Safety | Volume 32

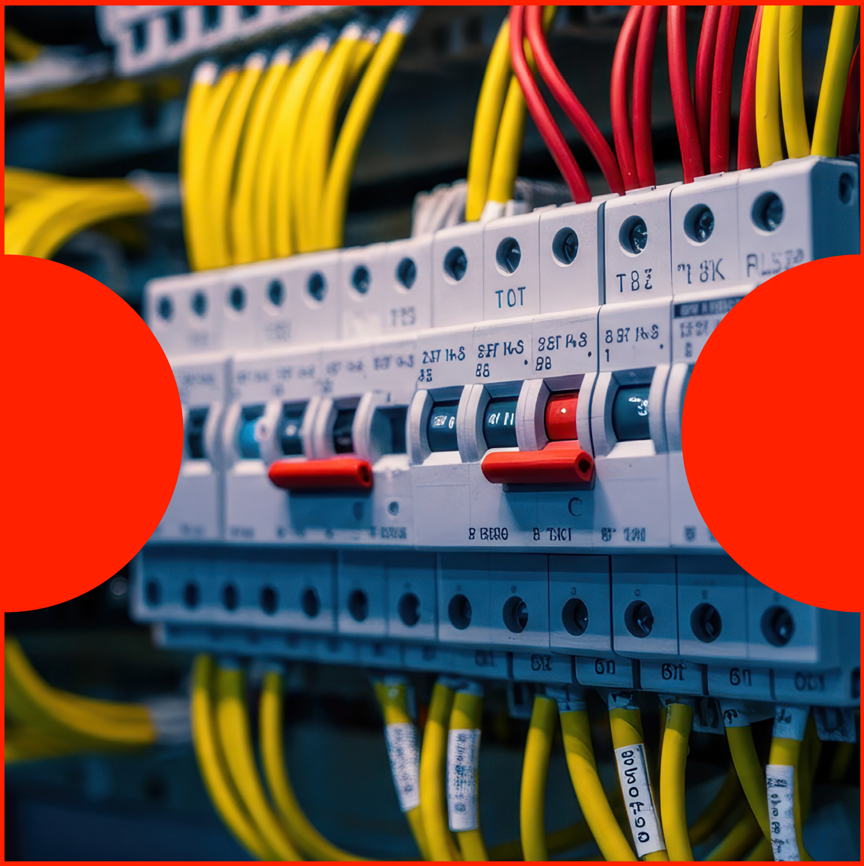
We get technical

How to apply hybrid AC surge protection devices for improved surge protection

Protecting USB-PD and PoE circuits from industrial power surges

How to protect circuits from high-temperature overload and fault currents

Why and how to effectively use electronic fuses to protect sensitive circuits



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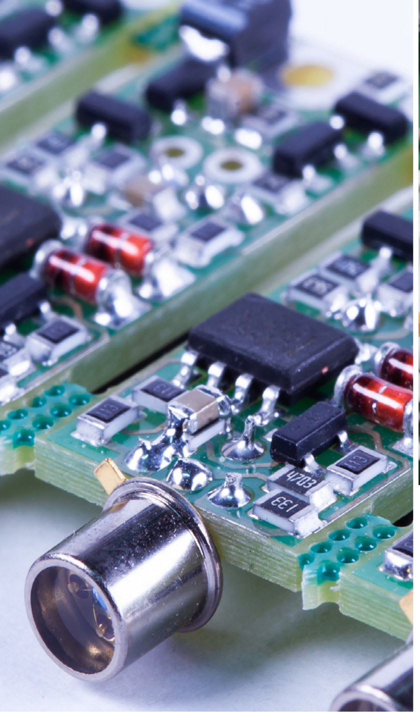
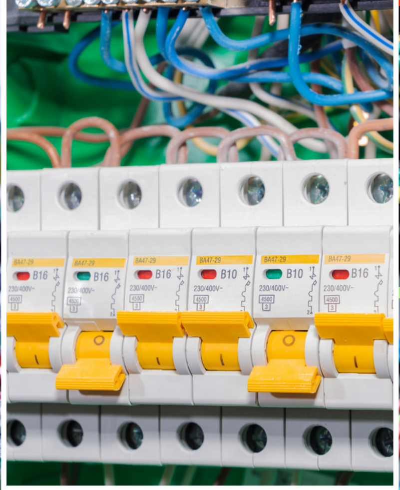
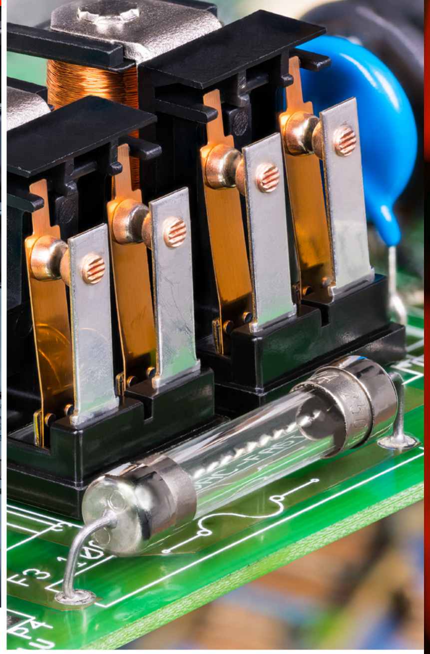





contents

DigiKey

Editor's note

Welcome Welcome to the DigiKey eMagazine Volume 32 – Safety.

Safety remains a critical priority in modern electronic and industrial system design. As systems become more powerful, connected, and complex, engineers must ensure reliable protection against surges, faults, and harsh operating conditions. This issue of our eMagazine focuses on technologies and design strategies that help safeguard equipment, data, and users.

Our featured articles highlight innovative solutions from leading manufacturers. HARTING introduces its Han® Protect Fuse-Integrated Connectors, combining connectivity and circuit protection in a single streamlined solution. Littelfuse explores the advantages of Omnipolar Magnetic Sensors for flexible and reliable system monitoring, while TRACO Power presents its TXO Series AC/DC Power Supplies, designed to deliver dependable power conversion for demanding industrial applications.

Additional articles explore key protection topics, including applying hybrid AC surge protection devices for improved surge defense, protecting USB-PD and PoE circuits from industrial power surges, and safeguarding circuits from high-temperature overload and fault currents. We also examine the effective use of electronic fuses to protect sensitive electronics and how robust digital isolation enhances safety in high-voltage applications.

Together, these insights highlight practical ways engineers can design safer, more resilient systems across a wide range of applications.

Pushing Performance Since 1945

Expertise Applied | Answers Delivered

Powering the tight squeeze in industrial control systems

By Abhishek Jadhav

TRACO POWER

Open up an industrial control cabinet, and the first thing you'll notice is how much is being asked of a very small space. Controllers, communication modules, and I/O systems are being packed more tightly, even as power levels continue to climb. It creates an almost pressure-cooker effect if you consider the issue of keeping heat under control within such a limited footprint.

This leaves design engineers in a position where they have to weigh some trade-offs. Higher-end power supplies can address thermal and safety requirements but may exceed the budget of the application. Lower-cost options may reduce upfront cost, but can bring about concerns related to efficiency, cooling, and compliance.

TRACO Power addresses these challenges with its TXO series (Figure 1). Spanning 45 W to 500 W, the open-frame AC/DC lineup is designed for cost-sensitive industrial applications that need to make careful use of space while supporting safe, predictable operation.

TXO 45

The TXO 45 is the entry point to the series, serving lower-power industrial applications. It provides 45 W in a compact 2" x 3" open-frame format, which fits easily into control boards, embedded systems, and sensor-based equipment. The unit uses a flyback converter topology, placing it at the simpler end of the TXO lineup.

Figure 1: A representative example of the TXO series. (Image source: TRACO Power)

The TXO 45's fanless, convection-cooled design is well suited to systems that do not require forced-air cooling—keeping thermal management straightforward. Typical efficiency is around 85%, and it is available in 12, 15, 24, and 48 V versions for a range of smaller automation and control tasks.

TXO 60

The TXO 60 is the next step up from the TXO 45, delivering 60 W in the same 2" x 3" form factor. It is a good fit for expanded control systems, retrofit designs, and applications that need a modest power increase without moving to a larger footprint.

The TXO 60 also uses natural convection cooling and delivers efficiency around 85%. No-load power consumption stays below 100 mW, keeping power draw low while the supply is idle. The TXO 60 also offers a hold-up time of 60 ms at 230 VAC, allowing the output to remain stable through brief dips in the incoming AC supply.

TXO 120

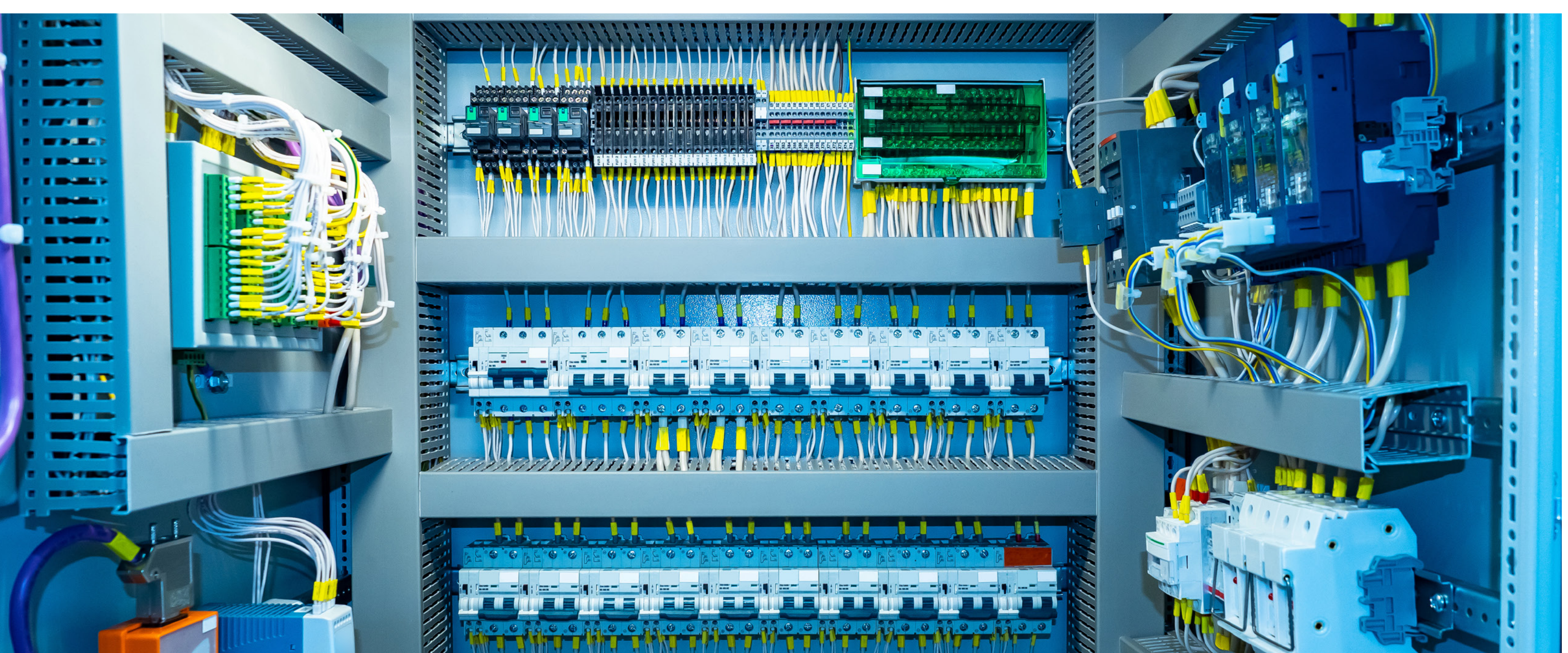
The TXO 120 has the same 2" x 3" footprint, pushing it to its highest output level at 120 W. It is intended for dense control panels, IoT gateways, communication hubs, and other systems where room is limited but power needs are growing.

The TXO 120 uses LLC converter topology, which helps raise efficiency to as high as 92% and reduces wasted heat at higher output levels. It also adds active power factor correction, drawing power from the AC line in a cleaner, more controlled way. Under natural convection, the unit is rated for 100 W up to +50°C. With forced-air cooling, it can deliver the full 120 W up to +50°C.

TXO 150

The TXO 150 is where the series moves beyond the compact 2" x 3" format and into a larger 2" x 4" footprint to accommodate a 150 W output. The added board area eases thermal demands at this power level and makes the unit a better match for industrial controllers, HMI systems, and mid-power automation equipment.

Like the TXO 120, it uses LLC converter topology and active power factor correction. With typical efficiency of 90%, the TXO 150 is built for higher sustained loads. It is rated for 120 W under natural convection up to +50°C, or the full 150 W with forced-air cooling.



TXO 300

The TXO 300 moves into a larger open-frame chassis of roughly 3" x 5", reflecting the increase to a 300 W output. It is aimed at complex automation platforms, industrial controllers, and test and measurement equipment, where the controller needs more visibility into power conditions.

The TXO 300 also uses LLC converter topology and active power factor correction. Efficiency reaches up to 88%. The larger shift is that the TXO 300 brings the power supply into closer coordination with the rest of the system. Remote on/off allows the system controller to place the power supply in standby without removing AC input power. A Power Good signal tells the controller when the DC output is stable and within tolerance, helping prevent startup during a brownout or fault. The 5 V standby output keeps low-power control logic running when the main output is off, while remote sense corrects for voltage drop across longer cable runs.

Full 300 W output requires forced-air cooling. Under natural convection, the output is 180 W for the 12 V and 15 V models, and 200 W for the 24, 36, 48, and 56 V versions.

TXO 500

The TXO 500 is the top end of the series, moving into a 4" x 6" package with an L-bracket for chassis mounting, delivering up to 500 W for larger machines, industrial automation lines, test and measurement platforms, and high-power control systems. Output current reaches as high as 37.5 A on the 12 V model, extending the series into applications such as motors, actuators, and high-end processing boards.

The TXO 500 carries the same smart integration features as the TXO 300 to coordinate power behavior at the system level. It includes remote on/off, a Power OK signal, a 5 V standby output, and remote sense. It also adds output voltage adjustment, allowing the nominal DC output to be trimmed within a limited range to better match system requirements. The TXO 500 uses LCC converter topology, helping it reach efficiency as high as 92%. It also retains active power factor correction.

Under natural convection, the output is rated at 240 W for the 12 V and 15 V models, and 290 W for the higher-voltage versions. With forced-air cooling, the output rises to 450 W for the 12 V and 15 V models, and the full 500 W for the other versions.

Shared characteristics zcross the TXO series

The TXO series features several core characteristics. Reinforced 3000 VAC input-to-output isolation appears throughout the lineup—rarely found outside of medically approved products—providing separation between AC input and low-voltage output to protect workers and sensitive electronics.

All TXO models are certified to IEC/EN/UL 62368-1 safety standards, enabling reliable integration into globally compliant industrial equipment without additional safety redesign. Built-in EN 55032 Class B EMC filtering limits electrical noise and interference while reducing the amount of external filtering required.

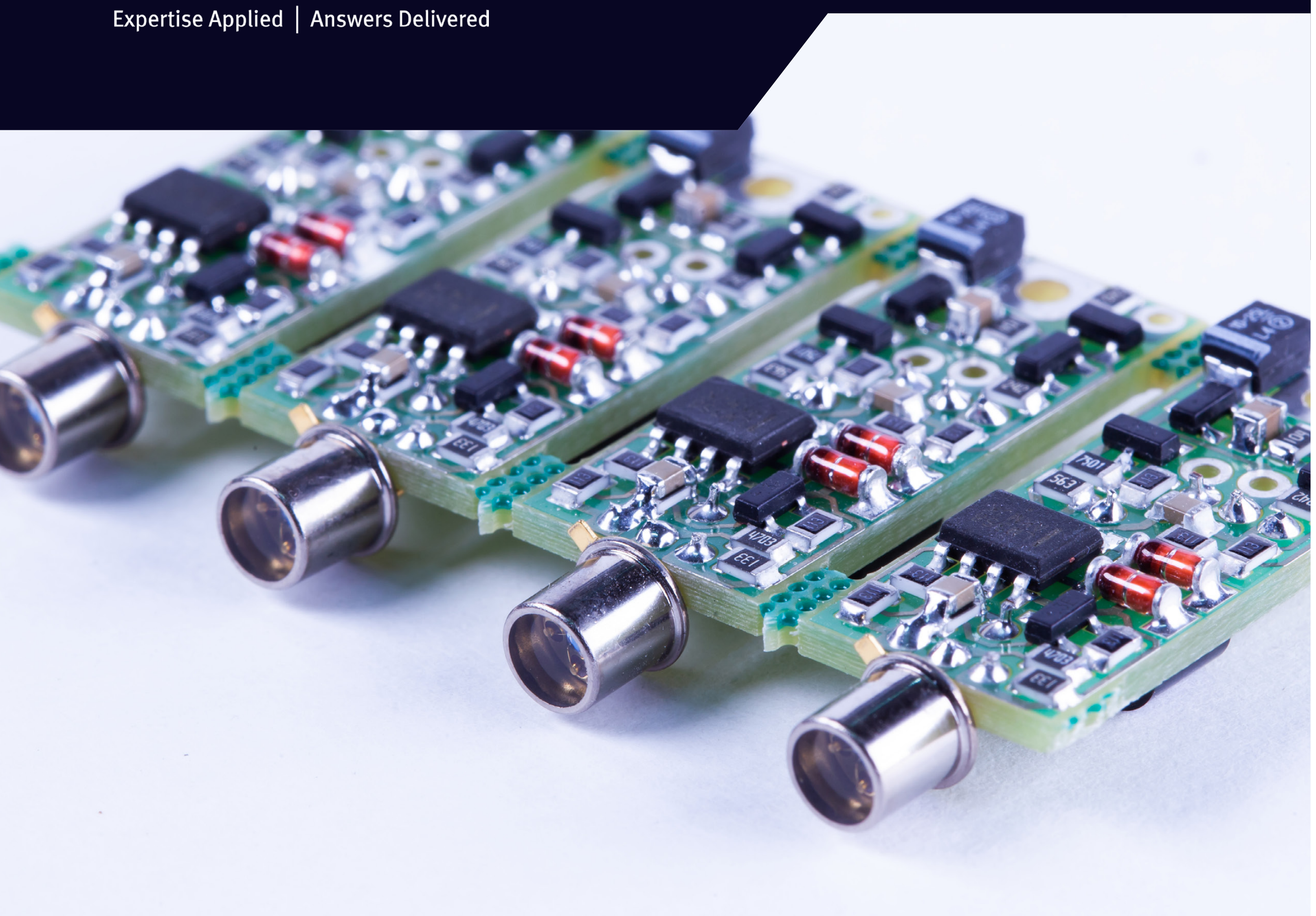
The TXO family incorporates short-circuit, overvoltage, and overcurrent protection, helping prevent damage to both the power supply and downstream components during fault conditions. The series operates from -20°C to +70°C, with full-load operation to +50°C and continued operation to +70°C with derating.

To learn more, visit Traco Power TXO Series AC/DC Power Supplies.

Designing position sensing with omnipolar magnetic sensors

By Abhishek Jadhav

Littelfuse
Expertise Applied | Answers Delivered



Position sensing is expected to be accurate and reliable in an industrial control knob or automotive steering system. But it rarely is. Traditional potentiometers depend on physical contact, causing them to suffer from wear, drift, and output inconsistency over time. Even the attempt to move to magnetic sensing is susceptible to low signal levels, sensitivity to alignment, and temperature-induced variables.

Omnipolar magnetic sensors based on Tunnel magnetoresistance (TMR) technology address these limitations. They generate high-amplitude, polarity-independent signals to reduce the reliance on external signal conditioning while improving tolerance to mechanical and temperature variations. This allows more consistent and long-term performance in contactless position sensing.

For example, Littelfuse offers the LF53464-08TMR and the LF53466-08TMR analog-output angle sensors that provide differential sine and cosine voltage signals corresponding to the 360° rotation of a nearby magnet to allow precise angle measurement. The ratiometric output architecture also improves robustness to maintain accuracy despite changes in supply voltage and magnetic field strength.

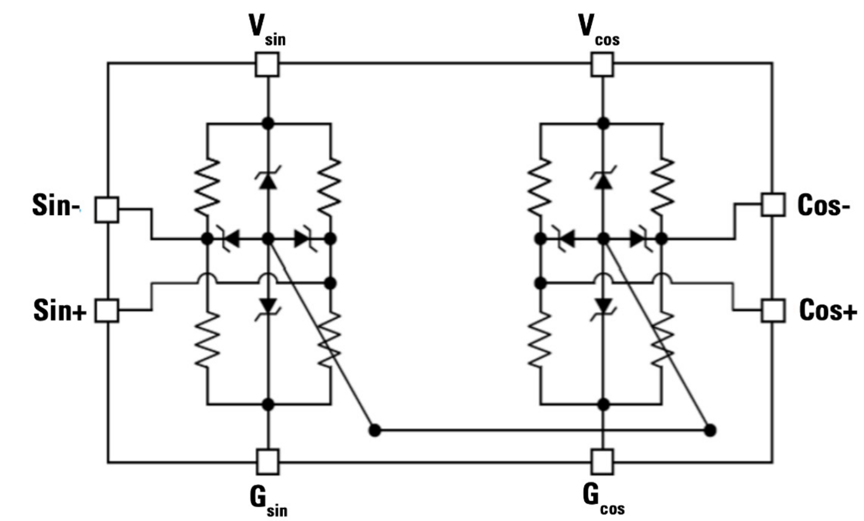


Figure 1. Littelfuse's LF53464-08TMR and LF53466-08TMR angle sensors' functional block diagram. (Image source: Littelfuse)

Inside Littelfuse omnipolar magnetic sensors

The core of Littelfuse LF53464-08TMR and LF53466-08TMR angle sensors is two complete and independent Wheatstone bridges that are physically oriented at a 90° angle to each other on the silicon die. The arrangement enables one bridge to measure the magnetic field component along an X-axis while the other measures the component along a perpendicular Y-axis. This two-dimensional measurement is essential to determine the direction of the magnetic field vector in the plane of the sensor.

Each bridge is in a push-pull configuration that integrates four high-sensitivity TMR elements (Figure 1). In a Wheatstone bridge circuit, a push-pull design is used to maximize the output signal in response to the stimulus, in this case, the direction of the magnetic field. As the field direction changes, the resistance of the TMR elements varies.

In this configuration, two of the four TMR elements in the bridge are oriented to increase their resistance while the other two are oriented to decrease their resistance. This coordinated, opposing change in resistance across the bridge generates a large differential voltage output, which is a key factor behind the high-voltage output specifications of these sensors.

When a diametrically polarized magnet rotates around the sensor, the orthogonal arrangement of the two bridges produces two different analog output signals. One changes in proportion to the cosine of the magnet's angle and the other to the sine. The differential nature is a direct result of the Wheatstone bridge topology.

