

Efficiency Improvements Using 10 Volt Schottky Diodes

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APPLICATION NOTE

ABSTRACT

This application note describes the advantages realized by using 10 volt Schottky diodes in a variety of applications. The major advantage of using a lower voltage Schottky is the reduced forward voltage drop. This lower drop results in a significant increase in efficiency. In addition, one can affect a substantial cost advantage of using a single Schottky diode as opposed to the use of a power FET as a synchronous rectifier.

Lower Forward Voltage Drop

Figure 1 shows the relative improvement in forward voltage drop, V_F , which is made possible by the new 10 volt Schottky technology. The comparison is made to industry typical Schottky diodes using traditional low voltage processes.

It is clear that such a significant improvement can have major impact on the efficiency of many circuit applications.

The typical forward voltage drop of various low voltage Schottky diodes is shown in Table 1. The data is taken from the data sheet of each device [1, 2, 3, 4, 5, 6, 7] at 25°C. A comparison can be made between a 10 volt device and a 20 or 30 volt device. Three surface mount packages are shown, POWERMITE™, SMA, and SMC. The forward voltage drop is presented at five test currents in order to make comparisons.

1. Notice the lower forward voltage drop of a 10 volt device compared to a 20 or 30 volt device.
2. Also notice that in order to obtain a smaller forward voltage drop, a higher current device can be chosen. For example, the 4 Amp device, MBRS410LT3 has a smaller forward voltage drop than the 1 Amp or 2 Amp devices.

All Schottky diodes have a negative temperature coefficient of approximately 1 mV/°C. The forward voltage drop can be as much as 0.100 volts lower at 125°C when compared to the voltage drop at 25°C.

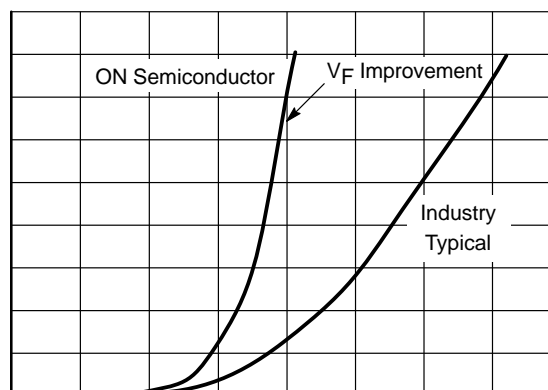


Figure 1. V_F Comparison

Table 1. Forward Voltage for Various Schottky Diodes as a Function of Forward Current, all values are at 25°C

	MBRM110L 1 A 10 V	MBRM120E 1A 20 V	MBRM120L 1 A 20 V	MBRA210L 2 A 10 V	MBRA130L 1 A 30 V	MBRS410L 4 A 10 V	MBRS320 3 A 20 V
Amps	POWERMITE	POWERMITE	POWERMITE	SMA	SMA	SMC	SMC
0.5	0.310	0.470	0.360	0.270	0.320	0.220	0.300
1.0	0.335	0.490	0.380	0.290	0.360	0.240	0.340
2.0	0.370	0.520	0.415	0.310	0.420	0.260	0.415
3.0	0.390	0.540	0.430	0.325	0.460	0.270	0.450
4.0	0.415	0.570	0.460	0.335	0.500	0.280	0.500

OR'ing Diode Applications

In the application shown in Figure 2, a low forward voltage drop part is desired. In this example, it is more cost effective to use a single diode than to use a synchronous rectifier constructed by using a power MOSFET. This can be useful where multiple power supplies are needed for redundancy to improve the mean-time-between-failure (MTBF) for a power supply system.

The current rating of the OR'ing device is often much higher than the current flowing through the device used. As an example, a MBRS410L might be used for applications where only 1.0 Amp of load current is need for the load. This is used only to keep the energy loss to a minimum. The forward voltage drop is approximately 0.24 volts for the MBRS410L at room temperature, as shown by Table 1 above.

If one of the power supplies is a battery, the forward voltage drop is important. The lower the forward voltage drop, the greater the amount of energy available for use as a standby power supply.

