What is Circuit Protection?
Circuit protection is a very broad area of expertise. Circuit protection protects electronics from the various faults that can occur. These faults can be generated internally because of internal problems in the system or can come from external sources. Internal problems would be a short circuit or an issue with the circuit, a failure of the component that can cause a short circuit, or an overload of current that goes through the system. All of these need to be addressed. There can even be lightning interference that induces surge inside the electronics — it travels from outside conductors from the grid to the inside of buildings and homes. Those are some examples of faults that can occur and why circuit protection is recommended, and definitely required in some applications.

Why is circuit protection so critical from a high-level standpoint, and what are we doing when we add additional circuit protection components to a board? Typically, circuit protection is an add-on — it’s not providing any additional performance. For example, for an Ethernet circuit or a data communication circuit, it’s not providing more bandwidth or higher performance. So why do you need to add it? It’s extremely important in protecting the end user. Circuit protection protects people. When you talk about electricity, it is dangerous — circuit protection guards against shock hazards, fire, and overheating. It protects technology from a reliability standpoint or a safety standpoint. If you have a server in a data center, if an overcurrent event or short circuit happens, you don’t want one board on that server taking down the entire chassis, the entire rack, or the entire data center.

Where is circuit protection used? It’s used everywhere — in consumer electronics, automotive, lighting, communications, industrial. It’s used in anything with an electronic circuit utilizing power: sending power out of a system or port; sending signal and power at the same time such as motors, batteries, smartphones, LED TVs and lights; and in wireless base station infrastructure equipment.

What are the types of circuit protection devices at the component level? Fuses are very well-known devices; resettable fuses, or positive temperature coeffi-
cient (PTC) fuses, provide overcurrent protection and then self-heal or reset themselves. Gas discharge tubes are commonly known as surge arrestors or lightning protectors. Varistors are used for lightning protection as well, but they are made up of a zinc oxide ceramic matrix. Polymer ESD suppressors protect against electrostatic discharge. Transient voltage suppression (TVS) diodes are silicon devices used as clamps. Protection thyristors, called SIDAcitor® devices, are also used as lightning protection.

Lots of different types of platforms provide circuit protection. Each one will have associated with it many series of products with specific functions and applications. Sometimes these devices are used together for optimal circuit protection. They all have pros and cons, weaknesses and strengths. You need to know the foundational technology behind these components. What are their strengths and weaknesses and where should I use them?

Why is it Important?
What happens when you don’t protect a circuit correctly? If you have a simple power port with a fuse in series, a Metal Oxide Varistor (MOV) in parallel, and then an integrated circuit to be protected, the MOV provides a clamp, so if a surge comes in, the MOV will conduct and clamp, and send that surge current to the ground away from the circuit. Why is that fuse in there? One reason is for over-current protection, but also sometimes to protect the MOV. If the MOV reaches an end-of-life scenario, they can thermally run away as they’re sitting in the system. Removing the fuse leaves the MOV unprotected. If the fuse is put back, how does it protect the MOV? The fuse senses current, not temperature. Littelfuse took the thermal fuse and put it inside the MOV and invented a device called a TMOV.

Typical battery systems are made up of lithium-ion chemistry, and lithium is an extremely volatile element—it catches fire at about 100°C, and will explode at 120°C. What causes that over-temperature event is really an overvoltage. If you charge a battery at a voltage higher than it’s designed for, you’ll make that battery thermally run away. Li-Ion batteries need to be well protected by several layers of circuit protection.

Circuit protection is a critical part of design—it shouldn’t be an afterthought. It needs to be thought of when you’re designing the initial architecture. You need to anticipate what faults can occur, what can cause reliability issues, what faults can come into the system that can cause surge events, how a short-circuit event occurs, and what will happen if you don’t protect against it. You may need to redo the board layout, costing money and lost development time. You may end up with a less-than-optimal protection device or location, which results in functional failures, poor reliability, and safety issues such as shock or fire.

Safety standards drive the need for circuit protection. Underwriters Laboratories (UL) Standard UL1449 is the standard for surge protection, describing what type of protection is required based on where the equipment is placed within an environment or building. If the equipment is outside and connected to the grid, exposure to surge is much higher than a piece of equipment that’s inside the building because the building already has several layers of protection.

In consumer electronics, an optimized fuse was developed for use in wall-mount chargers. The smartphone and tablet industries have evolved in such a way that chargers are now directly connected to the wall — the wire is just the USB cable. Any short-circuit condition in wall-mount chargers will come directly from the wall into that charger. It’s a very dangerous application if you don’t have adequate circuit protection. The charger can explode, catch on fire, or catch the other chargers bundled next to it on fire. For this case, a very small form factor axial fuse is placed inside wall-mount chargers.

