

TOSHIBA

Make way for the savvy fuse



How circuit protection is gaining intelligence with eFuses

Introduction

While the main passive component groups were honoured with units named after the famous scientists Ohm, Faraday and Henry, interest in according the humble fuse with the same deference had seemingly waned by the time of its invention. The fact that we don't really know who invented the fuse, possibly coupled with its perceived simplicity and lack of singular unitary dimensioning (they are often defined according to both time and current limits), may be the reason. We do know that Thomas Edison patented a fuse in 1890¹ and that fuses of varying construct had been in use before this as a protection mechanism, notably by the English physicist and inventor Sir Joseph Swan. Prior to this, Edward Nairne had documented in 1774 how Leyden bottles were discharged via lengths of wire that disintegrated, acting like a fuse².

The word fuse itself stems from the Latin *fundus*³ that can be translated as melted. Early fuses were integrated into electrical distribution as a protection mechanism in early DC lighting systems as cities around the world became electrified. This became of increasing importance for reasons of safety, due to the potential for fire by overheating conductors under short-circuit conditions, and as the available volt-amperes rose. It was A. C. Cockburn who took a scientific approach to the dimensioning fuses at the end of the 19th Century, determining that they should be rated to blow at around 150 – 200% of the rated current of the circuit being protected².

Fuses: capabilities and limitations

As a sacrificial device, fuses are designed to cut off the flow of current in order to limit worse damage. This may be to protect the source of power from damage, will likely stop power cables from overheating and causing fire, and, on high-voltage systems, protects users in contact with electrical devices from a potentially fatal electric shock under fault conditions. Early designs for telegraph systems described reduced-section conductors that would melt if they were hit by lightning⁴. Once blown, the systems being protected needs to be assessed for safety, ensuring that any short-circuit has been removed, before the fuse can be replaced and power restored. In some applications, having to replace a fuse is nothing more than a little frustrating. However, should the electrical device be hermetically sealed or installed in a remote location, replacement may be significantly more challenging or costly.

Resettable fuses, such as polymeric positive temperature coefficient (PPTC) devices, go some way to resolve the issue of replacement. When operated below the current protection limit, they are low in resistance. However, should the current rise above this limit the resistance of the PPTC rises significantly, restricting the current flow to the power consumer. The increase in resistance is caused by the heating of the device. Once the cause of the elevated power draw has been removed, the PPTC cools down and returns to close to its original, pre-failure resistance. This makes them ideal for protecting power outputs on computers, such as USB ports, where the device causing the failure can be easily removed by the user.

While PPTCs resolve the challenges posed by the sacrificial fuse after an over-current event has occurred, there are an array of limitations that need to be additionally considered during specification of both protection devices.

PPTCs can react in under a second, but some devices require several seconds before the current is fully restricted. It should also be noted that a small current continues to flow even under a tripped condition. For some applications this is unacceptable. Reviewing their datasheets it will also be noted that the ambient operating temperature can have a significant impact on the trip current of the device. Careful analysis of the thermal derating tables in such cases is highly recommended.

Fuses too have their limits. The current at which they blow is subject to significant tolerance and they too require a second or more to react. Many electrical devices suffer from an inrush current, commonly caused by capacitors

charging at initial turn-on, and a fuse may be required to temporarily withstand a higher current for short periods of time than specified under the device's normal use. This may require the specification of a timed fuse that increases the time before the fuse blows under overload conditions to accommodate inrush conditions. Whether this is acceptable in the context of the application will need to be determined by the engineering team.

Putting intelligence into fuses

There are very few applications that are not taking advantage of integrating intelligence in the form of a microprocessor, with the addition of Internet of Things (IoT) and its industrial counterpart IIoT providing some decentralised oversight and control via wired and wireless networks. The protection circuitry discussed so far lacks any intelligence that could easily help to resolve issues remotely or provide monitoring capability. To resolve this, silicon-based eFuses have come onto the market that provide more accurate protection, integrate additional features, and provide interfaces that enable them to be controlled by a programmable device such as a microcontroller.

eFuses make use of a low-resistance switch that is controlled primarily by current measurement circuitry. Should the current drawn rise above a pre-defined limit, the switch is disengaged causing the current flow to be halted thus replicating a traditional fuse. Perhaps the most impressive feature of the device is its sub-microsecond response time to overload conditions, ensuring excellent protection of power sources and cabling when compared to traditional alternatives.

Like a PPTC they can also be reset, quickly restoring power and under the control of the system they are part of. The overcurrent protection may be latching, allowing the eFuse to be reset via a signal, perhaps from a microcontroller, along with an output indicating the status of the device. But, being silicon devices, they can offer many further additional features. Other devices include a retry mechanism to retry automatically.

