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Review article

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Design of Undepressed Collector for Ka-band Gyro-TWT Amplifier

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Abstract
The design and analysis of an undepressed collector for Ka-band Gyro-TWT have been described in this paper. Initially, trajectory analysis has been carried out after preliminary design of the un-depressed collector. EGUN code and ANSYS software are used for trajectory and mechanical analysis respectively. Thermal design has also been carried out for finalization of collector geometry such as collector thickness, collector length and the estimations and optimizations of temperatures on the both inner and outer collector surfaces with the reasonable flow of coolant around the collector. The uniform electron beam spread of 300 mm has been achieved for wall loss of 0.43 kW/ cm2 for the collector diameter and length equal to 70 mm and 500 mm respectively. The maximum temperature has been obtained on the collector is 220oC.

Keywords: Gyro Traveling Wave Tube (Gyro-TWT), Thermal Analysis, Undepressed, Dissipation

1. Introduction

Gyro-TWTs are potential candidates in millimeter-wave communication system and high-power radar systems, under the design and development in various laboratories [1,2]. The collector is the very important component used for the final collection of the electron beam in a Gyro-TWT. The collector plays a significant role in Gyro-TWT as a power capacity holder of the device. The electron beam is generated from the magnetron injection gun and transfers some of its energy to RF in the interaction structure and then proceeds further in the device [3,4]. Obviously, a component is needed to collect all the electron beam after beam wave interaction and that component is normally called as an electron beam collector or simply collector. The beam collected on the collector is called as the spent electron beam. Although the electron beam loses some of its energy to RF power, however, a sufficient kinetic energy remains in the spent electron beam depending upon the efficiency of the device [5]. The collector is supposed to handle a large power coming from the spent electron beam as due to conversion of the kinetic energy electron beam remaining in the spent beam into the thermal energy leading to the increase of the temperature of the collector. Thus, the collector design should be such that there is not much rise in the temperature of the collector to avoid the melting or even softening of the collector material. Normally, collector is supposed to be cooled, particularly, in a high-power Gyro-devices to provide the smooth flow of heat flux from the inside surface to outside surface of the collector [6,7]. Thus, normally, oxygen free high conductivity (OFHC) copper is used as the collector material due to its high thermal conductivity capability along with other features like vacuum compatibility, ease of availability, etc. Collectors are normally of two types one is un-depressed collector and second is depressed collector, respectively.

In the un-depressed collector, the collector and the device body (control anode) are at the same potentials while at different potentials in the depressed collector. In a Gyro-TWT, the electron beam profile is designed to strike on a large extended length or surface of a collector so that there is no back reflection towards the interaction structure from the collector as well as there is no bombardment of electron beam on the RF window [8]. Design of electron beam spread is made is in such way that wall loading for collector surface should not be more 1.0 kW/cm2. Figure1 shows the schematic view of the Gyro-TWT. Electron beam experiences a reduced magnetic field after the beam-wave interaction and thus its larmor radius is increased in the collector and thus having a natural tendency to strike on the collector. However, it is also required to have a magnetic system around the collector too for the proper electron beam spread for the reduced power dissipation on the collector surface [9]. Cooling is done normally by conventional cooling where water is circulated around the collector to transfer the heat through its heat transfer capability. The proper electron beam spread is achieved with the optimization of collector and surrounding magnet parameters through an electron beam dynamics tool [10]. Similarly, the collector thermal behavior is achieved through the optimization of collector thickness and cooling system parameters with the help of a thermal analysis tool. Therefore, the collector system needs two design aspects related to electrical design and thermal design, respectively. The collector will influence the distribution of dissipated power, we proposed a curved profile collector to make the dissipated power more uniformly. This design has increase power capacity and reduced the maximum temperature of collector.

