HEWLETT® PACKARD

All Schottky Diodes are Zero Bias Detectors

Application Note 988

Introduction

Zero bias detectors with higher forward voltage have better voltage sensitivity. For example, the HSCH-3206 with a forward voltage of about 200 millivolts at 0.1 milliampere is better than the HSCH-5019 with a forward voltage of less than 100 millivolts. Application Note 969, “An Optimum Zero Bias Schottky Detector Diode”, analyzes this relationship but points out that conventional detector diodes such as the 5082-2755, with even higher forward voltage are not usable at zero bias because of losses in the matching circuit. Recent study has shown that the limitation of these diodes is not matching loss but is related to the load resistance. With proper load resistance voltage sensitivity above 30 millivolts per microwatt was measured at 10 GHz for the 5082-2755 diode at zero bias.

The Effect of Load Resistance

A detector diode may be considered as a video voltage source of impedance R_V feeding a load resistance R_L. The voltage across the load is reduced by the ratio of R_L to $R_V + R_L$.

The diode resistance R_V is related to the saturation current I_S appearing in the diode equation

$$I + I_S\, e^{\frac{V - I R_S}{0.026}}$$

where R_S is the parasitic series resistance of the diode. Note that high forward voltage corresponds to low saturation current. The relationship between diode resistance and saturation current is

$$R_V = \frac{0.026}{I_S + I_B}$$

where I_B is the bias current. Low saturation current corresponds to a high value of diode resistance.

The saturation current for the 5082-2755 diode is about 6.2×10^{-10} ampere so the diode resistance is about 42 megohms with zero bias current. This analysis assumes that the power level is low enough so that the rectified current is small compared to the saturation current. Rectified current lowers the diode resistance.

In the Hewlett-Packard diode catalog the voltage sensitivity of the 5082-2755 detector diode is specified with 20 microamperes DC bias and a load resistance of 100,000 ohms. In this case the diode resistance is 1300 ohms. The output voltage is reduced about 1% by the voltage division between diode and load.

Without bias the diode resistance is 42 megohms and the voltage across a 100,000 ohm load is reduced more than 99%. For this reason the 5082-2755 diode has not been considered useful at zero bias.

Proper Load Resistance

A detector might be considered useful when the degradation is not more than 90%. This requires a load resistance greater than 4.6 megohms with a 42 megohm diode. This is more than is provided by a typical oscilloscope (1 megohm) but the requirement is easily met by a DC voltmeter. Measurements were made with a Hewlett-Packard Model 3469B multimeter with an impedance rating above 10 megohms. This would provide a reading of 19% of the generated voltage. The meter impedance on the low scales is more than 10^{10} ohms so the full voltage is measured.

Measured Detected Voltage

Figure 1 shows the detected response of a Hewlett-Packard 5082-2755 diode at 10 GHz. The top curve shows the voltage on the Hewlett-Packard 3469B DC voltmeter.

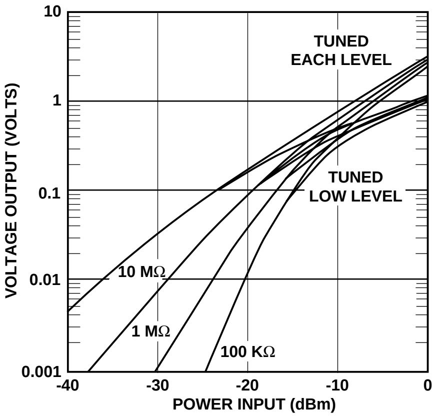

Figure 1. Zero Bias Transfer Characteristic, 5082-2755

The other curves show the reduced output when a resistor is placed across the meter. Note that the voltage sensitivity is well under one millivolt per microwatt when the load resistor is 100 kilohms.

Each load resistor curve splits into two curves at the higher power levels. The lower curve represents the output voltage when the tuning is fixed after adjusting for maximum output at a low power level such as one microwatt. The upper curve shows the output voltage tuned at each power level.

The load resistor has little effect on output voltage at the higher power levels. At these levels rectified current lowers the diode resistance well below 100 kilohms. The effect of load resistance on voltage output depends on

$$1 + \frac{R_{DIODE}}{R_{LOAD}}$$

and this remains close to unity for any of these loads.

