Design and Characterization of RF Cavity For an L-band Multi Beam Klystron

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***Abstract*- A five beam klystron operating in L band with 2 kW (CW) output power is being designed at CSIR-CEERI for its intended applications in communication. The present paper discusses the design of RF cavity for the klystron. The dimensional parameters of the five beam RF cavity have been calculated initially through standard analytic formulas and then optimized through simulations in CST Microwave studio and MAGIC -3d codes. The cavity has been fabricated and characterized, the measured results are in agreement with the simulation**.

I. INTRODUCTION

A conventional single beam L-band klystron was developed earlier at CSIR-CEERI [1], with specifications listed in Table 1 and the device has been used for tropo-scatter communication. Although the efficiency of the device was low but it was tunable over 1.7 GHz to 2.4 GHz as required for its intended applications.

Table I

Quantity	Value
Output Power	1 kW CW
Gain	40 dB
1dB Bandwidth	8 MHz
Beam Current	550 mA
Beam Voltage	6 kV
Beam Radius	2.2 mm

There exists a new requirement of a klystron operating in the frequency range of 1.8 GHz -2 GHz with output power of 2 kW (CW) with efficiency and 1 dB bandwidth more than 40% and 15 MHz respectively. Development of a multi beam klystron (MBK) is under consideration to meet the desired specifications. For ease of fabrication, it is planned to design a five-beam device where current for each beam is taken as 250 mA. If we consider the efficiency of power extraction from each beam as about 40% then for five beam configuration the beam voltage would be 4 kV for desired output power of 2 kW, as per the following equation [2] where η is the efficiency, N is the number of beams, and I_1 is the beam current per beam and V_{mbk} is beam voltage.

$$P_{out} = N \eta I_1 V_{mbk} \qquad (1)$$

Now after having the electrical parameters of beam, a cylindrical re-entrant cavity with five drift tunnels is to be designed for which the resonant frequency would be somewhere between 1800-1850 MHz. The drift tunnel has been designed with a beam fill factor of 0.65 while the beam coupling coefficient is taken as 0.85. Considering all these parameters the estimated drift tube radius is 3.3 mm as calculated using standard analytical formulas available in literature [3],[4].

II. SIMULATION OF A FIVE BEAM RF CAVITY

The parameters required for the design of a re-entrant cavity are cavity height, drift tube radius, gap length and cavity diameter. The height of cavity is chosen such that it is less than λ/4 over the whole frequency range of operation as small gap re-entrant type resonator oscillates when its height is somewhat less than λ/4 [5]. The drift tube radius that depends on the beam parameters has been already calculated as 3.3 mm, gap length is dependent on the beam coupling coefficient. The cavity radius for a simple cylindrical cavity (without re-entrancy) operating in TM mode can be given by the well-known formula [5]

$$R = c * x_{np} / \omega_c \qquad (2)$$

Here R = cavity radius, x_{np} = *A Bessel function value = 2.405 for* $TM_{0,1}$ *mode* ω_c = *angular frequency =* $2\pi f$ *and c = velocity of light =* $3x10^8$ *m/sec;*
The radius for a reentrant cavity will be lesser than this [6], yet we can start with this value while simulating the cavity, thereafter reducing the radius to get the desired frequency. The drift tube wall thickness, cavity radius and gap length are the variable parameters for optimization through iterative simulation process so as to get the desired resonant frequency.

When the conversion of a klystron RF cavity from single beam design to multi beam design is to be carried out, some scaling laws [2] are used. These laws relate the electron beam parameters such as beam voltage, beam current etc. of the single beam device and its equivalent multi-beam device respectively, depending upon the number of beams chosen for the multi-beam design. Here it is proposed to design a five beam klystron cavity.

Multi-Beam cavity design [7], [8] is a critical task in designing of MBK. Due to asymmetric cavity structure, a multiple beam cavity can be simulated by 3D codes only. The design of the five beam RF cavity for the required frequency has been optimized first by CST Microwave Studio then the same design has been simulated in particle–in-cell code MAGIC-3d.

The cavity radius has been optimized to a value of 39.0 mm and the five drift tunnels are placed azimuthally with the centers of the drift tunnels lying on a circle of 12 mm radius. Fig. 1 shows a model of the five beam cavity modeled in CST code. The simulated value of resonant frequency of the cavity is 1.834 GHz as shown by the eigen mode simulation result in Fig. 2 and the vector plot for the electric field across the multiple cavity gaps confirms that the E-field is concentrated between the nose cones as required for the desired mode of interaction between the RF field and electron beam. The same cavity dimensions have been simulated through MAGIC-3d code to get the eigen mode frequency which is found to be as 1.8277 GHz as shown in Fig. 3.

