HEWLETT PACKARD

Surface Mount RF Schottky Detector Diodes in SOT-363 (SC-70, 6 Lead)

Technical Data

HSMS-285L/P
HSMS-286L/P/R

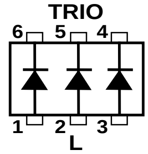
Features

- **Surface Mount SOT-363 Package**
- **High Detection Sensitivity:**
  Up to 50 mV/µW at 915 MHz
  Up to 35 mV/µW at 2.45 GHz
  Up to 25 mV/µW at 5.80 GHz
- **Low Flicker Noise:**
  -162 dBV/Hz at 100 Hz
- **Low FIT (Failure in Time) Rate***
- **Tape and Reel Options Available**

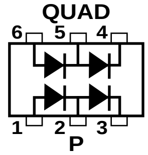
* For more information see the Surface Mount Schottky Reliability Data Sheet.

Package Lead Code Identification (Top View)

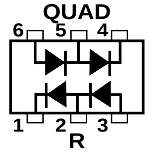
UNCONNECTED TRIO



BRIDGE QUAD



RING QUAD



Description

Hewlett-Packard's HSMS-285L/P family of zero bias Schottky detector diodes and the HSMS-286L/P/R family of DC biased detector diodes have been designed and optimized for use from 915 MHz to 5.8 GHz. They are ideal for RF/ID and RF Tag, cellular and other consumer applications requiring small and large signal detection, modulation, RF to DC conversion or voltage doubling.

Available in various package configurations, these two families of detector diodes provide low cost solutions to a wide variety of design problems. Hewlett-Packard's manufacturing techniques assure that when multiple diodes are mounted into a single SOT-363 package, they are taken from adjacent sites on the wafer, assuring the highest possible degree of match.

DC Electrical Specifications, T_C = +25°C, Single Diode

Part Number HSMS-	Package Marking Code[1]	Lead Code	Configuration	Maximum Forward Voltage V_F (mV)		Typical Capacitance C_T (pF)
285L 285P	PL PP	L P	Unconnected Trio Bridge Quad	150	250	0.30
286L 286P 286R	TL TP ZZ	L P R	Unconnected Trio Bridge Quad Ring Quad	250	350	0.25
Test Conditions				I_F = 0.1 mA[2]	I_F = 1.0 mA[2]	V_R = 0.5 V to -1.0 V f = 1 MHz[3]

Notes:
1. Package marking code is laser marked.
2. ΔV_F for diodes in trios and quads is 15.0 mV maximum at 1.0 mA.
3. ΔC_T for diodes in trios and quads is 0.05 pF maximum at -0.5 V.

RF Electrical Parameters, T_C = +25°C, Single Diode

Part Number HSMS-	Typical Tangential Sensitivity TSS (dBm) @ f =			Typical Voltage Sensitivity γ (mV/μW) @ f =			Typical Video Resistance R_V (KΩ)
	915 MHz	2.45 GHz	5.8 GHz	915 MHz	2.45 GHz	5.8 GHz	
285L 285P	-57	-56	-55	40	30	22	8.0
Test Conditions	Video Bandwidth = 2 MHz Zero Bias			Power in = -40 dBm R_L = 100 KΩ, Zero Bias			
286L 286P 286R	-57	-56	-55	50	35	25	5.0
Test Conditions	Video Bandwidth = 2 MHz I_b = 5 μA			Power in = –40 dBm R_L = 100 KΩ, I_b = 5 μA			

Absolute Maximum Ratings, T_C = 25°C, Single Diode

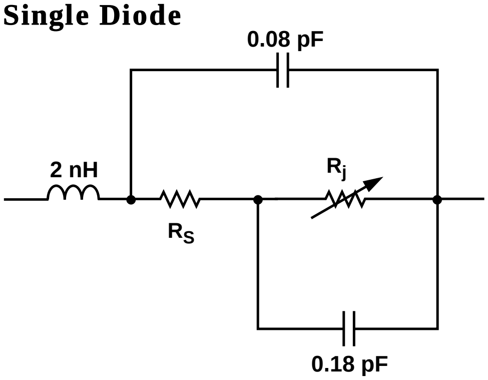
Symbol	Parameter	Unit	Absolute Maximum[1]
P_{IV}	Peak Inverse Voltage	V	2.0
T_J	Junction Temperature	°C	150
T_{STG}	Storage Temperature	°C	-65 to 150
T_{OP}	Operating Temperature	°C	-65 to 150
θ_{jc}	Thermal Resistance[2]	°C/W	140

Notes:
1. Operation in excess of any one of these conditions may result in permanent damage to the device.
2. T_C = +25°C, where T_C is defined to be the temperature at the package pins where contact is made to the circuit board.

