Computer-Aided Design and Optimization of High-Performance Vacuum Electronic Devices

SBIR Phase 1 *Option*
Final Report

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Executive Summary

During the Phase 1 Option we have focused on developing a suitable model for a more realistic optimization of the collector that was analyzed at the end of the Phase 1 project (Fig.1). Of particular interest are the minimum mesh density and the characteristics of the secondary populations that yield converged, or nearly converged, solutions in MICHELLE.

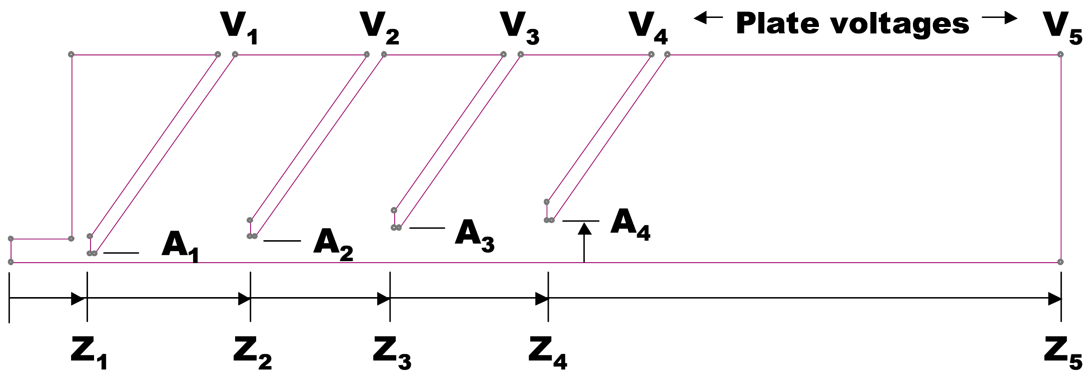

Fig. 1. Idealized collector model studied with optimization system. Parameters that were available for optimization included the plate voltages (V_1-V_5), the plate apertures (A_1-A_4), and the plate axial positions (Z_1-Z_5).

The result of our investigation was the determination that a modest-sized mesh (~550K elements), together with three generations of secondaries and 10 relaxation cycles, yields reasonably converged results. These parameters were used for an optimization of the collector.

This optimization resulted in a structure that showed an increase of over 24% in efficiency as compared to the initial design. However, the optimized parameter values showed some unusual characteristics that may reflect a local, not global, minimum. This will need further study during the Phase 2 project.

Detailed Optimization

As a concluding calculation for this project, the collector geometry shown in Fig. 1 was optimized using Nelder-Mead. Fixed model parameters used in this optimization included an element size that produced meshes with approximately 550,000 elements, 3 generations of secondary particles, 10 relaxation cycles, and approximately 3000 particles in the spent beam. Each analysis in the optimization took approximately 10 minutes on a Pentium 4 2.4 GHz machine. All 14 parameters we optimized at once, each with an initial +/- 5% range centered on their initial values. However, for unknown reasons, Mathematica looked outside of this range, with the maximum deviation from an initial parameter value of 17%.

A prior optimization using a much smaller computational mesh (11,000 elements) and no secondaries showed an increase in efficiency of 14% in 261 analyses. This analysis showed an increase of over 24% in 222 analyses as shown in Table 1. Fig. 2 shows the optimized geometry and Figs. 3 and 4 show the particle trajectories for both the initial and optimized structures.

Step	Initial	Optimized
Efficiency	**47.33%**	**71.39%**
V1	-2327	-2562.68
V2	-3421	-3424.27
V3	-3987	-4505.57
V4	-4998	-4420.09
V5	-5750	-6406.03
Z1	0.1715	0.1422
Z2	0.7339	0.6614
Z3	1.0176	1.0984
Z4	1.3244	1.2440
Z5	2.2756	2.3365
A1	0.0352	0.0353
A2	0.1078	0.1206
A3	0.1460	0.1244
A4	0.1812	0.1887
# of runs		222

Table 1. Initial and optimized model parameters for 550,000 element mesh. All runs were made with 3 generations of secondaries, linear field interpolation, and with magnetic fields.

Fig. 2. Cross section of optimized collector geometry.