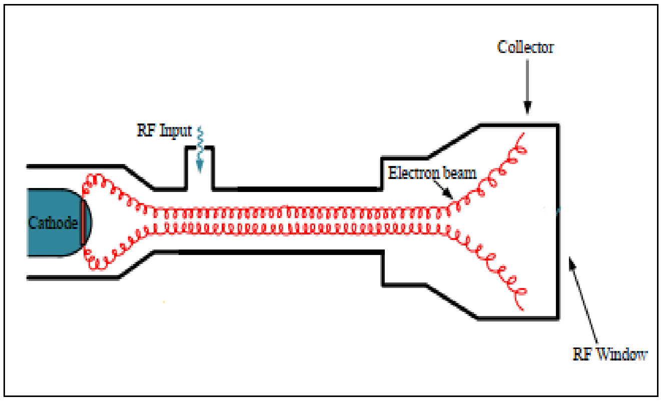

Figure 1: Schematic View of Ka-Band Gyro-TWT

2. Design of Undepressed Collector

In this paper design methodology of undepressed collector for a gyro-TWT has been described. The collector is a waveguide to collect spent electron beam and dissipated their energy on the collector as heat and dissipated as heat without any attempt to recover energy from it through voltage depression. EGUN code has been used for the design of the un-depressed collector for Gyro-TWT. The length and radius of the collector for Ka-band Gyro-TWT have been optimized using EGUN simulation and discussed. The analyses consider effective and the uniform electron beam spreading as well as the wall loading within the limits [11]. To avoid the melting of the collector surface, it requires thermal and structural analysis of the collector. The overall performance of the device depends upon the power dissipation process of the collector. The electron beam profile is designed to strike on a large extended length or surface around middle portion of a collector so that there is no back reflection towards the interaction structure from the collector as well as there is no bombardment of electron beam on the RF window. Design of electron beam spread is made is in such way that the wall loading for collector surface should not be more 1.0 kW/cm2. Electron beam analysis is needed for the electrical design of collector, which helps in getting the maximum electron beam spread. This is carried out with the help of a commercially available and widely used the electron beam analysis code EGUN [12]. Before the analysis, some design goals have been set up for the optimized collector design. These goals may be defined as collector length should be such that electron beam should not touch the collector end, electron beam spread should be maximum and should be around the center of the collector, magnetic field value around the collector should be as low as possible, coolant temperature should not be more than 50 degree centigrade etc.

The analysis of electron beam collector helps to optimize the collector dimensions and to achieve the maximum electron velocity spread on collector surface through the magnetic field optimization. It is found that the magnetic field plays a very important role in the optimization of the length and the radius of the collector. Electron beam analysis is carried out with the help of EGUN code to study the beam spread over the collector surface. Table 1 shows the electron spent beam parameters of collector for Ka-band Gyro-TWT. The electron beam simulation is carried out using 30 beamlets with the real energy distribution of the beam. The beamlets represent the beam power equivalent to the 550 kW. Initially, the electron beam energy is 650 kW generating from electron beam source and after the beam wave interaction 100 kW RF power is taken out of the window. The rest 550 kW power is remained with the electron beam and needs to be dissipated on the inner surface of the collector. Figure 2 shows the spent beam profile at collector surface without the use of any additional magnetic coil around the collector. The dimensions of collector has been optimized as length equal to 500 mm and radius equal to 35.0 mm, thickness is 20.0 mm after lot of iterations to get the best possible landing of the spent electron beam. The iterations is carried out to get best, that is, the maximum uniform electron beam spread in the middle part of the collector. It is found that a two-layer system of magnet systems yields the optimized result of the electron beam spread of 300 mm.

