Technical Article

LDO Basics: Preventing Reverse Current

Mark Sellers

In most low-dropout regulators (LDOs), current flow is like one-way street – go in the wrong direction and major problems can occur! Reverse current is current that flows from V_{OUT} to V_{IN} instead of from V_{IN} to V_{OUT}. This current usually traverses through the body diode of the LDO instead of the normal conducting channel, and has the potential to cause long-term reliability problems or even destroy the device.

There are three main components to an LDO (see Figure 1): the bandgap reference, error amplifier and pass field-effect transistor (FET). The pass FET conducts current, as any normal FET, between the source and the drain in a typical application. The doped region used to create the body of the FET, called the bulk, is tied to the source; this reduces the amount of threshold voltage change.

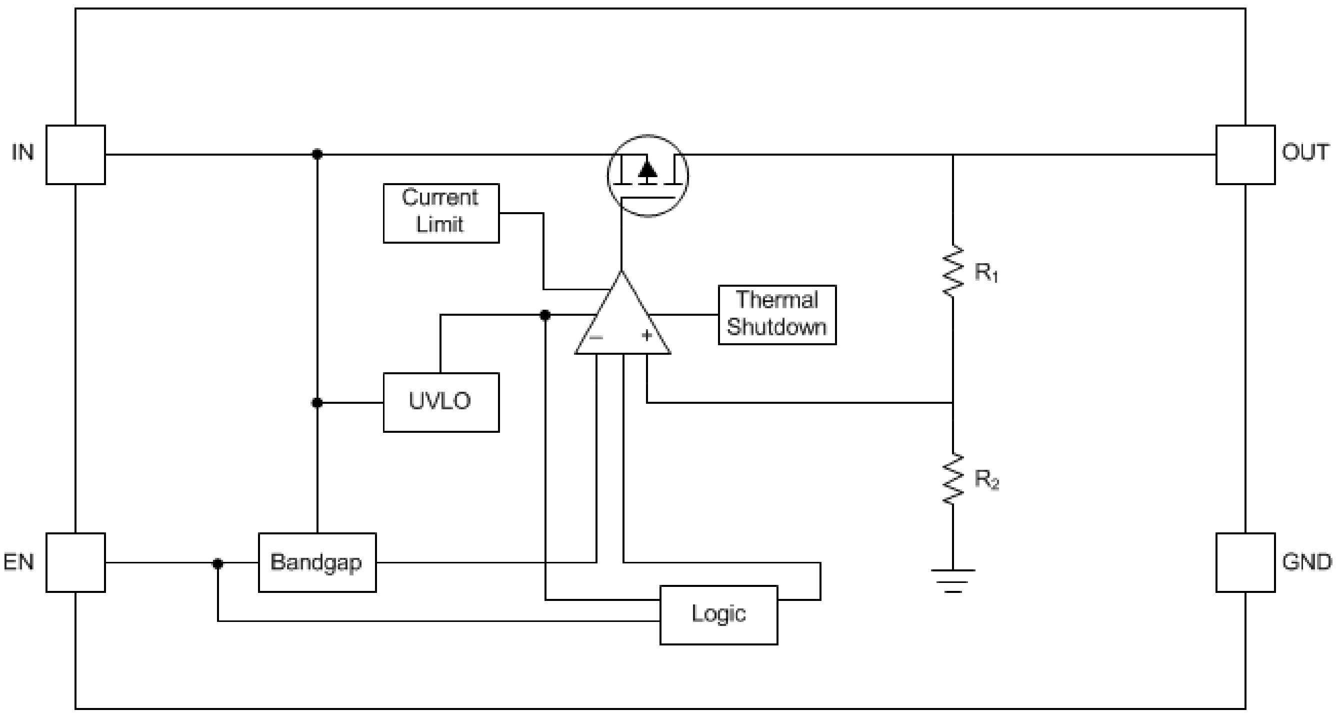

Figure 1. LDO Functional Block Diagram

One drawback of tying the bulk together with the source is that a parasitic body diode forms in the FET, as shown in Figure 2. This parasitic diode is called the body diode. In this configuration, the body diode can turn on when the output exceeds the input voltage plus the V_{FB} of the parasitic diode. Reverse current flow through this diode can cause device damage through device heating, electromigration or latch-up events.