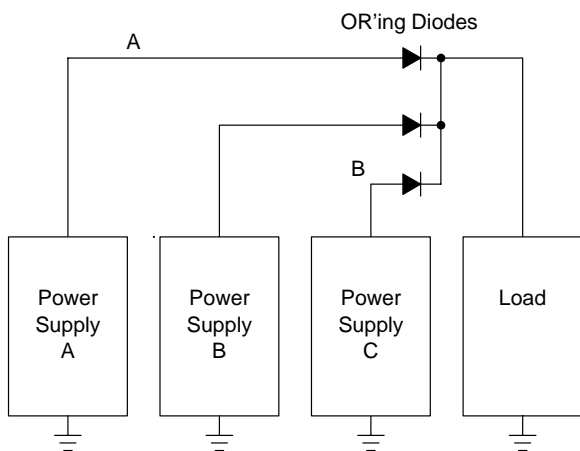


Figure 2. OR'ing Diode Application

Power-Up Sequence Protection

Some microprocessors (MPUs) require multiple power supply voltages like that shown in Figure 3. The reason for the different voltages is because there are different sections within the MPU. The main processor may operate at 1.8 volts; the external memory or memory transfer section may operate at 3.3 volts. There may be external peripherals such as sensors that need to operate at 5.0 volts. Because of this a power-up sequence may be required.

The main purpose of the power-up sequence is to prevent SCR latch up within the MPU. The various sections of the MPU must always be higher than other sections in order to prevent this SCR latching current from flowing. This means the 5.0 V supply must not be less than 2.7 volts (3.3 – 0.6) when the 3.3 volt supply is operational. The same holds for the 3.3 volt, its lower limit is 1.2 volts (1.8 – 0.6) when the 1.8 volt supply is functioning.

If there is a problem with the 5.0 volt and 3.3 volt sections, there may be a requirement to keep both of these (3.3 V and 5.0 V) above the 1.2 volt level to prevent damage and in addition preventing a SCR latch up condition. A Schottky diode will be required for each supply where the forward voltage drop would be less than 0.30 to 0.35 volts. The diagram is shown in Figure 3. A perfect part for this type of application is the MBRA210L, which is in a SMA package. The MBRA210L exhibits a typical forward voltage drop of 0.27 volts at 1.0 Amp, as shown in Table 1 above.

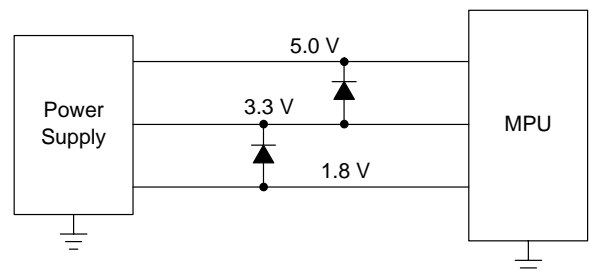


Figure 3. Power-Up Sequence Protection

Diodes for Reverse Battery Protection

Another application where a low voltage diode is often desired is reverse battery protection. This is shown in Figure 4. In many consumer type products there can be 3, 4, or 6 AA, or AAA batteries in series.

In order to prevent damage to the electronic circuits inside the product, a series diode, like a 1N4004 [8], is used. This device has a typical forward voltage drop of 0.9 volts at 1.0 Amps.

If the batteries are alkaline, the terminal cell voltage can be between 1.4 volts and 1.65 volts depending upon the state of charge and current draw. Using a 1.5 volt cell, the ratio of 0.9/1.5 indicates that 60 percent of one cell's voltage is used to overcome the protection diode. In a typical application where there are 4 alkaline cells, the ratio of forward diode voltage to battery voltage is between 13.64 and 16 percent: $(0.9 / (4 * 1.65)) = 0.1364$ or 13.64% or $(0.9 / (4 * 1.40)) = 0.16$ or 16%

Instead of using a 1N4004 diode, substitute a 1 Amp low voltage Schottky in a surface mount POWERMITE package or a 2 Amp in a surface mount SMA package. The burden voltage of the MBRM110L is only 0.335 volts, which is a 62.8 percent reduction, $(0.9 - 0.335 / 0.9 = 0.628)$ over a 1N4004 diode. Using the MBRA210L at 0.290 volts, which is in a SMA package, the percentage gain is even higher at 67.8 percent, $(0.9 - 0.29 / 0.9 = 0.678)$ over the industry standard 1N4004 rectifier.

The burden voltage is very critical if the batteries are nickel cadmium (NiCd) or nickel metal hydride (NiMH). There are many cordless phones that have three batteries in series. The use of a MBRA210L can provide protection and not be a major burden on the battery voltage needed for phone operation.

The forward voltage drop can be reduced further by using the 4 Amp Schottky, (MBRS410L), which has a forward voltage drop of only 0.240 volts at 1.0 Amp.

