

BERS™ IC (Better Efficiency Rectifier System) Reverse Recovery Operation

Prepared by: Alan Ball
ON Semiconductor



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APPLICATION NOTE

General Description

The NIS6111 is a hybrid diode containing a power MOSFET, polarity comparator and internal bias circuit. It is designed to operate as an ideal diode by sensing the voltage polarity across the FET and driving the gate accordingly such that the FET operates in the third quadrant, the same as with other synchronous rectifiers.

It may be used in either dc (ORing) applications or as a switching device. In either case, the reverse recovery of this device behaves differently than that of a conventional diode. This behavior will be explained in detail in this design note.

Circuit Description

A simplified schematic of the BERS device is shown in Figure 1. The basic operation is quite simple.

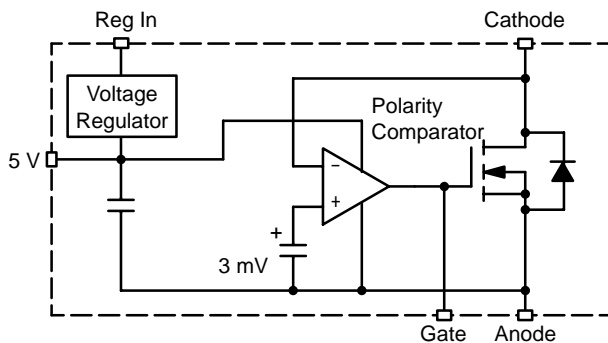


Figure 1. BERS Block Diagram

The FET must operate in the third quadrant so that when its body diode is forward biased it will turn on and provide a lower forward drop than that of the diode. When the body diode is reverse biased the FET is also off.

The polarity comparator senses the drain to source voltage of the FET, and when the drain (cathode) is more negative than the source (anode), the output of the comparator is high

and the FET is enhanced. Likewise when the drain goes positive with respect to the source, the output of the polarity comparator goes low and turns off the FET.

There is a 3 mV offset built in to the comparator. This offset is necessary to assure stability of this device.

Figure 2 shows the waveforms of the device with the offset as shown in Figure 1. When the current initially flows in the conducting direction, the voltage on the cathode is negative with respect to the anode and the voltage drop is due to the body diode conduction. After some number of nanoseconds the output of the comparator goes high and the FET is enhanced. At this point the forward drop reduces to the level of $I_d \times R_{DS(on)}$.

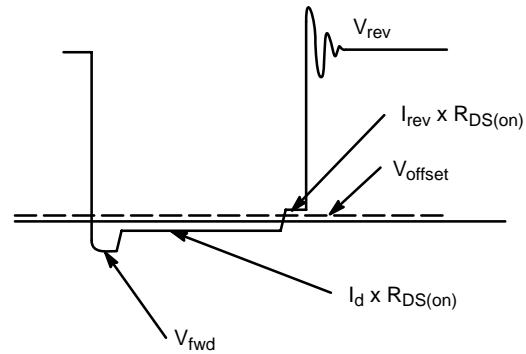


Figure 2. Voltage Waveforms

When the current reverses, the drop goes positive with a voltage of $I_{rev} \times R_{DS(on)}$. This positive voltage from cathode to anode trips the polarity comparator and turns the FET off. It is important to note that the cathode to anode voltage must go positive for the device to turn off. **In other words, some amount of reverse current must flow in the device for it to turn off.**

From this explanation it may seem desirable to change the offset to the other direction. There is a stability problem associated with this however. Figure 3 shows the voltage waveforms of the BERS with a negative offset.

At light loads, the forward drop with the FET enhanced could be a few millivolts or less. Under this condition, the comparator would sense the forward voltage of the diode and turn the FET on. Once the FET was enhanced, the drop would be too low to sustain the proper input level for the comparator and the comparator would turn the FET back off, only to sense the forward drop again. The resulting oscillation is shown in Figure 3.

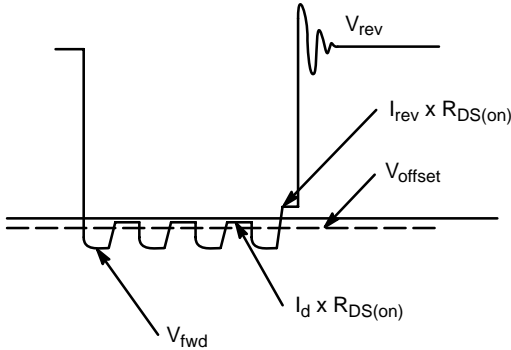


Figure 3. Voltage Waveforms for Negative Offset Voltage

The offset is required in the polarity shown to avoid oscillations. It is set as close to zero as possible while being able to assure that it never goes negative.

