure safe and efficient operation. Most of these circuits are also elements of other appliances as well. The Motor Drive circuit powers the drum and the agitator during the wash, rinse, and spin cycles. The Power Switches circuit powers the water pump, the water valves, and the water heater during the stages of the wash cycle. The Control Unit controls both circuits. The Control Unit receives input from the User Interface and Mechanical Sub-Systems circuit blocks.

Protecting the washing machine

The washing machine obtains its power from the AC power line,

which can deliver high current and apply high voltage transients to all products connected to the power line. Both overcurrent protection, transient voltage protection, and ESD protection are required to protect appliances such as washing machines from damage due to these electrical hazards. The following paragraphs describe the circuits requiring protection.

AC Input Protection circuit

The AC Input Protection circuit should have components to protect from overcurrent and overvoltage. A fuse can provide overcurrent protection to protect the washing machine from either a short circuit in the load or the appliance itself. Without a fuse, the AC power line will deliver a significant surge of current that will damage the appliance. The heat generated could lead to a fire. Consider a time lag fuse

that avoids nuisance openings due to inrush currents. The selected time lag fuse should have the following:

- An ampere rating as defined by the design requirements for the appliance
- A voltage rating that exceeds the maximum AC line voltage
- An interrupting rating at least 10 times the ampere rating
- Compliance with IEC 60127-2 and UL/CSA 248-1 and 248-14 safety standards.

As with potential damage from an overcurrent condition, transients induced on the power line impinge on the appliance and can destroy the electronic circuitry. Damaging transients can result from lightning and large inductive loads, such as motors switching on and off. Use a metal oxide varistor (MOV) for protection from transients. Place the MOV after the fuse but as close to the AC power entry point as possible. Select an MOV that:

- Withstands a voltage pulse of at least 1 kV
- Absorbs a peak current pulse of at least 1200 A
- Compliant with UL 1449 and IEC 61051-1 and 2.

AC/DC Power Supply

The AC/DC Power Supply is typically a switch-mode power supply that generates the DC voltages required by the control and power drive circuitry. For this circuit, a fast-acting fuse will provide secondary overcurrent protection for the supply and downstream circuitry. Since this fuse sees AC line power, ensure the selected component is compliant with UL/CSA 248-1 and 248-14. Also, minimize power loss using a fuse with low cold resistance, which can be under 1 Ω .

A transient voltage suppressor (TVS) diode will protect the power supply from portions of transients that propagate through the AC

Input Protection circuit. TVS diodes are available with the capability to absorb peak power pulses as high as 500 W. In addition, TVS diodes have:

- Electrostatic discharge (ESD) protection up to 30 kV
- Clamping voltages as low as 10 V
- Extremely fast response times of under 1 ps
- Bi-directional or uni-directional models
- Compliance with IEC 61000-4-2.

Power Switches circuit

The Power Switches circuit controls the water valves, pump motor, and heater if the washing machine has a water heater. In this circuit, a fuse protects the external load devices from an overcurrent condition. Consider a polymeric positive temperature coefficient resettable fuse. This type of fuse has fast trip times and can operate in circuits with voltages as high as 240 VAC or 240 VDC.

Wireless Interface circuit

The Wireless Interface supplies cellular and Wi-Fi links for communication with the appliance. The most significant risk to this circuit, which is exposed to the external environment, is from ESD and lightning. A TVS diode array, as shown in Figure 4, can provide the necessary protection. TVS diodes with capacitance as low as 0.2 pF on each I/O line to minimize RF transmission and reception disturbance are available. The diodes can provide at least 10 kV of ESD protection.

An alternative to the TVS diode is a polymer ESD suppressor. These components offer ESD protection to 15 kV for a through-the-air strike. They have a low capacitance of 0.25 pF, independent of frequency, and a very low leakage current of under 10 nA.

The set of components described supplies the protection the washing machine needs to be robust to electrical hazards. The design requires only six components.

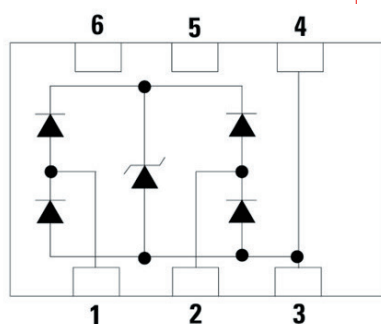
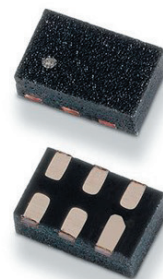


Figure 4. 2-channel TVS diode array with surface mount packaging



Efficient control of the washing machine

A prudent selection of components and sensors can minimize power consumption and offer unique solutions for sensing essential parameters. The following paragraphs detail components that provide important sensing functions and impart efficient control functions in the various circuits.

Power Switches circuit

A current sensing resistor in the heater circuitry can provide feedback to the Control Unit for water temperature control. Current sensing resistors can have low resistance under 60 mΩ to minimize power loss in the control circuit. The tolerance on most of these resistors is 1%. Their power ratings can be from 1 W to 3 W, and their temperature coefficients can be as low as 50 ppm/°C. Current sensing resistors with surface-mount packaging can save PC board (PCB) space.

Consider efficient TRIAC solid-state switches to control the water heater's power. Models are available with low gate power dissipation of approximately 0.5 W. They can have on-state current ratings of 16 ARMS and a blocking voltage of 600 V. Look for a TRIAC with a high operating junction temperature of 150° C.

TRIACs can also control power to the hot- and cold-water valves. To withstand inductive transients, models can have high voltage ratings of 800 V and high surge

currents of 55A. Gate power dissipation can be as low as 0.3 W.

User Interface

Designers can customize switches for the specific requirements of their appliance. They can use long-life, reliable, tactile feedback switches for the cycle control and other function settings. The switches should be sealed with at least an IP 40 rating against moisture and dust ingress. Switches can have resistances under 100 mΩ to minimize power consumption. Depending on the switch selected, operating life can be 200,000 to 5 million cycles. Other options include actuator style, switch height, termination, and actuator force.

Unique sensors for mechanical sub-systems

Water level monitoring is an essential feature of a washing machine. Consider a tunnel magnetoresistance (TMR) sensor for water level detection. Figure 5 shows one TMR sensor model. The TMR sensor provides a one-IC solution for sensing and signal conditioning. It also offers:

- High sensitivity of 17 Gauss
- Low power draw of only 1.5 μA
- IP 67 rated
- Interfacing with digital control levels from 1.8 V to 5 V
- Long life with up to 20 billion operations.

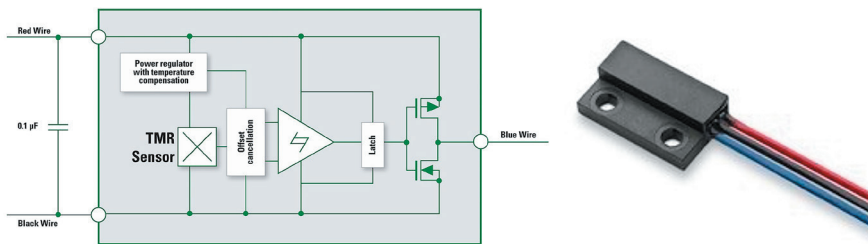


Figure 5. Tunnel Magnetic Resistance (TMR) Sensor

A TMR sensor like the one shown in Figure 5 uses a single IC to simplify level detection and data transmission.

An alternative to a TMR sensor is a customized reed sensor. Littelfuse offers a customized design service to enable designers to meet specific requirements for part geometry, material used, magnetic sensitivity, electronic circuitry, and mechanical components. Customized reed sensors are a less complex technology than TMR sensors. Also, the reed sensor does not consume any power when in its off state. Unlike the TMR sensor, the reed sensor design can allow switching load current. Figure 6 shows all the steps Littelfuse can use to create a custom design.

The two options give designers substantial flexibility in designing water-level detection systems. The TMR sensor or a customized reed sensor can provide an excellent solution.

Consider a thermistor probe assembly for water temperature monitoring. Thermistors can provide sensing over the -55 to +105° C range. House the sensor in a stainless-steel probe.

For user safety, the design must ensure that the washing machine cannot operate unless the door or top is fully closed and engaged. A reed switch and a metal actuator on the door provide a simple, low-power solution. Use a hermetically sealed reed switch, which can have sensitivities ranging from 17 to 33 Ampere-Turns.

Collaborate with experts for a robust, efficient product

Protection against electrical hazards such as overcurrent, overvoltage, ESD, and overtemperature is critical for ensuring reliable operation. Minimizing power consumption is also an essential design goal. The recommended components enable designers to develop safe, reliable, and low-power-consuming major appliances.

Designers should utilize the component manufacturers' application engineers to ensure they develop a robust and efficient product to save design time and compliance costs. The application engineers can help with the following:

- election of cost-effective protection, sensing, and high-efficiency components
- Knowledge of the applicable safety standards
- Some companies, such as Littelfuse, can perform pre-compliance testing to avoid compliance test failures and save on delays and added costs for multiple compliance test cycles.
- Collaborating with the component manufacturer's application engineers and using the recommended components will help to produce robust, reliable, and efficient, smart appliances.

References

Additional recommended resources, courtesy of Littelfuse, Inc.

- *Circuit Protection Product Selection Guide, 2023*
- *Sensing Products Selection Guide, 2023*
- *C&K® Switch Product Selection Guide, 2024*
- *Power Semiconductor & IC Selection Guide, 2024*
- *Integrated Circuits Selection Guide, 2024*
- *Fuseology Design Guide, 2022*

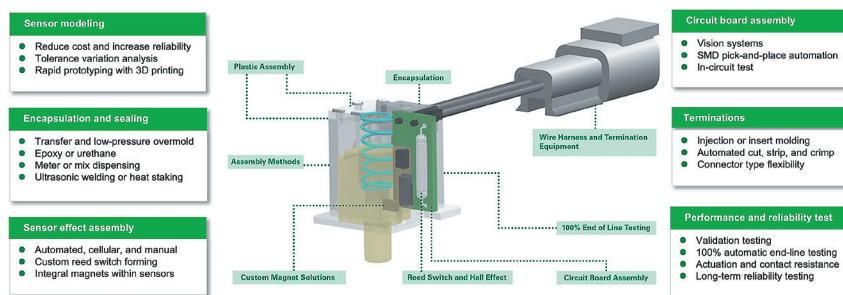
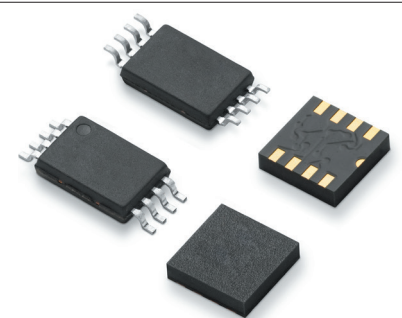


Figure 6. Custom magnetic sensor design considerations



TMR Magnetic Angle Sensors

Accurate magnetic angle sensing for smarter appliance and HVAC designs.



View the video

Designing Smart Small Appliances for IoT Homes

How to make safe, efficient, and robust products



Consumers enjoy the benefits of today's new "smart" appliances, which include more intelligent convenience features. These products range from air fryers to robotic vacuum cleaners. The appliances save the consumer time with various chores and with food and drink preparation. Intelligence and IoT-based interfaces allow users to control their home environment and have more free time.

Designers must incorporate smart technologies into their

new appliance designs to satisfy consumer demand. They must also make the appliances energy-efficient so that battery-operated products can operate with longer intervals between downtime and recharging.

The greater the appliance's electronic content, the greater the designer's challenge is to ensure the product is robust and reliable against electrical hazards such as overvoltage transients, overcurrent conditions, and electrostatic discharge. This

article introduces designers to circuit protection schemes and some unique components that protect circuits from electrical hazards. Furthermore, the article recommends components to reduce power consumption for energy savings. All these components will allow the designer to develop a safe, efficient, robust, smart small appliance.

Recommended component types for developing robust and efficient small appliances

Figure 2 illustrates a few examples of smart small appliances and presents the circuits in these appliances that can use components for circuit protection, maximizing efficiency, and detecting the machine's state. These components will protect the circuits from electrical hazards such as overcurrent conditions and overvoltage transients. In addition, specific components will detect

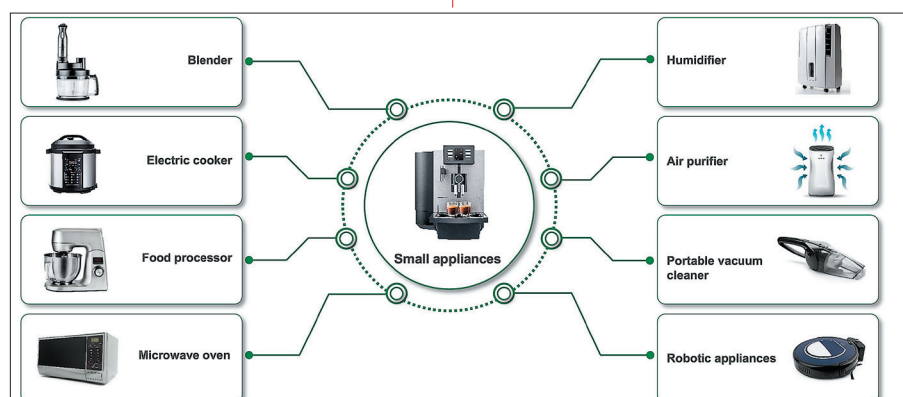


Figure 1. Small appliances are getting "smart" and many now include IoT-based interfaces

overtemperature conditions and improperly positioned parts of the appliance. Also, some components will contribute to higher efficiency appliances.

Block diagram of a typical small appliance

Figure 3 breaks an example home appliance down into individual circuit blocks. The circuits include AC-DC power conversion, microprocessor control, motor drive, heating, manual controls, and a display. The table in the figure highlights recommended component types for the circuit blocks requiring circuit protection, efficient operation, and sensing.

Protecting the small appliance circuits from damaging electrical hazards

Protection components for the AC Input Primary Protection circuit

AC line-powered products must contend with the AC line's voltage transients and high current capacity, typically 15 A for a 120 VAC line in North America. The AC Input Primary Protection circuit must protect downstream circuit blocks from overcurrent conditions and voltage transients.

Use a time-lag fuse to protect the circuits from an overcurrent, such as a short circuit. Due to the product's inrush current, a time-lag fuse will avoid nuisance fuse openings. Ensure that the selected fuse has a voltage rating that exceeds the voltages in single-phase worldwide power line circuits. Also, ensure that the fuse's interrupting rating exceeds the current rating for typical worldwide single-phase AC power lines. To enable product sales in all regions of the world, consider a fuse that complies with IEC 60127-2. AC power lines are susceptible to overvoltage transients that can strike products such as appliances that are connected to an AC line. Transients

include lightning induced on power lines. Large motors switching on and off also induce transients. Using a metal oxide varistor (MOV) after the fuse and in parallel with the AC line will protect downstream circuitry. Select an MOV with:

- Peak current absorption from a single transient pulse of at least 4.5 kA
- Operating temperature rating of 105° C
- Ability to survive a 6kV/3kVA wave surge in compliance with Annex G of IEC 62368-1.

Protecting the AC-DC Power Supply

Portions of transients that get through the MOV due to its non-ideal response time can damage downstream components. In addition, electrostatic discharge (ESD) can damage integrated circuits. Protect the AC-DC power

Supply with a transient voltage suppressor (TVS diode) from overvoltage conditions. Types of TVS diodes offer:

- As much as 600 W of pulse power absorption
- 30 kV withstand voltage from ESD strikes in compliance with IEC 61000-4-2
- Fast response time of under 1 ps
- Bi-directional and uni-directional models
- Space-saving surface mount packages.

Protecting the Motor Control Circuit

The appliance motor needs protection from damage due to short circuits, mechanical overloads, and overheating. Consider a polymeric positive temperature coefficient device (PPTC), a resettable fuse for short circuit protection. Ensure the PPTC fuse is rated for operation



Figure 2. Small appliances and components recommended for safe and efficient operation

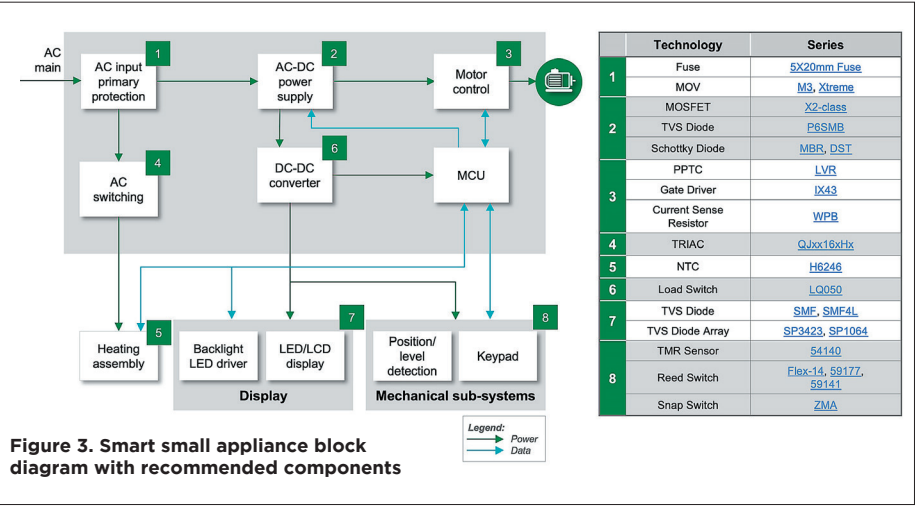


Figure 3. Smart small appliance block diagram with recommended components

in excess of the circuit's maximum voltage. Look for models that include hold current capacities of at least 2 A and fast trip times under 30 s. A good PPTC fuse will be compliant to EN 60730-1.

To prevent motor damage from mechanical overloads and overheating, monitor motor current with a current sense resistor. Use a current sense resistor with as low a resistance as possible to minimize power loss in the Motor Control circuit. Sense resistors are available with resistances that range from as low as 1 mΩ to 56 mΩ. Tolerances can be 1% for accurate current measurements, and the sense resistors can save PC Board (PCB) space with surface mount packaging.

Heating Assembly protection

For appliances that are heating liquids, avoid damage due to the heater reaching a dangerous temperature. Include a sensor to monitor the liquid temperature so that the appliance is not exposed to damaging high temperatures. Consider a NTC thermistor that can reside in a stainless-steel probe housing. Littelfuse can help designers with customized solutions for a liquid temperature probe.

The Display block - Backlight LED Driver and LED/LCD Display

The Display block communicates and receives its data from the MCU. To maintain error-free data between the MCU and the Display circuit, use a TVS diode to protect the integrated circuits from ESD. TVS diodes can have low clamping voltages to ensure the safety of the ICs in the circuit. As with the TVS diodes recommended for the AC-DC Power Supply, models can absorb as much as a 30 kV ESD strike. In the Display circuits, 200 W peak pulse power absorption capacity is sufficient along with less than 1 ns

response time. Choose from uni-directional or bi-directional versions and take advantage of surface mount packaging.

As an alternative to a single TVS diode, consider a TVS diode array which can protect two data lines and reduce component count. Figure 4 illustrates a two-line TVS diode array with a Zener diode for ESD protection. This TVS diode array offers low capacitance of around 0.2 pF per I/O signal line. The array consumes minimal power with a leakage current of 10 nA.

