

# Non-RF Applications for the Surface Mount Schottky Diode Pairs HSMS-2802 and HSMS-2822

## Application Note 1069

### Introduction

Schottky diodes, based on silicon or gallium arsenide substrates, are used in many receiver and transmitter circuits for mixing and detecting at frequencies up to 100 GHz.

Today, advanced wafer and packaging processes allow Hewlett-Packard to manufacture low cost surface mount Schottky diodes in high volumes for commercial and consumer applications. Traditionally many of these diodes are used for mixing and power monitoring in RF applications such as mobile and cordless phones, satellite television receivers, RFID (radio frequency identification) systems and many others. However, an increasing number of these diodes are also used in digital and non-RF applications such as the speed-up of transistor, optocoupler and operational amplifier circuits, over-voltage protection, clipping, and clamping.

### Schottky Diode Fundamentals

The Schottky diode is a rectifying metal-semiconductor contact formed between a metal and an n-doped or p-doped semiconductor. When a metal-semiconductor junction

is formed, free electrons flow across the junction from the semiconductor and fill the free-energy states in the metal. This flow of electrons builds a depletion potential across the junction. The difference in energy levels between semiconductor and metal is called a Schottky barrier.

P-doped Schottky barrier diodes excel at applications requiring ultra low turn-on voltage (such as zero biased RF detectors), but their very low breakdown voltage and high series resistance make

them unsuitable for the applications discussed in this note. As a result, we will focus entirely on n-doped Schottky diodes.

Under forward bias (metal connected to positive in an n-doped Schottky), there are many electrons with enough thermal energy to cross the barrier potential into the metal. Once the applied bias exceeds the built-in potential of the junction the forward current  $I_f$  will increase rapidly with increase in  $V_f$ . See Figure 1.

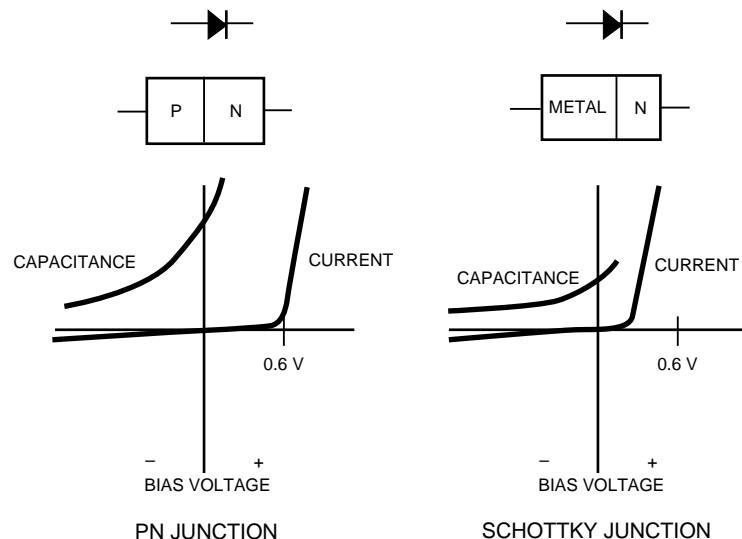


Figure 1.

When the Schottky diode is reversed biased, the potential barrier for electrons becomes large: hence there is a small probability that an electron will have sufficient thermal energy to cross the junction. The reverse leakage current will be in the nanoampere range.

In contrast to a conventional p-n junction, current in the Schottky diode is carried only by majority carriers. Because no minority carrier charge storage effects are present, Schottky diodes have carrier lifetimes of less than 100 ps and are extremely fast switching semiconductors.

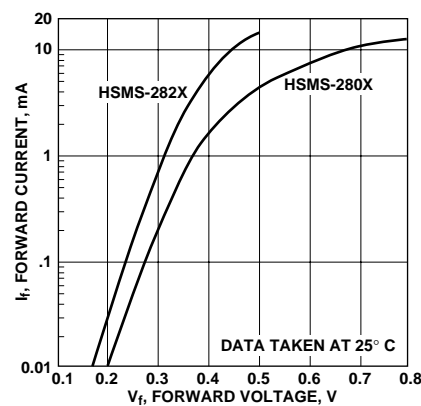
Another significant difference between Schottky and p-n diodes is the forward voltage drop. Schottky diodes have a threshold of typically 0.3 V compared to 0.6 V of p-n junction diodes. See Figure 1.

