Triplet cavity for X-Band Sheet Beam Klystron

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Abstract – **Design and cold characterization of triplet bar-bell cavity to be used in X-band sheet beam klystron has been reported in this article. The bar-bell triplet cavity has been designed and optimized using three dimensional electromagnetic simulation code. After optimizing the triplet for uniform electric field profile across cavity width, cold test model of the same has been fabricated and characterized in terms of resonant frequencies.**

Keywords – **cold test, flat field, sheet beam klystron cavity, triplet, X band.**

I. Introduction

APPLICATIONS like microwave powered space vehicles, particle accelerators, plasma heating in tokamaks entail megawatts of power at GHz frequency range[1]-[3]. Sheet Beam Klystron (SBK) is a potential high power microwave amplifier for such applications [4]. When sheet beam of aspect ratio as high as 25:1 [5] is employed, power scales down only linearly with frequency [6]. Thus, SBK can provide high RF power at high frequency. Besides, rectangular beam cross section can deliver higher beam current at lower current density. Hence, magnetic field required to focus the beam is lesser than that for pencil beam [7]. Due to these advantages, SBK is being actively investigated currently. In this paper, we discuss design, simulation and cold test results of fabricated intermediate cavity for a SBK working in X-band frequency range.

SBK deploys unconventional rectangular cavities with large drift tunnel. Unlike cylindrical cavities, SBK's cavities have to be cold tested along with drift tube. In cylindrical cavities, electric field is concentrated only at nose cone gap, whereas in SBK, there are series of cells with discrete beam wave interaction zones. Uniform electric field has to be maintained across width in all these cells.

In Section II design and simulation results are presented. In Sections III cold test of fabricated triplet is described.

II. Design and Simulation Results

SBK employs rectangular bar-bell cavity which encompasses a rectangular waveguide, called a cell, terminated by two quarter wave section bar-bell ends. In these cavities, uniform electric field profile along beam width is important to maintain uniform beam-wave interaction [8]. The cell is operated near cut-off and terminated with quarter wave sections on both sides [9]. The resonant frequency is determined by cell dimensions and the beam-wave interaction takes place along the length of the cell. Drift tunnel is of dimension 90×12mm in the design under consideration [10]. A single cell cavity with these initial design parameters, optimized for flat field at 11.43 GHz has R/Q around 13Ω only. As R/Q, which governs the gap voltage developed across the cells, is a geometrical parameter, it can be improved with more number of cells [11]. However, multi-gap cavities have poor mode separation and stability [12-13]. As a trade-off, intermediate cavities have been designed with 3 cells. Spacing between cells decides the phase shift between cells and hence the mode of operation [14].

With this design, a simulation model has been done in CST Design Studio [15] with an aim to optimize the cavity dimensions to achieve uniform electric field profile as well as maximum possible R/Q. Across the beam width of 80mm, electric field is sufficiently flat as shown in Fig.1. After successful convergence test in CST, this model has been validated using another three dimensional electromagnetic simulation code, MAGIC 3D [16]. Simulation results obtained from both the codes have been found to be in close agreement with each other as compared in TABLE I.

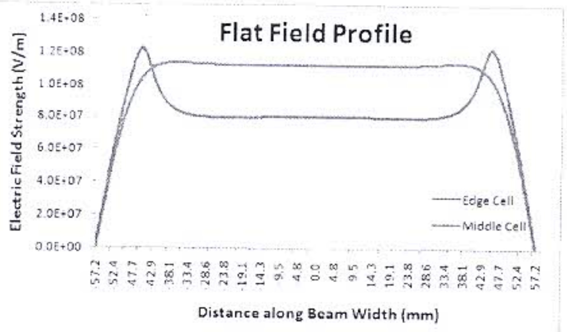

Fig. 1. Flat electric field profile across beam width of 80mm in edge cell and middle cell of simulated triplet.

TABLE I
SIMULATION RESULTS OF TRIPLET

Parameter	Simulated Value	
	CST	MAGIC 3D
Frequency	11.43 GHz	11.436 GHz
R/Q (Cells)	48.605 Ω	48.52 Ω

III. COLD TEST RESULTS

Cold test model of the triplet sheet beam cavity with optimized dimensions from simulation has been fabricated and characterized. The cavity has been excited using a straight metallic wire probe (exciter) of length closely equal to drift tube length [Fig.7].

Initially an Aluminum end plate as shown in Fig. 2, with apertures for exciter was used. However, with this end plate, the exciter was shorted with the end plate. Cavity could be properly excited with either dielectric end plate or a metal end plate with dielectric beads embedded in aperture. Similar results have been obtained with both these endplates. 90mm wide drift tube can support TE modes which are not driven in triplet [6], [17]. Cell of height 14.2mm has TM modes which cannot exist in drift tunnel of height 12mm (at least ~13mm height is needed to support 11.43 GHz). Thus, theoretical design ensures that drift tube is in cut-off. It was observed through cold testing that the drift tube as such does not support any modes but fringing fields exist at the end of drift tube due to its short length. When 50mm long drift tunnel is deployed, resonant frequency is unaffected and fringing fields die off. However, with longer drift tunnel, proper length of the exciting probe and sufficient input RF power is required to excite the cavity.

Fig. 3 shows resonant dips for various modes obtained in vector network analyzer during cold test of the triplet. Modes, distinguished by nulls of electric field across the width of triplet as shown in fig. 4 and fig. 5, have been identified during cold test by perturbing through appropriate apertures in endplate. Mode separation of ~100 MHz has been achieved. Besides, mode 1 with desired flat electric field profile along width is the dominant TM mode (No resonant dips have been observed below 11.31 GHz).