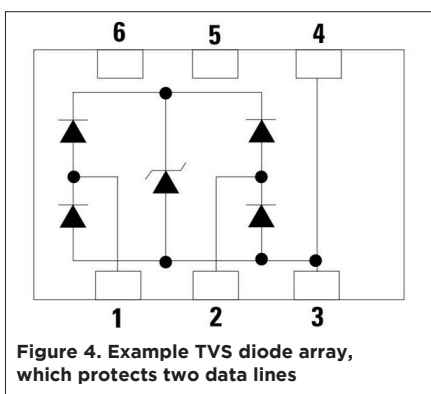


Figure 4. Example TVS diode array, which protects two data lines

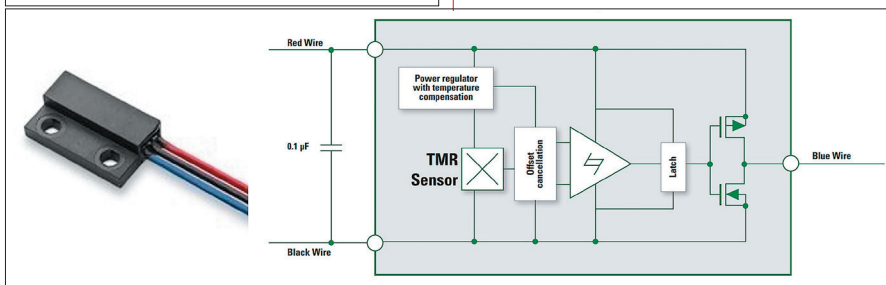


Figure 5. TMR sensor for position sensing - 6 x 14 mm component and block diagram

Mechanical Sub-System – Position/Level Detection and Keypad

Ensure that fluid levels are at appropriate levels and lids or chambers are properly closed for safe operation of the appliance. One solution for level and proximity detection is a tunneling magnetoresistance (TMR) sensor. Figure 5 shows a TMR sensor with active power drive. TMR sensors offer the benefits of excellent sensitivity, 17 G, and ultra-low power consumption drawing only 1.5 μA at supply voltages from 1.8 to 5.5 V. TMR sensors have an exceptionally long life that can be as

much as 20 billion cycles. The sensor also has an environmental rating of IP67 against ingress from moisture and dirt.

As an alternative for position sensing, consider a reed switch. A reed switch does not consume any power. Versions are hermetically sealed and can switch up to 10 W at either 200 V or 0.5 A. A third option, depending on the type of small appliance, is a snap switch. A snap switch is the simplest of the three sensor types to implement position detection. This type of mechanical switch can have a contact rating of 3 A at either 125 VAC or 24 VDC. Operating life can range from 10,000 cycles at 3 A to 300,000 cycles at 0.1 A.

These protection and sensing components can help to ensure a robust and reliable design for the appliance. Furthermore, the recommended components do not interfere with the primary circuitry that makes the product functional.

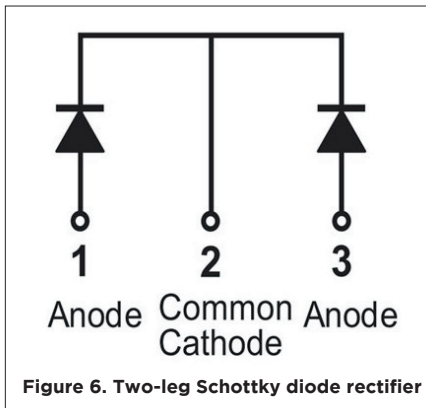
Designing efficiency into the appliance

AC-DC Power Supply

MOSFETs can help to maximize the efficiency of the AC-DC Power Supply by allowing operation of the switch-mode power supply at a high switching frequency. To obtain minimal power loss in the circuit, select a MOSFET with the following characteristics:

- Low RDS(ON) below 450 mΩ
- Low gate charge in the 10's of nC
- Fast slew rates with dV/dt values in the range of 50 V/ns.

In the DC rectification stage, consider using Schottky diodes. An example Schottky diode package, shown in Figure 6, contains two legs of a full wave rectifier. An effective Schottky diode will have a low forward voltage drop under 0.5 V, low junction capacitance of around 84 pF, and low leakage current under 14 mA.



Motor Control circuit

Gate driver ICs provide efficient driving of MOSFETs or IGBTs. Gate drivers have low propagation delays and fast rise and fall times to facilitate high frequency operation of power transistors. Versions can be either single or dual drivers, and they can source and sink at least 2 A.

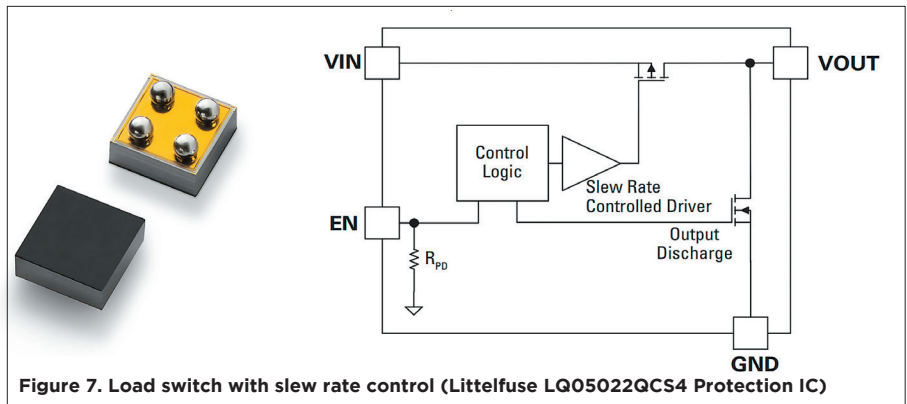
AC Switching circuit

In this circuit, an alternistor triac can control an AC heater. The thermally robust component can operate with a junction temperature that can reach 150° C. These components can carry 16 A to power the heater.

DC-DC Converter

Consider using a low power load switch for efficient distribution of power to the MCU, Display, and the Mechanical Sub-Systems (see Figure 7). The load switches provide:

- Current delivery of up to 2 A
- Operating current of 1 μ A
- On-resistance under 120 m Ω
- A typical quiescent current of 7 nA
- A 335 μ s controlled rise time to mitigate effects of inrush currents.



These components will enable the appliance to run with maximum efficiency. Not only does low power consumption save on annual utility costs for the consumer, but lower power circuits contribute to longer life appliances.

Collaborate with experts for a robust efficient product

Protection against electrical hazards such as overcurrent, overvoltage, ESD, and overtemperature is critical for ensuring reliable operation. The recommended components enable designers to develop safe, reliable, and low power-consuming small appliances.

To ensure they develop a robust and efficient product, designers should take advantage of the component manufacturers' application engineers to save design time and compliance costs. The application engineers can help with:

- Selection of cost-effective protection, sensing, and high-efficiency components
- Knowledge of the applicable safety standards
- Pre-compliance testing, which Littelfuse can perform, to avoid compliance test failures and save on delays and added costs for multiple compliance test cycles.

Collaborating with the component manufacturer's application engineers and using the recommended components will help to produce robust, reliable, and efficient, smart small appliances. ■

References: Standards

- IEC 60127-2 Ed. 3.0 b:2014 - Miniature fuses - Part 2: Cartridge fuse-links (ansi.org)
- IEC 62368-1 Ed. 1.0 en:2010 - "Audio/video, information and communication technology equipment - Part 1: Safety requirements" (ansi.org)
- IEC 61000-4-2 Ed. 1.2 b:2001 - Electromagnetic compatibility (EMC)- Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test (ansi.org)

References: Additional resources, courtesy of Littelfuse, Inc.

- Circuit Protection Product Selection Guide
- Sensing Products Selection Guide
- C&K® Switch Product Selection Guide
- Power Semiconductor & IC Selection Guide
- Integrated Circuits Selection Guide

Scan the QR code to learn more about protecting appliance designs with proper circuit protection, courtesy of Littelfuse, Inc.



TECHNOLOGIES

Selecting Optimal Overcurrent Protection for Modern Electronics Design

Choosing the right overcurrent protection can make or break your next appliance design. Discover how traditional fuses, PPTCs, and eFuses stack up—and which option delivers the safety, performance, and flexibility your product needs.

How to Design Safe and Reliable Robotic Appliances

Work smarter, not harder, to protect your next design

BY PAULIUS JUSKEVICIUS



Consumers are taking advantage of the benefits that automation and the Internet of Things (IoT) bring to their lives. Robotic appliances can make life easier by reducing the work of cleaning and maintenance. As a result, there is a growing demand for these devices as they can integrate into smart home systems. In addition, developments in artificial intelligence (AI), machine learning, and sensor technologies are enabling more sophisticated domestic robots. These robots can navigate complex environments, recognize objects, and respond to voice commands. **Figure 1** illustrates some examples of robotic appliances.

Developers have the challenge of designing complex electronic circuitry that creates robotic appliances. They also have the challenge of protecting their product from electrical hazards and ensuring efficient control and reliable sensing. This article will focus on the most ubiquitous of these products, the robotic vacuum cleaner. This article introduces designers to the latest solutions that support safety, efficiency, and reliability.

Protection, efficient power control, and reliable sensing for a robotic vacuum cleaner

Figure 2 highlights the different functions of an example robotic vacuum cleaner. Each function lists components that provide circuit

protection, energy-efficient control, and reliable sensing.

Figure 3 provides a detailed block diagram of the example robotic vacuum cleaner. The adjacent table offers recommended components for specific circuit blocks requiring protection, efficient power control, and reliable sensing. Some of these unique components can ease the designer's development task.

Protection and efficient control for the Docking Station

We will start with the external system, the Docking Station. The Docking Station supplies the power to charge the robotic vacuum cleaner's battery. **Figure 4** expands upon **Figure 3** and presents a block diagram of the Docking Station. The Docking Station connects to the AC mains and is subject to high current if an overcurrent occurs in the Docking

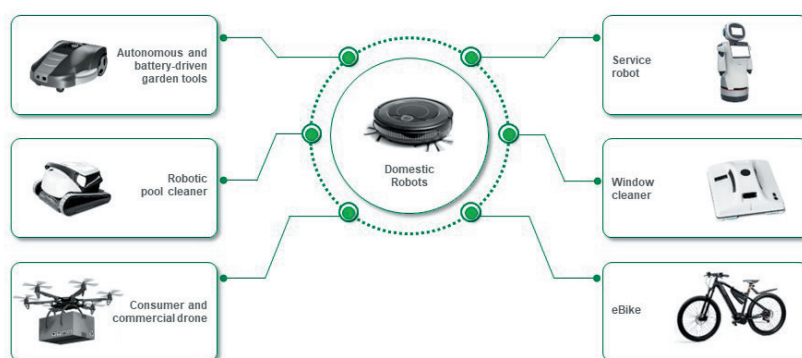


Figure 1. Home Robotic Appliances share common safety and control requirements

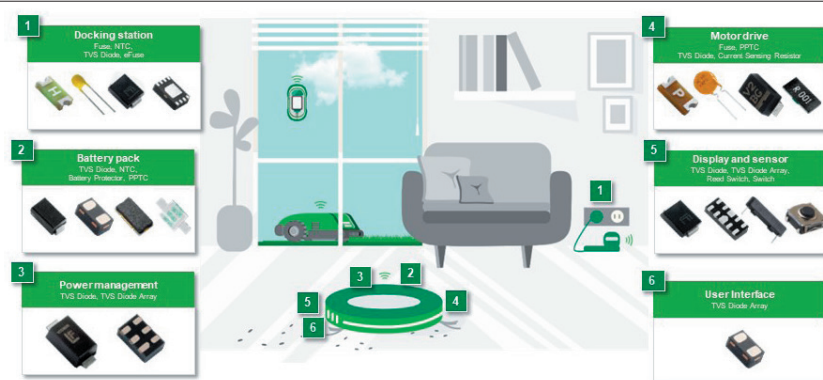


Figure 2. Robotic Vacuum Cleaner – Protection, control, and sensing components

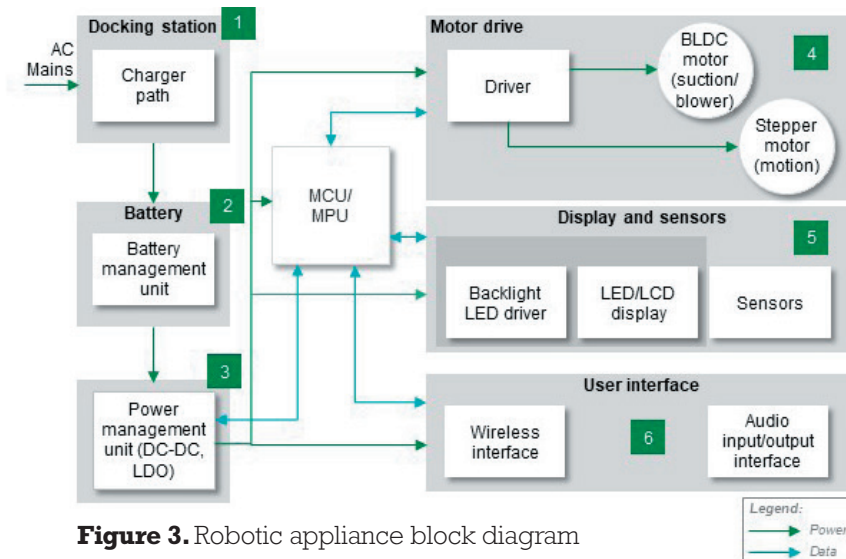


Figure 3. Robotic appliance block diagram

	Technology	Product series
1	Docking station	
2	Battery	
3	Fuse	466, 467
	PPTC	2920L
	TVS Diode	SMAJ, SMBJ
4	Protection IC (eFuse)	LS24
	NTC	Leadedthermistor
	Current Sensing Resistor	WSTC
5	PPTC	16R, RGEF
	Gate Driver	LF2136BTR
	TVS Diode	SMF4L
6	TVS Diode Array	SP3423, SP1064
	Reed Switch	59050
	Switch	KSE
	TVS Diode Array	SP1064

Station. It is also susceptible to transients induced on the AC mains due to lightning strikes and transients resulting from the effects of inductive loads switching on and off. The circuitry needs protection from high-capacity current and transient surges to ensure a robust and reliable Docking Station.

AC Input Primary Protection block

The AC Input Primary Protection circuit requires a fuse for overcurrent protection from an internal circuit failure. Look for a time lag fuse with:

- An ampere rating that prevents an excess of current from entering the circuit but avoids nuisance tripping
- A low internal resistance to minimize power loss and heat rise

- Vibration resistance
- Voltage rating exceeding 110% of the AC mains voltage
- Compliant with IEC 60127-4 or an equivalent UL standard.

To protect the circuitry from a transient, a metal oxide varistor (MOV) can safely absorb a 2 ms pulse of energy as high as 530 J or a 20 μ s current pulse as high as 10 kA. For further protection, MOVs are available with internal thermal elements that will open to protect the MOV from overheating due to the overvoltage condition. As with the fuse, which is in contact with the AC mains, save compliance certification time by selecting an MOV compliant with UL 1449 or an equivalent standard.

Rectification, PFC, High Frequency Converter, and Output DC Protection circuits

The Rectification, PFC, High Frequency Converter converts the AC input voltage to a DC voltage. Then, it converts it into a pulsed signal for the transformer to couple to the secondary rectifier and filter circuit. The power factor correction circuit reduces the phase magnitude of the circuit block to minimize both the apparent power and the harmonics drawn by the Docking Station circuit. The Output DC Protection block prevents transients or ESD from propagating into the battery pack.

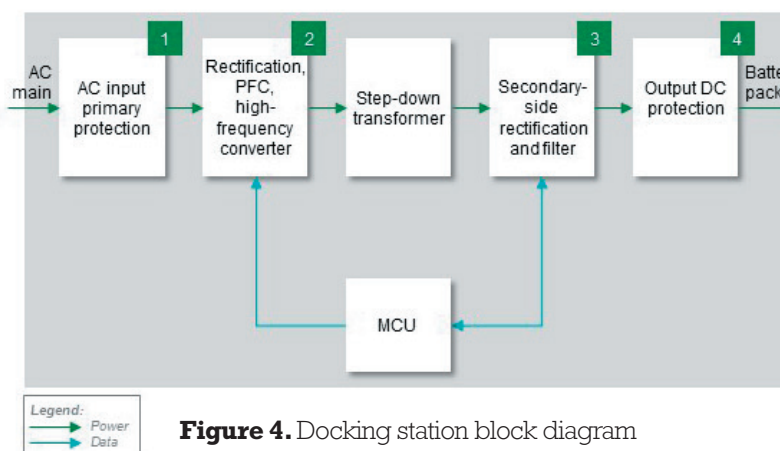
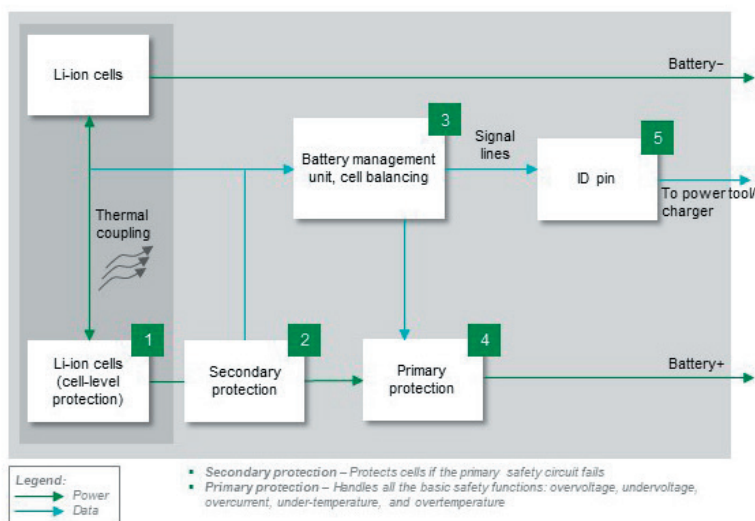


Figure 4. Docking station block diagram

	Technology	Series
1	Fuse	5x20mm Fuse, TR, TE
	MOV	LA, CII, TMOV
2	MOSFET	X2-class
	TVS Diode	P6SMB
3	Schottky Diode	MBR, DST
4	TVS Diode	SMBJ





	Technology	Product series
1	NTC	KC
2	Fuse OR Battery Protector	881, 688 OR ITV
3	PPTC OR Fuse	0805L OR 458
	TVS Diode Array	SP1003, SC1006
	Current Sensing Resistor	L4CL
4	TVS Diode Array	SMF, SMF4L
5	TVS Diode Array	SP3021, SP1007
	PPTC	zeptoSMDC

Figure 5. Battery Pack block diagram

For both these circuits, transient voltage suppressor (TVS) diodes can safely absorb fast transients and ESD strikes to protect downstream circuitry and the load, the battery pack. The recommended TVS diodes:

- Can absorb 600 W of peak pulse power from a 10/1000 μ s waveform
- Withstand an ESD strike up to 30 kV
- Have models with either uni-directional or bi-directional (two diodes in a cathode-cathode connection) polarity protection
- Have very fast response times
- Low clamping voltages
- IEC 61000-4-2 and 61000-4-4 compliance.

Consider using a power MOSFET and a Schottky diode to maximize efficiency in the Rectification and Secondary-Side Rectification circuits. Milliohm-level RDS(ON) values reduce on-state power loss and nanocoulomb gate charge, voltage-per-nanosecond dV/dt rates, and nanosecond switching times reduce switching power losses. The high switching rates of these MOSFETs allow higher frequency switch-mode AC-DC converter circuits to maximize efficiency. Similarly, Schottky barrier power diodes offer low forward voltages, significantly under 1 V, and can operate at high switching frequencies to contribute to improved converter efficiency.

Protecting the Battery Pack

The battery pack supplies the power to operate the robotic vacuum. The individual batteries are Lithium-ion (Li-ion) cells, which have high power density but can be susceptible to substantial damage due to mechanical or electrical abuse.

The Battery Pack circuitry, including the battery cells, monitoring circuits, and the Battery Management Unit, require monitoring and protection components. Figure 5 details the circuit blocks of the Battery Pack.

Li-Ion Cells

Monitoring the temperature of the Li-ion cells is the most critical parameter for ensuring the safety of the Battery Pack during charging and discharging cycles. Thermistors offer accurate temperature readings, fast thermal response, and a small form factor for a solid connection to the battery.

Secondary Protection circuit

The Secondary Protection circuit provides backup protection to the Primary Protection circuit. A high-current rating, surface mount fuse can interrupt a current overload on the battery. Alternatively, Littelfuse offers a unique component, a battery protector, which provides overcurrent and overcharge protection. The battery protector is a three-terminal fuse component.

See Figure 6. The fuses protect

the battery from an overcurrent, and an IC in the Secondary Protection circuit activates the heater, which blows the fuse if an overvoltage occurs during charging.