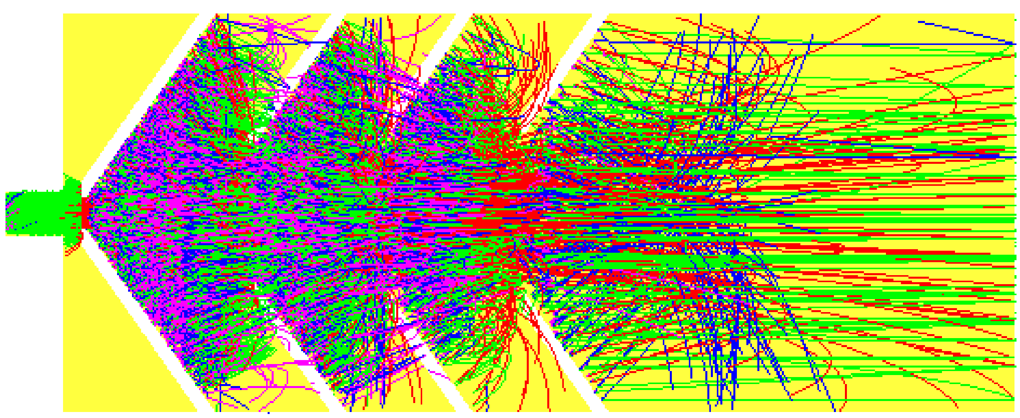

Fig. 3. Particle trajectories in initial collector geometry. The colors of the particles represent their generation.

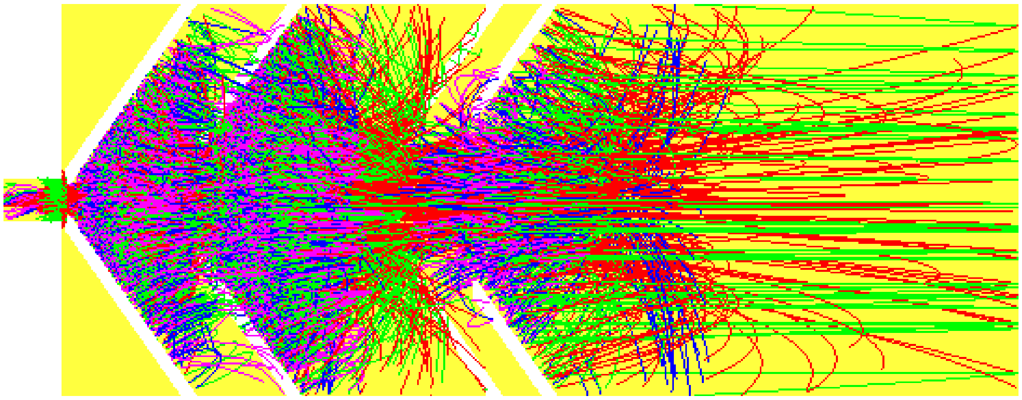

Fig 4. Particle trajectories in optimized collector geometry. The colors of the particles represent their generation.

Of particular interest is the observation that the voltage on plate 4 (V4) is smaller than the voltage on plate 3 (V3). This is the result of Mathematica failing to obey the constraints that were placed on the parameter values. Of additional interest is the relatively close proximity of plates 3 and 4. It is likely that Nelder-Mead became trapped in a local minima and that another algorithm, such as differential evolution, would avoid this minima. Although time constraints did not allow us to optimize this structure with differential evolution, additional work on constraints and optimization algorithms will be performed in Phase 2.

Detailed Analysis of the "Optimized" Structure

The model that resulted from the above optimization was subjected to a number of additional analyses to confirm the result. Specifically, the size of the computation mesh was increased to determine if the result was sensitive to the mesh. These results are illustrated in Table 2. Quite reasonable convergence is seen, with a mesh containing elements with less than half the edge length of the original mesh yielding an efficiency within 1% of the original.

Element Count	Efficiency	Analysis Time (min)
578,000	71.39	10
1,432,000	71.12	23
2,605,000	70.83	37
5,830,000	70.48	82

Table 2. Efficiencies for various computational meshes. All runs were made with 3 generations of secondaries, linear field interpolation, and with magnetic fields.

Likewise, this model was analyzed for additional relaxation cycles. These results are illustrated in Table 3. It is clear that the 10 relaxation cycles that were run during the optimization were sufficient to produce a reasonably converged result.

Relaxation Cycles	Efficiency	Analysis Time (min)
10	71.3895	10
20	71.3953	15
30	71.3881	20

Table 3. Efficiencies for various numbers of relaxation cycles. All runs were made with 3 generations of secondaries, linear field interpolation, and with magnetic fields.

Conclusions

A detailed optimization was performed over 14 geometric and voltage parameters of a collector. The analyses involved 3 generations of secondaries, 10 relaxation cycle, and approximately 550,000 computation mesh elements. The resulting optimized structure show an increase in efficiency of over 24% from the initial structure.