Overcurrent protection function and reverse current prevention function of the load switch IC

Outline

The load switch is a switch used to turn on and off the power line. Various protection functions are integrated into a Load Switch ICs.

This document explains the overcurrent protection function and backflow prevention function, which are the most requested functions.

- Overcurrent protection function: A function to protect the elements of the load from damage when a load current exceeding the expected value flows in the event of an abnormality.
- Backflow prevention function: Function to prevent current from flowing backward when the voltage on the output side becomes higher than the input side

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1. Introduction

The load switch ICs are used in various electronic devices to switch power lines on and off. For example, the load switch ICs are used between the PMIC(Power Management IC) and the load as shown in Fig. 1.1.1. Although discrete load switch circuits, such as MOSFET, may be used to switch power lines on and off, the use of load switch ICs can save more space than discrete load switch circuit. Load switch ICs have a variety of additional functions, making them suitable for use in complex and compact mobile devices such as smartphones.

Among the additional functions of the load switch IC, a particularly important function is the protection function. For example, if an error occurs in the power supply line and an overcurrent flows too much than expected at the time of device design, or if the voltage on the IC output side becomes larger than that on the input side and the reverse current is occurred, the devices connected to the power supply line may be damaged, and measures are necessary. For this reason, this application note discusses the overcurrent protection that protects the load switch IC from excessive current flow, and the reverse current blocking that prevents reverse current. The purpose of this application note is to assist in the design of electronic devices.

Example of functions of load switch IC

- Inrush current reduction
- Slew rate control
- Over temperature protection
- **Overcurrent protection**
- **Reverse current blocking**
- Output discharge
- Control

Fig.1.1.1 Using the load switch IC

2. Overcurrent Protection

2.1. What is the Overcurrent Protection?

The overcurrent protection of the load switch IC protects the power supply line from excessive current flow. This section explains the case where this function is required by exemplifying the case where a plurality of SoCs for WiFi are ON/OFF as described above. In Fig. 2.1.1, the load-switch ICs are used to turn off the WiFi SoCs when the communication function is not needed to save power. At this time, the overcurrent protection function is useful for the following purposes.

●Load switch ICs and input-side PMIC protections

The load switch IC has an overcurrent protecting function to limit the current when an overcurrent occurs due to an abnormal load change such as an unintentional short-circuit mode at the output terminal. This function can reduce the risk of damage to the load switch IC itself and the PMIC due to heat generated by the current.

●Reducing system downtime due to PMIC output-voltage drop

If an irregular situation occurs in which the WiFi SoC is turned on at the same time, such as an error in control timings, when only one SoC is used to operate the WiFi SoC at the time of communication, the current may suddenly increase and the output voltage may drop beyond the current supply capability of the PMIC. Since lowering the output voltage of the PMIC may result in system down, the load switch ICs have a current limiting function to prevent the output voltage of the PMIC from lowering even when the load switch ICs are abnormal.

