Beam Focusing in a Satcom TWT Including Thermal Electrons

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In a Traveling Wave Tube (TWT), it is critically important to minimize the amount of beam current that intercepts the delay line. This is especially important for TWTs with helical delay lines, as these flimsy structures have a very limited thermal capacity.
The beam is radially de-focused by its own space charge field. In order to counteract this force, a magnetic field coaxial with the beam axis is applied.
It is therefore necessary that the beam rotates to produce a focusing force in combination with the axial field. The beam rotation is created by the onset of the magnetic field, as, according to Busch's theorem, the rotation is given by the change in magnetic flux the beam has experienced since its emission from the cathode.
Instead of a solenoidal field, a system of periodic permanent magnets (PPM) is used in satcom TWTs, in order to limit the magnetic field to the beam area and due to efficiency and weight considerations. It behaves much like a solenoidal field, if the period is not too long.
The current density that can be drawn from the cathode is limited, especially considering the required lifetime of satcom TWTs (15y). It is therefore necessary to use a cathode that is much larger than the delay line, and to compress the beam with suitable electrodes. Figure 1 shows schematically the beginning of the focusing system with the cathode, the focusing electrodes in the gun and the start of the PPM stack.
The beam focusing is much degraded at the output of the TWT, because there the beam is strongly modulated due to the interaction with the electromagnetic wave. Also, the beam decelerates, because a significant part of its kinetic energy has been converted to the rf signal. For these reasons, the space charge density is locally increased (typically by a factor of 2-3). When designing the focusing system by numerical modelling, it is therefore necessary to chain a simulation of the electron gun (usually an electrostatic trajectory tracker) with a simulation of the beam-wave interaction.

Historically, the design of the focusing system usually assumes that the electrons start with zero velocity from the cathode. However, this is not accurate. The electrons do have an average initial kinetic energy of roughly 0.2eV, part of which is in transverse direction ("thermal" electrons). This is a major cause of disorder in the beam, and much complicates the design of the focusing system.
Thermal electrons are included in simulation by emitting a set of particles from each emission point (5 is an efficient number) instead of only one. The initial velocities of these particles are chosen to represent the (continuous) distribution of emission angles, which obeys Lambert's Law, as closely as possible. The effect of the thermal electrons is shown exemplary in Figure 2 and Figure 3.
In order to achieve acceptable focusing with thermal electrons, the strength of the first few magnets of the PPM stack has to be tuned carefully. Figure 4 shows an acceptable beam in the delay line under rf drive.

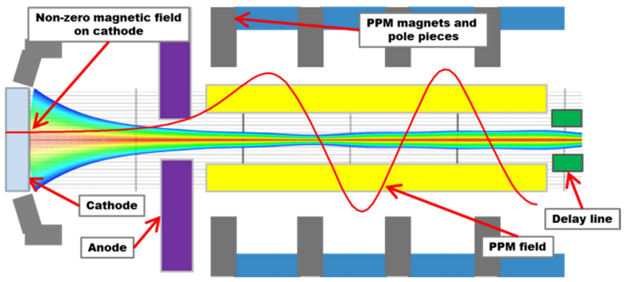

Figure 1 Schematic of the electron gun and the start of the PPM stack

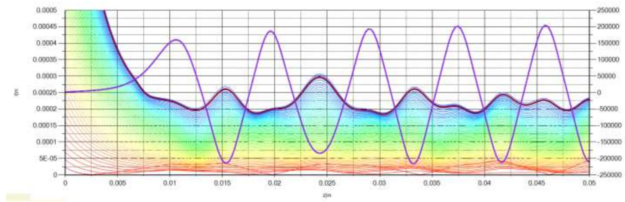

Figure 2 Electron gun trajectories without thermal electrons

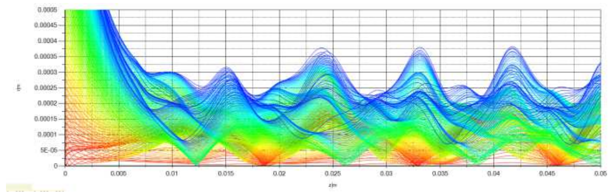

Figure 3 Electron gun trajectories including thermal electrons

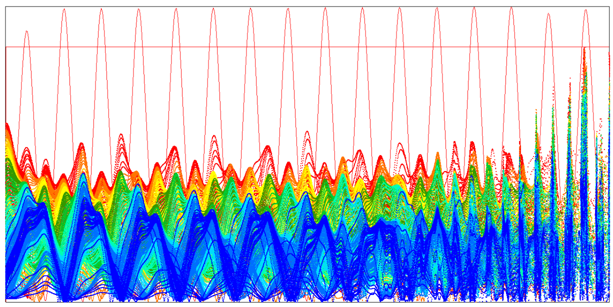

Figure 4 Thermal electron trajectories in the delay line of a satcom TWT with rf drive