eFuse ICs Enhancing Protection of Power Supply Lines in Compliance with IEC 62368-1

In recent years, attention has become increasingly focused on the safety of various electronic devices worldwide. Particularly in Europe and the United States, IEC (International Electrotechnical Commission) 62368-1(*1), a new safety standard for audiovisual and information and communication equipment, will be introduced in December 2020. In order to enhance the protection of power supply lines of such equipment in compliance with IEC 62368-1, which is a hazard based standard, demand has arisen for electronic fuse integrated circuits (eFuse ICs) offering higher protection performance compared with conventional protective devices, as typified by physical fuses.
Toshiba Electronic Devices & Storage Corporation has developed and released a lineup of eFuse ICs compliant with the IEC 62368-1 standard that provide various protection functions comprising inrush current suppression, overvoltage protection, overheating protection, and reverse current protection, in addition to a high-speed, high-precision overcurrent protection function.

1. Introduction

In recent years, attention has become increasingly focused on the safety of electronic devices. In Europe and the United States, the IEC 62368-1 standard, a safety standard for audio/video, information, and communication technology equipment, came into effect in December 2020 (**Figure 1**). To comply with IEC 62368-1, it is necessary to provide fast and accurate protection of power supply lines from overcurrent conditions. Conventionally, glass tube fuses, chip fuses, and polyswitches have been used for this purpose. However, in the face of growing safety awareness, demand is growing for eFuse ICs since they provide various protection features in addition to overcurrent protection.

(*1) IEC 62368-1 is a new safety standard developed based on the principles of hazard-based safety engineering (HBSE) that emphasizes the protection of the human body from harm.

In order to contribute to the safety of electronic devices, Toshiba Electronic Devices & Storage Corporation has developed eFuse ICs compliant with IEC 62368-1. This report describes the technologies for the protection features available with the TCKE800, TCKE805, and TCKE812 eFuse ICs.

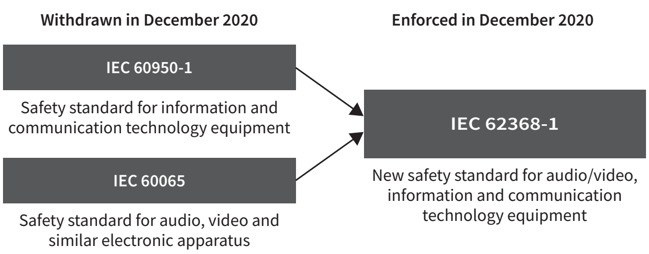


Figure 1. New IEC 62368-1 safety standard

In addition to meeting growing demand for eFuse ICs, compliance with the IEC 62368-1 standard is required.

2. Overview of eFuse ICs

2.1 eFuse ICs

An eFuse IC is a semiconductor device with a fuse function designed to protect an electronic circuit from overcurrent conditions.

At present, glass tube and chip fuses are commonly used to provide protection from destruction, fire, and other hazards. These fuses rely on the Joule heat generated by excessive current to melt a metal wire and thereby interrupt a power supply.

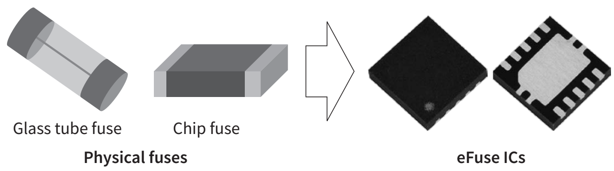
In contrast, an eFuse IC uses a metal-oxide-semiconductor field-effect transistor (MOSFET) to control current conduction through a power supply line. In the event of an overcurrent condition, the eFuse IC turns off the MOSFET to interrupt current flow in order to protect an electronic device.

2.2 Benefits of using an eFuse IC

Figure 2 compares the characteristics of eFuse ICs and physical fuses. eFuse ICs provide many advantages over glass tube fuses and other types of conventional fuses.

Conventional physical fuses use a metal wire that melts with Joule heat when excessive current flows through it, thereby interrupting a current path. The downsides of physical fuses are that they take a long time to blow and do not provide current interruption at exactly the desired ampere level. In addition, physical fuses must be replaced once they blow.

