A Better ORing Diode for Intermediate Bus Voltages

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Abstract

This paper discusses a novel approach to improve the efficiency over the present solution of using Schottky diodes in an ORing application. The efficiency performance advantage of the new solution is calculated. The performance advantage of this new solution is compared to some recently introduced solutions from competitors X (two chip solution) and Y (single chip solution).

Introduction

ORing diodes are a necessary evil of high reliability systems. They are used to isolate redundant power sources so that a failure of one source will not bring down the entire system. There are several inherent problems associated with this isolation system.

One of those problems is the loss due to the insertion of a component directly into the power path. The full load current must pass through this device and the associated power loss is simply that load current multiplied by the voltage drop across the device.

This can be a substantial amount of power, and along with decreasing the efficiency of the system, it generates heat in the isolation diode which must also be dealt with.

The other issue associated with isolation diodes is the reverse recovery time. When a short circuit occurs in one of the sources, this device must limit the flow of many amps of current in a very short period of time. If not, the bus can be degraded to the point where the load will fail due to undervoltage or transient conditions.

The Schottky Diode Solution

Schottky diodes are a simple method of providing isolation in such a system. They are simple to use, have a lower voltage drop than a conventional silicon rectifier and have a very fast recovery time.

All this said, there are two problems with Schottky rectifiers. The forward drop is still a good fraction of a volt. If we use an MBR1635 16 amp, 35 volt Schottky rectifier, with a 10 amp load current and a 100°C junction temperature, the power loss is:

$$P_{loss} = 0.5V \text{ x } 10A = 5W$$

Even for a TO-220 package, this is a lot of heat to dissipate.

The other problem with Schottky diodes is their leakage. Depending on the worst case junction temperature, the leakage can be significant. This diode has a leakage current of 8 mA at a 125°C junction temperature and a 10 volt reverse bias. That’s 80 mW of dissipation when it is in it’s off state.

FET Diodes

An alternate solution is to substitute a power MOSFET for the Schottky rectifier. This has the advantage of a lower forward drop, but added complexity due to the required drive circuitry and slower turn off time. This solution also requires an external bias voltage to operate the gate of the FET, assuming that an N-channel device is used.

In order to just equal the power loss as the Shottky diode in the above example, a FET would be required with an R_{DSon} of:

$$R_{DSon} = \frac{5W}{10A^2} = 50m\Omega$$

This on resistance can be easily obtained with current low voltage FETs that are available on the market. The difficulty comes in designing a circuit that can accurately and quickly detect a change in polarity, so that the FET can be turned off before the bus voltage is degraded to the point where the system crashes.

Even with some of the high speed comparators available on the market today, it is quite a challenge to couple that with a driver and minimize the switching delays to achieve speeds in the 100 ns range, that would allow for reliable fault protection in the event of a shorted source.

FETs with on resistances as low as 2 mΩ exist today, with voltage ratings of 20 to 30 volts. A 2 mΩ FET would have a total loss of:

$$P_{Loss} = 10A^2 \cdot 0.002\Omega = 0.2W$$

This results in a power savings of 4.8 watts, or a decrease in ORing losses of 96%. It also eliminates any need for heatsinking of the ORing diode.

However, in selecting the FET a tradeoff must be made between lowest on resistance and a higher gate charge. Since you also want quick reverse recovery from a failed supply, a slightly higher on resistance may be preferable since it will have a lower gate charge and faster turn-off time.

Better ORing Diode Solution

The solution is to integrate as much circuitry as possible. This allows optimization of interface impedances between the comparator, driver and FET. There are several solutions on the market, each using a slightly different approach.

The Better ORing diode is a hybrid rectifier consisting of a high speed analog control circuit, 24

Figure 1. Block Diagram of the Better ORing Diode

volt, 4.7 mΩ typical, N-Channel power MOSFET and decoupling capacitor all in one package The MOSFET is operated in the third quadrant, making the the source of the MOSFET the anode and the drain the cathode. Figure 1, illustrates the design of this device.

This device was designed to function as similarly as possible to an actual diode. The comparator senses the polarity of the voltage across the "diode" and turns the FET on when the body diode is forward biased and off when it is reverse biased.

