Linear Regulators

Reverse Voltage Protection

No.16020EBY21

A linear regulator integrated circuit (IC) is a DC-to-DC buck converter system that reduces a DC supply from higher voltage level to a lower voltage level, thus it requires that the input voltage is always higher than the regulated voltage. Output voltage, however, may become higher than the input voltage under specific situations or circuit configurations, and that reverse voltage and current may cause damage to the IC. A reverse polarity connection or certain inductor components can also cause a polarity reversal between the input and output terminals. This application note provides instructions on reversed voltage polarity protection for ICs.

Input /Output Voltage Reversal

In a bipolar linear regulator using an NPN output transistor, input/output voltage reversal causes the base-to-emitter input to be applied with a reverse voltage. A voltage higher than the reverse breakdown voltage specific to the base-emitter junction may result in damage to the semiconductor elements and may consequently destroy them (see Figure 1). In some cases, parasitic elements may be activated in the IC, allowing electrical current to flow from the output to the input. Because the effect of the parasitic elements is often disregarded in terms of the regulator behavior, that could damage or destroy the semiconductor elements.

In an MOS linear regulator, a parasitic element exists as a body diode in the drain-source junction portion of its power MOSFET. Reverse input/output voltage triggers the current flow from the output to the input through the body diode. The inverted current may damage or destroy the semiconductor elements of the regulator since the effect of the parasitic body diode is usually disregarded for the regulator behavior.

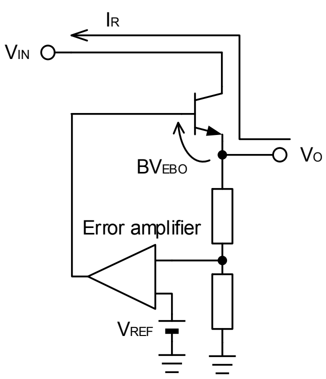


Figure 1 Reverse Current Path in a Bipolar Linear Regulator

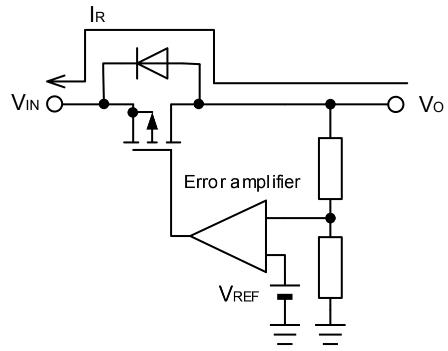


Figure 2 Reverse Current Path in an MOS Linear Regulator

Now, let's take a look at how reverse voltage protection works under different circuit conditions. Reversed input/output voltage allows a reverse current flow from the output to the input in an output capacitor having a large capacitance, if the charge to the capacitor remains after the power source is cut off, or the power off rate of the supply is very fast (see Figs. 3 and 4).

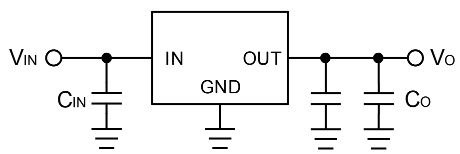


Figure 3 Linear Regulator Circuit

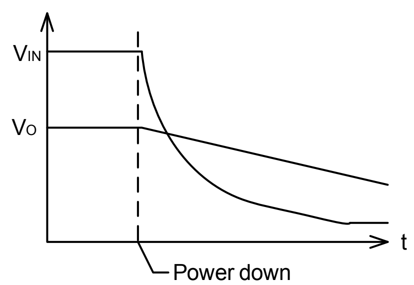


Figure 4 Typical Voltage Decrease When Electrical Charge Remains in an Output Capacitor

An effective solution to this is an external bypass diode connected in-between the input and output to prevent the reverse current flow inside the IC (see Figure 5). Figure 6 lists the requirements for the bypass diode. Note that the bypass diode must be turned on before the internal circuit of the IC. Bypass diodes in the internal circuits of MOS linear regulators must have low forward voltage V_F. Some ICs are configured with current-limit thresholds to shut down high reverse current even when the output is off, allowing large leakage current from the diode to flow from the input to the output; therefore, it is necessary to choose one that has a small reverse current. Specifically, select a diode with a rated peak inverse voltage greater than the input to output voltage differential (derating ≤ 80 %) and rated forward current greater than the reverse current (derating ≤ 50 %) during use.