Instead of a single output referenced to ground, each bridge provides a pair of outputs. The useful signal is the voltage difference between the positive and negative terminals. This differential signaling scheme is beneficial in an electrically noisy environment as it provides common-mode noise rejection.

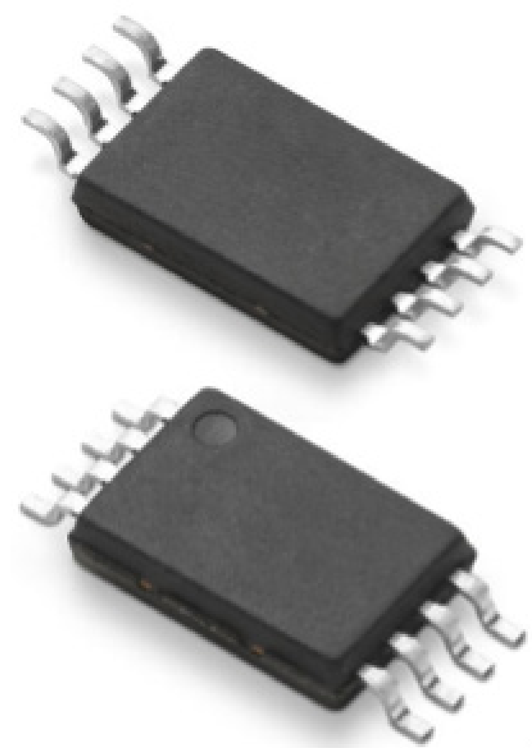


Figure 2. Littelfuse's LF53466-08TMR angle sensor. (Image source: Littelfuse)

Thermal stability and signal integrity

Temperature change is a primary source of error in precision position measurement systems. It affects the permanent magnet, whose field strength varies with temperature. Within the sensor, the base resistance and magnetoresistive response of the TMR elements are also temperature-dependent.

The Littelfuse LF53464-08TMR and LF53466-08TMR have thermal stability, allowing the sensor to adjust to ambient temperature changes. The LF53466-08TMR is engineered for harsh environments with an operating temperature range of -40°C to 150°C. This high temperature capability is a requirement for automotive applications and industrial processes. It comes housed in a TSSOP8 package.

The LF53464-08TMR is specified for a more moderate operating temperature range of -40°C to 85°C, which is suitable for most consumer and standard industrial environments. It is housed in a compact 3 x 3 mm leadless LGA8L package, which is ideal for space-constrained designs. The choice between the two depends on the requirements of environmental resilience and a package suited for the available PCB real estate.

In addition to thermal stability, the dual Wheatstone bridge architecture offers improved noise immunity. The noise from motors or switching regulators coupled onto signal lines is canceled out by the differential voltage. This preserves the integrity of the angle information for a better signal-to-noise ratio and a more accurate final measurement.

Both sensors provide a high output signal. The LF53464-08TMR specifies a typical peak output voltage of 340 mV/V, which means a peak-to-peak differential swing of 680 mV/V, while the LF53466-08TMR has a typical peak-to-peak swing of 600 mV/V. On a 5 V supply, this becomes a robust signal of over 3 V peak-to-peak. This large intrinsic signal can significantly simplify or even eliminate the need for an external analog front-end (AFE) amplification stage.

Application-driven sensor differentiation

The requirements for position sensing depend on the application.

Safety-critical automotive systems: Applications such as automotive steering and pedal position require the highest levels of reliability and robust performance under extreme conditions. These systems must operate across wide temperature ranges and maintain accuracy despite electric noise and thermal variations. The LF53466-08TMR is designed for this domain. It supports a wide operating temperature range of -40°C to 150°C, which is vital for near-powertrain placement. The leaded packaging facilitates automated optical inspection required in automotive quality control.

Industrial automation and motion control: In industrial systems such as valve position sensing and rotary encoders, the emphasis is on precise angular feedback. TMR sensors are ideal for making absolute encoders that provide exact angular position over 360° without returning to a zero point. For a high-resolution encoder in a temperature sensitive application, the LF53464-08TMR's higher typical accuracy (0.6° vs. 0.8° for the LF53466) and lower power consumption might be advantageous.

While Littelfuse's LF53464-08TMR and LF5346-08TMR offer compelling performance advantages, engineers must understand the design tradeoffs to successfully integrate them into a final product. A primary consideration is that these are analog-output sensors that provide raw sine and cosine voltage signals, and they delegate the entire angle reconstruction calculation to an external MCU. The designer must allocate MCU resources to continuously sample the two analog channels and execute the computation in software.

Conclusion

Modern angular position sensing requires extremely high accuracy and reliability in real-world conditions. Omnipolar magnetic sensors combine contactless operation with differential outputs and thermal stability, providing a balance between signal integrity, durability, and design complexity, yielding a more resilient and scalable position-sensing architecture.

To learn more, visit Littelfuse omnipolar magnetic sensors.

A new approach to circuit protection in industrial control cabinets

By Abhishek Jadhav

Pushing Performance
Since 1945

Figure 1. A Han® Protect size 3A heavy-duty power connector. (Image source: Harting)

Circuit protection in smart infrastructure control cabinets depends on rows of fused terminal blocks or internal circuit breakers. This approach consumes significant cabinet space and requires engineers to open the enclosure for troubleshooting and fuse replacement. As a result, maintenance becomes more time-consuming, downtime increases, and sensitive components are exposed to environmental contaminants.

These challenges require integrating protection directly at the point of connection. Embedding overcurrent protection within the connector reduces system complexity, minimizes failure points, and improves serviceability. Instead of distributing protection across discrete DIN-rail-mounted components and interconnecting wiring, protection can be consolidated into a single interface.

The HARTING Han® Protect addresses this issue by integrating a standard 5 x 20 mm fuse and an LED blown-fuse indicator in a compact Han 3A form factor. It eliminates the need for external fuse holders and reduces wiring complexity to deliver benefits in space savings, faster diagnostics, and simplified maintenance.

Architecture and operating principle of Han® Protect

The Han® Protect centers on adapting the widely used M12 A-coded interface for input/output signals, combined

Figure 2. The Han® Protect 10810071141 with crimp termination. (Image source: Harting)

with a protective housing that supports field-serviceable fuse replacement. By moving the protection into the connector, designers can reduce the control cabinet size by up to 30 percent.

In the 1-fused line configuration, the protected conductor passes through a fuse clip assembly in series before continuing to the internal wiring. Under overload or short conditions, the fuse element melts and opens the circuit. The LED indication on the Han® Protect implies an auxiliary circuit that senses an open-fuse state (Figure 1).

A practical engineering impact is that the Han® Protect aims to make the protected boundary coincide with the removable interface. The protection element is not inside the DIN rail but at the point where the harness meets the cabinet, reducing fault-finding time and enabling modular swap and restore operations.

Product configurations and mechanical design

The Han® Protect 10810071141 (Figure 2) is designed as a male hood with a top cable entry for use with crimp-terminated conductors. It features a single M12 cable interface and is rated for 4 A at 24 V, making it suitable for low-voltage control and signal applications. Mechanically, it supports at least 100 mating cycles to ensure durability for repeated connections.

On the other hand, the Han® Protect 10810070302 is the female bulkhead-mounted counterpart that is designed to be fixed onto a panel or enclosure wall. This version includes a pre-assembled 0.76 meter cable to simplify installation and is secured with M3 screws, tightened to 1 N·m for mechanical stability.

Electrical and thermal design considerations

These connectors are engineered with a low contact resistance of ≤1 mΩ for Han 3A that reduces localized heat generation. This is a critical factor when hundreds of connectors are densely packed in a smart infrastructure cabinet. Since the Han® Protect functions as an alternative to internal circuit breakers, it reduces the system-level thermal cutoff for a more predictable thermal environment within an enclosure.

In terms of operating temperature, they are rated up to +70 °C limiting temperature, but the fuse's effective continuous capability depends on the ambient. Therefore, an engineering approach is to treat the Han® Protect connector's 4 A rating as a connector envelope, while selecting fuse rating and time-current behavior to meet load profile, ambient temperature, and tolerance requirements.

Supporting the connectivity ecosystem

Han® Protect can be deployed as part of an end-to-end interconnect architecture that addresses data-plane density and internal electronics modularity because cabinets increasingly combine protected I/O and Ethernet networking.

ix Industrial®

HARTING positions ix Industrial as standardized to IEC 61076-3-124 to provide a miniaturized alternative to RJ45 for industrial Ethernet. The IEC 61076-3-124 describes 10-way shielded rectangular connectors specified up to 500 MHz with anchoring suitability for high-speed Ethernet PHY requirements.

The ix Industrial interfaces are cited as ≥5,000 mating cycles, IP20, with 360° shielding. HARTING claims that the modular part takes up to ~70% less space than RJ45. For data center infrastructure cabinets and edge nodes, the system consequence is higher port density on control elections without sacrificing locking robustness, which reduces the probability of intermittent links in high vibration and high cable strain cabinets.

har-flex® board-to-board connectors

The har-flex family provides miniaturized board-level connectivity with SMT and THR hold-downs to absorb shock and vibration while isolating signal contacts from mechanical stresses. The pin count ranges from 6 to 100 with various mezzanine stacking heights for highly customized PCB layouts.

For higher power requirements, the har-flex Power series uses a 2.54 mm pitch and can handle currents between 12 A and 26 A, depending on the pole count and ambient temperature. The connectors also feature a vibration-proof catch mechanism on both sides to prevent accidental loosening under high dynamic loads.

har-modular® PCB connector system

For prototyping, the har-modular provides multiple combination possibilities for data, signal, and power. The modular approach follows a three-step configuration process where the user selects signal, power, high voltage, data, or optical modules and unifies them onto a single yellow fixing rail. By combining different transmission media in one connector, har-modular reduces the footprint on the PCB and simplifies the system integration process.

The har-modular PCB connector system is built on the DIN 41612 standard. The power contacts are rated to 40 A with up to 1000 V, 500 mating cycles, IP20, and a temperature rating of -55 °C to +125 °C. For infrastructure designers, har-modular supports scalable cabinet electronics where power and data modules are combined in one field-replaceable unit, and where protection partitioning can be aligned with modular boundaries.

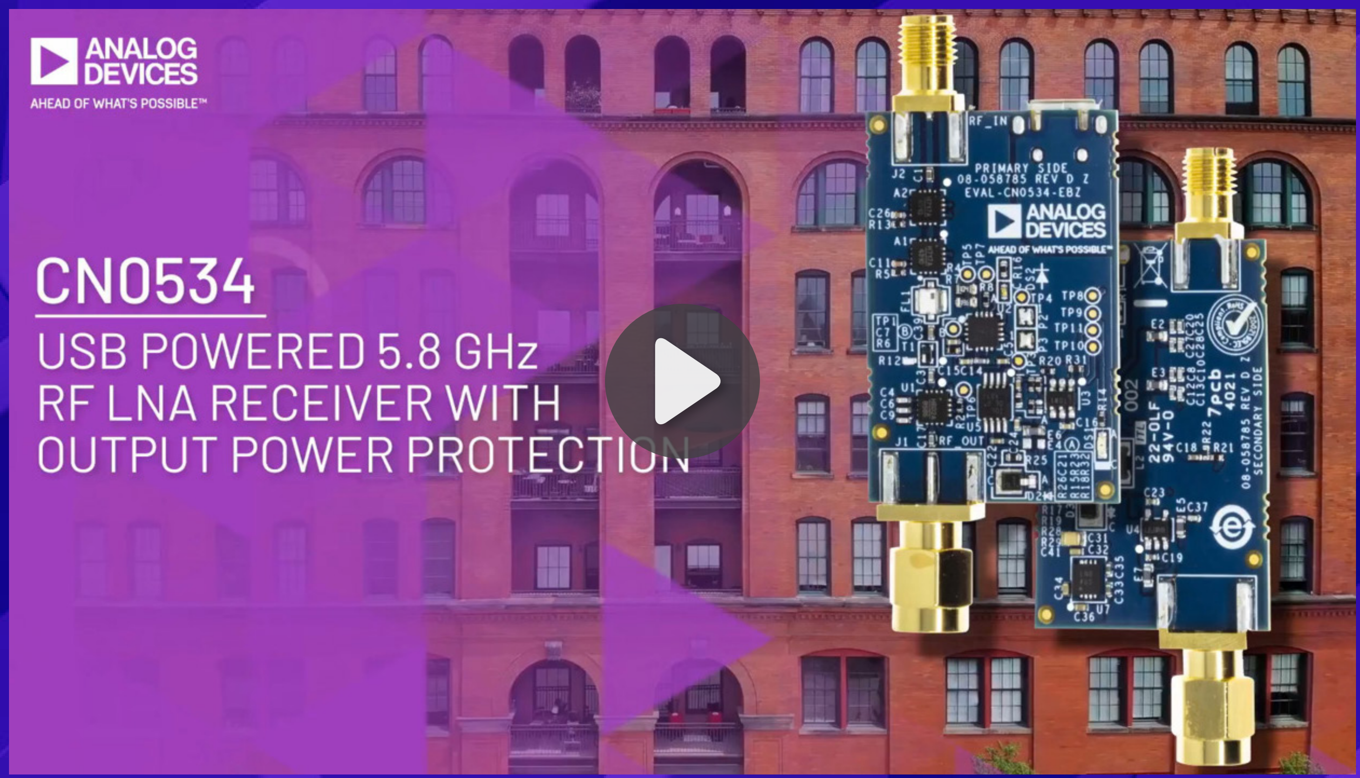
Conclusion

Data centers and smart infrastructure cabinets are reaching physical and electrical limits. Today's circuit protection architectures are not suited for this environment due to physical footprint, wiring complexity, and diagnostic opacity. Therefore, connector-level integration of circuit protection is the necessary response.

The HARTING Han® Protect fuse-integrated connector with its LED indicator, compact Han 3A form factor, and IP54 rating shows the practical viability of this approach. The solution results in up to 30 percent space savings in the cabinet, simplified maintenance processes, shorter repair times, and higher availability.

To learn more, visit HARTING Han® Protect.

Video spotlight



3M Authorized Distributor

Enhancing Safety Through EMI Control

3M EMI shielding and grounding tape helps maintain signal integrity in critical systems by creating a conductive barrier that reduces electromagnetic interference. This protection supports the reliable operation of sensitive electronics, helping to prevent noise-related malfunctions that could impact performance or safety in mission-critical environments.

Learn more

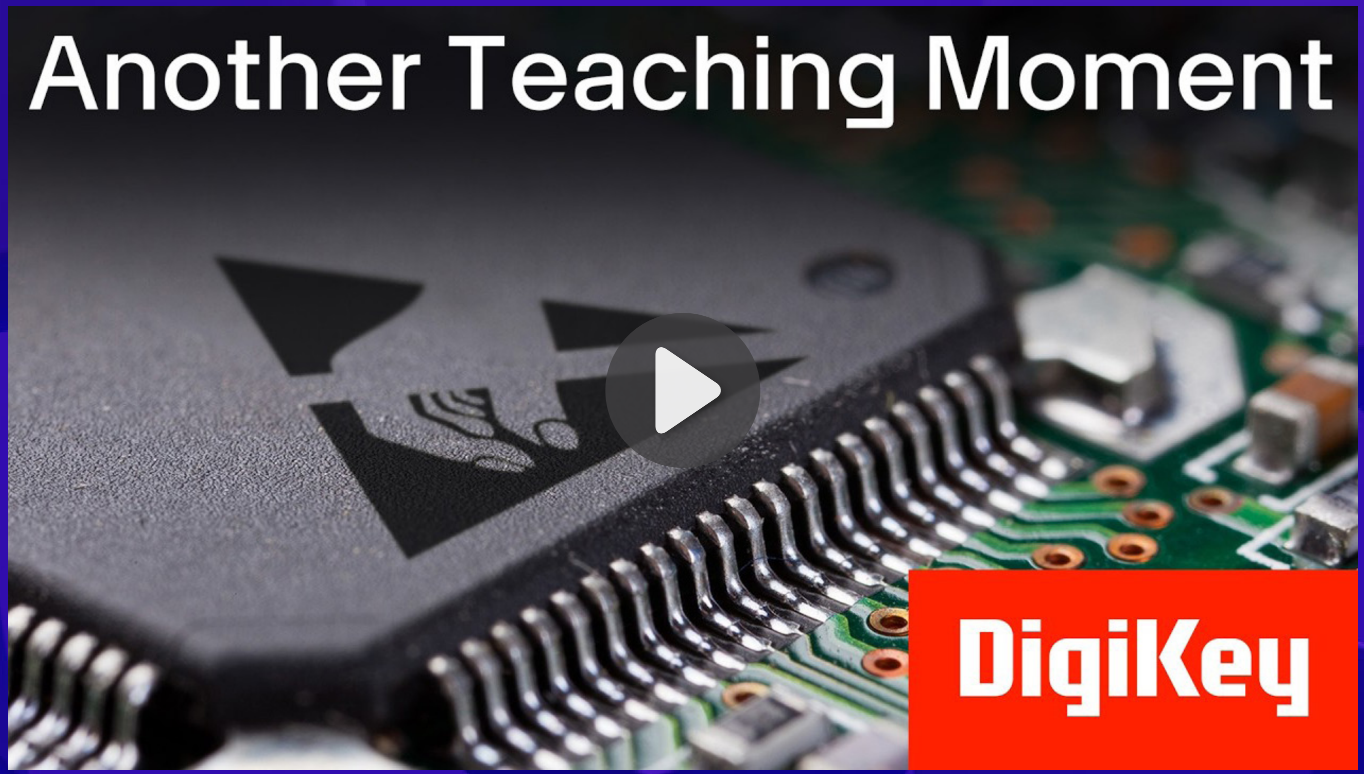
ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™

ACN0534 Reliable Wireless Signal Booster

The CN0534 delivers high gain and robust overpower monitoring with integrated receiver protection—all in a compact footprint. Designed for today's demanding short-range wireless communication systems, it supports additional bandwidth needs in a popular frequency band, making it ideal for applications where performance and space are at a premium.

Learn more

Video spotlight



What is ESD & How to Prevent it?

Electrostatic discharge can occur between the human body and electronic components at very low voltages and current or at levels up to 3000 volts without knowing the discharge occurred. Static sensitive devices can be rendered useless in an instant causing downtime, rework, and production loss. Static safety safeguards and equipment may be put in place to minimize the risk as this video demonstrates.

Learn more

How to Safely Discharge a Capacitor

One question that comes up frequently is, "How do I discharge my capacitor?" A lot of us have seen it done in some not-so-safe ways; the screwdriver placed across the terminals shorting them together. While this works, it can be very dangerous and is not recommended. Instead, there are safer alternatives from using resistors or lightbulb to slowly discharge the capacitor.

Learn more

The mark that made it safe: The origins of Underwriters' Laboratories

By David Ray,
Cyber City Circuits

By the end of the nineteenth century, electricity was transforming American cities. Factories hummed with electric motors, streets glowed with incandescent lamps, and new power stations pushed current through miles of copper wire strung above crowded streets and through densely packed buildings. The technology was spreading faster than anyone could fully understand its risks. Fires caused by gas lighting were already familiar hazards, but the new electrical age introduced dangers that were harder to see and even harder to predict. Overheated wires, poorly insulated conductors, and experimental equipment installed by enthusiastic inventors could turn a modern building into a tinderbox.

Insurance companies were among the first institutions forced to confront this problem. Fire underwriters were responsible for evaluating the risk of buildings and determining the cost of insuring them. Their inspectors traveled from city to city examining construction practices, gas lighting systems, and increasingly, electrical installations. By the late 1880s, these inspectors were encountering equipment that had never been tested before. Electric lamps, switches, motors, and wiring systems were manufactured by dozens of companies, each claiming safety and reliability but offering little evidence beyond demonstration.

One of the young engineers working at the center of this problem was William Henry Merrill, an electrical engineering graduate of the Massachusetts Institute of Technology. Employed by the Boston Board of Fire Underwriters, Merrill spent his early career examining the growing network of electrical devices appearing in American buildings.

> "We are doing something for manufacturers and buyers and users and property-owners everywhere. We are doing something for humanity." – William H Merrill. Founder of Underwriters' Laboratories

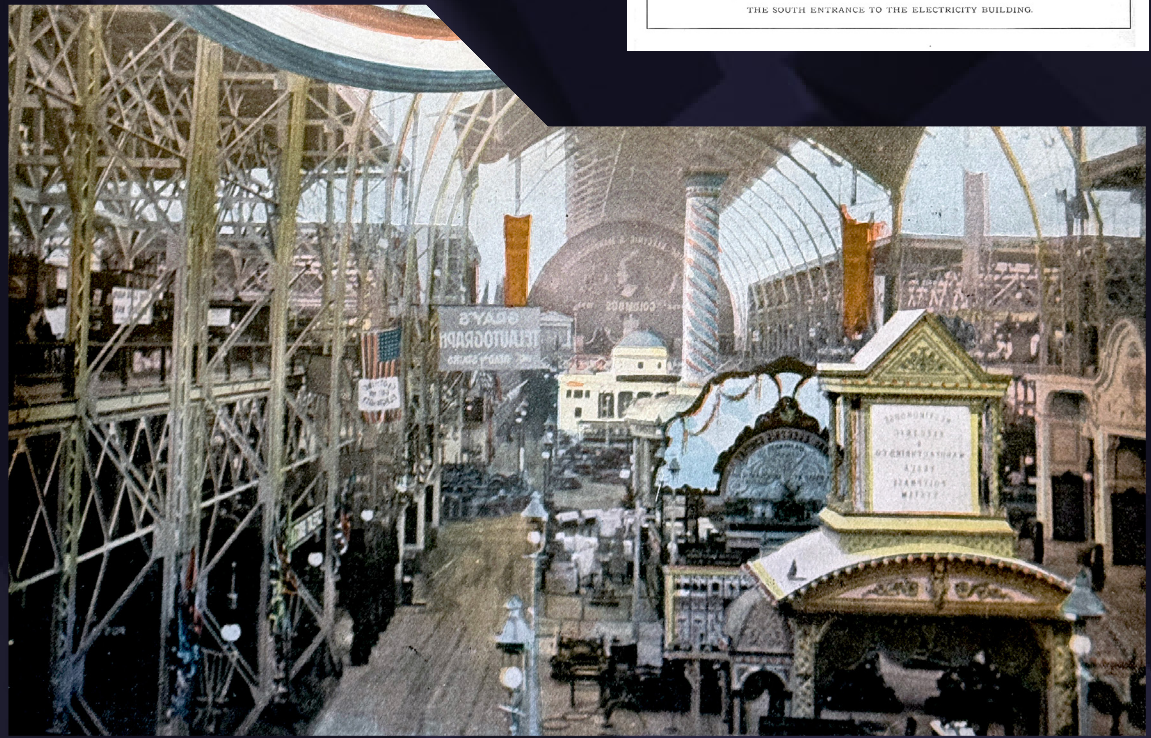
William H Merril, Founder of Underwriters' Laboratories

The Inter Ocean

ILLUSTRATED SUPPLEMENT.

WEDNESDAY OCTOBER 11, 1893.