S.N	Parameters	Values
1.	Beam Voltage	65 kV
2.	Beam Current	10 A
3.	Velocity Ratio	1.2
4.	Larmor Radius	0.4 mm
5.	Beam Radius	4.2 mm
6.	Wall loss	0.51 kW/cm^2
7.	Dissipation Power	0.43 kW/cm^2
8.	Collection Area	1231 cm^2

Table 1: Design Parameters of Collector for Ka-Band Gyro-TWT

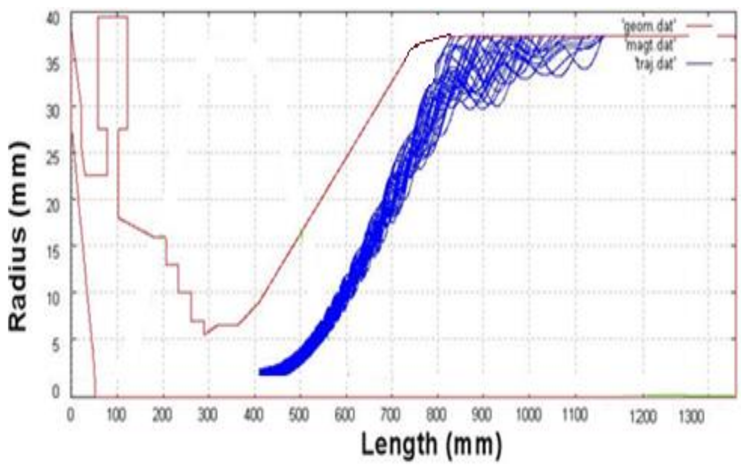

Figure 2: Spent Beam Profile at Collector Surface

3. Thermal Design of Collector

A system is heated under the influence of some sort of heat flux. This is also true for the collector. The high energetic spent electron beams are incident on the collector surface and thus the temperature of the collector is increased. It is always preferable to maintain the temperature of the collector within the limit so that there is no thermal stress on the collector body during the operation of the device. The thermal behavior is estimated through thermal analysis. The ANSYS code has been used for the thermal analysis [13]. Two types of thermal analysis can be performed, such as steady state analysis and transient analysis, respectively. The equilibrium temperature distribution within a structure is estimated through a steady state thermal analysis to determine steady heat flow rates. A transient thermal analysis is used to determine the temperature distribution in a structure. Heat load can be applied on the wall surface in the form of heat flux or heat generation rate or specified temperature in each of the thermal analyses [14]. The thermal design of collector for Gyro-TWT is carried out to estimate the safe collector temperature. On the basis of the simulation, the thickness of the collector, collector shape and the water flow rate have been finalized. Figure 3 shows the 3D view of the collector geometry for Ka-band Gyro-TWT. In the cooling system water is used as coolant for the thermal study. The thermal and mechanical properties of water and OFHC copper are given in Table2 and Table3 respectively [15]. After meshing in the collector geometry, the material properties are applied. After that, the loads and the boundary conditions are applied. The power density of 300 mm spread is 0.43 kW/cm2. However, in the thermal analysis, for the sake of convenience, the average wall loss is applied on the collector surface along the length or surface equivalent to the electron beam spread.