Through the careful manipulation of the diameter of the Schottky contact and the choice of metal deposited on the n-doped silicon, important characteristics of the diode (junction capacitance  $C_j$ , parasitic series resistance  $R_s$ , breakdown voltage  $V_{br}$  and forward voltage  $V_f$ ) can be tailored to specific applications. The HSMS-2800 series and HSMS-2820 series of diodes are a case in point, as is illustrated by their SPICE [1] parameters. See Table 1.

The differences in these two lines of Schottky diodes can also be seen by examining their forward characteristics, as shown in Figure 2.

**Table 1.**

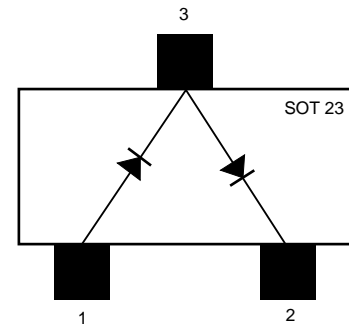
Parameter	HSMS-280X	HSMS-282X
$C_{jO}$	1.6	0.7
$V_{br}$	75	9
$R_s$	30	5
$E_G$	0.69	0.69
$I_{BV}$	10.0E-5	10.0E-4
$I_S$	3.0E-8	2.2E-8
N	1.08	1.08
$P_B$	0.65	0.56
$P_T$	2	2
M	0.5	0.5



**Figure 2. Forward Current vs. Forward Voltage.**

It can be seen that, at low levels of forward current, the forward voltage of the HSMS-282X diode is lower than that for the HSMS-280X. This is due to the lower barrier height of the former. At high values of forward current,  $V_f$  is lower for the HSMS-282X because of its lower  $R_s$ . The tradeoff, however, is a lower value of  $V_{br}$  for the HSMS-282X. Thus, the circuit designer has a choice of Schottky diode characteristics with which to optimize his circuit.

When the last digit of the part number of a Hewlett-Packard



PART NUMBER	TYPE
HSMS-2802	n
HSMS-2812	n
HSMS-2822	n
HSMS-2852	p*
HSMS-8202	n*

\*NOTE THAT POLARITY OF THE DIODES IS THE OPPOSITE SHOWN IN THE DIAGRAM.

**Figure 3.**

surface mount Schottky diode is 2, this indicates that the product is a series pair of diodes in a SOT-23 package. See Figure 3.

Because the automatic pick-and-place equipment used to assemble these products selects dice from adjacent sites on the wafer, the two diodes which go into the HSMS-XXX2 product are closely matched without the expense of testing. It is the HSMS-2802 and HSMS-2822 diode pairs which are discussed in the following sections.

## Clipping Circuits

### Waveform Clipping

Illustrated in Figure 4 is a basic diode clipping circuit and its output waveform in response to a sinusoidal input. While the instantaneous value of the input voltage is less than the sum of the reference voltage  $V_{ref}$  and the diode turn-on voltage  $V_f$ , the diode is reverse-biased off, and the output waveform follows the input. When

[1] Hewlett-Packard Communication Components *Designer's Catalog*, Application Design Tools chapter.

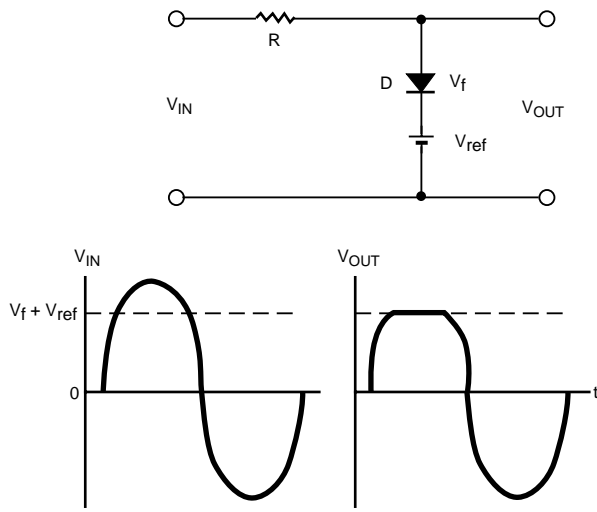


Figure 4.

the input voltage becomes equal to or greater than  $V_{ref} + V_f$ , the corresponding output waveform exhibits clipping of the positive peak above the voltage  $V_{ref} + V_f$ . The flatness of this clipped portion is dependent upon the degree that the forward biased resistance  $R_d$  is less than the circuit resistance  $R$ , where  $R_d$  is the dynamic resistance of the diode.

