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Design of Magnetic Focusing System for a Compact Ka-band Helix TWT

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ABSTRACT

In this paper we discuss the design of Magnetic focusing system (MFS) for a compact helix travelling wave tube (TWT) operating in Ka-band. Issues related to the design of the magnetic focusing system have been discussed in detail along with practical measurement results. The key design parameters considered for this TWT are: the cathode voltage is around 9.3 kV, beam current is 200 mA and total length of the tube not more than 6 inch with minimal weight.

Keywords: Ka-band TWT; Electron Gun; Helix TWT; Magnetic focusing system

1. INTRODUCTION

Helix TWT is one of the versatile microwave amplifiers that finds extensive use in satellite transponders[1], radars, electronic warfare and electromagnetic interference/compatibility test platforms[2] due to its light weight and high bandwidth. At Ka-band due to its smaller dimension of the components and other complexities, these type of devices are not readily available. One of the major criticality in the design of these type of TWTs is the generation of pencil beam and focusing of the beam along the interaction region. This paper investigates the design of magnetic focusing scheme for this class of TWTs. The MFS was optimised in CST-Studio[3]. Experimental measurements of peak magnetic field of MFS and the beam transmission using the designed MFS has been completed and the initial result are presented.

2. DESIGN OF MFS

To transport the fine beam along the interaction tunnel, a periodic permanent magnetic focusing system is used, as it offers compact and light weight MFS. The initial required magnetic field on the axis may be calculated by the Brillouin field formula[4]

$$B_B = 0.83*10^{-3}\frac{\sqrt{I}}{aV^{1/4}}T$$

where,

B_B Brillouin magnetic field
a Beam radius
I Beam current
V Beam Voltage

After obtaining this Brillouin field value, for getting peak axial magnetic field, we multiply this $\sqrt{2}$ to provide RMS of periodic field with an intensification factor of 1.4 considering other factors like beam stiffness, beam stability, etc. for effective beam transmission.

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To achieve this MFS, initially we have to find the magnet size. If a magnetic material is selected with a suitable remanence, then magnet size can be find by using the below formula[5] (Fig. 1).

$$B=\frac{B_r}{2}\left[\frac{D+Z}{\sqrt{R_a^2+(D+z)^2}}-\frac{z}{\sqrt{R_a^2+z^2}}-\left(\frac{D+z}{\sqrt{R_i^2+(D+z)^2}}-\frac{z}{\sqrt{R_i^2+z^2}}\right)\right]$$

where,

B_r Remanence field of magnet
Z Distance from a magnet face
D Thickness of magnet
R_a Outside radius of magnet
R_i Inside radius of magnet

As the magnetic field requirement to focus this magnet is very high, higher energy Sm_2Co_{17} type of magnets are chosen. Magnets used in present MFS is of grade 33[6] whose energy product is 31MGoe, and Br value is about 11400 Gauss.

CST Particle Studio was used to study the axial peak magnetic field and beam transmission with achieved field with this MFS. In this simulation, beam transmission from electron gun to collector was studied. A beam current of 200mA was emitted from the electron gun with required beam diameter at throw distance, providing an entry of constant beam diameter at the start of MFS. This provides an accurate and quick insight of beam transmission studies over the required length. The actual electron gun has been used in the simulation which has been experimentally evaluated for its performance before carrying out this complete beam transmission studies.

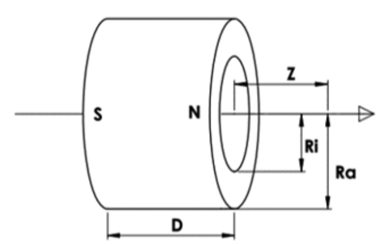

Figure 1. B-field on axis of charged magnet.

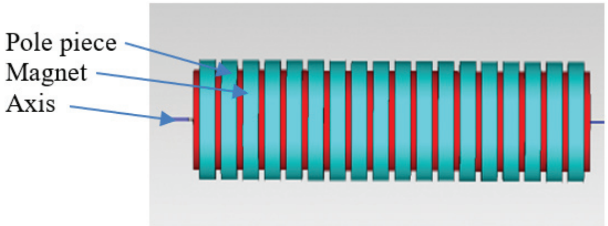

Figure 2. MFS model in CST studio.