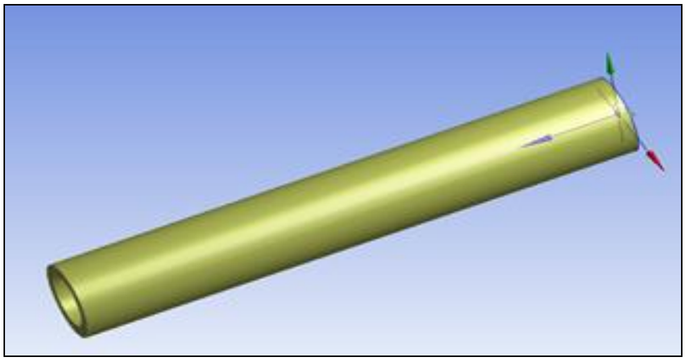

Figure 3: 3D view of Collector Geometry for KA-Band Gyro-TWT

The basic property of water like density, viscosity, thermal conductivity, etc. change with the rise in temperature and in the thermal analysis, the changed values of these parameters are used. After finding the optimized heat film coefficient, the hydraulic diameter is found for a given coolant flow rate through. In this respect, a typical plot has been created between water flow rate and hydraulic diameter for various values of heat film coefficients [16]. It is very clear that the hydraulic diameter increases with increase in the water flow rate at a given value of heat film coefficient whereas hydraulic diameter decreases with increase of heat film coefficient at a given water flow rate. However, the collector surface temperatures decrease with the increase of the heat film-coefficient. Two cases of power dissipations have been studied, such as, 550 kW dissipated spent electron beam power when 100 kW RF power is generated and total 650 kW spent electron beam power when no RF power is generated. The studies have been carried for various inlet water temperatures such as 288K - 293K and hydraulic diameters ranging from 4.5- 5.0 mm diameter. It is always desired to achieve the inner collector surface temperature around or less than 473 K which is easily obtained in the simulations through these simulated results. Figure 4 shows the temperature distribution on the collector geometry. The maximum temperature on the surface of collector is 220oC.The typical thermal analysis results for both situations related to 550 kW and 650 kW power dissipations have been carried out. Figure 5 showing the temperatures of inner and outer surfaces of the collector with the 550 kW and 650 kW power dissipations for different water flow rates. From these simulated results, it is very clear that in all the cases the inner and outer temperature rise time becomes constant after 2-3 sec. and decreases with increase in water flow rate. The maximum inner and outer temperature variation of depressed collector with heat film coefficient (h) shown in Figure 6. The dissipated power is distributed in the axial range of 300-1000 mm and maximum dissipated power is 0.43 kW/cm2. The analytical dissipated power with axial distance of collector shown in the Figure 7. In this paper thermal design of the collector for ka-band gyro-TWT has o been carried out using ANSYS. Figure 8 shows the fabricated collector by OFHC copper. The thermal analysis of the collector, during extreme case of operation has been carried out. A transient thermal analysis has been used to determine the temperature distribution as a function of time.

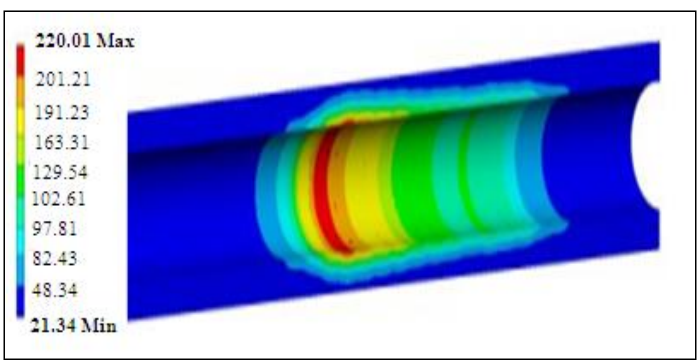

Figure 4: Simulated temperature distribution on the collector

Parameters	Units	Values
Density	Kg/m^3	988.21
Viscosity	NS /m^3	$0.855x10^{-3}$
Conductivity	W/m K	0.58

Table 2: Properties of Water as a Coolant for the Cooling System

Parameters	Units	Values
Density	Kg/m^3	8960
Thermal Conductivity	W/m K	334
Emissivity	-	0.4
Specific Heat	J/(kg.K)	385
Young's Modulus	GPa	110
Poisson's Ratio	-	0.33
Thermal expansion Coefficient	K	17E-6

Table 3: Thermal and Mechanical Properties of OFHC Copper

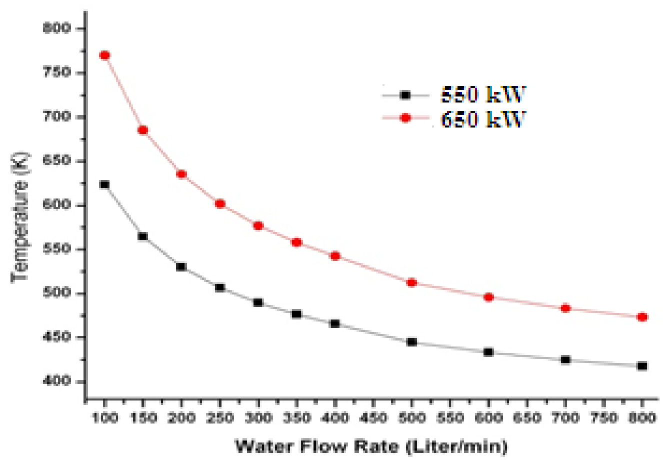

Figure 5: Effect of Temperature with Water Flow Rate for Different Power Dissipation

