Square Law and Linear Detection

Application Note 986

Introduction

Schottky diode detectors are used to detect small signals close to the noise level and to monitor large signals well above the noise. From the noise level up to about -20 dBm (Figure 1) the slope of the response curves is constant. This is the square law region. Video receivers usually operate in this range. The diode receives the signal directly from the antenna in most systems, although a preamplifier may be used to improve sensitivity. This type of receiver is used in short range radar or in counter-measure equipment where the sensitivity of the more complicated superheterodyne receiver is not needed.

Above about -10 dBm the slope is closer to linear but may vary about 30% for different values of frequency, diode capacitance, and load resistance. The slope may be controlled by tuning at the proper power level. Linear detection is used in power monitors. In some applications the linearity is important because the detected voltage is a measure of power input.

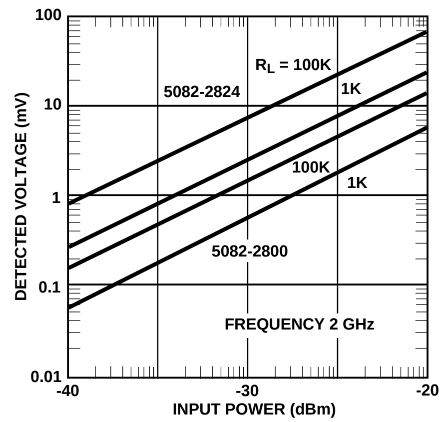

Figure 1. Square Law Response

Detection Law

Over a wide range of input power level, P, the output voltage, V, follows the formula

$$V = K\left(\sqrt{P}\right)^{\propto}$$

At low levels, below -20 dBm, ∝ is two. This is the square law region. When DC bias current is used (usually microamperes), the diode impedance is independent of power level so the tuning can be done at any level. Usually the diode is tuned at -30 dBm. The detected voltage at this level is called the voltage sensitivity.

At higher power levels the diode impedance changes with power. At these levels, the value of ∝ can be as low as 0.8 (Figure 2). The slope is related to diode capacitance, frequency, and load resistance. When the circuit is retuned at each power level, the output and the slope increase.

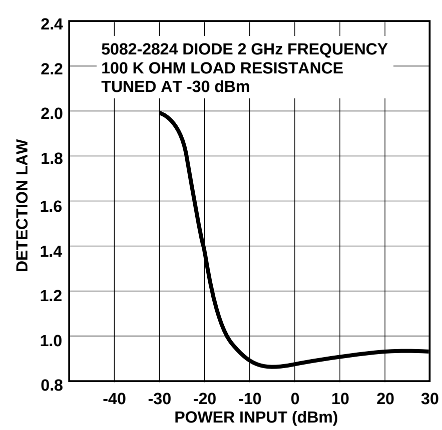

Figure 2. Variation of Detection Law with Input Power

Frequency and Diode Capacitance – Effect on Voltage Sensitivity

The diode junction capacitance shunts the junction resistance. Detected voltage is reduced because some of the input current flows through the capacitance and never reaches the resistance where detection takes place. The effect is more serious at higher frequencies because capacitance susceptance is proportional to frequency. Similarly, the effect is more serious for higher capacitance diodes.

To illustrate these effects, measurements of voltage sensitivity at 20 microamperes bias were made (Figure 1) with a 5082-2800 diode with a zero bias junction capacitance of 1.40 pF and a 5082-2824 diode with 0.88 pF.

Ratio of Voltage Sensitivity at 2 GHz to Voltage Sensitivity at 1 GHz

Diode	-2800		-2824	
Load Resistance	1 K	100 K	1 K	100 K
Measured Ratio	0.30	0.29	0.46	0.52
Computed Ratio	0.30		0.48	

Two values of load resistance were used. The detected voltage is about 70% less at the higher frequency for the 5082-2800 diode, about 50% less for the lower capacitance 5082-2824 diode. Load resistance has little effect on the ratio. The results are summarized in the table. These measurements agree with the computed ratios. See Appendix.

