Design of an Asymmetric Multistage Depressed Collector for K-Band 100W Traveling Wave Tube

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Abstract. Efficiency and back-streaming current are important indicators in a traveling wave tube (TWT). A new asymmetric multistage depressed collector (MDC) is needed when designing a K-band 100W space TWT for high collector efficiency and low back-streaming current. In the new collector, the second, third, and fourth electrodes are asymmetrically designed to form an asymmetric electric field, and the potential and geometry of the electrode are appropriately optimized. The simulation shows that when the electronic efficiency is 27.28%, the collector efficiency is 85.34% with zero back-streaming current.

1. Introduction
As an important member of the vacuum electronic device family, the space traveling wave tube (TWT) is mainly used as the terminal power amplifier device on the aircraft. Due to the limited energy sources in space, it is hoped that the TWT can have higher efficiency to save the energy of the aircraft. In addition, modern satellite communication systems have a strict demand for linearity, which requires more attention to the suppression of back-streaming current when designing high efficiency collector. Various of techniques for high performance collector have been used over the past few decades: 1) use of multiple stages of depressed collector [1]; 2) use of electrode material with low secondary electron emission [2],3) use of asymmetric electrical [3] and magnetic [4] fields,4) modification of electrode geometry [5]. In this paper, a new MDC has been designed for a K-band TWT with high efficiency and zero back-streaming current. In this MDC, an asymmetric electric field is constructed, and the geometry of the electrode is adjusted appropriately.

2. Principle of MDC
In the space TWT, the electron beam emitted by the electron gun enters the slow wave structure with high speed, then the electron beam interacts with the signal to be amplified in the slow wave structure. The vast majority of the electrons lose energy and slow down, some electrons’ energy remains unchanged, and a small number of electrons get energy from the field to be accelerated. However, whether they are accelerated or decelerated, the degree of modulation by electric field is different. Besides, the electrons have different initial velocities when they are emitted from the cathode, so the electrons in the electron beam have different velocities. The working principle of the MDC is to classify spent-electron-beam according to its energy, and recycle it by the electrode at different potential according to the different speed.
Figure 1 The energy recovered by a single-stage depressed collector.

Figure 2 The energy recovered by a four-stage depressed collector.

For the single-stage depressed collector and four-stage depressed collector shown in Fig. 1 and Fig. 2, the recoverable energy of the collector is $P_1$ and $P_2$ [6], respectively.

$$P_1 = V_{\text{bo}} \cdot I_0$$

$$P_2 = I_1 \cdot V_1 + I_2 \cdot V_2 + I_3 \cdot V_3 + I_4 \cdot V_0$$

Theoretically, if the stage of MDC increases indefinitely, all the energy of electrons will be recovered, then the recovery efficiency of the collector is 100%. However, in practice, when the stage of the collector is higher than four, the efficiency improvement brought by more stage is very limited, but will bring problems such as complex power supply structure, high cost and so on. Therefore, the number of the stage of the MDC in this paper is four.

If the number of electrode and the electrode potential is determined, it can be seen from formula (2) that the more electrons are absorbed by the subsequent electrode, the more power recovered by the collector, and the higher the recovery efficiency. In this paper, the design of asymmetric electric field is based on above principle.

3. Design and optimization

3.1. Initial conditions of MDC

The electron energy distribution at the entrance of the MDC analysed by MTSS software is shown in Fig. 3, it can be initially determined that the potential of each electrode is around -4200V, -4500V, -
4700V, and -6600V respectively. Fig. 4 shows the asymmetric collector designed in this paper, there is a beam refocusing section (BRS) at the front of the collector to improve the laminar of the incident electron beam. The symmetric axis (Axis 1) of the BRS and the first stage of the MDC coincides with the direction of electron injection, the symmetry axis of the front part of the second stage also coincides with Axis 1, while the latter part of the second stage' symmetric axis coincides with the symmetric axis (Axis 2) of the third and fourth stages. The distance(D) between the two symmetric axes is 4mm.

Figure 3. Energy distribution of the spent-electron-beam.

Figure 4. 2-D cut view of the asymmetric MDC.

The simulation of the electron trajectory is shown in Fig. 5, the collector efficiency is 80.27%, and the back-streaming current is 0.82mA. It is worth noting that there are some electrons "escape" from the gap between the first and second stages. In addition, it is found that a large number of secondary electrons excited by the third and fourth electrodes are absorbed by the pre-stage electrode under the effect of the electric field.
3.2. Optimization of MDC’s geometry

Add “baffle” at the entrances of the third and fourth electrodes of the collector, adjust the internal structure of the first, second and fourth electrodes. The “baffle” can suppress the reverse movement of these secondary electrons, the simulation of the electron trajectory is shown in Fig. 6.

At this time, the collector efficiency increases to 82.87%, and the back-stream current increases to 1.48mA. The number of electrons captured by each electrode can be estimated by the current of the electrode, the total current of the third electrode and the fourth electrode is 16.8 mA. The total current of the third and fourth electrodes in Fig. 5 is 11.1 mA, and the current of the fourth electrode has increased from 3.91 mA to 8.32 mA. This indicates that more electrons (including secondary electrons) are absorbed by post-stage electrode, which improves the collector efficiency. As for the increase of the back-streaming current, that is because some primary electrons are blocked by the “baffle”, which indicates that the collector efficiency and back-streaming current are sensitive to the length of the “baffle”.

3.3. Optimization of the length of “baffle”
As shown in Fig. 7, a2 and a4 represent the length of the two “baffles” respectively. The simulation result of a2 together with a4 scanning is shown in Fig. 8 and Fig. 9. Considering the recovery efficiency and back-streaming current comprehensively, choose a2=8.2mm, a4=11.4mm, then the collector efficiency is 85.49%, the back-stream current is 0.04mA.

3.4. Optimization of electrode potential
Further geometry optimization cannot reduce the back-streaming current, this is because some of the electrons return backwards at the entrance of the electrode. The above situation can be avoided by adjusting the potential. Finally, the potential of each electrode is selected as -4000V, -4300V, -4800V and -6700V respectively, the simulation result is shown in Fig. 10. Almost all the secondary electrons excited by the latter two electrodes are absorbed by themselves, and no electron would backflow to the BRS. At this time, the collector efficiency is 85.34% with zero back-stream current.

4. Conclusions
An asymmetric four-stage depressed collector has been designed for a K-band traveling wave tube in this paper. When the electronic efficiency is 27.28%, the collector performs well with high collector efficiency (85.34%) and zero back-streaming.

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