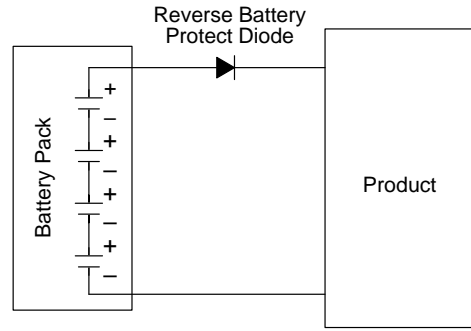


Figure 4. Reverse Battery Protection

DC to DC Converters

Another application where the use of low voltage Schottky diodes improves efficiency is the DC to DC converter circuit. In portable type products where a multiple cell NiCd, NiMH, or a dual cell lithium ion (Li+) rechargeable battery pack is used as a power source, a buck regulator can produce output voltages such as 1.5 volts, 2.2 volts, or even 3.3 volts. A buck regulator can be very efficient. An alternative method of obtaining 1.8, 2.2 or 3.3 volts at the output is to use a linear regulator, but this is very inefficient. When implementing the CS51411 as a buck regulator and using different Schottky rectifiers, it can be shown that the lower the forward voltage drop of the catch diode, the greater the efficiency of the buck regulator. Such a schematic is shown in Figure 5.

Figure 5 is a modified schematic shown in the data sheet [9], and demo board, CS51411DEMO/D [10]. Several changes were made to the demo board circuit to improve circuit operation. First, the 1N4148 diode was replaced with a MBRM130L. This was done to lower the line-conducted noise, electromagnetic interference (EMI). The 1N4148 is a signal diode that has a reverse recovery time. The recovery time is a source of EMI noise between 10 MHz and 30 MHz in many switching power supplies.

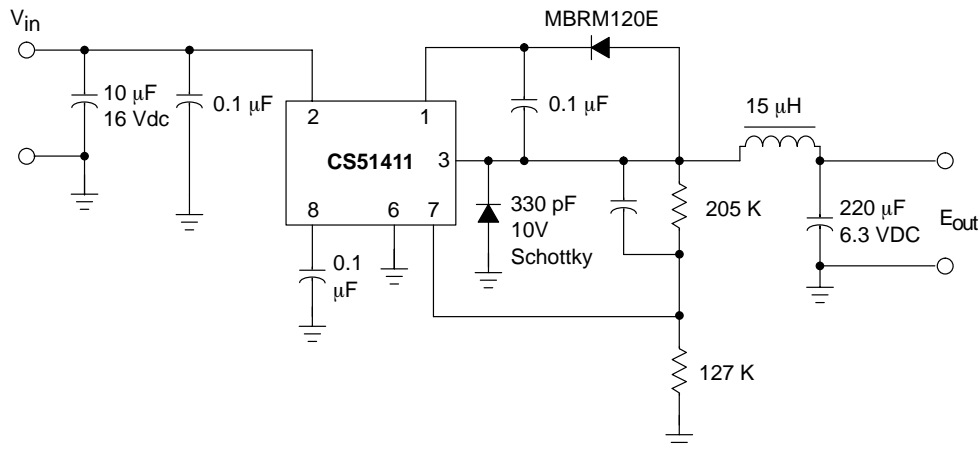


Figure 5. CS51411 Buck Regulator Circuit

To show where the losses are in a buck regulator, Figure 6 is used to write equations. These equations are solved for the effect of the forward voltage drop, V_f , on the efficiency of the system.

Using Figure 6, two voltage loop equations are written using Kirchoff's voltage law. The first loop is written during the switch conduction time, t_1 . The second loop equation is written during the diode conduction time. These equations are found in various power electronic test books and application notes [11, 12, 12].

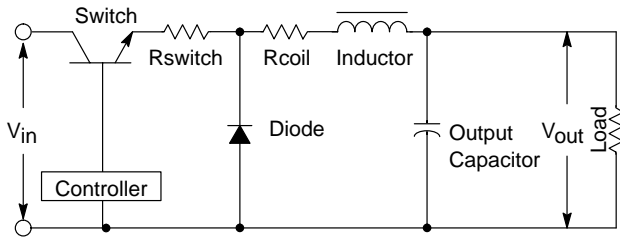


Figure 6. Simple Buck Regulator

During the switch 'On-time' or Δt_1 period.

$$V_{IN} = V_S + V_{RS} + L \frac{\Delta i}{\Delta t_1} + V_O \quad (\text{eq. 1})$$

- V_S = Saturation voltage of the switch
- V_{RC} = Voltage due to inductor resistance, Load current X R_{coil}
- V_{IN} = Input voltage
- V_O = Output voltage under regulation
- Δt_1 = On-time of the power switch
- Δi = Change in inductor current

During the switch 'Off-time' or Δt_2 period.

$$0 = -L \frac{\Delta i}{\Delta t_2} + V_{RC} + V_O + V_f \quad (\text{eq. 2})$$

- Δt_2 = Off-time or diode conduction time
- V_f = Forward voltage drop of the diode

In some text, V_d is used in place of V_f to describe the forward voltage drop of the diode.