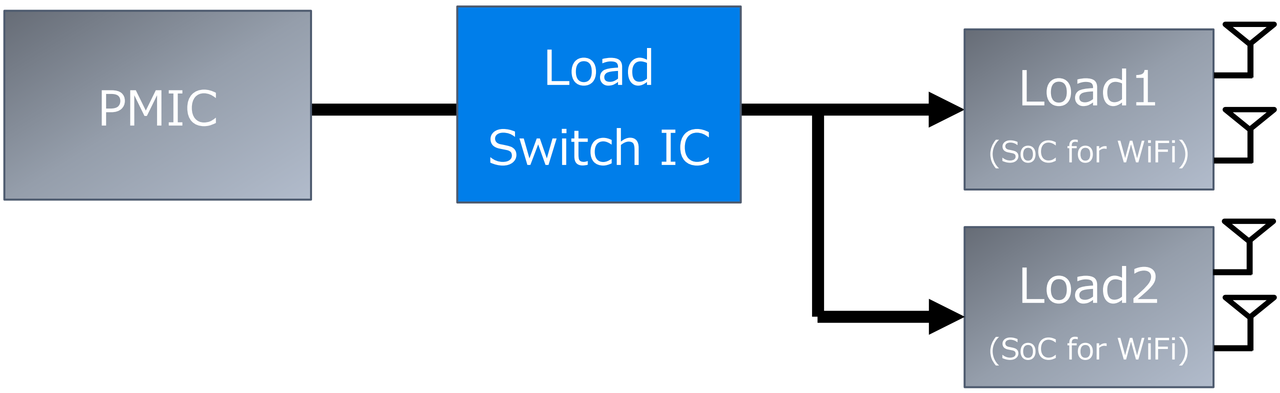

Fig.2.1.1 ON/OFF of a plurality of loads with load switch ICs

2.2. Operation of the Overcurrent Protection

The Toshiba Load Switch IC employs a foldback type protection circuit control system. Figure 2.2.1 shows the operation. If the output current (I_{OUT}) increases when an error such as a short-circuit occurs at the output of the IC, the I_{OUT} increases from point A. When the output reaches the limit current (I_{CL}) at point B, the I_{OUT} does not increase due to the current limiter, and the output voltage (V_{OUT}) drops to point C. When the V_{OUT} drops to point C, the foldback circuitry reduces both V_{OUT} and I_{OUT}. At this time, the current at point D at which the V_{OUT} is zeroed is called the short-circuit current (I_{SC}).

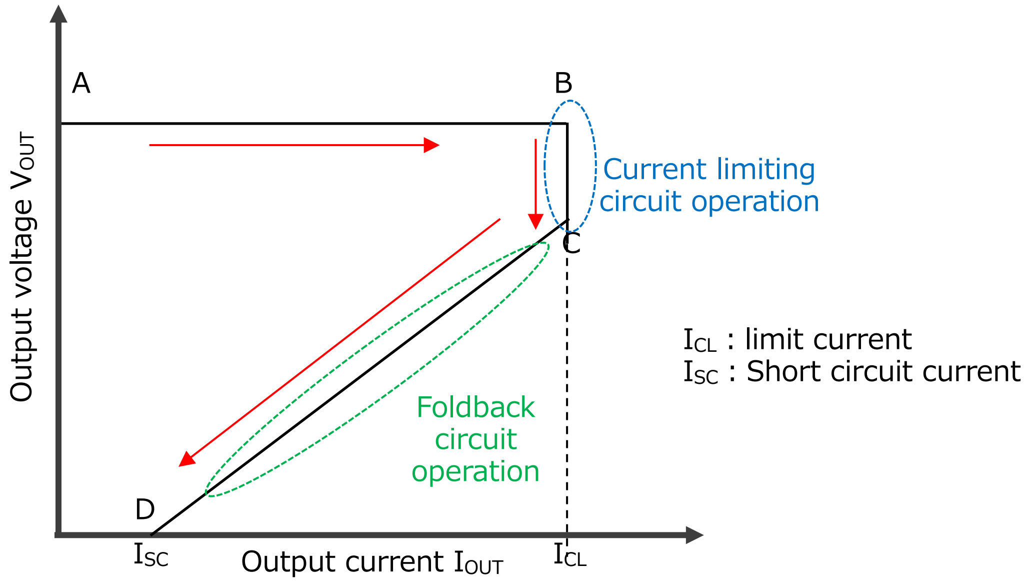

Fig.2.2.1 Operation of the Overcurrent Protection

As shown in Table 2.2.1, Toshiba's Load Switch IC offers a wide range of output-limited currents of 400mA to 1540mA, with overcurrent protection. Fig. 2.2.2 shows the characteristics of foldback circuit as an example of the characteristics when the actual overcurrent protection function works. Select the product according to the required output limit current.

Table.2.2.1 TOSHIBA Load Switch IC with OCP

Part Number	Function				
	OCP*	True RCB	Output discharge	UVLO	Control logic
TCK22946G	400 mA	✓	✓	✓	Active High
TCK22891G		N/A	✓	N/A	Active High
TCK22951G	740 mA	✓	✓	✓	Active High
TCK22892G		N/A	✓	N/A	Active High
TCK2065G	1110 mA	✓	✓	✓	Active High
TCK22893G		N/A	✓	N/A	Active High
TCK1024G	1540 mA	✓	✓	✓	Active High
TCK22894G		N/A	✓	N/A	Active High