### Sine Wave to Square Wave Conversion

Double ended clipping (known as limiting) of signal waveforms can be accomplished with the use of a pair of diode clippers in a parallel series configuration shown in Figure 5. The use of the HSMS-28X2 Schottky diode series pair in the SOT-23 plastic package helps to reduce the circuit layout size. If  $V_{ref1}$  is made equal to  $V_{ref2}$  and the amplitude of the sinusoidal input is sufficiently high, the output waveform will approach that of a square wave. This application represents in essence sine wave to square wave conversion.

### Diode Requirements for Clipping Circuits

In clipping or limiting circuits, the

forward bias diode resistance  $R_f$  must be much less than the circuit resistance  $R$  in order to maintain the flatness of the clipped portion of the waveform. The reverse bias resistance of the diode,  $R_r$ , must be much larger than  $R$  to avoid loading the circuit and distorting the waveform. These requirements are important in providing precise voltage reference in the circuits shown in Figures 4 and 5. Thus, the ratio of  $R_f / R_r$  can serve as a figure of merit for a clipping diode. The larger the ratio, the better the performance.

The low turn-on voltage of the HSMS-2800 series Schottky barrier diodes (particularly the HSMS-282x family) allows clipping and clamping closely to the desired reference level. The HSMS-280x family Schottky diodes has a high minimum breakdown voltage of 70 V and is suited for high voltage applications.

### Voltage Protection of CMOS Gates

CMOS gates have a very high input resistance (typ. 50 M $\Omega$ ) and a low output resistance of approxi-

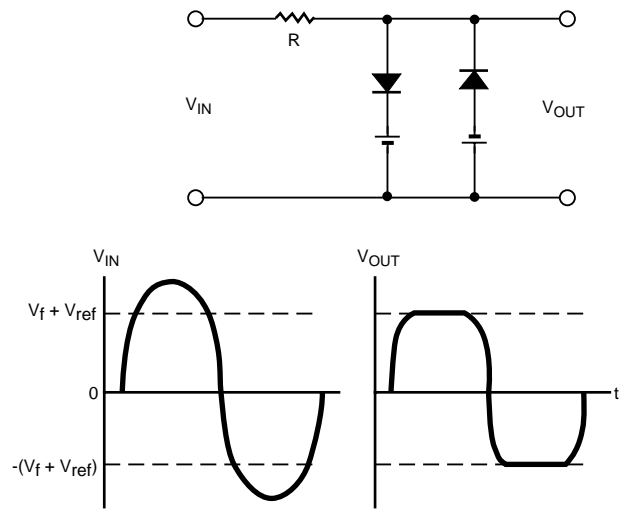
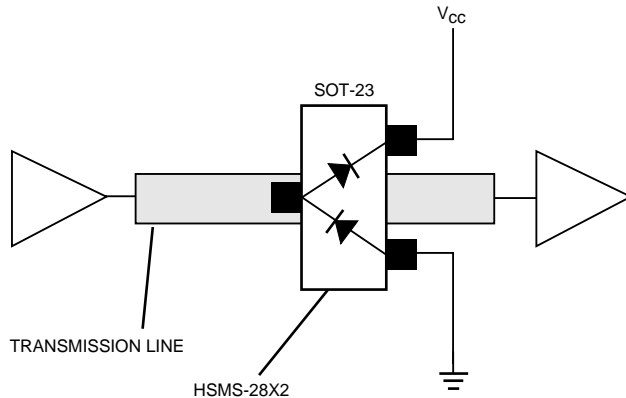


Figure 5.

mately 50  $\Omega$ . When an output gate is connected to an input gate using a microstrip transmission line, the line is terminated by the high input resistance of the input gate, thus it can be considered as “open”. Due to the open transmission line a rising or falling signal will overshoot and can exceed the maximum or minimum allowed voltages (JEDEC) of the input gate. Usually “built-in” Schottky diodes are used to limit the input signal to  $V_{cc} + 0.5$  V and -0.5 V because of its low turn-on voltage.

Quite often the “built-in” ESD protection diodes are too slow and connected via a resistor to the input pin of the integrated circuit. Therefore, external Schottky diodes connected to the power supply and ground line as shown in Figure 6 are necessary to provide a “dynamic” termination to the transmission line to clip the input signal below the JEDEC specification. It has been proved that the HSMS-2822 series configuration Schottky diode pair in the SOT-23 package, with its low turn-on voltage and fast switching response, is the best solution for such application.