***ESD WARNING:* Handling Precautions Should Be Taken To Avoid Static Discharge.**

Equivalent Circuit Model

HSMS-285A Series, HSMS-286A Series Single Diode



R_S = series resistance (see Table of SPICE parameters)

$$R_j = \frac{8.33 \times 10^{-5}\, nT}{I_b + I_s}$$

where
I_b = externally applied bias current in amps
I_S = saturation current (see table of SPICE parameters)
T = temperature, °K
n = identity factor (see table of SPICE parameters)

SPICE Parameters

Parameter	Units	HSMS-285A	HSMS-286A
B_V	V	3.8	7.0
C_{JO}	pF	0.18	0.18
E_G	eV	0.69	0.69
I_{BV}	A	3 x 10E-4	10E-5
I_S	A	3 x 10E-6	5 x 10E-8
N		1.06	1.08
R_S	Ω	25	5.0
P_B (V_J)	V	0.35	0.65
P_T (XTI)		2	2
M		0.5	0.5

Typical Parameters, Single Diode

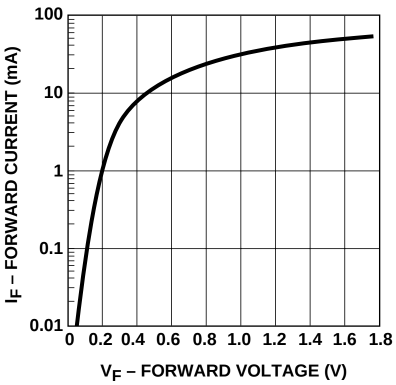


Figure 1. +25°C Forward Current vs. Forward Voltage, HSMS-285A Series.

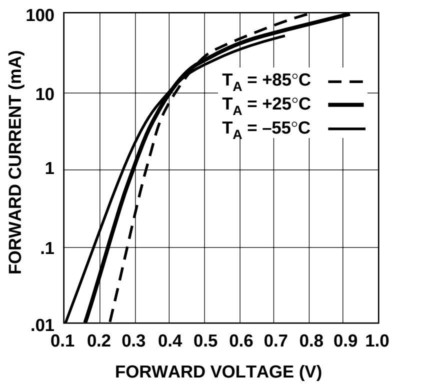


Figure 2. Forward Current vs. Forward Voltage at Temperature, HSMS-286A Series.

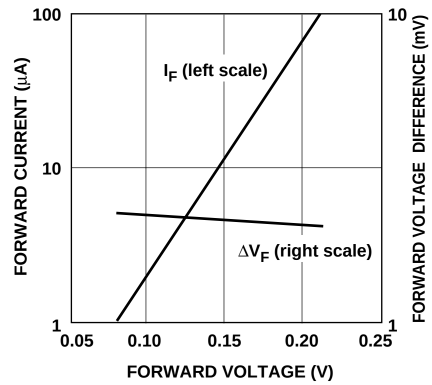


Figure 3. Forward Voltage Match, HSMS-286A Series.

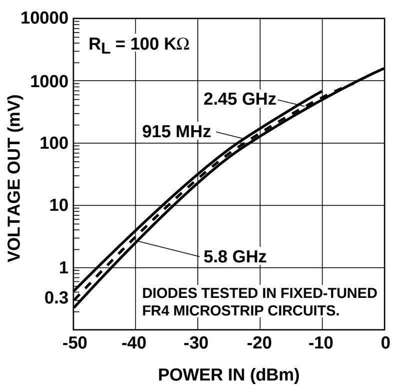


Figure 4. +25°C Output Voltage vs. Input Power, HSMS-285A Series at Zero Bias, HSMS-286A Series at 3 µA Bias.

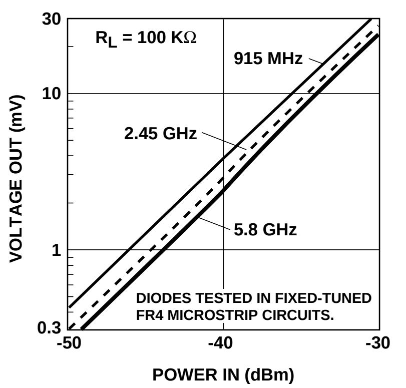


Figure 5. +25°C Expanded Output Voltage vs. Input Power. See Figure 4.

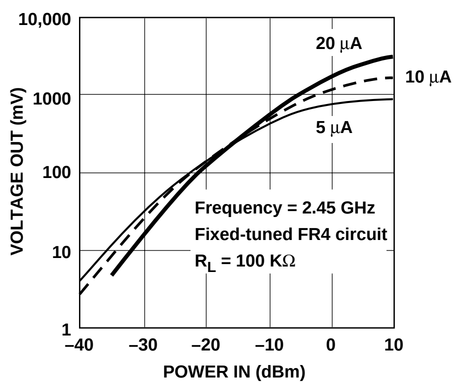


Figure 6. Dynamic Transfer Characteristic as a Function of DC Bias, HSMS-286A.