Effective Turn-off Time

The polarity comparator is a very high speed device which is coupled to a high speed, high current driver. The turn off time of the NIS6111 is comprised of two components; the propagation delay through the comparator, driver and FET, and the time required for the current to reach the required level to meet the comparator offset voltage.

The comparator response time is normally about 40 ns, however the time required for the current to reach the reverse level required for turn off is generally much longer. This means that the effective turn off time is very di/dt dependant. The amount of reverse current required for turn off is:

$$I_{rev} = \frac{V_{offset}}{R_{DS(on)}}$$

If parallel FETs are added for higher current applications, as is often the case for ORing applications, $R_{DS(on)}$ is the equivalent on resistance for all FETs connected in parallel.

The turn off waveforms for switching applications vary depending on the circuit. Figure 4 shows the response of a BERS diode used as the low side rectifier in a synchronous buck converter for computing applications.

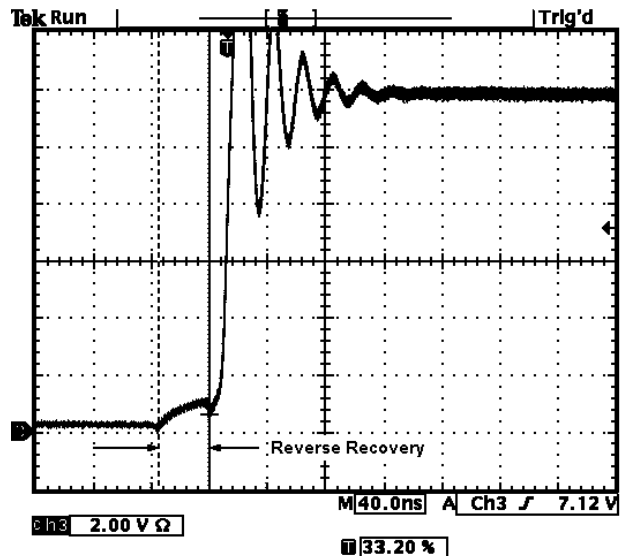


Figure 4. Voltage Waveform for Synchronous Buck Converter

The reverse recovery time can be seen as a small increase in voltage across the device. This is a function of the $R_{DS(on)}$ and reverse current as described above. This converter design has a very low value of stray inductance and very low impedance in the power path.

Figure 5 shows the current through the BERS diode in a discontinuous mode flyback. It can be seen that the effective recovery time (t_{eff}) is about 250 ns. Roughly 200 ns of this is the time required to reach the level of negative current required to trip the polarity comparator. The remainder of the time, is the propagation delay (t_{pd}) of the comparator and FET.

For this waveform the di/dt is very slow since it is controlled by the bulk inductance of the secondary of the flyback transformer and not the circuit parasitics as was the case in the synchronous buck regulator of Figure 4.

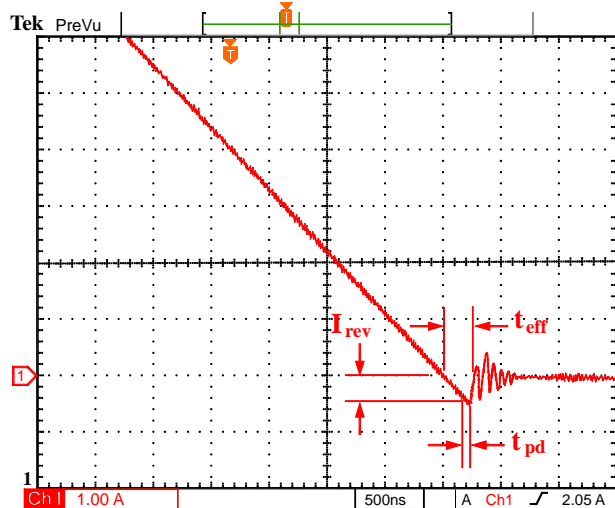


Figure 5. Current Waveform for a Discontinuous Mode, Flyback converter

The NIS6111 is very effective in a discontinuous flyback converter, since the effective recovery time does not overlap with the turn on of the switch. In this circuit, the efficiency was increased by 1.5% compared to that of a Schottky diode.

ORing Applications

BERS devices can easily be implemented as ORing diodes. In ORing circuits an external power source is required for high side applications. For 12 volt low side diodes, the device is self-biasing. The high and low side circuits are shown in Figures 6 and 7.

