Intelligent Power Protection

Introduction

Since the early days of electrical distribution, fuses have played a critical role in protecting circuits from overcurrent conditions. While traditional fuses offered simplicity, they lacked flexibility and intelligence. Modern applications, ranging from industrial automation to consumer electronics, require advanced protection features to ensure safety, reliability, and longevity. Key features such as adjustable current limits, thermal shutdown, and rapid fault response help safeguard users, prevent equipment damage, and maintain operational integrity.

Toshiba introduced its first eFuse series in 2020, and since then, the portfolio has grown to meet evolving demands: the TCKE6 series for 40 V systems, TCKE9 for high-current applications, and the TCKE14 series designed for up to 80 V. This whitepaper explores how eFuses deliver smarter, safer, and more efficient power protection compared to conventional solutions.

Limitations of conventional fuses

Fuses have long served as simple, sacrificial devices to protect circuits from overcurrent conditions. By interrupting the flow of current during a fault, they prevent damage to power sources, reduce the risk of fire from overheated conductors, and safeguard users from electric shock. However, once a fuse blows, the system must be inspected and the fuse replaced - a minor inconvenience in accessible devices, but a costly challenge in sealed or remote installations.

Functionally, conventional fuses also suffer from a slow response time, with reactions typically taking longer than one second to occur. This slowness is compounded by tolerance issues, as the specific current required to blow the fuse can vary by ±25%. This wide variance complicates the implementation of precise protection strategies. Additionally, conventional fuses lack adaptability when dealing with inrush currents; to handle startup surges without failure, specific timed fuses may be required. Ultimately, the combination of these factors - lack of precision, limited adaptability, and maintenance demands - makes conventional fuses increasingly problematic for modern electronics and industrial technology.

Resettable fuses, such as polymeric positive temperature coefficient (PPTC) devices, address the single-use design issue of conventional fuses. They increase resistance under fault conditions and return to near-normal values upon cooling. This protection mechanism makes them suitable for applications like USB ports. - primarily because they provide automatic, resettable overcurrent and overtemperature protection without requiring manual replacement, as mandated by the USB specification. Yet PPTCs have drawbacks: slow reaction times (often several seconds), residual current flow even when tripped, and sensitivity to ambient temperature, which requires careful thermal derating analysis.

Modern electronic systems demand more than simple overcurrent protection. Traditional fuses and PPTCs lack precision, adaptability, and remote control capabilities - features that are increasingly critical in applications ranging from industrial automation to consumer electronics. To address these challenges, silicon-based electronic fuses (eFuses) have emerged as a smarter alternative, providing advanced features such as adjustable current limits, thermal shutdown, and integrated fault diagnostics.

How eFuses work

eFuses employ a low-resistance MOSFET switch controlled primarily by the integrated current-sensing circuitry. Should the current exceed a pre-defined limit, the switch opens within a sub-microsecond response time, thereby preventing damage to power sources and cabling more effectively than traditional alternatives. Like PTTC fuses, eFuses are resettable, either automatically or via a signal from a microcontroller, enabling rapid recovery and reducing downtime.

Advanced features beyond protection

As semiconductor devices, eFuses offer a rich set of configurable features designed to handle complex power scenarios. Key among these is inrush current control, which utilises an adjustable slew rate to prevent surges during startup, and a voltage clamp that maintains the output voltage below a designated safe threshold. To ensure stability, under-voltage lockout (UVLO) ensures that the device operates only within valid input ranges, while reverse-current protection prevents reverse current from flowing back into the source. Furthermore, eFuses include an adjustable current limit tailored to system requirements and a thermal shutdown feature to protect against overheating. Finally, they provide a status feedback and control interface, enabling ongoing monitoring and remote resets. These capabilities make eFuses particularly suitable for systems that require high reliability, a compact design, and intelligent fault management.

Implementation considerations

When implementing eFuses, the integration process is designed to be straightforward, allowing engineers to incorporate advanced protection without significant design complexity. Key configuration steps involve setting the current limit using an external resistor, known as RILIM. Furthermore, inrush current control is managed by configuring a specific capacitor (Cdv/dt) (Figure 1).

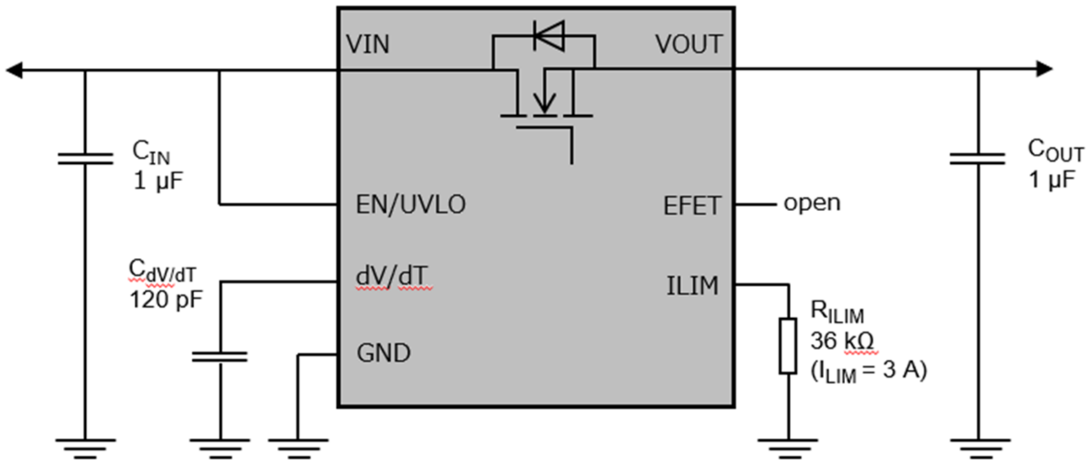

Figure 1: Example application circuit for an eFuse protection solution [Source: Toshiba]

