HEWLETT PACKARD

APPLICATION NOTE 956-3

Flicker Noise in Schottky Diodes

INTRODUCTION

At frequencies above a few megahertz, Schottky barriers emit noise at a power level which is half as much[1] as the familiar Johnson noise of a resistor. The presence of series resistance in the diode substrate and contacts makes the effective noise output comparable to resistor noise. The ratio of diode noise power to resistor noise power, the noise temperature ratio, is close to unity.

At lower frequencies, diode noise gradually increases and soon reaches an inverse frequency [2] behavior. This excess noise contribution is called flicker noise. The frequency at which the extended inverse frequency line crosses unity noise temperature ratio is called the noise corner frequency. All Schottky diodes have lower corner frequencies than those of either pn junctions or point contact diodes.

SCHOTTKY DIODE TYPES

There are four types of Schottky barrier diodes, each with different noise corner frequencies. Figures 1 & 2 show typical characteristics of these diodes. The measurement technique is described in the appendix.

Silicon dioxide passivated diodes with n-doped epitaxial layers have the highest corner frequencies among Schottky diodes. This type of diode is used primarily for X and P Band mixers. For most applications the intermediate frequency is well above the corner frequency and the flicker noise does not degrade the performance. The HP 5082-2701 diode is an example of this type.

Improved flicker noise performance in passivated diodes is obtained by substituting p-type doping for n-type. The Hewlett-Packard X-band 5082-2750 detector diode is an example. The improvement in detection sensitivity over that of an n-type diode is noticed when a significant portion of the video bandwidth extends below the corner frequency.

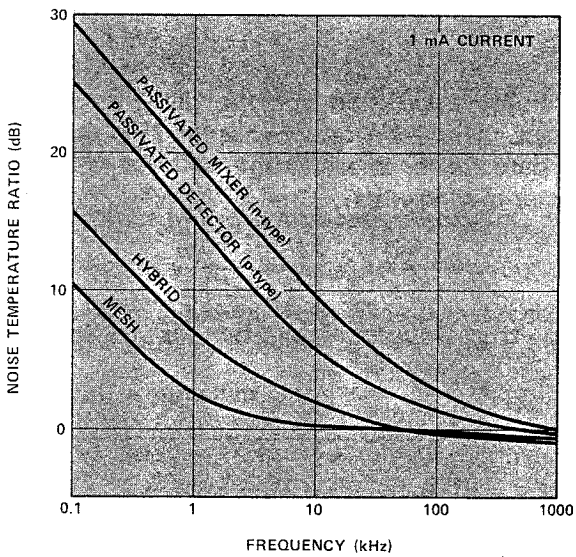


Figure 1. Typical Mixer Noise

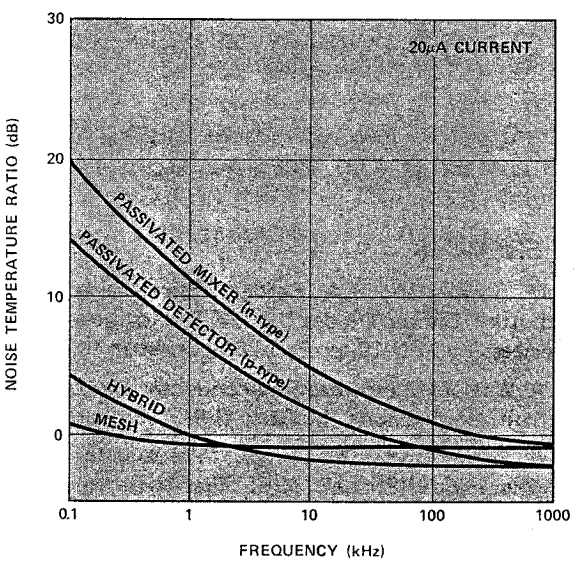


Figure 2. Typical Detector Noise

Even lower flicker noise is obtained with the hybrid (guard ring) diode[3], such as the 5082-2824. These diodes are optimized for performance up to 2 GHz.

The lowest flicker noise in Schottky diodes, or for that matter any type of diode, is found in the mesh diode, such as the HP 5082-2565. These diodes will give the best performance in applications requiring low flicker noise at frequencies below 3 GHz.