THE SOUTH ENTRANCE TO THE ELECTRICITY BUILDING.



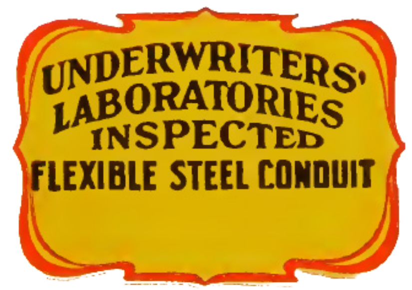
His work placed him directly between two powerful forces of the new industrial age: inventors racing to electrify the world, and insurers trying to understand whether those inventions would burn it down.

The conflict between innovation and safety became impossible to ignore in 1893 when Chicago hosted the World's Columbian Exposition. Spread across hundreds of acres and illuminated by an unprecedented display of electric lighting, the fair was the most ambitious electrical installation ever attempted. To the public, it was a dazzling vision of the future. To the insurance industry, it was a potential disaster waiting to happen.

This story leads to the most influential safety organizations in modern engineering: Underwriters Laboratories.

The Great Chicago Fire of 1871

In the late nineteenth century, Chicago, Illinois, was one of the fastest-growing cities in the United States. Focused on expansion, the city was filled with wood-framed buildings tightly packed together, with wood-planked boardwalks and roads, and factories made of wood lining the rivers. With a priority on growth, there were no meaningful building codes or fire-prevention measures. By 1870, the reported population was approximately 300,000 people.



The 1871 Chicago fire displaced over 100,000 people.

The 1871 Chicago fire caused over $200M in property damage.

In 1871, Chicago burned for two days. Many of the city's fire plans fell apart immediately. The wooden boardwalk led the fire throughout the city in quick order. The fire jumped over the Chicago River, spreading in ways nobody could have possibly predicted. The city's water pumphouse caught fire and was destroyed, causing the firefighters to lose its entire water supply in the middle of the fight, left helpless.

Approximately 17,500 buildings were destroyed, more than 300 people died, over 100,000 people were left homeless, $200M ($5.3B in 2026) in calculated damages, and dozens of insurance companies were left bankrupt. While the true cause of the fire was never determined, many believe it was caused by Catherine O'Leary's cow kicking over a lantern in a barn. The reconstruction effort was quick, and by the 1890s, Chicago was the second most populous city in the United States, behind New York City.

The Boston Board of Fire Underwriters

The Second Industrial Revolution of the late 1800s led to the rise of urban manufacturing, resulting in taller buildings, increased population density, and greater hazards. Building fires were common. Gas lights would ignite theater curtains, electrical shorts sparked factories ablaze, and there were no established safety practices in place to prevent this.

Fire underwriters played a key role in managing these risks. They were responsible for evaluating the fire risks of buildings and helping determine the appropriate insurance premiums based on the construction and hazard exposure. They often conducted on-site inspections and worked with local municipalities to encourage safe building practices, including the use of fire-resistant materials and proper fire escapes. These organizations pooled information together on fire hazards and helped standardize insurance practices.

Merrill sitting in his Chicago office in 1893.

Retro Electro fun fact: In 1892, in preparation for the 1893 Columbian Exposition, Frank Sprague installed the original 'Chicago El' elevated train lines, helping move millions of Fair visitors across the city. Read the story of the earliest electric train lines in the Retro Electro article 'Frank J Sprague and the Richmond Union Passenger Railway.'

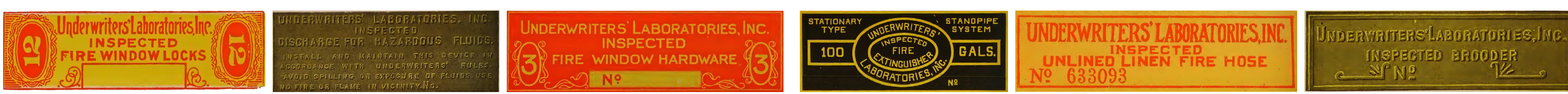
Among the most influential organizations of this era was the Boston Board of Fire Underwriters. Established in the mid-nineteenth century as Boston grew denser and more industrialized, the Board played a critical role in shaping municipal fire codes and promoting safer construction practices. It coordinated inspections, standardized risk assessments, and issued detailed guidance to both builders and insurers. The Board's emphasis on technical rigor and preventative measures, especially around electrical and gas infrastructure, made it a model for other cities. It was within this context that a young William H. Merrill began his career, gaining the expertise that would later shape the founding mission of Underwriters Laboratories.

William H Merrill and the Chicago World's Fair

William Henry Merrill was born in 1868 in Warsaw, New York. His father was a journalist and instilled a sense of public service into his son. He graduated from the Massachusetts Institute of Technology in 1889 with a degree in Electrical Engineering. He began his career working for the Boston Board of Fire Underwriters. Here, he made a reputation for himself and gained the attention of the National Board of Fire Underwriters.

The 1893 World's Columbian Exposition was to be the largest electrical installation ever attempted. The insurance companies had to cover the fair but had no way to evaluate the risk. Merrill's expertise made him the right candidate for this special assignment. Merrill left Boston and set up a test laboratory on the third floor of the Chicago fire station with $350 worth of test equipment.

The fair ran from May to October 1893 and covered nearly 700 acres of the area around Chicago. The city that was built up to host the fair was known as 'The White City.' Giant beautiful buildings were erected to house dozens of different



specialties, mining, agriculture, transportation, horticulture, machinery, and electricity.

The Electricity Building

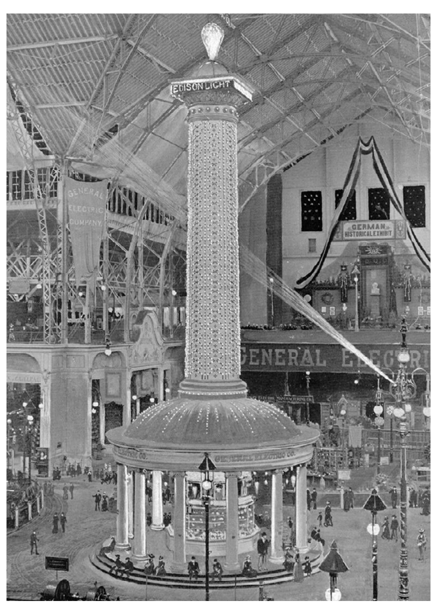
History shows that there was really only one building that was the center of everyone's attention. The Electricity Building showcased innovations in electrical technology by notable inventors like Nikola Tesla, Westinghouse, Bell, Sprague, and Edison. President Grover Cleveland was present to personally throw the switch that lit 100,000 incandescent bulbs at once at the fair's inauguration.

Bell Telephone was front and center when you first walked in. Behind Bell was the Westinghouse booth, where he was showcasing the latest AC generator technology, along with examples of the Niagara Falls generator his company had recently completed. Nikola Tesla was demonstrating his Tesla coils and wireless electricity transmission with dazzling lighting effects. Taking up the entire middle of the floor, General Electric's impressive models of its direct current distribution networks and motors. Further down, the North American Phonograph Company was demonstrating Thomas Edison's new phonograph. Elisha Gray was showing his latest form of 'Teleautograph,' an early form of a fax machine. Dozens of companies were packed into this building, using more electrical power than any single building had ever before.

Merrill was there to personally ensure that every aspect of these electrical exhibits was installed and maintained safely. Records show that twenty-seven million people from all around the world took a walk through The Electrical Building.

A year after the close of the fair, the White City that was built to host the fair was overrun by vagrants, burning to the ground due to 'unknown causes' in 1894.

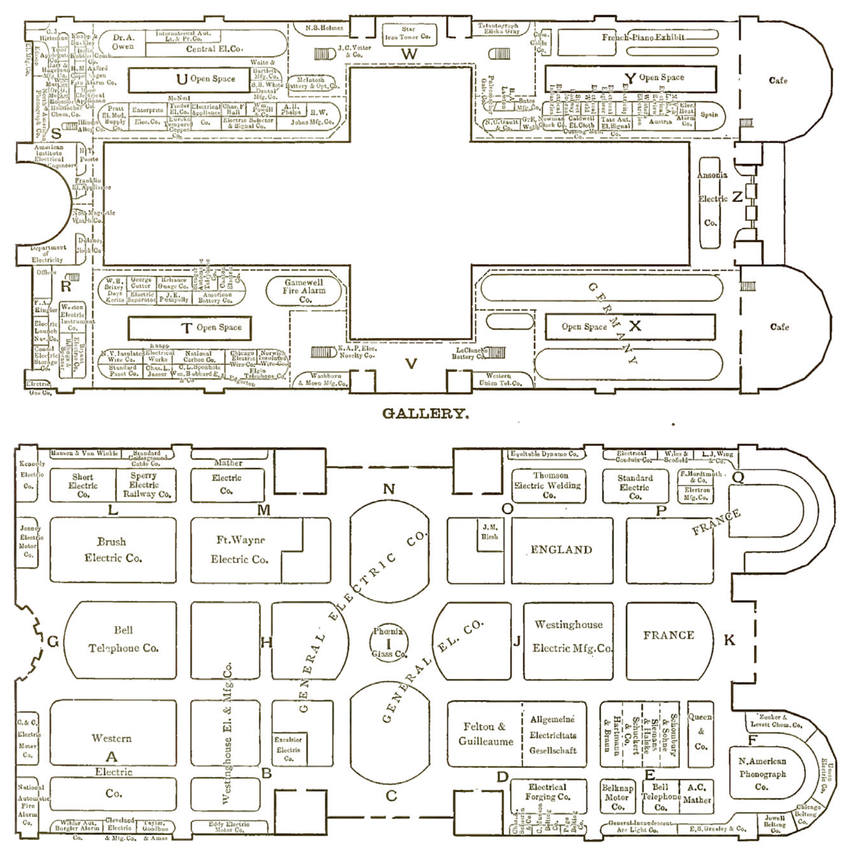
Retro Electro fun fact: A few years earlier, following the 1889 Paris World's Fair, where Westinghouse unveiled the Stanley AC Transformer, Thomas Edison was removed from his companies by the investors, chiefly J. P. Morgan. Several Edison companies were merged together to form the company 'General Electric.' You can read more about that story in the Retro Electro article "Builder of Tomorrow: Reginald Fessenden's Legacy in Radio and Beyond."



General Electric's light display in the Electrical Building.

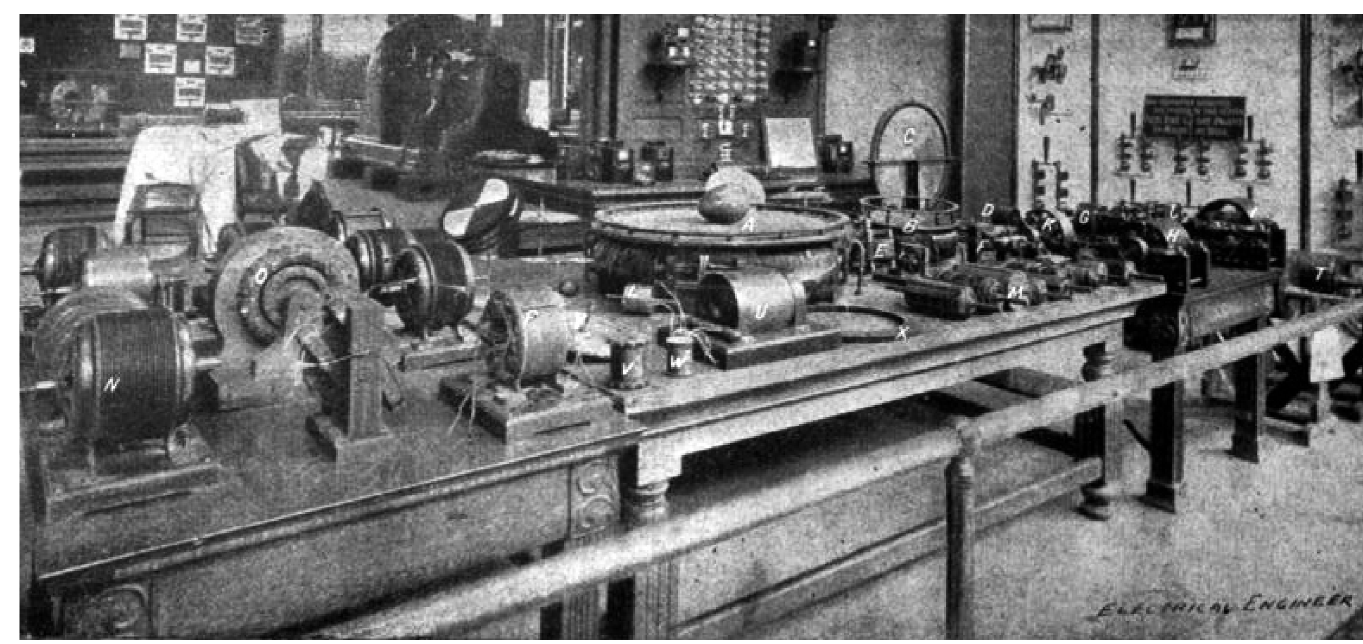
10 ELECTRICAL INDUSTRIES.

ELECTRICITY BUILDING—EXHIBITORS AND THEIR LOCATION.



Exhibitor.	Section.	Exhibitor.	Section.	Exhibitor.	Section.	Exhibitor.	Section.
Austria	Y	Electrical Review	Y	Jaeger, Chas. L.	T	Reliauce Guage Co.	T
Ansonia Electric Co.	Z	Electricity	Y	Johns Mfg. Co., H. W	U	Roessler & Hasslacher Chem. Co.	S
Am. Inst. of Elec. Eng.	S	Electric Gas Co.	R	Jewell Belting Co.	F	Street Railway Jonrnal	Y
American Battery Co.	T	Electrical Engineer	Y	Jenney Elec. Motor Co.	L	Strowger Aut. Telph. Co.	T
Axford, H. M	S	Electrical World	Y	Knapp Electrical Works	T	Standard Paint Co.	T
Allg. Elec. Gesellschaft	D	Eddy Electric Motor Co	B	K. A. P. Elec. Novelty Co	V	Sponholz, C. L	T
Bates Mfg. Co	Y	Excelsior Electric Co	B	Knapp & Buckley	S	Star Iron Tower Co.	W
Bryant Electric Co	R	Electrical Forging Co.	D	Kennedy Electric Co	L	Spain	Y
Billings & Spencer	R	Eqnitable Dynamo Co	O	Lawton, H. A	Y	Schieren, Chas. A. & Co	D
Brixey, W. R	T	Elektron Mfg. Co	P	LeClanche Battery Co.	V	Schomhnrg & Sohne	E
Belknap Motor Co	E	Electrical Conduit Co	P	McNeil-Tinder Elec. Co	U	Siemeus & Halske	E
Bell Telephone Co	E–G	Englaud	O	Marcus, W. N	S	Schuckert & Co	E
Brush Electric Co	L	Empire China Works.	S	Meeker, Dr. G	S	Short Electric Co	L
Caldwell El. Cloth Cnt. Mch. Co	Y	Franklin Elec. Appliances	S	McIntosh Bat. & Opt. Co	W	Sperry Elec. Railway Co.	L
Consol. Elec. Storage Co	R	French Piano Exhibit	Y	Munson, C., Belting Co	D	Standard Underg. Cable Co	L
Cutter, George	T	Felton & Guilleaume	D	Mather, A. C.	E	Standard Electric Co.	P
Canton Elec. Co	T	France	K–P–2	Mather Electric Co	M	Samson Battery Co	S
Chicago Elec. Wire Co.	T	Ft. Wayne Elec. Co	M	Newman Clock Co	Y	Tate Aut. El. Signal Co	Y
Copenhagen Fire Alarm Co	S	Ganlt & Co., N. C	Y	Non-Magnetic Watch Co.	R	Todd, Applegate Co	S
Central Electric Co.	U	Gamewell Fire Alarm Co	T	N. Y. Insulated Wire Co	T	Taylor, Goodhue & Ames	A
Commercial Cable Co.	Y	General Electric Co.	B–H–N–C–& J	National Carbon Co	T	Thomson Elec. Welding Co	O
C. & C. Elec. Motor Co	A	General Incand's't Arc L't Co.	E	Norwich Ins. Wire Co.	T	Telautograph, Elisha Gray	W
Cleveland Elec. & Mfg. Co.	A	Greeley, E. S., & Co	E	North Am. Phonograph Co	S–F	Union Electric Co	F
Chicago Belting Co	F	Germany	X	N. Y. & L. E. A	Y	Vetter J. C. & Co.	W
Dulaney Clock Co	R	Hubbard, Wm., & Co	T	Nat. Aut. Fire Alarm Co.	A	Webb, G. F	Y
Department of Electricity	R	Hirleman, C. J	S	Nat. Engraving Machine Co.	S	Weston El. Instrument Co.	R
ELECTRICAL INDUSTRIES	Y	Hart & Hegeman Mfg. Co	S	Owen, Dr. A.	U	Washhnrn & Moen Mfg. Co	V
Elec. Launch & Nav. Co.	R	Hope Elec. Appliance Co.	S	Phoenix Glass Co.	I	Western Union Tel. Co	V
Electric Separator	T	Hall, Chas. F	U	Paiste, H. T	S	Waite & Bartlett Mfg. Co.	U
Edgerton, E. M	T	Holmes, N. S	W	Pulvermacher Galv. Co	Y	White, S. S., Dental Mfg. Co.	U
Elgin Telephone Co	T	Hartman & Braun	E	Pumpelly, J. K	T	Western Electrician	Y
Edison Elec. Mfg. Co	S	Hanson & Van Winkle	L	Pratt El. Med. Sup. Co	U	Wilder Aut. Burglar Al. Co.	A
Enterprise Elec. Co	U	Hirsh, J. M	O	Powell, Wm. & Co.	U	Western Electric Co	A
Eureka Temp. Copper Co	U	Hardtmuth, F., & Co	P	Phelps, A. H	U	Westinghouse El. & Mfg. Co	B-H-J
Electric Appliance Co	U	Illinois Alloy Co.	S	Page Belting Co.	D	Wiles & Scofield	P
Elec. Sel. & Sig'l Co	U	Internat. Aut. L't & P'r Co	U	Queen & Co	E	Wing, L. J., & Co.	P
Electric Heat Alarm Co	Y	India Rubber Comb Co.	S	Ringler, F. A.	R	Zucker & Levett Chem. Co.	F

The Electrical Building held the entirety of the world's cutting-edge electrical inventions all in one building.



Nikola Tesla's display in the Electrical Building

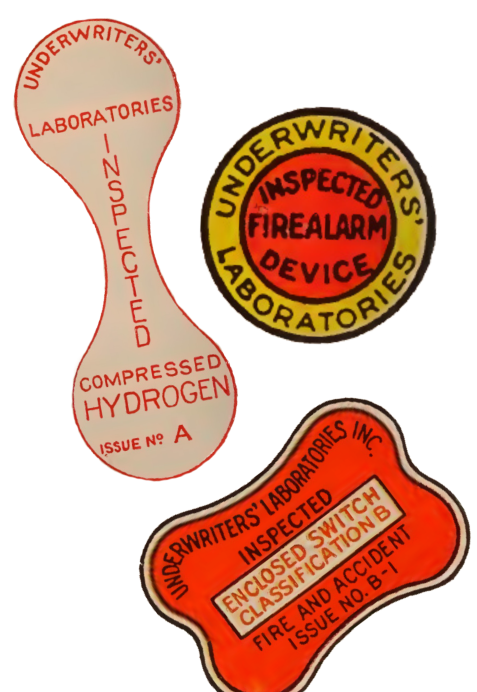
Merrill's test bench as it was when he started the Underwriters' Electrical Bureau.

Underwriters' Laboratories

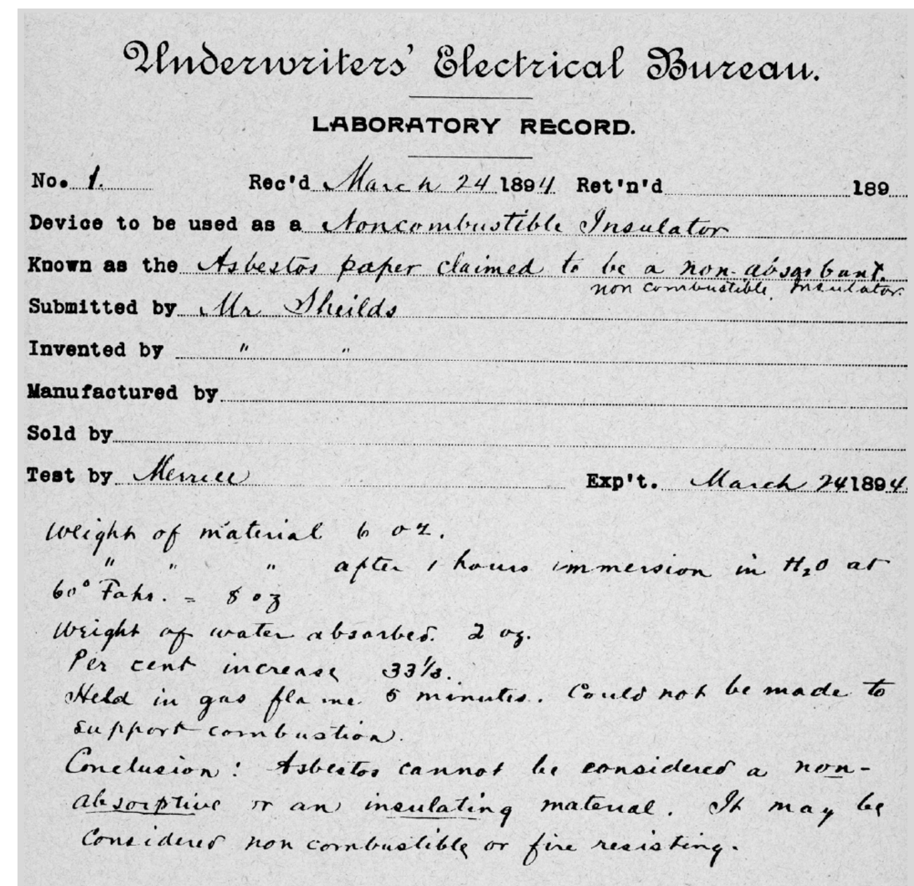
"Testing for public safety. Our only function is to serve, not to profit."

Following the fair, Merrill decided to stay in Chicago rather than return to Boston. He started his first company, named the Underwriters' Electrical Bureau, on the third floor of the Chicago fire station. The lab was modest by any measure. A heavy pine floor, a workbench along the west wall, and a toolbox of basic electrical tools. Every workday, Merrill and his men breathed the soot of factory smoke mixed with the scent of hay and horses. It was not glamorous, but it was a start.

The first official test was conducted on March 24, 1894, on a set of asbestos paper claimed to be both fireproof and insulative. Merrill found it to be fireproof but concluded it could not be considered a non-absorptive or insulating material. The product failed. It was a small, unglamorous beginning, one rejected sheet of industrial paper, but it established something important: Merrill would report what the tests showed, not what manufacturers hoped they would show.