For control and communication, the enable function and UVLO are typically handled through a single pin. This streamlined approach facilitates easy interfacing with a microcontroller, ensuring that the advanced features of the eFuse are accessible through simple design steps

Where eFuses make the difference

Modern electronic systems often supply power to external devices that were not originally designed by the manufacturer, creating potential risks for overcurrent, short circuits, and voltage anomalies. eFuses are currently implemented across a wide range of industries where protecting sensitive components and minimising downtime are critical priorities.

In consumer electronics, these devices are most effectively used to safeguard USB ports, charging circuits, and storage interfaces (**Figure 2**). Their application extends into industrial automation, where they are used to protect 24 V power rails, programmable logic controller (PLC) expansion modules, and factory control systems.

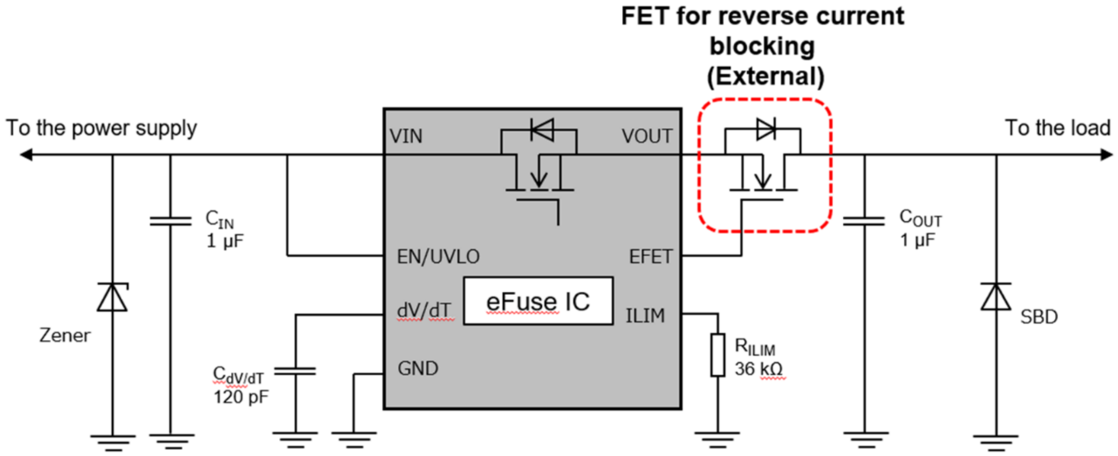

Figure 2: Protection of a USB charging outlet using Toshiba's TCKE805NA eFuse [Source: Toshiba]

Beyond these sectors, eFuses play a vital role in the internet-of-things (IoT) and portable devices, specifically within battery-powered sensors and smart appliances. They are also increasingly prominent in high-voltage applications, supporting power distribution and automation systems that require voltages up to 80 V.

The widespread adoption of eFuses in these specific applications is driven by their operational superiority over traditional fuses or PPTCs. Unlike standard fuses, eFuses provide sub-microsecond fault response to protect sensitive electronics and offer automatic or manual reset capabilities, thereby significantly reducing system downtime. Furthermore, they allow for configurable protection features, such as inrush current control, voltage clamping, and thermal shutdown, and provide status feedback that enables seamless integration with microcontrollers or system monitoring tools.

Summary and outlook

The introduction of eFuses has transformed circuit protection from a passive safeguard into an intelligent, configurable solution. Compared to traditional fuses, eFuses are non-sacrificial, offer precise current limiting, and integrate advanced features such as overvoltage and undervoltage protection, thermal shutdown, and inrush current control. They combine the reset capability of PPTCs with the speed and accuracy of solid-state technology, all in a compact, surface-mounted form factor requiring minimal external components. Compliance with standards such as IEC 62368 and UL further simplifies end-product certification.

Toshiba has continuously expanded its eFuse portfolio to address evolving market needs. The TCKE8 series serves as the foundation, providing compact, intelligent protection. Building on this, the TCKE9 series is optimised for consumer and IoT applications that require high current handling and a compact form factor. In contrast, the TCKE6 series is designed for industrial 24V systems, with a capability rating up to 40V. Finally, the TCKE14 series targets higher voltage environments up to 80 V in factory automation and power distribution.

As power systems become more complex, driven by IoT, Industry 4.0, and higher voltage architectures, the demand for smarter, faster, and more integrated protection will continue to grow. Future eFuse generations will likely offer extended voltage ranges for industrial and automotive sectors, enhanced diagnostics and communication interfaces for predictive maintenance, and integration with system-level monitoring for fully connected power management. By adopting eFuses today, designers position their systems for greater reliability, safety, and scalability in tomorrow's connected world.

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