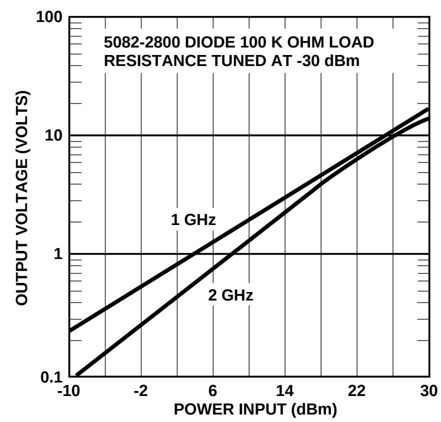

Figure 3. Higher Frequency Increases Slope

Frequency and Diode Capacitance – Effect on Slope in High Level Detection

Figure 3 shows how the slope of the detection characteristic becomes steeper at higher frequencies. The output voltage at 2 GHz is nearly equal to the 1 GHz voltage above 22 dBm. The main reason for this behavior is the lower value of junction resistance at higher power. This is explained in greater detail in the Appendix.

Since frequency and diode capacitance appear in the degradation factor as the product fC, the increasing slope at higher frequency also happens at higher capacitance. This is shown in Figure 4 where the detection characteristic for the higher capacitance 5082-2800 diode is steeper than the characteristic for the -2824 diode.

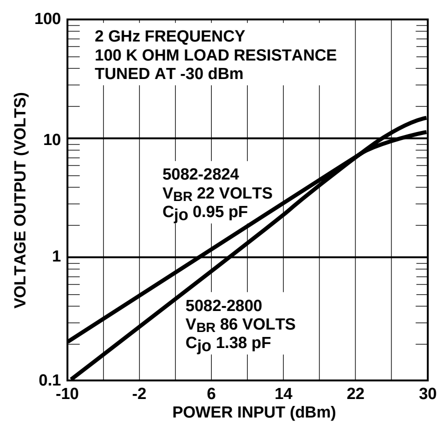

Figure 4. Higher Capacitance Increases Slope

Effect of Breakdown Voltage

In Figure 4 the curves cross so that above 22 dBm the voltage detected by the -2800 is higher than the voltage detected by the lower capacitance -2824 diode. The degradation factor analysis does not explain this crossover. It is related to the effect of breakdown voltage.

At high power levels the negative portion of the input signal is large enough to cause reverse conduction. This negative detected voltage reduces the output level and the curve levels off. At higher levels the negative detected voltage will predominate and the curve will reverse direction and have a negative slope.

The -2800 diode has a high voltage breakdown and so does not exhibit this reverse conduction effect.

Effect of Load Resistance on Detection Slope

Figure 5 shows that the slope of the detection curve increases when the load resistance is decreased from 100 K ohms to 1 K ohms. The detection law increases from 0.9 to 1.0. The Appendix analysis shows that the rectified current at high power causes a decrease in the degradation factor due to low C and Rj. When the load resistance is decreased the rectified current increases, as seen in Figure 6. The degradation factor decreases so the slope is steeper.

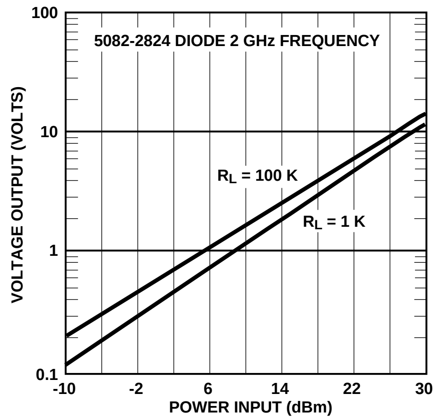

Figure 5. Load Resistance Effects Slope

Tuning for Linear Response

In applications where the detector is used as a power meter linear detector response is needed. Microprocessors are often available to correct the diode response but this involves added expense. Reducing the load resistance can often produce the desired response but the sensitivity is reduced. Figure 7 shows how the sensitivity can be improved while the response is corrected. When the slope is too shallow (the usual case) the correction can be made by tuning at a higher level instead of tuning at -30 dBm. In this case the tuning level was +20 dBm. If the circuit is tuned for maximum output at 20 dBm the response will be too steep. A few iterations are necessary to get the response shown.

