Design Tip
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Notes on differential detector circuits

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Introduction

In large signal AGC (automatic gain control) detector circuits, the differential detector[1] offers excellent linearity and stability over temperature if the DC bias current is kept sufficiently high. See Figure 1 for a typical differential detector.

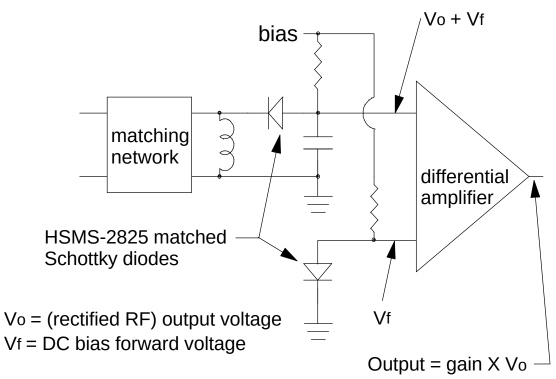

Figure 1 -- Typical differential detector

This note will cover several topics related to this circuit.

The high isolation HSMS-282K diode pair

As was pointed out in reference [1], the differential detector only works when the two diodes (detector and reference) are very well matched at all operating temperatures and at the selected bias level. This cannot be achieved with diodes in separate packages -- it is necessary to use two diodes in the same four or six lead package, where dice from adjacent sites on the wafer are used[2]. When the differential detector is used at input power levels of +20dBm or higher, RF energy can couple from the detector diode to the reference diode, due to the close proximity of the two in the SOT-143 four-lead package. The result is some rectification in the reference diode, leading to errors due to the additional DC voltage produced.

The solution to this problem followed the introduction of the SOT-363 six-lead package in HP's product line. This package allows the addition of an isolation bar between the two diodes, as shown in Figure 2. The HSMS-282K not only has the isolation bar, but it is physically smaller than the four-lead HSMS-2825, and offers much better package thermal resistance.

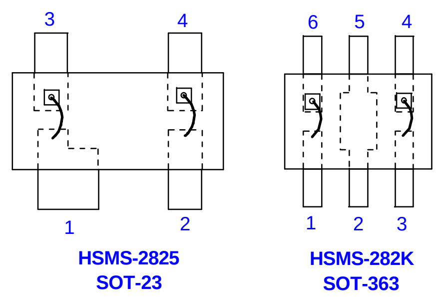

Figure 2 -- four and six-lead diode pairs

In order to achieve the highest isolation between the two diodes, leads 2 and 5 of the HSMS-282K must be grounded as close to the package as possible. One possible method is shown in Figure 3.

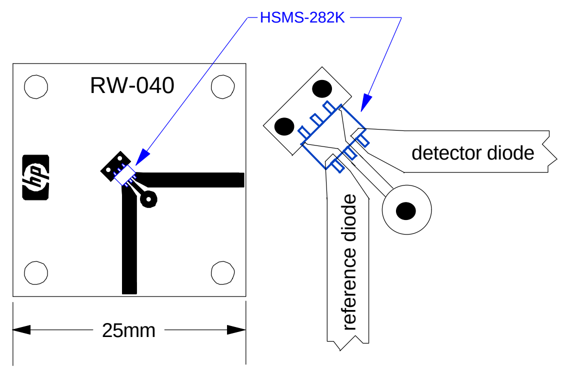

Figure 3 -- Test circuit

Tests were run on the HSMS-282K, using the evaluation board shown in Figure 3. Three via holes were used to ground leads 2, 4, 5 and 6 of the diode pair, which was then evaluated in a differential detector. RF signals were brought into one of the two microstrip lines shown, which were at right angles to each other to minimize coupling between them. Both diodes were monitored for signs of rectification of the RF signal. The DC bias level was set to 3μA in order to maximize the detection sensitivity of the diodes. This test was performed on both the four-lead

HSMS-2825 and the six-lead HSMS-282K. The results of the measurements can be seen in Figure 4.

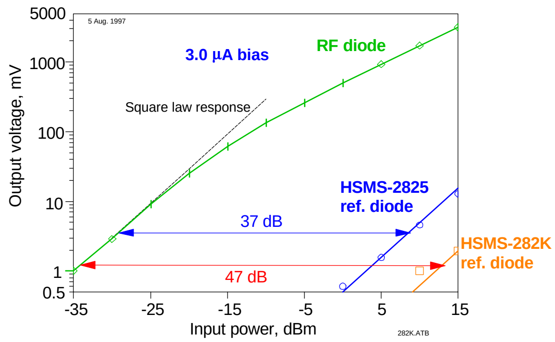

Figure 4 -- results of tests

For both the four-lead and the six-lead product, the detector diode's transfer curve follows the classic curve labeled "RF diode." The detected signal in the reference diode of the four-lead device is shown to the right, 37 dB down from the output of the detector diode. The detected signal in the six-lead product's reference diode is 47 dB down.

