Collector Efficiency Enhancement in TWTs through Beam Refocussing Section

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Abstract: Travelling wave tubes are generally known for their broadband operation, high gain and high efficiency of ~60%. Typically, such high efficient TWTs are highly desirable for space applications in satellite transponder. The overall efficiency of the TWT is increased by increasing any of its constituent – electronic, circuit or collector. Collector efficiency enhancement is an easier and effective way of increasing the overall efficiency. Here, to increase the collector efficiency, optimization of the magnetic field profile in beam refocusing section (BRS) has been performed. The percentage magnetization of the three periodic permanent magnets (PPM) in the BRS section has been changed to maximize the collector efficiency. The corresponding collector potential optimizations have been performed using genetic algorithm and the results have been compared with the ones obtained by manual optimization.

Keywords: multi-stage depressed collector, collector efficiency enhancement, beam refocusing section, genetic algorithm based optimization

INTRODUCTION

Travelling wave tubes (TWTs) offer unique combination of broad band operation, high efficiency and high gain making it a preferred choice for space applications [1]. The requirements imposed on the space TWTs are very severe and demands very high overall efficiency. Although there are several mechanisms to improve the overall efficiency of the TWT, the dependence of collector efficiency on the overall efficiency is very significant as shown in fig. 1.
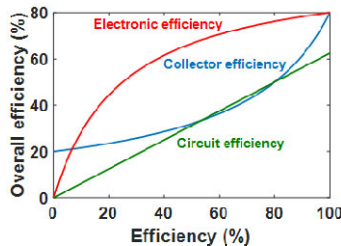

Fig. 1. TWT overall efficiwncy versus elelctronic, collector and circuit efficiencies

Increasing the collector efficiency is facilitated by several techniques such as (1) multiple stages of depression, (2) modification of electrode geometry, (3) variation of electrode material, (4) optimization of leakage magnetic field [2], etc. Among these methods, the method of optimization of leakage magnetic field is comparatively least explored. Providing suitable magnetic field in beam refocusing section (BRS) which extends from the termination of output helix till the beginning of first electrode of MDC, defocuses the electron beam after its energy transfer process. The leakage of the magnetic field from the BRS helps in proper distribution of electrons within the MDC and, hence, in efficiency enhancement. Optimization of the leakage magnetic field

within the collector region can be done by (1) changing the percentage of magnetization of the magnets in the beam refocusing section (BRS) or by (2) choosing different magnetic material for the collector adapter and envelope [3]. Here, in this work, the optimization of the leakage magnetic field using BRS magnets has been employed. The details about the methodology adopted and the result obtained by the optimizations are presented in the subsequent sections.

METHOLOGY

The methodology adopted for the study has been shown in the flowchart (fig. 2). The percentage magnetization of the three BRS magnets ($M_{BRS1}\%$, $M_{BRS2}\%$ and $M_{BRS3}\%$ represent percentage of magnetization of the first, second and third BRS magnets, respectively) have been varied and optimized manually. The corresponding magnetic field for each individual combination of these three magnets have been evaluated using MAGFLD [4] and then used in EGUN [5] to estimate collector efficiency. However, this iteration is continued till maximum efficiency is achieved by suitably optimizing the collector electrode potentials. Optimization of collector potentials is highly stochastic and involves a larger search space. Further, manual optimization of collector potentials involves varying one potential at a time, keeping all other three constant and so consumes a lot of time. Hence, genetic algorithm based optimization has been carried out for the collector potentials.
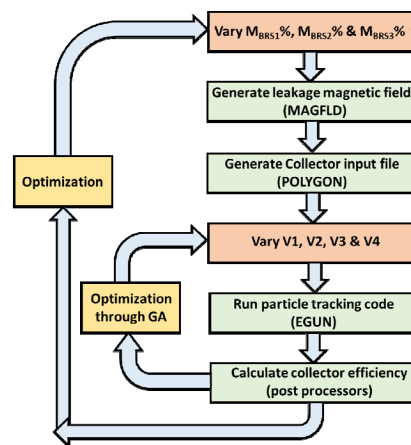
Fig. 2. Flowchart of the methodology employed to perform the optimization studies