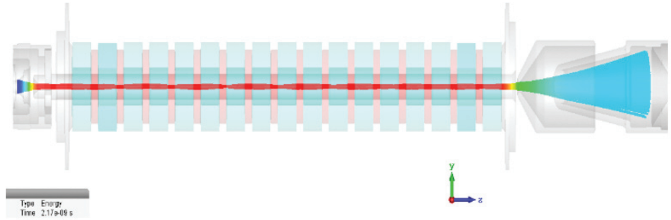

Figure 4. Beam transmission study in CST.

3. SIMULATION OF BEAM TRANSMISSION

Initially MFS structure with eight PPM periods were modelled in CST studio (Fig. 2) with required magnetisation for magnets to achieve the required peak magnetic field (Fig. 3). For the present case, Magnetostatics module of CST was used with open boundary condition. Mesh density of 0.1 mm chosen for precise field values to suitable resolve the magnetic field.

Beam transmission from electron gun to collector was studied using particle tracking module of CST in presence of computed values of magnetic field of MFS over entire required length of interaction structure. The actual electron gun design was used to generate electron beam to simulate practical beam transmission study including the beam entry effects. The gun used here is of shielded gun type and hence till the start of the magnetic field electron beam is electrostatically focused. Keeping this in mind the iron pole-pieces are so designed that it produces the magnetically shielded region in cathode to anode region and after then a sharp transition was achieved within the gun flange to achieve the maximum magnetic field to focus the electron beam with required diameter. All these needs to be achieved without saturation of the soft iron pole-pieces[7].

To find the beam interception on helix with more precision, provision was made in the model by setting the inner diameter of beam tunnel equal to helix inner diameter. The beam was found to travel with no interception within the body and over the entire MFS (Fig. 4).

In addition to beam transmission through the tunnel, beam cross section across the axis and closer to exit was also monitored to study the obtained beam diameter. The required beam diameter of 0.4 mm was achieved which matches our requirement. Figure 5 shows the X-Y cross section of beam obtained at the end of tunnel.

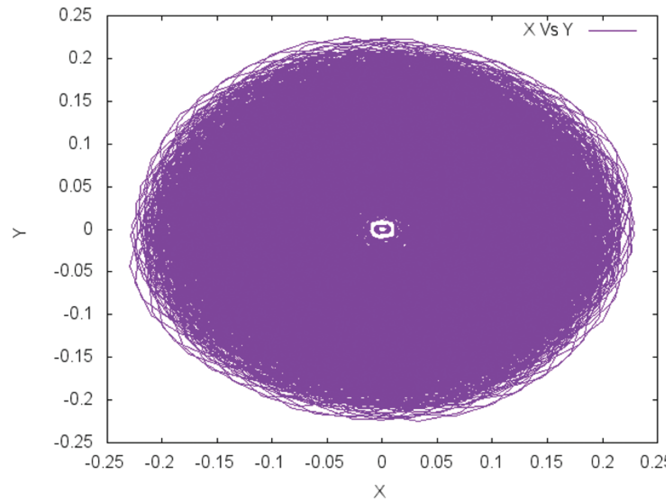

Figure 5. Beam cross section.

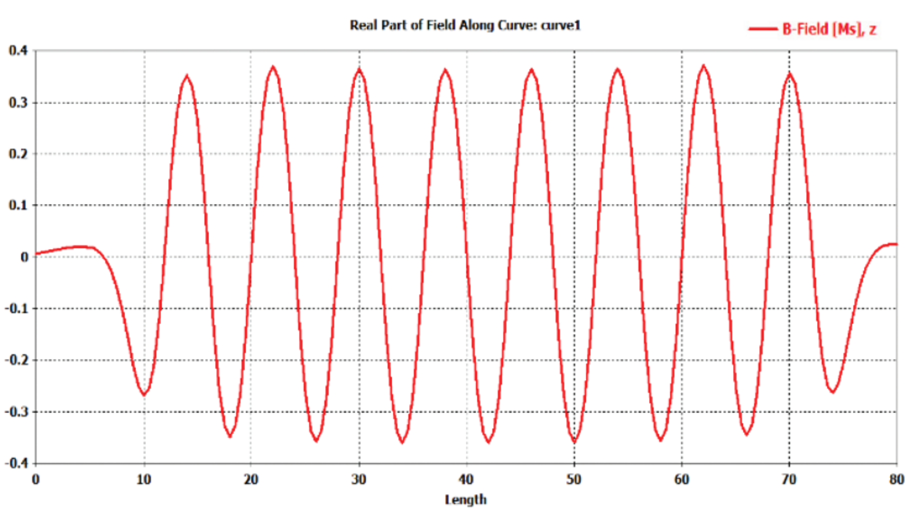

Figure 3. Simulated magnetic field in CST.