The first of these is inrush current protection. This can be either a fixed or adjustable feature that defines the slew rate at the output of the device. A second common function is a voltage clamp that guarantees the output voltage remains below a predefined level, providing additional protection to the circuitry behind the fuse. The third function is an adjustable under voltage lockout. This ensures that connected circuitry is only supplied when the input voltage is in the correct range, minimising the potential for partially-on or off transistors and logic circuits operating incorrectly. An option to control an additional switch in the output to protect against reverse currents is a fourth feature. The ability to current limit the output can also be implemented. Finally, an over-temperature shutdown is also commonly provided as well.

Applications benefitting from eFuses

There are many applications that can supply power to user devices that were not defined or built by the manufacturer of the product. The home PC and laptop, with their USB and SATA interfaces, are a typical example. eFuses can protect the internal circuitry from faulty devices that may be connected, with feedback provided by the operating system to the user should a failure occur. Test and measurement equipment, such as oscilloscopes and spectrum analysers, often provide power to their probes or feature a rechargeable battery for portable use. Again, here eFuses could protect their power supplies. Industrial systems, such as Programmable Logic Controllers (PLC), could also make use of eFuses at the connectors used to power sub-modules that are attached to expand functionality.

Solutions such as the TCKE8xx series from Toshiba provide compact, easy-to-use eFuses suitable for use in all the above types of application. The family provides differing fixed options around fault response, over current and over voltage clamping, and all while also offering short-circuit trip point of up to 5.0 A at an accuracy of $\pm 11\%$. The integrated switch has a low R_{ON} of 28 m Ω and both slew rate and under voltage lockout can be set using external components. Most important is the fast-trip comparator delay that ensures power is removed in 150 ns upon detection of a short-circuit event. An external NFET can be controlled via a separate output pin for reverse current protection, while control of the output is provided via an enable pin.

Thermal shutdown occurs at 160°C and has a 20°C hysteresis. Once the thermal limit has been reached, the output is automatically turned off. Depending on the version of eFuse selected, the device will either automatically attempt to supply power once the temperature has dropped using its auto-retry function, or will await the signal to enable the output via the EN pin from an external control signal.

The integration of an eFuse requires some planning, but it is not significantly more challenging than configuring other integrated power devices. The current limit resistor R_{ILIM} determines the current limit of the device, providing accurate clamping across the operational temperature range of the device. The datasheet provides guidance here with regard to dimensioning of this component. To limit the inrush current the slew rate at the turn-on can be set using a suitable value capacitor. $C_{dv/dt}$ can be dimensioned according to the datasheet. If output control via a microcontroller or other circuitry is required, this can be attached to the EN/UVLO pin of the TCKE8xxx device. Under voltage lockout can also be defined using a pair of resistors attached to the same pin. The EFET output can, if required, be used to control an NFET in the output path if reverse current blocking is also required (figure 1).

As such it can be clearly seen that eFuse implementations offer significant advantages in protection speed, feature set and use-case options when compared to both traditional fuses and PPTC alternatives. Furthermore, the device has been certified to the IEC 62368 standard, making it easier for design teams to certify their entire application to this standard if these devices are used for the power protection.

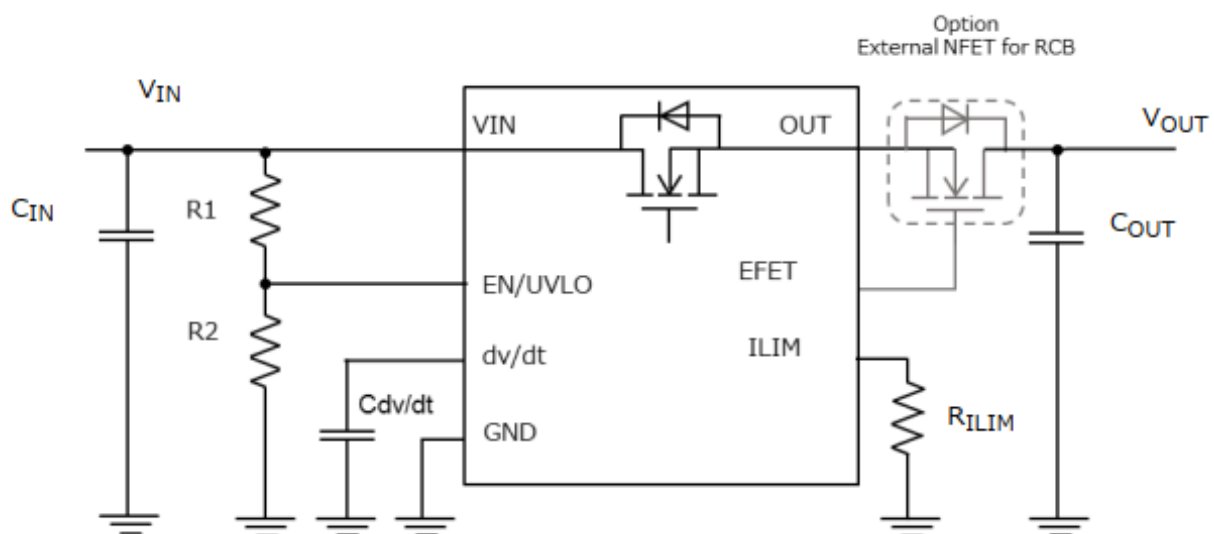


Figure 1: Example application circuit for an eFuse protection solution.