That year, Merrill and his small team of engineers completed 75 tests on various products on a $3,000 budget. Soon, he attracted increased investment from insurance companies and changed the name to 'The Electrical Bureau of the National Board of Fire Underwriters.' In 1901, the testing lab moved to an old two-story brick schoolhouse at 67 East 21st Street in Chicago, and the company rebranded again to the now-famous Underwriters' Laboratories.



Underwriters' Electrical Bureau.

LABORATORY RECORD.

No. 1. Rec'd March 24 1894 Ret'n'd ____ 189__

Device to be used as a Noncombustible Insulator

Known as the Asbestos paper claimed to be a non-absorbant non combustible insulator.

Submitted by Mr Sheilds

Invented by " "

Manufactured by

Sold by

Test by Merrill Exp't. March 24 1894.

Weight of material 6 oz.
" " " after 1 hours immersion in H_2O at 60° Fahr. = 8 oz
Weight of water absorbed. 2 oz.
Per cent increase 33⅓.
Held in gas flame 5 minutes. Could not be made to support combustion.
Conclusion: Asbestos cannot be considered a non-absorptive or an insulating material. It may be considered non combustible or fire resisting.

The first lab report for 'noncombustible insulator' that failed because it was a poor insulator.

Work soon started on what was designed to be the most fireproof building ever constructed. The company moved into its new purpose-built headquarters at 207 East Ohio Street and would remain there until 1979. Built from brick, terra cotta, concrete, and steel, with automatic sprinklers and metal-framed windows throughout, the building was a living demonstration of everything UL preached. Employees called it "the one place where it pays to play with fire." When a fire broke out in a barn across the alley in 1924, heat-sensitive shutters automatically closed across the UL building's openings, and the lab emerged without damage. The building was so well constructed that when it was finally demolished in 1981, the wrecking contractor remarked it was one of the toughest structures he had ever taken down.

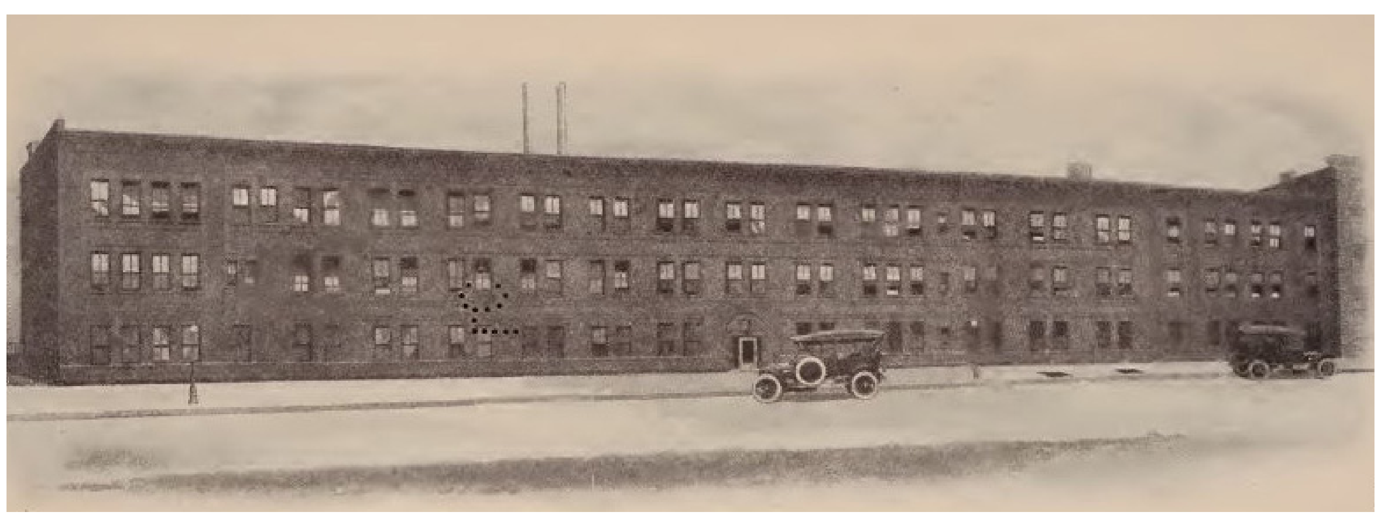
The label

As UL's reputation grew, Merrill recognized that a test report alone was not enough. Manufacturers needed a way to communicate safety to buyers, insurers, and building inspectors at the point of sale, something visible, portable, and immediately recognizable. In 1906, UL launched its Label Service, and the certification label was born.

Earning a UL label was not a simple matter of passing a single test. The process began with preliminary conferences between UL engineers and the manufacturer, followed by extensive laboratory testing designed to push the product to its failure point under conditions it might plausibly encounter in the field. If the product passed, the findings were reviewed by a UL Council of independent experts, men with no financial stake in the outcome, who had final approval authority over the lab's conclusions. Even after certification, the work was not finished. UL conducted follow-up inspections at the manufacturer's factory at least once a year, and a dedicated label inspector reviewed each new production lot against the approved specifications. The label, in other words, was not a one-time award. It was an ongoing guarantee.

The integrity of the label was something Merrill guarded with fierce consistency. Clients paid for the evaluation, whether their product passed or failed, which meant UL had no financial incentive to approve anything it shouldn't. UL also refused to serve as a consulting engineer for products that had failed. Manufacturers who wanted to resubmit were directed to UL's published safety standards and expected to do the engineering work themselves. This separation between testing and consulting was deliberate, and it was central to why the label meant something.

The market responded. Between 1915 and 1923, the annual output of UL labels grew from 50 million per year to 50 million per month. By the mid-1920s, the UL label was recognized alongside the Good Housekeeping Seal and the Consumers Union rating as one of the most trusted marks a product could carry. When the New York Times covered UL's automobile testing program in April 1925, it noted that in the previous year alone, the UL label had appeared on more than 700 million separate items of merchandise. For a label that had started on a failed piece of asbestos paper above a horse stable, that was a remarkable distance to have traveled in thirty years.



The one place where it pays to play with fire.

Know by test and state the facts

William Henry Merrill passed away in 1923, from a cerebral hemorrhage, at the age of 55. He had started with a workbench in a hayloft and four employees. By the time of his death, Underwriters Laboratories had over 400 engineers and inspectors working out of offices in more than 140 cities across the United States and Canada. The Label Service alone was processing 50 million certifications every month. Branch offices had been established in New York, San Francisco, and Toronto. UL had tested automobiles, aircraft, building materials, fire extinguishers, and household appliances. It had advised the White House on fire safety, made the front page of the New York Times, and broadcast fire-prevention messages to millions of families over the air. Merrill set out to make things safer, and an empire followed.

He was succeeded by Dana Pierce, who had joined UL in 1906 and worked alongside Merrill for nearly two decades. The Board trusted Pierce to carry the mission forward, and he did, expanding UL's national network, deepening its expert councils, and steering the organization through the consumer boom of the Roaring Twenties and into the difficult years of the Great Depression.

Merrill's memorial captured what those who knew him understood about why the organization had worked. He had built it on a philosophy that was simple enough to say with seven words and rigorous enough to hold up for more than a century:

"Know by test and state the facts."

Those words still guide the organization today. UL, now known as UL Solutions, operates in over 100 countries, with more than 13,000 employees and 170 facilities worldwide. It oversees more than 1,500 safety standards and conducts nearly 100,000 product investigations every year, covering everything from surgical robotics and dietary supplements to electric vehicles and cybersecurity systems.

Suggested Reading

Our History

A History

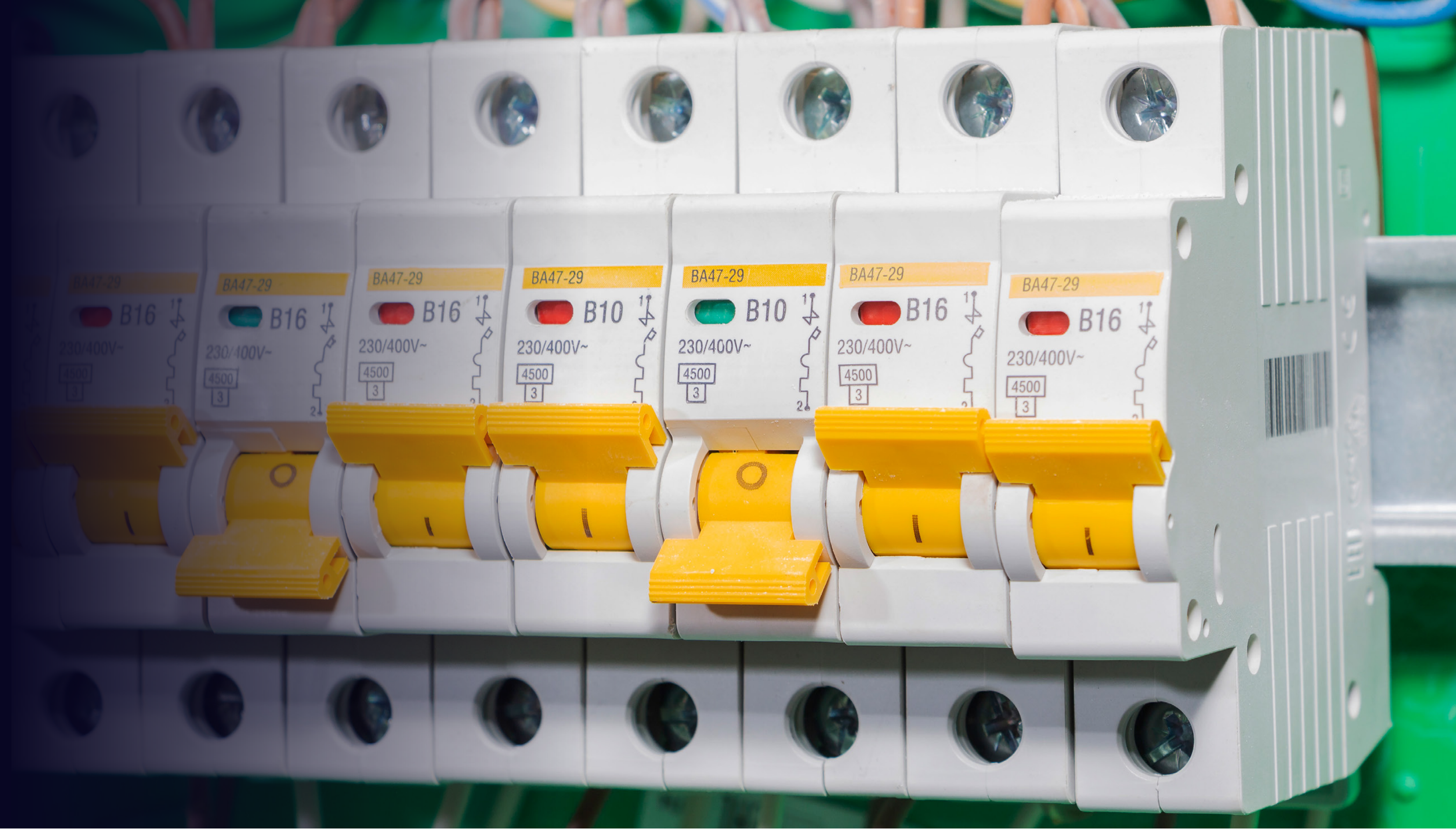
"Engineering Progress" by UL (2016)

"The organization, Purpose, and Methods of Underwriters' Laboratories" by UL (1921)

'World's Columbian Exposition of 1893' from Architecture.com

"Behind the U.L. Label" by E. D. Morgan, Popular Electronics, August 1955

How to apply hybrid AC surge protection devices for improved surge protection



By Art Pini
Contributed By DigiKey's North American Editors

Electronic devices are pervasive and advancing rapidly with increasingly sensitive circuitry that depends heavily on front-end protection as they access electrical infrastructure, that may or may not have the most up-to-date protection against voltage surges and transients. These transients can be the result of lightning strikes, switching, or similar voltage surge incidents that can cause overvoltage and overcurrent events that may damage or otherwise degrade sensitive electronic devices.

Existing low-cost surge protection technologies, such as gas discharge tubes (GDTs) and metal oxide varistors (MOVs), divert or limit the surge energy thus preventing it from reaching the protected device. Each has its respective advantages, but both of these devices have limits to the number of transients they can handle before they fail. Also, GDTs may not shut off current completely, while MOVs may be subject to failure due to thermal runaway after a number of transient event activations.

To capture the best of both GDTs and MOVs, while mitigating their deficiencies, hybrid technology components have emerged in a single integrated device with a comparatively smaller physical size for a given level of surge protection. While the complementary nature of the integrated components improves the performance of both and extends their operational life, to be effective, careful matching of the GDT and MOV elements is required. Implemented correctly, these IsoMOV™ hybrid surge protectors are especially useful for ensuring compliance with IEC/UL62368-1, a hazard-based standard for information technology and audio/visual equipment.

This article briefly discusses how GDT and MOV surge protectors operate before examining the characteristics of real-world IsoMOV hybrid protector examples from Bourns. It concludes by showing how to implement IsoMOV technology to meet IEC/UL62368-1.

How do SPDs work?

Surge protection components operate in one of two ways - they may operate as a switch, diverting the surge to ground (sometimes called crowbarring), or they may limit the surge voltage by clamping the maximum voltage to a reduced level by absorbing and dissipating the transient energy.

The GDT is an example of a crowbar limiter. It consists of a spark gap in a nonreactive gas like argon and is wired across the power line. If the voltage level is below the GDT breakdown voltage, the device is basically in a high impedance "off" state. If a transient increases the voltage level above the GDT's breakdown voltage, the GDT goes into a conducting - or "on" - state (Figure 1).

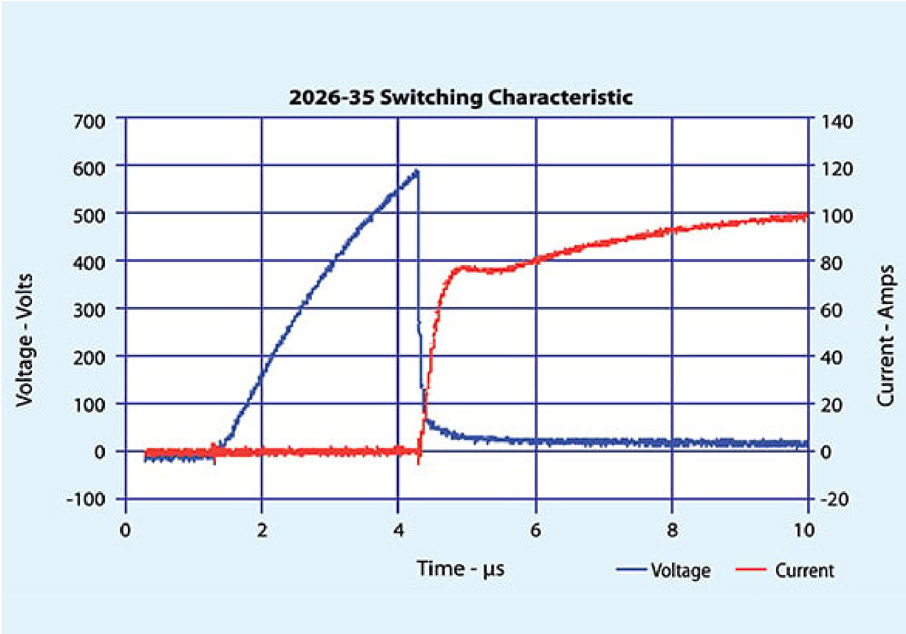


Figure 1: Shown are the voltage and current waveforms for a GDT being triggered on. Once the breakdown voltage is exceeded, the voltage falls to about 10 volts, and the current increases significantly. (Image source: Bourns)

Since the GDT is wired across the power input, it basically shorts out the power source. This triggers a fuse, circuit breaker, or other serial protective device, thereby protecting the circuits downstream of the GDT. Note that in the off state, the voltage is high, and the current is low. In the on state, the opposite occurs and the dissipated power is very small, except at the transition between states. Resetting the state of the GDT requires that the input voltage be reduced below the breakdown voltage. In the event that the power line input does not drop low enough, the GDT may not reset and continue to conduct a "follow-on" current, keeping it on. The possibility of the GDT staying on is a significant limitation for this type of surge protection technology.

The MOV is a clamping device. Like the GDT, it is placed across the power line. In normal operation, the MOV is in a high impedance state and draws only a small leakage current (Figure 2).

In the event of a voltage surge, the impedance of the MOV falls and draws more current, dissipating the power; this reduces and limits the voltage of the transient. When the transient ends, the MOV impedance increases and returns to its normal state. MOVs are rated based on the number of such transient events they can tolerate. After a number

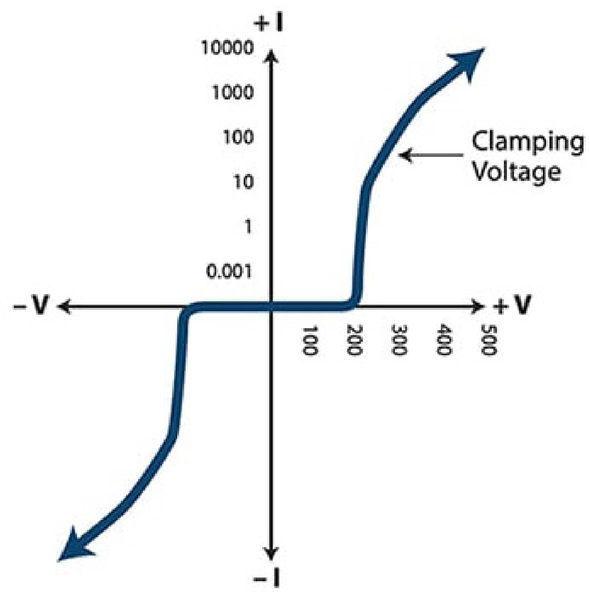


Figure 2: The current-voltage characteristic of an MOV shows the bipolar clamping action. (Image source: Bourns)

of transient events, the leakage current of the MOV may increase. This increases the power dissipated by the device, causing it to heat up. Heating increases the leakage current and may cause the MOV to enter thermal runaway, resulting in a catastrophic device failure.

Neither of these surge protection technologies by themselves is ideal. However, if the GDT and MOV are placed in series across the power line, their complementary behavior becomes clear. In normal operation, the GDT is off, and there is no leakage current flow in the MOV. During a voltage transient the GDT fires, thereby placing the MOV in the circuit. The MOV then clamps the transient voltage surge. When the transient has passed the MOV turns off, reducing the current through the GDT, allowing it to turn off as well.

For the GDT and MOV to be placed in series requires careful matching of their characteristics so that they complement each other precisely. Discrete implementations are subject to a wide range of variables from design through manufacturing, testing, and packaging - making it challenging for designers to find good matches. To address the challenges, Bourns' IsoMOV hybrid protectors combine a carefully matched set of MOVs and a GDT element into a single package that is much smaller than the individual components (Figure 3).

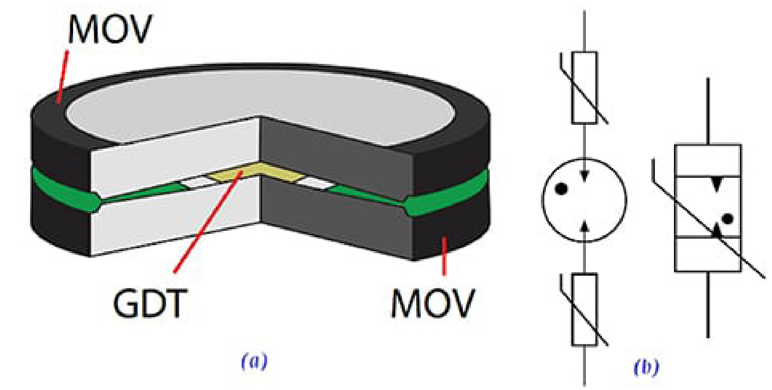


Figure 3: The IsoMOV SPD is formed by incorporating the GDT between two MOVs (a). The composite schematic symbol is shown on the right in (b). (Image source: Bourns)

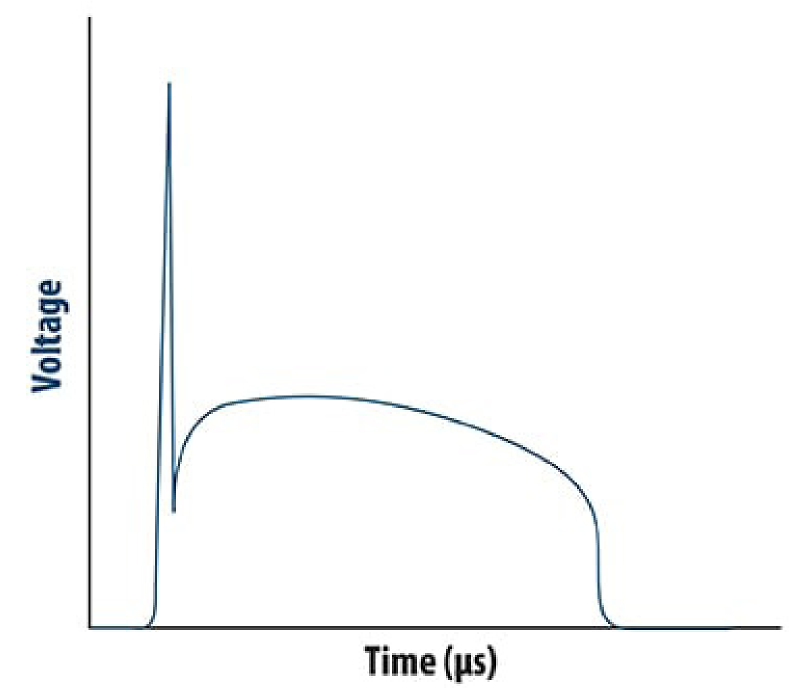


Figure 4: The voltage response of the IsoMOV hybrid protector shows the GDT component breaking down to activate the MOV components, protecting the downstream circuits. (Image source: Bourns)

The composite transient voltage response of the IsoMOV hybrid protector in Figure 4 shows how both elements work together.

Both elements of the IsoMOV hybrid protector are engineered to independently withstand the maximum continuous operating voltage (MCOV). As mentioned, the GDT blocks the MOV leakage currents when there is no transient present. Even after many transients, the GDT cuts off the rising MOV leakage current levels. The MOV prevents the follow-on current after a transient surge, thereby protecting the GDT. The geometry of the IsoMOV device increases the surge capacity per unit area compared to a single MOV.

From a design engineer's perspective, IsoMOV devices provide enhanced protection in a small integrated package that minimizes both component count and board space. For example, the ISOM3-175-B-L2 is an IsoMOV hybrid protector with an MCOV of 175 volts root mean square (V_{RMS}), capable of handling at least fifteen 3 kilo ampere (kA) nominal surges with a maximum clamping voltage of 470 volts (Figure 5). It has a diameter of 13.2 millimeters and a thickness of 6.1 mm. The diameter varies with the maximum current capability, and the thickness increases with an increasing MCOV.