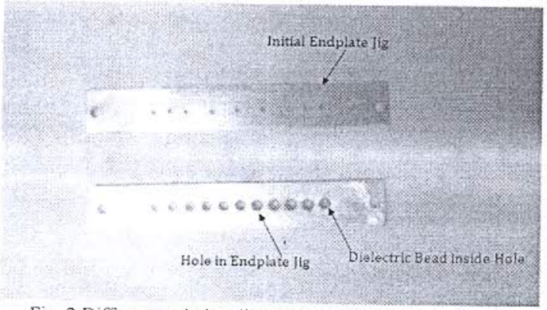

Fig. 2. Different end plate jigs used during cold test of triplet

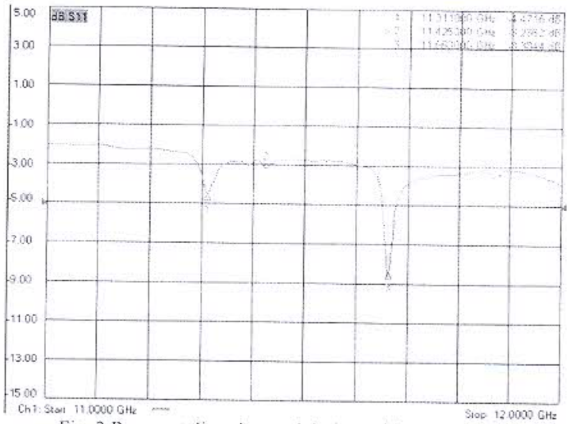

Fig. 3. Resonant dips observed during cold test of triplet

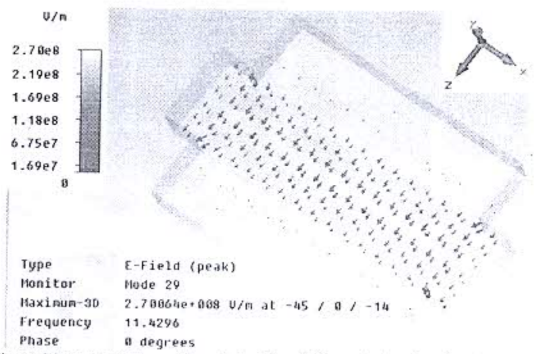

Fig. 4. Electric field profile of the first TM mode in simulated triplet. Electric field is uniform across width of triplet (x axis).

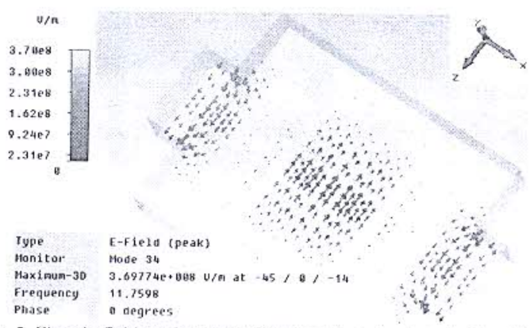

Fig. 5. Electric field profile of third TM mode in simulated triplet. This higher order mode electric field has 2 nulls across width of triplet.

Practically observed resonant frequency is down shifted from simulated value as compared in TABLE II due to following reasons. Firstly, triplet is fabricated cell wise as shown in Fig. 6 and is then made press fit. However, due to mechanical limitations, press fit is not perfect thus increasing effective cell length. Down shift from resonant frequency has been observed in simulations carried out with longer cells. Secondly, at millimeter wavelength, stringent dimensional tolerance in micrometer range is required [17]. However, we have only 0.02mm mechanical tolerance in the fabricated cold test model of the cavity. Discontinuity seen by electric field, introduced by imperfect press fit of cells, which has increased length of cells and down shifted resonant frequency, can be avoided by fabricating the cavity as two parts each having half of the beam tunnel. There is no vertical electric field in the cavity to see the vertical discontinuity introduced by this configuration.

TABLE II
COMPARISON BETWEEN SIMULATED AND MEASURED RESONANT FREQUENCY

Mode Number	Resonant Frequency (GHz)	
	Simulated	Measured
Mode 1	11.43	11.31
Mode 2	11.51	11.42
Mode 3	11.76	11.66

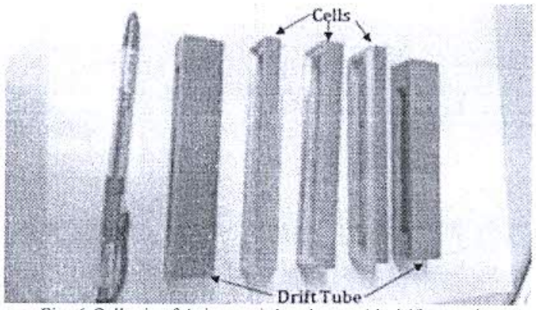

Fig. 6.Cell wise fabricate triplet along with drift tunnels.

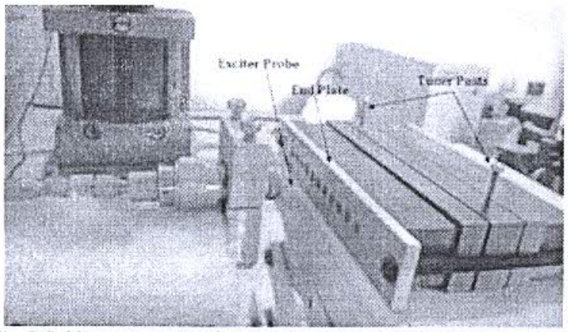

Fig. 7.Cold test set-up showing the triplet along with vertical tuner posts inserted symmetrically in both bar-bell ends.

VI. CONCLUSION

Design of a rectangular bar-bell type RF cavity triplet for X-band sheet beam extended interaction klystron has been carried out using three dimensional electromagnetic simulation tools. Cold test model of the cavity has been carried out which agrees well with simulation.

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