

On the prospects of high power wideband multibeam klystrons with depressed collector

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Abstract. A new approach for bandwidth increasing of output resonator system in multibeam klystron is proposed. Significant lowering of loaded Q-factor is accompanied by decreasing of electron efficiency and output power which is compensated by depressing of collector voltage and enlarging total electron current by means of gaining the number of beams (bundles). We use dissected collector magnetic polepiece to restrict its heating by secondary electrons and to make possible rising of the depression level. Problems of temperature regime of collector polepiece are considered. Calculation demonstrates acceptable level of temperatures on polepiece.

1 Introduction

Multibeam klystron is very robust, effective and low voltage microwave amplifier. However, it concedes to travelling wave tube in bandwidth – one of the most important characteristics of radar or communication system. Relatively narrow bandwidth is main drawback of phased arrays based on vacuum devices comparing solid state phased arrays. Klystron bandwidth depends on the design of bunching section and output cavity with appropriate filter system. Bandwidth of bunching section doesn't have fundamental restrictions and can be enlarged at the expense of increasing of number of the cavities (length of the tube) or possible gain reduction.

Bandwidth of output system depends mainly on output cavity loaded Q-factor Q_{load} and can be expressed through cavity characteristic impedance ρ , interaction coefficient M , electron efficiency η_e , relative first harmonic of electron current I_1 and power supply voltage U_0 :

$$\frac{\Delta f}{f_0} = \frac{k}{Q_{load}} = k \frac{\rho I_0}{U_0} \frac{M^2 I_1^2}{2\eta_e} \quad (1)$$

where $k \approx 1 \div 2$ coefficient depending on type of output filter system. Usually U_0 is determined by output power and values of k , M , ρ , I_1 has already been maximized. Thus further bandwidth increasing can be achieved by significant diminishing of Q_{load} and electron efficiency η_e . Electron efficiency drop can be compensated using depressed collector [1]. At low electron efficiency rf voltage in output gap is small comparing anode voltage resulting in reduced electrons energy dispersion at the entrance of collector. This makes possible deep depression at operation in small signal regime (large back-off) in

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highly-linear amplifiers for telecommunication [2, 3]. However diminishing of η_e is accompanied with significant drop in output power which can be compensated in single-beam tubes only by significant increasing in anode voltage [1].

2 Depressed collector in multibeam klystron

In multibeam klystrons output power reduction can be repealed using total current I_0 increasing by enlarging the number of beams instead of rising anode voltage [4].

However traditional design of depressed collector in multibeam devices possesses problem connected with significant expansion of the beams after passage of the aperture in collector magnetic polepiece. It leads to necessity to use common large aperture in collector for all beams instead of individual apertures for each beamlet. Large aperture in collector results in remarkable penetration of depression electric field inside the collector and significant return electron current from collector which lowers depressed collector efficiency. In addition these returned electrons are accelerated by depression potential and can heat collector polepiece. To overcome this drawback we proposed design of dissected magnetic polepiece [4], having central part (with individual apertures for beams) which is connected to collector body and is isolated from the rest of polepiece (**Fig. 1**) :

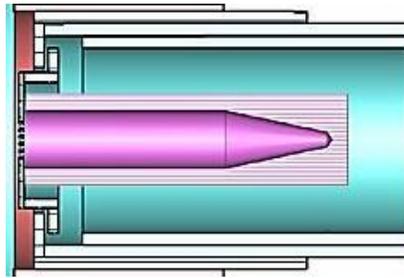


Fig. 1. Design of multibeam depressed collector with dissected collector polepiece.

This approach has made possible significantly suppress return current from collector.

Electrons intercepted by polepiece heat its central part. This power can be removed only by cooling system of isolated high-voltage collector. Taking in account poor thermal conductivity of iron and its sensitivity to overheating it is very important to calculate temperature regime of collector polepiece.

3 Thermal simulation of collector polepiece

We consider design of X-band klystron with cavities operating on high-order eigenmodes having 9 maxima of electric field in the gap. This design provides opportunity of significant increasing of beams number. In each field maximum the bundle of 5 beams is propagated, so total number of beams is 45. In each bundle drift tubes having diameter 2.7 mm are located on circle with diameter 8 mm. Diameter of collector cavity is 70 mm. Iron polepiece has thickness 2 mm. Temperature of collector body was adopted to be equal to 150°C. We suppose that average power 10 W is dissipated in polepiece on walls of each channel due beam current intercept. The simple design of central part of polepiece having copper wafer welded to iron with recesses in each bundle is shown on **Fig. 2**:

External part of the polepiece is not shown since it doesn't influence temperature profile in collector. We used Stationary Thermal Solver in CST Studio Suite for calculation of temperature distributions in all designs presented in the work. The result of temperature spreading simulation in simple design on **Fig. 2** is shown on **Fig. 3**:

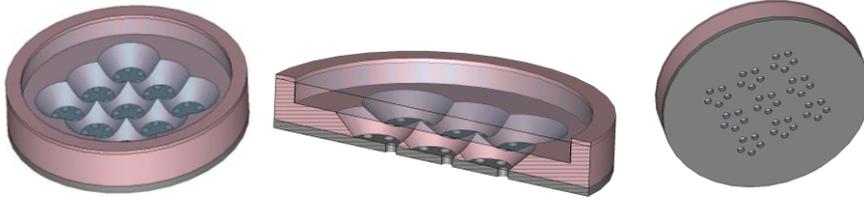


Fig. 2. Design of central part of dissected polepiece in multibeam depressed collector.

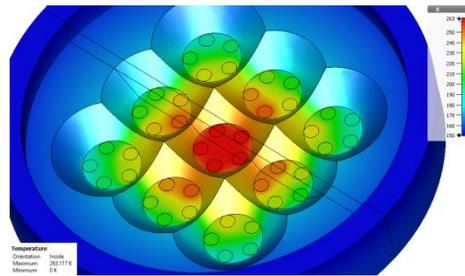


Fig. 3. Temperature distribution in polepiece for the design on Fig. 2.

Temperature difference between hottest point in the center and collector body is 113°C, so maximal temperature achieves 263°C which is quite acceptable.

In second design an additional copper wafer is welded to iron from the outside of collector to enhance heat removing from center of polepiece(Fig. 4):

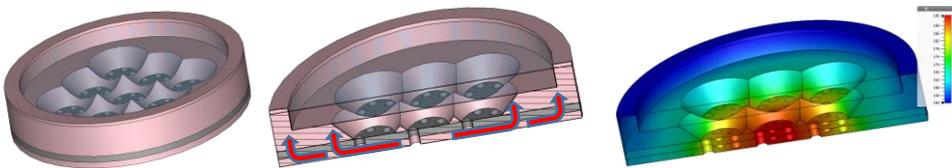


Fig. 4. The design with additional copper wafer and its temperature distribution.

In the design with additional copper wafer temperature drop across polepiece doesn't exceed 45°C, so maximal temperature is 195°C.

In third version of design recesses in copper wafer are fabricated individually for each drift tube instead of common recesses for the bundles (Fig. 5):

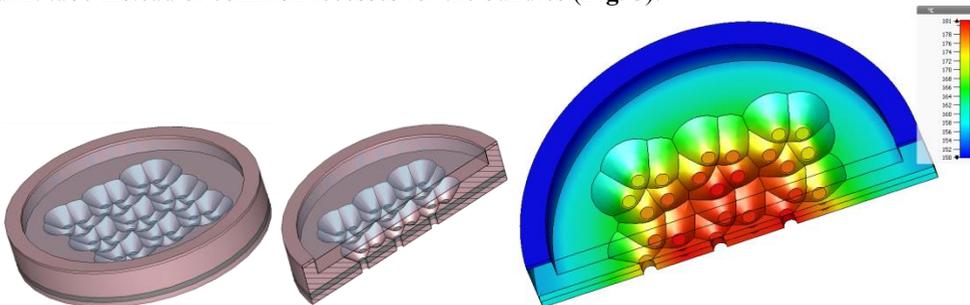


Fig. 5. The design with two additional copper wafers and its temperature distribution.

Temperature difference to hottest point falls to 31°C and maximal temperature doesn't exceed 181°C.

We collected results for three designs in the table 1.

Table 1. Results for three designs.

Design no.	Max temperature	Temperature drop
1	263	113
2	195	45
3	181	31

4 Conclusion

We considered the approach to bandwidth enlarging in multibeam klystrons which is based on the use of overloaded output cavity, depressed collector and significant increasing number of beams at unaltered anode voltage. Three possible 45-beam designs of dissected polepiece were simulated at average dissipated power of intercepted electrons 450 W. Calculation of temperature distribution has demonstrated that maximal temperature doesn't exceed 263°C which is quite acceptable, and can be easily diminished to 181°C

It should be emphasized that temperature drops calculated here are proportional to heating power (450 W in examples above) which in turn proportional to average power of the klystron and beams current intercept. So these drops can be respectively scaled at variations of average power.

References

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