Microwave Tube Electron Gun Simulators: A Cost-benefit analysis

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Abstract: *To evaluate the computational time performance of three computational tools: EGUN2, XMGUN and CST, a 0.47μPerv, 1kV axis-symmetric gridless electron gun, working under the space charge-limited flow, was analyzed. It was observed, between the three codes, a good electric current agreement but the 2.5D codes presented better time responsive.*

Keywords: TWT; klystrons; electron gun; space-charge-limited flow.

Introduction

Dedicated 3D electron gun codes are indispensable design tools, especially those who work with multiple electron beam emission, grids, and shadow-grids. The use of multi-beam, an emerging technology, overcomes some limitations observed in conventional tubes such as larger bandwidth and lower high voltage operation. Grids and shadow-grids are indispensable when it is necessary to operate the tube in pulsed mode such as in radar and in electronic countermeasure systems.

It is well known that along the past 30 years many electron gun codes [1]-[4] were developed and became important tools to reduce linear microwave tubes design cost and time [5]. Nowadays, highly complex electron gun geometries can only be modeled using 3D codes. On the other hand, 2D axisymmetric electron gun codes still in use providing to tube designer a good electron gun behavior insight.

In this work three tools were used to investigate an axis symmetric electron gun beam behavior operating under the space charge limited flow: CST, EGUN, and XMGUN. The first one is a 3D while the last ones 2.5D tools. Relevant aspects such as interface, pre-processing, running-time and beam characteristics, for each tool, are presented and discussed.

The electron gun physical characteristics

Relevant geometric and physical electron gun parameters, used in all simulations, by the three tools, are presented in TABLE I.

TABLE I – Electron gun relevant parameters

Parameter	Value	Unit
Cathode radius r_c	13.90	*mm*
Cathode radius disc r_k	6.2	*mm*
Electrode focusing angle θ	46	degrees
Cathode-anode separation	36.28	*Mm*
Anode voltage	1.0	*kV*
Compression rate	2.84	---

Fig. 1 shows the results of the gun simulated with XMGUN.

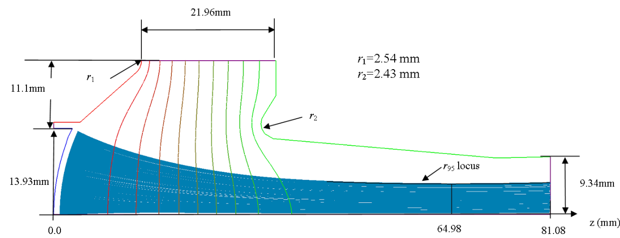


Figure 1. The electron gun geometry shown by XMGUN, and also used by EGUN and CST. 100*V* equipotentials, beam waist size and position and r_{95} *locus* are also presented. It was observed an electric current of 19*mA*.

The Tools

(a) EGUN

The EGUN version, released in 1993, was used to model the electron gun under analysis. In the EGUN, the Poisson's equation is solved by the finite difference method and particle trajectory equations are fully relativistic taking into account electric and magnetic fields. In order to design the electron gun and visualize the results two others software are necessary: GPED and Eplot2 [1].

(b)XMGUN

It was developed in 2009 [3] and makes use of the finite element method associated to the conjugate gradient method to solve the Poisson's equation. To establish the macro particles non-relativistic trajectory, the particle path equation (1) is solved using an in-house forth order Runge-Kutta integrator with constant step. The path equation writes

$$\frac{d^2 r_i}{dz_i^2} = \frac{1}{2\psi_i}\left[1+\left(\frac{dr_i}{dz_i}\right)^2\right]\left(-E_{r_i} + E_{z_i}\frac{dr_i}{dz_i}\right), \qquad (1)$$

where the subscript i represents the ith macroparticle path, r_i and z_i are its radial and axial positions, respectively. E_{r_i} and E_{z_i} are the electric field components applied over the ith macroparticle which are obtained from $\vec{E} = -\nabla\psi$, where ψ is the electric scalar potential.

