Application Note:
Designing Reliable Drones using Proper Circuit Protection

Are you safe with Drones in the sky?

Designing Reliable Drones using Proper Circuit Protection

A drone filming a Pamplona-style "running of the bulls" at Virginia Motorsports Park suddenly dips into the crowd below, injuring spectators... a 15kg. camera drone drops out of the sky during a ski race in Italy, narrowly missing Austrian Marcel Hirscher before smashing into the slope behind him... a rogue drone smashes through a fifth-story office window in Cape Town, South Africa, striking unsuspecting race car driver David Perel in the head... a drone narrowly misses colliding with an Airbus A320 as it takes off from London's Heathrow airport… a drone hits the Seattle Great Wheel - believed to be the largest Ferris wheel of its kind on the West Coast, standing 175 feet tall - near downtown Seattle's waterfront, crashing into a nearby pier and prompting a police response.

Introduction/Overview

No doubt "pilot losing control" is behind many drone incidents and crashes. **But what's behind that "loss of control?"** After all, even small recreational drones depend on a host of subsystems – GPS, receiver antennae, WiFi I/O ports and electronic speed controllers – to stay in the air. Lose one and that UAV becomes a UFO pretty quickly.

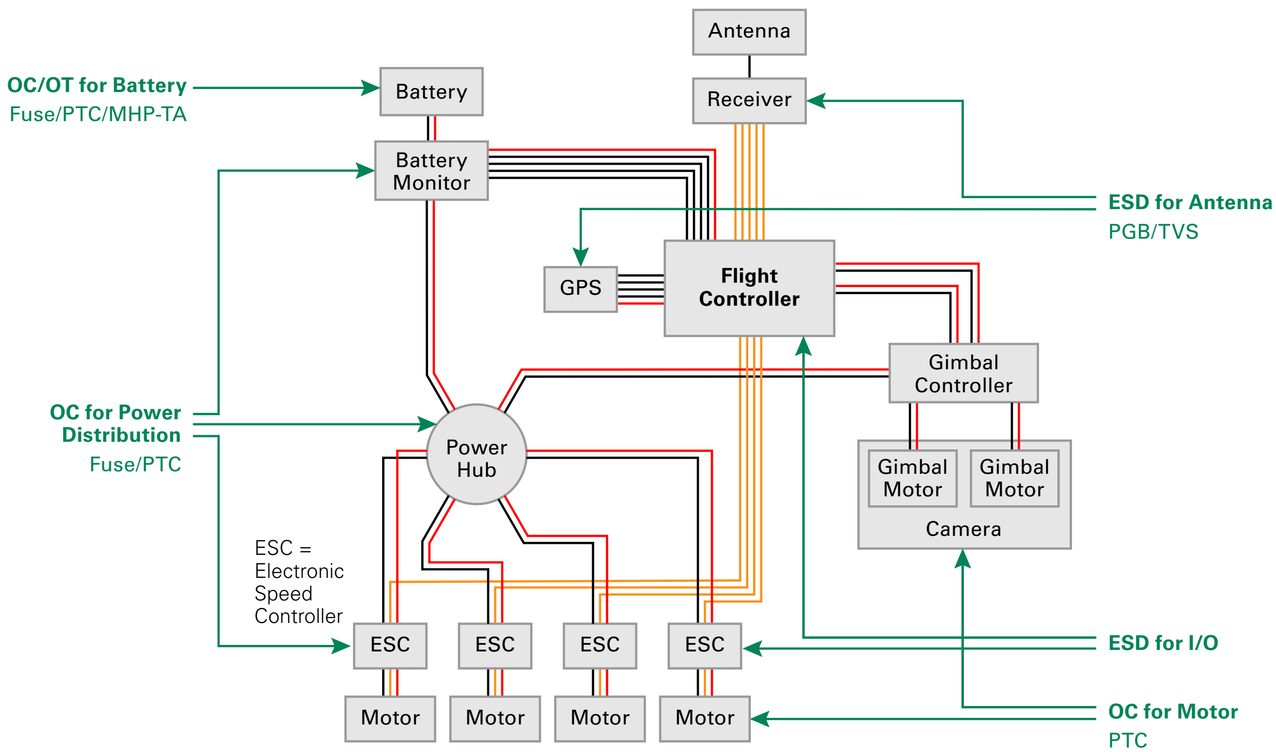
The number of consumer, professional, and commercial drones, sometimes called unmanned aircraft systems (UASs) or unmanned aerial vehicles (UAVs), sold annually has risen rapidly over the last few years. Future sales growth looks even more rapid, with the Federal Aviation Administration predicting that sales will grow from roughly 2.5 million this year to 7 million by 2020, with 4.3 million being sold to hobbyists and 2.7 million units being sold for professional and commercial applications. Non-military drones are available at a wide range of price points, anywhere from toys that cost less than $100 to sophisticated commercial drones for use in fields like aerial photography, public safety services, agriculture, and wildlife management that can cost thousands (**Figure 1**).

