Design of Multistage Depressed Collector For Ka-Band 40W High Efficiency Helix TWT

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***Abstract*-Multistage depressed collector (MDC) plays an important role in enhancing overall efficiency of a space TWT. A high efficiency four-stage depressed collector has been designed for Ka band 40W high efficiency helix TWT using EGUN code coupled with In-house developed pre-processor, and post processor modules. The spent beam data has been used from In-house developed SUNRAY 2.5-D code, a large signal model. The collector electrodes geometries and different depressed potentials on four stages have been optimized to enhance the collector efficiency and minimize the back streaming current. Collector efficiency with 4-stage depression using high-density graphite electrodes (with secondary electron emission coefficient (δ) =0.6) has been achieved more than 81%. The back streaming current has also been controlled within 0.7mA, while the total beam current is 75mA. The variation in collector efficiency with the different operating power level of the tube has also been studied.**

I. INTRODUCTION

One of the most versatile microwaves RF power amplifiers is the travelling-wave tube (TWT). The main advantage of TWT is its extremely wide bandwidth operation with high linearity and reliability. The stringent qualifying parameters for space TWTs include the long life, high efficiency, high reliability and high linearity. Multistage depressed collector (MDC) plays a major role in determining the overall efficiency of the TWTs for space applications [1-5]. It is used to enhance the overall efficiency and to reduce the cooling requirements of the tube. During the beam-wave interaction the rf wave interacts with a dc beam and extracts some energy from it and rest of the energy remains within the spent beam. The MDC employs velocity-sorting techniques to direct the high velocity electrons to the stage having greatest depression and slow electrons to the stages having least depression. Due to this principle the MDC recovers most of the power from the spent beam and thereby increases the collector and the overall tube efficiency. Design and development of Ka-band 40W high efficiency (>50%) helix TWT is being carried out at CEERI for space communication. For this tube, a four-stage depressed collector has been designed to recover maximum possible kinetic energy of the spent beam, which has a large variation in electron velocities. Each successive electrode in the collector has been depressed, with reference to body potential, more than the preceding one. The number of stage in MDC is defined as the number of potential on the electrode other than the body potential. The main purpose of a MDC is to sort the electrodes according to their energies and collect them at the lowest possible potential. The potential of the last electrode is usually kept at close to the cathode potential. The amount of power that can be recovered by a collector depends on the nature of spent beam. To recover more power from the spent beam the number of stages in the collector should be increased. But number of stage in the collector is restricted due to the compromise between efficiency, weight, and complexity in fabrication and power supply. Most modern multistage collectors have a maximum of 4-stages. As shown in Fig. 1, up to 4-stage there is a significant increase in the collector efficiency while after stage four it has very small increment in collector efficiency, but at the cost of significant increment in the complexity of the power supply and weight [4-5]. Secondary electrons are the major factor, which cause the degradation in collector performance in terms of reducing collector efficiency, and increase the back streaming current etc. In order to reduce the emission of secondary electrons [5-6] various techniques are suggested like (i) either using electrode material having low secondary electron coefficient like high density graphite or coating of carbon and TiC layers on inner surface of copper electrodes [4-5], [7], (ii) using symmetric, asymmetric magnetic field in the collector region, (iii) using asymmetric collector electrodes [8] etc. This paper presents the design of 4-stage depressed collector for Ka-band 40W high efficiency helix TWT.

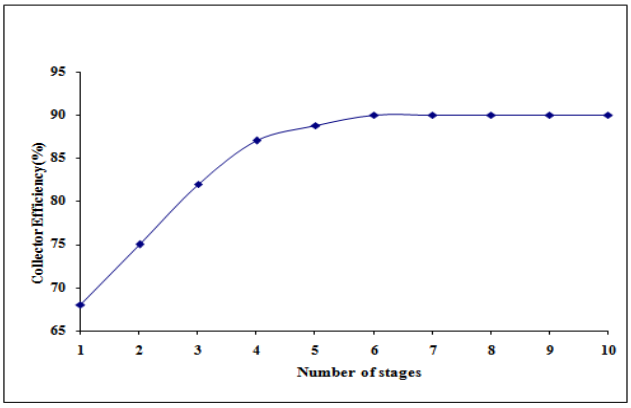

Fig.1 Increment in collector efficiency with the increase in the number of stages

II. APPROACH FOR DESIGN OF 4-STAGE DEPRESSED COLLECTOR

The design of 4-stage depressed collector has been accomplished using code EGUN [9] along with in-house developed pre- and a post-processor [3], [10]. The pre-processor is used to make the EGUN package user-friendly and to generate the starting conditions of the primary trajectories. The post-processor includes the effects of secondary electron emission and analyses the performance of the collector. The spent beam data has been used from In-house developed SUNRAY 2.5-D code [11], a large signal model.