It can be seen that the use of the HSMS-282K six-lead pair results in a 10 dB improvement in isolation between detector and reference diodes.

Differential voltage doubler

The voltage doubler[3] has long been recognized for offering the advantage of twice the output voltage and half the input impedance when compared to a single diode Schottky detector. This concept can be applied to the differential detector as shown in Figure 5. As is the case in

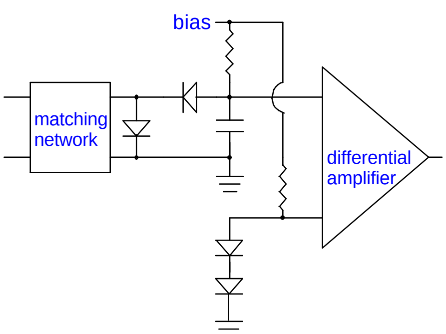

Figure 5 -- Differential voltage doubler

any differential detector, the diodes must be matched to each other -- in this case, a set of four matched devices is required. This can be achieved through the use of the HSMS-282P matched quad, as shown in Figure 6. The

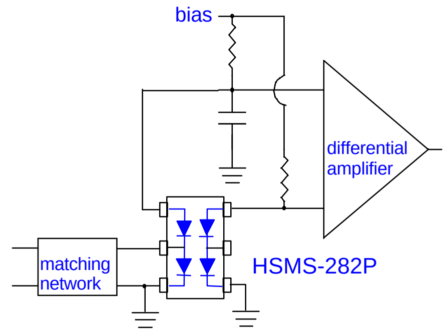

Figure 6 -- Implementation of the differential doubler

four diodes in this quad are taken from adjacent sites on the wafer, leading to a very high degree of match.

Op-amp circuits

One op-amp circuit[4] which can be used in the differential detector is shown in Figure 7.

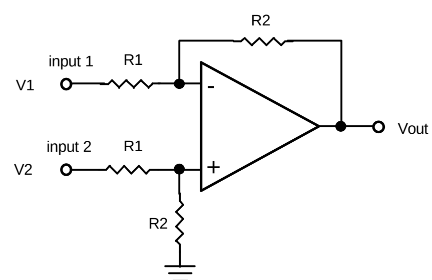

Figure 7 -- op amp circuit for the differential detector

The behavior of this circuit is given by the following equations:

$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1) \qquad (1)$$

$$R_{in2} = R_1 + R_2 \qquad (2)$$

$$R_{in1} = \frac{R_1 + R_2}{\left[1 + \frac{R_2}{R_1}\left(1 - \frac{V_2}{V_1}\right)\right]} \qquad (3)$$

The input load resistance $R_{in1} = R_{in2} = R_1 + R_2$ only if $V_2 = V_1$. Of course, this is not the case with the differential detector except in the case when input RF power is zero. One solution is to keep $R_1 >> R_2$. Reference to equation (1) will show that this will result in gain << 1, a condition which if often undesirable.

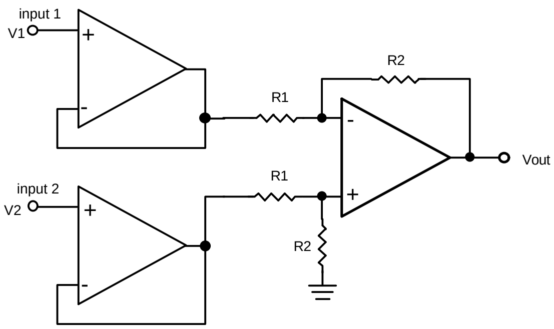

Figure 8 -- Op-amp network

In order to keep gain at or above one, the circuit shown in Figure 8 may be used. This can be implemented as a single IC to save both cost and size.

<u>Performance problems in the small signal region</u>

The discussions in this note and in reference [1] centered around the use of the differential detector in the large signal region, as in an AGC detector. For the purposes of this note, that is defined as input power over -20 dBm. Attempts to use this circuit as a DC biased small signal detector, operating in the square law region ($-55 < P_{in} < -20$ dBm) have proven to be problematical[5].