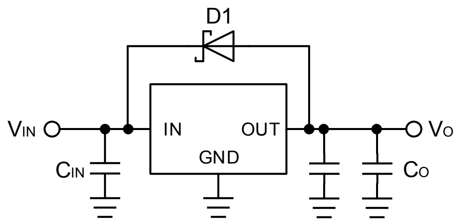
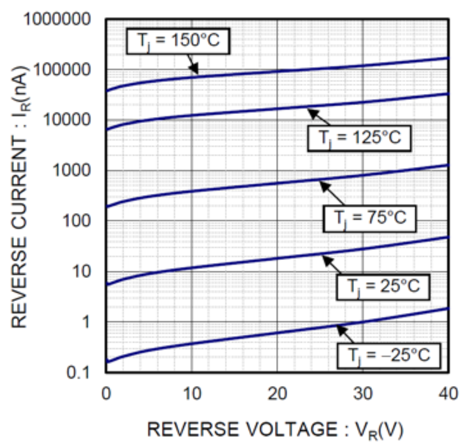


Figure 5 Bypass Diode for Reverse Current Diversion

- A low V_F if for an MOS regulator (≤ approx.0.6 V)
- A low peak inverse current I_R (≤ approx. 1 μA)
- Rated peak inverse voltage greater than the input to output voltage differential (derating ≤ 80 %)
- Rated forward current greater than the reverse current (derating ≤ 50 %)

Figure 6 Requirements for Bypass Diode

Diodes come in various types designed for a wide range of applications. Figure 7 shows the features of diodes commonly used in electronics. Both switching diodes and rectifier diodes have slow reverse currents (I_R), but their high forward voltages (V_F) make them unsuitable choices for MOS linear regulators. The range of applications switching diodes offer is relatively limited because of their low forward current ratings. The lower forward voltage (V_F) of Schottky barrier diodes cater to requirements of MOS linear regulators, however the main drawback is found in the level of their reverse current (I_R), which is relatively high. So, one with a low reverse current is recommended when choosing a Schottky diode. The V_R-I_R characteristics versus temperatures show increases at higher temperatures (see Figure 8). Detailed information can be found on the datasheet available from the diode's manufacturer. Rohm provides Schottky barrier diodes that use multiple metals to achieve low V_F and I_R. The electrical characteristics of a Rohm Schottky barrier diode are given in Figure 9.



(Source: Rohm RB168MM-40 Datasheet 2015.09 - Rev. B)

Figure 8 V_R-I_R Characteristics

Parameter	Schottky Barrier Diode	Switching Diode	Rectifier Diode
Construction	Planar Metal-semiconductor junction	Planar P-N junction	Mesa P-N junction
Forward Voltage V_F Max.	Low (0.4 V - 0.85 V)	High (0.9 V - 1.2 V)	High (1.0 V - 1.3 V)
Reverse Current I_R Max.	Small-large (0.55 μA - 1 mA) Thermal characteristics: Large	Small (≤ 0.2 μA)	Small-medium (1 - 10 μA)
Reverse Voltage Rating	≤ 150V	≤ 80V	≤ 600V
Forward Current Rating	≤ 5A	≤ 100mA	≤ 2A
Application	Bipolar linear regulators MOS linear regulators	Bipolar linear regulators	Bipolar linear regulators

Figure 7 Features of Diodes

●**Absolute Maximum Ratings** (T_c= 25°C)

	Parameter	Symbol	Conditions	Limits	Unit
	Repetitive Peak Reverse Voltage	V_{RM}	Duty≦0.5	40	V
▶	Reverse Voltage	V_R	Direct Reverse Voltage	40	V
▶	Average Forward Rectified Current	I_o	Glass epoxi mounted, 60Hz half sin Wave, resistive load,	1	A
	Non-repetitive Forward Current Surge Peak	I_{FSM}	60Hz half sin wave, one cycle, Non-repetitive at T_a=25°C	30	A
	Operating Junction Temperature	T_j	-	150	°C
	Storage Temperature	T_{stg}	-	–55 to +150	°C