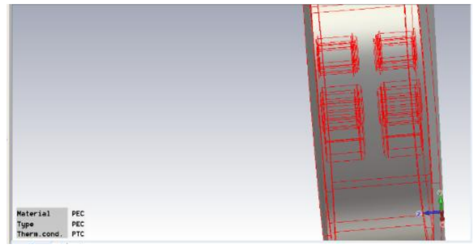

Figure 1. The model of five beam cavity

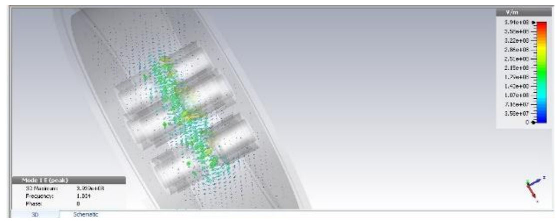

Figure 2. Electric field across the cavity gaps

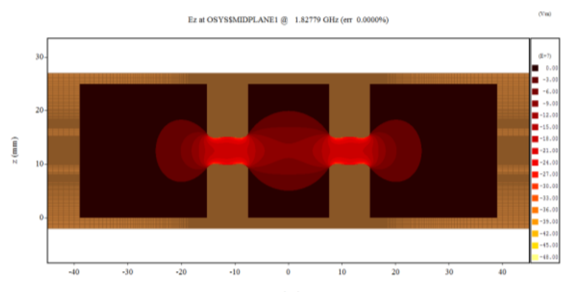

Figure 3. Eigen mode simulation in MAGIC-3d

III. FABRICATION AND CHARCATERIZATION

Based on the dimensional design after simulation through both codes, the five beam cavity has been fabricated by assembly of the piece parts as shown in the Fig. 4 where five drift tubes are individually shown.

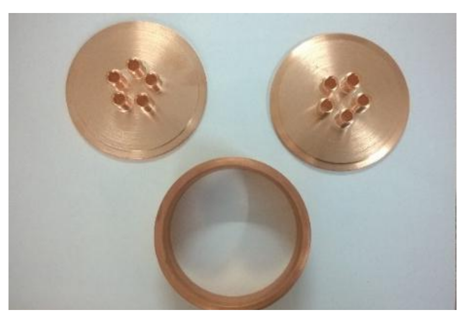

Figure 4. The piece parts of a five beam cavity

The assembled cavity has been characterized with network analyzer for its resonant frequency with the measurement set-up as shown in Fig. 5. The cavity is excited by inserting one probe in one of the drift tube and the reflection coefficient is being observed. The measured resonant frequency for the fabricated cavity is found to be 1.815 GHz as shown in Fig. 6 where a screen shot of the network analyzer displays the S_{11}-parameter plot.

Figure 5. The Measurement Set-up

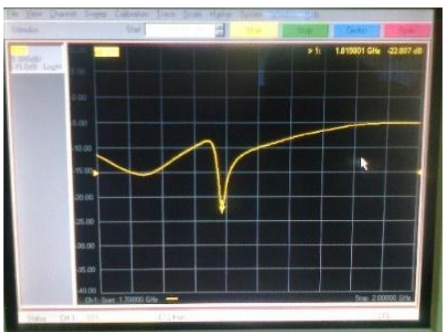

Figure 6. Measured frequency of the cavity

IV. CONCLUSION

The design of a five-beam RF cavity for the L-band klystron has been designed, developed and characterized. The measured results for resonant frequency of the five beam cavity are in good agreement with the simulated results through two different codes. A comparison of the simulated results from CST Microwave Studio and MAGIC-3d along with measured results are shown in Table 2, the optimized dimensions of the cavity are also shown in the table.

Table 2

Cavity Dimensions after optimization through simulation	**Eigen mode frequency found through CST**	**Eigen mode frequency found through MAGIC-3d**	**Measured Resonant Frequency of the fabricated cavity**
Cavity radius = 39.0 mm Cavity gap = 5.0 mm Drift tube inner radius = 3.3 mm Drift tube outer radius = 5.3mm Cavity height = 25.0 mm	1.834 GHz	1.8277 GHz	1.815 GHz

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