DOPPLER MIXERS

Doppler system intermediate frequencies usually extend into the flicker noise region, so a diode with low flicker noise is often the optimum Doppler mixer diode. However, conversion loss, L, will be higher when S band diodes are used in X band mixers, so the trade-off between flicker noise and conversion loss must be considered. The choice may be made by comparing the overall noise figure of the mixer diode, $L_m\ (F_{IF} - 1 + t_m)$, with the corresponding expression for the detector or mesh diode, $L_d\ (F_{IF} - 1 + t_d)$. F_{IF} is the IF noise figure. The detector or mesh diode will provide better Doppler mixing when

$$\frac{L_D}{L_M} < \frac{F_{IF} - 1 + t_m}{F_{IF} - 1 + t_d}$$

When the Doppler frequency is so low that $t_d \gg F_{IF} - 1$, the criterion may be considered as

$$\frac{L_D}{L_M} < \frac{t_m}{t_d}$$

In other words, the diode noise figure L_t is the proper criterion.

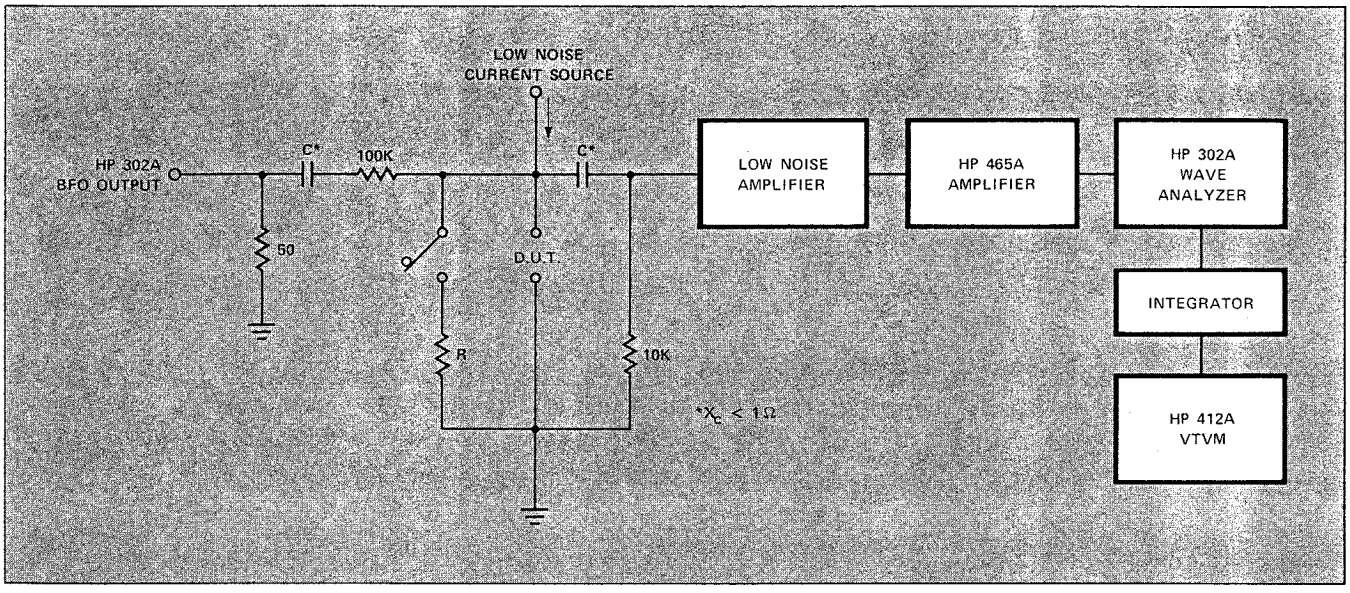
This criterion makes it possible to consider the low flicker noise mesh diode at frequencies above its normal operating range. For example, at an operating frequency of 8 GHz and a Doppler frequency of 100 Hz, the 5082-2701, the usual mixer diode for this frequency, has a diode noise figure of 9 dB, the 5082-2750, the detector diode for this frequency, has a diode noise figure of 8 dB, and the 5082-2565, the 3 GHz mesh diode, has a diode noise figure of 7.5 dB. In this case, the detector diode would be better than the mixer diode and the S band mesh diode would be best of all.