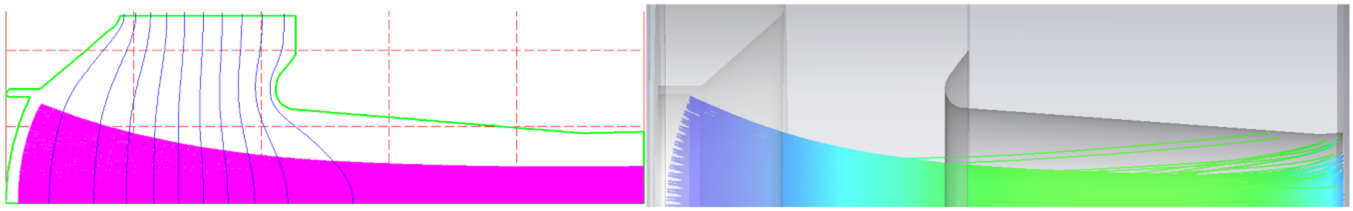
The only third party software needed by XMGUN to design electron guns is a freeware mesh generator denominated Easymesh [6].

(c) CST

CST, a finite integration code, was developed to provide computational solutions for all kind of 3D electromagnetic problems. The CST Particle Studio is the specific module that leads directly to particle dynamics in 3D electromagnetic fields. As a state of the art tool, it also performs Multi-CPU and Multi-GPU computing [4].

Results

Table II summarizes for each tool the simulation parameters, such as number of cell and particles and time response. All simulations were run on an Intel Core2 Q6600 CPU at 2.6MHz with 4Gb DDR2 under XP. The EGUN simulation time was used as reference to the others tools considering an electron gun emitting 400 particles. Regarding EGUN, it was observed that even when the number of particles were reduced to 100 the electric current remained the same, that is I=0.017 A, while the computational time to solve was reduced by a factor of 3.52. This improvement is justified because of the reduction of the amount of text file sent to the output window, especially those regarding the number of particle.



(a) (b)

Figure 2. The EGUN (a) and CST (b) electron gun simulation results.

TABLE II – Electron Gun simulations results

	EGUN	**XMGUN**	**CST**
***I* (*A*)**	0.017	0.019	0.015
μPerv	0.52	0.60	0.47
Mesh	5171 nodes	39062 cells	256000 cells
Particle number	400	400	1513
Time simulation (sec)	95	95	95

Using XMGUN, it was observed when the number of particles was reduced to 100, the electric current remained the same and the time to solve this problem was reduced by a factor of 1.06. This indicates that most of time is dedicated to solve the Poisson's equation rather than the ray tracing the particles. XMGUN automatically furnishes r_{95} *locus* and the beam waist size and position that were 4.9 *mm* and 64.98 *mm*, respectively, see Fig. 1.

It was observed using CST, Fig. 2b, an electric current of 15 *mA* and some particles hitting on anode surface. Keeping the same number of particles, the mesh was refined and, as result, no longer was the anode hit by the particles but the time to solve this problem was increased by a factor of 2.4 and the electric current grows to 0.018*mA*. Despite this, CST warns that the mesh is still greater than particle size and that would lead to inaccurate results. To solve this, the mesh was further refined and the particles density was set to automatically adjust to the mesh. The sign was eliminated but the number of particles was increased to 21301 and the solver took over 20min. In this case, CST was almost 13 times slower than EGUN, and the gun furnished an electric current of 18 *mA*.

Conclusion

For a given electron gun geometry, it was analyzed the time performance of three tools: EGUN, XMGUN and CST. At all simulations, it was observed the attempt to improve CST current response, the simulation time increased significantly implied in an increasing time to the tool due to the increase of mesh cells and particle number. On the other hand, even decreasing the number of particles a good electric current agreement was observed for EGUN and XMGUN. Considering time processing as a concern and a design need, the use of 2.5D tools seems to be a good option whenever the device is axisymmetric.

Acknowledgements

This work was supported in part by FINEP (Research and Projects Financing) under contract 01.06.0911.01.

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