Battery Management Unit and Cell Balancing circuit

The Battery Management Unit and Cell Balancing circuit monitor the battery's health and ensure all cells carry an equal amount of load current. Protect this vital circuit block with a fast-acting, small surface mount fuse or a surface mount, resettable polymer positive

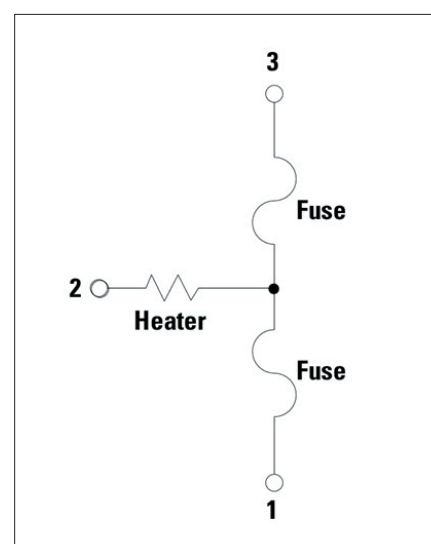


Figure 6. Battery Protector

temperature coefficient (PPTC) fuse. Also, use a TVS diode to protect the circuit from ESD strikes. Select a TVS diode that can absorb strikes of at least 8 kV.

Using a current sensing resistor allows the Battery Management Unit to monitor the battery charge and discharge current accurately. Surface-mount 4-wire connection resistor elements are available with milliohm resistances and maximum resistance tolerances of 1.0%. The 4-wire contacts enable a Kelvin connection of current sourcing on two terminals and voltage measurement on the other two terminals to provide an accurate battery current measurement.

Primary Protection circuit

The Primary Protection circuit protects and controls the battery pack from overvoltage, undervoltage, overcurrent, under-temperature, and overtemperature. Keeping this circuit operational is essential for ensuring the battery is kept safe. Since it interfaces with a charger or the load, the Primary Protection circuit needs protection from ESD. A TVS diode with 30 kV of absorption capacity is the recommended component to protect the circuit. Versions can have either uni-directional or cathode-cathode bi-directional configurations.

ID Pin circuit

The ID Pin circuit ensures that only the correct model charger can apply power to the battery pack. This circuit has I2C interface lines. A TVS diode can prevent the data lines from getting corrupted by ESD transients. Look for TVS diodes capable of absorbing at least 8 kV of ESD strikes, are bi-directional, and have low capacitance to minimize distortion to the data transmissions. Prevent

damage to the TVS diodes from overcurrent with a resettable PPTC fuse in a small, space-saving, surface mount, 0201-sized package.

Protecting the Power Management Unit

The Power Management Unit, in the Figure 3 block diagram, provides all necessary voltages for the robotic vacuum circuitry. One option for protecting the Power Management Unit includes discrete components for overcurrent protection from a short in the motor or in another part of the circuitry and voltage transient protection. Either a fast-responding one-time fuse or a fast-responding resettable PPTC fuse can provide overcurrent protection due to a short in the motor or in another circuit. A TVS diode offers the necessary overvoltage surge protection for the downstream circuitry. The TVS diode in the table in Figure 3 recommends 400 W pulse absorption capability and 30 kV absorption of an ESD strike.

The alternative to the discrete components is a unique Littelfuse component, the eFuse. The eFuse combines programmable overcurrent protection, overvoltage protection, inrush current limiting,

and reverse current blocking in a single IC. **Figure 7** shows a schematic of one type of eFuse. In addition, eFuse ICs offer:

- Overtemperature protection, which effectively disconnects the load from the supply when the detected temperature exceeds a specific limit.
- Under voltage lockout, which prevents powering the load until the supply voltage is high enough to power the load safely.
- Models with operating voltages down to 2.5 VDC and up to 24 VDC
- Models with current ratings up to 6 A
- Low power loss between supply and load with power control MOSFETs having RDS(ON) values $\leq 50 \text{ m}\Omega$.

An eFuse provides a complete array of protection modes in a single package. One component can save printed circuit board (PCB) space and save circuit development time.

Protecting the Motor Drive circuit

The Motor Drive circuit powers the motor that draws the dust and dirt into the vacuum and the stepper motor that transports the vacuum.

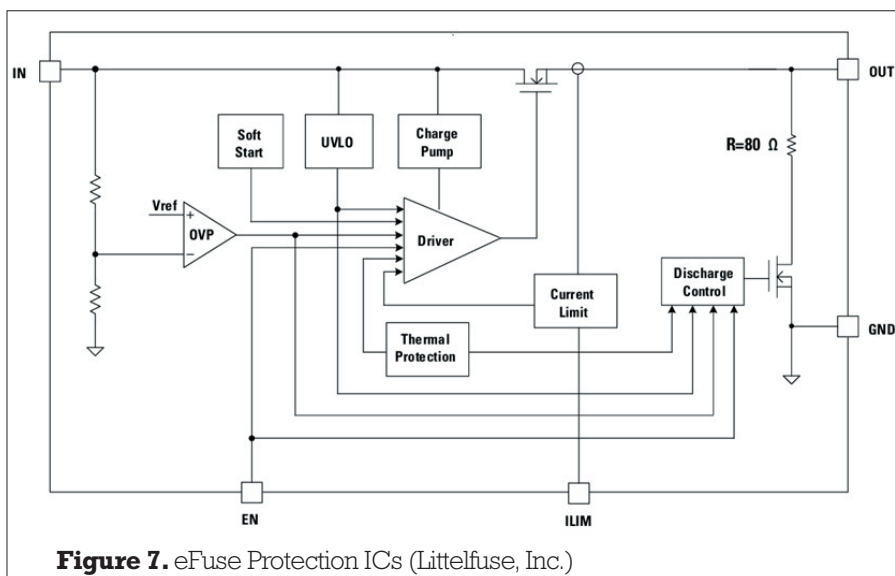


Figure 7. eFuse Protection ICs (Littelfuse, Inc.)

Protecting the motors requires monitoring for overtemperature and overcurrent. Failure to monitor either can severely damage the motors and the robotic vacuum cleaner circuits. NTC thermistors are excellent temperature sensors for monitoring overtemperature. They are high-reliability components with fast thermal response, exceptional accuracy, and small packages for placement in the most appropriate locations.

Monitor motor current with current sensing resistors in series with the motors. The recommended current sensing resistors consume minimal PCB space, have low resistances under 50 mΩ, and have low-temperature coefficients of resistance no higher than 100 ppm/°C.

When the thermistor detects a high temperature on the motor, include a resettable PPTC fuse to interrupt the motor current. Resettable PPTC fuses can have fast trip times and low resistance values under 60 mΩ.

Protecting the Display and Sensors circuit and the User Interface circuit

The LCD touchscreen display is subject to ESD from charge buildup on users. TVS diodes can safely absorb the strikes to protect the display and display driver ICs. TVS diode options are available with either low leakage current or low device capacitance. Low capacitance TVS diodes minimize distortion on digital signal lines. Low leakage current TVS diodes minimize signal loss on analog sensor lines. Models can include protection for a single data or sensor line or multiple data/sensor lines.

The User Interface is also subject to ESD from the external environment. ESD can propagate through the antenna of the Wireless Interface and through the circuitry of the Audio Input/Output Interface. Multi-line TVS diodes can efficiently protect the multiple signal lines of the two interfaces.

Protecting the User

When the lid of the robotic vacuum cleaner is open, the user could expose themselves to active mechanical parts or electrical shock from the internal circuitry. A hermetically sealed reed switch can act as an interlock to shut

down the moving parts and de-energize the vacuum when the lid is open. By using a magnetic actuator to control the reed switch, the designer can help minimize power consumption.

Reliable and efficient controls for the Motor Drive and Display and Sensors circuits

Designers can maximize the efficiency of the Motor Drive circuit with gate drivers to control the MOSFETs that power the motor. Three-phase, floating half-bridge drivers are available from Littelfuse in a single IC to control three-phase brushless DC motors. The IC combines high voltage and high speed. The propagation delay between each phase is matched to within 50 ns. The gate driver IC can safely withstand negative voltage transients. It also has internal protections including under voltage lockout, overcurrent protection, and shoot-through protection logic, which prevents the fault state of high outputs with low inputs. Furthermore, the IC has design features that enable operation in high-noise environments.

Standard	Sub-section requirement	Components supporting standard	How Littelfuse benefits OEMs
UL 1017, IEC 62784, GB4706.7	4.17: Any protective component must be evaluated to it's basic component standard	All safety critical components (Fuse, MOV, PPTC, NTC)	Approved by third party safety certification agencies: UL, IEC, and CSA
	4.15.3: Clearance requirement in accordance with UL 840	MOV	Use of MOV allows for reduction in spacing requirements
	5.8: Limit temperature to acceptable levels	NTC	Prevent appliances from reaching temperatures that constitute risk of fire or material damage
	Section D8.3: Limited circuits	PPTC	Maximum available current in secondary circuit inherently current limited
UL 2595, IEC 62133-2	7: Rechargeable battery-powered appliances	PPTC, NTC	Meet the general requirements of battery-operated appliances UL 2595
UL 1310, UL 1012 IEC/EN 61000	Section D2: Class 2 circuits	PPTC, Fuses	Docking station: charging station shall meet requirements of UL 1310
UL 1434; UL 248	4.9.3: Motor overload protection	SMD PPTC, SMD Fuse	PPTC approved to UL-1434 spec, UL60730-1 for motor overload protection; Fuses approved to UL- 248
	5.26: Abnormal overload test	Fuses approved to UL 248	Product will withstand overload conditions at 110%, 135%, 200%
UL 1017	Section D8.3: Limited circuits	PPTC	Maximum available current in secondary circuit inherently current limited

Table 1. Home robotic appliances safety standards

Select a reliable, long-life, on-off switch for use in the Display and Sensor circuits. Low-profile tactile switches are available with a 300,000-cycle life and IP67-rated protection from moisture and dust.

Applicable safety and compliance standards for robotic appliances

Table 1 lists the standards that robotic appliances must meet so they can be marketable products. The table indicates the components that support standard compliance. It also describes how Littelfuse supports product development.

The solution for a safe, reliable, and robust robotic appliance

By making wise choices, electronics designers can protect their circuits from electrical hazards and minimize energy consumption. They need to consider certification requirements and potential application hazards when considering component selections. Fortunately, they can get assistance and save development time by utilizing the manufacturers' expertise. Working with a manufacturer's application engineers, such as application engineers at Littelfuse, can help with:

- Selection of cost-effective efficient, and compact components for protection, control, and sensing
- Advice on applicable safety and compliance standards for enabling sales in worldwide markets
- Performing pre-compliance testing to save time and costs with certification standards testing.

Collaborating with Littelfuse can help designers create safe, low-power consumption, reliable, and robust robotic appliances. ■

References: Additional resources, courtesy of Littelfuse, Inc.

- Circuit Protection Product Selection Guide
- Sensing Products Selection Guide
- Power Semiconductor Selection Guide
- Integrated Circuits Selection Guide

Learn more about protecting appliance designs with proper circuit protection, courtesy of Littelfuse, Inc.

Stop ESD in Its Tracks with Littelfuse Solutions



Find the best protection strategy for sensitive ICs, data lines, and ports. The **ESD Suppression Design Guide** covers layout tips, device options, and selection criteria for ESD suppression.



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Tips for Designing Robust & Efficient Cordless Power Tools & Chargers

BY PAULIUS JUSKEVICIUS

The power tool market is growing, with a compound annual growth rate of more than 6%. The fastest-growing product sector is cordless power tools, representing about half of all power tool shipments. The market growth is spurring the introduction of new technology into the products. The cordless power tool industry is transitioning to lithium-ion batteries

to obtain the advantages of higher power density and longer discharge cycles. Furthermore, the industry is taking advantage of improved reliability, greater longevity, smaller size, and improved output performance from brushless DC motors.

While lithium-based batteries provide more power in a smaller package and longer battery

life, these batteries challenge designers to ensure battery safety. Brushless DC motors challenge designers to drive the motor more efficiently.

This article provides recommendations to assist cordless power tool designers make their product designs more robust and efficient. The article includes recommended components for protecting the power tool's battery pack, the power tool itself, and its battery charger. In addition, designers will receive recommendations for improving the efficiency of the power tool and the battery charger.

Ensuring a Robust Cordless Tool Battery Pack

A cordless tool battery pack includes the battery pack, battery management circuitry, and protection circuitry to ensure safe operation. Figure 1 illustrates an example battery pack. Surrounding the battery pack are the function blocks performed by the battery pack and the recommended protection components for each function.

Figure 2 shows a block diagram of the battery pack circuitry. The adjacent table lists the protection and sensing components recommended for each circuit. The

1 Thermal cell protection

- Thermal cut-off
- NTC

2 Secondary protection

- Fuse
- Battery Protector

3 Battery management unit

- PPTC
- Fuse
- TVS Array



4 Primary protection

- TVS Diode

5 ID communication

- TVS Diode Array
- PPTC

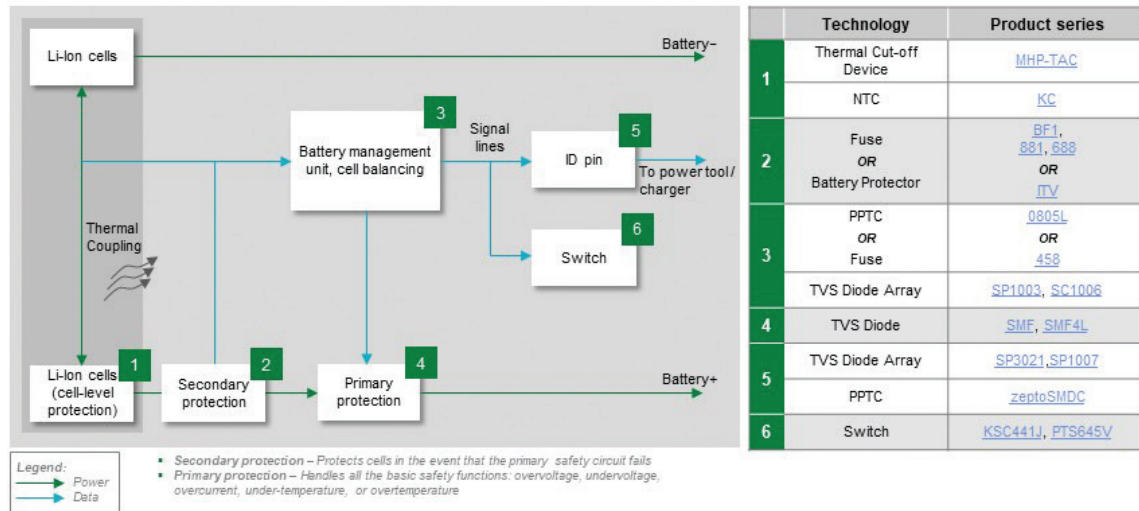
6 Switch

- Tactile Switch

Figure 1. A battery pack and its function blocks

Acronyms:
TVS: Transient Voltage Suppressor
PPTC: Positive Temperature Coefficient Device
NTC: Negative Temperature Coefficient Device
ESD: Electrostatic Discharge

Figure 2. Battery pack circuit block diagram



Li-Ion Cells Thermal Protection Circuit [1]

Lithium batteries, while providing high energy density capacity, can overheat if damaged. Left unchecked, an overheated Lithium battery can erupt in flames. To prevent this failure mode, use a temperature sensor-based monitoring circuit and a temperature-controlled switch to disconnect the battery from the load.

A thermistor, a negative temperature coefficient sensor, can quickly detect a temperature rise with a thermal response of 10 s. With nominal room temperature resistances from 100 Ω to 100 k Ω , the sensor can adapt to a wide range of detection circuit designs. Look for minimal-sized thermistors, such as those with diameters under 0.1 inch, to enable fast thermal response. Also, look for an epoxy coating for high reliability.

Consider a device that directly disconnects the cell from the power tool circuitry to protect individual battery cells. Use a thermal cut-off

device, such as one that contains a parallel combination of a bimetal switch with a polymeric positive temperature coefficient (PPTC) device. Figure 3 shows a schematic of a thermal cut-off component. The PPTC device heats up in response to the battery cell temperature and causes the bimetal switch to open. The switch remains open until the PPTC element cools, providing resettable overtemperature protection. Versions of thermal cut-off devices are available with selectable temperature activation ratings.

Secondary Protection Circuit [2]

In the Secondary Protection circuit, a backup for the Primary Protection circuit, a three-terminal Lithium-ion battery protector (see Figure 4), can provide both battery overcharge and overcurrent protection. The three-terminal component includes a distributed embedded fuse and heater elements. The fuse element interrupts an overcurrent condition;

additionally, if the monitoring circuitry detects lithium-ion battery parameters outside the designated range, the heater element will cause the fuse to blow.

As a simpler alternative, a high-current fuse provides overcurrent protection. Save space with a surface mount fuse model and simplify compliance requirements with a UL/CSA-recognized component.

Battery Management, Cell Balancing Circuit [3]

Protect the Battery Management, Cell Balancing Unit from overcurrent and electrostatic discharge (ESD). This circuit ensures that all cells individually supply an equal portion of the load current. Protect this circuit from a current overload with either an

Figure 3. Parallel bimetal switch and PPTC thermal cut-off device

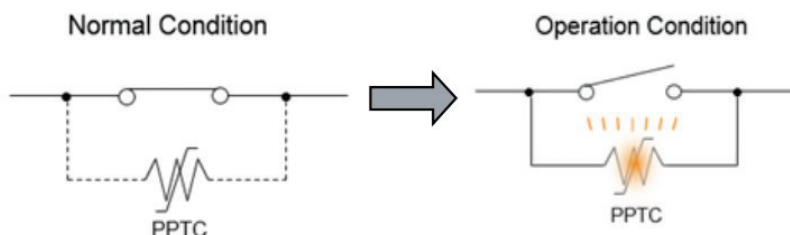
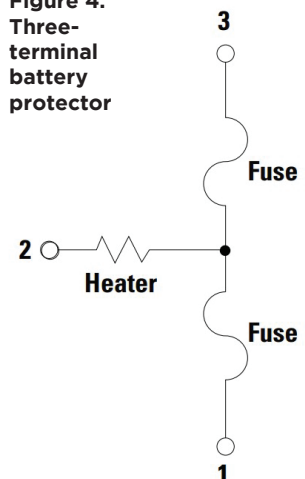


Figure 4. Three-terminal battery protector



inrush withstand fuse or a polymer positive temperature coefficient (PPTC) resettable fuse. Either component is available in surface mount packaging for PC board (PCB) space-saving.

A transient voltage suppressor (TVS) diode is an excellent component for ESD protection of semiconductor components such as those in the Battery Management circuit. Versions of TVS diodes can safely absorb ESD strikes as high as 30 kV from direct contact or through the air with sub-nanosecond response times.

Primary Protection Circuit [4]

The Primary Protection circuit interfaces directly with the battery pack and protects the battery pack from overvoltage, under-voltage, overcurrent, under-temperature, and overtemperature. A problem with the charging process can cause these conditions. A TVS diode can prevent damage to the semiconductors in this circuit. As well as providing ESD protection to 30 kV, TVS diodes can safely absorb 200 W of a transient pulse. A surface

mount model can save PCB space. Figure 5 shows bidirectional and uni-directional models of TVS diodes.

ID Pin [5]

The ID Pin circuit ensures that the power tool battery pack can only connect to the proper charger for safe charging of the battery pack. Consider a PPTC resettable fuse to protect the circuit from a current overload and a TVS diode for ESD protection. Look for a TVS diode with two diodes in an anode-to-anode series connection (Figure 6) for bipolar protection.

Switch Circuit [6]

The Switch circuit helps to indicate the status of the charge on the battery. Consider a sealed switch with at least an IP67 rating against moisture and dust ingress. Microminiature switches are available to conserve PCB space. Look for a long life, with a minimum of 100,000 operating cycles. Also, look for a switch with repeatable haptic performance and a short activation distance. All these characteristics enable a reliable

switch.

The components presented in the individual circuits will provide protection from hazardous thermal and electrical states. One major element of a cordless power tool, the battery pack, is now more robust and reliable.

Designing a More Robust Cordless Power Tool with Optimum Efficiency

To design a reliable power tool, designers must provide protection mechanisms from electrical hazards and ensure maximum battery life so that the portable power tool can operate through a work shift. Figure 7 illustrates a professional-grade cordless power tool and lists the components needed to protect the tool from current overloads, transient overvoltage, and overtemperature. Furthermore, the power drive circuit has opportunities to optimize the design for efficiency.

Figure 8 shows a block diagram of brushless DC motor circuitry in a cordless electric drill. The brushless DC motor drives the drill bit. The table on the right lists recommended protection, sensing, and high-efficiency control components for use in specific circuits.

DC Input Protection and Battery Communication Circuit [1]

The DC Input Protection and Battery Communication circuit provides overcurrent and overvoltage protection for the brushless DC motor circuitry. The circuit also energizes and de-energizes the motor. Provide overcurrent protection with a fuse. Consider using a:

- A fast-acting fuse
- A fuse that can operate at temperatures up to 150° C
- A surface mount fuse package to minimize PCB space.