In contrast, an eFuse IC constantly monitors current and, in the event of an overcurrent condition, turns off an internal MOSFET immediately. The eFuse IC can therefore provide fast and accurate protection. The eFuse IC can also be used repeatedly and therefore helps reduce the maintenance cost since it uses a MOSFET to interrupt current. Furthermore, in addition to overcurrent protection, an eFuse IC allows various advanced protection features to be integrated on the same chip, including inrush current limiting, overvoltage protection, thermal shutdown, and reverse-current blocking.



Characteristic	Glass tube fuses	Chip fuses	eFuse IC
Repeated use	✕	✕	○
Speed and accuracy of overcurrent protection	✕	✕	◎
Additional protection features (e.g., thermal shutdown)	✕	✕	◎
Sensitivity to ambient temperature	✕	✕	◎
Fuse footprint	✕	○	△
Total footprint required, including protection circuitry	✕	✕	◎
Fuse cost	○	○	△
Totalcost, includingcostsof protectioncircuitryandmaintenance	✕	✕	◎

Relative superiority: ◎Excellent, ○Good, △Moderate, ✕Poor

Figure 2. Comparison of characteristics of physical fuses and eFuse ICs

eFuse ICs provide many more features than conventional physical fuses.

3. Various protection features

As described in Section 2.2, eFuse ICs provide multiple advanced protection features that cannot be realized with conventional fuses.

3.1 Overcurrent protection

3.1.1 Protection through constant-current control

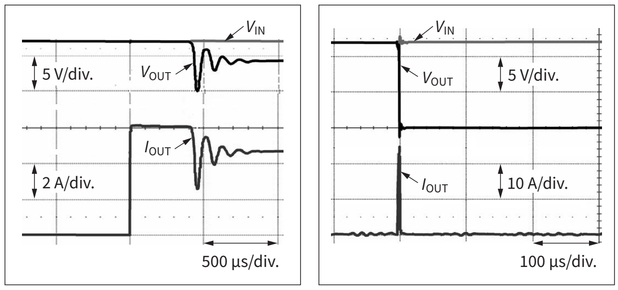
Our newly developed eFuse ICs incorporate a current-limiting droop controller to achieve overcurrent protection.

When the output current (I_{OUT}) exceeds the prescribed limit (I_{OUT_CL})

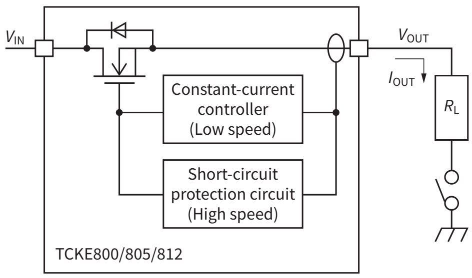
because of a load failure, the constant-current controller limits current to I_{OUT_CL} by controlling the gate of the output MOSFET to increase on-resistance (R_{on}).
If an overcurrent condition persists, the heat generated by power dissipation ($I_{OUT\_CL}{}^2 \times R_{on}$) causes the chip temperature to increase. When the chip temperature reaches the prescribed point, a thermal shutdown (TSD) circuit is activated to turn off the output MOSFET in order to protect an electronic device.

3.1.2 Short-circuit protection

The constant-current controller described in Subsection 3.1.1 provides advanced protection for various applications since its I_{OUT_CL} has an accuracy of 11% (at I_{OUT_CL}=4 A) and is programmable via an external resistor.
In practice, however, the constant-current controller and the TSD circuit provide adequate protection only in limited situations. Our new eFuse ICs have an R_{on} of roughly 30 mΩ during normal operation. Suppose, for example, that the output voltage (V_{OUT}) is short-circuited to ground when the input voltage (V_{IN}) is 12 V. Then, a simple calculation indicates that a current of more than 100 A might flow instantaneously. This could destroy an electronic device and the eFuse IC within several hundreds of microseconds before the constant-current controller is activated.
It is therefore crucial to increase the speed of protection against overcurrent conditions, including short-circuit events. For constant-current control, an amplifier is generally used with negative feedback. There is a limit, however, to its speed since it requires an internal capacitor for phase compensation.
Instead, our eFuse ICs incorporate a short-circuit protection circuit (fast-trip function) that interrupts current at ultrahigh speed when the output is hard-shorted through extremely low resistance. The fast-trip function uses a comparator instead of a negative-feedback amplifier to turn off a switch at ultrahigh speed (150 ns typical) when I_{OUT} exceeds a threshold (which is set to 1.6 times I_{OUT_CL} for the newly developed eFuse ICs). **Figure 3** compares the waveforms of the constant-current controller and the fast-trip circuit when an overcurrent load is connected to the eFuse IC.
The combination of the constant-current controller and the fast-trip circuit provides rugged protection against overcurrent conditions, including short-circuit events.