**Figure 6.**

### Protection and Improving Performance of Operational Amplifiers

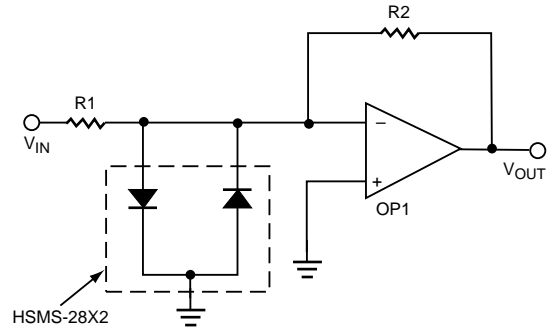
Operational amplifier input overload, which can occur in the form of excessive common-mode or differential voltages, can result in a voltage breakdown that will damage or destroy the input transistors of the device.

#### Amplifier Protection

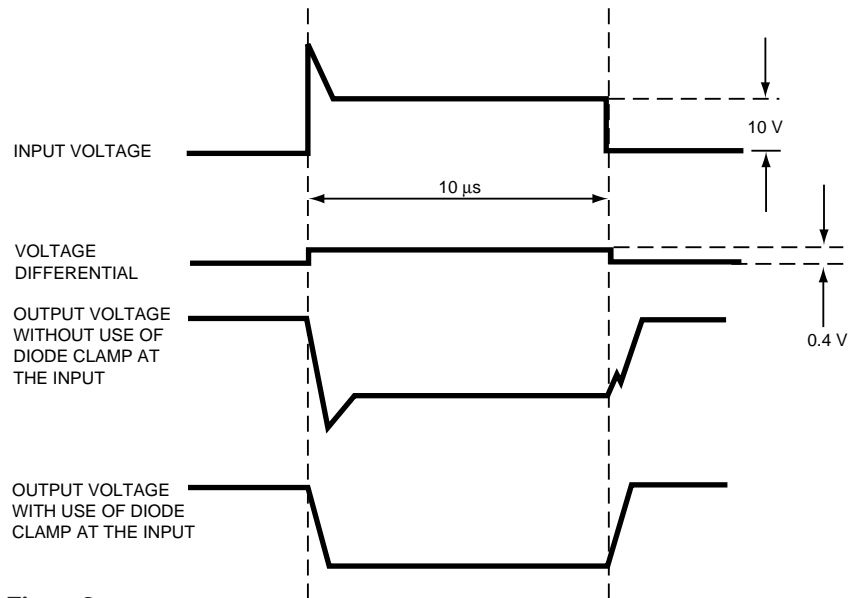
Protection of an operational amplifier from high input voltages can be achieved by using a series diode (HSMS-28X2) as shown in Figure 7. The diodes limit the voltages at the input to the operational amplifier to safe levels (approx. 0.4 V) without restricting the signal swing.

#### Settling Time Speedup

An important consideration for operational amplifier performance in high speed applications is settling time. Settling time is the total time needed for the output to slew through a specified voltage change and settle to the final voltage within a prescribed percentage error. A typical operational amplifier includes a differential amplifier stage at the input followed by an integrating circuit. The differential amplifier stage and the external feedback circuit help to reduce the differential volt-



**Figure 7.**



**Figure 8.**

age,  $V_3 - V_2$ . Since the integration circuit typically has a slow response time, it cannot respond to fast input spikes, thus resulting in ringing in the output signal and delays in the settling time.

With the addition of the Schottky clamp, the fast spikes are limited to the turn-on voltage of the Schottky diode shown in Figure 8. This also results in a reduction in settling time.

#### Conclusion

The HSMS-2802 and HSMS-2822 Schottky diode pairs have been described and shown to be an ex-

cellent choice for a variety of non-RF applications. For further information, contact your local Hewlett-Packard sales office.

#### [www.hp.com/go/rf](http://www.hp.com/go/rf)

For technical assistance or the location of your nearest Hewlett-Packard sales office, distributor or representative call:

**Americas/Canada:** 1-800-235-0312 or (408) 654-8675

**Far East/Australasia:** Call your local HP sales office.

**Japan:** (81 3) 3335-8152

**Europe:** Call your local HP sales office.

Data Subject to Change

Copyright © 1998 Hewlett-Packard Co.

Printed in U.S.A. 5962-9465E (2/98)