A Guide to the Fundamentals of Circuit Protection

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MOUSER ELECTRONICS

Introduction

Reliability is crucial in the modern world. When systems or devices fail prematurely, the issue will soon become known through user groups, especially on social media, and reputations can be damaged, sometimes irretrievably. So, whatever you are designing, ensuring that the circuits are protected from issues such as excess current flow and overvoltage conditions is always a primary consideration.

While many may think that protecting the supply rails is the priority, there are other equally important parts of a circuit or system—especially interfaces that reach the outside world via connectors as well as sensitive analogue inputs and any voltage or current output stages.

The degree of protection required varies considerably depending on several factors. However, just because a circuit has no high-current features (e.g., an IoT sensor gateway) doesn't mean that protection isn't required. An analogue signal chain, from sensor element to analogue-to-digital converter (ADC), might use a sensor outputting just in millivolts. Such circuitry is particularly prone to damage and potential failure due to electrostatic discharge (ESD) and electrical fast transients (EFT).

This article investigates why protection from overcurrent, overvoltage, ESD, and EFT is critical in modern design and showcases a wide range of protection components.

Taking protection for granted

Because protection is present in the devices we use in our day-to-day lives, we naturally assume that they are robust and not prone to failure. However, if the protection had not been designed in, then failures would be more common than they are now.

As consumers, we tend to take protection for granted; at one level, we can afford to, as we trust that the devices we buy have been thought through and are well-designed. However, as electrical/electronics designers, we cannot take protection for granted. It is an essential element of every design that we undertake.

Even performing everyday tasks, such as walking across a synthetic carpet or removing an item of synthetic clothing, can produce levels of static electricity that are harmful to unprotected technology. Almost everyone has experienced a static jolt from time to time as we discharge ourselves into something that is earthed, like a radiator or a faucet. Many would be surprised to know that it is easy for a human to generate up to 8kV, which explains the jolt that we feel.

Increasingly, we come into direct electrical contact with electronic circuits, whether plugging in a data cable or touching a conductive screen. Without protection, these devices could easily be damaged by several kilovolts of static energy.

What do we need to protect against?

Alongside static energy, two other primary causes of premature failure are an excess of current (overcurrent) and an excess of voltage (overvoltage), both of which can cause catastrophic failure if the device does not protect against them.

There are many potential causes of overcurrent and overvoltage. Some will occur during normal operation, while others will result from a fault condition, either elsewhere in the system or in a connected device.

Short circuits can have a multitude of causes, including component failure, misaligned plug, or even conductive dirt getting into the device, all of which can cause overcurrent. Similarly, component failure can be a source of overvoltage, as can activities such as switching inductive loads (e.g., motors, heating elements) where the back electric and magnetic field (EMF) must be protected against.

Natural phenomena such as lightning can also inject momentary voltage spikes which, although short in duration, have a large amplitude that can cause irreparable damage to a circuit.

Connecting two devices can sometimes result in a fault in one device damaging the other—for example, plugging a faulty charger into a smartphone or plugging a tablet with an input short into a good, but unprotected, charger. However, circuit protection has a far wider scope than just power. For example, similar damage can occur when connecting peripherals to computers as well as when conductive foreign objects get inside a device or its connectors.

Primarily, circuit protection is required everywhere there is an external connection to a circuit. This includes power connections as well as all manner of data ports (e.g., USB, RF, DVI, DisplayPort, Ethernet), external sensors, and other peripherals.

Within a circuit, protection is often used to prevent a failure in one area from propagating too far, thereby causing more significant damage. For example, a faulty power rail could damage anything attached to it while a simple protection arrangement could significantly limit this damage.

Given the large number of ways in which a circuit can be damaged, it comes as no surprise that there is a plethora of devices available to be incorporated into circuit protection. These range from simple fuses to thermistors, diodes, varistors, thyristors, and gas discharge tubes. Engineers select these devices depending upon the type of protection needed and will often combine them to provide a broader degree of protection for circuits.

Dealing with overcurrent situations

An overcurrent is simply defined as any current in excess of what the equipment, conductor, or device is designed to carry. If this situation is not addressed swiftly, overcurrents will rapidly cause the overheating of nearby components. This will often lead to irreparable damage within the system and can even have external impacts such as damaging the insulation of connecting cables.

In the worst cases, the result of an overcurrent can be a fire, explosion, or the release of noxious fumes from components or insulation. This damages electrical systems and equipment and may cause serious harm to people in the vicinity.