It was necessary to design the comparator with a small offset voltage to keep the device stable. When the current through the diode initially switches to the forward conducting mode, the FET is not on, and the body diode conducts. Figure 2 shows the waveforms for the voltage and current through the FET/body diode.

Since no comparator is perfect, there will always be some offset. If the offset were ever negative, the device would oscillate at low currents. This is due to the fact that the forward voltage across the body diode will always be in the hundreds of millivolts range, but the drop across the FET may only be a few millivolts. If the offset is between these two levels, the device will switch between its off state, in which case the body diode is conducting, and its on state, in which case the voltage drop is the current multiplied by the on resistance of the FET.

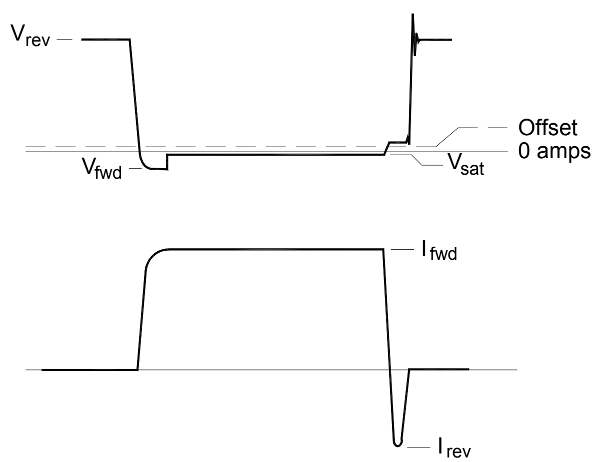

Figure 2. Better ORing Diode Waveforms

The offset voltage was designed to be two millivolts (typical) positive. This assures stable operation, but also increases the propagation delay time of the circuit, since the current has to actually go past zero and into the reverse polarity, before the comparator can respond. The typical current required to trip the comparator will be Voffset/Rds(on) is 0.43 amps.

Typical propagation delays have been measured at 100 ns, with the total time required for the current to recover at 260 ns.

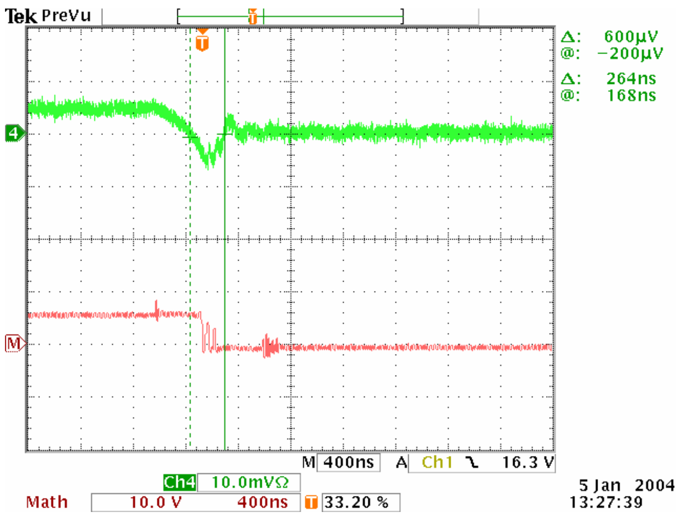

Figure 3. Better ORing Response to a Short Circuit

Figure 3 shows the current through the Better ORing diode in the top trace, on a scale of 1 amp/div, and the gate drive signal on the lower trace. The delay times are measured from the time at which the current drops to zero. The reverse current can be seen to be about 0.5 amps, and lasts for a duration of 260 ns.

The turn off speed of this device was the top priority for the design. This began with the electrical design of the integrated circuit. The comparator, driver and MOSFET were both designed to optimize speed above all else. This included allowing for more shoot-through current in the driver than would normally be allowed. Even with speed being the number one priority, the bias current is only 2 mA when the device is not switching.

After the electrical design was completed, the layout of the die was done such that the high current, high speed paths were as short as possible – especially the output stage of the driver. The package for the die was then designed for optimum speed. Included in this package are the dice for the driver and power FET as well as an internal bypass capacitor. This optimization resulted in a rather unusual footprint for the Better ORing diode.