Bandwidth

Although the voltage sensitivity of a higher barrier diode is significantly better without bias, the application is limited by the problem of matching the high diode impedance to the usual 50 ohm system. A waveguide slide screw tuner was adequate for the single frequency test described here. When operation over a band of frequencies is needed, the bandwidth, Δf, is limited [1] by the RC product of the circuit to

$$\Delta f = -\frac{1}{2\ RC\ 1n\ |\rho|}$$

where ρ is the maximum reflection coefficient over the frequency band. For example, for $C = 0.1$ pF, $R = 3 \times 10^7$ ohms, and $|\rho| = 0.5$,

$$\Delta f = 240 \text{ kHz}$$

Temperature Effects

Detection characteristics are related to temperature because both series resistance and junction resistance are functions of temperature. The constant 0.026 in the diode equation is proportional to temperature and can be expressed as

$$\frac{0.026T}{295}$$

where T is temperature in degrees Kelvin. Saturation current is also related to temperature:

$$I_S = AA^*\ T^2\ e^{-q}\ \frac{\phi}{kT}$$

A is the diode area, about 6.4×10^{-7} cm^2

A* is a constant, 120 A/cm^2 degree^2

$\frac{kT}{q}$ is the constant mentioned above, $\frac{0.026T}{295}$

ϕ is barrier voltage, related to the metal semiconductor combination

Inserting these expressions in the expression for junction resistance gives

$$R_V = \frac{0.026T\ e^{\frac{11350}{T}\ \phi}}{295 \times 6.4 \times 10^{-7} \times 120\ T^2} = \frac{1.15}{T}\ e^{\frac{5600}{T}}$$

where ϕ was chosen to give reasonable agreement with measured sensitivity.

Series resistance is proportional to temperature. Assuming 16 ohms at room temperature,

$$R_S = (16)\ \frac{T}{295} = \frac{T}{18.4}$$

Notes:

[1] Bode, H.W., Network Analysis and Feedback Amplifier Design, Robert E. Krieger Publishing Co., Huntington, N.Y, 1975, p. 367

The basic voltage sensitivity, $\beta R_V = 0.020\ R_V$ is degraded by the diode parasitics to

$$\frac{0.02\ R_V}{1 + \omega^2 C^2 R_S R_V}$$

and is further degraded by the diode - load voltage divider action

$$\frac{R_L}{R_L + R_V}$$

In this experiment the load resistance is 10^{10} ohms, much larger than R_V for temperatures above -30°C. For $\omega = 2\pi \times 10^{10}$ and $C = 0.1 \times 10^{-12}$ the sensitivity is

$$\gamma = \frac{9320}{T + 1.15 \times 10^{-10}\, e^{\frac{5600}{T}}}$$

Figure 2 shows this sensitivity behavior compared to measured sensitivity. Above -30°C the variation of R_V is not significant so the behavior follows

$$\gamma = \frac{9320}{T}$$

following the change in R_S. Below -30°C the exponential increase in R_V raises the resistance close to the load resistance, reducing the sensitivity. The departure of the calculated sensitivity from measured data at low temperatures may be due to losses in the tuner when the diode resistance value becomes extremely high.

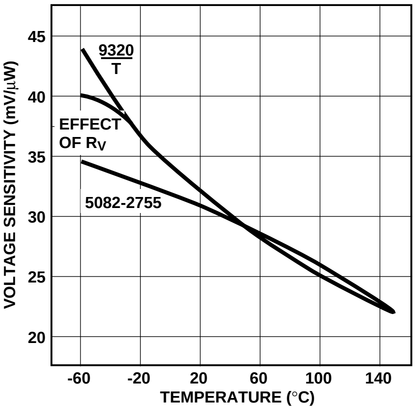

Figure 2. Detector Temperature Characteristic

Summary

All Schottky diodes have high voltage sensitivity at zero bias. Diodes which are normally biased do not appear to detect when the bias is eliminated and the load resistance is less than a megohm. When the load is a high impedance digital voltmeter the voltage sensitivity is better when the bias is eliminated. This effect is illustrated with a Hewlett-Packard 5082-2755 detector diode. Similar performance is obtained with mixer diodes.

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Printed in U.S.A. 5953-4449 (3/82)