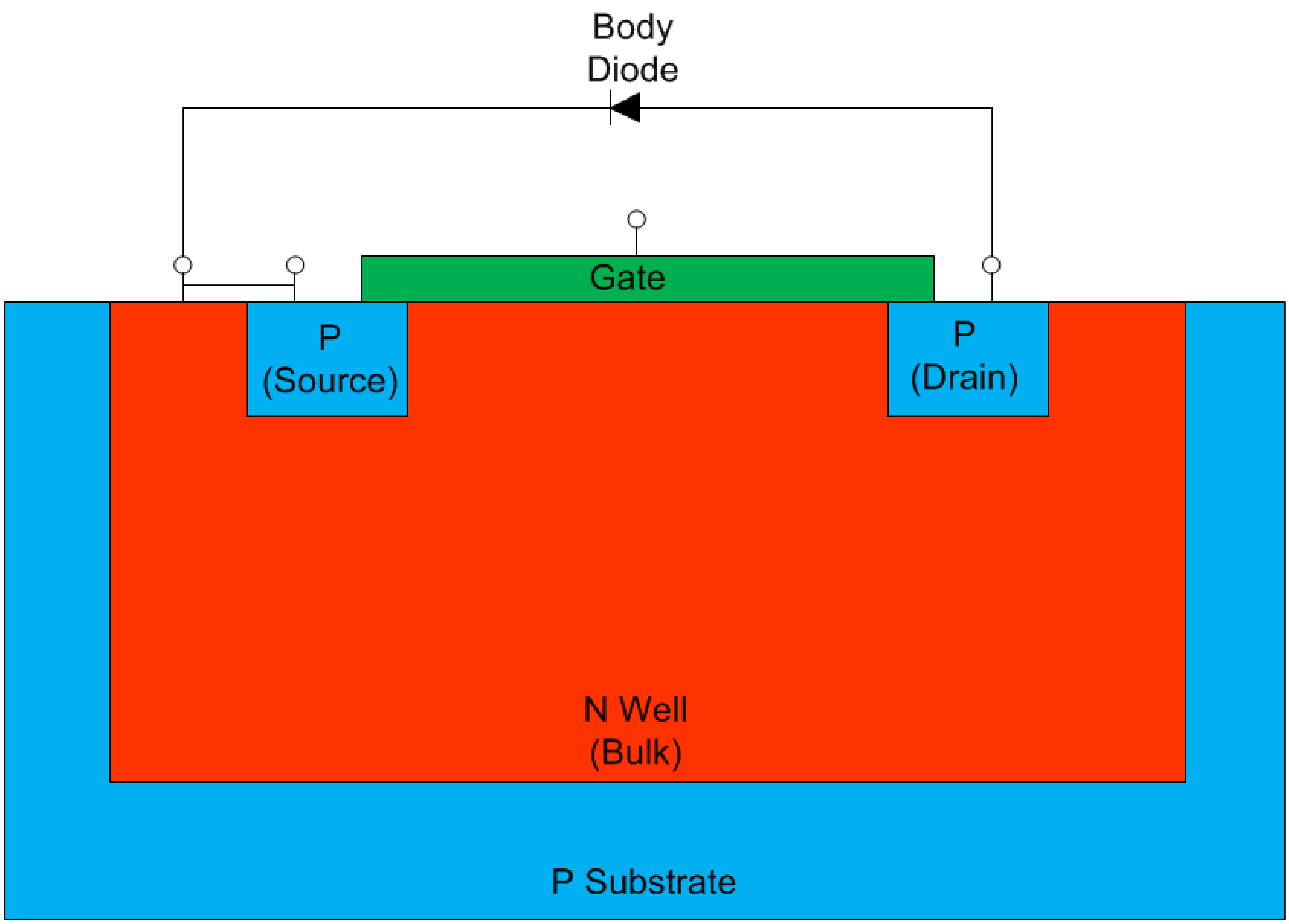

Figure 2. Cross-sectional View of a P-channel Metal-oxide Semiconductor (PMOS) FET

When designing your LDO, it is important to consider reverse current and how to prevent it. In this post, I'll cover two ways of preventing reverse current at the application level and two ways during the integrated circuit (IC) design process.