The function of the differential detector is to separate V_f, the DC bias forward voltage (found in both diodes) from V_o, the rectified or detected voltage. At room temperature and at bias levels of 100 to 500 µA, V_f falls in the range of 220 to 300mV for the HSMS-282x family of Schottky diodes. Reference [1] shows that the value of V_o varies from 5mV to 5V over the input power range of -20 to +25 dBm (large signal operation). For a small signal detector having a reactive input matching network, Vo will be in the range of 0.3 to 100mV.

Consider a differential detector having two diodes with SPICE parameters which are identical but for n, ideality factor. See reference [2]. The value for n of the detector diode is 1.08 while that for the reference diode is 1.00. If this circuit is operated at a bias level of 100µA, the difference in the value of V_f for the two diodes will be 17.2mV. This is a substantial voltage when compared to V_o in the small signal detector.

In a situation such as this, one can modify the op-amp circuit of Figure 8 to include a fixed offset voltage of 17.2mV to correct for the ΔVf of the two diodes. This offset would be set, by hand, for each diode pair.

However, an examination of the V-I equation for the Schottky diode reveals a problem with the use of a fixed offset voltage if the small signal differential detector is to be used over a range of temperatures.

$$I_f = I_S\left[e^{\frac{q\left(V_f - I_v R_S\right)}{nkT}} - 1\right] \qquad (4)$$

$$I_S = I_0\left(\frac{T}{298}\right)^{\frac{2}{n}} e^{-\frac{qEG}{k}\left(\frac{1}{T}-\frac{1}{298}\right)} \qquad (5)$$

where
n = ideality factor
V_f = forward voltage
I_f = forward current
T = temperature in °K
R_s = diode series resistance
I_s = diode saturation current
q = electronic charge ≈ 1.6e-19
k = Boltzman's constant ≈ 1.38e-23
I_o = saturation current at 25°C
EG = energy gap, eV

Ideality factor, which is different in the two diodes, appears in both equations (4) and (5). As a result, the V-I curves of the two diodes will have different slopes. The result is that the value of ΔV_f will vary with temperature from 14.3mV at -25°C to 20.0mV at 75°C. As a result, the

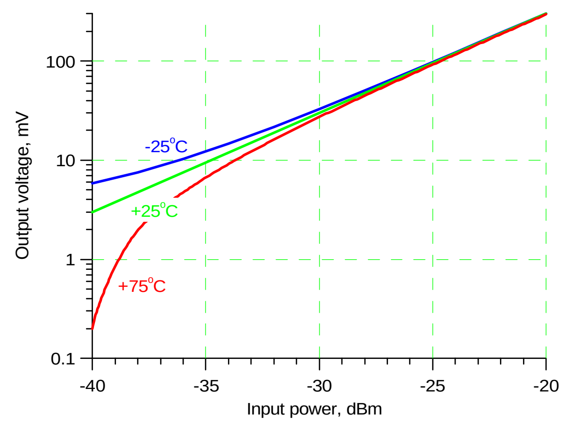

Figure 9 -- transfer curves vs. temperature

circuit with a fixed 17.2mV offset will have 2.9mV too much offset at -25°C and 2.8mV too little at +75°C. If the two diodes have other differences in their SPICE parameters, the variation in offset could be higher.

In our example, the error in offset is 2.8mV at temperature extremes, which is higher than V_o for the detector at input power levels under -40dBm. The result of this variation in offset can be seen in Figure 9, where the detector's transfer curve is shown for all three temperatures. At low levels of input power, the error in offset voltage creates a "fan" effect.

Note that the curves of Figure 9 assume that V_o, the detected output voltage, has been temperature compensated. A description of the techniques for doing this are beyond the scope of this note.

Summary

Thus, it can be seen that the differential detector is a useful circuit for large signal detectors, but is not indicated for use as a small signal detector when stability over temperature is required. New six-lead products from HP can be used to obtain higher isolation between the detector and reference diode in a differential circuit, and can be used to create a differential voltage doubler.

[1] Raymond W. Waugh, "Designing Large-Signal Detectors for Handsets and Base Stations," *Wireless Systems Design*, Vol. 2, No. 7, July 1997, pp 42 – 48.

[2] HP Design Tip D002, "A Schottky Diode Optimized for Consistency"

[3] HP Application Note 956-4, "Schottky Diode Voltage Doubler"

[4] Private communication with Alan Rixon, Hewlett-Packard U.K.

[5] Private communication with John Cerny of Motorola