Figure 5: The ISOM3-175-B-L2 is an example of the IsoMOV hybrid protector's compact form factor. Although it includes two MOVs and a GDT, it measures just 13.2 mm in diameter with a thickness of 6.1 mm. (Image source Bourns)

The Bourns IsoMOV family includes three distinct nominal current ratings of 3 kA, 5 kA, and 8 kA, with MCOV ratings from 175 to 555 V_{RMS}. The mid-range devices include the ISOM5-300-B-L2, a 300 V_{RMS}, 5 kA device with a diameter of 17 mm and a thickness of 7.1 mm. At the high current end is the ISOM8-555-B-L2 which is an 8 kA device with a 555 V_{RMS} MCOV. It has a diameter of 23 mm and a thickness of 9.4 mm. All of these devices have an operating temperature range of -40°C to +125°C.

Bourns' IsoMOV hybrid protectors offer these state-of-the-art surge ratings in a space-saving form factor compared to using separate MOVs and GDTs. They have ultra-low leakage currents, and the series GDT extends the life of the MOV. Additionally, all IsoMOV SPDs are listed as UL1449 type 4 components, making it easier to design them into surge protection devices.

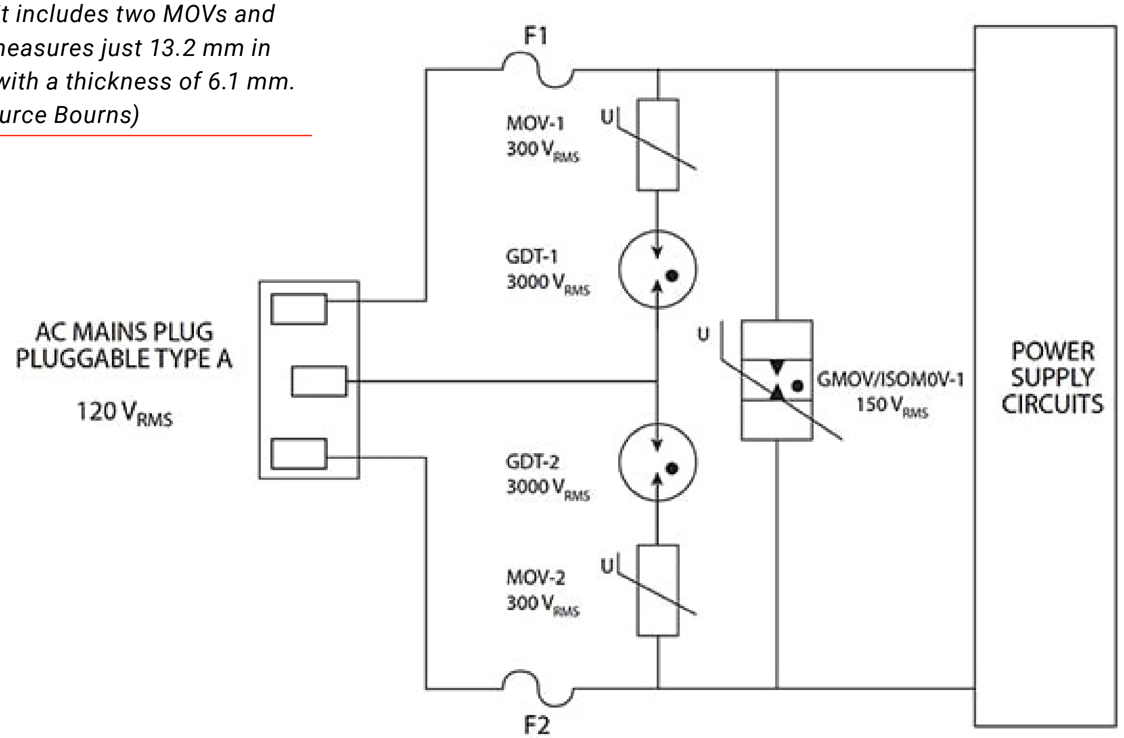


Figure 6: The recommended power input protective circuit consistent with IEC/UL62368-1 has protective devices from line to neutral, line to protective ground, and neutral to protective ground. (Image source: Bourns)

Implementing protection to IEC/UL62368-1 levels

IsoMOV components are useful solutions for achieving compliance with IEC/UL62368-1. The new IEC/UL 62368-1 safety standard for audio/visual and information communications technology equipment, is based on the Hazard Based Safety Engineering (HBSE) principles for the physical safety of equipment users and the realization of safety measures. It identifies potentially hazardous energy sources and the processes by which energy can be transmitted to a user, both in normal operation and under faulty conditions.

The recommended power input protection design in Figure 6 includes protective devices from line to neutral, line to protective ground, and neutral to protective ground.

The GDTs in series with MOVs or IsoMOVs between line and ground or neutral to ground are needed to protect from electric shock that could occur if an MOV were used alone. If the protective ground was not connected, the leakage current of the MOV alone might be high enough to cause injury if the user touched the isolated ground path. Placing the GDT in series eliminates that leakage current.

Hazards associated with MOVs and devices containing MOVs include shock due to excessive leakage currents and the possibility of fire. Due to their failure mode, MOVs are considered potential ignition sources (PIS), requiring that the design includes steps to reduce the possibility of ignition and block the spread of any fire.

Surge protectors help increase product reliability and must conform with specific tests required by the standard. For example, The MCOV of an MOV must be at least 1.25 times the upper voltage limit of the equipment voltage range. For equipment with a power input range of from 85 to 250 volts AC, the minimum MCOV for a line protection MOV in that equipment should be 313 volts. Line protection circuits that include an MOV across the line are subject to a test based on a line voltage of twice the nominal rating. The input current is sequentially limited by resistors to values of 0.125, 0.25, 0.5, 1, and 2 A. Since the MOV is a potential fire source, testing continues until the MOV fails. This test is not required for MOVs with MCOV greater than two times the maximum rated line voltage due to the very low possibility of MOV failure under those conditions.

Conclusion

IsoMOV hybrid protectors provide improved and more compact protection for electronic systems as they advance, shrink, and proliferate at an accelerating rate, against a backdrop of aging or poorly protected infrastructure and ever-evolving user protection standards. Along with exceptional performance and space savings, they have an extended temperature range, low leakage, and high energy-handling capability. While they are especially advantageous to industrial applications exposed to high surges, they can be readily implemented in audio/visual and information communications technology equipment to meet the IEC/UL62368-1 standard based on Hazard Based Safety Engineering (HBSE).

Protecting USB-PD and PoE circuits from industrial power surges

By Brandon Lewis
Contributed By DigiKey's North American Editors

Evolving technologies, such as USB Type-C® Power Delivery (USB-PD) and Power over Ethernet (PoE), continuously drive expectations for fast-charging applications and streamlined power design. With these protocols being used in highly integrated and industrial applications, protecting their circuits from electrical overstress (EOS) and electrostatic discharge (ESD) events is essential to ensure user safety and device reliability. However, as power demands increase across continually shrinking form factors, surge protection becomes more challenging.

This article outlines the evolving landscape of USB-PD and PoE technologies, illustrating the essential need for circuit protection. It then introduces transient diverting suppressors (TDSs) from Semtech and explains how these devices can be used to provide low clamping with excellent temperature stability in industrial and other applications.

The expanding power levels of USB-PD and PoE

USB-PD and PoE have become the standard for combining high-speed data communications and power into a single cable connection. Their data rates today far exceed 1 gigabit per second (Gbit/s), and in recent years, their power levels have seen a dramatic increase:

- *PoE:* In 2003, PoE (Type 1) initially provided 15.4 W per port for powering wireless access points. By 2018, PoE++ (Type 4) supported 100 W per port, enabling PoE in high-power applications such as advanced industrial cameras.
- *USB-PD:* In 2014, USB Type-C cables were required to support 60 W USB-PD for devices such as tablet PCs. By 2021, the USB-C PD 3.1 standard enabled USB Type-C to deliver 240 W to charge larger systems.

With such large power loads being transmitted through such finely pitched connectors, surge events have become a very real risk to safety and reliability in systems using PoE and USB-PD. This makes surge protection a vital part of product design, especially as these products become more compact.

Protecting space-constrained devices from supply voltage transients

For compact devices that are charged via USB-PD, high levels of design integration can increase the risk of surge events. For example, shorter distances between components make it easier for voltage spikes or ESD to cause arcing between traces. This arcing can damage components or cause data errors through increased electromagnetic interference (EMI).

Surge-related heat is more likely to cause insulator breakdown between pins, leading to arcing and short circuits that further damage nearby circuitry. When power spikes occur on I/O or data lines, a device's more sensitive components are at risk of severe and immediate damage due to EOS or ESD.

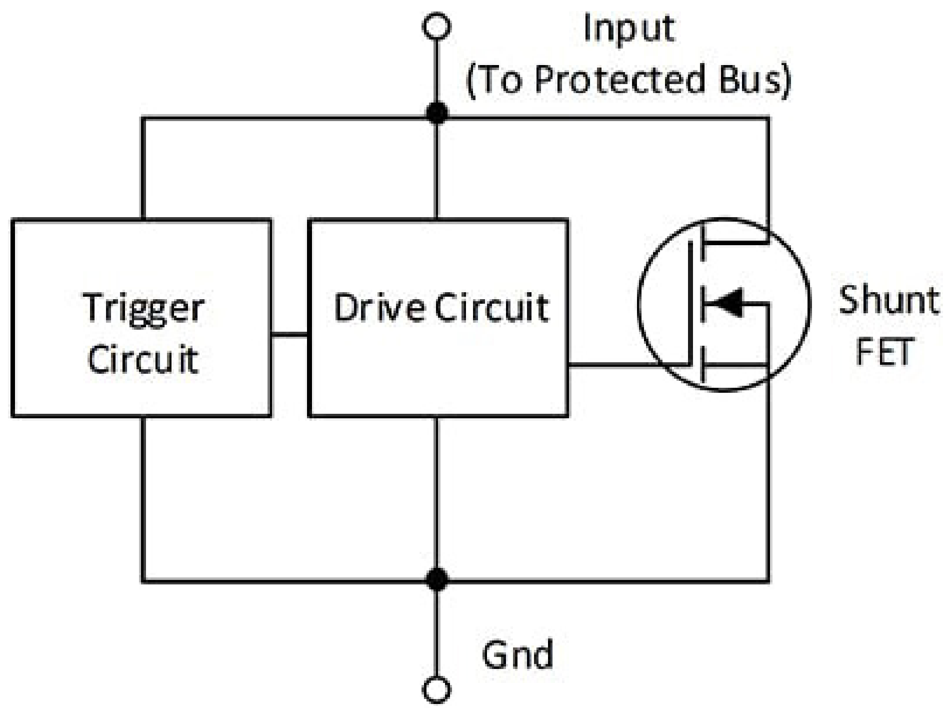


Figure 1: The FET-based shunt mechanism of SurgeSwitch TDS devices offers consistent clamping in unpredictable surge conditions. (Image source: Semtech)

Supply voltage transients can also compromise electrical safety and increase the risk of fire due to high-current short circuits. These factors make it essential that incoming power anomalies are quickly detected, and high voltages and currents are diverted away from critical application circuits before damage can occur.

For effective protection across many applications, transient suppression components should offer the following performance characteristics:

- Clamping voltages should be very close to the operating voltage of the protected circuit to ensure that even slight overvoltage or ESD events are suppressed. Suitable clamping will depend on the USB-PD or PoE standard used.
- A consistent clamping voltage, regardless of pulse current amplitude or operating temperature, streamlines protection in systems where conditions are varied.
- Surge and ESD immunity protection components must be highly robust to remain functional even during the harshest events, such as lightning strikes.
- Compac90 components suitable for increasingly space-constrained installations are required.

A novel approach to surge protection

Semtech SurgeSwitch TDSs are designed to meet or exceed these application requirements. This family of compact devices provides single-line protection against high EOS and ESD events for the full range of USB-PD and PoE operating voltages. Key specifications across the series include:

- Peak pulse current capability of 40 A at 8/20 µs
- Surge immunity to level 2 ±1 kV as per IEC 61000-4-5
- ESD immunity exceeding level 4 (8 kV contact and 15 kV air discharge)

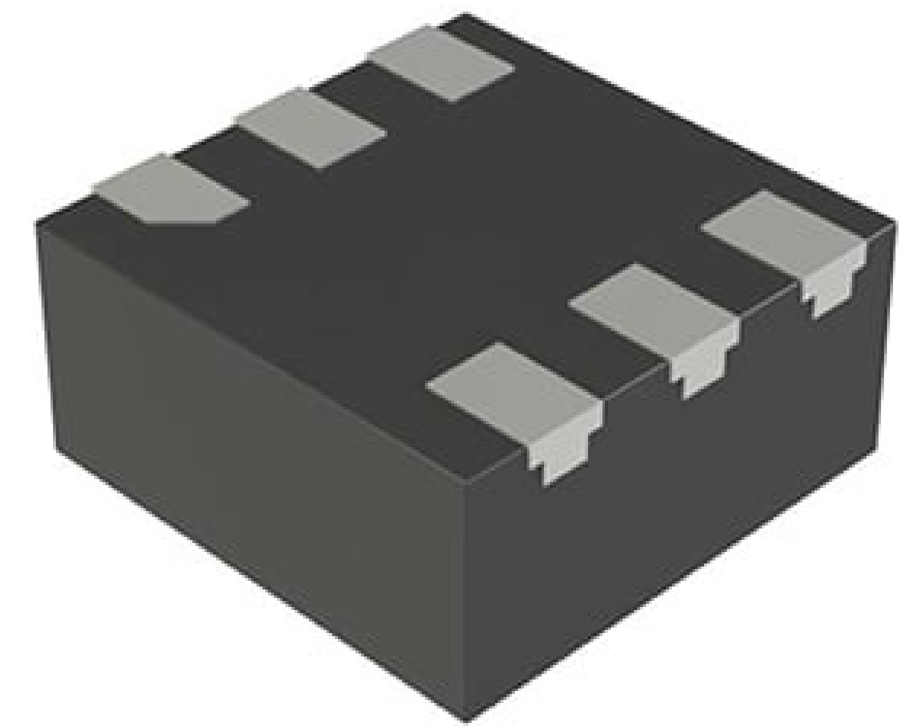


Figure 2: The TDS5801P.C provides robust surge protection for lines operating at 58 V. (Image source: Semtech)

The internal mechanism of the SurgeSwitch TDS (Figure 1) differs significantly from that of traditional surge protection devices, such as transient voltage suppressor (TVS) diodes.

Instead of relying on a conventional PN junction for breakdown, Semtech TDSs use a surge-rated field-effect transistor (FET) to protect sensitive components from EOS and ESD events. Paired with a drive circuit, this FET is activated by a precisely tuned trigger circuit to form a voltage-controlled switch that acts as the breakdown mechanism. When a transient voltage increases beyond the rated breakdown voltage of a device, the trigger circuit activates the shunt FET, switching it on and diverting the transient current to ground.

By utilizing a FET-based switching mechanism with an ultra-low ON resistance, SurgeSwitch devices can achieve consistent clamping voltages across a wide range of operating temperatures and peak pulse currents. This enables the integration of USB-PD and PoE into more demanding industrial applications that require predictable surge protection to support deployments across a wide range of operating conditions.

Selecting the right TDS solution

Selecting the right SurgeSwitch device primarily depends on the working voltage of the application, as this determines the clamping voltage required for circuit protection. For higher voltages, the TDS5801P.C (Figure 2) protects one I/O or power line operating at 58 V, which is typical of PoE. This device is available in a 1.6 mm × 1.6 mm × 0.55 mm package for high levels of space optimization.

- The TDS5801P.C offers:
- Peak pulse power rating: 1,490 W at 8/20 µs
- Peak pulse current: 20 A at 8/20 µs
- Supply clamping voltage: 70.2 V (typ.)
- ESD clamping voltage: down to 4.4 V
- ESD voltage ratings:
  - Air: ±20 kV
  - Contact: ±15 kV

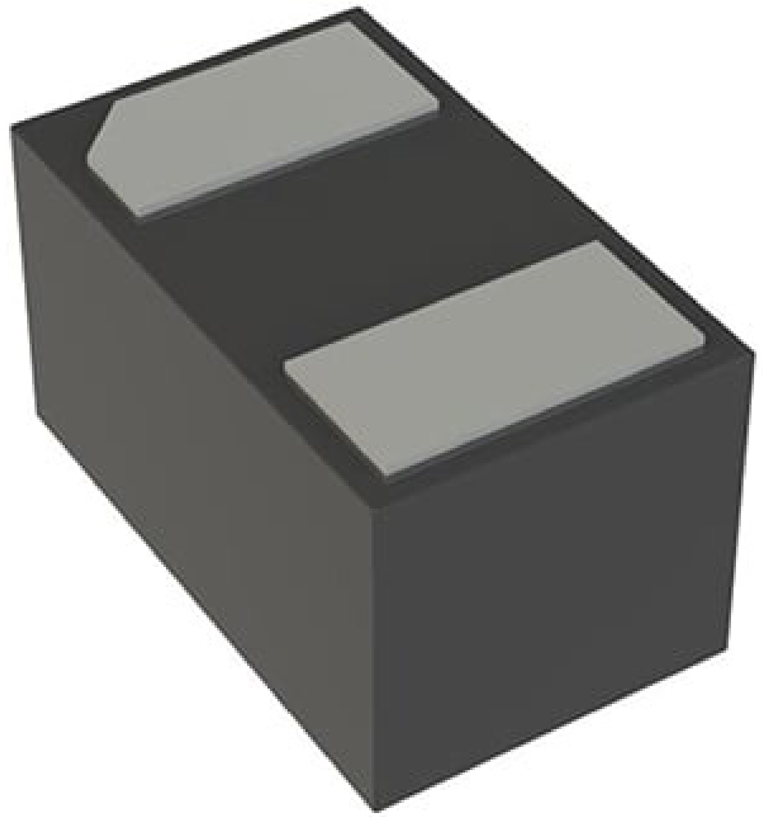


Figure 3: With a compact two-lead package, the TDS0521PW.C enables surge protection in space-constrained designs. (Image source: Semtech)

With a high pulse power rating and low ESD clamping voltage, the TDS5801P.C TDS is suitable for outdoor PoE applications such as surveillance cameras, remote meters, and networking equipment, where adverse weather can heighten ESD. In these applications, the extended operating temperature range of -55°C to +125°C is also essential for maintaining consistent protection, regardless of seasonal conditions.

In contrast, the TDS0521PW.C (Figure 3) provides a solution for 5 V working voltages used in Internet of Things (IoT) devices and VBUS lines for low-power USB-PD. To serve highly integrated devices, the TDS is available in a 1.6 mm × 1.0 mm × 0.55 mm package, with side-wettable flanks for flat mounting.

Key specifications of the TDS0521PW.C include:

- Peak pulse power rating: 412 W at 8/20 µs
- Peak pulse current:
  - 40 A at 8/20 µs
  - 8 A at 10/1000 µs
- Supply clamping voltage: 8.7 V (typ.) for 40 A pulse
- ESD voltage rating: ±30 kV (air and contact)

For sensitive, low-voltage equipment, this device provides excellent protection against high-level surge events, especially when connected to the primary power source during charging.

For similar protection at 22 V working voltages, the TDS2261P.C (Figure 4) is a TDS suitable for mid-range USB-PD applications such as industrial tablet PCs. The TDS2261P.C offers:

- Peak pulse power rating: 1120 W at 8/20 µs
- Peak pulse current:
  - 40 A at 8/20 µs
  - 3 A at 10/1000 µs
- Supply clamping voltage: 27.7 V (typ.) for 40 A pulse
- ESD voltage ratings:
  - Air: ±30 kV
  - Contact: ±20 kV

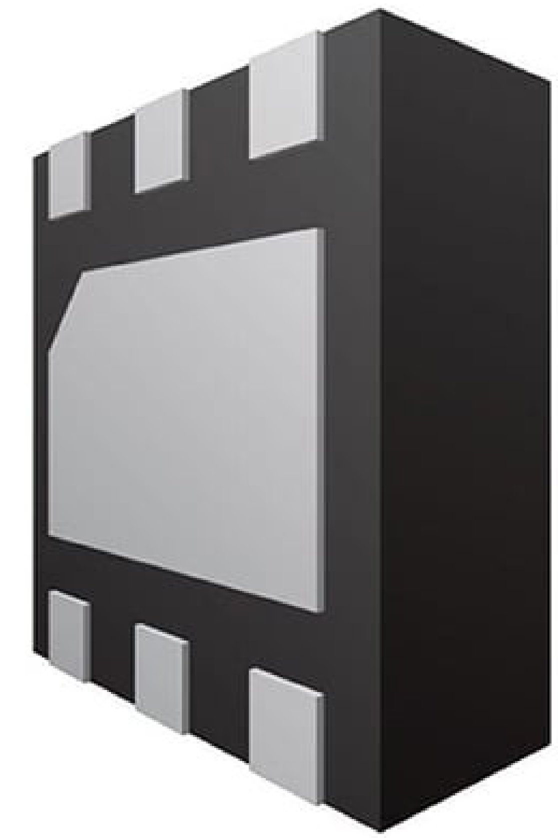


Figure 4: The TDS2261P.C offers versatile protection for 22 V systems where short-duration pulse currents reach 40 A. (Image source: Semtech)

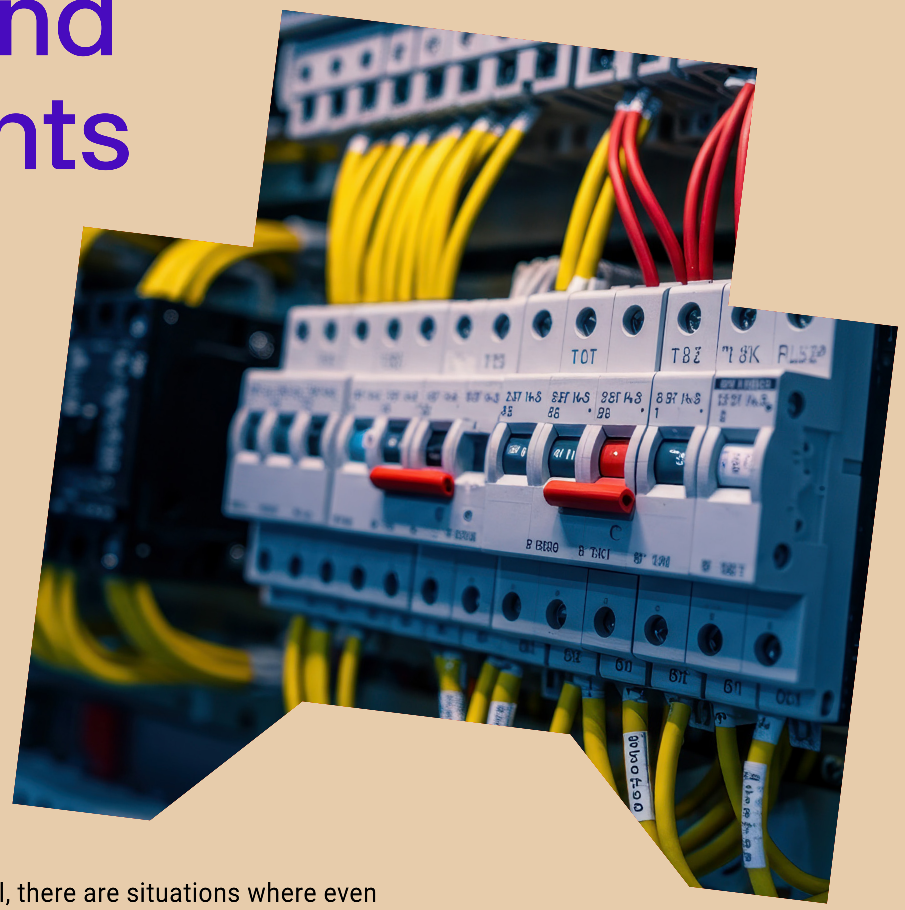
Despite being the largest of the SurgeSwitch devices, measuring 2 mm × 2 mm × 0.75 mm, the TDS2261P.C still offers a compact solution for high EOS and ESD protection in space-constrained devices. In addition to USB-PD, other target applications include storage devices and industrial sensors.

