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STUDY OF CROSSED-FIELD AMPLIFIERS

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SHIELDED-GUN CROSSED-FIELD AMPLIFIER

Prof. T. Van Duzer
R. A. Rao

The aim of this project is to design and test a shielded-gun, crossed-field amplifier. As part of this project, a design procedure for crossed-field guns is being developed.

The crossed-field electron gun discussed in the last report has been fabricated and tested. The shape of the beam in the gun was observed by introducing a small amount of hydrogen into the tube, thereby raising the pressure to about 10^{-5} to 10^{-6} mm of mercury. For the theoretically calculated operating parameters, the beam shape in the tube did not agree with the theoretical predictions. The physical dimensions of the tube were checked by using an optical comparator and a small error was discovered in the assembly of the tube. Theoretical calculation of trajectories confirmed that this was indeed the cause for the observed discrepancy. The error is now being corrected and the tests will resume shortly.

Meanwhile, a computer program has been written to solve the paraxial ray equation when the magnetic field is non-uniform. This is in preparation for the design of a transition from a magnetically shielded gun to the uniform field region.

BACKWARD-WAVE NOISE-FIGURE STUDIES

Prof. T. Van Duzer

N. R. Mantena

The aim of this project is to study the noise-figure characteristics of crossed-field amplifiers with emphasis on the backward wave amplifier. Recent efforts have been directed toward using noise-figure measurements in conjunction with linear transformation theory to determine the level of fluctuations in various kinds of crossed-field guns.

A modification has been made on the amplifier for which low noise figures have been reported previously. The gun was changed to the long Kino design. As a result of a failure in bake-out, the gun has not yet been tested. It is expected that the evaluation will take place during the next quarter.

NOISE-FIGURE STUDIES ON FORWARD-WAVE CROSSED-FIELD AMPLIFIER

Prof. T. Van Duzer

A. Sasaki

The aim of this work is to develop understanding of the noise characteristics of forward-wave crossed-field amplifiers to a degree sufficient to permit appreciable noise-figure reductions. The normal mode approach will be used in the study of noise transducing schemes.

The velocity jump through the ideal narrow gap has been analyzed. It shows that there is a coupling among the space-charge waves and the cyclotron waves if the jump in velocity does not happen along the y (transverse) - direction but only along the z (longitudinal) - direction. It suggests that the change in velocity along only the z-direction might give a coupling which is significant in reducing the noise-figure of the space-charge wave amplifier. Three different cases can be considered for change in velocity along the z-direction: the first is an abrupt change in velocity which corresponds to the velocity jump, the second is a periodic change and the third is a gradual change in velocity. The latter two are being studied to find a still more effective noise transducer than the abrupt velocity jump.

The differential equations by which one can analyze the various kinds of transducers have been derived using the normal wave amplitudes, which give a physical understanding of wave coupling. The differential equations have been applied to a simple case in which there is a small periodic spatial change of dc electric fields in both longitudinal and transverse directions. The result is that the cyclotron waves couple and form a pair of waves, one increasing with distance and the other decreasing. It means that this kind of transducer is a dc pump for a crossed-field tube. In continuing the project, the analysis will be extended to other transducers.

CATHODE-REGION STUDIES ON CROSSED-FIELD TUBES

Prof. T. Van Duzer
R. Y. C. Ho

The airm of this work is to study the effect of a crossed magnetic field on potential minimum stability. The procedure is to calculate the shot noise smoothing factor for a wide range of crossed magnetic field values.

As mentioned in the last quarterly report, the method previously used for calculating the shot noise smoothing factor r^2 did not include the effect of magnetic sorting at the potential minimum. Now, the current sorting effect caused by the electric potential minimum as well as the crossed magnetic field is considered. The beam current density J_a is calculated by integrating the velocity distribution function over the region above the critical initial velocity curve in phase space as follows:

$$J_a = \frac{2J_s}{\sqrt{\pi}} a^{3/2} \int_0^{\infty} \dot{x}_0 d\dot{x}_0 \int_{-\infty}^{(\dot{x}_0 - k_2)/k_1} e^{-a(\dot{x}_0^2 + \dot{z}_0^2)} d\dot{z}_0$$

where

$$a = \frac{m}{2kT} \qquad k_1 = \frac{\omega_c}{\Omega} \qquad k_2 = -\frac{2\eta\nu_m}{\Omega x_m}$$

$$\Omega = \sqrt{-\frac{2\eta\nu_m}{x_m^2} - \omega_c^2}$$

The ratio of beam current density to emission current density J_a/J_s is calculated with respect to the different crossed magnetic field B values for a given space-charge-limited condition, namely, $V_m = -0.12$ volts and $X_m = 0.81 \times 10^{-5}$ m, which is shown in Fig. 1. It shows that in the presence of crossed magnetic field more electrons are turned back to the cathode and for small enough magnetic field the ratio J_a/J_s approaches the ordinary diode current sorting limit, $J_a/J_s = \exp(e\nu_m/kT)$. Furthermore, a relation for the perturbation of beam current density due to the potential minimum perturbation in the presence of crossed magnetic field has been derived. It is seen that