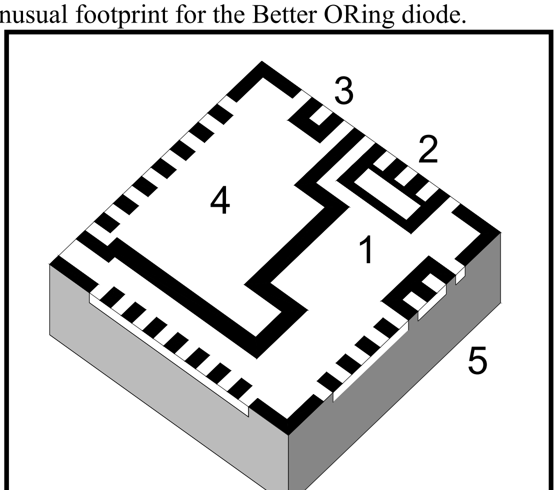

Figure 4. BORing Diode Footprint

Other Solutions

Several other manufacturers have designed solutions using a FET and controller. Company X has a controller that drives an external FET. The advantage of this is that the user can select the FET. The disadvantage is that the impedances between the driver and FET gate are greater, and the switching speed will be slower and more likely to ring at turn off. The signal quality of this type of device is very dependant on the skill of the pcb designer.

The current sense threshold for this part can be as high as 40 mV. This means that if a 4 mΩ FET is used, the reverse current must equal 10 amps before the circuit even begins to turn off.

This device includes an internal charge pump to provide the gate voltage for the n-channel FET. The advertised turn off time for this device is 300 ns. This is from the time that the fault is sensed to the time the gate drive goes low. The time from the beginning of the fault until the current is shut off is of course longer.

Company X's product also includes over and undervoltage sensing and a fault flag to signal an overvoltage, undervoltage or reverse current condition.

Company Y has an integrated solution combining controller and FET. This device has a 2 mΩ internal FET for a very low forward drop. It also has a thermal fault flag and remote voltage sensing.

Test data

A test board was designed to allow all three devices to be tested under nearly identical conditions. One 12 volt power supply was set 50 millivolts above a second 12 volt supply, and then shorted. The diode of the higher source was monitored for its current, which is shown in the following waveforms. Before the event, there is 0.50 amps of load current flowing in the diode. The current probe measured the current in the diode between the short and the load, so that it can be seen going to zero once the diode had turned off.

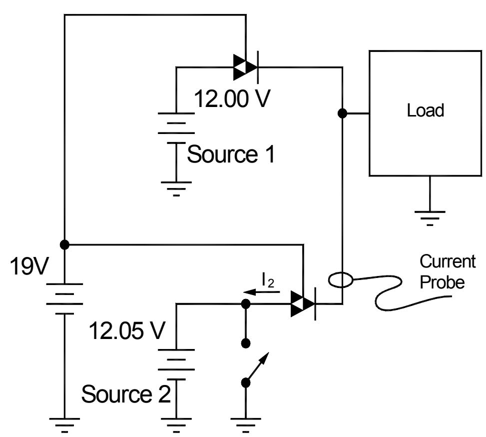

Figure 5. Short Circuit Test Circuit

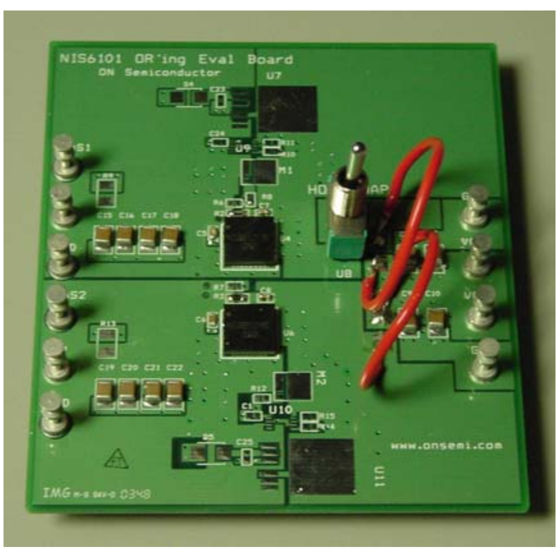

Figure 6. Short Circuit Test Board with Better ORing Diode Mounted.