Design of MDC is carried out in the following three steps (i) decided 4-stage depression (in light of Fig. 1), (ii) optimization of electrode potentials that give the maximum theoretical efficiency based on the spent beam distribution curve [3], and finally (iii) optimization of electrode geometry to achieve maximum collector efficiency. The collector efficiency is calculated from the ratio of power recovered to the total spent beam power. Optimisation is done through several iterations by changing the electrode angles, inner and outer diameter of the electrodes, electrode thickness etc. To reduce the secondary electron emission the electrodes are made from high density POCO either graphite (δ=0.6) or the OFHC copper collector electrodes are coated with carbon through RF sputtering or the OFHC copper electrodes are coated with TiC coating (δ=0.9) [6-7].

III. DESIGN OF 4-STAGE GRAPHITE MDC

For the design of Ka-Band 4-stage collector, the initial geometry has been taken from in house developed 4-stage collector for Ku-band 140W space TWT. Potential at different electrodes has been taken with the help of spent beam energy distribution (Fig. 2). There may be slight adjustment of potential at different electrodes. For that a number of iterations have been done to optimise potentials (Table 1) in order to minimize back streaming current and enhance the collector efficiency. Then the number of iterations have been done for optimisation of geometry by changing the electrode angles, inner and outer diameter of the electrodes, electrode thickness etc. Design has been analyzed for all condition i.e. for DC condition (when no input signal is applied), and for RF condition (when input signal is applied).

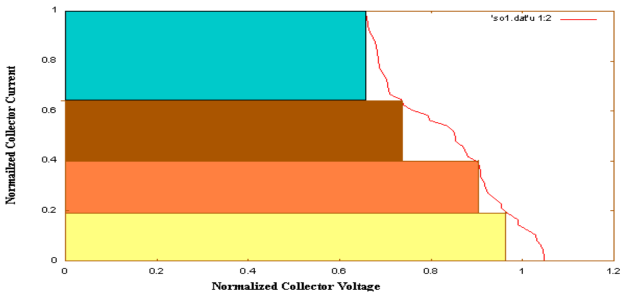

Fig. 2. Power recovered by the 4-stage Ka-band MDC

Table1. Optimised electrodes potentials

Electrode Number	Potential (V)
Body	0
1	2350
2	3600
3	4500
4	5320

A. *Simulation of graphite collector under DC conditions:*

Figs. 3(a) and Fig. 3(b), show the simulated results of graphite 4-stage collector under DC condition. In an ideal case all trajectories should land on the fourth stage under DC condition which is at highest depression potential. The simulated graphite collector efficiency with primary is 87 % (Fig. 3(a)) with no back streaming power, and with secondary electrons, it is 80% with 0.7 mA back streaming (Fig. 3 (b)).

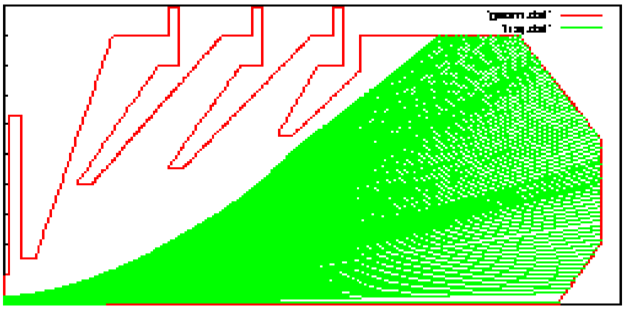

Fig. 3 (a), EGUN simulated graphite collector with only primaries in DC condition (efficiency 87%).

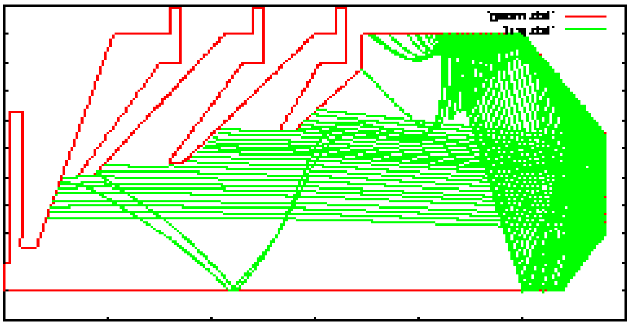

Fig. 3(b), EGUN simulated graphite collector with secondary in DC condition (efficiency 80%).