*OCP:Overcurrent Protection

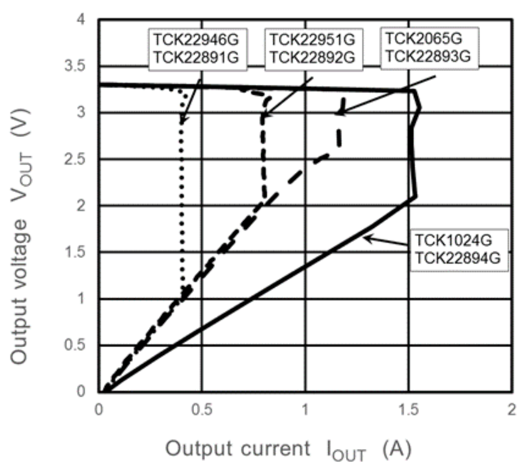

Fig.2.2.2Characteristics of foldback circuit

3. Reverse Current Blocking

3.1. What is Reverse Current Blocking?

The function to prevent reverse current when the voltage (V_{OUT}) at the output side of the load switch IC becomes higher than the voltage (V_{IN}) at the input side ($V_{OUT} > V_{IN}$) is used to prevent reverse current. Causes for the voltage on the output side to become higher than that on the input side include, for example, a case in which electric charge remains on the power supply line on the output side when the connector of the power supply is disconnected, and a case in which the power multiplexer is configured by the load switch circuit as shown in Fig. 3.1.1. If backflow countermeasures are not taken in the load switch circuit, the switch itself and the power supply circuit on the input terminal side may be damaged if backflow occurs.

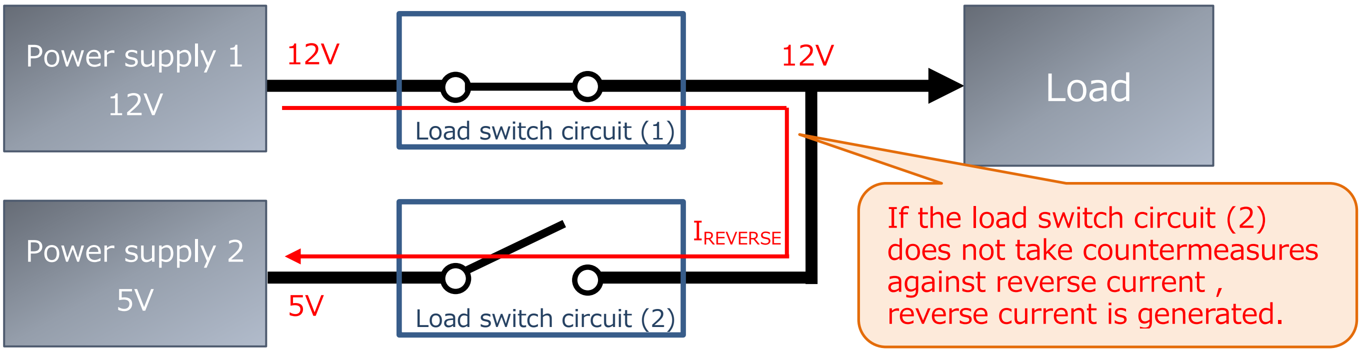

Fig.3.1.1Example of Power Multiplexer Configurations

3.2. Cause of Reverse Current

When the load switch circuit is configured with a discrete configuration of a single MOSFET circuit as shown in Fig. 3.2.1, the body diode (parasitic diode) of the MOSFET causes a reverse current to flow when the output-side voltage is higher than the input-side voltage.

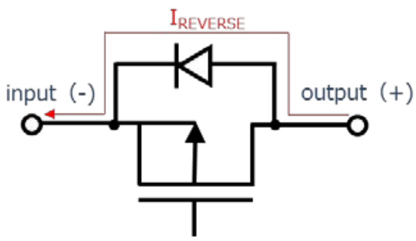

Fig.3.2.1 Reverse current of MOSFET

3.3. Countermeasures

In the load switch circuit, the following countermeasures are considered.