RESULTS AND DISCUSSION

The optimization methodology as described in the previous section has yielded in following results. Twenty three different

combination of percentage magnetization had been chosen for the studies. The manually optimized collector potentials for each of the 23 cases are shown in fig. 3. The variation of peak magnetic field and collector efficiency on magnetic field at the entrance of the collector for the 23 cases, is shown in fig.4. It could be observed that the peak magnetic field and collector efficiency follow the same trend with the maximum collector efficiency (82.3%) occurring when magnetic field is close to 0 G. The optimized percentage magnetization of the BRS magnets which yielded in high collector efficiency (of 82.3%) are 70%, 40% and 10% respectively starting from the output coupler. The corresponding optimized collector potentials (with respect to the cathode) for the optimized high collector efficiency are 4470 V, 3810 V, 3330 V and 980 V starting from first to the fourth electrodes.
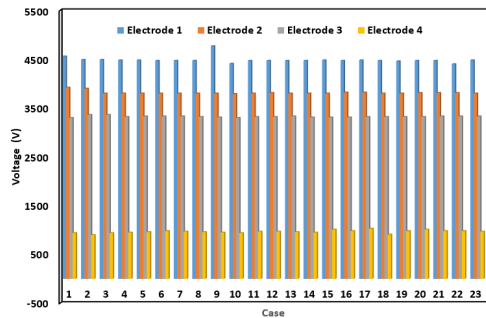

Fig. 3. Manually optimized collector electrode potentials for different combination of BRS magnets magnetization percentages
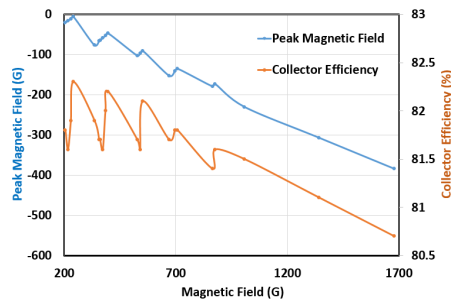

Fig. 4. Variation of peak magnetic field and collector efficiency on magnetic field at entrance of the collector (by manual optimization)

Further improvements in collector efficiency could not be obtained by manual optimization. Hence, genetic algorithm has been implemented for the optimization of the collector electrode potentials. The population size has been fixed to be 24. 50% replacement of the population with the new generation children (obtained by crossover and mutation on the elite parents) and 50% retaining of the elite parents has been done to achieve the objective of maximum collector efficiency with zero back-streaming and body currents. Average collector efficiency computation time for one individual in the population is ~22 seconds. Hence, for a population of 24 individuals, for 50 generations, it takes ~7 hour 20 minutes. The convergence of the genetic algorithm based optimization of the collector potential is shown in fig. 5 with a maximum of ~84%. However, it could be seen that saturation occurs beyond ~40 generations. Hence, for all the

GA optimizations, the total number of generations have been chosen as 50.

This GA based optimization of the collector potentials have resulted in saving of huge optimization time involved in manual optimizations. Further, manual optimization is limited by the number of combinations of potentials simulated and also prone to human bias (maximum collector efficiency obtained by manual optimization is 82.3% only). Moreover, the average manual optimization time ranges between 2 to 4 days for one particular leakage magnetic field case. With the implementation of GA based optimization, further improvements in the collector efficiency of ~84% have been achieved. Also, the collector potential optimization takes a maximum of 8 hours for one particular case and facilitates unattended operation. Hence, this whole BRS magnets optimization study has been completed in less than 10 days.
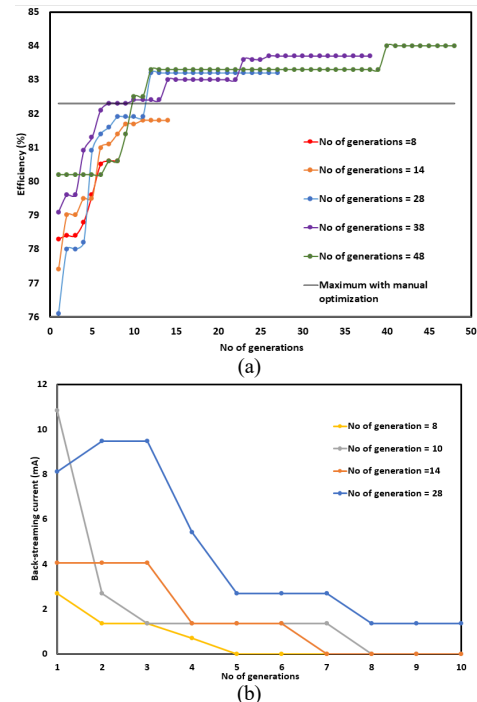

(a)

(b)

Fig. 5. Variation of (a) collector effiency and (b) backstreaming current with respect to the number of generations used in GA optimization

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