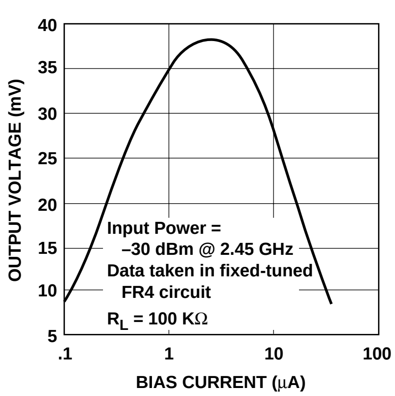


Figure 7. Voltage Sensitivity as a Function of DC Bias Current, HSMS-286A.

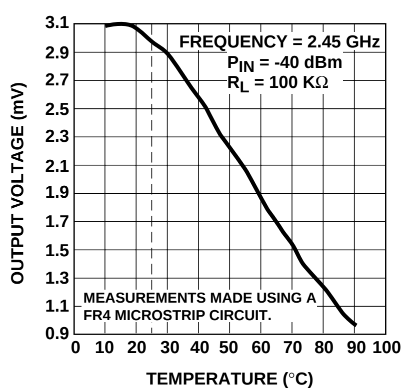


Figure 8. Output Voltage vs. Temperature, HSMS-285A Series.

Applications Information

Introduction

Hewlett-Packard's HSMS-285L and HSMS-285P zero bias Schottky diodes have been developed specifically for low cost, high volume detector applications where bias current is not available. The HSMS-286L, HSMS-286P and HSMS-286R DC biased Schottky diodes have been developed for low cost, high volume detector applications where stability over temperature is an important design consideration.

Schottky Barrier Diode Characteristics

Stripped of its package, a Schottky barrier diode chip consists of a metal-semiconductor barrier formed by deposition of a metal layer on a semiconductor. The most common of several different types, the passivated diode, is shown in Figure 9, along with its equivalent circuit.

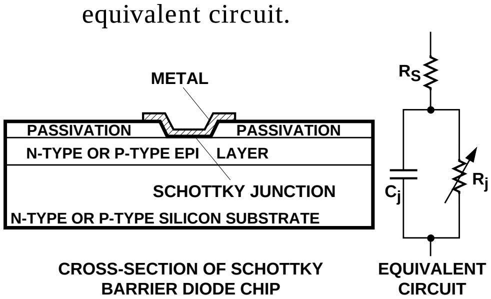


Figure 9. Schottky Diode Chip.

R_S is the parasitic series resistance of the diode, the sum of the bondwire and leadframe resistance, the resistance of the bulk layer of silicon, etc. RF energy coupled into R_S is lost as heat—it does not contribute to the rectified output of the diode. C_J is parasitic junction capacitance of the diode, controlled by the thickness of the epitaxial layer and the diameter of the Schottky contact. R_j is the junction resistance of the diode, a function of the total current flowing through it.

$$R_j = \frac{8.33 \times 10^{-5}\, n\, T}{I_S + I_b} = R_V - R_s$$

$$= \frac{0.026}{I_S + I_b} \text{ at } 25°C$$

where

n = ideality factor (see table of SPICE parameters)

T = temperature in °K

I_S = saturation current (see table of SPICE parameters)

I_b = externally applied bias current in amps

I_S is a function of diode barrier height, and can range from picoamps for high barrier diodes to as much as 5 µA for very low barrier diodes.

The Height of the Schottky Barrier

The current-voltage characteristic of a Schottky barrier diode at room temperature is described by the following equation:

$$I = I_S \left(e^{\left(\frac{V - IR_S}{0.026}\right)} - 1\right)$$

On a semi-log plot (as shown in the HP catalog) the current graph will be a straight line with inverse slope 2.3 x 0.026 = 0.060 volts per cycle (until the effect of R_S is seen in a curve that droops at high current). All Schottky diode curves have the same slope, but not necessarily the same value of current for a given voltage. This is determined by the saturation current, I_S, and is related to the barrier height of the diode.

Through the choice of p-type or n-type silicon, and the selection of metal, one can tailor the characteristics of a Schottky diode. Barrier height will be altered, and at the same time C_J and R_S will be changed. In general, very low barrier height diodes (with high values of I_S, suitable for zero bias applications) are realized on p-type silicon. Such diodes suffer from higher values of R_S than do the n-type. Thus, p-type diodes are generally reserved for detector applications (where very high values of R_V swamp out high R_S) and n-type diodes are used for mixer applications (where high L.O. drive levels keep R_V low).

Measuring Diode Linear Parameters

The measurement of the five elements which make up the equivalent circuit for a packaged Schottky diode (see Figure 10) is a complex task. Various techniques are used for each element. The task begins with the elements of the diode chip itself.