Figure 1. Drones are available with a wide range of functionality at a variety of price points, but all share a number of common circuit protection requirements.

Regardless of how a particular drone is used or how much it costs, all drones are susceptible to similar fault and failure conditions. These conditions can cause problems that range from the merely annoying (a drone that won't start or take flight) to the catastrophic (a crash that causes major property damage or personal injury). A battery that catches fire during charging or a mid-flight failure due to any of a number of electrical issues are common examples that highlight why robust electrical protection is essential. Fortunately, a growing array of tools and techniques are available to implement passive battery safety systems, electrostatic discharge (ESD) protection, and stalled motor protection.

Drone Sub-systems and Circuit Protection

Figure 2 illustrates a generic drone design that highlights some of the areas that drone makers must take into account when designing circuit protection for their products' various electrical subsystems and some of the most common circuit protection components for each application.



Circuit Protection Legend

ESD	Electrostatic Discharge
MHP-TA	Over temperature breaker
OC	Over Current
OT	Over Temperature
PGB	Polymer ESD Suppressor
PTC	Positive Temperature Coefficient (resettable fuse)
TVS	Transient Voltage Suppressor (diode)

Figure 2. Drone sub-systems that require circuit protection.

Protecting the Battery and Charging Circuits

Obviously, drones require on-board batteries to power their operation. Lithium polymer (LiPo) batteries are among the most common battery types used for drones because they offer the advantage of high energy density in relation to their size and weight, with a higher voltage per cell, so they can power the drone's on-board systems with fewer cells than other rechargeables. They also discharge more slowly than other types, so they'll hold a charge longer when not in use. However, if not charged or used properly, they can't provide peak performance for long and can even begin to smoke and catch fire.

Over-discharge and over-charge are two externally created events that can cause problems in lithium-ion batteries. During over-discharge, if the cell voltage drops lower than approximately 1.5V, gas will be produced at the anode. When voltage drops to less than 1V, copper from the current collector dissolves, causing internal shorting of the cell. Therefore, under-voltage protection is required and is provided by the battery protection IC. Over-charge creates gassing and heat buildup at the cathode when cell voltage reaches approximately 4.6V. Although cylindrical cells have internal protection from pressure, activated CIDs (current interrupt devices) and internal PTCs (positive temperature coefficient discs that increase in resistance when heated), LiPo cells do not have internal CIDs and PTCs. External overvoltage, over-gas, and over-temperature protection is especially critical for Li-polymer cells.

A variety of circuit protection options are available to guard drone batteries against over-current and over-temperature conditions, including Metal hybrid PPTC with thermal activation (MHP-TA) devices (**Figure 3**), PolySwitch PPTC devices, low resistance SMD PPTC devices, and surface-mount fuses.

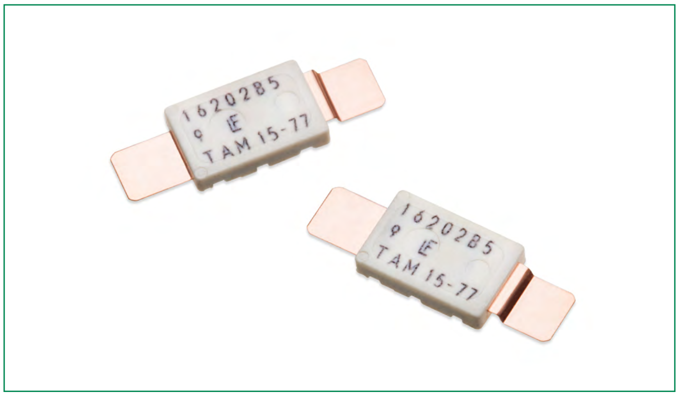


Figure 3. Metal hybrid PPTC with thermal activation (MHP-TA) devices.

MHP-TA devices combine the advantages of low thermal cut-off temperatures, high hold-current ratings and compact size, which are invaluable for protecting LiPo batteries. The latest MHP-TA devices offer a 9VDC rating and a higher current rating than typical battery thermal cutoff (TCO) devices. They are capable of handling voltages and battery charge rates common in high-capacity LiPo cells (**Figure 4**). Many provide resettable and accurate over-temperature protection and their compact footprint and thin form factor simplifies circuit protection in ultra-thin battery pack designs.

