Panel: Noise in Microwave Transmission Applications of Gunn and IMPATT Diodes

THEORETICAL ASPECTS OF GUNN AND IMPATT DIODE NOISE

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Summary of Introductory Statement

A brief review of small-signal noise theories of Gunn and IMPATT diodes, and large-signal noise theories of IMPATT diodes is the purpose of this presentation. Some issues requiring further investigation will be pointed out.

The small-signal theories of Gunn diode noise attribute the noise to the random transitions of the carriers from the low mobility valley to the high mobility valley and viceversa, and to the diffusion (random walk) of the drifting carriers. This noise can be expressed in terms of an effective diffusion constant[1] if certain conditions are met[2]. One can show[3] that the noise measure of spatially uniform Gunn devices is limited by

$$M \geq -\frac{T}{T_o} \frac{1}{1+\gamma} \left[1 + \frac{q\overline{v}\,\tau_2 E_o}{kT(1+\tau_2/\tau_1)} \right]$$

where T is the temperature of the carriers, γ is equal to $-(1/n_1)(\partial n_2/\partial E)E_o$, usually a negative quantity, with n_1 the equilibrium density of the high mobility carriers, n_2 that of the low mobility carriers, E_o the dc electric field; τ_1 and τ_2 are the respective relaxation times, the $\overline{v}$ is the average velocity. The traveling wave Gunn device can be shown to achieve the lower bound. For a reasonable choice of parameters this bound can be as low as 12.8db.

The results of the small-signal Gunn diode noise theory have been applied to predict FM noise of Gunn diode oscillators.[4,5]

The linear noise theories of IMPATT devices are generally in agreement[6,7,8,9]. The noise is attributed to the probabilistic nature of the avalanche process - the time instants of the ionizing events are randomly distributed. The statistics may be assumed stationary in the small signal limit. It is possible to show[10] that a structure with equal ionization coefficients for both carriers ($\alpha = \beta$), consisting of a single region of constant $\alpha' = \partial\alpha/\partial E$, must possess a noise measure M that is greater than, or at best equal to, $q/(2\alpha' kT_o)$, where q is the charge of the carriers. Analysis shows that this lower limit on M can be achieved at a transit angle somewhat smaller than 2π. For GaAs, the lower limit can be as low as 16.8db. There are theoretical indications that proper combinations of tapered avalanche regions and drift regions may lead to lower noise measures than $M = q/(2\alpha'_{max.}\, kT)$, where $\alpha'_{max.}$ is the highest value of α' in the tapered region[11]. Also, unequal ionization rates may be, at times, beneficial[9].

The large-signal noise theories of the IMPATT diode[12,13] agree in that they predict an increase of noise measure with increasing signal level. The reason for this is that, at large signal levels, the avalanche current builds up from lower initial values than at small signal levels, and more noise is generated in such a situation. This prediction agreed with experiments, but the computed numerical values were often higher than the measured values. One explanation starts from the hypothesis[14] that ionization in the drift space causes initial currents larger than the usually assumed I_s-value. Another explanation is[15] that tunnelling accounts for the increased initial current. Very recent measurements[15] on high efficiency diodes show a noise measure that is relatively independent of signal level at appr. 46db.

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