●**Electrical Characteristics** (T_j = 25°C)

	Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
▶	Forward Voltage	V_{F1}	I_F=1.0A	-	0.60	0.65	V
▶	Reverse Current	I_R	V_R=40V	-	0.05	0.55	μA

(Source: Rohm RB168MM-40 Datasheet 2015.09 - Rev. B)

Figure 9 Specifications of Schottky Barrier Diode RB168MM-40

If V_{IN} is open in a circuit as shown in Figure 10 with its input/output voltage being reversed, the only current that flows in the reverse current path is the bias current of the IC. Because the amperage is too low to damage or destroy the parasitic element, a reverse current bypass diode is not required for this type of circuit.

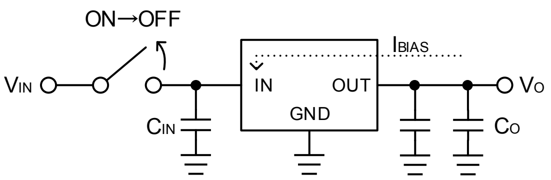


Figure 10 Open V_{IN}

If a load exists in-between different power supplies as in Figure 11, time lags that occur during the rising/falling of the power supplies allow current to flow through the load from one power output terminal to the other. A reverse current bypass diode is required for the reverse voltage produced between the input and output at this point.

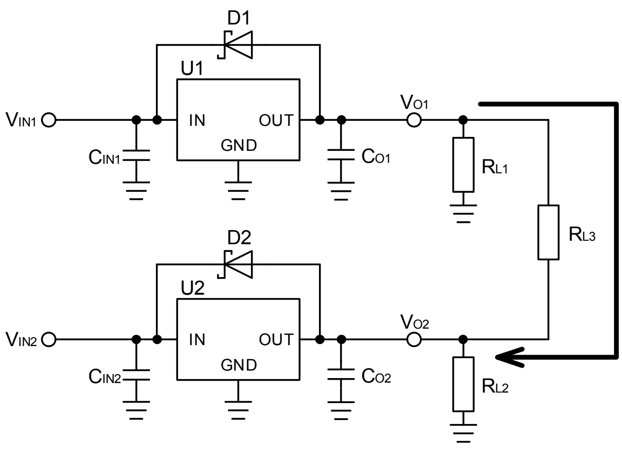


Figure 11 Current Path with Different Power Supplies and Diode Arrangement

Protection against Output Reverse Voltage

If the output load is inductive, electrical energy accumulated in the inductive load is released to the ground upon the output voltage turning off. In-between the IC output and ground pins is a diode for preventing electrostatic breakdown, in which a large current flows that could destroy the IC. To prevent this from happening, connect a Schottky barrier diode in parallel with the diode (see Figure 12).

Further, if a long wire is in use for the connection between the output pin of the IC and the load, observe the waveform on an oscilloscope, since it is possible that the load becomes inductive. An additional diode is needed for a motor load that is affected by its counter electromotive force, as it produces an electrical current in a similar way.

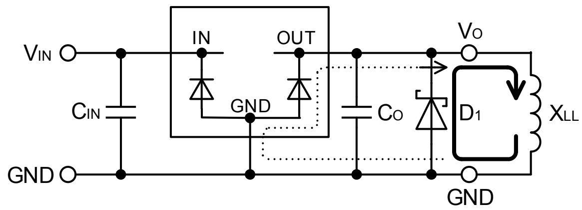


Figure 12 Current Path in Inductive Load (Output: Off)

Protection against Input Reverse Voltage

Accidental reverse polarity at the input connection flows a large current to the diode for electrostatic breakdown protection between the input pin of the IC and the GND pin, which may destroy the IC (see Figure 13).