$$\Delta J_a = B_m \left\{ -\frac{1}{4\Omega x_m \alpha} \sqrt{\frac{\pi}{\alpha}} \left[\frac{1}{2} + \int_0^{\theta_0} \phi(\theta) d\theta - \theta_0 \phi(\theta_0) \right] + \frac{1}{2\alpha}\left(1 - \frac{\beta}{2\Omega x_m}\right) e^{\frac{-\alpha\beta^2}{4}} + \frac{\beta}{2}\sqrt{\frac{\pi}{\alpha}}\left(1 - \frac{\beta}{4\Omega x_m}\right)\left[\frac{1}{2} + \int_0^{\theta_0} \phi(\theta) d\theta\right] \right\} \Delta \nu_m$$

where

$$\phi(\theta) = \frac{1}{\sqrt{2\pi}} e^{-\theta^2/2}$$

$$\alpha = a\left(1 + \frac{1}{k_1^2}\right)$$

$$\beta = \frac{2k_2}{1 + k_1^2}$$

$$\theta_0 = \beta \sqrt{\frac{\alpha}{2}}$$

$$\gamma = \frac{k_2^2}{1 + k_1^2}$$

$$\beta_m = \frac{3a^{3/2} J_s}{\omega_c x_m} \sqrt{\frac{2}{\pi}} \, e^{-\alpha[\gamma - (\beta/2)^2]}$$

The perturbation constant $\Delta J_a / J_s \Delta \nu_m$ is also calculated with respect to the different magnetic fields for the same space-charge-limited condition as shown in Fig. 2. It shows that the perturbation constant decreases with the increase of magnetic field, and it approaches ordinary diode limit

$$\frac{\Delta J_a}{J_s \Delta \nu_m} = \frac{e}{kT}$$

for the small magnetic field.

With the consideration of the effect of magnetic field on potential-minimum behavior as described above, the shot-noise smoothing factor r^2 is calculated with respect to the different magnetic fields for a given space-charge-limited condition. The current generation is displaced from the center of the stream (where the perturbation field is calculated) by an amount sufficient to give the correct value of the ordinary diode. Two kinds of calculations have been made: (1) the transverse displacement Z_m is kept constant, namely, $Z_m = 0.34 \; 10^{-4}$ m; (2) $Z_m = 0.34 \times 10^{-4} (1 - e^{-221/B})$, as shown in Fig. 3. and Fig. 4 respectively. Fig. 3. shows that the shot noise smoothing factor is less than unity for the magnetic field range that we considered, and for the magnetic field $B \leq 200$ gauss it is almost equal to the shot noise smoothing factor of the ordinary diode, namely $r^2 = 0.01$. Fig. 4 shows that $r^2 > 1$ for $B \geq 500$ gauss. That is, the temperature-limited shot noise is enhanced by the space charge instead of smoothed. The reason for doing the second kind of calculation is that for large enough magnetic field more electrons travel through small cycloids near the cathode before they return to cathode and those electrons will effect the electric field at the cathode of their own part very much.

In continuation of this work we will use more streams from one segment of the cathode to eliminate the errors brought by discreteness, and will take more electron trajectories for each current generator at the cathode in order to simulate the electrons which pass through different cycloids before they either reach the exit plane or return to the cathode.

CHARACTERISTICS OF THE SMOOTH-BORE MAGNETRON

Prof. C. Susskind
K. Mouthaan

The objective of this research is to give a theoretical description of the static characteristics of the smooth-bore magnetron. The motion of the electrons in the interaction space is described as diffusion; the diffusion coefficients transverse to the magnetic field have been obtained. On the basis of the diffusion theory, the following expressions for the space-charge density p, the current field E, the anode current density J_a, and the circulating current per unit axial length, i_c, have been found:

$$\rho = -\frac{\epsilon_0 V_a}{6\gamma d^2} \frac{1 - \frac{y}{d}}{\left[\frac{y}{2d}\left(1 - \frac{y}{2d}\right)\right]^{2/3}},$$

$$E = -\frac{V_a}{Vd}\left[\frac{y}{2d}\left(1 - \frac{y}{2d}\right)\right]^{1/3},$$

$$J_a = \frac{g\epsilon_0}{6\eta\gamma^3} \frac{1}{d^5} \left(\frac{V_a}{B}\right)^3,$$

$$i_c = \frac{\alpha\epsilon_0}{3\gamma^2} \frac{V_a^2}{d^2 B} .$$

In these expressions, d is the cathode-anode spacing, y the distance from the cathode, V_a the anode voltage, B the strength of the magnetic field, ϵ_0 the permittivity of vacuum, and N the charge-to-mass ratio of the electron. The numerical constants γ and α are

$$\gamma = 0.5300,$$
$$\alpha = 0.5953.$$

The constant g is given by the theory of the diffusion; the value of g is 0.06.

So far, the expressions for the space-charge density p and the electric field E have been compared with the available experimental evidence. The agreement of the theoretical results with the experimental results is good. Most conclusive for the confirmation of the diffusion theory will be the comparison of the predicted anode current with the experimentally observed anode current, since here the constant g is involved. This comparison is now in progress. Further, attention is being devoted to the refinement of the diffusion theory.