There are four common methods for preventing reverse current flow, two at the application level and two during design.

Use a Schottky Diode

As shown in Figure 3, using a Schottky diode from OUT to IN will keep the body diode in the LDO from conducting when the output voltage exceeds the input voltage. You must use Schottky diodes because of their low forward voltage. Traditional diodes have a much higher forward voltage than Schottky diodes. During normal operation, the Schottky diode is reverse-biased and will not conduct any current. Another advantage of this approach is that the LDO's dropout voltage will not increase when placing a Schottky diode between the output and the input.

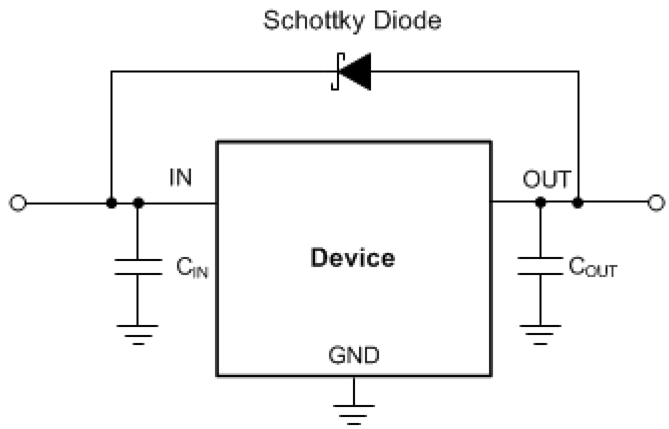

Figure 3. Preventing Reverse Current Using a Schottky Diode

Use a Diode before the LDO

As shown in Figure 4, this method uses a diode in front of the LDO to prevent current from flowing back into the supply. This is an effective method at preventing reverse current, but it also increases the necessary input voltage needed to keep the LDO out of dropout. The diode placed at the supply of the LDO becomes reverse-biased during a reverse current condition and does not allow any current to flow. This method is similar to the next method.

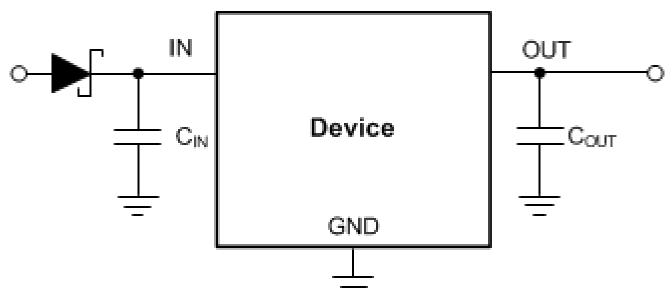

Figure 4. Reverse Current Prevention Using a Diode before the LDO

Use a Second FET

LDOs designed to block reverse current flow often use a second FET to help prevent reverse current flow. The two FETs are placed with the sources back to back, as shown in Figure 5, so that the body diodes face each other. Now, when a reverse current condition is detected, one of the transistors will turn off and current cannot flow through the back-to-back diodes.

One of the biggest drawbacks to this approach is that the dropout voltage essentially doubles when using this architecture. To decrease the dropout voltage, you will have to increase the size of the metal-oxide semiconductor field-effect transistors (MOSFETs), thus increasing the overall solution size. Automotive LDOs like TI's TPS7B7702-Q1 use this approach to prevent reverse current flow.

