Towards the Design of 100 kW, 95 GHz Gyrotron for Active Denial System Application

Udaybir Singh, Nitin Kumar, Anil Kumar, Vivek Yadav and Ashok K Sinha

Gyrotron Laboratory, MWT Area
Central Electronics Engineering Research Institute (CEERI)/ Council of Scientific and Industrial Research (CSIR)
Pilani, Rajasthan, INDIA-333031

E-mail: uday.ceeri@gmail.com

Abstract: *The design work for 95 GHz, 100 kW gyrotron for Active Denial System (ADS) application is presented. The mode selection is performed considering the various technical constraints. Particle-in-Cell code is used for the beam-wave interaction computation and cavity design. In addition, the designs of electron beam source, collector and RF window are also discussed. The design results confirm the RF power >100 kW with ≈50 % tube efficiency.*

Keywords: Gyrotron, Electron Gun**,** interaction structure, Active Denial System.

Introduction

Gyrotron oscillators are high power sources of coherent millimeter wave and THz wave radiation based on the cyclotron resonance maser effect. During the last two decades, several other possibilities of gyrotron applications such as material processing, THz spectroscopy, etc. were explored and the detail review can be found in Ref. [1]. A novel application of gyrotron is purposed recently in non lethal, counter personnel, directed energy weapon system also called Active Denial System (ADS) which can be used against human targets at a distance beyond the effective range of small arms [1]. 95 GHz radiation with 100 kW of power is suitable for ADS application due to the minimum atmospheric absorption at 95 GHz. Gyrotron is a perfect device for the generation of 100 kW, 95 GHz radiation and is used in the current development of ADS system.

The design and development of 95 GHz gyrotron is planned at CEERI considering the application in strategic area of ADS system. Here the design results for this gyrotron are presented and discussed. The design goals and specifications of 95 GHz gyrotron are given in table 1. The design task is completed through the proper combination of indigenously developed and commercially available design codes.

Table 1. Design specifications and goals

Frequency (f)	95 GHz
Power (P_{out})	100 kW
Beam current (I_b)	6-8 A
Beam voltage (V_b)	50-55 kV
Total efficiency (η)	≈ 50%
Wall loss (dP/dA)	< 1 kW/cm^2
Voltage depression (V_d)	< 10% of V_b
Magnetic field at cavity (B_0)	3.55-3.57 T

Cavity Design

$TE_{7,3}$ mode is selected as the operating mode as it satisfies all the mode selection parameters with in limit (V_d<10% of V_b, I_L>2I_b, dP/dA<1 kW/cm^2). For the selected operating mode, the cavity radius and beam radius are 8.25 mm and 3.75 mm, respectively. Particle-in-Cell (PIC) code MAGIC is used for the cold cavity analysis and beam-wave interaction computations [2]. The optimized interaction cavity and electron beam parameters are shown in table 2. Fig. 1 shows the typical plots of MAGIC simulations representing the power and frequency growth with respect to time. The power and frequency growths become stable around 150 ns. The simulation results confirm more than 100 kW power with 37 % interaction efficiency at $TE_{7,3}$ mode.

Table 2. Optimized cavity and electron beam parameters

Cavity radius	8.25 mm
Cavity length	20 mm
Q value	776
Beam current (I_b)	7 A
Beam voltage (V_b)	52 kV
Magnetic field at cavity (B_0)	3.56 T

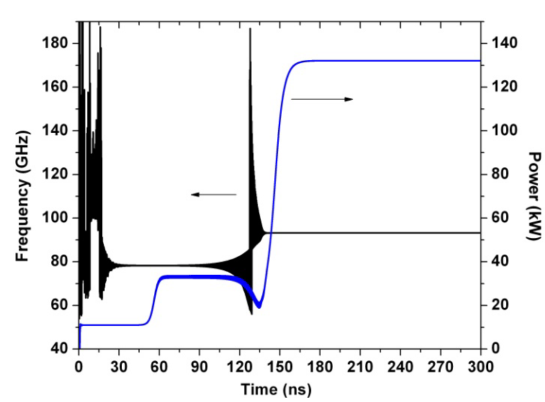

Figure 1. Frequency and power growth with time (V_b= 52 kV, I_b= 7 A, α= 1.35, B_0= 3.56 T)

Electron gun Design

The interaction cavity simulation results give the optimum values of electron beam parameters as shown in table 2. A triode type magnetron injection gun (MIG) is designed for this gyrotron. The initial design is obtained by using analytical expressions [3]. Optimization of the MIG geometry is performed by using the commercially available code EGUN. Fig. 2 shows the optimized MIG geometry and electron beam profile. The simulation results confirm optimum values of velocity ratio = 1.36 and velocity spread = 1.11 %.

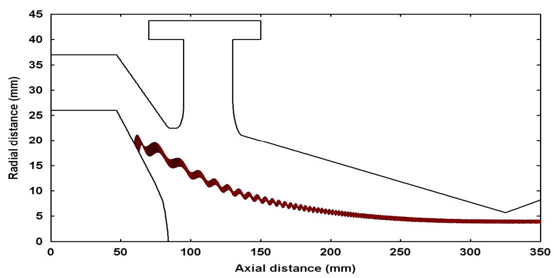

Figure 2. Electron beam trajectory with MIG geometry

Collector and RF window

The depressed collector is designed for 95 GHz gyrotron to enhance the overall efficiency. Trajectory code EGUN is used for the optimization of collector geometry and beam spreading. Extra magnetic coils are used to enhance the electron beam spreading. Fig. 3 shows the electron beam spreading at collector wall including magnetic field profile and collector geometry. The simulation results show uniform spreading of 308.5 mm at collector wall, which results 0.131 kW/cm^2 of heat load.

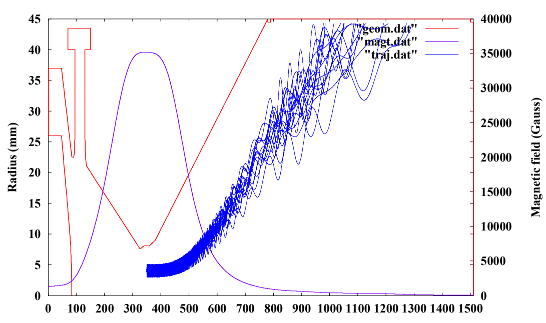

Figure 3. Electron beam spreading at collector wall including magnetic field profile and collector geometry

For the present design, CVD diamond is selected as the window material due to its excellent thermal, mechanical and dielectric properties. Fig. 4 shows the simulation results for the optimized window geometry (Disk thickness = 1.325 mm, disk radius = 40 mm). The transmission more than 99 % is achieved for the designed RF window.

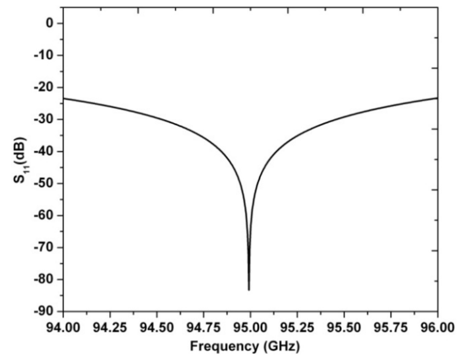

Figure 4. S_{11} with respect to frequency

Conclusion

The design of 95 GHz, 100 kW gyrotron operating at $TE_{7,3}$ mode for ADS application is presented in this manuscript. The design results show more than 100 kW RF power with 37 % interaction efficiency. The collector efficiency (66.5 %) enhances the overall tube efficiency up to 50 %.

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