Conclusion

As USB-PD and PoE standards continue to expand power delivery performance, robust surge protection becomes challenging in highly integrated device designs. The Semtech SurgeSwitch series overcomes design challenges with clamping voltages that remain consistent across a wide range of temperatures and pulse currents. They also provide reliable protection from harsh power anomalies across different line voltages and operating conditions.

How to protect circuits from high-temperature overload and fault currents

Steven Keeping
Contributed By DigiKey's North American Editors



Circuit protection is vital in order to safeguard electrical machinery and equipment from hazardous current increases. There are two classes of hazardous situations; one is where the overcurrent potentially overloads the powered equipment, and the other is where there is a short circuit or line-to-ground fault, causing a rapid and damaging increase in current.

A popular, mature, and proven technology for the protection of valuable assets is the electromechanical circuit breaker. This type of device covers a wide range of applications but is less useful for things like electric motors which are subject to inrush current on start-up. A better option in these situations is to use thermal magnetic circuit breakers, as they provide a slight delay before tripping.

Still, there are situations where even thermal magnetic circuit breakers are unsuitable. Examples include applications with extreme swings in temperature or applications such as generator rooms where temperatures are constantly elevated. The answer for combined overload/fault current protection in such applications is the hydraulic magnetic circuit breaker. This device offers the advantages of thermal magnetic circuit breakers—without the drawback of being affected by large ambient temperature swings.

This article describes the function and characteristics of thermal and hydraulic magnetic circuit breakers, and why the latter suits applications with widely varying temperatures. The article then describes the various types of hydraulic magnetic circuit breakers using real-world examples from Sensata Technologies, including a design example.

Magnetic and thermal circuit breakers

The protection mechanism of a magnetic circuit breaker comprises a solenoid and a metal lever. Above a predefined current threshold, the solenoid's magnetic field is sufficient to attract the circuit breaker's lever and open the circuit. The device is the simplest and least expensive type of electromagnetic circuit breaker and is suitable for many situations where straightforward overload and line-to-ground fault protection is needed. Once tripped, the circuit breaker is reset by manually flipping its lever.

The main downside is that the magnetic circuit breaker will trip immediately—even if the excess current lasts for only a very short time. This is a disadvantage if the device is protecting a large electric motor, for example. Such motors are prone to large inrush currents as they start up. The inrush current typically exceeds the overload current but lasts for a short time so it doesn't cause motor damage. However, such currents do trip magnetic circuit breakers.

The thermal circuit breaker offers an alternative. This device is based on a bimetallic strip (or "thermal element"). The most common thermal element is a sandwich of two or three different metals. The low-expansion side is typically invar, a nickel steel alloy that has a low coefficient of thermal expansion. The center element is typically made of copper, for low resistivity, or nickel, for high resistivity, depending upon the application. Metals used in the high-expansion side vary considerably. The size of the thermal element, configuration, physical shape, and electrical resistivity determine the current capacity of the circuit breaker.

For overload situations, where the peak current only causes damage if applied for longer periods, the thermal element provides good protection. The relatively high current heats the thermal element due to its resistance and causes the contacts to open. There is a sufficient delay in the thermal element's operation such that the circuit breaker doesn't trip for transient overloads like motor inrush currents. The trip time is generally inversely proportional to the overload current (Figure 1).

Thermal magnetic circuit breakers combine both thermal and magnetic elements into a single device. Overload currents don't generate a strong enough magnetic field in the solenoid to operate the trip lever but do heat the thermal element so that it eventually trips. On the other hand, fault currents immediately generate a high magnetic field

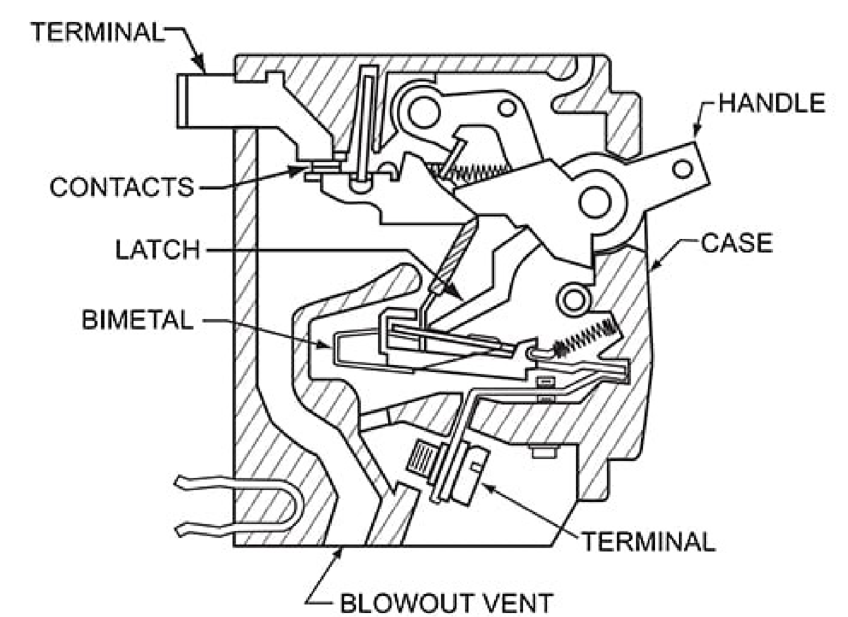


Figure 1: This cross-section of a thermal circuit breaker shows the thermal element which trips the device when heated by overload currents. The resistive heating generates a time delay that prevents tripping due to transients such as electric motor inrush currents. (Image source: Sensata)

in the solenoid, overriding the thermal element and immediately opening the circuit.

One drawback to thermal magnetic circuit breakers shows up in applications where equipment is particularly sensitive. In such instances, overload currents are typically lower than 5 amperes (A), and don't generate enough heat to activate the bimetallic strip. This can be overcome by adding a heating coil to the strip to prewarm it and increase its sensitivity—with the downside of added complexity.

A critical drawback of both thermal and thermal magnetic circuit breakers is their sensitivity to ambient temperature changes. For example, a 10 A circuit breaker may trip at currents as low as 7 A in high temperature environments, or at currents as high as 13 A in a colder environment. Manufacturers assist by producing derating tables to indicate actual trip currents in hot or cold environments, but there are compromises to be made.

For example, engineers often overspecify thermal circuit breakers destined for use in hot environments to combat nuisance tripping, thereby increasing the possibility of the equipment being exposed to high currents. Similarly, for use in colder environments, the circuit breaker can be derated to ensure it trips at a lower current, which can increase the likelihood of unnecessary tripping (Table 1).

Overspecifying or derating is a satisfactory solution in environments where the temperature is relatively consistent—either hot or cold—but is less than optimum for areas with wide temperature swings. A derated circuit breaker designed for a warm environment could fail to protect equipment when the temperature drops.

How to address wide temperature swings

Hydraulic magnetic circuit breakers eliminate the thermal element and thus remove any problems associated with temperature variations. The devices are consistent in rating and performance across the industrial temperature range of -40°C to +85°C.

As the name suggests, the devices use a magnetic element from a simple magnetic circuit breaker, but here the solenoid core is held by a spring in a tube, and movement is damped by hydraulic (silicone) fluid. If the current flowing through the unit remains at—or below—the rated current, the mechanism will not trip. If an overload current increases to between 100% and 125% of the rated current, the magnetic flux generated in the coil is sufficient to move the core against the spring to trip the device.

In the case of overload currents, generating relatively weak magnetic fields, the spring and damping fluid slow down the movement of the core enough such that it doesn't trip for transient overloads such as motor inrush currents. Different time-delay curves can be obtained by using fluids of different viscosities. However, for genuine fault currents, the solenoid magnetic field is strong enough to instantly overcome the damping and break the circuit (Figure 2).

TEMPERATURE / IN	-30°C	-20°C	-10°C	0°C	+10°C	+20°C	+30°C	+40°C	+50°C	+60°C	+70°C
6 A	7.2	7.09	6.91	6.73	6.54	6.31	6	5.66	5.33	4.94	4.5
10 A	12	11.8	11.5	11.2	10.9	10.5	10	9.44	8.89	8.23	7.5
13 A	15.6	15.4	14.9	14.5	14.1	13.6	13	12.2	11.5	10.7	9.75
16 A	19.2	18.9	18.4	17.9	17.4	16.8	16	15.1	14.2	13.2	12
20 A	24	23.6	23	22.4	21.8	21	20	18.8	17.7	16.5	15
25 A	30	29.5	28.8	28	27.2	26.3	25	23.6	22.2	20.6	18.8
32 A	38.4	37.8	36.9	35.9	34.9	33.6	32	30.2	28.4	26.3	24

Table 1: Manufacturer's derating table indicating actual trip currents for thermal circuit breakers at specified temperatures. Note that the rated current is specified at +30°C. Trip currents are higher than the rating at colder temperatures and lower at warmer temperatures. (Image source: Sensata)

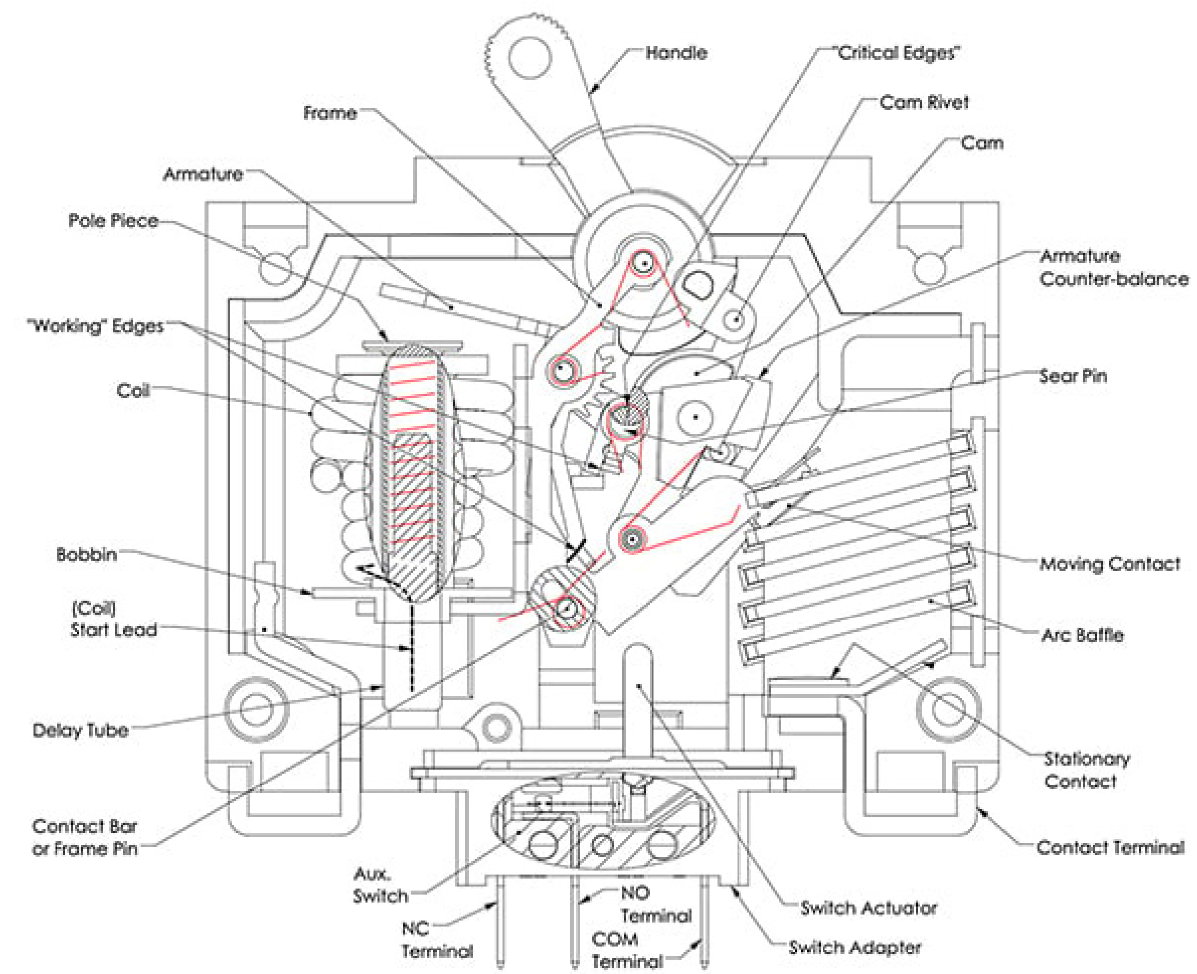
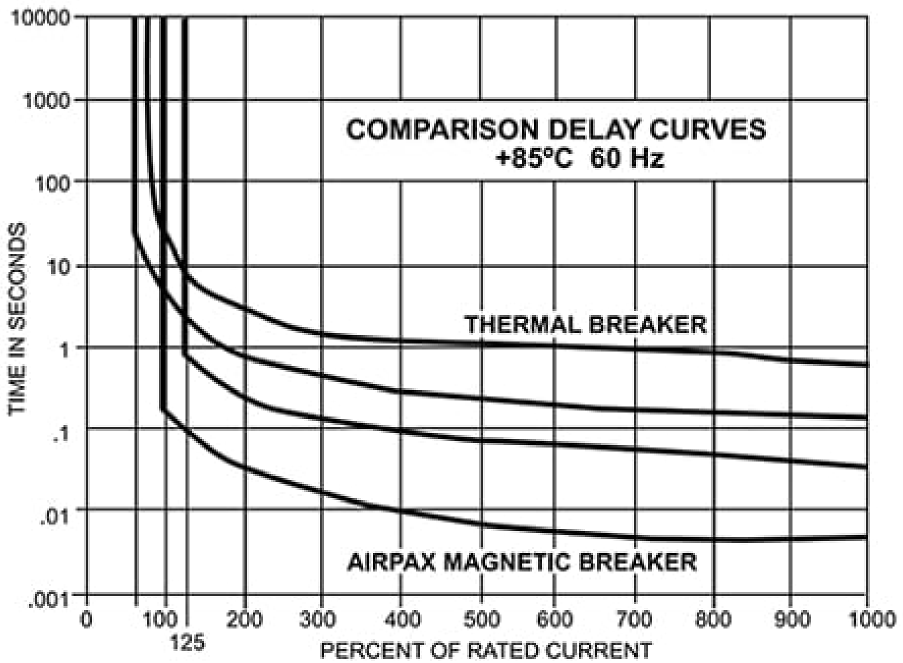


Figure 2: This cross-section of a hydraulic magnetic circuit breaker shows the magnetic element and inner damped core (at left) that trips the device when overload or fault currents generate a sufficiently large magnetic field. The damping fluid in the core tube creates a time delay. Trip operation is largely unaffected by temperature. (Image source: Sensata)



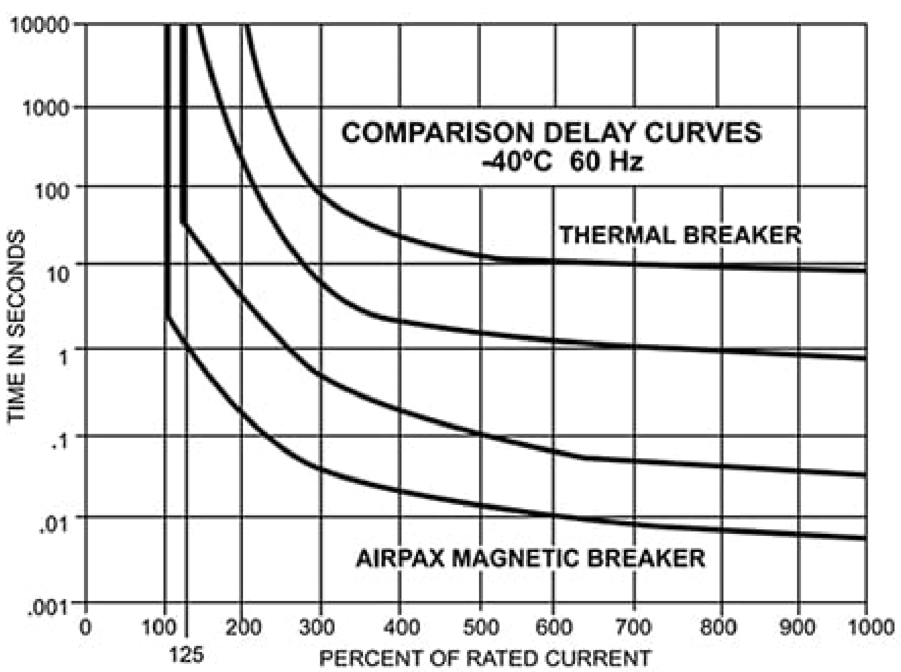


Figure 3: The impact of large temperature variations on the delay of thermal circuit breakers is much greater than it is on hydraulic magnetic devices. (Image source: Sensata)

Figure 3 compares the impact of temperature extremes on the time-delay curves for a thermal circuit breaker and a hydraulic magnetic circuit breaker (from Sensata's Airpax line). The graphs define curves for the 100% and 125% rating currents for both product types.

For the Airpax product, a temperature swing of +125°C has little effect on the delay curve. For example, at +85°C and for an overload of 250% of the rated current, the trip delay is between 0.013 and 0.2 seconds (s). At -40°C the delay for the same current is between 0.018 and 1 s. For higher currents, the differences between the delay curves at these temperature extremes are even less.

For the thermal circuit breaker, the impact of temperature is much greater. Furthermore, at the high temperature, the minimum trip level is well below the 100% rated current, and for the low temperature, it is well above the 100% rated current. This is due to the temperature effects on the thermal element discussed above. At +85°C, and for an overload of 250% of the rated current, the trip delay is between 0.8 and 3.0 s. At -40°C, the delay is between 40 and 600 s. For higher currents, the differences between the delay curves are less extreme, but still significant.

Design considerations for hydraulic magnetic circuit breakers

Apart from its tolerance to wide temperature fluctuations, a key reason for selecting a hydraulic magnetic circuit breaker over other types is to ensure the device doesn't keep tripping due to the inrush current to electric motors, transformers, or large capacitors. Such tripping is disruptive to machinery operation.

Before even considering the impact of inrush currents on circuit breaker selection, the engineer needs to work out a rating for the circuit breaker for standard overload and fault protection. A rule-of-thumb is to choose a circuit breaker rating equal to 100% of the continuous load demanded by the connected circuit. However, it is important to consider the magnitude and duration of any surges that occur during normal equipment operation.

The engineer also needs to specify the maximum operating voltage—typically 80, 125, 240, 250, or 277 volts—and the operating frequency—typically direct current (DC), or 50/60 or 400 Hertz (Hz) alternating current (AC).

A common mistake is to waste money by overspecifying the circuit breaker's rating to build in a margin of safety and prevent nuisance tripping. However, unlike a fuse, the rating of a circuit breaker is the maximum current that can be continuously carried, not the current at which it will trip.

A 20 A circuit breaker will easily accommodate a temporary surge of 25 A. However, if surge currents typically last longer than 60 s, it is good design practice to specify a circuit breaker rated at 100% of the surge current rather than the normal continuous current.

The other key performance characteristic is to decide on the appropriate delay curve for the circuit breaker. To do this, the engineer needs to know how large and how persistent the inrush current will be. One way to check the inrush current peak and duration is to start up the machinery while the circuit is monitored via an oscilloscope. Repeating the measurement several times will allow the average peak and inrush current to be determined. The designer could also consult

the equipment manufacturer's datasheet. However, this is less precise because of local factors such as line loss and the impact of other components.

Selecting a hydraulic magnetic circuit breaker for an electric motor application

Once designers have determined the maximum operating voltage, operational frequency, continuous current, surge current and duration, and inrush current and duration, they can select an appropriate hydraulic magnetic circuit breaker.

Sensata's Airpax IEG series is available in a wide variety of configurations, including units with auxiliary switch, shunt, and relay, with a choice of delays and ratings, operating voltages between 80 and 250 volts, and either DC, 50/60 or 400 Hz versions. Handles come in seven different colors, and international markings are standard.

For example, the IEG1-1REC5-69-.100-21-V is rated at 100 milliamps (mA). In the mid-range is the 20 A IEG11-1-61-20.0-01-V (Figure 4), and at the high end is the 100 A IELK1-1-72-100.-01.

Consider an example of a hydraulic magnetic circuit breaker protecting a large AC

Figure 4: Sensata's IEG11-1-61-20.0-01-V hydraulic magnetic circuit breaker is rated at 20 A and is available for several supply inputs, including 250 volts, 50/60 Hz. (Image source: Sensata)

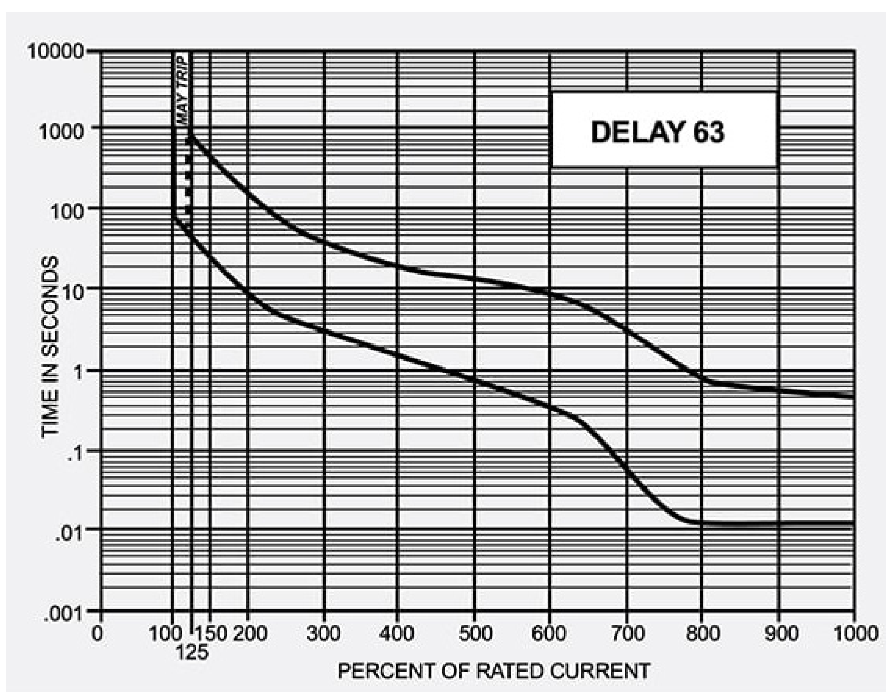


Figure 5: Sensata's hydraulic magnetic circuit breaker Delay 63 features a longer delay for special motor operations. Even at 650% of the rated current, the trip time is no less than 0.2 s. (Image source: Sensata)

electric motor. The supply voltage is 250 volts AC at 50/60 Hz, and when normally running the motor current is a continuous 20 A. There are temporary current surges—as other equipment connected to the power circuit starts and stops—of up to 25 A for between 20 and 45 s. At start-up, the inrush current peaks at 100 A (500% of continuous current) for 0.6 s, and drops to the continuous operation level in just under 1 s.