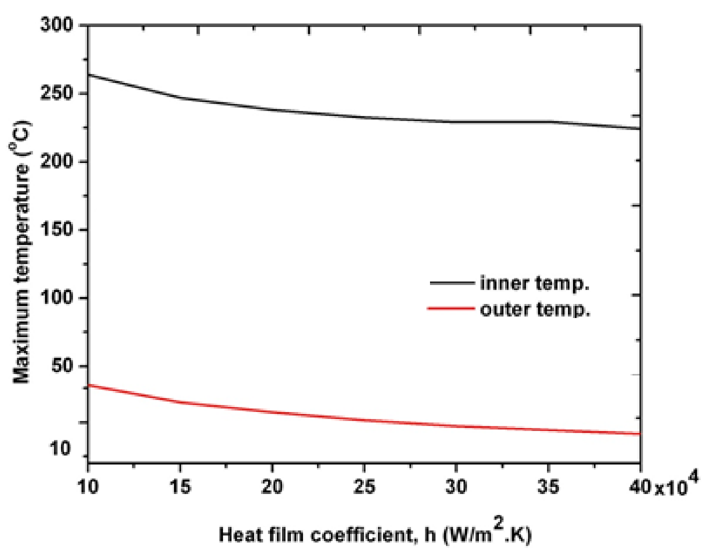

Figure 6: Maximum Outer and Inner Temperature Variation With Heat Film Coefficient (h)

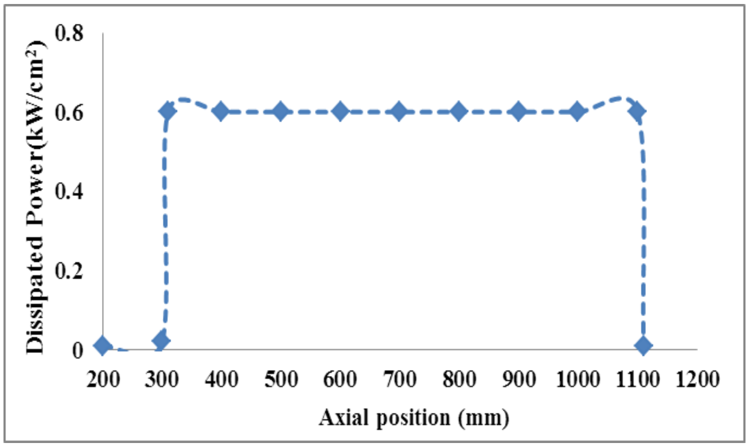

Figure 7: Dissipated Power with Axial Distance of Collector

Figure 8: Fabricated Collector by OFHC Copper

4. Conclusions

In conclusion, it has been established that available collector design is capable of handling the thermal and mechanical loading in a 100-kW power. The design of Un-depressed collector for Ka-band Gyro-TWT is presented in this paper. The initial estimation of collector dimensions length and diameter have been estimated with the help of analytical expressions subjected to the technical limit of wall loss. The trajectory, thermal and structural analysis is carried out for the design of Un-depressed collector. The simulated results have been optimized the collector length 500 mm and collector radius 35 mm with the minimum heat loading of 0.43 kW/cm2 for uniform electron beam spread. The maximum temperature is 220 0C on the inner surface of the collector and 47 0C on the edge of the collector outer surface at optimized 3x105W/m2.K heat film coefficient (h).

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