A PROPOSED MECHANISM FOR THE BROADBAND NOISE IN LONG CROSSED-FIELD GUNS

by

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Guns used to produce beams for crossed-field microwave amplifiers can be broadly divided into two categories. If the width of the cathode in the direction normal to the magnetic field is small compared with a cycloid length, the gun is called <u>short</u>. Many practical guns, especially for high-power devices, have cathode widths which are comparable with, or even much larger than, a cycloid length. These <u>long</u> guns have been found to produce a beam with much greater broadband noise when operated space-charge limited than when temperature limited.[1,2] The possibility of operating with a temperature-limited cathode is not available in practice so the reasons for high noise under space-charge-limited conditions are of considerable importance. In this note we wish to propose a mechanism for the noise generation and give some evidence for the proposition.

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Trajectory calculations have been made for a particular type of long gun. This gun was designed by G. S. Kino[3] on the basis of a theoretical flow in an infinite diode. It shows promise of being very important for high-power devices since, in principle, it can be made arbitrarily wide and excessive cathode current densities can be avoided. The trajectories in an infinite crossed-field diode, according to the single velocity theory, are parabolas if all charge leaves the cathode with a particular value of initial normal velocity and zero transverse velocity. This flow is the basis of the long-gun design. As has been pointed out by Kino, these initial conditions do not fit with the existence of a Maxwellian distribution of normal and transverse velocities at a real cathode. The argument is made that if the required initial velocity is in the range of thermal velocities, it should be just as good a value as is zero.

To see what actually transpires, we have attempted to make trajectory calculations, taking account of the initial distribution of velocities. The Litton resistance network was used to find the potential distributions. Trajectories were calculated on an IBM 7090 computer. We chose to use the parameters of the gun studied by Midford and Kino.[2] The calculations were made for two different conditions of current limitation. In one case, the saturation current was set to five times the cathode current prescribed for the gun. In this case a potential minimum exists in front of the cathode and the current is limited to approximately the design value. In the second case the saturation current was set to the design value of cathode current. In the theory, a zero field exists at the cathode surface: the computer interpretation of the voltages on the resistance board for the latter case matched this condition quite well. In this case there is very little sorting of the emission current. To permit increasing the scale, only the left one-third of the cathode was simulated. A dummy accelerator was inserted along theoretical equipotentials since the actual accelerator did not fit on the resistance network with the enlarged scale.

At each of 23 points along the cathode, 34 velocity classes were considered. The trajectory followed by the median electron of each class was calculated. The calculations are necessarily iterative. The first approximation for potential distribution was obtained from a Monte Carlo calculation using the program developed by Pollack.[4] Trajectories using the second, third, and fourth approximations for the space-charge distribution for the case with a potential minimum are shown in Fig. 1. It is seen that there are large differences between successive steps of the iteration; there appears to be no evidence of convergence. The trajectories for the case with no potential minimum are shown for the third and fourth space-charge approximations in Fig. 2. The trajectories plotted in these figures are representative; some were omitted for clarity. Only a partial plot of the trajectories for the second space-charge approximation was made but the results were similar to those of Fig. 2a. We note that there is little difference between the trajectories of Figs. 2a and 2b. The calculation appears to converge.

The proposal we wish to make for a mechanism which explains the high noise in space-charge-limited long guns is suggested by the lack of convergence of the trajectory calculations described above for the case with a potential minimum. For the purpose of this proposal we consider the beam above the cathode to be divided into two parts: (1) the low-velocity region around the potential minimum, and (2) the beam beyond the minimum. The configuration and density of the charge cloud beyond the potential minimum strongly determines the shape and depth of the minimum and, therefore, the current and electron velocities passing into the beam beyond. If, in turn, these current and velocity changes lead to sufficiently important changes of the charge cloud, a feedback, leading to instability, is possible. The lack of convergence of the trajectory calculations when a potential minimum is present appears to be a zero-frequency manifestation of this instability. On the basis of the above argument, one would expect the observed convergence of trajectories and freedom from instability for the case in which there is little sorting action in the neighborhood of the cathode. The proposed mechanism would be expected to produce a broadband noise, as is observed, since a wide range of transit times are involved in the process.