In this example, the surge current occurs for less than 45 s, so it's safe for the designer to select the rating based solely on the continuous current of 20 A. The Sensata IEG11-1-61-20.0-01-V has a 20 A rating and is available in a 250-volt, 50/60 Hz version, so it would be a good choice for this application.

Sensata provides delay charts for this model on the datasheet. For example, Delays 42, 52, and 62 are suitable for use with 50/60 Hz devices and are long enough to cater to the inrush currents of certain types of motors and most transformer and capacitor loads. Delays 43, 53, and 63 feature longer delays for special motor applications. Figure 5 shows Delay 63, and from the curve, at the peak surge current of 100 A (500%), the device will trip between 0.8 and 15 s. This enables it to cope with the example motor's inrush current—which peaks in 0.6 s and rapidly tails off—without tripping.

It is good practice to mount hydraulic magnetic circuit breakers vertically; otherwise, the core can drag in the tube and extend the trip time.

Conclusion

Electromagnetic circuit breakers are a robust option for machinery circuit protection, though thermal and thermal magnetic devices are often a better option as their built-in time delay prevents repetitive nuisance tripping. However, when equipment is subject to a wide variation in temperature, hydraulic magnetic circuit breakers have the time delay necessary to protect equipment subject to inrush currents—while keeping that delay consistent across a wide temperature range.

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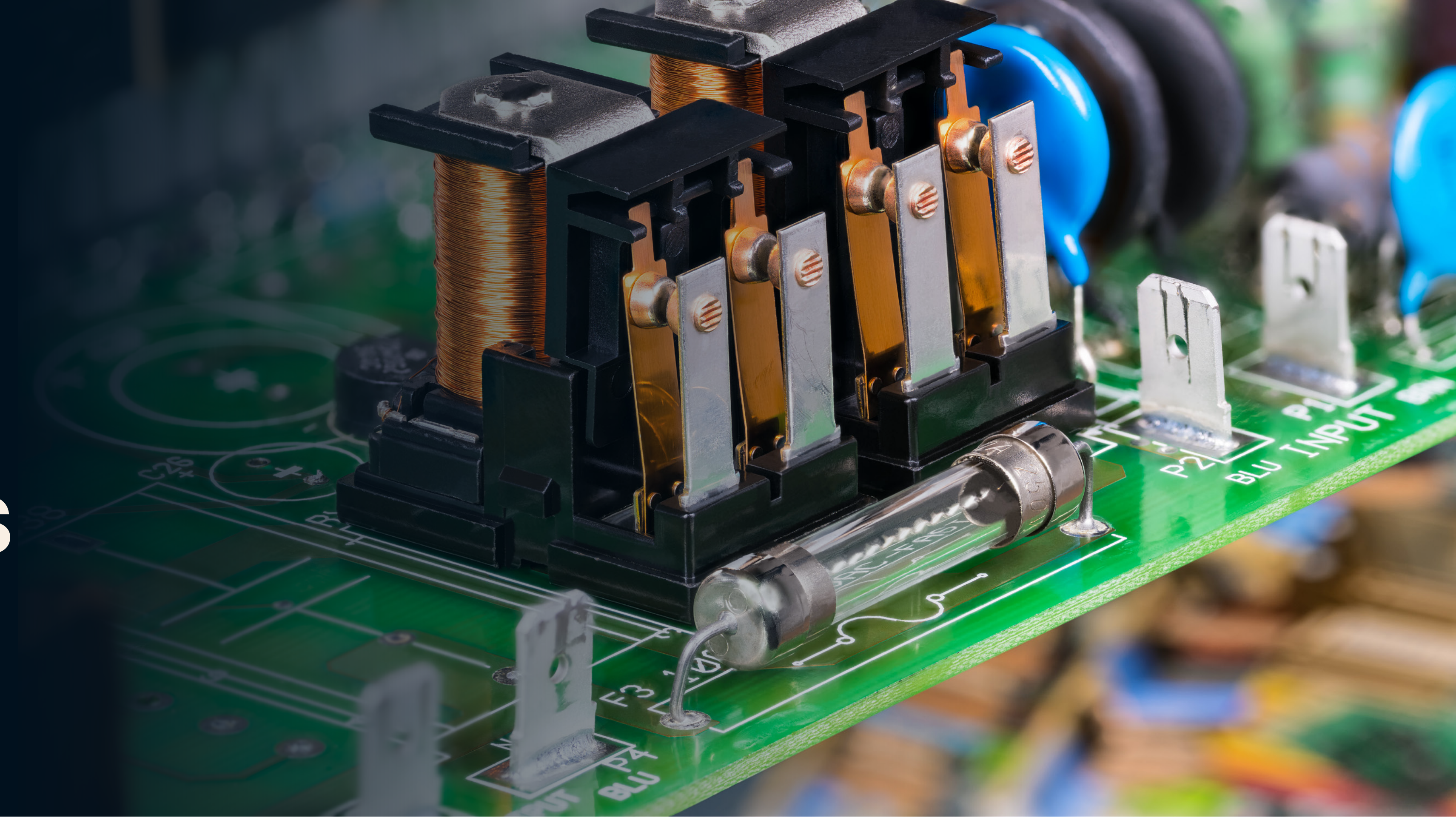
Why and how to effectively use electronic fuses to protect sensitive circuits



By Bill Schweber
Contributed By DigiKey's North American Editors

Thermal fuses have been used successfully for over 150 years as a basic circuit-protection device. They are effective, reliable, easy to use, and come in a range of values and variations to meet different design objectives. However, they have unavoidable shortcomings for designers looking for extremely fast current cutoff, the ability to self-reset, as well as the ability to function at relatively low current values. For these designers, electronic fuses—often written as eFuse or e-Fuse—are an excellent solution, sometimes replacing but usually supplementing the thermal fuse.

eFuses are based on a simple concept of current sensing by measuring voltage across a known resistor, and then turning off the current flow via a field-effect transistor (FET) when it exceeds a design limit. The eFuse offers features, flexibility, and functions which a thermal fuse cannot provide.

This article will describe how eFuses work. It will then explore the features, additional functionality, and effective use of these active-circuit fuses. Along the way, example solutions from Texas Instruments, Toshiba Electronic Devices and Storage, and STMicroelectronics will be introduced and their effective use outlined.

How do eFuses work?

The operating principle of a conventional thermal fuse is simple, well-known, and reliable: when the current passing through the fusible link exceeds its design value, that element heats up sufficiently to melt. This breaks the current path, and the current goes to zero. Depending upon fuse rating and type, as well as the amount of overcurrent, a thermal fuse can react and open the current path in a few hundred milliseconds to several seconds. Of course, as with all active and passive components, there are many variations, subtleties, and shadings of operation available for this entirely passive device that is simple in principle.

In contrast, electronic fuses operate on a very different principle. They provide some of the same functionality but also add new, different functions and features. The basic eFuse concept is also straightforward: the current to the load goes through a FET and a sense resistor and is monitored via the voltage across that sense resistor. When it exceeds a preset value, the control logic turns the FET off and cuts the flow of current (Figure 1). The FET, which is in series with the supply line and load, must have very low on-resistance so it does not induce excessive current-resistance (IR) drop or wasted power.

It may seem that an eFuse is simply a more complicated, active version of the classic, passive thermal fuse. While that is true, the eFuse also offers some unique attributes:

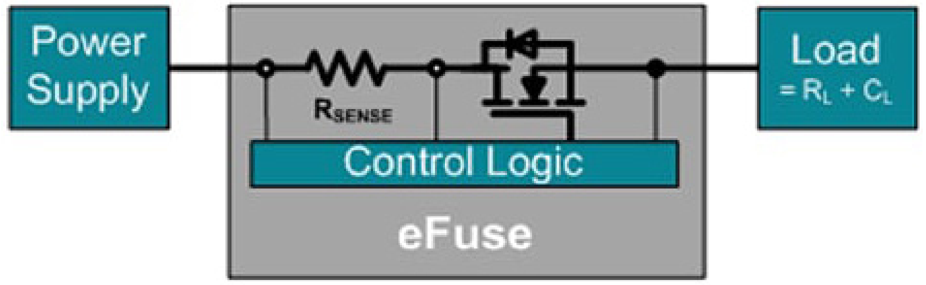


Figure 1: In an eFuse, as current from supply to load passes through a sense resistor, it is monitored via the voltage across that resistor; when it exceeds a set value, the control logic turns the FET off, blocking the flow of current to the load. (Image source: Texas Instruments)

Speed: They are fast-acting devices with cutoff reaction times on the order of microseconds, with some designed to provide nanosecond response. This is important for today's circuits with relatively sensitive ICs and passive components.

Low-current operation: Not only can eFuses be designed to work at low currents (on the order of 100 milliamperes (mA) or less), but they also work well at low, single-digit voltages. At these levels, thermal fuses often cannot be supplied with sufficient self-heating current to induce melting of their fusible link.

Resettable: Depending on the specific model, the eFuse offers the choice of remaining off after it is activated (called latch-off mode), or to resume normal operation if the current fault subsides (auto-retry mode). The latter setting is especially useful in transient inrush-current situations where there is no "hard" fault, such as occurs when a board is plugged into a powered bus. It is also useful where replacement of the fuse would be difficult or costly.

Reverse current protection: An eFuse can also provide reverse current protection, which a thermal fuse cannot do. Reverse currents can occur when the voltage at the system output is higher than at its input. This can occur with a set of redundant power supplies in parallel, for example.

Overvoltage protection: With some additional circuitry, the eFuse can also provide overvoltage protection from surges or inductive kicks, turning off the FET when the input voltage exceeds the set overvoltage trip point, and remaining in the OFF condition as long as that overvoltage condition persists.

Reverse polarity protection: The eFuse can also provide reverse polarity protection, quickly cutting off the current flow if the source is reverse connected. An example is a car battery that is reverse connected for a brief moment due to accidental cable contact.

Slew rate ramping: Some advanced eFuses can also provide defined power-down/power-up current slew rate ramping by controlling the on/off transition of the pass element FET, via an external control or by using fixed components.

For these reasons, eFuses are an attractive current-flow control solution. While they can be used in place of thermal fuses in some cases, the two are often paired. In such an arrangement, the eFuse is used for localized, fast-response protection for a subcircuit or pc board such as in hot-swap (hot plug) systems, automotive applications, programmable logic controllers (PLCs), and battery charge/discharge management; the complementary thermal fuse provides system-level protection against large, gross failures where a hard and permanent shut off is needed.

In this way, the designer gets the best of both worlds, with all the capabilities of eFuses plus the clear, unambiguous operation of the thermal fuse. This is achieved without technical tradeoffs or drawbacks. There are, of course, some tradeoffs as with any design decision. In this case it's an incremental increase in real estate and a slightly larger bill of materials (BOM).

Picking an eFuse: Functions and applications

When choosing an eFuse, there are some basic parameters to consider. The top-tier consideration is, not surprisingly, the current level at which the fuse acts. This typically can range from under 1 ampere (A) up to about 10 A, as well as the maximum voltage the fuse can withstand across its terminals. For some eFuses, this current level is fixed, while for others it can be user set via an external resistor. Other selection factors include response speed, quiescent current, size (footprint), and the number and type of external support components needed, if any. In addition, designers must consider any additional features and functions the different eFuse models may offer.

For example, PLCs are an application where eFuses are beneficial in different subcircuits that may be prone to sensor I/O and power misconnection. There are also current surges as wire connections are made or boards are hot swapped. An eFuse such as the Texas Instruments TPS26620 is often used in these 24 volt applications. It is shown set for a 500 mA limit in Figure 2. It operates from 4.5 volts to 60 volts at up to 80 mA, with a programmable current limit, overvoltage, undervoltage, and reverse polarity protections. The IC can also control inrush current and provide robust protection against reverse current and field miswiring conditions for both PLC I/O modules and sensor power supplies.

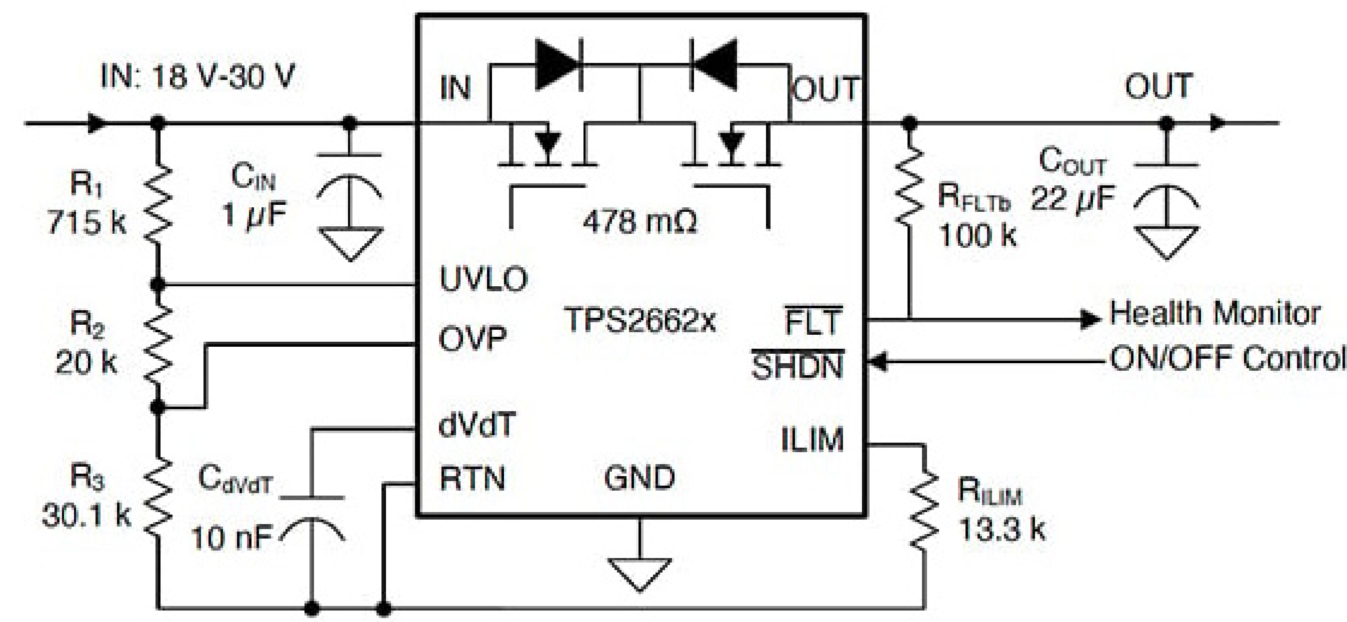


Figure 2: The Texas Instruments TPS26620 eFuse is shown set to trip at a current of 500 mA in this 24 volt DC PLC application. (Image source: Texas Instruments)

The timing diagrams in Figure 3 for Toshiba's TCKE805, an 18 volt, 5 A eFuse, show how one vendor has implemented the auto-retry versus latched modes. In auto-retry mode (set by the EN/UVLO package pin), the overcurrent protection function prevents damage to the eFuse and its load by suppressing power consumption in the event of a fault situation.

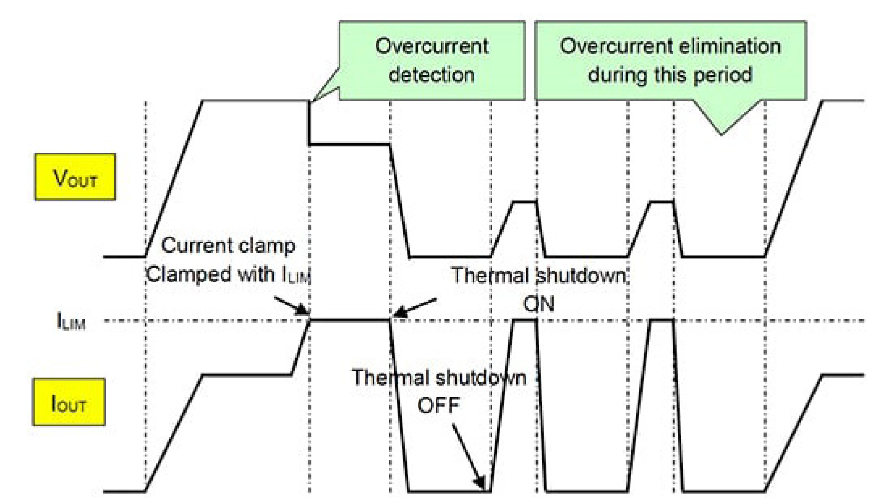


Figure 3: The Toshiba TCKE805 18 volt, 5 A eFuse uses a test-and-repeat cycle sequence to assess if it is safe to restore the current flow. (Image source: Toshiba)

If the output current, set by external resistor (R_{LIM}), exceeds the limit current (I_{LIM}) value due to a load error or short circuit, the output current and output voltage decrease, thereby limiting the power consumed by the IC and the load. When the output current reaches the preset limit value and overcurrent is detected, the output current is clamped so that no more current than I_{LIM} flows. If the overcurrent situation is not resolved at this stage, this clamped condition is maintained and the eFuse temperature continues to rise.

When the eFuse temperature reaches the operating temperature of the thermal shutdown function, the eFuse MOSFET is switched off, stopping the flow of current entirely. The auto-retry operation attempts to restore the current flow by stopping the current, which lowers the temperature and releases the thermal shutdown. If the temperature rises again, the cycle repeats and stops the operation until the overcurrent situation is eliminated.

In contrast, latch mode clamps the output until the eFuse is reset via the Enable (EN/UVLO) pin of the IC (Figure 4).

Some eFuses can be configured to overcome issues associated with current sensing across

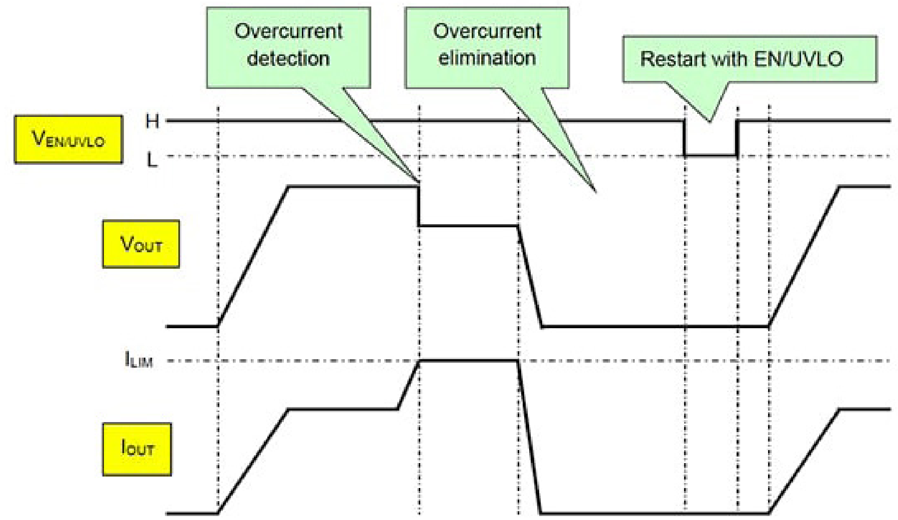


Figure 4: In latch mode, unlike the auto-retry mode, the Toshiba eFuse does not reset until directed to do so via the IC's Enable pin. (Image source: Toshiba)

a resistor, such as the associated IR drop which reduces the output-side rail voltage. For example, the 3.3 volt STEF033AJR from STMicroelectronics has nominal maximum current and FET on-resistance values of 3.6 A and 40 milliohms (mΩ), respectively, for the DFN package; and 2.5 A and 25 mΩ for the flip-chip package. In the conventional connection shown in Figure 5, at higher current values, even a modest IR drop of about 15 millivolts (mV) in the supply rail through the on-resistance may be significant and worrisome.

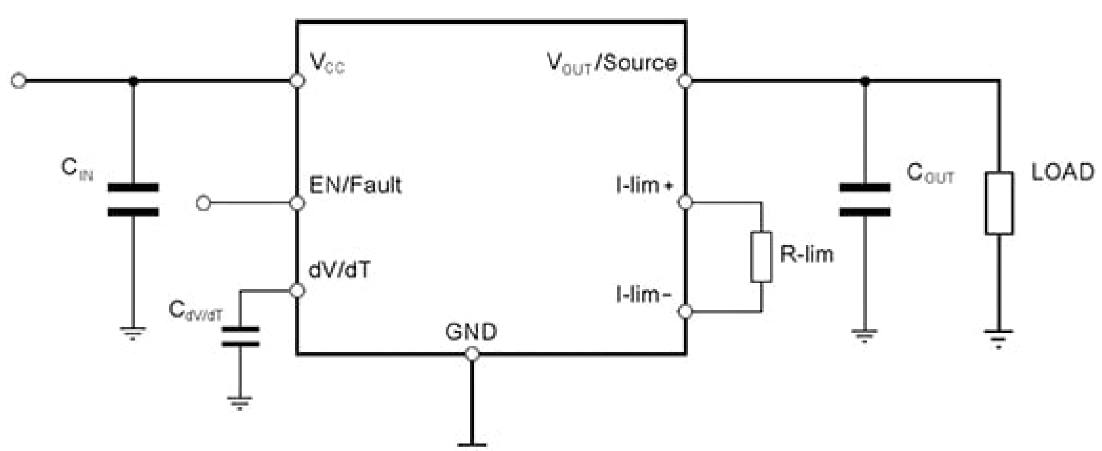


Figure 5: In the conventional wiring of the STEF033AJR, the resistor which establishes the limiting value, R-lim, is placed between two designated terminals. (Image source: STMicroelectronics)

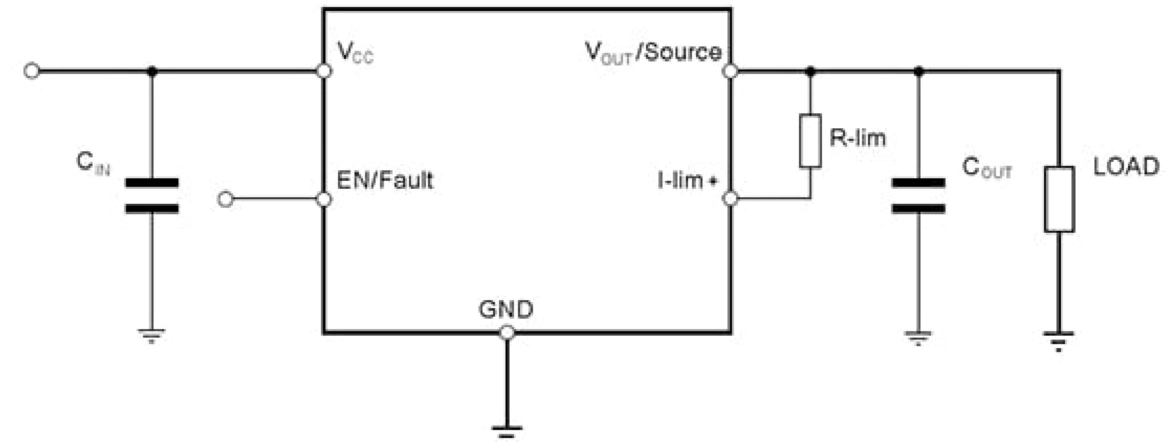


Figure 6: To reduce the effects of current-sense IR drop, the negative side of the limit resistor is connected to the voltage output (V_{OUT}/Source). (Image source: STMicroelectronics)

Modifying the conventional connection by putting the resistor between the positive-side limit connection and the output voltage connection (VOUT/Source), implements a Kelvin-sensing arrangement that compensates for the IR drop (Figure 6).