For overvoltage protection, use a

Figure 5. Schematic diagrams of two types of TVS diodes

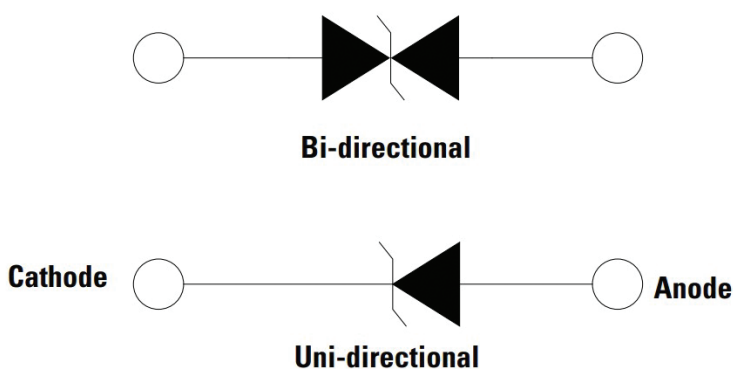
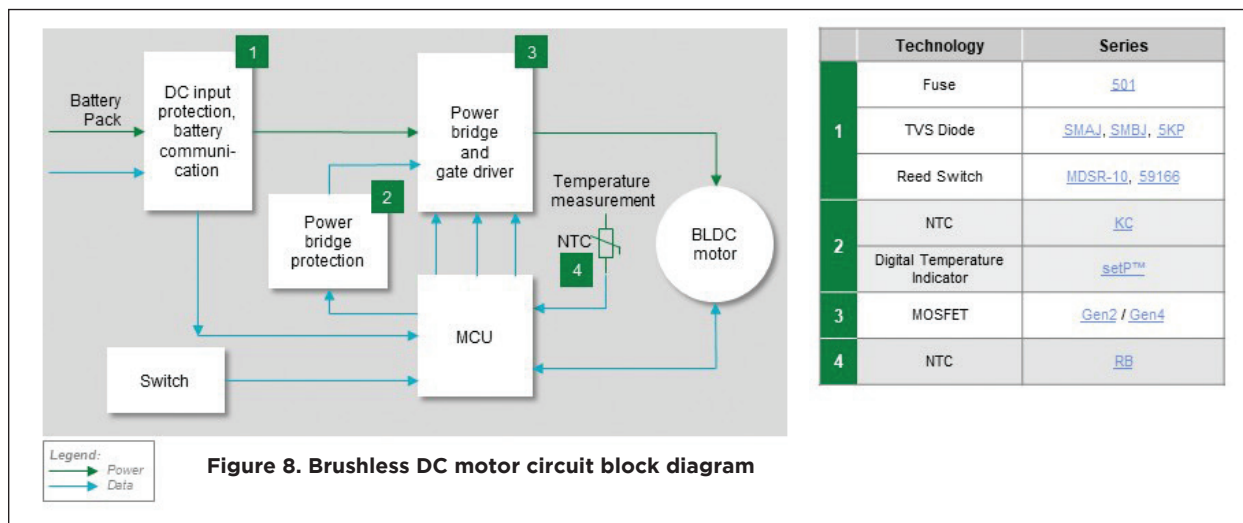
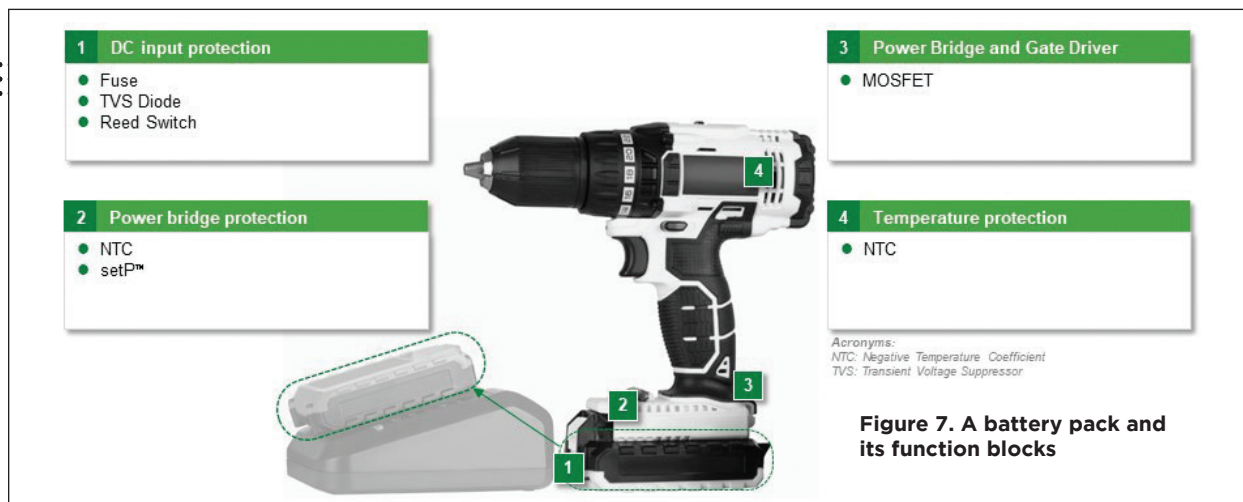


Figure 6. TVS diode array with diodes connected anode-to-anode





TVS diode. Consider a TVS diode that can absorb as much as 400 W of peak power.

Power Bridge Protection Circuit [2]

The Power Bridge Protection circuit block monitors the health of the motor drive circuit. Use an NTC thermistor, such as the one recommended for monitoring battery temperature, to monitor the temperature of the MOSFET driving the motor.

Consider a safety disconnect to reduce the MOSFET's current drive if its temperature rises too high. Littelfuse has a unique component, the setP™, whose resistance increases by six decades when a temperature threshold is exceeded. Figure 9 shows the characteristic of a setP digital temperature indicator. The high resistance change can trigger a control circuit to remove power from the MOSFET, preventing MOSFET thermal runaway. The setP device is integrated into a signal line.

NTC Temperature Measurement Sensor [4]

Monitoring the motor is essential for ensuring a reliable power tool. Use an NTC thermistor to monitor motor temperature and avoid excessive motor temperature due to an internal short or stalled motor. Surface mount NTC thermistors can mount on the motor using wire bonding, epoxy, or solder.

With the cordless tool protected from overcurrent, overvoltage, and overtemperature, the designer can concentrate on maximizing the tool's efficiency. Two circuit blocks offer opportunities to minimize energy consumption.

DC Input Protection Circuit [1]

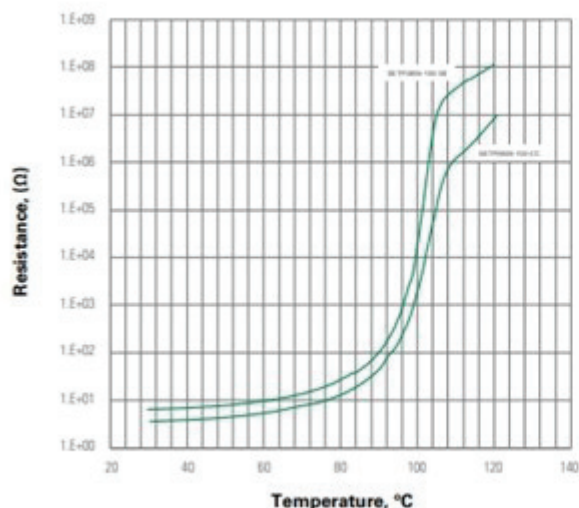
Use a reed switch to detect the state of the battery connection to ensure that the battery can energize the power tool circuitry. Look for a small reed switch with low contact resistance under 120 mΩ

for minimum energy consumption. Select a robust switch that can switch up to 0.5 A at up to 10 W of power.

Power Bridge and Gate Driver Circuit [3]

The Power Bridge and Gate Driver circuit uses a high-power MOSFET in the DC-DC converter circuit to allow high-power switching for maximum efficiency and minimum energy consumption. MOSFETs can supply current up to 600 A with RDS(On) values well under 100 mΩ. Low gate-source capacitance below 100 nC and switching times in the 10's of nanoseconds enable high efficiency, high-frequency DC-DC converter operation. Two significant cordless power tool design elements are now more robust and efficient. The third major element, the power tool charger, requires design consideration for circuit protection and high efficiency.

Figure 9. The resistance vs. temperature characteristic of a setP temperature indicator



Protection and Efficient Design For The Power Tool Charger

Figure 10 illustrates a power tool battery charger. The function blocks list components that make the circuitry robust to electrical and thermal hazards and optimize the circuitry for efficient operation. Figure 11 details the block diagram and indicates the recommended components for each circuit.

AC Input Primary Protection Circuit [1]

The AC Input Primary Protection circuit interfaces with the AC line and is subject to high current capacity in the event of an overcurrent condition and voltage transients induced in the power line from environmental

conditions such as lightning and large motors turning on and off. Use a fast-acting fuse for overcurrent protection. Ensure the fuse has an interrupting capacity of at least a kiloamp level at 125 VAC. Safely absorb overvoltage transients with a metal oxide varistor (MOV). MOVs can safely absorb a current surge from a voltage transient of at least 6 kA with power levels up to 480 J. Select UL and IEC-certified fuse and MOV components to make the product approval process an easier task.

Rectification, High-Frequency Converter, PFC Circuit [2]

Protect the Rectification, High-Frequency DC-DC Converter, and PFC Circuit from portions of transient waveforms that get through the AC Input Primary Protection circuit with a TVS diode. Consider using a TVS diode that can absorb as much as 600 W of pulse power. In addition, verify that the diode provides 30 kV of ESD protection.

Output DC Protection Circuit [4]

Use a TVS diode for transient and ESD protection on the Output DC Protection circuit. Ensure that the TVS diode used can protect against ESD strikes of at least 8 kV.

Rectification, High-Frequency Converter, PFC [2] and Secondary-Side Rectification and Filter Circuits [3]

Enable The Rectification, High-Frequency DC-DC Converter, and PFC Circuit to generate the DC voltage and to charge the battery pack efficiently. Use MOSFETs which allow the switch-mode circuit to operate at a high frequency. Look for MOSFETs with Low gate charges, low RDS(On), and fast switching times. MOSFETs are available with gate charges as low as 14 nC, RDS(On) under 150 mΩ, and switching times of 50 V/ns.

Figure 10. Example power tool charger

- 1 AC input primary protection**
 - Fuse
 - MOV
 - NTC
- 2 Rectification, high frequency converter**
 - MOSFET
 - TVS Diode

Acronyms:
MOV: Metal Oxide Varistor
NTC: Negative temperature co-efficient
TVS: Transient Voltage Suppressor



- 3 Secondary side rectification**
 - Schottky Diode
- 4 DC output protection**
 - TVS Diode

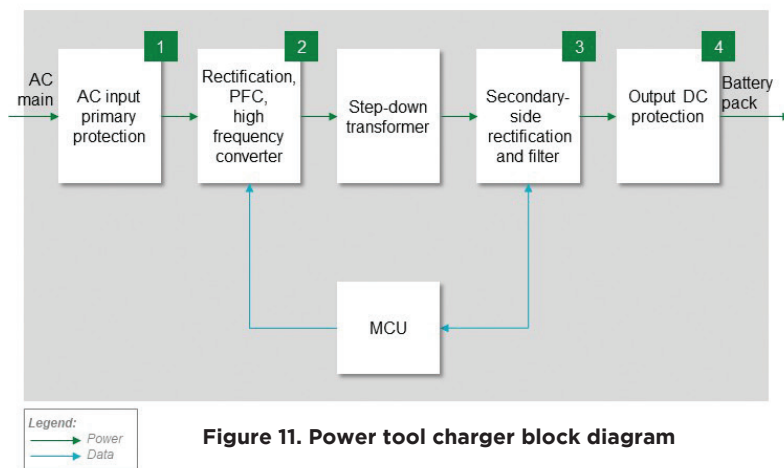


Figure 11. Power tool charger block diagram

	Technology	Series
1	Fuse	5X20mm Fuse, TR, TE
	MOV	LA, CIII, TMOV
2	MOSFET	X2-class
	TVS Diode	P6SMB
3	Schottky Diode	MBR, DST
4	TVS Diode	SMBJ

For efficient operation, consider low forward voltage drop Schottky rectifiers on the Secondary-Side Rectification and Filter circuit. Schottky diodes can operate at the high frequency of the switch-mode DC-DC converter.

Summary: A small number of components yield robust, efficient performance

The judicious selection of components can provide high protection to the battery pack, power tool, and battery charger. In addition, effective component selection can maximize the power tool's and its charger's efficiency. If designers would like assistance in selecting circuit protection and efficiency components, they can take advantage of a component manufacturer's expertise to save development time and get help with the following:

- Cost-effective component selection
- Compliance with applicable safety standards
- Pre-compliance testing (offered by some manufacturers) to minimize the cost of product certification by a national testing lab.

The result will be a safer, more reliable, and more efficient cordless power tool. ■

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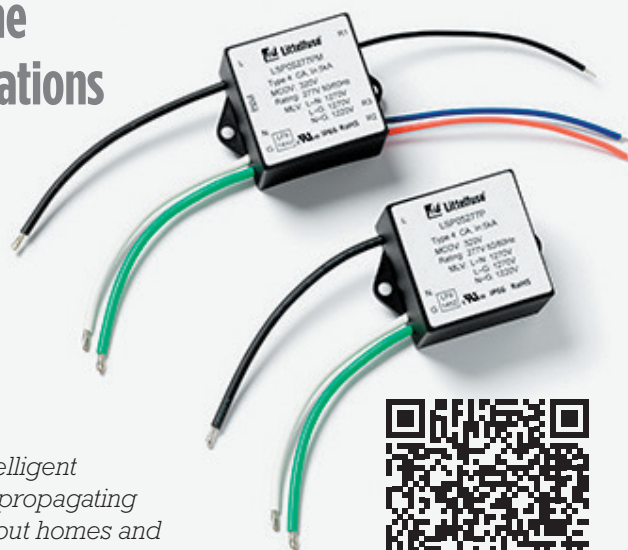
Circuit Protection
Product Selection Guide

Power Semiconductor
& ICs Selection Guide



TECHNOLOGIES

How to Make Surge Protective Devices More Robust for Building & Home Applications



With intelligent devices propagating throughout homes and building, surge protection has become very important.





Case Study:

Compact, Sealed Tactile Switch Solves Battery Indicator Challenges in European Power Tool Design

Helping engineering teams overcome integration, durability, and safety hurdles in harsh environments **BY PAULIUS JUSKEVICIUS**

Designing compact, durable, and user-friendly interfaces for handheld power tools presents a unique set of engineering challenges—especially regarding reliable switch performance in harsh environments. This success story explores how one European appliance manufacturer overcame issues related to size constraints, environmental sealing, user ergonomics, and lifecycle durability by integrating the Littelfuse KSC222J tactile switch into their battery-level indication system. This article, presented in a problem-cause-solution format, highlights key technical considerations and real-world performance benefits to help engineering teams facing similar design requirements.

The Challenge: Compact Reliability for Harsh, Demanding Environments

A leading European appliance manufacturer developing battery-

powered handheld power tools—primarily drills and rotary devices—faced a critical challenge in the design of their latest generation cordless product line. The engineering team needed to implement a compact, rugged, and highly reliable tactile switch that would activate the battery level indicator on the tool's interface.

While this may sound like a relatively simple component to specify, the application presented a range of demanding design requirements. The switch had to operate consistently in tough jobsite environments, where exposure to dust, moisture, vibration, and frequent mechanical impact is routine. It needed to fit into an already space-constrained PCB layout, provide excellent tactile feedback for ergonomic operation, and meet stringent safety standards without increasing manufacturing complexity or cost.

The battery level indicator is a

key user interface element that gives real-time feedback on battery capacity. For professional users, especially those in construction, carpentry, and renovation, this feature must work reliably under all conditions and over the full life of the tool—often several years of intensive use.

The Root Cause: Standard Push Buttons Aren't Built for This

Initially, the team explored standard push-button switches that were already used in other appliance and consumer electronics projects. However, these switches quickly revealed limitations during prototyping and early field testing.

Durability was a major issue. Standard push buttons were typically rated for 100,000 actuations—sufficient for light-duty devices, but inadequate for professional-grade tools used multiple times daily. The switches began showing



signs of degradation well before the expected lifespan of the tool, prompting concerns about warranty returns and customer dissatisfaction.

Environmental sealing was another pain point. During extended testing, fine drilling dust began penetrating the switch housing, leading to mechanical sticking and electrical failure. Water splashes and high-humidity environments also caused corrosion and leakage, especially in unsealed or semi-sealed models.

Form factor and integration also presented recurring issues. The switches were too large to fit comfortably within the compact layout of the tool's handle without design compromises. Misalignment during assembly sometimes caused inconsistent actuation, requiring rework or triggering customer complaints.

Ergonomics and safety added further complexity. The team needed a switch that could be activated easily—even while wearing gloves—yet not so sensitive that it caused false triggers during normal tool operation or accidental contact. Moreover, the switch had to safely interface with the battery management system (BMS) and any associated circuit protection devices, such as fuses or transistors, to prevent short circuits and meet EU safety regulations.

At this point, the engineers began asking more targeted discovery questions:

- What safety certifications and ingress protection levels are needed to ensure field reliability?
- Can we find a tactile switch that is already tested and rated for dust-tight and water-resistant applications?
- How will the switch interact with the power control circuitry and BMS logic?
- Is it possible to reduce the component footprint without sacrificing functionality?

The Solution: Littelfuse KSC222J Tactile Switch Delivers Precision, Protection, and Longevity

After extensive testing and consultation, the team selected the KSC222J LFS Tactile Switch from the KSC2 Series as the ideal solution. This sealed surface-mount tactile switch delivered the right combination of ruggedness, compactness, and electrical performance to meet all application requirements.

human-machine interfaces (HMIs), design engineers must consider two critical dimensional characteristics: Electrical Travel (Te) and Electrical Height (He). Electrical Travel refers to the vertical movement of the actuator's top required to activate the switch. At the same time, Electrical Height denotes the fixed height from the PCB to the point where the switch electrically actuates. Traditionally, designers relied on Electrical Travel and a stack-up analysis to determine the switching point location. However, this method accumulates tolerances

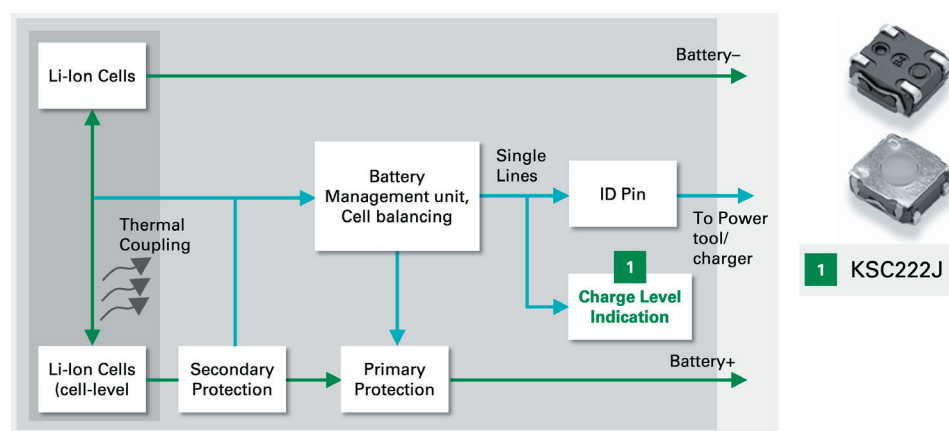


Figure 1. Tactile switch charge level indicator

Here's how the KSC222J met or exceeded every design challenge:

Compact & Space-Efficient

Measuring just 6.2 x 6.2 x 3.5 mm, the KSC222J occupies 20% less PCB space than the previous design, making it easier to integrate into the already-dense layout of the drill's control board. The tight ± 0.2 mm dimensional tolerance also reduced alignment issues by 50%, improving both placement accuracy and overall assembly yields.

Electrical Travel (Te) and Electrical Height (He)

When integrating tactile switches into applications where precise actuation is essential, such as in

across multiple components, often resulting in a wide variation of ± 0.4 mm; this can lead to overtravel, inconsistent tactile response, and potential long-term reliability issues.