All photos are shown on the same current and time scales. The gate signal for Company Y's device was not shown, as it is an internal signal.

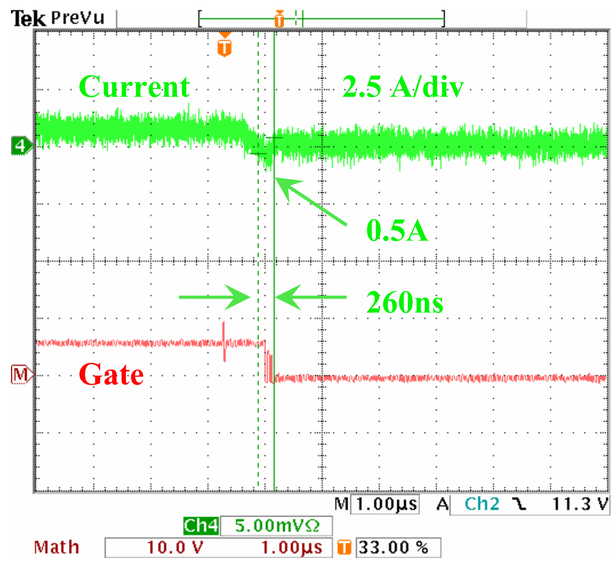

Figure 7. Better ORing Diode Waveforms

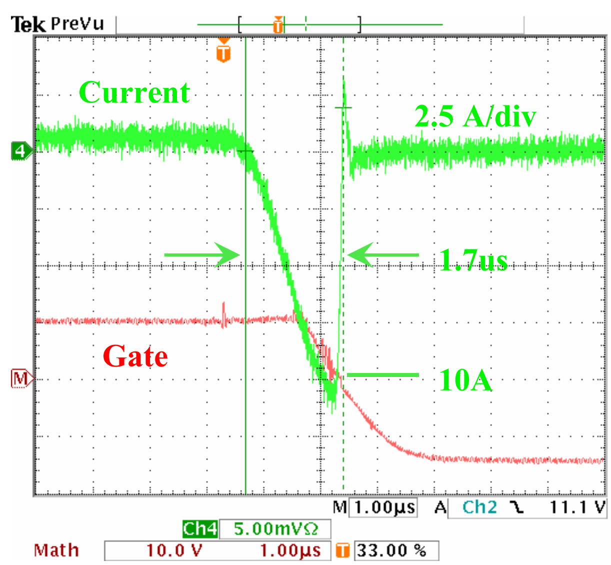

Figure 8. Company X's Waveforms

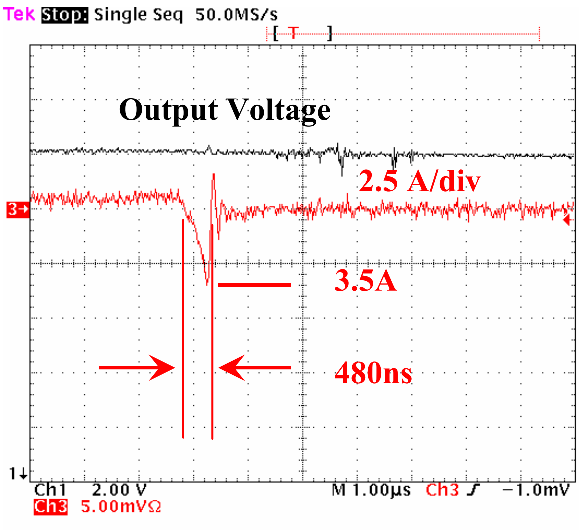

Figure 9. Company Y's Waveforms

Conclusion

While all devices performed the ORing function, there was a significant difference in the speed and magnitude of the reverse current pulse that occurred when the conducting input was shorted. This transient can have a significant effect on the system bus voltage, and in some cases may cause the system to crash if excessive ringing or voltage spikes occur.

Turn off speed is the critical factor in minimizing the disturbance to the bus for a solid state ORing diode. It can make the difference between a robust, reliable system and once that experiences random failures.