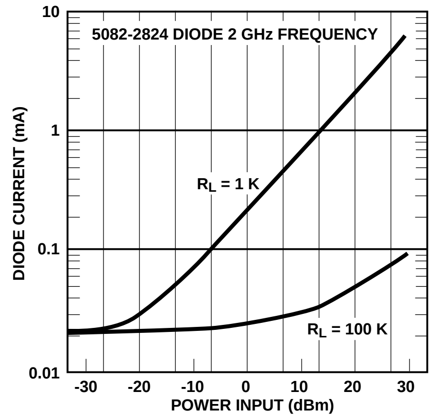

Figure 6. Diode Current

Summary

At low power levels (receiver applications) detected voltage is proportional to input power. This is the square law detection region. At higher levels (power monitor applications) the slope of the transfer characteristic depends on the frequency, diode capacitance, and load resistance. Linear detection can be obtained by tuning the diode at a high power input level.

Appendix

Detection Degradation

Parasitic series resistance and junction capacitance degrade the performance of Schottky detectors. Some of the voltage applied across the diode appears across the series resistance Rs and is not available to be detected by the junction resistance Rj. A more serious effect is the division of current between the junction resistance and the junction capacitance Cj. The degradation factor is:

$$1 + \frac{R_S}{R_j} + 4\pi^2 f^2 C_j^2 R_S R_j$$

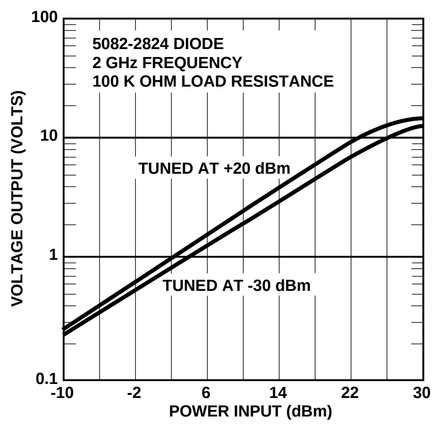

Figure 7. Tuning for Linear Response

The resistance values are 1400 ohms for junction resistance for both diodes at 20 microamperes forward bias, 20 ohms for -2800 series resistance, and 8 ohms for -2824 series resistance. Junction capacitance at zero bias is 1.4 pF for the -2800 diode and 0.95 pF for the -2824 diode. At forward bias the capacitance increases by the factor

$$\sqrt{\frac{V_B}{V_B - V_F}}$$

where V_B is the barrier voltage, 0.64 voltage for these diodes, and V_F is the forward voltage, 240 mV for the -2800, 260 mV for the -2824. The degradation factor is

$$1.01 + 3.42\, f^2$$

for the -2800, and

$$1.01 + 0.57\, f^2$$

for the -2824.

The ratio of this factor at 1 GHz to that at 2 GHz is 0.30 for the -2800 and 0.48 for the -2824.

This degradation factor also explains the increasing slope of the detection curve at higher values of frequency and diode capacitance. Consider the -2800 at 1 and 2 GHz. We have seen that the ratio of the degradation factor for these frequencies at low power is 0.3.

The power supply voltage is 2.24 volts, 2 volts for 20 microamperes through the 100 K resistor and 0.24 volts for the diode forward voltage. At 1 watt input level the rectified current increases the diode current to 93 microamperes. This changes the diode voltage to 2.24 - 9.3 = -7.06 volts. This back bias lowers the junction capacitance to 0.5 pF. In addition, the junction resistance decreases to 2800/93 = 300 ohms. The degradation factor is now

$$1.07 + 0.059\, f^2$$

and the 1 to 2 GHz ratio is 0.86. At 2 GHz the slope increases to bring the curves closer together at the higher levels.

Notice that the -2800 diode junction capacitance of 1.4 pF is reduced to 0.5 pF at higher input power level. Diodes that are rejected for high capacitance at lower levels may be quite acceptable for high level detection.

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