To address these concerns, C&K—now part of Littelfuse—has refined the specification approach by prioritizing Electrical Height. By specifying the switching point directly relative to the PCB with tighter process controls and manufacturing precision, Electrical Height provides a more consistent and predictable integration point with a tighter standard tolerance of ± 0.2 mm. In some cases, tolerances as precise as ± 0.1 mm or even ± 0.08 mm can be achieved. This shift simplifies design validation, reduces cumulative error, and

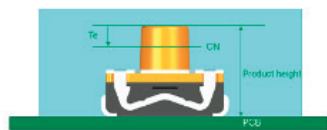


Figure 2: Electrical Travel Version

ensures a more uniform tactile experience across units. For electromechanical designs requiring precise actuation, whether finger- or lever-operated, relying on Electrical Height over Electrical Travel improves integration accuracy and product performance.

Extreme Mechanical and Electrical Durability

The switch is rated for up to 1 million cycles—a 10x improvement over typical push-button alternatives. This extended life rating ensures that even under frequent daily use, the switch will remain operational for the full-service life of the power tool, reducing field failures and support costs.

The small switch has maximum contact current ratings of 50 mA at a maximum voltage of 32 VDC. That is more than sufficient capacity to interface with a BMS circuit and ensures long-life electrical performance.

IP67 Sealing for Dust and Water Resistance

The KSC222J's IP67 rating means it is completely sealed against fine dust particles and can withstand immersion in up to 1 meter of water for up to 30 minutes. For a jobsite environment, this provides critical protection from:

- Drilling debris and drywall dust
- Rain, water splashes, and humidity
- Grease and chemical exposure

This level of sealing significantly extends product longevity and simplifies compliance with EU appliance safety standards.

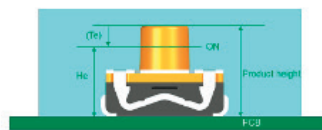


Figure 3: Electrical Height Version

Improved Ergonomics and Activation Control

The KSC222J features a tactile feedback mechanism optimized for glove-friendly actuation. The force and travel profiles are tuned to reduce finger strain, while helping to prevent accidental or unintended activation—a common issue with overly sensitive designs.

This improvement not only enhances the user experience, but also improves operational safety, especially when tools are used in elevated positions or awkward angles.

Seamless Circuit Integration

The momentary electrical connection provided by the KSC222J easily interfaces with the tool's battery management system (BMS). This helps the BMS interpret the button press as a trigger to wake up and display battery capacity—without impacting power regulation or interfering with the main control loop.

The sealed switch also complements circuit protection strategies, since its robust housing helps isolate the control circuit from moisture or conductive particles that could cause shorts or component failure.

The Result: A Rugged, User-Friendly Battery Indicator Activation System

The implementation of the KSC222J tactile switch enabled the engineering team to meet all critical product objectives:

- Reduced PCB space requirements, enabling a sleeker and more balanced tool design
- Improved assembly tolerances and reduced rework caused by switch misalignment

- Longer switch lifecycle, minimizing warranty claims and increasing customer satisfaction
- Robust performance in tough environments, aligning with IP67 and regional safety standards
- Enhanced user interface, contributing to the premium feel and usability of the tool.

Ultimately, this design change helped the OEM differentiate its cordless power tools in a competitive market, while also ensuring compliance, reliability, and long-term durability.

Take the Next Step

If your application demands sealed, space-efficient, long-life tactile switches, explore the KSC2 series. Whether for power tools, industrial equipment, or other sealed appliance controls, the KSC222J offers a proven path to solving mechanical and electrical design constraints.



View the video

[KSC2 Series Sealed Tact Switch for SMT](#)

[Tactile Switch Electrical Height Versus Electrical Travel Application Note](#)

[Download the Datasheet](#)

[View the Cordless Power Tools Spotlight Presentation](#)



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How to Improve Smart Thermostats for Reliably Efficient Environmental Control

BY BARRY BRENTS

Intelligent or smart thermostats have become a popular method of energy conservation for homes, office buildings, and retail facilities. Since 2018, the market for smart thermostats has been growing at a high CAGR of 22%. With such high growth, manufacturers can easily justify continuing innovation in new models. Future smart thermostats will provide a wide range of information, including energy usage audits and comparative data on energy consumption before and after an HVAC system upgrade.

Today, smart thermostats employ more technology, such as a wide range of IoT interfaces for control and data communication. Additionally, these devices operate from AC line power and have battery backup power to remain operational during a power outage.

To ensure highly reliable smart thermostats, design engineers should incorporate robust components that protect the thermostat from potentially damaging external threats, including power line current overloads, voltage transients, and electrostatic discharge (ESD) strikes.

In this article, designers will learn how to protect their sensitive electronic circuits from these hazards. With this information, designers will confidently be able to develop smart thermostats that can withstand hazardous transients and be highly robust and reliable.

Smart Thermostats: Operation Overview

Smart thermostats perform a wide range of functions. First and foremost, the thermostat's primary function is to monitor the surrounding environment's temperature and activate the HVAC system, when necessary, to maintain the thermostat setpoint temperature.

The features that make the thermostat smart include:

- communicating HVAC system status,
- processing control information from remote devices (e.g., smartphones, tablets, etc.), and
- alerting the homeowner

Figure 1. Smart thermostat example

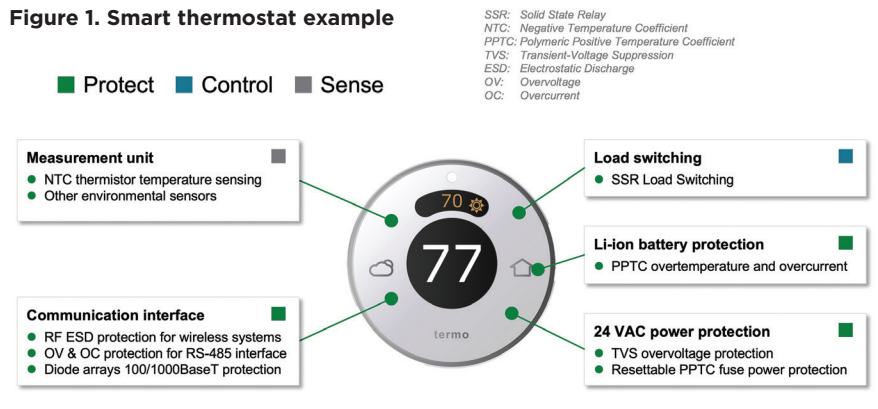
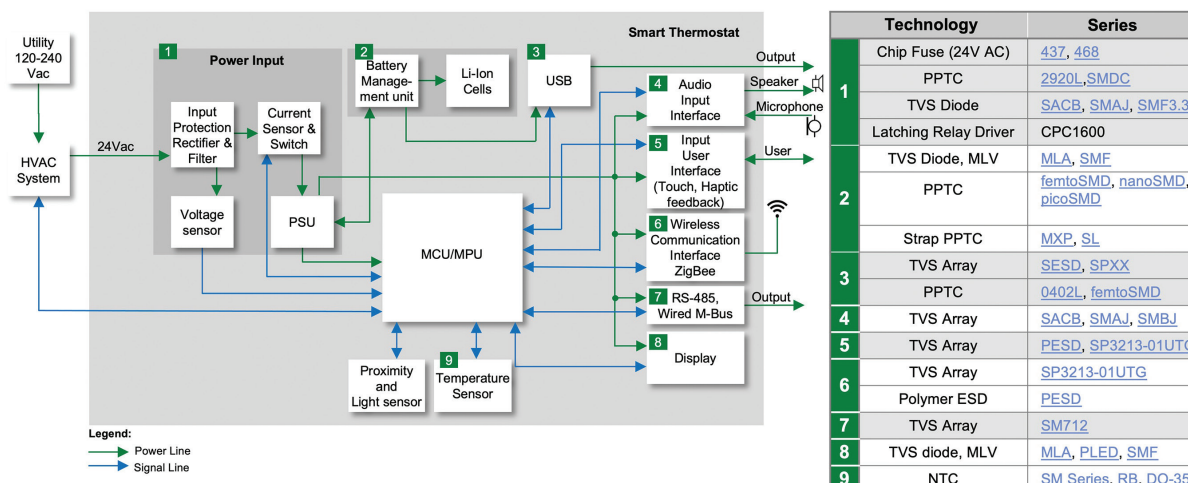


Figure 2. Smart thermostat block diagram



or facilities manager if an action is required.

Many smart thermostats have a battery pack for backup power if AC line power is interrupted. Figure 1 illustrates an example smart thermostat. The boxes around the image describe its functions and list recommended technologies for the protection, control, and sensing that will help improve the smart thermostat's reliability and efficiency.

Figure 2 shows a detailed smart thermostat block diagram. The table provided lists recommended components that protect the circuit blocks and enable efficient control and sensing. The following paragraphs describe the hazards that can damage the circuitry and the recommended protection, control, and sensing components needed for high reliability and efficiency.

Protecting the SmartThermostat From Overloads, Transients, and Electrostatic discharge

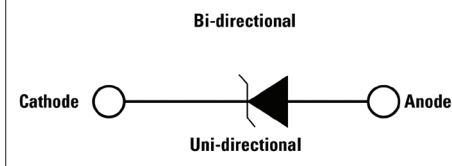
The Power Input block converts the 24 VAC input from the HVAC system into the DC voltage that powers all other circuit blocks. Although the HVAC system reduces the power line AC voltage for the thermostat to 24 VAC, the 24 VAC line is still susceptible to power line overload currents and voltage transients that can pass through the HVAC system.

To protect the Power Input from sustained current overloads, use a time delay fuse to enable the fuse to withstand inrush currents caused by motors turning on and turning off. A time delay fuse will avoid nuisance shutdowns resulting from inrush currents. Miniature axial lead and surface mount fuses are available for low voltage circuits to save on precious pc board space.

A Polymeric Positive Temperature Coefficient (PPTC) resettable fuse is an alternative to a standard, one-time overload fuse.

The fuse opens due to heat from an overload current; however, it resets when its temperature falls below a threshold level and does not need replacement after it has opened.

Lightning strikes on the power line and large motors inducing back EMF voltages on the power line can



result in damaging transient overloads. These voltages can reach kV levels. While the HVAC

Power and Protect Intelligent Building Systems



Design smart, efficient HVAC, security, and lighting controls. The **Smart Building Application Guide** highlights circuit protection and sensing solutions tailored to modern home and building automation applications.



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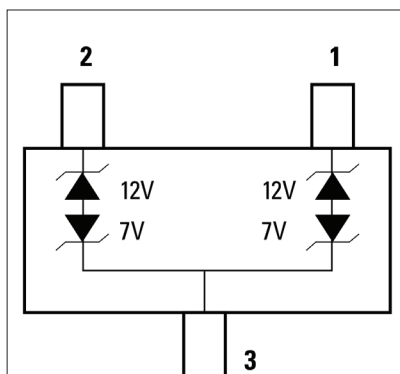


Figure 4. Schematic of an asymmetrical TVS diode array for absorbing voltage transients and ESD on each of the RS-485 data lines

system can have protection from these overloads, some of the energy can pass through the HVAC circuit to the Power Input block. Use a transient voltage suppressor (TVS) diode to clamp and absorb the residual transient voltage and its energy. TVS diodes offer:

- Ultra-fast response time of under 1 ps
- Low clamping voltages to protect sensitive semiconductors
- Ability to safely absorb peak pulse power of 400 W
- Bi-directional and uni-directional configurations
- Versions with surface mount form factors.

Figure 3 illustrates the symbols for the bi-directional and the uni-directional TVS diodes. The two diodes, shown in the bi-directional configuration, use cathode-cathode connected diodes.

The Battery Management unit ensures that all battery cells equally power the load and monitors the state-of-charge of the cells. Protect the semiconductor control circuitry from voltage transients and ESD with a TVS diode. Consider a TVS diode or a multilayer varistor (MLV). Either device can provide very low clamping voltages to protect low voltage semiconductors and provide ESD protection compliant to IEC 61000-4-2, the electromagnetic compatibility standard.

Designers should prevent battery overcharging and battery overtemperature conditions by using PPTC resettable fuses. Versions of PPTC fuses can be either surface-mount PC board components or directly mountable on the battery pack to quickly detect an overtemperature condition.

Input/Output Interfaces. A smart thermostat can have several wired and wireless interfaces. The interfaces are subject to hazards from the external environment, which is typically ESD strikes.

For the USB interface, use TVS diodes for ESD protection. Look for:

- A minimum safe absorption ± 20 kV ESD either through the air or via direct human contact
- A maximum of 1 pF capacitance for minimum distortion of transmitted and received signals
- A low clamping voltage of no more than 10 V
- A uni-directional or bi-directional diode
- Leakage current under 100 nA.

Consider a PPTC resettable fuse to protect the USB interface from current overloads. Look for a small model to save PC board space.

The Audio Input Interface outputs alarms and has voice-activated input. Protect this interface's I/O lines with a TVS diode. Consider either a uni-directional or bi-directional diode for each line.

The Input User Interface provides a data entry panel. The Zigbee Wireless Communication Interface transmits data and receives control information from devices such as a smartphone or a tablet PC. Both interfaces require protection from an ESD strike. A TVS diode array that provides at least 10 kV of bi-directional energy absorption will protect these two interfaces safely. An alternative to the TVS diode for the Wireless Communication Interface is a polymer ESD suppressor. A polymer ESD suppressor has very low capacitance, typically around 0.25 pF, to minimize its impact on the RF signals, under 1 ns response time, and a typical leakage current of under 10 nA.

The RS-485 Wired M-Bus in a commercial smart thermostat provides data to an external system. Use an asymmetrical TVS diode array to protect the -7 V and +12 V working voltages on the RS-485's data lines. Also, look for high ESD absorption above 20 kV. One component, as shown in Figure 4, protects both data lines.

The last interface is the Display which, at a minimum, shows the

Table 1. Safety standards for smart thermostats

Standard	Title
UL 873	Temperature-Indicating and Regulating Equipment
ANSI/UL 60730-1	Automatic Electrical Controls – Part 2-9: Particular Requirements for Temperature Sensing Controls
UL 60730-2-1A	Automatic Electrical Controls for Household and Similar Use; Part 2: Particular Requirements for Energy Regulator
UL 1449	Standard for Surge Protection Devices
UL 1434	Standard for Thermistor-Type Devices
UL 4248-9	Standard for Fuseholders
IEC 60334-2-30 Ed. 5.1b: 2016	Household and Similar Electric Appliances – Safety – Part 2-30: Particular requirements for room heaters
UL 1642	Lithium Batteries
UL 2054	Household and Commercial Batteries
IEC 62281	Safety of Primary and Secondary Lithium Cells and Batteries during transport

temperature setting and actual room temperature. A TVS diode such as the one recommended for the Battery Management Unit or a multilayer varistor can protect the display circuitry.

Efficient Control and Sensing

Consider a solid-state latching relay to control power to the smart thermostat's circuit blocks. To avoid generating electromagnetic interference (EMI) during switching, look for a relay that switches when the AC line voltage passes through 0 V. Also, latching relays save on power consumption since they do not draw power in the closed-contact state.

The most critical element of the smart thermostat is the temperature sensor. Consider using a thermistor, a negative temperature coefficient (NTC) element. Thermistors offer better accuracy than other temperature sensor types and detect a wide temperature range, -55 to + 220° C. Use a hermetically sealed thermistor to obtain long-term reliability and stability. Small, surface-mount versions save PC board space and allow automated insertion.

Applicable Safety Standards For Smart Thermostats

Designers need to be aware of the standards that apply to smart thermostats, and Table 1 lists these safety standards. Failure to comply with the appropriate standards can result in failure to pass compliance certification testing, additional development costs, and delayed introduction to the market.

Designing in Protection and Long-Life Components Achieves High Reliability

Designers need only a small number of components to protect a smart thermostat and enhance its reliability thoroughly. It is

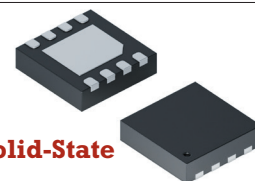
challenging to be an expert in all aspects of electronic design, so designers can take advantage of the expertise of a manufacturer's application engineers on circuit protection and efficient control. They can help with:

- Cost-effective component selection
- Guidance on complying with the applicable safety standards
- Pre-compliance testing to help identify problems before compliance testing (service provided by some manufacturers).

Using the recommended protection, control, and sensing components will ensure a reliable smart thermostat with robust protection from external hazards while providing efficient operation. ●

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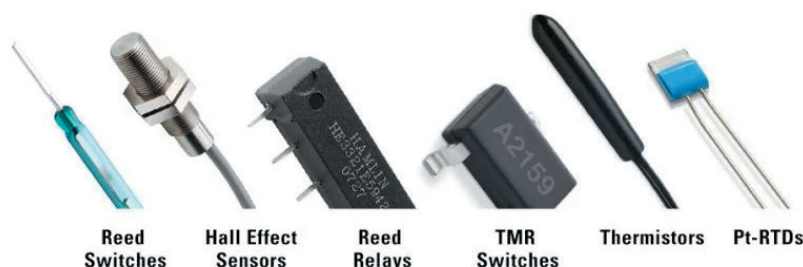
CPC1601M Latching Solid-State Relay

Efficient solid-state switching for smart thermostats and building-automation systems.



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TECHNOLOGIES



Common Sense About Sensors: Four Important Questions to Ask Before Selecting Sensors for Your Next Design

Essential facts about your sensor choices and four crucial questions whose answers should carry significant weight in the decision process



How to Design Smart Meters that Out-Smart the Hazards

Protect your design from damaging electrical transients and unethical users.

As buildings and other facilities work toward achieving a net-zero future, utility meters such as electricity meters and water meters must provide more functionality than just recording usage data. The meters must become part of the infrastructure of an integrated structure, as shown in Figure 1 for a building and Figure 2 for a residential home.

The latest generation of “smart” electricity, water, and gas meters offers commercial and residential customers the information they need to use these resources more wisely. They also allow utility companies to monitor usage remotely, essentially eliminating the need for manual readings. These intelligent meters also enable managing grid power

peaks and identifying tampering.

The switch from traditional electromechanical meters to smart meters presents various challenges for meter designers as they strive to develop solutions compatible with Advanced Metering Infrastructure (AMI). This approach allows for integrating smart meters into the fast-growing Internet of Things (IoT), which

BY BARRY BRENTS

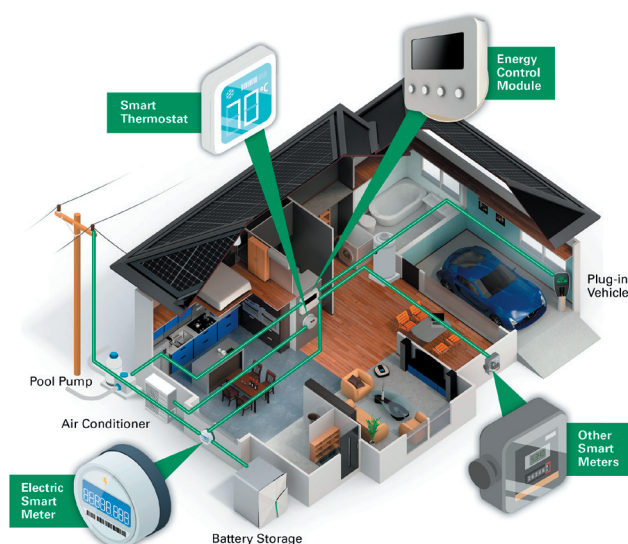


Figure 2. Smart metering accumulates information on energy generation and consumption

supports remote communication and fault detection. However, one thing that has remained the same is that the utility companies that install these meters need them to be robust enough to operate reliably for decades and provide accurate measurements over their lifetimes. They must incorporate a growing array of circuit protection, sensing, and power control components to do that. This article offers an overview of the various component options and how utilizing them in the design can improve the operation of the meters.