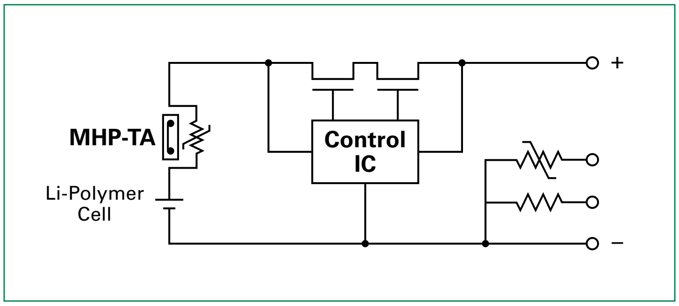


Figure 4. MHP-TA LiPo battery pack circuit diagram.

For other battery chemistries, such as lithium-ion (Li-ion), nickel metal hydride (NiMH), or nickel cadmium (NiCd), PolySwitch PPTC resettable devices (**Figure 5**) may offer a better solution. Not only are they compatible with high-volume electronics assembly, but their UL, CSA, and TÜV agency recognitions make it easier for designers to meet regulatory requirements. Their low resistance helps increase battery operating time and they enhance over-temperature protection from thermal events (**Figure 6**).

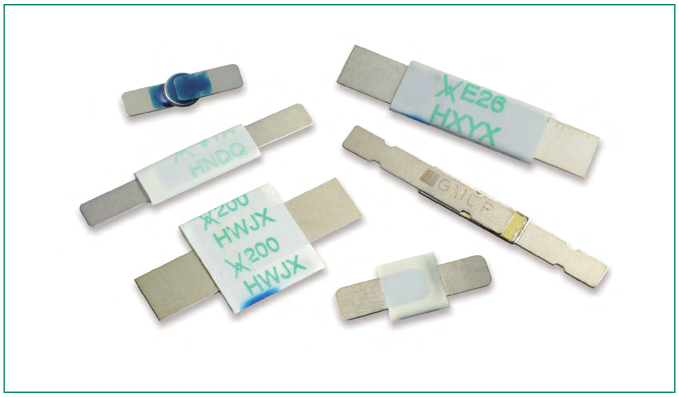


Figure 5. PolySwitch PPTC (Polymeric Positive Temperature Coefficient) resettable devices.

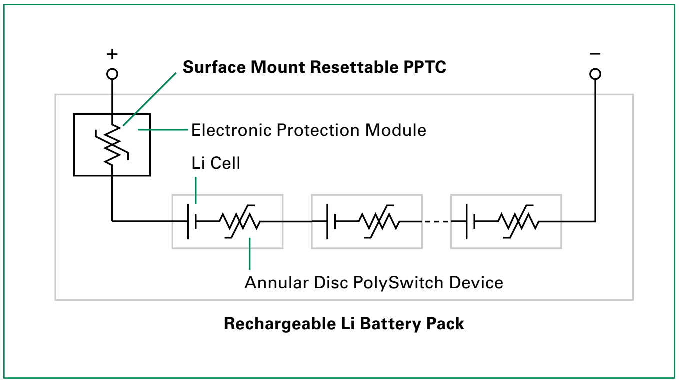


Figure 6. Typical rechargeable lithium battery pack circuit diagram.

Small-footprint, low-height-profile POLY-FUSE LoRho Surface Mount Resettable PPTCs (**Figure 7**) are well-suited for protection circuit modules for Li-ion and LiPo battery packs, providing fast over-current and over-temperature protection with ultra-low internal resistance, voltage drop, and power dissipation. By resetting automatically, they provide a low maintenance alternative to one-time fuses for over-current protection. Because they're packaged for surface-mounting on a printed circuit board, they can be mounted within an electronic protection module on the board, simplifying the assembly process.

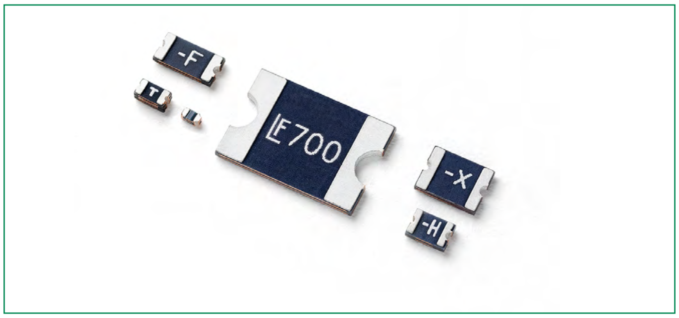


Figure 7. POLY-FUSE LoRho Surface Mount Resettable PPTCs.