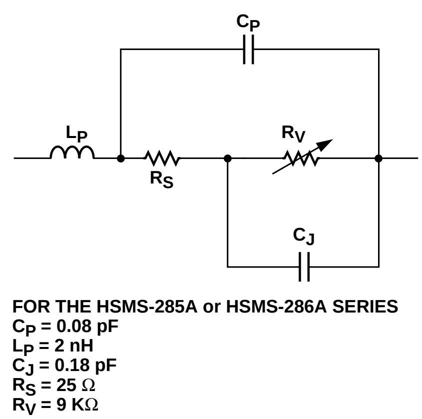


Figure 10. Equivalent Circuit of a Schottky Diode.

R_S is perhaps the easiest to measure accurately. The V-I curve is measured for the diode under forward bias, and the slope of the curve is taken at some relatively high value of current (such as 5 mA). This slope is converted into a resistance R_d.

$$R_S = R_d - \frac{0.026}{I_f}$$

R_V and C_J are very difficult to measure. Consider the impedance of C_J = 0.16 pF when measured at 1 MHz — it is approximately 1 MΩ. For a well designed zero bias Schottky, R_V is in the range of 5 to 25 KΩ, and it shorts out the junction capacitance. Moving up to a higher frequency enables the measurement of the capacitance, but it then shorts out the video resistance. The best measurement technique is to mount the diode in series in a 50 Ω microstrip test circuit and measure its insertion loss at low power levels (around -20 dBm) using an HP8753C network analyzer. The resulting display will appear as shown in Figure 11.

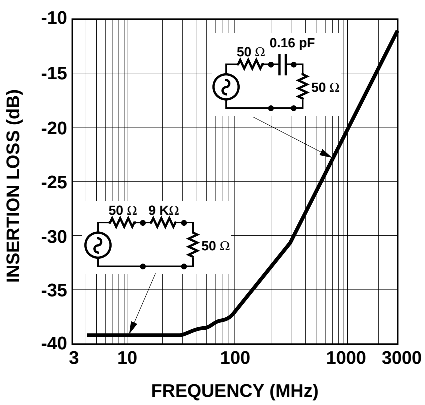


Figure 11. Measuring C_J and R_V.

At frequencies below 10 MHz, the video resistance dominates the loss and can easily be calculated from it. At frequencies above 300 MHz, the junction capacitance sets the loss, which plots out as a straight line when frequency is plotted on a log scale. Again, calculation is straightforward.

L_P and C_P are best measured on the HP8753C, with the diode terminating a 50 Ω line on the input port. The resulting tabulation of S_{11} can be put into a microwave linear analysis program having the five element equivalent circuit with R_V, C_J and R_S fixed. The optimizer can then adjust the values of L_P and C_P until the calculated S_{11} matches the measured values. Note that extreme care must be taken to de-embed the parasitics of the 50 Ω test fixture.

Detector Circuits

When DC bias is available, Schottky diode detector circuits can be used to create low cost RF and microwave receivers with a sensitivity of -55 dBm to -57 dBm.[1] Moreover, since external DC bias sets the video impedance of such circuits, they display classic square law response over a wide range of input power levels[2,3]. These circuits can take a variety of forms, but in the most simple case they appear as shown in Figure 12. This is the basic detector circuit used with the HSMS-286X family of diodes.

Where DC bias is not available, a zero bias Schottky diode is used to replace the conventional Schottky in these circuits, and bias choke L_1 is eliminated. The circuit then is reduced to a diode, an RF impedance matching network and (if required) a DC return choke and a capacitor. This is the basic detector circuit used with the HSMS-285A family of diodes.

Output voltage can be virtually doubled and input impedance (normally very high) can be halved through the use of the voltage doubler circuit[4].

In the design of such detector circuits, the starting point is the equivalent circuit of the diode, as shown in Figure 10. Of interest in the design of the video portion of the circuit is the diode's video impedance—the other four elements of the equivalent circuit disappear at all reasonable video frequencies. In general, the lower the diode's video impedance, the better the design.

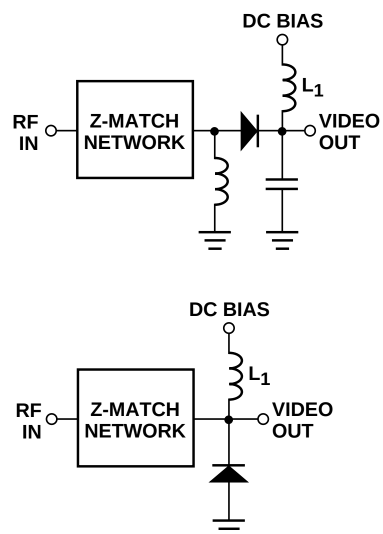


Figure 12. Basic Detector Circuits.