Equating the two equations using $L\Delta i$ as the common item results in Equation 3, 4 and 5.

$$(V_{IN} - V_S - V_{RS} - V_O)\Delta t_1 = L\Delta i \quad (\text{eq. 3})$$

$$(V_O + V_{RC} + V_f)\Delta t_2 = L\Delta i \quad (\text{eq. 4})$$

$$(V_{IN} - V_S - V_{RS} - V_O)\Delta t_1 = (V_O + V_f + V_{RC})\Delta t_2 \quad (\text{eq. 5})$$

$$\frac{\Delta t_1}{\Delta t_1 + \Delta t_2} = \delta = \text{duty cycle} \quad (\text{eq. 6})$$

$$\frac{\Delta t_1}{\Delta t_1 + \Delta t_2} = 1 - \delta \quad (\text{eq. 7})$$

$$\delta = \frac{V_O + V_{RC} + V_f}{V_{IN} - V_S + V_f} \quad (\text{eq. 8})$$

Once the duty cycle or duty factor, δ , is determined; the loss calculation and efficiency calculations can be made. An assumption is made that this is a continuous duty inductor current system. The load current has an effective DC value and is constant. The Δi terms are very small and not considered for a first order approximation. The efficiency is calculated by using Equation 9.

$$\eta = \frac{W_{OUT}}{W_{OUT} + W_{LOSSES}} \quad (\text{eq. 9})$$

$$W_{LOSSES} = V_S I_O \delta + V_f I_O (1 - \delta) + I_O^2 R_C \quad (\text{eq. 10})$$

$$W_{OUT} = V_O I_O \quad (\text{eq. 11})$$

$$V_S = I_O R_D S - O_N \quad (\text{eq. 12})$$

$$\eta = \frac{V_O I_O}{V_O I_O + V_S I_O \delta + V_f I_O (1 - \delta) + I_O R_C I_O} \quad (\text{eq. 13})$$

The load current term, I_O , cancels for a first order approximation that results in Equation 14.

$$\eta = \frac{V_O}{V_O + V_S \delta + V_f (1 - \delta) + I_O R_C} \quad (\text{eq. 14})$$

The last term, $I_O R_C$, is small and can be eliminated for a first order approximation. When η is plotted for various outputs and for various diodes, the efficiency depends upon several factors, switch voltage (V_S) and diode voltage (V_d). To show the effect of the diode voltage drop, the efficiency is plotted using the CS51411, for two outputs, 1.8 and 3.3 volts. This efficiency plot is shown in Figure 7.

The output rectifier is changed from a 20 or 30 volt Schottky to a 10 volt Schottky for each output. Taking only one input voltage point, 7 volts, a comparison is made between the use of the 10 volt Schottky diode to that of the 30 volt Schottky. The 10 volt Schottky produces 5 percent improvement in efficiency when the output is 1.8 volts. The improvement is just over 2 percent with a 3.3 volt output is needed.

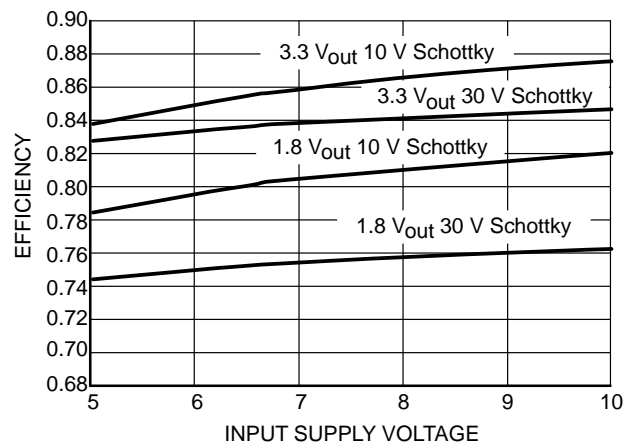


Figure 7. Buck Regulator Circuit Efficiency Using CS51411 with Various Schottky Diodes


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Notes

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