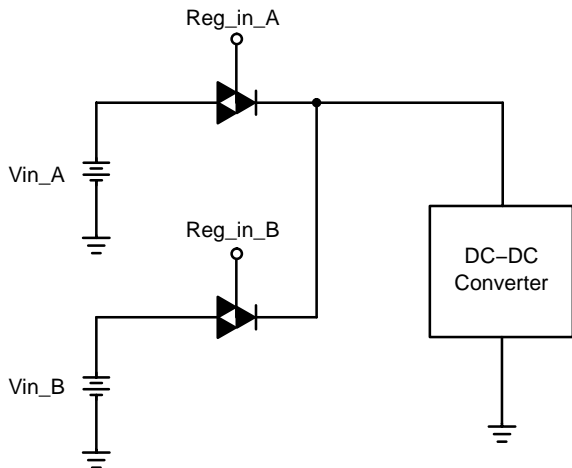


Figure 6. High Side ORing Circuit

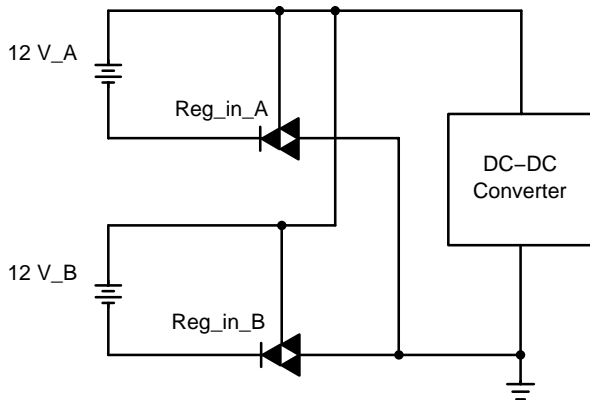


Figure 7. Low Side ORing Circuit with Self Biasing Devices

The BERS rectifier is very efficient in ORing applications and is simple to use. As has been explained, the device needs a small amount of reverse current to turn it off. Turn off waveforms for a high side system are shown in Figure 8.

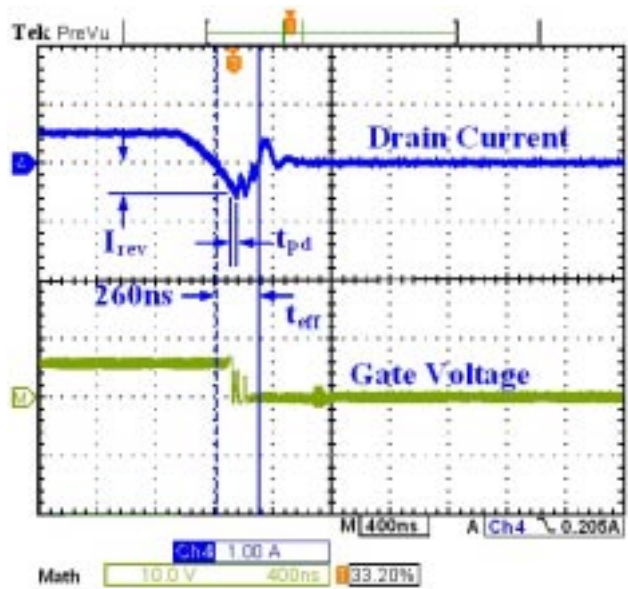


Figure 8. ORing Diode Reverse Current

There is a behavioral trait of this device that is linked to the turn off mechanism that is important to understand. In a real application where one supply fails, there is a surge of reverse current applied to the corresponding BERS if that BERS was conducting at the time of failure. This reverse current is necessary to turn off the device as has been explained.

When testing such a circuit, it is tempting to simply shut off the power supply to simulate a failure. Under this condition, there is no reverse current. If the BERS device in series with the “failed” supply was conducting, it will continue to conduct current since there was no surge of reverse current. The alternate supply will now provide the power to the load but will also feed back into the input of the “failed” supply through the BERS device and keep its output capacitor charged.


Turning off a power source in order to simulate a shorted output is not a valid method of testing an ORing circuit using a BERS diode. The shorted output must go into a low impedance state (the same as it would in the real case) to make the device function properly.

Conclusion

The BERS (NIS6111) is a hybrid diode that closely approximates an ideal diode for synchronous rectification and ORing applications. For reasons of stability, it is necessary to design this device with a small positive offset voltage on the polarity comparator.

This offset voltage creates a requirement for a small reverse current in order to switch the internal FET into an off state. It is important to understand this subtlety in order to use this device effectively in a circuit.

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