B. *Simulation of graphite collector under RF condition*:

Collector performance has also been analyzed under the RF condition. Large signal model SUNRAY 2.5D [3],[11] has been used to generate the trajectory data which is made compatible for the simulation of the MDC in code EGUN. Total 96 trajectories have been considered here. Fig. 4(a) and Fig. 4(b), show the EGUN simulated graphite collector under RF Conditions. It is observed that almost all the trajectories landing on the backside of the electrodes. This will reduce the back streaming significantly by recapturing the secondary within the collector.

Simulated result for Primary Analysis under RF condition is given in Fig. 4(a), where collector efficiency is achieved more than **87%.** Fig. 4(b), shows secondary analysis results, where efficiency is more than **81%** and back streaming current is only **0.6mA**. The performance of designed collector (with respect to efficiency) has also been studied for different power level (Table 2).

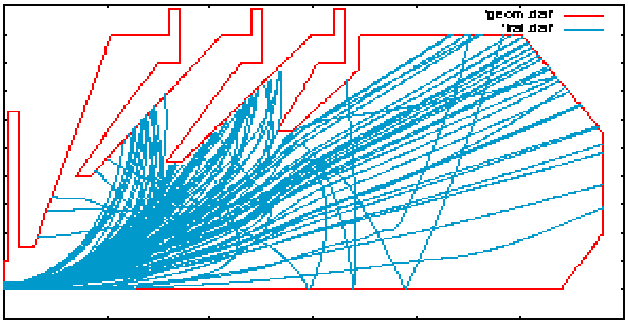

Fig. 4(a). EGUN simulated graphite collector with only primaries in RF condition (efficiency 87%).

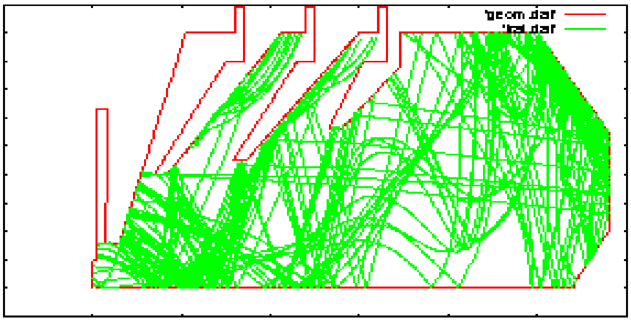

Fig. 4(b), EGUN simulated graphite collector with secondary electrons in RF condition (efficiency 81%).

Table 2. Ka-band 4-stage graphite Collector efficiency at different power levels

Output Power (Watt)	Collector efficiency (%)
40	81.6
20	81.6
10	79.6
5	78.6

In addition to above the dependency of collector efficiency on collector material has also been studied through simulation, like, for carbon coated copper (δ=0.4) [5] the collector efficiency with secondary electrons can be achieved around 83% with 0.3 mA back streaming current, using textured graphite (δ=0.2) [5], the collector efficiency with secondary electrons can be achieved around 85% with 0.283 mA back streaming current.

Sensitivity analysis of designed MDC has been carried out for different geometrical and electrical parameters, e.g. the inter-electrode axial distances, aperture diameter, electrode potential etc. It has been observed that design has good tolerance in electrode aperture diameter as well as inter-electrode axial gaps, for a ± 0.1 mm small deviation in above geometrical parameters and ± 25 volts in electrode potential there is no significant change in collector efficiency and other collector performance in terms of back streaming of current etc. Based on the above design, development of graphite electrodes 4-stage depressed collector is in progress.

IV. CONCLUSION

An approach to modelling and optimisation of multistage depressed collector has been discussed in detail. This approach is adopted to model a collector of a Ka-band 40W high efficiency helix TWT. The predicted graphite collector efficiency is around 81%. Design has been analysed in DC as well as RF conditions using different materials.

ACKNOWLEDGEMENT

The authors are thankful to CSIR for funding this project under network programme and the Director, CEERI, for granting permission to present this work. They are also thankful to other team members for their support.

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