While the outcome is often the same, there are two primary causes of overcurrent situations:

Short circuits: The most common causes of short circuits include an internal fault within a component, a foreign object bridging conductors, or insulation breakdown. This allows current to flow differently to its normal current path (which may include a different path within a faulty component). In this type of fault, the current finds its own shorter path (the path of least resistance), hence the term ‘short circuit’.

As the current is not controlled, the short-circuit current can be many times the normal operating current, only stopping once further failures occur, causing an open circuit that stops current from flowing.

Overloads: These incidents are often less dramatic than a short circuit and relate to an abnormality within the system that causes more current than normal to flow along the normal current path. Nevertheless, these currents are also damaging and, if allowed to continue, will cause failures (which may then lead to a short circuit).

Overloads can also be caused by a partial or complete component failure within a system as well as other faults (such as a mechanical fault in a motor causing the winding to draw more current than normal). They can also be the result of human error, such as connecting an incorrect or inappropriate load to a system.

Often an overload-related overcurrent will manifest itself in the form of overheating of one or more components. Depending upon the severity and longevity, this may cause long-term damage. The sooner the fault is rectified (or the equipment is turned off), the better the chance that damage is avoided.

Although overload currents may be many times the normal current, in most cases, they are significantly less severe than short circuits.

Simply dealing with an overcurrent involves creating an open circuit in the current path to prevent the overcurrent from flowing. Often this is performed by a fuse, which can either have a one-time operation or be resettable once the fault has been rectified.

Littelfuse offers a wide range of fuses for use in automotive and electric vehicle charging, industrial, consumer, domestic appliances, computer, telecom and renewables applications (Figure 1). The range is complemented by a comprehensive line of fuse blocks, fuse holders, and other accessories.

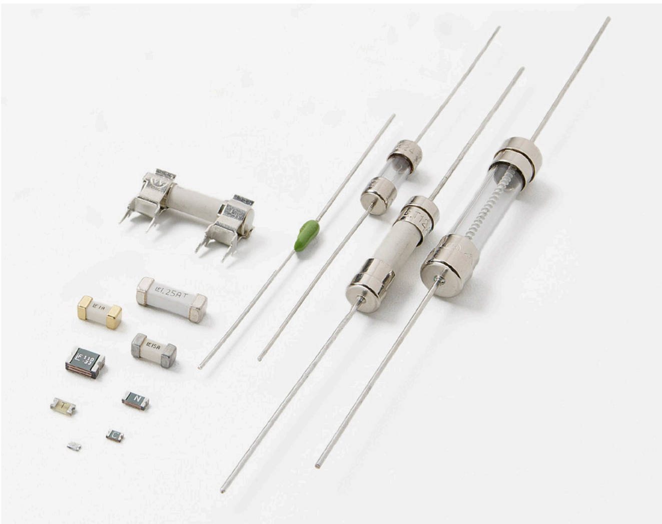

Figure 1: Littelfuse offers a wide range of fuses for circuit protection. (Source: Littelfuse)

Additionally, Littelfuse offers a full range of surface-mount, radial-, and axial-leaded PPTC resettable overcurrent suppression devices (Figure 2). It also offers surface mount Li-ion battery protectors including Three-Terminal Fuses designed to guard against overcurrent and overcharging, and a range of eFuse Protection ICs. The range of ICs utilize innovative design that provides a wide range of power input (3.3V to 28V) and integrated protection.

These electronic fuses protect against overcurrent, short circuit, overvoltage, inrush current, reverse current, and overtemperature events with real-time diagnostics—all in one chip.

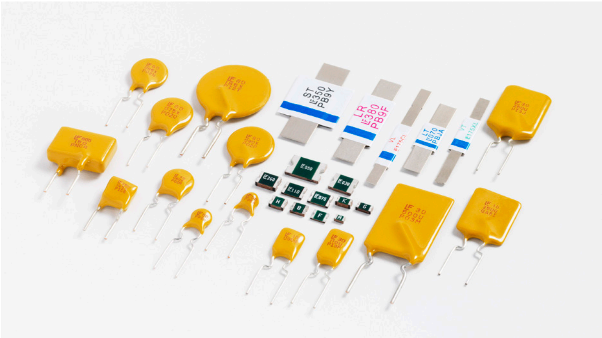

Figure 2: Littelfuse offers a full range of PPTC devices. (Source: Littelfuse)

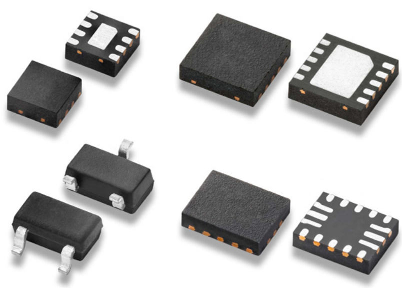

Figure 3: Littelfuse offers a range of Protection ICs. (Source: Littelfuse)

Overvoltage protection

Overvoltage is another issue that can be very destructive. This fault typically involves a transient voltage event, where short-duration surges or spikes are encountered. Left unsuppressed, these surges and spikes can cause severe damage to circuits and components, potentially resulting in complete system failure. There are several types of overvoltage events, each of which can be safeguarded against by the correct selection of protection components.