Applications for Circuit Protection
There is a trend to put more electronics inside a vehicle. There are safety devices, cameras, infotainment, WiFi connectivity, as well as electronic systems that control the powertrain system, ABS, and door and window lock motors. Those electronics are highly susceptible to surge events that can occur inside the automobile. One of those transient surge events is what we call load dump — when the battery is accidentally disconnected from the alternator. It dumps, or surges, current inside the electronics. How do we protect against that? An automotive varistor (AUMOV) is placed in parallel to those electronics and will divert that load dump surge away from the vehicle’s electronics.

In LED lighting, it’s being installed in both indoor and outdoor environments, which presents a problem.
The power-supplied LEDs and LED drivers are highly susceptible to surge events. The old legacy lights had robust components at the front ends of those circuits that protected against surge events. When you replace those lights with LED lights indoors, that LED bulb is a complete power supply with the LEDs. Any surge that comes into the line will damage the power supply and take out that light.

DC power supplies are another data center and telecom application requiring high breaking capacity, high-reliability design, and wide operating range. DC is very different from AC when it comes to designing circuit protection and fuses. AC has the advantage of going through zero cross. When a fuse opens at very high current and voltage, it tends to arc before the fuse fully opens, which creates a lot of heat and plasma, causing a fuse to explode.

Industrial controls is another application in which you want superior peak surge current rating in small disc sizes and low-voltage DC varistors. These are applications such as PLCs, industrial control contact relays, and alarm systems. A lot of these applications require the use of surge protection, but sometimes it's not surge protection from the outside, but from inductive spikes — lots of equipment being turned on and off can cause inductive spikes that can be transferred into the electronics.

ESD is a big issue for wearable technologies and other very small, sensitive electronics. The devices are on the user, who is running around a dry environment, on and off carpeting, touching a lot of equipment. This requires higher levels of ESD protection, which is typically implemented using very small form factor TVS diode arrays.

**Selecting a Fuse**

What is a fuse and how do you select one? A fuse is an intentionally weak link in the circuit that interrupts overload and short-circuit conditions when its metallic element melts. A fuse is placed in series with the circuit it’s protecting. Voltage protectors like TVS diodes and MOVs are placed in parallel to the circuit.

In choosing the right fuse for a specific application, you need to know the environment in which the fuse is being used. There are several factors used to select the proper fuse. One is normal operating current — how much steady-state current is going through the system. You need to design a fuse that is at a rated amperage level above that. A fuse has to be designed to operate without opening for the lifetime of the circuit. Fuses can weaken over their lifetime by temperature cycling and by current that’s causing heating. This makes the fuse melt somewhat and cause brittleness of alloys. Then, it can open when it’s not supposed to — what we call nuisance blowing.

The second factor is application voltage — you never want to exceed the maximum operating voltage of the fuse. You should know DC and AC voltage. The voltage rating marked on a fuse indicates that the fuse can be relied upon to safely interrupt its rated short-circuit current in a circuit where the voltage is equal to, or less than, its rated voltage. Fuses are sensitive to changes in current, not voltage. It is not until the fuse element melts and arcing occurs that the circuit voltage and available power become an issue. A fuse may be used at any voltage that is less than its voltage rating without detriment to its fusing characteristics.

The third factor is ambient temperature, which can affect the fuse’s reliability. The current carrying capacity tests of fuses are performed at 25°C and will be affected by changes in ambient temperature. The higher the ambient temperature, the hotter the fuse will operate, and the shorter its life. Conversely, operating at a lower temperature will prolong fuse life. A fuse also runs hotter as the normal operating current approaches or exceeds the rating of the selected fuse.
A fuse serves as an intentional weak link in an electrical circuit, interrupting overload and short-circuit conditions when its metallic element melts.

Practical experience indicates fuses at room temperature should last indefinitely, if operated at no more than 75% of the catalog fuse rating.

Overload current condition is the time it takes to damage. You want to know how quickly that fuse needs to trip for a given current. Fault conditions may be specified for current only, or for both current and the maximum time the fault can be tolerated before damage occurs.

The next factor is maximum fault current, also called interrupt rating or breaking capacity. A fuse must meet or exceed the maximum fault current of the circuit. The interrupt rating is the maximum approved current that the fuse can safely interrupt at a rated voltage. During a fault or short-circuit condition, a fuse may receive an instantaneous overload current many times greater than its normal operating current. Safe operation requires that the fuse remain intact and clear the circuit.

Pulses are another factor. Over its lifetime, a fuse can experience inrush currents that happen on startup. Electrical pulse conditions may vary from one application to another. Electrical pulses produce thermal cycling and possible mechanical fatigue that could affect the life of the fuse. For some applications, startup pulses are normal and require the use of fuses that incorporate a thermal delay design to enable them to survive normal startup pulses, while providing protection against prolonged overloads. It’s important to define the startup pulse and then compare it to the fuse’s time-current curve.

Remember to consult the manufacturer’s data sheet for details on a specific device’s agency approvals, such as UL, CSA, etc. Also check the data sheet for information on axial leads, mounting type and form factor, visual indication, etc. Examine the data sheet for details on fuseholder features and rerating, and always request samples for testing in the actual circuit to verify you made the right selection.

**Author/P presenter**

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