The situation is somewhat more complicated in the design of the RF impedance matching network, which includes the package inductance and capacitance (which can be tuned out), the series resistance, the junction

[1] Hewlett-Packard Application Note 923, *Schottky Barrier Diode Video Detectors.*
[2] Hewlett-Packard Application Note 986, *Square Law and Linear Detection.*
[3] Hewlett-Packard Application Note 956-5, *Dynamic Range Extension of Schottky Detectors.*
[4] Hewlett-Packard Application Note 956-4, *Schottky Diode Voltage Doubler.*

capacitance and the video resistance. Of these five elements of the diode's equivalent circuit, the four parasitics are constants and the video resistance is a function of the current flowing through the diode.

$$R_V \approx \frac{26{,}000}{I_S + I_b}$$

where

I_S = diode saturation current in μA

I_b = bias current in μA

Saturation current is a function of the diode's design,[5] and it is a constant at a given temperature. For the HSMS-285X series, it is typically 3 to 5 μA at 25°C. For the medium barrier HSMS-2860 family, saturation current at room temperature is on the order of 50 nA.

Together, saturation and (if used) bias current set the detection sensitivity, video resistance and input RF impedance of the Schottky detector diode. Since no external bias is used with the HSMS-285A series, a single transfer curve at any given frequency is obtained, as shown in Figure 4. Where bias current is used, some tradeoff in sensitivity and square law dynamic range is seen, as shown in Figure 6 and described in reference [3].

The most difficult part of the design of a detector circuit is the input impedance matching network. A discussion of such circuits can be found in the data sheet for the HSMS-285A/HSMS-286A single SOT-323 detector diodes (Hewlett-Packard publication 5965-4704E).

Six Lead Circuits

The differential detector is often used to provide temperature compensation for a Schottky detector, as shown in Figure 13.

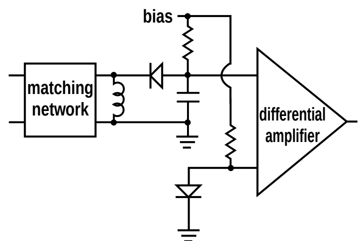


Figure 13. Voltage Doubler.

These circuits depend upon the use of two diodes having matched V_f characteristics over all operating temperatures. This is best achieved by using two diodes in a single package, such as the HSMS-2825 in the larger SOT-143 package. However, such circuits generally use single diode detectors, either series or shunt mounted diode. The voltage doubler (reference [4]) offers the advantage of twice the output voltage for a given input power. The two concepts can be combined into the differential voltage doubler, as shown in Figure 14.

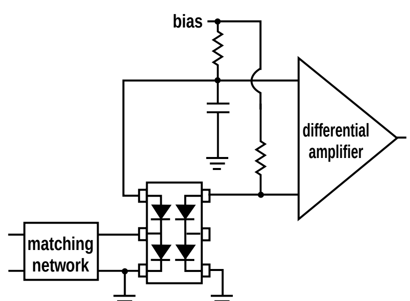


Figure 14. Differential Voltage Doubler.

Here, all four diodes of the HSMS-286P are matched in their V_f characteristics, because they came from adjacent sites on the wafer. A similar circuit can be realized using the HSMS-286R ring quad.

Other configurations of six lead Schottky products can be used to solve circuit design problems while saving space and cost.

Thermal Considerations

The obvious advantage of the SOT-363 over the SOT-143 is combination of smaller size and two extra leads. However, the copper leadframe in the SOT-363 has a thermal conductivity four times higher than the Alloy 42 leadframe of the SOT-143, which enables it to dissipate more power.

The maximum junction temperature for these three families of Schottky diodes is 150°C under all operating conditions. The following equation, equation 1, applies to the thermal analysis of diodes:

$$T_j = (V_f I_f + P_{RF})\,\theta_{jc} + T_a$$

where

T_j = junction temperature

T_a = diode case temperature

θ_{jc} = thermal resistance

$V_f I_f$ = DC power dissipated

P_{RF} = RF power dissipated

Equation (1).

Note that θ_{jc}, the thermal resistance from diode junction to the foot of the leads, is the sum of two component resistances,

$$\theta_{jc} = \theta_{pkg} + \theta_{chip}$$

Equation (2).

[5] Hewlett-Packard Application Note 969, *An Optimum Zero Bias Schottky Detector Diode.*

Package thermal resistance for the SOT-363 package is approximately 100°C/W, and the chip thermal resistance for these three families of diodes is approximately 40°C/W. The designer will have to add in the thermal resistance from diode case to ambient—a poor choice of circuit board material or heat sink design can make this number very high.

Equation (1) would be straightforward to solve but for the fact that diode forward voltage is a function of temperature as well as forward current. The equation, equation 3, for V_f is:

$$I_f = I_S \left[e^{\frac{11600 (V_f - I_f R_s)}{nT}} - 1 \right]$$

where

n = ideality factor

T = temperature in °K

R_s = diode series resistance

Equation (3).

and I_S (diode saturation current) is given by

$$I_s = I_0 \left(\frac{T}{298} \right)^{\frac{2}{n}} e^{-4060 \left(\frac{1}{T} - \frac{1}{298} \right)}$$

Equation (4).