Electrostatic Discharge (ESD) – ESD can affect many devices, but it is a particular concern in devices with which humans interact directly. This includes handheld devices such as smartphones and tablets as well as computers, televisions, and anything else that humans touch. ESD is the release of static electricity when two electrically charged objects come into contact. It is especially concerning in low-humidity environments where voltages as high as 15kV are possible—and highly destructive. Even lower-voltage ESD events have the potential to cause damage, either immediately or via latent defects that will eventually result in failure.

Whenever a person interacts with a screen, presses a button on a control panel, and plugs or unplugs a cable, there is potential for damaging ESD to enter the equipment. Therefore, protection is vital.

Damage from ESD may result in faulty circuit operation, latent defects, and even catastrophic failure of sensitive components. For the electronics engineer, ESD suppressors provide a tried and trusted means of protecting electronic components and systems from electrostatic discharge. But a critical consideration is ensuring that the selected ESD suppressor has a fast enough response time and can handle high peak voltages and currents for short durations. In addition to ESD suppressors such as PulseGuard® from Littelfuse, other components such as Multi-Layer Varistors (MLVs) and transient-voltage-suppression (TVS) diode arrays can be deployed to suppress these types of events.

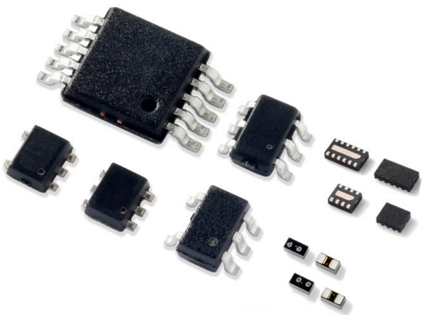

Figure 4: Littelfuse offers TVS Diode Arrays. (Source: Littelfuse)

Inductive load switching - Switching of inductive loads, such as those that occur with transformers, generators, motors, and relays, can create transients up to hundreds of volts and amps, and can last as long as 400 milliseconds, affecting both AC and DC circuits. For these applications, commonly used suppressor devices include Metal Oxide Varistors (MOVs), Gas Discharge Tubes (GDTs), and TVS Diodes.

Figure 5: The Littelfuse range of varistors includes both MOVs and MLVs (Source: Littelfuse)

Lightning-induced transient - Most transients induced by nearby lightning strikes result in an electromagnetic disturbance on electrical and communication lines connected to electronic equipment. Devices that protect against these transients must have a fast response time and must be able to dissipate a large amount of energy. MOV, TVS Diodes, and GDTs are typically used to protect against these events.

Automotive load dump - Load dump refers to what happens to the supply voltage in a vehicle when a load is removed. If a load is removed rapidly (such as when the battery is disconnected while the engine is running), the voltage may spike before stabilizing and damage electronic components. In a typical 12V circuit, load dump can rise as high as 120V and take 400 ms to decay - more than enough to cause severe damage. Again, Littelfuse's TVS Diode and MLV products can provide comprehensive protection against these types of events.

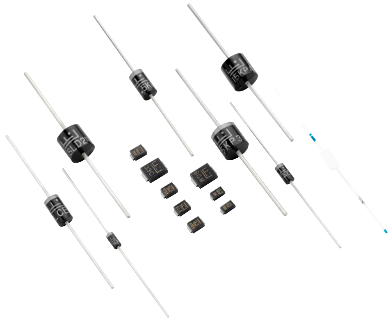

Figure 6: Littelfuse offers TVS Diode. (Source: Littelfuse)

Conclusion

As we have seen, electronic circuits are susceptible to many external effects which can cause damage and even failure, either immediately or in the longer term. Reliability is crucial to protect manufacturers' reputations, and to ensure this, manufacturers must implement circuit protection.

In a good design, the engineer will consider all of the weak points in the system (including connectors, sockets, keypads, and screens) as well as the environment in which the device will be operated. From this, you can then develop a circuit protection strategy to cover eventualities such as overcurrent, overvoltage, ESD, and EFT.

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