Note that although eFuses are semiconductors and can work down to single-digit voltages, they are not limited to that low region. For example, eFuses in the Texas Instruments TPS2662x family are rated for operation from 4.5 to 57 volts.

eFuse: Make or buy?

In principle, it is possible to build a basic eFuse from discrete components using a couple of FETs, a resistor and an inductor. The earliest eFuses were built this way, with the inductor serving two purposes: filtering the DC output and also acting as a sense resistor using the DC resistance of its windings.

However, an enhanced eFuse with more consistent performance which takes into account the characteristics of its components, as well as real-world operational considerations, requires more than a few discrete components. Even with the additional components, it can provide only basic eFuse functionality (Figure 7).

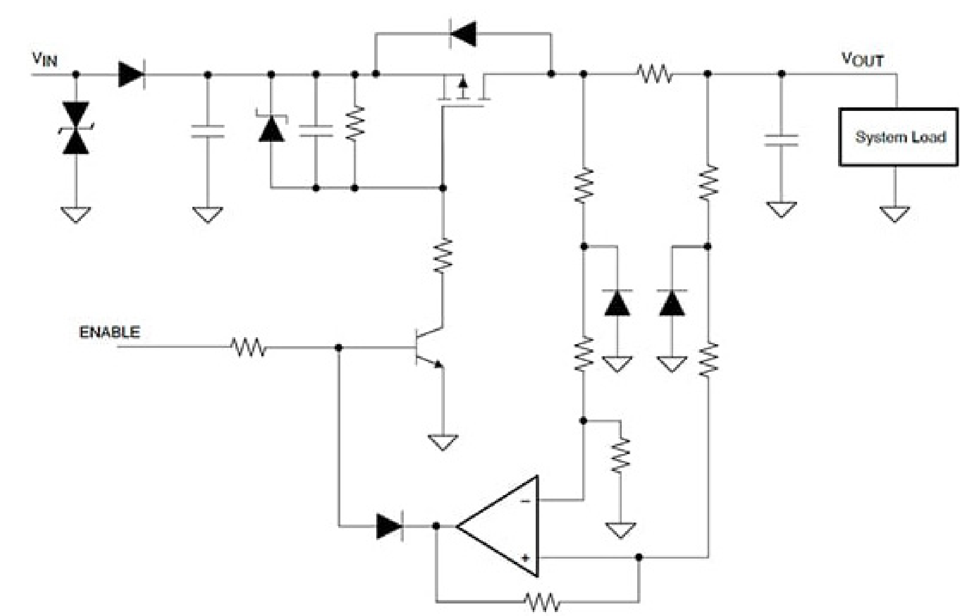


Figure 7: An eFuse with basic functionality using discrete components must anticipate and overcome their inherent limitations. (Image source: Texas Instruments)

The reality is that the accumulation of active and passive discrete components soon gets unwieldy, is prone to unit-to-unit performance variations, and has issues related to initial tolerance, component aging, and temperature-induced drift. In short, a DIY "make" discrete solution has many limitations:

- Discrete circuits generally use a P-channel MOSFET as a pass element, which is more expensive than an N-channel MOSFET with respect to achieving the same on-resistance value ($R_{DS(ON)}$).
- Discrete solutions are inefficient as they include power dissipation across a diode with a corresponding rise in board temperature.
- It is difficult for discrete circuits to include adequate thermal protection for the pass element FET. As a result, that critical enhancement must be left out, or the design must be substantially oversized to provide a suitable safe operating area (SOA).
- A comprehensive discrete circuit needs many components and considerable board space, and the need for protection circuit robustness and reliability add additional components.
- Though the output voltage slew rate in discrete designs is adjustable using resistor and capacitor (RC) components, these components must be sized with careful understanding of the gate characteristic of the pass FET.

Even if a discrete component solution was acceptable, it would be limited in its features compared to an IC solution. The latter can include some or all of the many additional functions previously cited, as seen in the Figure 8 eFuse block diagram. In addition, the IC solution is smaller, has more consistent and fully characterized performance, and offers an implementation "peace of mind" that a multicomponent solution cannot offer, and does so at a lower cost. Note that the TPS26620 data sheet has several dozen performance graphs and timing diagrams covering a variety of operating conditions, all of which would be difficult to create for the discrete "make" approach.

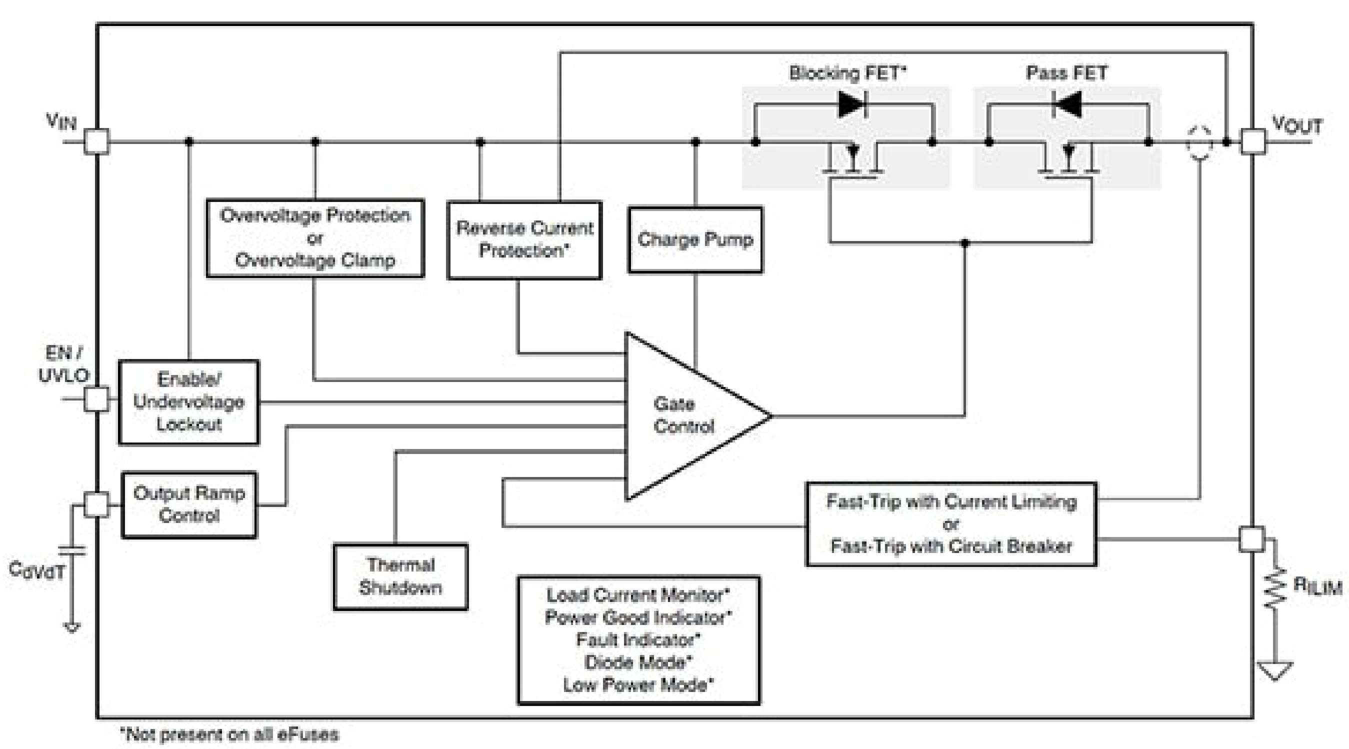


Figure 8: The outward simplicity and appearance of a full-featured eFuse conceals its internal complexity, which would be very difficult to reproduce using discrete components. (Image source: Texas Instruments)

There is another critical reason to buy a standard eFuse IC rather than take the DIY discrete route: regulatory approval. Many fuses—thermal and eFuse—are used for safety-related functions to prevent conditions where excessive current can cause component overheating and possibly fire, or cause harm to users.

All conventional thermal fuses are approved by the various regulatory agencies and standards to provide a fail-safe current shutoff when used appropriately. However, it would be very difficult and time-consuming, and likely even impossible to get the same approvals for a discrete solution.

In contrast, many of the eFuse ICs are already approved. For example, eFuses in the TPS2662x series are UL 2367 Recognized ("Special-purpose Solid-state Overcurrent Protector") and IEC 62368-1 Certified (Audio/video, information, and communication technology equipment - Part 1: Safety requirements). They also meet IEC 61000-4-5 ("Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test"). To be so certified, these eFuses are tested for performance in their basic role, as well as under conditions that include minimum and maximum operating temperatures, minimum and maximum storage and transportation temperatures, extensive abnormal and endurance tests, and thermal cycling.

Conclusion

eFuses, which use active circuitry rather than a fusible link to cut off current flow, help designers meet requirements that include fast cutoff, self-reset, and reliable operation under low current conditions. They also come with various protection features as well as adjustable slew rates. As such, they are a valuable addition to the engineer's kit of circuit and system protection components.

As discussed, eFuses can replace conventional thermal fuses, though in many instances they provide localized protection and are supplemented by the thermal fuse. Like the venerable thermal fuse, many of the eFuses are also certified for use in safety-related functions, thus expanding their versatility and applicability.

Further reading

"IEC 62368-1 Is on Its Way: The New Safety Standard for ICT and AV Equipment"

"The Right Power Supply is Critical to Meet the New IEC/UL IEC-62368 Consumer Product Safety Mandate"

"Fuse Tutorial"

"How to Select and Apply Smart Current Sensing and Monitoring Technologies (Instead of Fuses)"

Robust digital isolation adds safety to high-voltage applications

By Jessica Shapiro
Contributed By DigiKey's North American Editors

Wherever powered electrical circuits have the potential to interact with other circuits, hardware and infrastructure, or human users, there's a potential for damaging overvoltage conditions. Physically or electronically isolating the current from potential points of interaction, commonly known as galvanic isolation, is essential for safety and the continued functioning of the circuit. As an added benefit, isolation often reduces unwanted noise in the output signal.

Isolation requirements are prevalent in robotics, high-voltage power grid equipment, factory floor equipment, automotive applications, and consumer products. Application specifics like variable input voltages, the use of battery power, or the need for a compact footprint are further requirements to consider when designing an isolation system.

To choose the right isolation components, designers need to understand the pros and cons as well as the makeup of various isolator architectures. With this understanding, they can incorporate the most effective, reliable, and space-efficient isolators into their electronic designs.

Identifying isolators

Galvanic isolation can be achieved in several ways, but they all share a basic principle: A higher voltage input on the primary side is separated from the lower voltage, low-current secondary side by some physical barrier. The details of the barrier, as well as the method of transmitting power, signals, or both across it, depend on the type of isolator.

Optocouplers use LEDs to convert the signal on the primary side from electrical impulses into photons. On the secondary side, a photosensitive component like a phototransistor, photodiode, or photo-field-effect-transistor (FET) receives the photons and converts them back into an electrical signal. Along with physical isolation of the primary and secondary circuits, optocouplers automatically remove unwanted noise from the output signal and prevent ground loops.

In magnetic couplers, voltage across the primary-side winding of a transformer generates a magnetic field. This magnetic field induces a voltage across a winding on the secondary side, transmitting an electrical signal while maintaining galvanic isolation. Transformers can have two separate windings on a single iron core or can be two inductors, each with one winding around its own iron core, separated by a dielectric material. Designers choose magnetic coupling for its high-voltage capabilities, relatively quick response times, and its ability to filter out signal noise. However, the size of the isolator, the possibility of heat generation, and the production of electromagnetic interference should also be considered.

Capacitive couplers employ capacitors, which are components with two electrodes separated by a dielectric material. Charge builds up on the primary-side electrode due to the input voltage. This creates an electric field that induces a voltage in the secondary-side electrode. Capacitive couplers are known for their small size, low power usage, and their rapid response to changes in input, making them convenient and efficient to deploy in transmitting electrical signals across an isolation barrier. Designers must take steps to protect capacitive couplers from an input voltage that exceeds their capabilities, environmental humidity, and dielectric breakdown.

Deploying digital isolators

Any of the isolator types discussed above can be incorporated into digital isolator systems on integrated circuits (ICs). These topologies can be further integrated with power modules or signal transmission components to form complete digital isolation systems on single chips. Some common digital-isolator system topologies include flyback, half-bridge, and push-pull.

A flyback power supply is a form of magnetic isolation that creates a transformer by combining a split inductor with a buck-boost converter that can increase or reduce the voltage of a direct current (DC) input to match the desired output. Feedback to the buck-boost converter is supplied by a tertiary inductor winding or an optocoupler. Flyback power supplies are recommended for low-power applications, but designers must be aware of the potential for unwanted EMI.

Half-bridge (H-bridge) designs include an H-bridge square wave generator, a resonant circuit containing two inductors and a capacitor (LLC), and two rectifiers that deliver the desired DC output voltage. The rectifiers allow for higher output power than some designs, and H-bridge isolation designs are recommended for medium-power applications.

Push-pull isolated power supplies use two transformers for magnetic coupling. Two switches alternate which transformer receives the input voltage. Two full-bridge rectifier diodes on the secondary side anticipate changes to the voltage and regulate it into a symmetrical output.

For greater control, designers may choose to add a transformer driver into a push-pull setup. The driver integrates an oscillator, a frequency divider, and a logic controller to coordinate the opening and closing of the switches in a break-before-make (BBM) pattern. This pattern produces a relatively constant output signal while protecting internal and downstream components from being damaged by having both switches connected at once.

Systems with transformer drivers may also control the output with low-dropout linear voltage regulators (LDOs) that replace or augment the function of the rectifier diodes. Dropout voltage is the minimum difference between the input and output voltage below which the circuit cannot adequately regulate the output. In LDOs, this difference is extremely small, ensuring reliable operation over a wide range of input voltages.

Leaning into LDOs

An LDO contains a FET, a differential amplifier, and a bandgap voltage reference. The differential amplifier compares the output voltage to the reference voltage, and, if the difference between them is too high, the amplifier signal triggers the FET to adjust the circuit resistance to keep the output voltage steady.

In addition to the dropout voltage, several other specifications should be considered when selecting an LDO for a digital isolation application, including load and line regulation, power supply rejection ratio (PSRR), output noise, and quiescent current (I_Q). Load regulation is an LDO's ability to handle variations in input current while maintaining a stable output voltage, while line regulation concerns variations in the input voltage. Many specifications also quote PSRR, which measures the regulator's ability to manage ripple in a rectified alternating current (AC) input.

Designers also want to ensure that output noise is kept to a minimum. A low I_Q, the current needed to operate the regulator's internal circuitry, simplifies the system and preserves battery life in mobile applications.

One example of an LDO designed specifically for battery-connected systems is 3PEAK's TPL8031Q-S (Figure 1). These regulators generate fixed-voltage outputs of 3.3 V or 5 V with ±2.5% accuracy. They have maximum dropout voltages of 720 mV for the 5 V output version and 900 mV for the 3.3 V output version.

TPL8031Q-S regulators tolerate input voltages between 3 V and 42 V with transients as high as 45 V, and can output up to 300 mA of current. At the same time, they consume little power, with a typical I_Q of 3 µA. Internal current limits protect the regulators from fault conditions, such as shorting to ground, by stopping voltage regulation. In addition, over-temperature protection shuts down the regulator if its internal temperature reaches a thermal shutdown (TSD) threshold, and allows it to resume operation once it has sufficiently cooled.

Figure 1: Low-dropout linear voltage regulators (LDOs) provide reliable output voltages for digitally isolated systems like automotive electronic control units. (Image source: 3PEAK)

Reliability, along with low power consumption and high-voltage capabilities, makes the TPL8031Q-S voltage regulators good LDO candidates for many space-limited automotive applications that rely on battery power. These include electronic control units (ECUs), domain and body control modules, microcontrollers and transceivers, interior and exterior lights, infotainment systems, instrument clusters, and other subsystems powered by or connected to the vehicle battery.

Conclusion

Automotive applications exemplify systems that need robust digital isolation to protect delicate electronics from overvoltage and to ensure human operators, passengers, and others who come into contact with the systems are safe from dangerous voltages. There are many permutations of power and signal isolation that can accomplish this, and LDOs are a critical component of carefully designed digital isolation systems.

This month in history

1752

June 10

Benjamin Franklin's lightning experiment

Benjamin Franklin is believed to have conducted his famous kite-and-key experiment near Philadelphia, demonstrating that lightning is electrical in nature. Newspapers around the world published detailed instructions for building a kite to fly in a lightning storm and recreate the experiment at home.

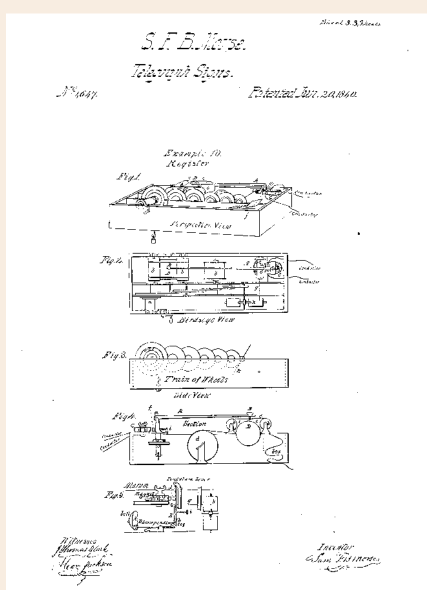
Franklin was inspired by French natural philosophers like Jean Jallabert.

1840

June 10

Samuel Morse patents the telegraph

Samuel F.B. Morse received U.S. Patent 1,647 for his telegraph system. Though he had demonstrated the device earlier, this patent formalized his claim to the technology. Lore has it that he invented the telegraph out of grief when he missed his wife's death while working due to a lapse in communication.



Improvement in the Mode of Communicating Information by Signals by the Application of Electromagnetism

1896

June 2

Marconi patents wireless telegraphy

Guglielmo Marconi filed a British patent for his wireless telegraphy system, the world's first radio communication patent. Marconi's invention would transform global communications, enabling ships at sea to send distress signals and eventually leading to commercial radio broadcasting.

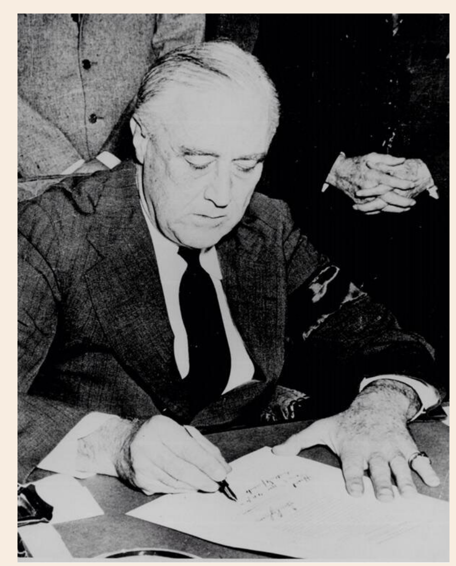
Young Marconi giving a demonstration of wireless telegraphy.

1934

June 6

FCC established by Communications Act of 1934

President Roosevelt signed the Communications Act of 1934 into law, establishing the Federal Communications Commission to regulate interstate and international communications by radio, television, wire, and cable. The FCC remains the primary authority over American telecommunications to this day.



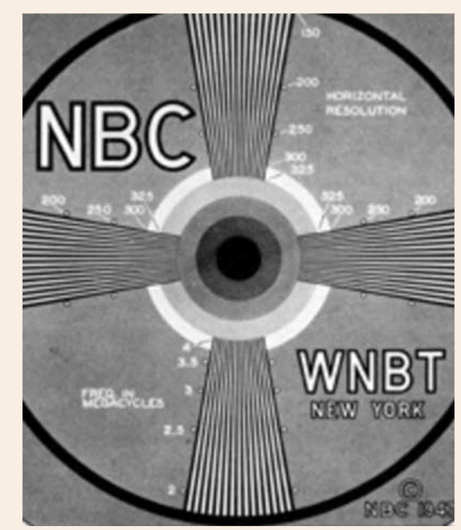
President Roosevelt signing the 1934 Communications Act into law.

1948

June 24

First commercial television station in the United States

WNBT in New York (today's WNBC) became the first commercially-licensed television station in the United States, broadcasting regularly-scheduled programming, including news and entertainment. The station's launch marked the practical beginning of commercial television as an industry.



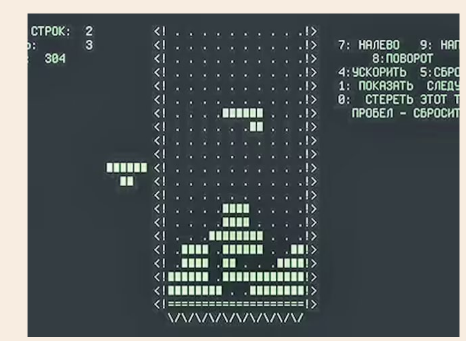
Commercial television, as created by NBC and RCA, was so successful that the model was used throughout the country, and broadcast television spread through every major city in the US within a handful of years.

1984

June 6

Tetris is created

Soviet software engineer Alexei Pajitnov completed the first working version of Tetris on an Electronika 60 computer at the Soviet Academy of Sciences. The game, built from falling blocks derived from a pentomino puzzle set, would become one of the best-selling video games of all time.



Tetris on the original hardware looks far different than the modern incarnations.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is demanding
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