- Adding a diode to the output path (Fig. 3.3.1)
- Adding a MOSFET to the output path (Fig. 3.3.2)
- Using a load switch IC with a reverse current blocking (Fig. 3.3.3)

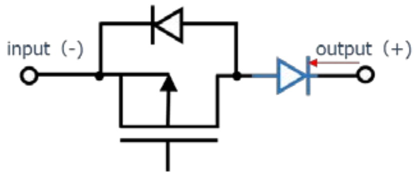

Fig.3.3.1 Added Diode

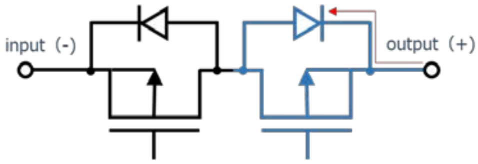

Fig.3.3.2 Added MOSFET

Fig.3.3.3 Using the Load Switch IC

Among the above measures, the addition of diodes causes a problem that the voltage drops when the voltage passes through the diodes in the forward direction, while the addition of MOSFET causes a problem that the on-resistance (R_{ON}) increases. Both will increase in size due to the need for additional parts. On the other hand, the load switch IC with the reverse current blocking function has an optimum countermeasure circuit inside the IC, and it is possible to carry out the backflow prevention countermeasure in a small size and easily.

3.4. Operation of the Reverse Current Blocking

The reverse current blocking function of the load switch IC generally works only when the load switch IC is turned off. Fig. 3.4.1 is a block diagram of Toshiba's load-switch ICs using TCK207G, which is one of the low-voltage, low-on-resistance line-up. As shown in Table 3.4.1, the TCK207G turns off between the V_{IN} terminal and the V_{OUT} terminal when the CONTROL terminal is set to Low, and the reverse current blocking function is enabled when the CONTROL terminal is set to Low.

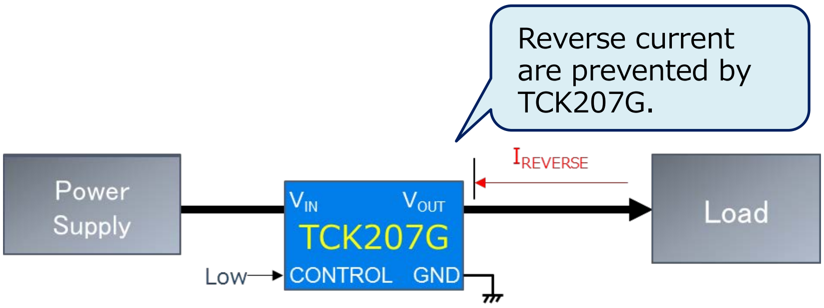

Fig. 3.4.1 Using TCK207G

Table 3.4.1 TCK20xG Series

Part Number	RCB*	Auto-discharge	CONTROL
TCK206G	✓	N/A	Active High
TCK207G	✓	✓	Active High
TCK208G	✓	✓	Active Low

*RCB:Reverse Current Blocking

Fig. 3.4.2 shows the reverse current characteristics when a voltage is applied to the output when the reverse current blocking function of the TCK207G is enabled. As shown in the figure, the reverse current does not flow even when the voltage is applied to the output with the V_{IN} =0V.

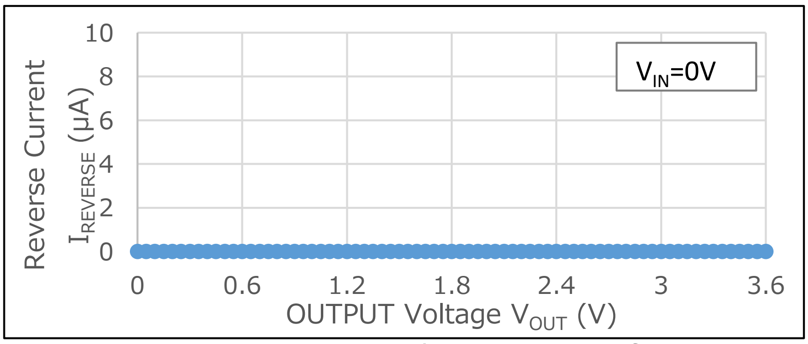

Fig. 3.4.2 Reverse current characteristics of TCK207G

Fig. 3.4.3 shows the configuration of the power multiplexer in TCK206G. When the 5V on the power supply 1 side is supplied to the load, the TCK206G connected to the power supply 2 side needs to be turned off. However, a 5V is applied to the output side of the IC, so that the reverse current blocking function of the TCK206G is useful.