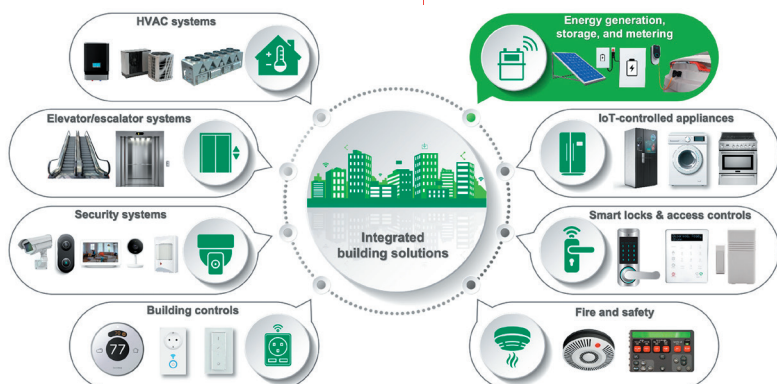
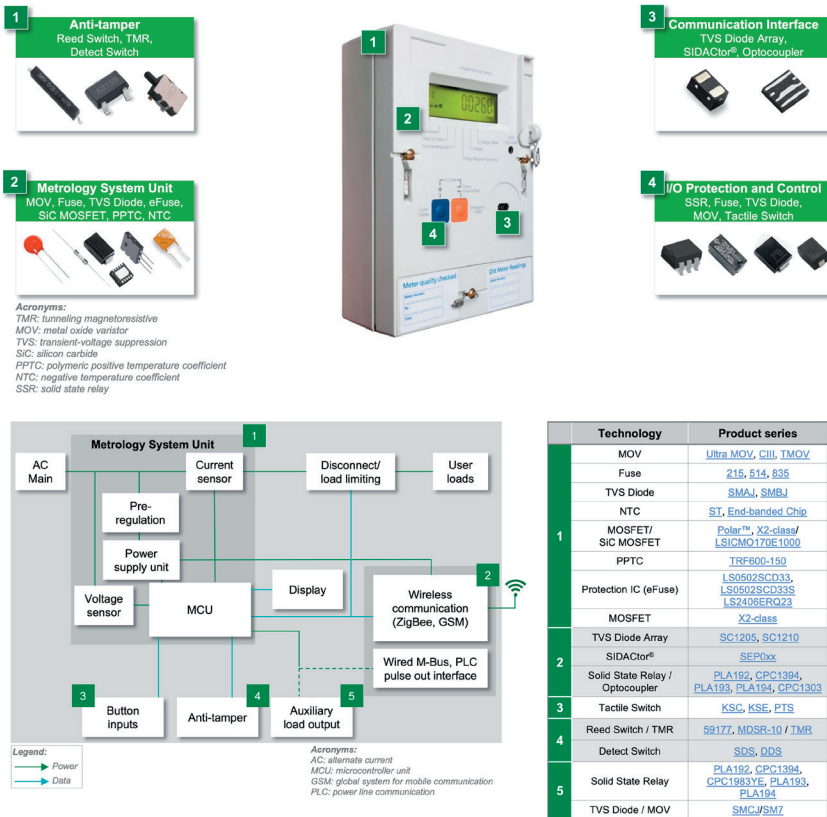


Figure 1. Building electric and electronic systems to help reach net-zero goals



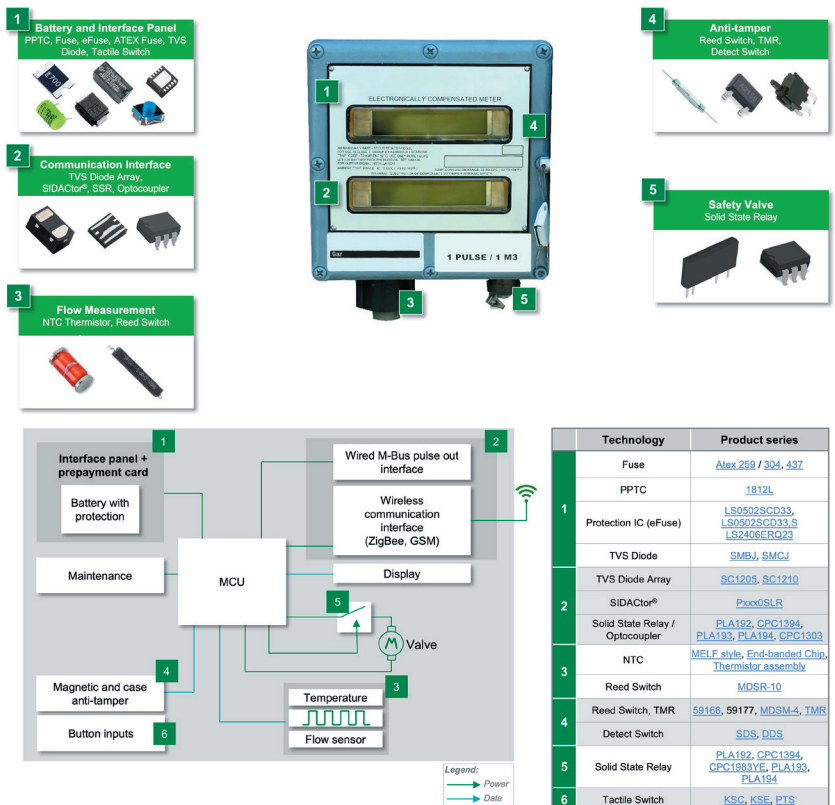
Protecting the Electricity Meter

Electricity meters draw their power from the electrical grid, which is subject to high energy transients resulting from lightning, inductive load switching, or capacitor bank switching. The AC power lines have, by necessity, high current capacity to support the loads in a home or building. A fuse and a metal oxide varistor (MOV) placed at the AC power input can be the first line of defense against an overcurrent condition and high energy transients. A fuse provides protection from the high current capacity AC line that can flow if an internal short circuit develops. Recommended fuses can be either a fast-acting or a time-lag type. A time-lag fuse will be less susceptible to opening due to in-rush current and will avoid nuisance shutdowns. In addition to sizing the fuse for the smart meter's normal

Smart Meter Overview

The sophisticated electronics in today's smart meters require even greater protection from electrical transients such as electrostatic discharge (ESD), power surges (such as from lightning strikes), and other occurrences than in earlier designs. Figure 3 shows an example of a smart electricity meter and presents a high-level block diagram of the subsystems within the meter. Figure 4 illustrates a smart gas or water meter and its block diagram. The smart electricity, gas, and water meters have multiple common functional blocks. Each Figure highlights multiple component options for protection, sensing, and efficient control of the smart meter circuit blocks.

Figure 4. Smart gas and water meter, their circuit blocks, and recommended component options



current draw, ensure the voltage rating exceeds the line voltage. Also use a fuse with a high interrupting rating of at least 1000 A so failure in a shorted state is avoided even under the most extreme conditions. Always use UL and CSA-approved fuses to save standards compliance test costs and time.

An alternative to a one-time fuse is a polymer resettable fuse. These fuses offer fast trip times with UL and CSA certification.

When an overvoltage transient impinges on the meter, the MOV quickly clamps the transient to a suitable voltage level. However, if the MOV is subjected to a sustained, low current overvoltage, the MOV can go into thermal runaway, resulting in overheating, gaseous emission, and potentially fire. In cases where this is likely to occur, such as in electrical meters, the designer can choose a thermally protected varistor (TMOV, Figure 5), which integrates a thermally responsive element within the body of the device that will open-circuit the varistor in case of overheating. A version of this type of MOV shown in Figure 5 includes a third terminal that can connect to a circuit that displays the status of the MOV.

The required level of surge immunity dictates the rating and size of the MOV. For basic surge protection between 2 kV and 4 kV,

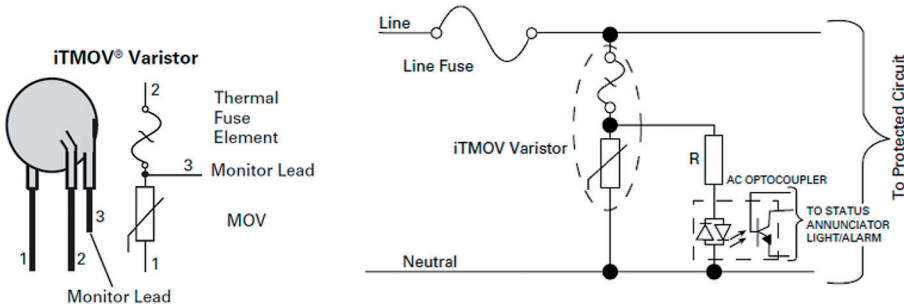
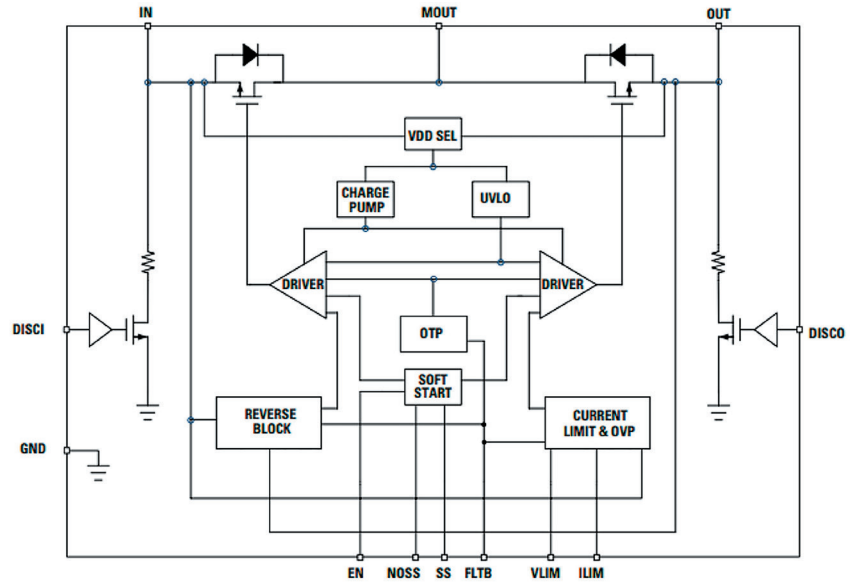


Figure 5. Indicating TMOV with annunciator circuit

Figure 6. eFuse multiple protection function IC



a 14 mm MOV can be adequate. However, for protection levels of 20 kV, a larger MOV or TMOV would be needed. Furthermore, MOVs have a finite number of surges they can absorb, and once the MOV has reached its end-of-life, it can no longer protect the meter. Thus, to ensure that the MOV remains operational during the specified lifetime of the smart meter, derating the MOV is essential.

For further protection, designers can supplement the MOV with a transient voltage suppression (TVS) diode. TVS diodes offer secondary protection for sensitive downstream electronic components. They have under-picosecond response to voltage overloads and do not have lifetimes dictated by the number of surge strikes. These devices clamp

the fast-rising transients to low voltages while the front-end MOV absorbs the bulk of the high energy in those transients.

As an alternative to discrete fuses and TVS diodes at the smart meter input, Littelfuse has a single-device solution for overcurrent and transient voltage conditions. In addition to current overload and input voltage surge protection, the chip protects against inrush currents, excessive temperature, undervoltage, and reverse currents. These Littelfuse components are known as eFuses. The recommended eFuse shown in Figure 6 shows the source-to-load pathway controlled by a MOSFET with ultra-low RDS(ON) resistance of 24 mΩ for minimal power loss during normal operation. The chip works in circuits with operating voltages ranging from 3 V to 24 V, and the eFuse allows a programmable current limit up to 6 A. Discharge control lines limit the voltage rise on the input and output lines. With all this capability, an eFuse can save designers development time and printed circuit board (PCB) space while providing robust protection.

Protecting the Microcontroller

A microcontroller unit (MCU) controls a smart meter's energy measurement and processing functions. The MCU is very sensitive to transients. Fast-rising transients can sometimes pass through the input protection and the filters on input signal lines. To prevent damage to the microcontroller, use TVS diodes on the signal input lines. In addition, the microcontroller I/O communication lines require surge suppression, typically from ESD. TVS diodes, such as the Littelfuse SMAJ or SMBJ, can ensure the necessary level of protection. These diodes can respond in under 1 ps and withstand ESD strikes up to 30 kV.

To further enhance the microcontroller's protection, designers can use Littelfuse opto-isolated solid-state relays for galvanic isolation between the microcontroller and external circuitry. An optically coupled solid-state relay isolates the pulse-out signal between the MCU and the M-Bus. These components have low drive power requirements for minimum power consumption and do not generate any electromagnetic interference (EMI).

Industrial electricity meters employ optically isolated solid-state relays (SSRs) for control by programmable week calendars, dynamic commands, or Active Information Management Systems. Other smart meter applications of SSRs include:

- Custom load output.
- Active/reactive power.
- Tariff switching.
- Alarm outputs.
- Limiting power consumption.
- Energy-direction contact.

Protecting the Communication Interfaces and Auxiliary I/O Lines

The meter uses wireless communication ports with either the GSM cellular protocol or the Zigbee mesh network protocol to transfer usage and other data back to the utility company. These communication ports interface with the external environment and need protection from ESD due to transients such as lightning. TVS diode arrays can provide the necessary protection from ESD. In addition, components with low capacitance will minimize distortion to the transmitted and received RF signals. TVS diode arrays such as the SC1205-01ETG (Figure 7) can absorb ± 30 kV ESD strikes and safely dissipate a 7A 8/20us surge event as defined in IEC 61000-4-5. It safely clamps transient voltages to, typically, 10 V and has a maximum capacitance of 9 pF.

Protecting the Battery



Figure 7. SC1205-01ETG bidirectional TVS diode array for ESD protection on transceiver lines

Smart gas and water meters are usually powered by a fixed internal battery pack designed to last 10 years. The most used battery chemistry is lithium-ion (Li-ion). These battery packs have significant capacities; the most important is protecting the battery against short-circuit failures caused by faults in the pack or the meter's circuitry. A PCB space-saving, surface-mount

resettable fuse can quickly remove the battery pack from its load in case of an internal or external failure. Miniature resettable fuses are available with low internal resistance under 150 mΩ and fast trip times.

Efficient Sensing Components

One use for sensors in utility meters is flow measurement. Reed switches like the Littelfuse MDSR-10 series offer an accurate and proven technology for flow counting and offer the advantage of not drawing any power.

Unfortunately, there will always be a certain percentage of utility customers who want to "game the system" by tampering with their meters to manipulate the readings and reduce (or eliminate) the amount they will be charged. Smart meter designs include a variety of tamper-detection strategies to help combat the problem. The most common tampering method is simply to open the meter cover and damage the circuitry. Using a detect switch in the design allows the meter to determine when the cover is opened and send a signal to the microcontroller. Versions of detect switches can have a very low activation force, either under 40 grams or 75 grams. These switches allow 2 mm of overtravel, a valuable feature for detection applications. Side-activated detect models can have a minimal profile of 2 mm above the PCB. In low voltage 1.8 V logic circuits, versions can switch current as low as 10 μA.

Another method of meter tampering involves bringing a powerful electromagnet close to the meter's body, which can cause a magnetic transformer to saturate or affect other components. However, by employing a sensitive tunneling magnetoresistance (TMR)/CMOS logic sensor in the design, the meter can detect a small magnetic field and send a trigger to the MCU to record the tampering event. With either tampering method, after recognizing the attempt, the microcontroller notifies the monitoring support staff at the utility company, which can schedule an on-site follow-up and potentially impose a tampering penalty on the user.

Efficient Power Control Components

Many smart meter designers are turning to power MOSFETs for power conversion functions like input voltage pre-regulation and step-down conversion. Although the internal power supplies that feed the meter electronics typically use simple, inexpensive flyback converters, the latest high voltage silicon carbide power MOSFETs allow power supplies to work with a very wide input voltage range from 85 Vac to 440 Vrms or even higher for polyphase meters. SiC MOSFETs improve the reliability and robustness of the power converter.

Power MOSFETs with voltage ratings of more than 600 V are essential to accommodate wide AC input voltage ranges combined with the primary transformer's reflected voltage and lightning surges coming from the grid.

Manual Controls

Regardless of the application, smart meters require manual interfaces. For a reliable switch, look for sealed switches that prevent moisture from entering the switches' internal structure. Also, investigate switches with a long operating life. The Littelfuse C&K line of switches offers a number of options for

Table 1. Safety standards for electricity meters

Standard	Title	General Scope	Market
UL 2735	Safety standard for Electric Utility Meters	These requirements cover the electrical safety of electric utility (revenue) meters rated up to 600 V, which measure, monitor, record, transmit, or receive electrical energy generation or consumption information	United States
ANSI C12.1	Code for Electricity Metering	This Code is a reference for utilities, manufacturers, and regulatory bodies. It establishes acceptable performance criteria for new types of AC watt-hour meters, describes acceptable in-service performance levels for meters and devices used in revenue metering, and includes information on related subjects such as recommended measurements, installation requirements, test methods, and test schedules	United States
ANSI/IEEE C62.41.1	Guide on the Surge Environment in Low-Voltage (1000 V and less) AC Power Circuits	Describes the mutual interactions between surge protective devices (SPDs) and power system disturbances	United States
ANSI/IEEE C62.41.2	Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits	Provides guidance on how to assess by testing the effects of surges	United States
IEEE C62.45	IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits		United States
UL 2735C	Electric Utility Meters for Canada	Similar to UL 2735	Canada
CAN3-C17-M84	Alternating-Current Electricity Metering	Applies to the types of meters and associated devices normally used in the measurement of energy, power, or both in the supply and distribution of electricity as a commodity	Canada
EN 62052 Series	Electricity metering equipment – General requirements, tests, and test conditions	Similar to IEC 62052 Series	Europe
EN 62053 Series	Electricity metering equipment – Particular requirements	Similar to IEC 62053 Series, with the exception of DC (part 41), not yet published by CENELEC	Europe
IEC 61000-4-2	Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test	This standard is made to check the capability of the equipment to survive repetitive electrical fast transients and bursts	Global
IEC 61000-4-4	Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – 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	Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test	Evaluate the immunity of equipment when subjected to surges	Global
IEC 62052 Series	Electricity metering equipment – General requirements, tests, and test conditions	This part of IEC 62052 covers type tests for electricity metering equipment for indoor and outdoor application and applies to newly manufactured equipment designed to measure the electrical energy on 50–60 Hz networks, with a voltage up to 600 V	Global
IEC 62053 Series	Electricity metering equipment – Particular requirements	Part 21: Static meters for active energy (classes 1 & 2) Part 23: Static meters for reactive energy (classes 2 & 3) Part 24: Static meters for reactive energy at fundamental frequency (classes 0.5 S, 1 S, and 1) Part 41: Static meters for DC energy (classes 0.5 & 1) Part 61: Power consumption and voltage requirements	Global

		Standard	Title	General scope	Market
Component	Surge protection	UL 1449	Surge Protective Devices	Surge protective devices including MOVs shall comply with the requirements in the Standard for Surge Protection Devices.	United States
		UL 497B	Standard for Safety Protectors for Data Communications and Fire-Alarm Circuits	These requirements apply to TVS Diodes.	United States
	Overcurrent protection	UL 1434	Thermistor-Type Devices	Thermistors (PTCs and NTCs) shall comply with Standard for Thermistor-Type Devices.	United States
		UL 248-1	Standard for Safety Low-Voltage Fuses – Part 1: General Requirements	Fuses shall comply with Standards for fuses.	United States
		UL 248-14	Standard for Low-Voltage Fuses - Part 14: Supplemental Fuses		United States
	Battery	UL 1642	Lithium Batteries	Applicable standards that Li-ion batteries shall comply with.	United States
		UL 2054	Household and Commercial Batteries		United States
		IEC 62281	Safety of Primary and Secondary Lithium Cells and Batteries During Transport		Worldwide

Table 2. Safety standards for smart meter components

environmentally protected and long-operating-life switches.

Applicable Standards

The national and international standards that define the safety requirements for electricity meters. Table 2 covers safety standards for many of the components used in smart meters. These tables can help designers determine the standards their product must comply with based on the markets where the product is intended for sale.

Support for the Wide Range of Protection, Control, and Power Components

By consulting with component manufacturers' application engineers, designers can save precious development time and development costs. They can help with:

- Appropriate component selection,
- Identification of the appropriate standards with which the product must comply,
- Pre-compliance testing services which some manufacturers (such as Littelfuse) offer.

With applications engineering assistance, designers can optimize their design for rugged, reliable, and efficient performance. To learn more about emerging circuit protection, sensing, and power control technologies shaping the next generation of smart meters, visit www.littelfuse.com.

Download the Building and Home Automation Application Guide, courtesy of Littelfuse, Inc.




Nano² 415 SMD Fuse
Compact, high-interrupting protection for smart meters and IoT connected devices.