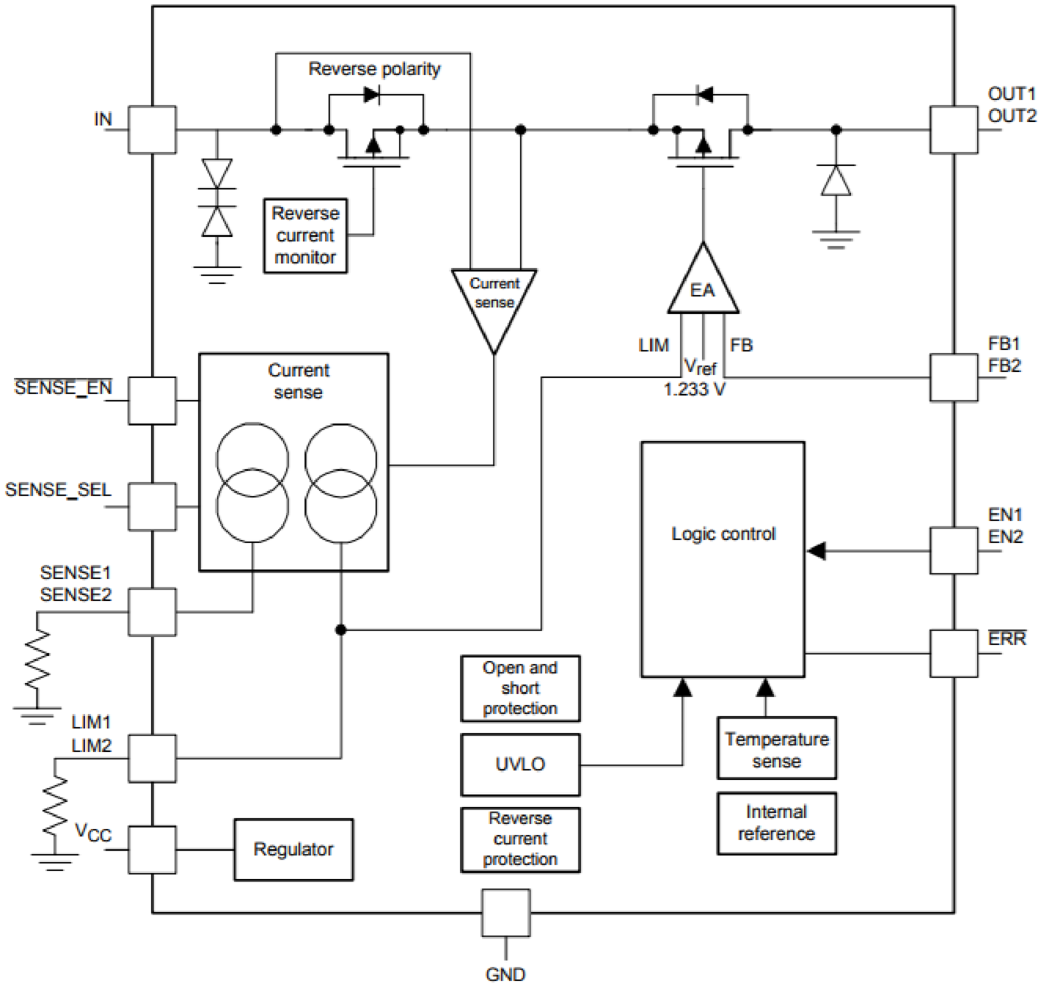

Figure 5. Back-to-back FETs to Prevent Reverse Current

Connect the Bulk of the MOSFET to GND

This method is the least common way of implementing reverse current but is still extremely effective, as it eliminates the body diode of the MOSFET. This method ties the bulk of the MOSFET to GND, eliminating the connection to the source that was causing the parasitic body diode. TI's TPS7A37 uses this method to implement reverse current protection. One advantage is that tying the bulk of the MOSFET to GND does not increase the dropout of the LDO.