When you configure the power multiplexer shown in Fig. 3.4.3, if you select a load switch IC with a discharge circuit that connects the V_{OUT} and GND when the power multiplexer is turned off, such as TCK207G, current will continue to leak from the discharge circuit of the load switch IC to GND. Therefore, when configuring the power multiplexer with the load switch IC, caution must be exercised, such as selecting a product that does not have a discharge function.

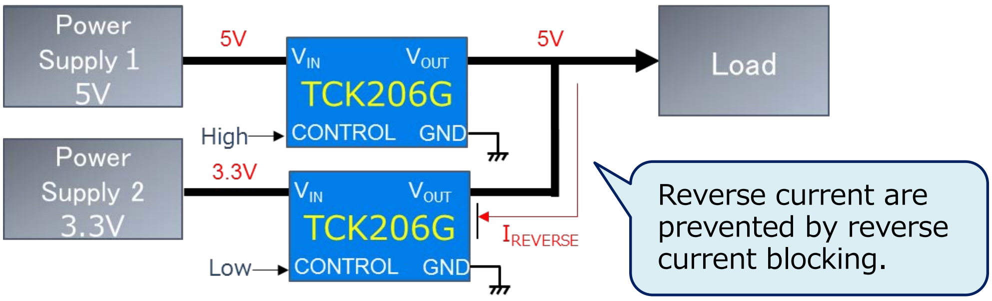

Fig. 3.4.3 Using TCK206G for multiplexer

3.5. True Reverse Current Blocking

However, the function of the load switch IC to prevent reverse current from the output terminal to the input terminal is also available regardless of the ON/OFF of the load switch IC. This function is called a true reverse current blocking function. The load-switch IC with the true reverse current blocking function compares the input voltage (V_{IN}) with the output voltage (V_{OUT}) in the IC, and the backflow prevention circuit works when $V_{OUT}>V_{IN}$. Fig. 3.5.1 shows the operation of the true reverse current blocking in detail. When $V_{OUT}>V_{IN}$, the reverse current ($I_{REVERSE}$) starts to flow. However, care must be taken to prevent $I_{REVERSE}$ when the difference between V_{OUT} and V_{IN} becomes the reverse current blocking operating voltage (V_{RB}), as shown in (1) of Fig. 3.5.1. In addition, when V_{IN} is raised again while the backflow prevention circuit is operating, and V_{IN} becomes larger than V_{OUT} by the reverse current blocking return voltage (V_{RBR}) as shown in (2), the backflow prevention circuit stops operating and the forward current ($I_{FORWARD}$) begins to flow. The maximum-value I_{PEAK} of the reverse current can be calculated by the following equation.

$$I_{PEAK} = \frac{V_{RB}}{R_{ON}}$$

※R_{ON} : ON resistance of load switch IC

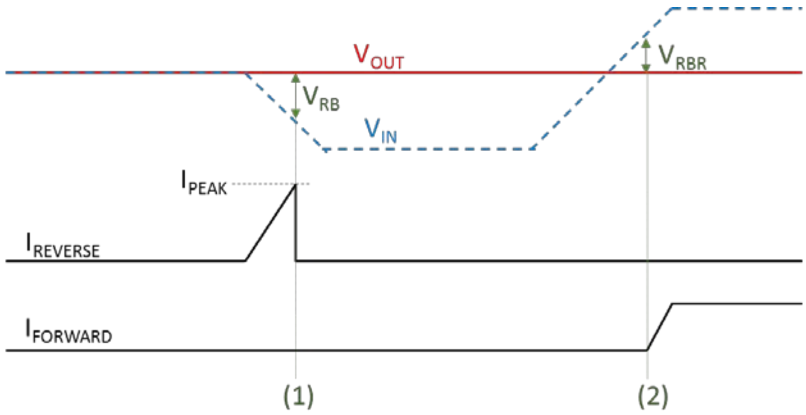

Fig. 3.5.1 Operation Image of True Reverse Current Blocking

Fig. 3.5.2 shows the reverse current characteristics of the actual true reverse current blocking in TCK111G, which is a Toshiba Load Switch IC with a true reverse current blocking. As indicated by the line (1), the $I_{REVERSE}$ increases as the difference (V_{OUT}-V_{IN}) between the output voltage and the input voltage increases. However, the reverse current blocking works at the point A, which is a difference of about 40mV, and the $I_{REVERSE}$ does not flow. As indicated by the line (2), after the backflow prevention circuit is activated, the backflow prevention circuit stops at the point B where V_{IN} is approximately 30mV larger than V_{OUT}, and current begins to flow in the forward direction.