Equations (1) and (3) are solved simultaneously to obtain the value of junction temperature for given values of diode case temperature, DC power dissipation and RF power dissipation.

Temperature Compensation

The compression of the detector's transfer curve is beyond the scope of this data sheet, but some general comments can be made. As was given earlier, the diode's video resistance is given by

$$R_V = \frac{8.33 \times 10^{-5}\, nT}{I_S + I_b}$$

where T is the diode's temperature in °K.

As can be seen, temperature has a strong effect upon R_V, and this will in turn affect video bandwidth and input RF impedance. A glance at Figure 7 suggests that the proper choice of bias current in the HSMS-286A series can minimize variation over temperature.

The detector circuits described earlier were tested over temperature. The 915 MHz voltage doubler using the HSMS-286A series produced the output voltages as shown in Figure 15. The use of 3 µA of bias resulted in the highest voltage sensitivity, but at the cost of a wide variation over temperature. Dropping the bias to 1 µA produced a detector with much less temperature variation.

A similar experiment was conducted with the HSMS-286A series in the 5.8 GHz detector. Once again, reducing the bias to some level under 3 µA stabilized the output of the detector over a wide temperature range.

It should be noted that curves such as those given in Figures 15 and 16 are highly dependent upon the exact design of the input impedance matching network. The designer will have to experiment with bias current using his specific design.

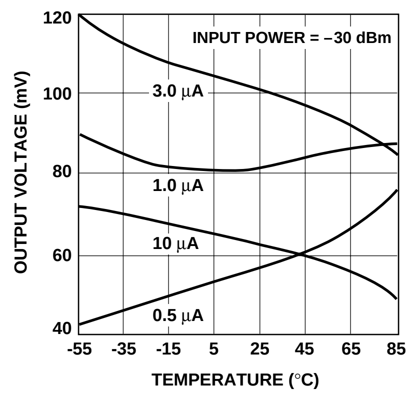


Figure 15. Output Voltage vs. Temperature and Bias Current in the 915 MHz Voltage Doubler using the HSMS-286A Series.

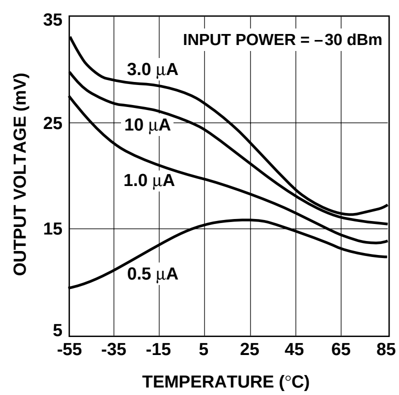


Figure 16. Output Voltage vs. Temperature and Bias Current in the 5.80 GHz Voltage Detector using the HSMS-286A Series.

Diode Burnout

Any Schottky junction, be it an RF diode or the gate of a MESFET, is relatively delicate and can be burned out with excessive RF power. Many crystal video receivers used in RFID (tag) applications find themselves in poorly controlled environments where high power sources may be present. Examples are the areas around airport and FAA radars, nearby ham radio operators, the vicinity of a broadcast band transmitter, etc. In such environments, the Schottky diodes of the receiver can be protected by a device known as a limiter diode.[8] Formerly available only in radar warning receivers and other high cost electronic warfare applications, these diodes have been adapted to commercial and consumer circuits.

Hewlett-Packard offers a complete line of surface mountable PIN limiter diodes. Most notably, our HSMP-4820 (SOT-23) can act as a very fast (nanosecond) power-sensitive switch when placed between the antenna and the Schottky diode, shorting out the RF circuit temporarily and reflecting the excessive RF energy back out the antenna.

Assembly Instructions

SOT-363 PCB Footprint

A recommended PCB pad layout for the miniature SOT-363 (SC-70 6 lead) package is shown in Figure 17 (dimensions are in inches). This layout provides ample allowance for package placement by automated assembly equipment without adding parasitics that could impair the performance.

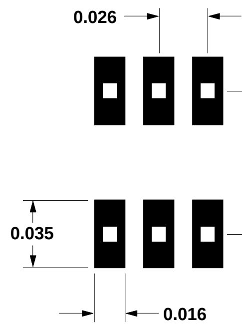


Figure 17. PCB Pad Layout (dimensions in inches).

SMT Assembly

Reliable assembly of surface mount components is a complex process that involves many material, process, and equipment factors, including: method of heating (e.g., IR or vapor phase reflow, wave soldering, etc.) circuit board material, conductor thickness and pattern, type of solder alloy, and the thermal conductivity and thermal mass of components. Components with a low mass, such as the SOT-363 package, will reach solder reflow temperatures faster than those with a greater mass.