Another technique for optimizing Doppler mixer performance is the adjustment of local oscillator level to trade off flicker noise for conversion efficiency. Figure 2 compared to Figure 1 shows how the flicker noise level drops with decreasing diode current. Unfortunately, conversion efficiency degrades as L.O. power drops. The optimum level is best found empirically. By optimizing the bias load line[4], further reductions in L.O. level are possible.

REFERENCES

1. A.M. Cowley and R.A. Zettler, "Shot Noise in Silicon Schottky Barrier Diodes", IEEE Transactions Electron Devices, Vol. ED-15, pp 761-769. October 1968.
2. H.A. Watson, Microwave Semiconductor Devices & Their Circuit Applications, McGraw-Hill, 1969, pp 378-379.
3. R.A. Zettler and A.M. Cowley, "PN Junction-Schottky Barrier Hybrid Diode", IEEE Trans. Electron Devices, Vol. ED-16, pp 58-63, Jan. 1969.
4. Carl W. Gerst, Jr., "New Mixer Designs Boost D/F Performance", Microwaves, Vol. 12, No. 10, October 1973, p. 60.

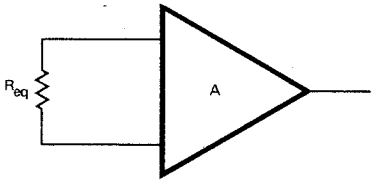
APPENDIX
NOISE TEMPERATURE RATIO MEASUREMENT



The reference resistor, R, is chosen to equal the desired diode video resistance. In order to set the bias, BFO output is connected as shown, the reference resistor switch is closed, and BFO level is adjusted to give approximately one volt output on the 412A voltmeter. Reference resistor switch is then opened, the diode is inserted, and bias is adjusted to give the same output on the 412A. If bias current is specified the procedure is reversed as reference resistor value is then chosen to give one volt output after the BFO level is set with the diode in place.

The BFO output is disconnected and the 412A output is recorded as V_D when the diode is in place and resistor switch opened, and V_R when the diode is removed and resistor switch closed.

This system can be represented by one amplifier of gain A and an equivalent input resistance R_{eq}.



The system noise can be represented by a noise current through R_{eq}: i_a. The input noise voltage is $i_a R_{eq}$. The output noise voltage is $A R_{eq} i_a$.

A resistor at the input contributes noise output voltage $AR_{eq}i_R$.

Total output is

$$V^2_R = A^2 R^2_{eq} (i^2_R + i^2_a)$$

If the input resistor is replaced by a diode, the noise current i_R is replaced by i_D. Then

$$V^2_D = A^2 R^2_{eq} (i^2_D + i^2_a)$$

The difference in squared output voltage is

$$V^2_D - V^2_R = A^2 R^2_{eq} (i^2_D - i^2_R)$$

Because R is equal to diode video resistance, R_D, noise temperature ratio is $t = i^2_D/i^2_R$, where

$$i^2_R = 4k\ TB/R_D$$

$$i^2_D - i^2_R = (t-1)\ i^2_R$$

and

$$V^2_D - V^2_R = A^2\ R^2_{eq} \frac{4k\ TB}{R_D} (t-1)$$

$$t = 1+(R_D/4k\ TB)\ (V^2_D - V^2_R)/(AR_{eq})^2$$

AR_{eq} may be measured by supplying current to the system from a current source at the measurement frequency. Close the reference resistor switch, remove the diode, and connect the BFO output as shown. Use a coax tee to measure the BFO voltage, e. This voltage should be well above the noise level. The input current is 10^{-5} e, because R_{eq} is small compared to 100K. The input voltage is $10^{-5} e R_{eq}$. Output voltage, V, can be measured on the 412A.

$$A = \frac{V}{10^{-5}\ e\ R_{eq}}$$

$$A\ R_{eq} = 10^5 \frac{V}{e}$$

Noise temperature ratio may now be computed from measured voltages.

$$t = 1 + \frac{R_D}{4k\ TB} (V^2_D - V^2_R)(10^{-5} \frac{e}{V})^2$$



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