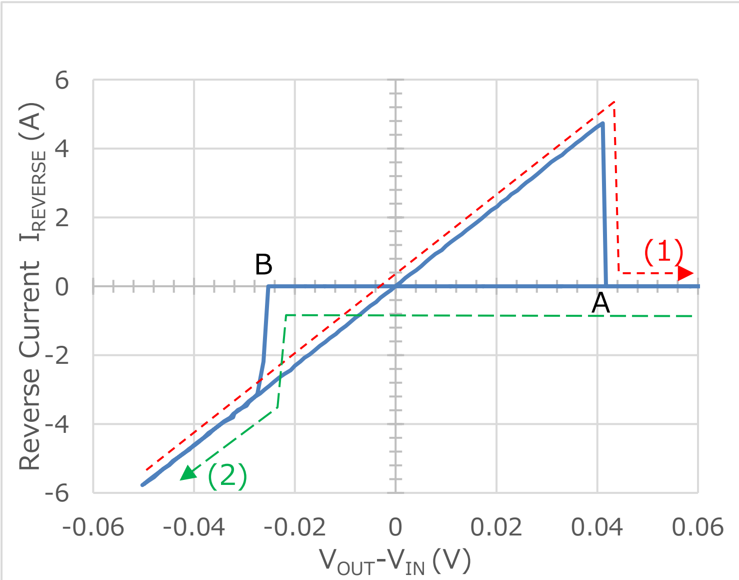

Fig. 3.5.2 Reverse current characteristics of TCK111G

4. Conclusion

This application note describes the overcurrent protection and the reverse current blocking, which are important as the protection function of the load switch IC. Load switch ICs are not only smaller in size than discrete components, but also offer a variety of additional functions, including protection. These additional functions contribute not only to the characteristics of the product, but also to the improvement of the quality and performance of the equipment. We hope that this document will be referred to and that our load switch IC will be utilized.

We have developed a load switch IC with various additional functions. Please visit the following product introduction site.

〇Toshiba's load switch IC with overcurrent protection

Part Number	Feature									
	OCP	V_{IN}	R_{ON}(typ.) *V_{IN}=1.8V	R_{ON}(typ.) *V_{IN}=5V	RCB	Auto-Discharge	UVLO	TSD	Control logic	Product HP
TCK22946G	400 mA	1.1 to 5.5V	70mΩ	31mΩ	✓True	✓	✓	✓	Active High	Click
TCK22891G					N/A		N/A			Click
TCK22951G	740 mA	1.4 to 5.5V	70mΩ	31mΩ	✓True	✓	✓	✓	Active High	Click
TCK22892G					N/A		N/A			Click
TCK2065G	1110 mA	1.4 to 5.5V	70mΩ	31mΩ	✓True	✓	✓	✓	Active High	Click
TCK22893G					N/A		N/A			Click
TCK1024G	1540 mA	1.4 to 5.5V	70mΩ	31mΩ	✓True	✓	✓	✓	Active High	Click
TCK22894G					N/A		N/A			Click

〇Toshiba's load switch IC with reverse current protection in this application note

Part Number	Feature										
	OCP	V_{IN}	R_{ON}(typ.)	R_{ON}(typ.)	RCB	Auto-Discharge	UVLO	TSD	Control logic	I_{OUT}	Product HP
TCK206G	N/A	0.75V to 3.6V	18.4mΩ *V_{IN}=0.75V	18.1mΩ *V_{IN}=3.3V	✓ OFF only	N/A	N/A	N/A	Active High	2A max	Click
TCK207G						✓					Click
TCK208G						✓			Active Low		Click
TCK111G	N/A	1.1 to 5.5V	8.5mΩ *V_{IN}=1.1V	8.3mΩ *V_{IN}=5.0V	✓True	N/A	N/A	✓	Active High	3A max	Click
TCK112G						✓					Click

〇Toshiba's other load switch IC line-up Click

〇Load switch IC application note : Click

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