HP's SOT-363 diodes have been qualified to the time-temperature profile shown in Figure 18. This profile is representative of an IR reflow type of surface mount assembly process.

After ramping up from room temperature, the circuit board with components attached to it (held in place with solder paste) passes through one or more preheat zones. The preheat zones increase the temperature of the board and components to prevent thermal shock and begin evaporating solvents from the solder paste. The reflow zone briefly elevates the temperature sufficiently to produce a reflow of the solder.

The rates of change of temperature for the ramp-up and cool-down zones are chosen to be low enough to not cause deformation of the board or damage to components due to thermal shock. The maximum temperature in the reflow zone (T_{MAX}) should not exceed 235 °C.

These parameters are typical for a surface mount assembly process for HP SOT-363 diodes. As a general guideline, the circuit board and components should be exposed only to the minimum temperatures and times necessary to achieve a uniform reflow of solder.

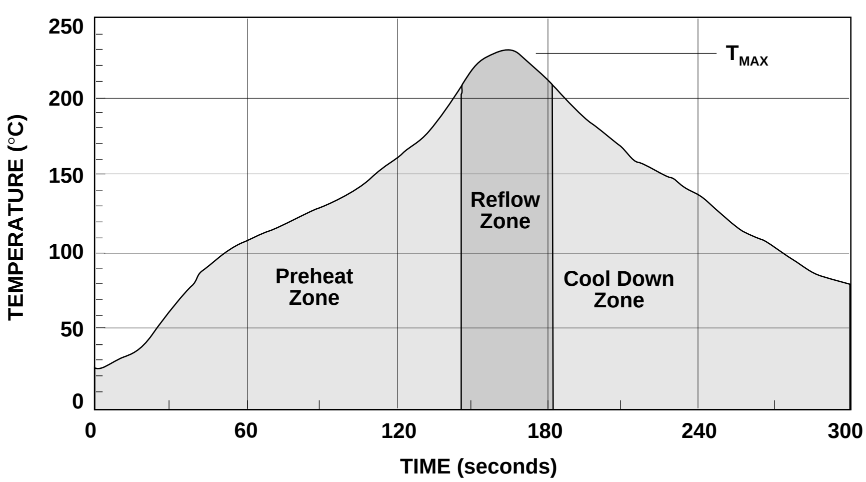
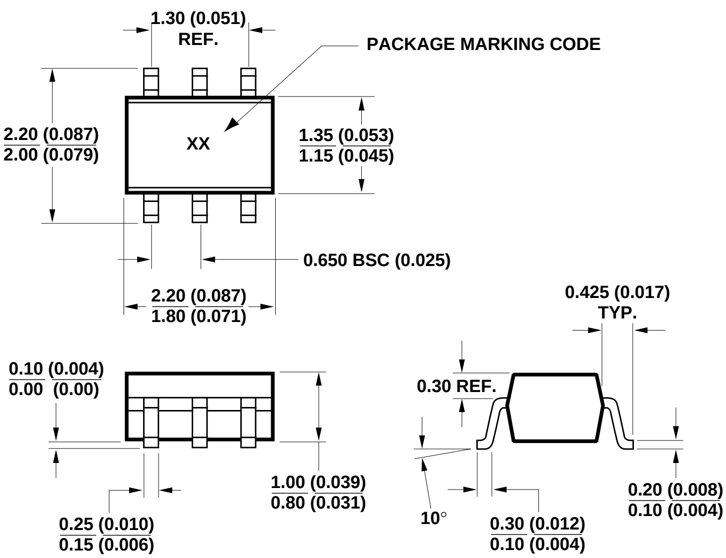


Figure 18. Surface Mount Assembly Profile.

[6] Hewlett-Packard Application Note 956-4, *Schottky Diode Voltage Doubler*.

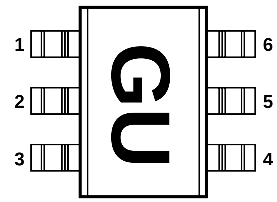
Package Dimensions

Outline SOT-363 (SC-70, 6 Lead)



DIMENSIONS ARE IN MILLIMETERS (INCHES)

Pin Connections and Package Marking



Notes:

1. Package marking provides orientation and identification.
2. See “Electrical Specifications” for appropriate package marking.