It should be noted that trajectory calculations for short guns have converged.[5, 6, 7] In these calculations the cathode current depends on the fields near the cathode so the sorting action is present. Furthermore, rather than the potential minimum being unstable in the short gun, appreciable smoothing has been observed recently.[8] Arnaud and Doehler[9] have reported a reduction of noise when a grid is placed over a space-charge-limited cathode. This can be explained on the basis of the proposed mechanism. The grid would act to shield the potential minimum from the field fluctuations resulting from shifting beam positions, thus opening the feedback path. Finally, it may be of interest to note that trajectory calculations made for a cylindrical magnetron with an r-f field by Lehr, et al.[10] exhibited a behavior with respect to the type of current limitation similar to those described above. That is, when the current was space-charge limited, 34 successive iterations yielded no convergence. When temperature was limited, convergence was attained in a few steps. Obviously, there are differences between the model for the magnetron calculations and the long-gun model of this paper but the similarities between the models and between the results are worth noting.

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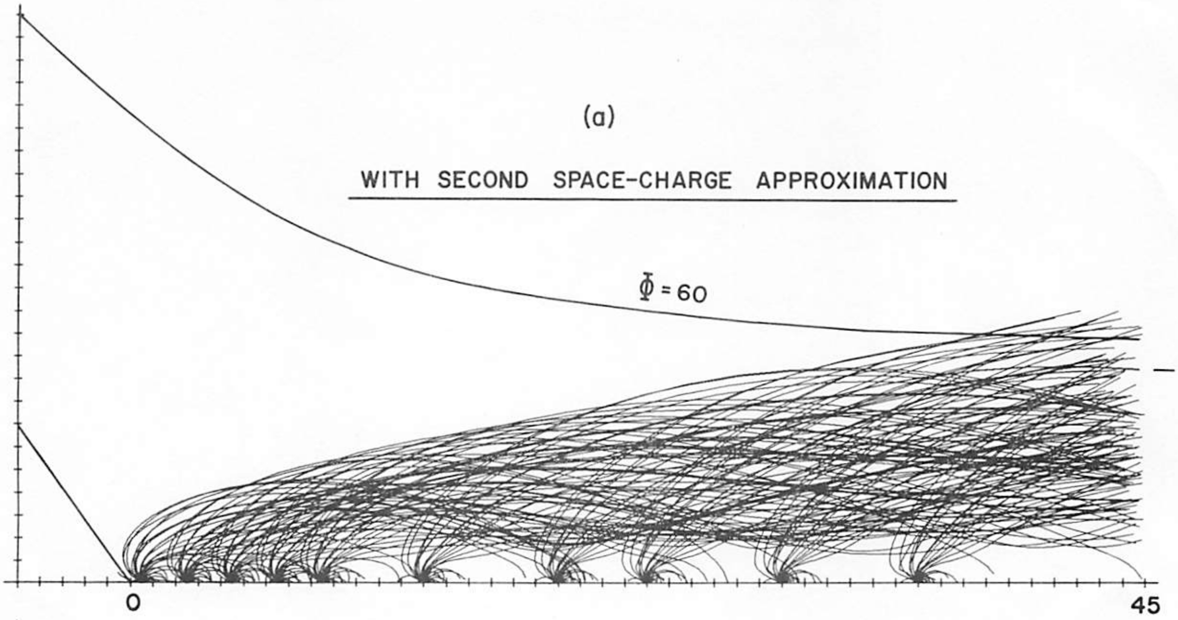
FIGURE CAPTIONS

Fig. 1. Three successive steps in iterative calculation of trajectories in a long Kino gun with potential minimum taking account of initial velocities.

Fig. 2. Two successive steps in iterative calculation of trajectories in a long Kino gun without potential minimum taking account of initial velocities.