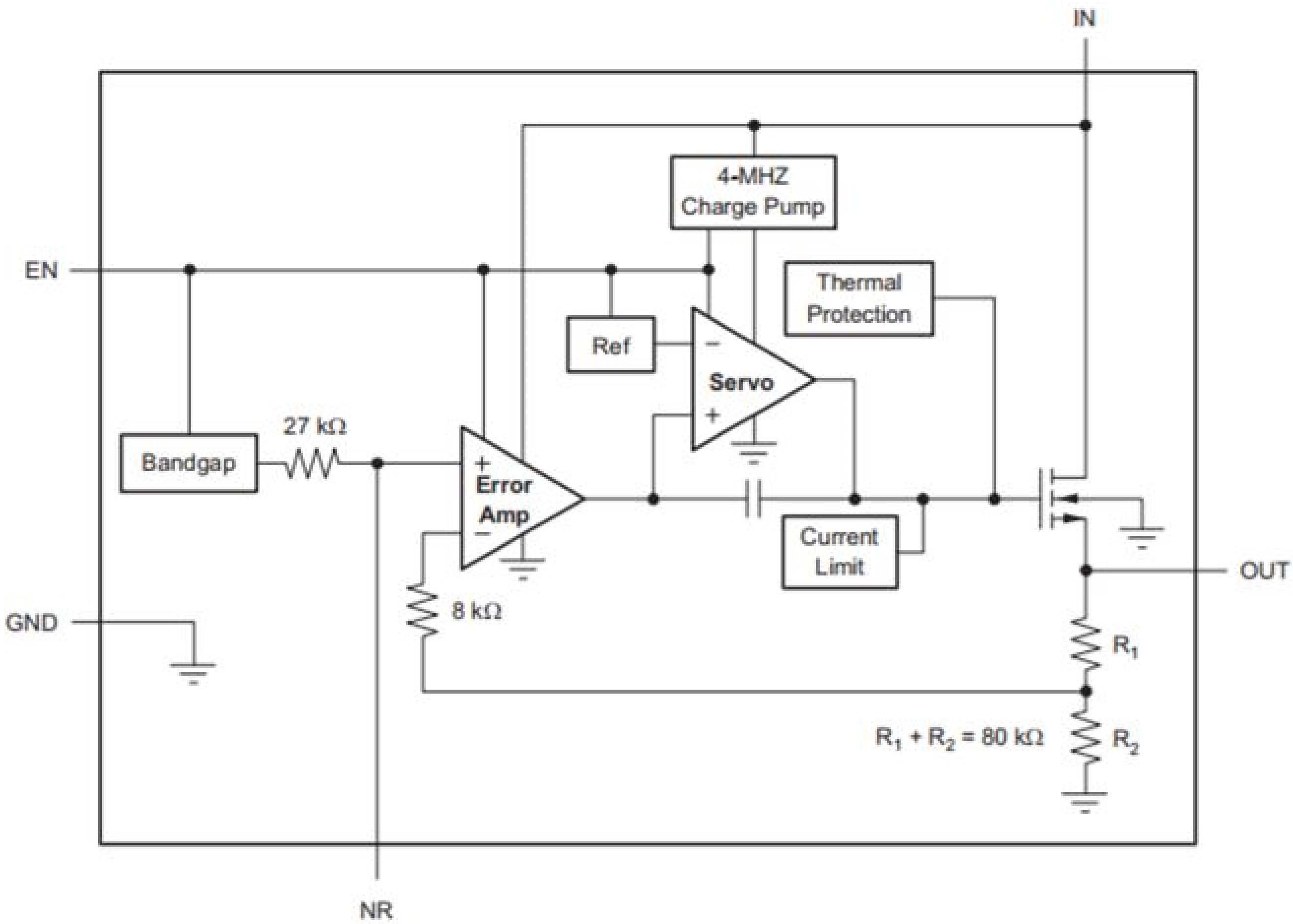

Figure 6. Connecting the Bulk of the FET to GND

Conclusion

When reverse current protection is needed in your application look for the LDO topologies that provide the level needed. If an LDO with reverse current protection does not meet all the system requirements, consider implementing reverse current protection using a diode.