View the video






Keep Your Smoke and Heat Detector Designs From Going Up in Smoke

BY BARRY BRENTS

Smoke and heat detectors provide early warning to save lives and protect properties from damage. The National Fire Protection Association (NFPA), in NFPA 101 Life Safety Code, contains guidelines for smoke detectors in various types of facilities, including residential facilities. Many government entities mandate smoke detectors in facilities such as multi-family residential and commercial buildings, and smoke detectors are recommended or required in all bedrooms of a residential building.

Both rising awareness of the importance of fire protection and regulation drive the global growth of the smoke and heat detector market. As a result of increased regulation, population growth, and growth in cities, unit shipments of smoke detectors are expected to grow from 98 million units in 2020 to 150

million units in 2025, representing a significant compound annual growth rate of around 8.8%. Currently, the Americas and Europe have the largest markets for smoke and heat detectors, but the Asia Pacific region is growing at the highest rate.¹

The latest smoke detector designs incorporate more features, including wireless communication interfaces, that enable the devices to integrate into a smart home or building, providing automated warning capability. Thus, a house or building can have continuous, smart monitoring.

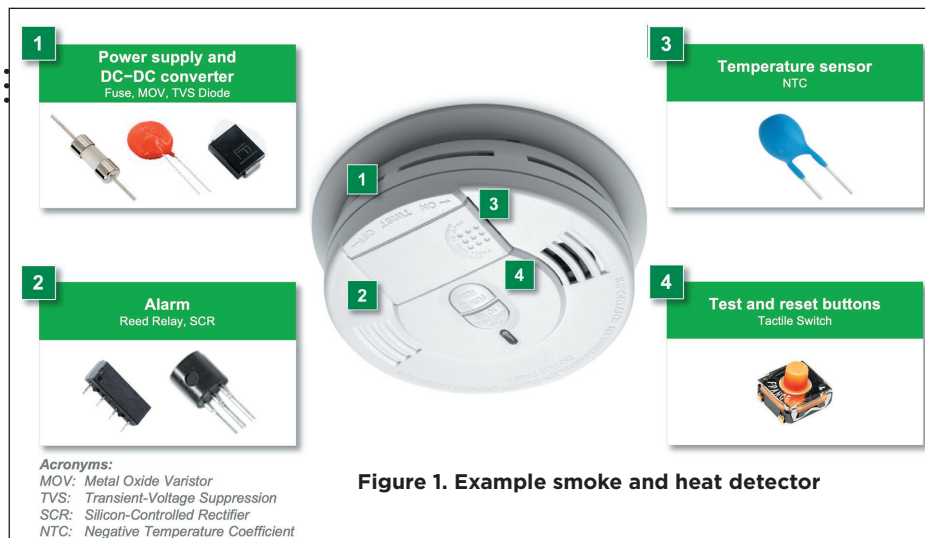
The design engineer's challenge is including all the new capabilities and maintaining maximum safety-critical device reliability. Secondary challenges require maximizing energy efficiency and minimizing the detector's size. This article will help designers overcome these challenges by providing techniques

and recommended components for protection from electrical hazards, long-life reliability, and energy efficiency of new smoke and heat detector designs. The article will conclude with recommendations on resources for designers that will not only assist with component selection but can also help with compliance with the applicable safety standards.

Overview of a Smoke and Heat Detector Design

The example smoke and heat detector version in Figure 1 is a line-powered model with a battery backup. The diagram recommends components for protecting the detector from overcurrent, transient overvoltage, and electrostatic discharge (ESD). In addition, the text blocks list recommendations for sensing, control, and energy efficiency. Designers only need a few components to protect the smoke and heat detector, with the added advantages of robust control and efficient operation.

The block diagram in Figure 2 details the circuit blocks in a high-performance smoke and heat detector. Microcontroller (MCU)-based intelligence with digital signal processing and wireless communication enables the device to have more functionality than conventional smoke and heat detectors. With this capability, the detector can collect a wide range of data and transmit the data and detector status to a monitoring station. A universal asynchronous receiver/transmitter (UART) allows the programming of the MCU so that the detector can perform additional functions. Greater functionality challenges the designer to ensure a reliable and robust product that remains operational on a 24/7 basis.



Electronics engineers must overcome multiple design challenges, including:

- protecting the smoke and heat detector from electrical hazards
- incorporating reliable sensing and control
- accommodating space limitations, and achieving operating energy efficiency.

Continue reading to learn about the recommended solutions to these challenges.

Protecting a Line-Powered Smoke and Heat Detector From Overcurrent, Overvoltage, and ESD

The AC power line, a high-power delivery source, can supply an undesirable, very high current if a short circuit occurs in the detector. Protect the AC/DC Power Stage and the whole detector with a fast-acting fuse to interrupt an overcurrent. Look for a fuse element with a low resistance under

10 Ω to minimize energy loss during normal operation. To avoid a potential arc in the fuse during an overcurrent condition, always select a fuse with a voltage rating higher than the maximum rated voltage of the AC power line. Of most importance, use a fuse that has nationally recognized testing lab (NRTL) certification. Certified or component-recognized components reduce compliance testing time and costs.

Transients can induce on the AC line from phenomena such as lightning strikes and large motors connected to the line that are turning on and off. All electronic products, including smoke and heat detectors connected to the AC line, are subject to these potentially high-voltage transients. A metal oxide varistor (MOV) can protect the AC/DC Power Stage from voltage transients. Look for a MOV with a high surge voltage rating and current absorption

of at least 1 kV and 500 A, respectively. Also, select a MOV that can safely operate at temperatures up to 125° C to ensure robust operation. As with the fuse, save certification time by choosing an NRTL-recognized component.

Some portion of a voltage transient will get through the AC/DC Power Stage and impinge upon the DC-DC Converter. A transient voltage suppressor (TVS) diode can respond quickly and clamp the transient to a safe voltage to protect the semiconductors in the DC-DC Converter stage and downstream circuitry. Consider the following properties that make TVS diodes excellent for both secondary transient protection and ESD protection:

- Ultra-fast response times of under 1 ps
- Capacity for at least 1500 W of peak power absorption
- ESD protection up to 30 kV
- Low clamping voltages
- Space-saving surface mount packages as small as the 0402 configuration.

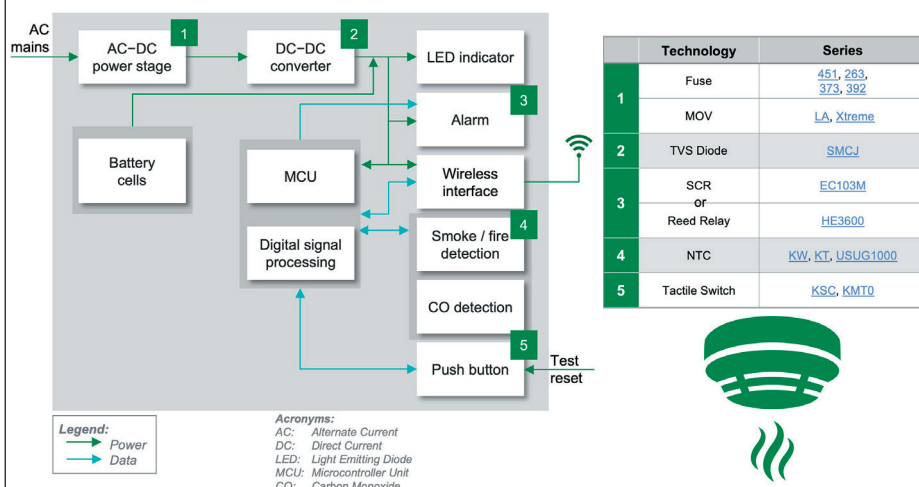
TVS diodes can be uni-directional or bi-directional, as shown in Figure 3. A bi-directional TVS diode has two diodes connected cathode-to-cathode, and its I-V curve is symmetric for positive and negative polarity voltages and currents. The bi-directional TVS diode clamps positive and negative voltage transients.

It only takes a few components to protect a smoke and heat detector from electrical hazards. Judicious selection of the protection components can contribute to a robust, reliable device.

Providing Reliable, Energy-Saving Control and Sensing

The Alarm, Smoke/Fire Detection, and Pushbutton circuit blocks equip the smoke and fire detector with the audio indication of a potentially hazardous condition, monitor the surrounding temperature, and initiate a test or a

Figure 2. Smoke and heat detector block diagram



reset state. These circuit blocks need to be robust and energy efficient.

Consider a silicon-controlled rectifier (SCR) or a reed relay to activate the audio alarm in the Alarm circuit. An SCR offers a low-power drive for the alarm. Energy-efficient SCRs can have gate currents under 500 μA . Another advantage of SCRs is that versions are available in surface mount packages for PC board (PCB) space savings.

If the design requires isolation between the audio alarm load and the other circuit blocks, use a reed relay. Reed relays have:

- Minimum coil power consumption for energy savings
 - Hermetically sealed contacts for both maximum reliability and maximum operating life
 - Sub-miniature, single-in-line packaging for conserving PCB space
 - Coil suppression diodes to protect coil drive circuits from coil back EMF
 - Optional magnetic shielding to minimize EMI generation.
- Temperature monitoring is a critical function of the smoke and heat detector.

In the Smoke/Fire Detection circuit, use a negative temperature coefficient (NTC) thermistor. A vital feature of a thermistor to consider is accuracy. Look for a rated accuracy of $\pm 0.5^\circ\text{C}$ or better. Investigate the thermistor's thermal response. Consider thermal time constants in air of under 10 s. Ensure a reliable, long life with epoxy encapsulation. For space savings, thermistors are available with diameters under 0.1 inch.

Select a high-reliability tactile switch for use in the Push Button circuit, which tests and resets the smoke/heat detector. Consider:

- Using a small, compact switch that can meet the design requirements for operating force.
- Selecting a sealed switch with an environmental rating of at least IP67, indicating the switch is waterproof and protected from dust.
- Specifying contact materials with high corrosion resistance.
- Selecting a long-life switch rating of 1 million operations.

Using components with the above characteristics will ensure reliable, energy-efficient control and sensing.

Consuming minimal power will maximize battery operating life in the event of a lengthy power outage.

Taking Advantage of a Component Manufacturer's Services to Achieve Design Goals

It is extremely difficult to have expertise in all aspects of product design and be aware of all the components that serve specific purposes. Designers can help themselves while saving development time and costs by taking advantage of the knowledge and expertise of the component manufacturer's application engineers. They can help with cost-effective component selection. In addition, the application engineers can assist developers with guidance on the requirements of applicable national and international standards that a specific product, such as a smoke and heat detector, must meet. Furthermore, some component manufacturers can perform pre-compliance testing on a product to help avoid costly, multiple test cycles at a nationally recognized testing lab due to non-compliance to a standard.

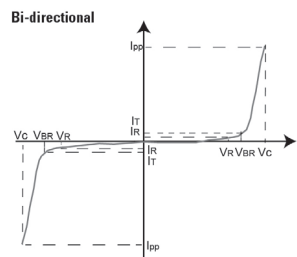
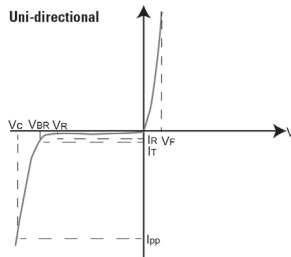
By partnering with a component manufacturer, designers can develop a high-reliability product and reduce time-to-market, contributing to maximized revenue.

Figure 3. Uni-directional and bi-directional TVS diode functional diagram

Functional Diagram: Uni-directional and Bi-directional TVS Diodes



I-V Curve Characteristics



- P_{PPM} Peak Pulse Power Dissipation** – Max power dissipation
 V_s Stand-off Voltage – Maximum voltage that can be applied to the TVS without operation
 V_{BR} Breakdown Voltage – Maximum voltage that flows through the TVS at a specified test current (I_T)
 V_c Clamping Voltage – Peak voltage measured across the TVS at a specified I_{ppm} (peak impulse current)
 I_R Reverse Leakage Current – Current measured at V_R
 V_F Forward Voltage Drop for Uni-directional

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Smart Water Heater Design: Three Important Technologies You Shouldn't Forget to Use

BY BARRY BRENTS

New technologies, including the Internet of Things (IoT), enable every product, including appliances, lighting, and HVAC systems, to be computer-controlled smart devices. In essence, any product that performs some level of control can become a smart device. That concept is also true for the ubiquitous water heater. As a result, the market for electric water heaters is growing at an attractive rate with a CAGR of 7.4%. Governments are spurring growth by incentivizing consumers to convert their gas-based water heating systems to electric systems to achieve the Net-Zero

Emissions Initiative. In addition, new building codes in some regions will not permit a natural gas hook-up, further accelerating the growth of all-electric products such as water heaters.

The addition of intelligence to a water heater adds sensitive electronic circuitry. It is incumbent upon the designer to ensure the reliability of the water heater by protecting the electronics from current overloads, voltage transients, electrostatic discharge (ESD), and overheating. Protecting the electronics also ensures that individuals who contact the water heater are safe from thermal and

electric hazards. The designer also needs to ensure the use of long-life components.

This article provides designers with information on three critical technologies: protection, control, and sensing, for developing an electric water heater robust to external overloads, transients, and ESD. The components representing these technologies will help create a safe, efficient, long-life water heater that safely controls water temperature. By using the recommended components, design engineers will achieve the goal of developing high-quality, reliable, smart water heaters.

Overview of a Smart Electric Water Heater

Like almost every electrical and electronic product available today, electric water heaters use a microcontroller to process programming information and deliver water at the required temperature. The water heater uses AC line power to control the heating element and power the microcontroller and the other DC circuitry, such as the touch-screen display and the wireless interface. Temperature probes provide the input and output water temperatures,

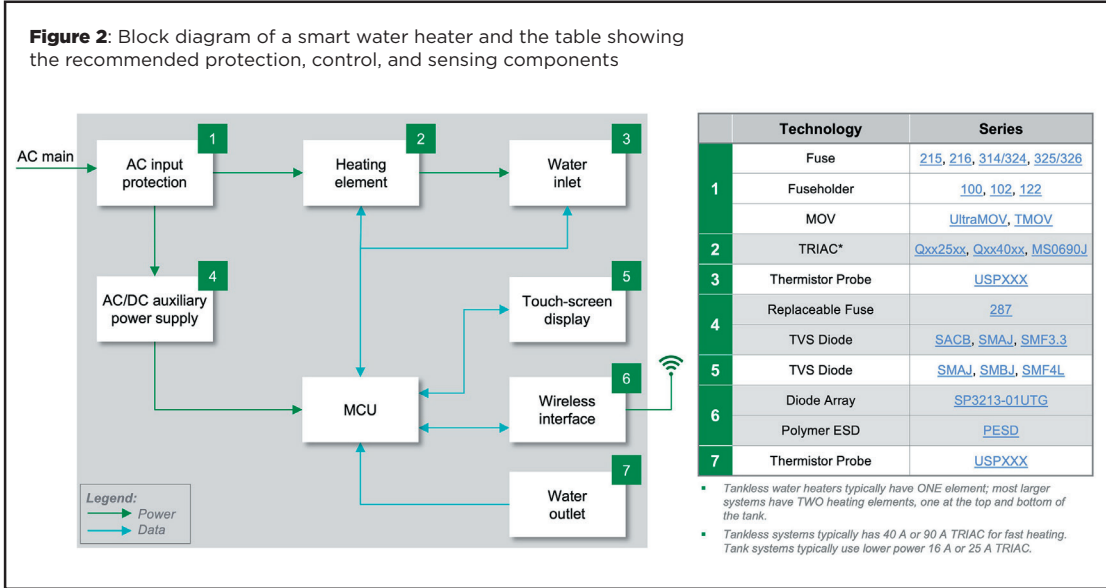
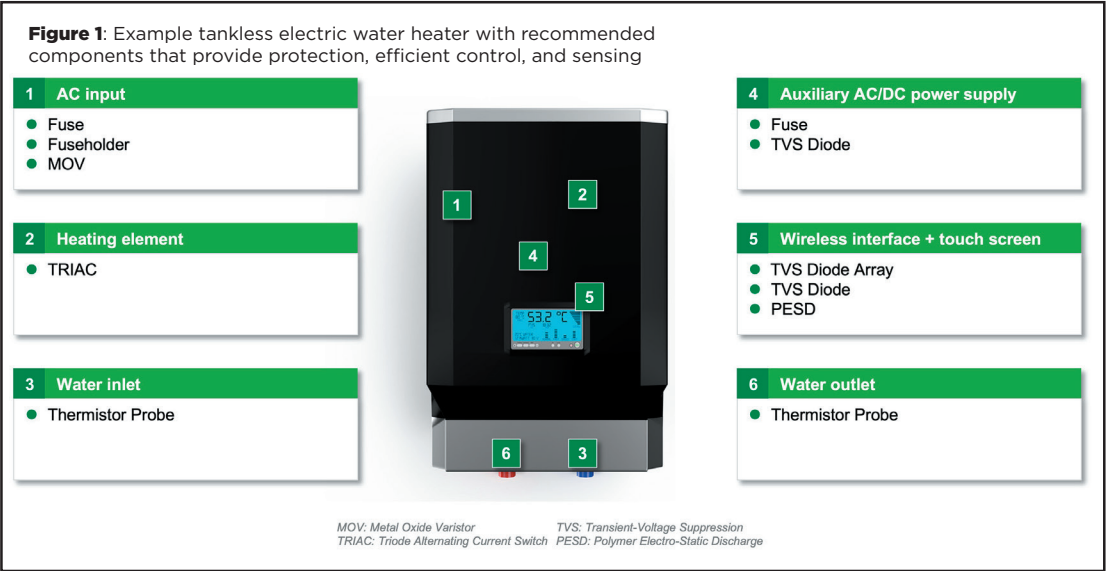
enabling the microcontroller to control the heating element. Figure 1 shows a typical water heater, its primary circuit blocks, and recommended components for protection, efficient control, and sensing.

Figure 2 shows the block diagram for an electric water heater in greater detail with the recommended protection, control, and sensing components listed in the adjacent table. This article presents how to protect the circuit blocks and offers appropriate component solutions that apply control and sensing.

Protecting the Water Heater From Overloads, Transients, and ESD

The AC Input Protection block protects the water heater circuitry from the current overloads and high voltage transients inherent on the AC line. Use a fuse to protect against current overloads and a metal oxide varistor (MOV) to absorb voltage transients induced on the AC line.

Consider using a cartridge fuse to allow easy replacement in the event a current overload causes the fuse to trip. Ensure the fuse holder that supports the



fuse is UL/CSA/IEC compliant.

Use a metal oxide varistor (MOV) to absorb AC line-induced voltage transients from machinery, appliances, and even lightning. Look for a MOV with:

- The ability to absorb as much as 10 kA of transient current
- The capacity to absorb at least 400 J of transient energy
- Compliance to IEC 61051-1 and 61051-2, Varistors for Use in Electronic Equipment.

The AC/DC Auxiliary Power Supply powers the MCU, the Touch-Screen Display, and the Wireless Interface. Consider secondary fusing and transient protection for the sensitive semiconductors. Use a fast-acting DC fuse in this circuit. Also, consider a transient voltage suppressor (TVS) diode which can absorb up to 400 W of pulse power. TVS diodes can clamp a transient in less than 0.1 ps to avoid damaging sensitive semiconductors. To save PC board space, look for a surface mount TVS diode.

Touch-Screen Display users have direct contact with the display to set controls for the water heater and obtain the water heater's status. As a result, the display is susceptible to ESD from human contact. Use a TVS diode to protect the touch-screen display circuitry. Models of TVS diodes comply with IEC 61000-4-2, Electrostatic Discharge Immunity Test, and provide ESD protection up to 30 kV for either a through-the-air strike or through direct contact.

The Wireless interface transmits data and receives control information from PCs, PLCs, tablet computers, and smartphones. Protecting the data lines from ESD avoids corruption of data transmission and reception. Consider bi-directional TVS diode arrays shown in Figure 3. Versions of this TVS diode can safely absorb ± 12 kV of contact ESD discharge and 40 A from a fast transient. These diodes minimize signal distortion

capacitance added to the circuit.