(a) Constant-current limiting (b) Short-circuit protection



(c) Test circuit

div. : division R_L : load resistance

Figure 3. Response waveforms

when overcurrent load is connected—Our new eFuse ICs incorporate two types of overcurrent protection circuits to achieve rugged protection. R_L determines whether the constant-current controller or the short-circuit protection circuit is activated.

3.2 Reverse-current blocking

In the case of a MOSFET used as a switch, when $V_{OUT} > V_{IN}$, current flows in the reverse direction from the output pin (VOUT) to the input pin (VIN) through a pn diode between the drain and the source (p: p-type semiconductor, n: n-type semiconductor). eFuse ICs have various applications, many of which require the prevention of reverse current flow.
Generally, the reverse current through the pn diode is blocked by using two MOSFETs connected back-to-back in series. However, connecting MOSFETs back-to-back inside an IC causes an increase in R_{on}. Compared to a single MOSFET, the back-to-back MOSFET configuration causes a fourfold increase in R_{on} per area and a fourfold increase in area to achieve the same R_{on}. In the case of a low-R_{on} devices for high-current applications such as eFuse IC, MOSFETs occupy a large proportion of the chip area and directly affect the chip cost and package size.
Therefore, our new eFuse ICs are designed in such a manner that reverse-current blocking can be optionally achieved. In this way, these eFuse ICs help avoid extra costs when reverse-current

blocking is unnecessary while allowing reverse-current blocking with back-to-back MOSFET configuration simply by adding an external MOSFET. **Figure 4** shows the reverse-current blocking circuit formed by connecting an external MOSFET to an eFuse IC. The gate pins of the internal and external MOSFETs can be controlled simultaneously when the gate of the external MOSFET is connected to the EFET pin of an eFuse IC.

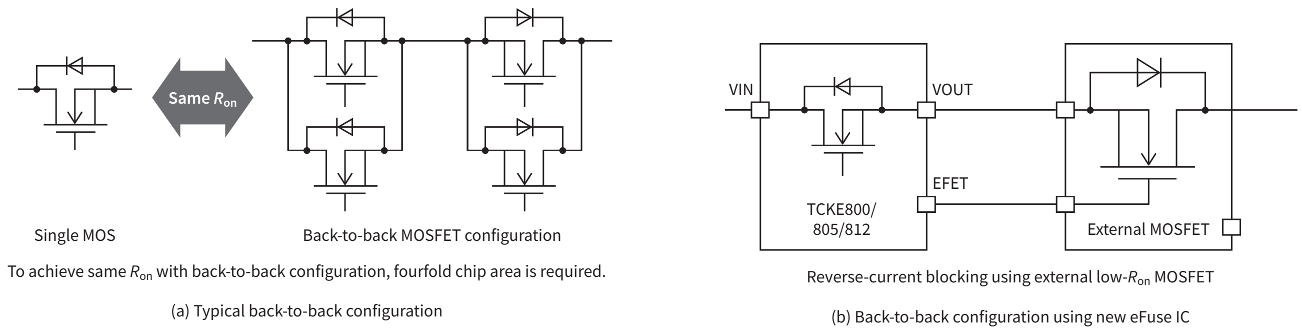


Figure 4. Reverse current protection through back-to-back connection of external MOSFET to eFuse IC

Our new eFuse IC allows the use of an external low-R_{on} MOSFET for reverse-current blocking.

4. Conclusion

This report has mainly discussed our technologies for the eFuse ICs that are ideally suited for the protection of power lines in electronic devices. We will continue to develop semiconductor devices suitable for power line protection so as to contribute to enhancing the safety of electronic devices.