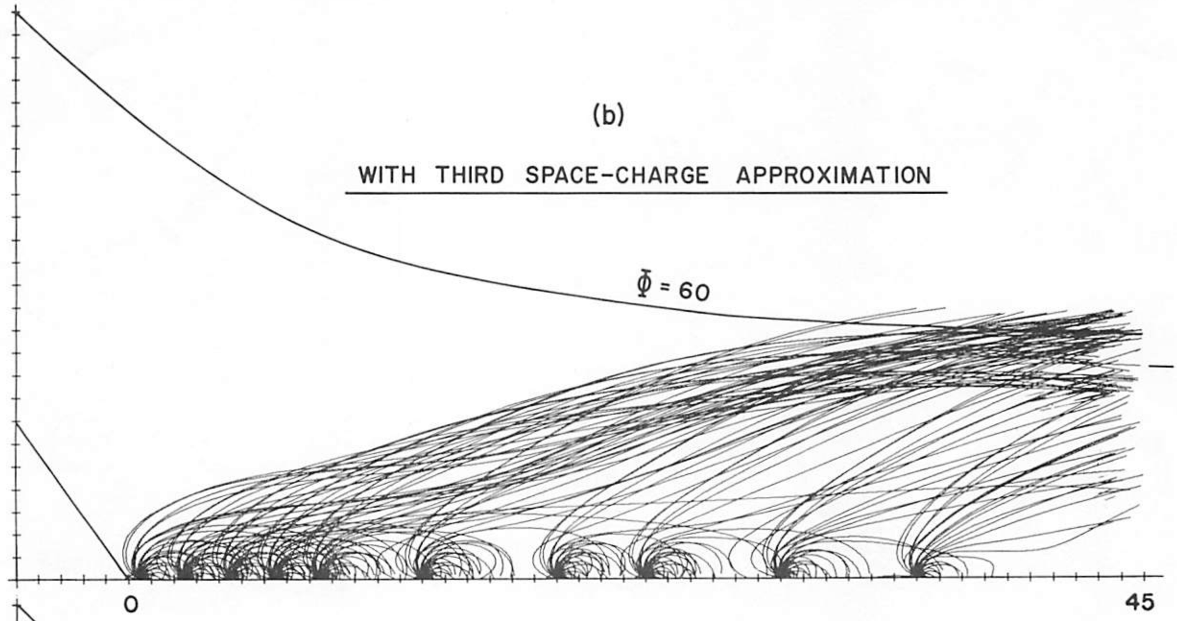
(a)

WITH SECOND SPACE-CHARGE APPROXIMATION



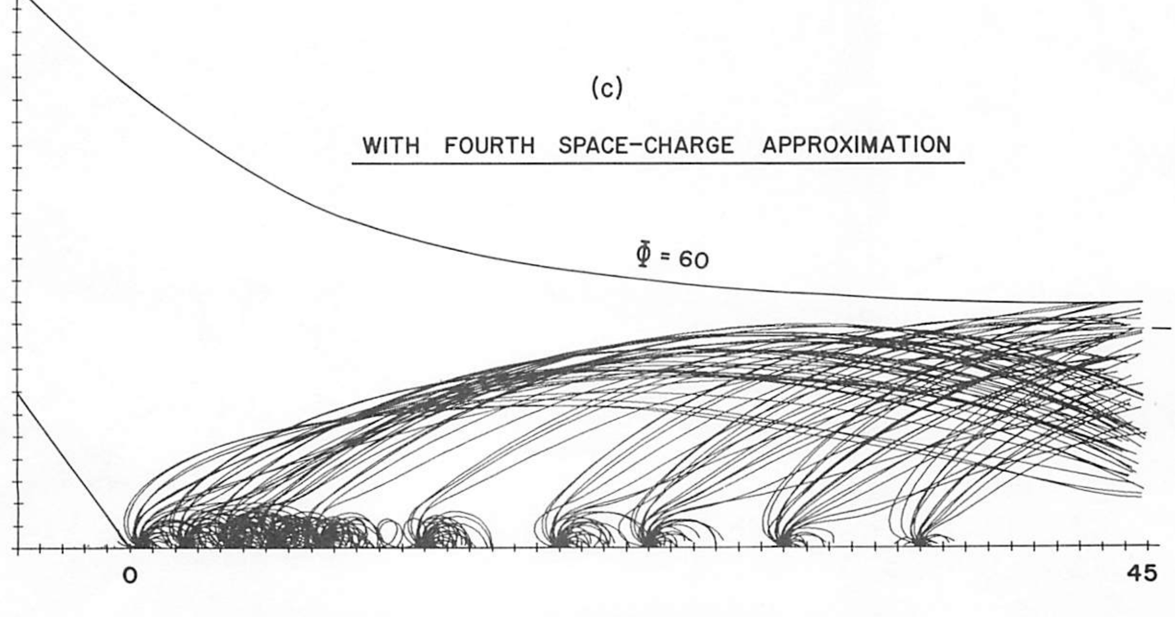
(b)