A Schottky barrier diode or rectifier diode connected in series with the power supply as shown in Figure 14 is the simplest solution to prevent this from happening. The solution, however, is unsuitable for a circuit powered by batteries because there is a power loss calculated as V_F x $I_{O,}$ as the forward voltage V_F of the diode drops in a correct connection. The lower V_F of a Schottky barrier diode than that of a rectifier diode gives a slightly smaller power loss. Because diodes generate heat, care must be taken to select a diode that has enough allowance in power dissipation. A reverse connection allows a negligible reverse current to flow in the diode.

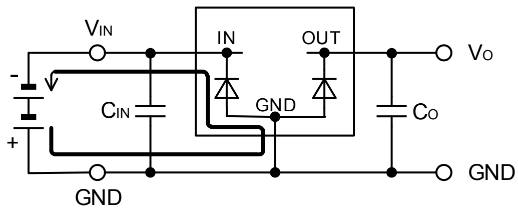


Figure 13 Current Path in Reverse Input Connection

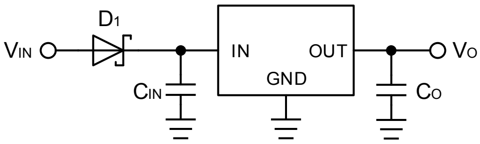


Figure 14 Protection against Reverse Polarity 1

Figure 15 shows a circuit in which a diode is connected in parallel with the power supply. Because the diode must be turned on before the diode inside the IC for electrostatic breakdown protection, a low V_F Schottky barrier diode becomes the choice for this circuit. If connected correctly, the circuit behaves as if the diode did not exist. In a reverse connection, all the current from the power keeps flowing to the diode, generating a significant amount of heat that may destroy the circuit if the previous stage has a large capacitance. This type of circuit may be designed to provide protection against accidental reverse connection, or must be designed assuming that the previous stage is equipped with overcurrent protection.

Add a fuse connected in series with the power, if enhanced protection focused on safety is required. That would give reliable protection for the circuit, though proper maintenance of the fuse becomes necessary (see Figure 16).

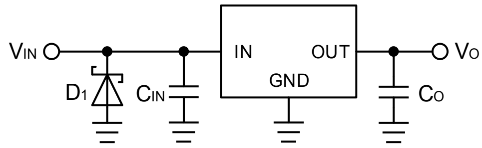


Figure 15 Protection against Reverse Polarity 2

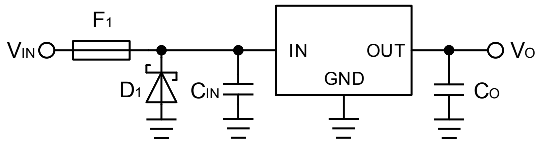


Figure 16 Protection against Reverse Polarity 3

Figure 17 shows a circuit in which a P-channel MOSFET is connected in series with the power. The diode located in the drain-source junction portion of the MOSFET is a body diode (parasitic element). The voltage drop in a correct connection is calculated by multiplying the resistance of the MOSFET being turned on by the output current I_O, therefore it is smaller than the voltage drop by the diode (Figure 14) and results in less of a power loss. No current flows in a reverse connection where the MOSFET remains off.

If the voltage taking account of derating is greater than the voltage rating of MOSFET gate-source junction, lower the gate-source junction voltage by connecting voltage dividing resistors as shown in Figure 18.

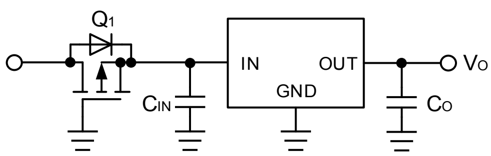


Figure 17 Protection against Reverse Polarity 4

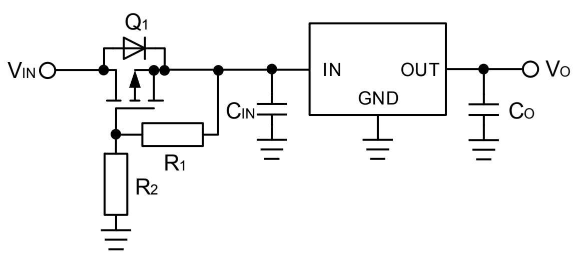


Figure 18 Protection against Reverse Polarity 5

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