Although fuses and PTCs are both over-current protection devices, PTCs are automatically resettable; traditional fuses need to be replaced after they are tripped. A fuse will completely stop the flow of current (which may be desirable in critical applications), but after most similar over-current events, PTCs continue to enable the equipment to function, except in extreme cases.

Surface-mount fuses like the 449 Series NANO2® SLO-BLO® Subminiature Fuse (**Figure 8**) are suitable for battery charging circuit protection applications. Their unique time delay feature helps reduce the incidence of nuisance "openings" by accommodating inrush currents that would cause a faster-acting fuse to open.

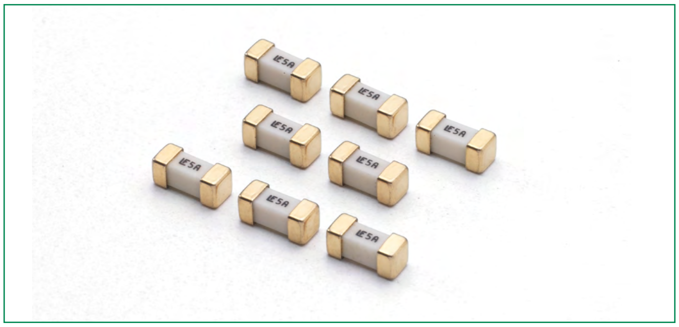


Figure 8. 449 Series NANO2® SLO-BLO® Subminiature Fuse

Protecting GPS, Receiver Antennae and I/O Ports

As **Figure 2** indicates, electrostatic discharge (ESD) is a concern for multiple drone subsystems, including the global positioning system (GPS) and receiver antennae, and the various I/O ports. Every access point multiplies the risk of both immediate and latent damage that can occur when these areas form an electrical path for high potential currents. For example, the power port is a low voltage input is used to charge the battery. As a true DC circuit, a high-capacitance suppressor is recommended. Because this circuit could also experience higher-energy transients (lightning, system surges, EFT), a multilayer varistor is recommended given that it has capabilities beyond ESD protection. Also, in the event of a sustained over-current event (battery malfunction, circuit failure, etc.), a fuse could be used to disrupt the over-current condition and protect the system.

Circuit designers have a variety of ESD protection options for antennae, including ESD Suppressors and TVS diodes. PULSE-GUARD® ESD Suppressors (**Figure 9**) use polymer composite materials to suppress fast-rising ESD transients (as specified in IEC 61000-4-2), while adding virtually no capacitance to the circuit. They supplement the on-chip protection of integrated circuitry and are best suited for low-voltage, high-speed applications where low capacitance is important to ensuring data signal integrity.

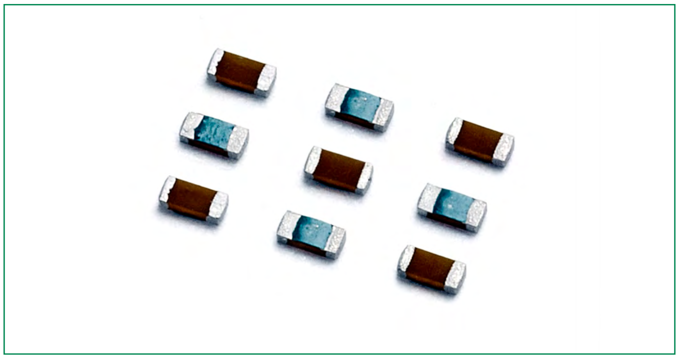


Figure 9. PULSE-GUARD® ESD Suppressors

TVS (Transient Voltage Suppressor) diodes are designed to protect electronic circuits against transients and overvoltage threats such as EFT (electrically fast transients) and ESD (electro-static discharge). TVS diodes are silicon avalanche devices typically chosen for their fast response time (low clamping voltage), lower capacitance and low leakage current. They are available in both uni-directional (uni-polar) or bi-directional (bi-polar) diode circuit configurations. Important parameters to be considered when selecting TVS diodes include reverse standoff voltage (V_R), peak pulse current (I_{PP}), and maximum clamping voltage (V_{Cmax}).

Protecting I/O Ports from ESD

ESD is also a concern for I/O ports on the flight controller and the electronic speed controllers (ESC) for the flight control motors. The primary factor to consider for protecting this signal port is the data rate of the signals. As data rates increase, it is crucial to consider the capacitance of the chosen suppressor so as not to introduce any signal integrity issues into the system. For example, circuits in this port running at low speeds should be protected with higher capacitance multilayer varistors or TVS diode arrays (**Figure 10**). Again, board designers will decide whether to use discrete MLVs vs. multi-line diodes according to their desire to maintain placement flexibility (discrete devices) or minimize part count (array products).

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