Alternatively, consider polymer ESDs for protecting data lines. These components have low capacitance, typically under 0.25 pF. The leakage current is under 10 nA to minimize power consumption in the Wireless Interface circuit

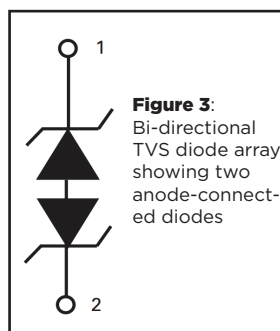


Figure 3: Bi-directional TVS diode array showing two anode-connected diodes

Maximizing Efficiency and the Life of the Water Heater

Electric water heaters typically use a TRIAC to control the heating element. A TRIAC only needs a low-power drive circuit for control, and it eliminates contact bounce when switching power to the heater and has no audible noise. TRIACs offer high reliability, with versions offering surge capacity up to 250 A and a voltage capacity up to 100 V. The solid-state switching provided by a TRIAC provides reliable long-life operation.

Tankless water heaters typically have one heating element, but larger systems can have two heating elements. One element is at the top of the tank, and the second heating element is at the bottom of the tank. For fast heating, tankless systems typically use a 40 A or a 90 A TRIAC which is a much smaller component than an electromechanical relay with a similar contact current rating. Tank systems typically use lower power, 16 A or 25 A TRIACs.

Controlling Water Temperature and Protecting the Water Heater From Overheating

Use thermistor temperature probes to monitor the water temperature at

A thermistor provides more accurate temperature monitoring than other temperature sensor types. The fast thermal response of a thermistor probe can contribute to the water heater's efficiency. Also, take advantage of a thermistor's small form factor.

The Benefits of Including Components for Circuit Protection, Efficient Control, and Sensing

It does not take many components to protect a water heater and enhance its reliability. Save development and compliance testing time by including the three technologies, circuit protection, efficient control, and sensing, into the project plan. Not emphasizing these aspects of the design can lead to re-design, introduction delays, and cost overruns.

Fortunately, the component manufacturer's application engineers can help save development time with:

- Cost-effective component selection
- Guidance on applicable standards
- Pre-compliance testing to help

catch problems before the water heater is submitted to a standards body for compliance testing.

Using the recommended components for protection, control, and sensing will ensure a high-reliability water heater with low in-warranty repair costs and high customer satisfaction.

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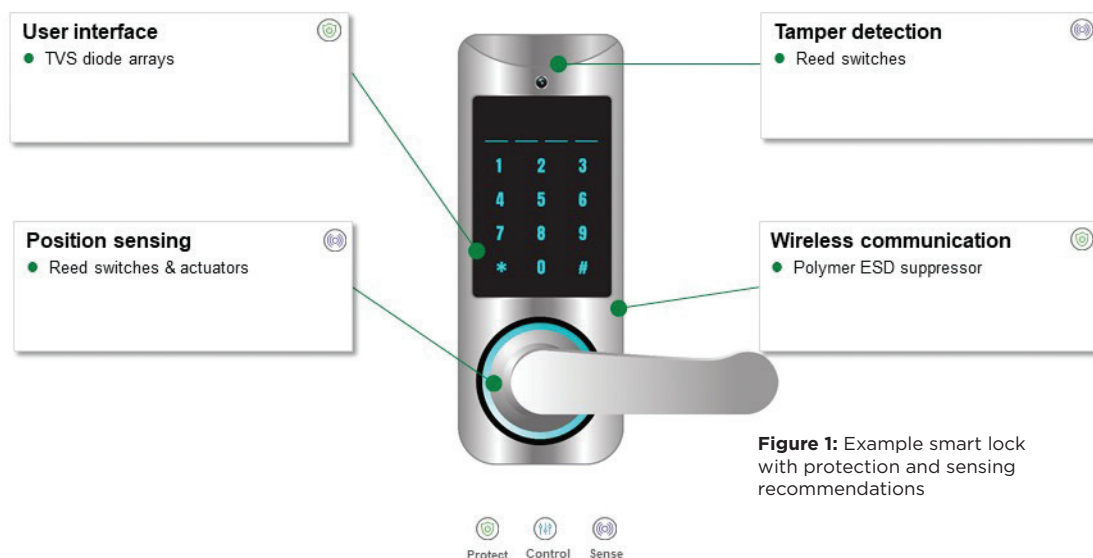


Figure 1: Example smart lock with protection and sensing recommendations

How to Design Intelligent Circuit Protection and Sensing For Smart Home Locks and Access Controls

BY BARRY BRENTS

The rapid development of both smart home and advanced building automation is enabled by a combination of smartphone, networking, and internet-of-things (IoT) technologies. These technologies provide increased automation, control, and security that gives homeowners and office occupants enhanced convenience and comfort along with greater safety. Wherever a homeowner or office occupant is, they can easily view the status of their door locks and window and door access.

Today's engineers that design home and building security products, such as smart locks and window and door sensing devices, need to ensure that their devices are not creating a false sense of security for their customers. An important step to improving overall reliability and safety is to understand the protection and sensing components required to

comply with applicable safety standards and to ensure safe, robust, and reliable products.

The smart locks market alone is seeing high growth and is opportunistic for innovation. The global growth for smart locks is expected to have a compound annual growth rate (CAGR) of 25 percent with unit growth expanding to about 23 million units in 2024¹. The residential market represents the majority of the growth, which will be around 70 percent. As with smart locks, the increased awareness of personal security will drive global growth of window and door sensors, especially in developing economies. Shipments are expected to increase to around 465 million units in 2024². This growth is at a CAGR of around nine percent. The market for smart home safety and security products is clearly a healthy, attractive market.

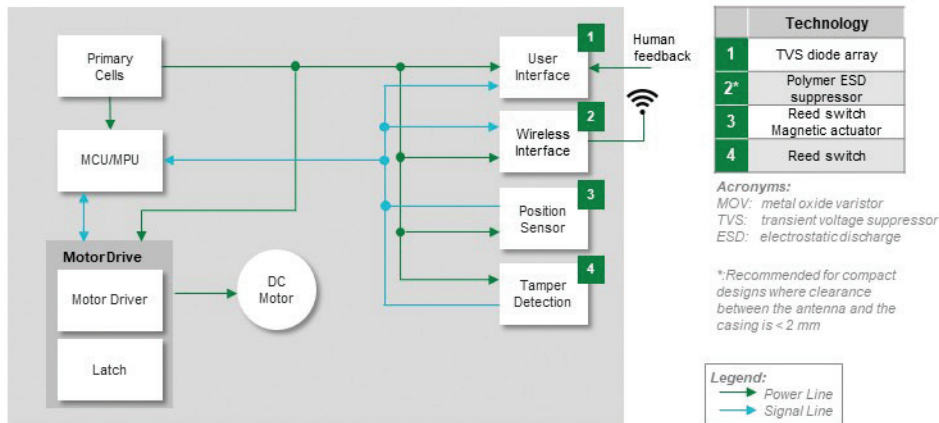
Protecting Smart Lock Designs

Smart locks consist of a keypad for manual access, a wireless protocol link for smartphone access through a software application, a sensor that monitors the position of the door handle, actuators to lock or unlock the door, and sensing to detect any effort to circumvent the lock. An example smart door lock with recommended circuit protection and sensing components to ensure reliable operation is shown in Figure 1. A detailed block diagram of a smart lock showing the recommended placement for the protection and sensing components is shown in Figure 2.

The prime danger to smart lock electronics is electrostatic discharge (ESD). Both the user interface and the wireless interface are susceptible to ESD from end-users.

The User Interface provides a keypad that a person must contact

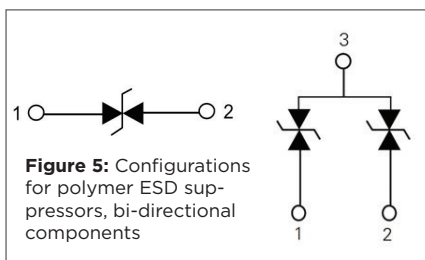
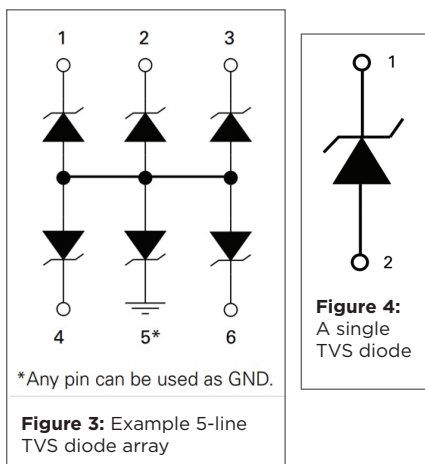
Figure 2: Smart lock block diagram showing the circuit blocks where protection and sensing components are recommended



with their finger to enter the pre-programmed access code. All users are a source of ESD, particularly in very dry environments. Designers should protect the User Interface circuitry from ESD to avoid damage to the sensitive electronics.

For ESD protection, consider using a transient voltage suppressor (TVS) diode or TVS diode array. TVS diodes are Zener diodes built with silicon avalanche technology and can offer a minimum protection level of ± 15 kV of ESD voltage. A TVS diode array can house up to six Zener diodes to protect five signal lines and provide a ground reference (Figure 3). The advantage of a TVS diode array is that one space-saving component in an 0402 surface-mount package can protect up to five lines. The impact on the circuit is minimal; a TVS diode array can have a leakage current of only 1 μ A. If a higher level of ESD protection is needed, individual diodes can provide ESD protection for each signal line. A single TVS diode (Figure 4) can withstand as much as ± 30 kV. Regardless of the configuration that is used, place the TVS diodes as close to the circuit's input as possible to prevent any ESD transient from penetrating into the circuitry.

The Wireless Interface links to a cellular network, wireless LAN, or WiFi network to communicate with



smartphones or other networked devices. Because it is exposed to the external environment, the Wireless Interface requires ESD protection. A polymer ESD suppressor is the recommended component. The benefit of a polymer ESD suppressor is its ability to respond to and absorb any ESD transients while having a negligible impact on the characteristic impedance of the Wireless Interface output. Polymer ESD suppressors withstand a ± 8 kV direct contact ESD and a ± 15

kV air strike. Typical capacitance for the component is a low 0.06 pF. Response time to a transient is very fast, under 1 ns. The ESD suppressor should be as close to the input antenna connector as possible. Figure 5 shows two configurations for polymer ESD suppressors, bi-directional components.

Sensing Recommendations For Smart Locks

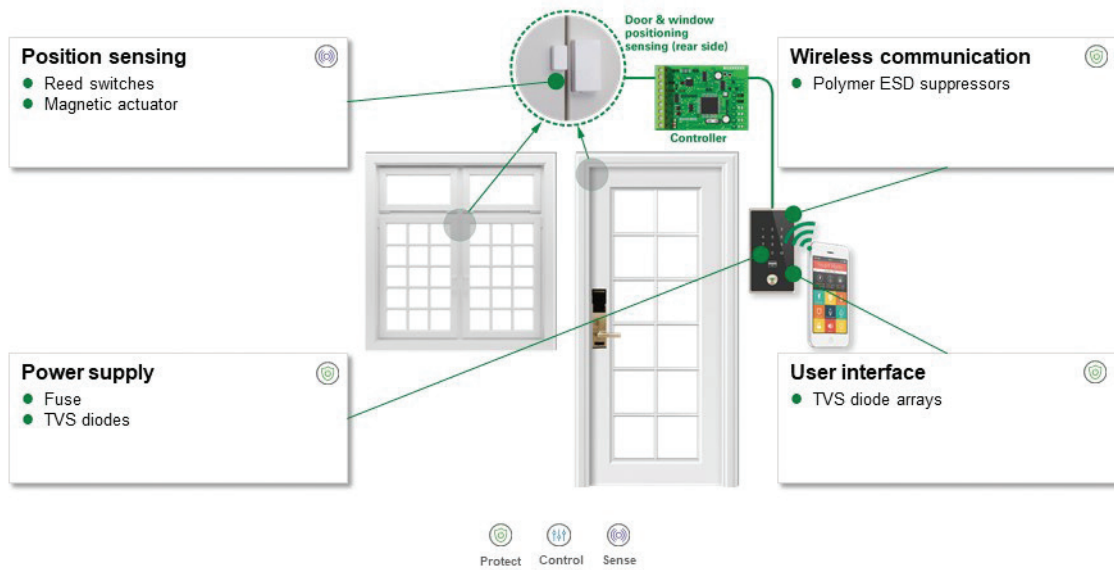
To ensure doors are completely seated in their door frames requires sensors at each location for detection. As a low-power sensing solution for battery-operated smart locks, consider a reed switch with a magnetic actuator. Reed switches do not require any drive power. They are also hermetically sealed for long life in any environment. Versions can switch 10 W with ratings up to 0.5 A or up to 200 V. The switches are very well-suited for use in low voltage controller circuits. In addition, surface mount versions are available for automated circuit board assembly.

Consider a cylindrical magnetic actuator designed for mounting on door frames. An AlNiCo magnet is the recommended material. The size can be as small as 5 mm x 25 mm.

The Tamper Detection circuit will also require a sensor. This sensor alerts the user if the lock has been compromised and the door has been opened. Again, a reed switch with an actuator is recommended. The combination reed switch-actuator consumes a minimal amount of power while maximizing battery life. Consider a reed switch-actuator pair with adjustable sensitivity to ensure a fast response to a tampered lock.

It takes only four components to provide protection and sensing for smart locks. These components consume a minimum of printed circuit board space and ensure a safe and reliable product.

Figure 6: Example wireless window and door sensing system with protection and sensing recommendations



Protecting Wireless Door and Window Sensor Designs

Sensors provide information on the state of wireless windows and doors throughout a home or building. Users can obtain information on whether windows and doors are open or closed from any location. An example hardware configuration for both a wireless door sensor and a wireless window sensor is shown in Figure 6. The diagram also shows several recommended circuit protection and sensing components for each of the hardware elements.

There are two main elements of the system (Figure 7). The sensor circuitry detects the position of the window or door and reports the information to a controller which is also the interface for the user and the transmitter of information to any location. The sensing circuitry that is on the door and window must allow for movement; thus, the circuitry itself must be battery-operated. The User Interface Controller (UIC) and keypad are in a fixed location so that it can be AC line powered. Using the AC line power is a typical commercial application.

As with the smart lock, designers should consider a reed switch-

magnetic actuator for proximity detection. With no activation power required, the reed switch extends the battery life of the sensor system. The Wireless Interface circuit blocks in the sensor and the user interface controller can use polymer ESD suppressors to ensure protection from ESD while maintaining the integrity of the RF transmission. Also similar to the smart lock, the User Interface circuit block with its keypad should have ESD protection from human contact. A TVS diode array can protect the sensitive signal lines from ESD transients.

Where AC power and an AC-DC power supply energize the User Interface Controller, designers need to protect the controller from potential threats from the AC line. Potential damage to the electronics can come from overcurrent conditions, lightning strikes and other voltage transients, and ESD transients. By using the correct fusing and voltage transient protection devices, designers can protect their designs from these conditions

There are numerous fuse specifications that should be taken into consideration including the fuse's

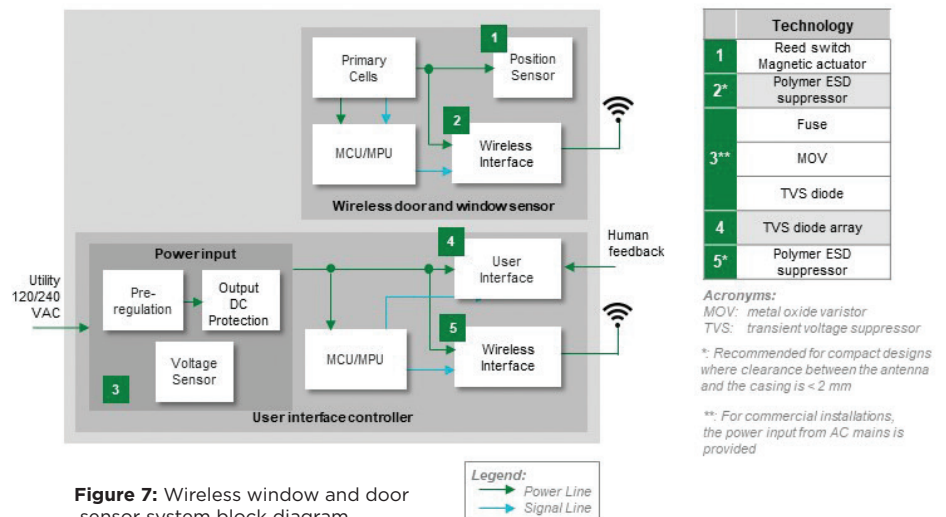


Figure 7: Wireless window and door sensor system block diagram

Standard	Title	General scope	Littelfuse Technology	Market
UL 1034	Standard for burglary-resistant electric locking mechanism	These requirements apply to the construction, performance, and operation of burglary-resistant electric locking mechanisms and their related devices, such as control units, control switches, and power supplies, and the like used to secure and release doors	Fuse, MOV	North America
GA 374	Burglary-resistant electronic locks	This standard is applicable to the design, manufacture, inspection, and acceptance of burglary-resistant electronic locks	Fuse, MOV	China
GA 701 - 2007	General specifications for burglary resistant fingerprint locks	This standard applies to fingerprints as an input signal to identify and address relevant information to electrically control the mechanical locking mechanism's opening and closing of certain anti-destructive power locks	Fuse	China

Table 1:
Applicable standards for electronic locking and related products

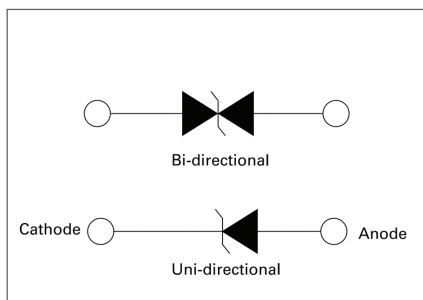


Figure 8: Bi-directional and uni-directional TVS diode configurations

operating characteristics and the case style to meet a wide range of design objectives. Consider time-delay or slo-blo fuses to avoid nuisance shutdowns. Also, designers should select the fuse current rating to accommodate short-term overloads such as in-rush currents where applicable. Other considerations include the interrupting rating which defines the maximum overload current the fuse can interrupt. This parameter trades off with fuse size. If a small fuse is needed, the designer will need to make sure that the fuse can withstand the available short circuit current supplied by the AC line. A final consideration is the fuses' cold resistance. If power consumption is a prime concern, then designers should look for a fuse with low cold resistance.

To safely absorb the energy from a voltage transient on the AC line from lightning or motor turn-on and turn-off spikes, consider employing a metal oxide varistor (MOV). These components can absorb a current surge as high as 10,000 A from an 8/20 μ s transient pulse. A 20mm MOV can also absorb greater than 500 J of energy.

As an alternative component to the MOV, consider using a TVS diode. These components are developed for protecting sensitive circuits from lightning and other transients and

can withstand as much as 1500 W of power from a 10/1000 μ s pulse. To minimize power consumption, TVS diodes will draw less than 1 μ A under normal operating conditions. Also, a TVS diode can respond quickly to transients in less than 1 ps. Surface mount (SMD) versions are available to both reduce the PC board space required and minimize assembly labor. Designers can select either a bi-directional diode or a uni-directional diode (Figure 8).

Just like smart locks, it does not take many components to protect window and door sensing circuits. Designers have numerous options to select the most suitable versions for their specific applications.

Understand and Comply With Applicable Industry Standards

Building automation and smart home electronics designers should have a working knowledge of the standards that apply to the products they are developing. It is important to incorporate these requirements during the development phase of any design project. Failure to accommodate the standards can lead to expensive re-design work, delays in product introduction, and potential cost overruns. In addition to general product safety standards such as the IEC 61000 series which define requirements for withstanding ESD, electrically fast transients, and lightning, specific standard exist for electronic locking and related products. Table 1 lists the applicable standards for electronic locking and related devices. The documents cover both North America and China and are

essential reference materials for engineering teams that design smart locks and window and door sensors.

Robust Reliability Results in End-User Satisfaction

It is a tremendous competitive advantage for manufacturers of smart locks and window and door sensing products to have a reputation for quality, reliability, and convenience. By using the appropriate protection and sensing components, designers will contribute to achieving safe and robust products for end-users. Fortunately, only a small quantity of components is needed to fully protect their product and comply with safety standards. With low-energy sensors, designers can maximize battery life to minimize the frequency of battery replacement. Electronics designers have a many alternative components that they can use. A final recommendation for achieving optimal home automation designs is to take advantage of the expertise of the component manufacturers and seek their advice.

References:

- 1 Smart Lock Market Size. Grandview Research. February 2020.
- 2 Window Sensors Market Outlook. Outlook Market Research. May 2019.

Circuit Protection

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