III-7. Analysis of Negative-Resistance Photodiodes

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Photodetectors for the detection of microwave-modulated optical radiation have recently received increasing attention. Passive microwave photodiodes (containing no negative resistance or other gain-producing mechanism) have been recently developed[1] and some experimental work has been presented on active parametric photodiodes.[2,3] An active photodetector is one in which a gain-producing mechanism, such as a negative resistance, appears.

The published work on active photodetectors has been entirely experimental and is limited to parametric photodiodes. This paper describes the theoretical performance of active photodiodes as represented by parametric and tunnel-diode photodetectors. The gain and noise properties are derived for active photodiodes. Passive photodiodes are a limiting case of the active devices. In particular, it is shown that the noise performance of active photodiodes will, in general, be inferior to passive photodiodes if both types are optimized. Comparative noise performance measurements should be made only under conditions in which both types are optimized.

The assumed detector equivalent circuit is shown in Fig. 1. This circuit can be used to describe the midband performance of both passive diode photodetectors and the active parametric and tunnel diode detectors by including the terms in $\bar{i}_T^2$ and R_D. This circuit is transformed into an equivalent parallel circuit that is used for subsequent calculations.

The available power for the detector is

$$P_{av} = \frac{\bar{i}_p^2}{4G_D\left[1 - \frac{G_n}{G_D} + R_S R_D (G_D - G_N)^2 + \omega^2 R_S R_D C_o^2\right]}. \tag{1}$$

This quantity becomes infinite for

$$G_N = G_D\left[\frac{1 \pm \sqrt{1 - 4\omega^2/\omega_C^2}}{2R_S/R_D}\right], \tag{2}$$

where $\omega_C = 1/R_S C_o$, which corresponds to self-oscillation. This condition also provides the basis for certain useful high-gain approximations. The quantity ω_C is used in Eq. (2) to be consistent with the normal cutoff frequency for varactor diodes. This is particularly convenient in parametric photodetectors. The limit for the P_{av} when the negative part of R_D approaches zero is the available power expression for the passive photodiode.

A power gain β can be defined as the ratio of power available with the negative R_D present to the power available with a only positive R_D. This gain is

$$\beta = \frac{1 + \frac{R_S}{R_D} + \omega^2 R_S R_D C_o^2}{\left(1 - \frac{G_N}{G_D}\right) + \frac{R_S}{R_D}\left(1 - \frac{G_N}{G_D}\right)^2 + \omega^2 R_S R_D C_o^2}. \quad (3)$$

Microwave approximations will be given for various conditions.

Due to the additional noise sources present in the active devices, the noise performance of the active detectors is not necessarily superior to the performance of passive detectors. The general signal-to-noise ratio for active detectors is:

$$\frac{P_S}{P_N} = \frac{\overline{i_p}^2 R_D G_D''}{4kTB\left(G_S + G_D R_D G_D''\left[1 + \frac{G_E}{G_D} + \frac{G_P}{G_D}\right]\right)}. \quad (4)$$

Note that the noise terms are not reduced by any gain factors. For simplicity, the double-primed quantities appearing in the parallel equivalent circuit have been retained.

The quantity of interest is the minimum detectable photocurrent

$$\overline{i}_{mpd}^2 = 4kTB\, G_D\left[1 + \frac{G_E}{G_D} + \frac{G_P}{G_D} + R_S R_D (G_D - G_N)^2 + \omega^2 R_S R_D C_o^2\right], \quad (5)$$

where G_E and G_P are equivalent conductances representing the excess tunnel diode and parametric noise sources.

The noise performance of a multistage system in which the gain of the detector is important may be improved by an active detector. However, this situation must be compared with the use of a passive detector and a low-noise amplifier as a first stage. This situation will be described and the level of improvement will be discussed. Various aspects of the measurement of photoparamps will be discussed, and some measurement pitfalls leading

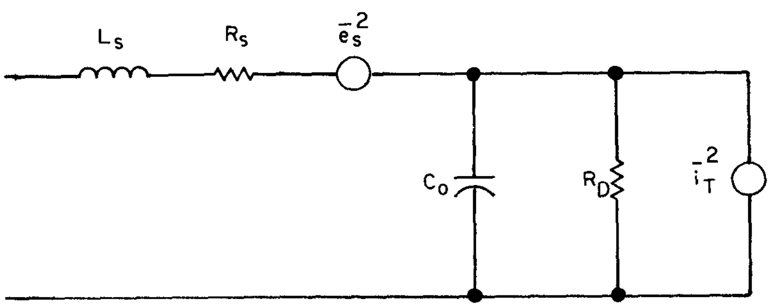

Fig. 1. Active photodetector equivalent circuit. $\overline{i_T}^2 = \overline{i_P}^2 + \overline{i_D}^2 + \overline{i_a}^2 + 4kTB\, G_D$; $\overline{i_P}^2$ = signal current; $\overline{i_D}^2$ - shot noise current; $\overline{i_a}^2$ = parametric amplifier excess noise; R_D = total diode resistance (positive and negative), = $1/(G_D - G_N)$; R_S = series resistance; L_S = series inductance; C_o = junction capacitance; $\overline{e_S}^2$ = R_S noise generator.

to over-optimistic results will be discussed. The advantages and limitations of active detectors for various situations will be described and a summary of the limited number of cases where active detectors are potentially useful will be given.

REFERENCES

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