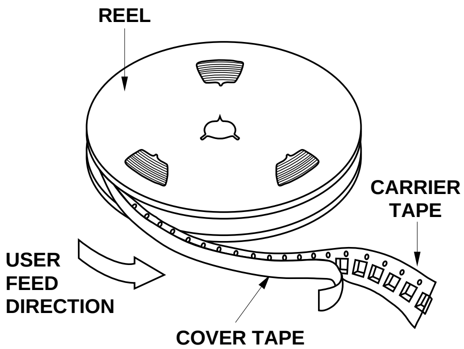
Part Number Ordering Information

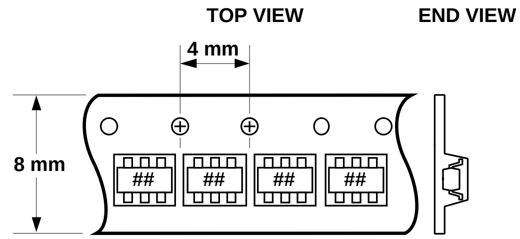
Part Number	No. of Devices	Container
HSMS-285A-TR1[1]	3000	7" Reel
HSMS-285A-BLK[1]	100	antistatic bag
HSMS-286A-TR1[2]	3000	7" Reel
HSMS-286A-BLK[2]	100	antistatic bag

Notes:

1. “A” = L or P only
2. “A” = L, P or R

Device Orientation

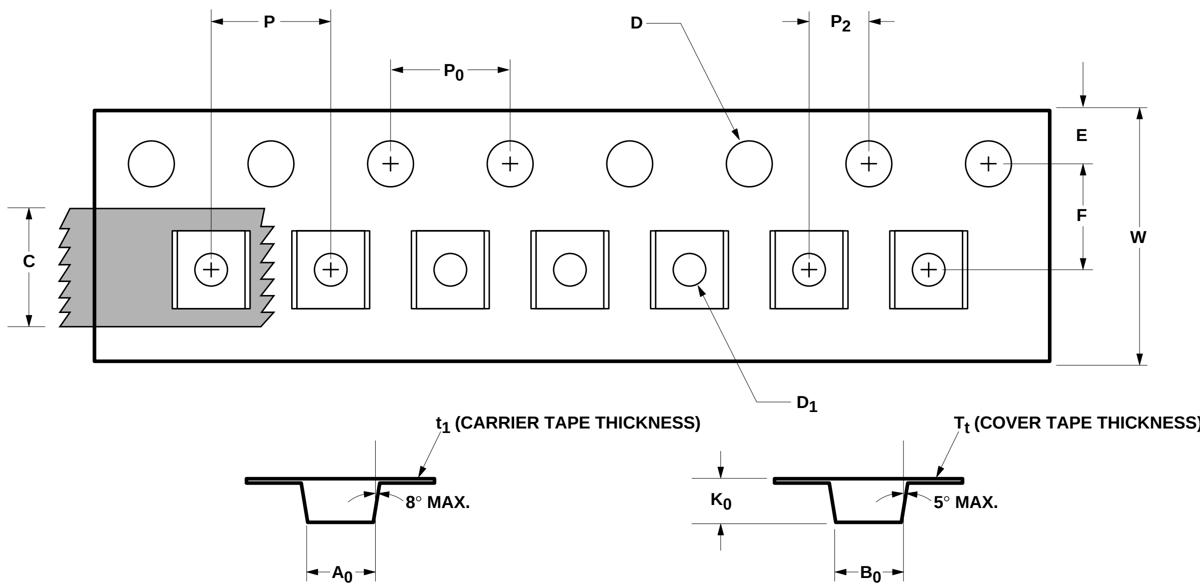




Note: "##" represents Package Marking Code. Package marking is right side up with carrier tape perforations at top. Conforms to Electronic Industries RS-481, "Taping of Surface Mounted Components for Automated Placement." Standard Quantity is 3,000 Devices per Reel.

Tape Dimensions and Product Orientation

For Outline SOT-363 (SC-70, 6 Lead)



DESCRIPTION		SYMBOL	SIZE (mm)	SIZE (INCHES)
CAVITY	LENGTH	A_0	2.24 ± 0.10	0.088 ± 0.004
	WIDTH	B_0	2.34 ± 0.10	0.092 ± 0.004
	DEPTH	K_0	1.22 ± 0.10	0.048 ± 0.004
	PITCH	P	4.00 ± 0.10	0.157 ± 0.004
	BOTTOM HOLE DIAMETER	D_1	1.00 + 0.25	0.039 + 0.010
PERFORATION	DIAMETER	D	1.55 ± 0.05	0.061 ± 0.002
	PITCH	P_0	4.00 ± 0.10	0.157 ± 0.004
	POSITION	E	1.75 ± 0.10	0.069 ± 0.004
CARRIER TAPE	WIDTH	W	8.00 ± 0.30	0.315 ± 0.012
	THICKNESS	t_1	0.255 ± 0.013	0.010 ± 0.0005
COVER TAPE	WIDTH	C	5.4 ± 0.10	0.205 ± 0.004
	TAPE THICKNESS	T_t	0.062 ± 0.001	0.0025 ± 0.00004
DISTANCE	CAVITY TO PERFORATION (WIDTH DIRECTION)	F	3.50 ± 0.05	0.138 ± 0.002
	CAVITY TO PERFORATION (LENGTH DIRECTION)	P_2	2.00 ± 0.05	0.079 ± 0.002

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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.

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