Overvoltage protection is determined by the precise TCKE8xxx device selected. Three options are provided including no protection and limitation to either 6.04 V or 15.1 V for targeting 5 V and 12 V applications. Latching and Auto-Retry functionality is also chosen according to the device used. Finally, input and output capacitors of 1.0 μF located closely to the VIN and after the NFET (if used) or OUT pins reduce voltage overshoot and undershoot during sharp changes in current draw.

An eFuse provides a perfect, compact protection solution for a USB port provided as a charging outlet on a portable audio device (figure 2). The TCKE805NL provides latched protection along with an over voltage clamp at 6.04 V. The microcontroller can monitor the output voltage and automatically reset the eFuse via the EN enable pin when required. The 75 k Ω resistor on ILIM limit sets the current limit to around 1.5 A, while the 2nF capacitor provides a turn-on output ramp time of around 4 ms. The device is housed in a 3.0 x 3.0 x 0.7 mm WSON10B package that is easily accommodated close to a USB A-type socket.

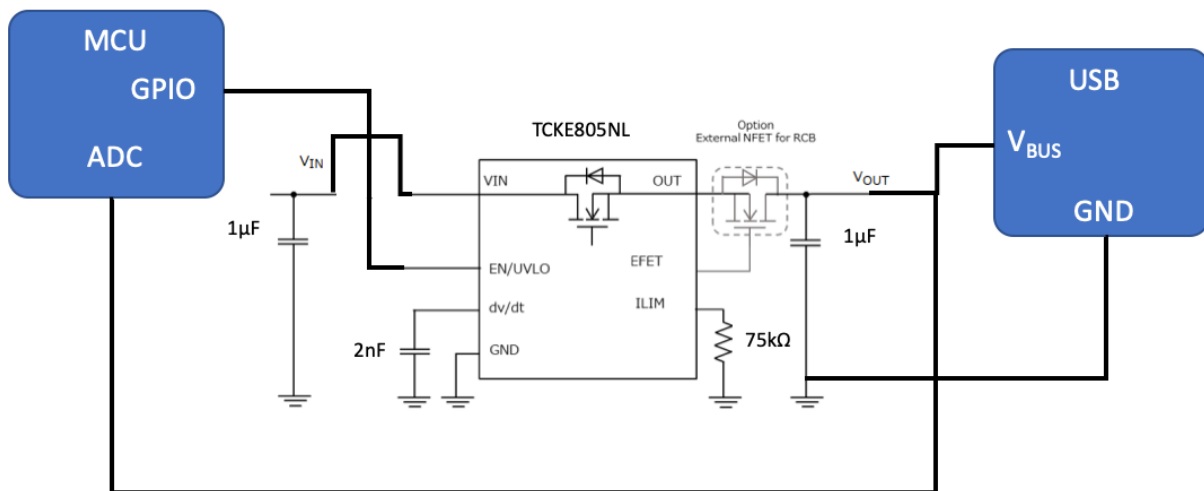


Figure 2: Protection of a USB charging outlet using a TCKE805NL eFuse

Summary

With the advent of the eFuse, circuit protection gains more control and an ability to monitor, making it easier to integrate into today's data centric monitor and control applications. Compared to traditional fuses it is not sacrificial. And when compared to fuses and PTCCs it provides tighter tolerances on current protection as well as offering additional features, such as over and under voltage protection and thermal protection.

Furthermore, they provide the reset feature of a PTCC but return to their low-resistance after reset. Surface mounted, low-profile and compact, and with a minimal quantity of external components, they easily find a home on the circuit board of target applications. Lastly, the path to IEC 62368 certification is significantly eased for those looking to comply with this standard.

References

1. [https://en.wikipedia.org/wiki/Fuse_\(electrical\)](https://en.wikipedia.org/wiki/Fuse_(electrical))
2. Electric Fuses, 3rd Edition, A. Wright and P. G. Newbury
3. <https://www.dictionary.com/browse/fuse?s=t>
4. [https://en.wikipedia.org/wiki/Fuse_\(electrical\)](https://en.wikipedia.org/wiki/Fuse_(electrical))
- 5.



Contact us to discuss incorporating
our products and solutions into your
design:
<http://apps.toshiba.de/web/ContactUs/>
toshiba.semicon-storage.com



Restrictions On Product Use

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as “TOSHIBA”.
Hardware, software and systems described in this document are collectively referred to as “Product”.

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA’s written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product’s quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life,

bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. **TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.**

- **PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE").** Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signalling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. **IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT.** For details, please contact your TOSHIBA sales representative or contact us via our website.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- **ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.**
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. **TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.**