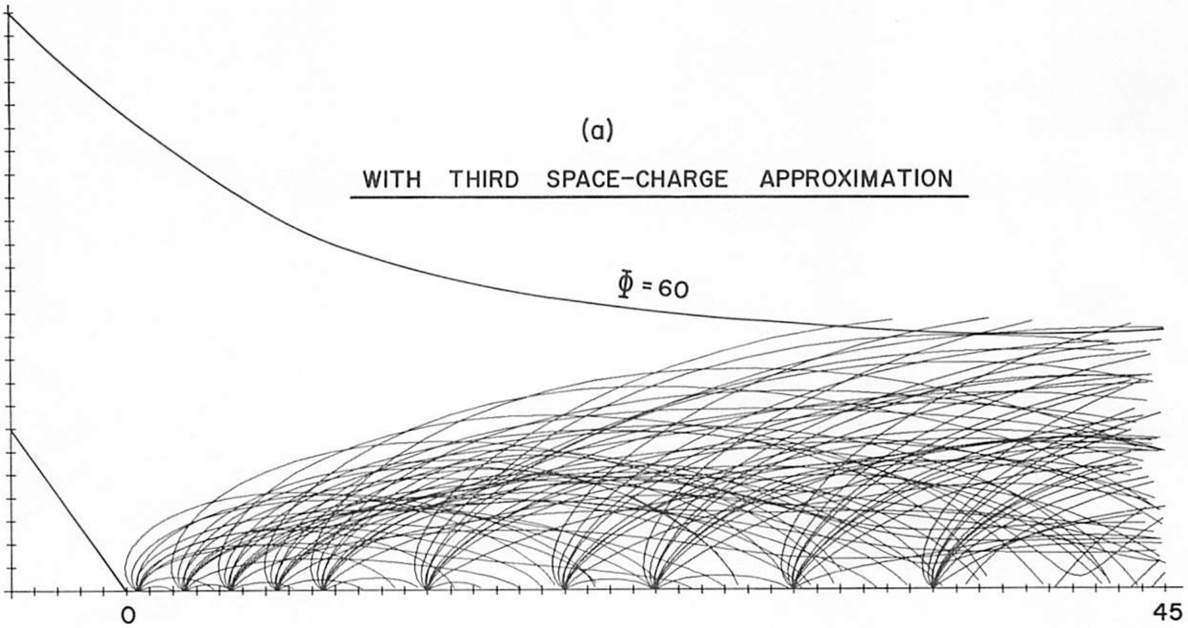
WITH THIRD SPACE-CHARGE APPROXIMATION



(c)

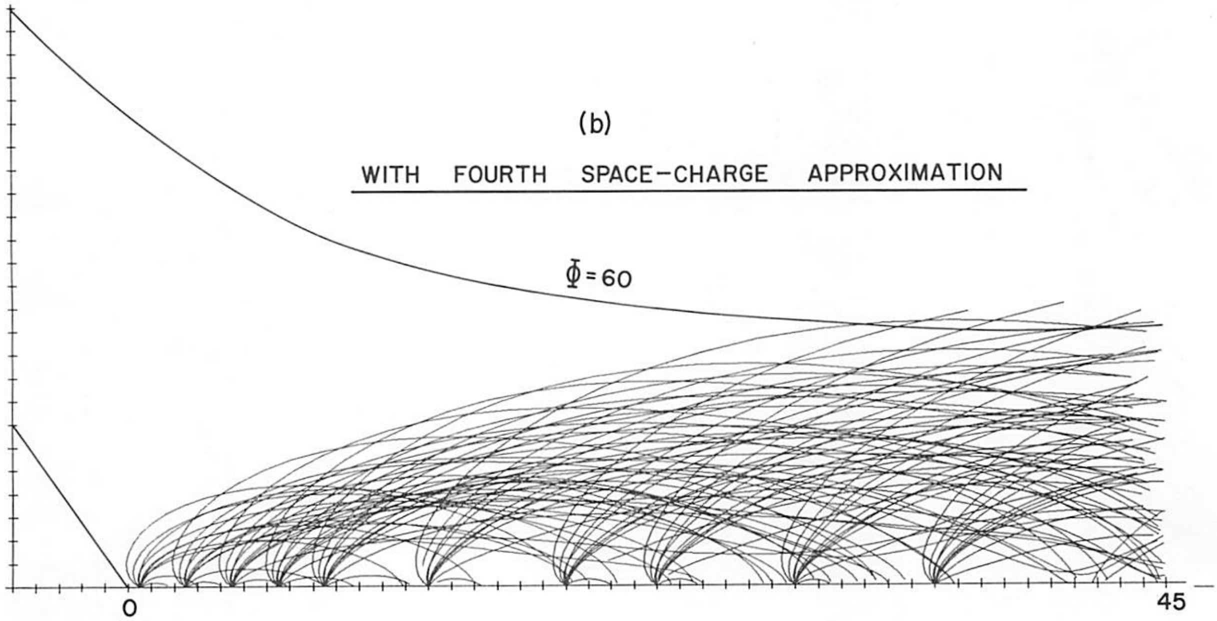
WITH FOURTH SPACE-CHARGE APPROXIMATION





(a)

WITH THIRD SPACE-CHARGE APPROXIMATION



(b)

WITH FOURTH SPACE-CHARGE APPROXIMATION