4. REALISATION OF MFS

As magnetic field requirement is quite high for this tube due to high beam charge density, a homogenous magnetic field within the beam envelope is preferred. To achieve this magnet must be homogenous. For this each magnet is checked for its field on each face at four places as shown in the Fig. 6. If variation is within 50 Gauss, then we get a more homogenous field.

To experimentally evaluate the proposed structure, a sample PPM stack with about 4 PPM periods (8 cells) were setup and axial magnetic measurements (Fig. 7) were carried out. Required peak magnetic field of about 3800G was achieved with this proposed structure which closely conforms to magnetic field simulation. After measurements, the same magnets were used for studying beam transmission using a beamstick tube.

A beam-stick tube is an actual sealed off device without microwave circuits which is normally used to validate designs of electron gun and the MFS. This tube (Fig. 8) has been developed which greatly assists to experimentally study the overall beam transmission within the beam tunnel before actual development of complete

TWT prototype. To predict the actual beam transmission inside the interaction region, the beam tunnel is made equal to the helix inner diameter. Hence the beam transmission obtained with this tube correlates directly to the interception with the helix assembly.

The assembled beamstick (Fig. 6) is of actual length of the interaction region with 9 periods of magnets. Initial testing has provided with a beam transmission more than 94% without any additional magnets or shunts for tuning. This proves the designed MFS is significantly closer to experiment results in achieving transmission of this pencil beam.

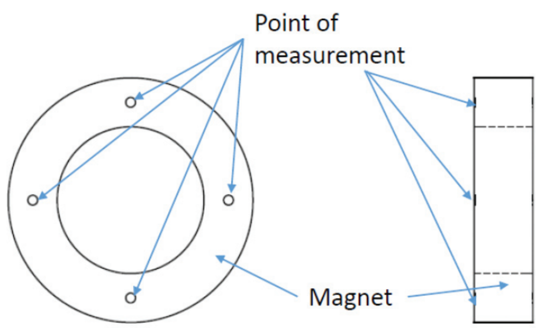

Figure 6. Measurement for magnet selection.

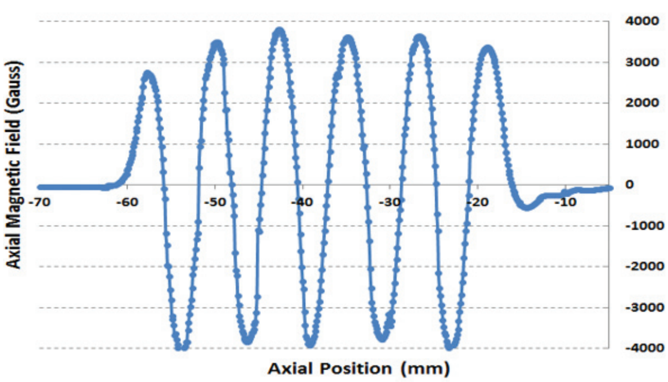

Figure 7. Measured magnetic field in a dummy barrel.

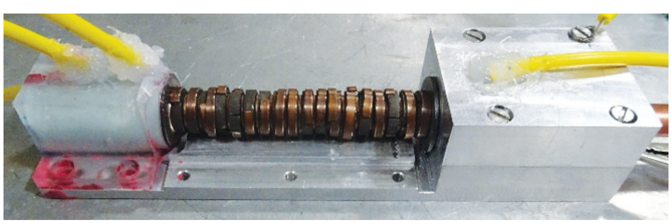

Figure 8. Beamstick tube.

5. CONCLUSION

This paper describes the design and development of magnetic circuit for Ka-band compact helix TWT, challenges and possible solution. Efforts are on to further study the ripple factor by fine tuning in magnetic focusing system with better magnet selection. The development work of beamstick tube has been completed and the test results had provided great insights in experimental validation of the proposed MFS.

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CONTRIBUTORS

Mr Mithilesh Kumar received his BTech in Electronics and Communication Engineering from MJP Rohilkhand University in 2007. After joining MTRDC he shows his interest in Electron Beam focusing and Magnetics. He is very much involved in electron-optic system of Multi Beam Device.
In the present paper, he is involved in realisation and practical aspects of integration of gun and magnetic focusing.

Ms M.K. Geetha obtained Diploma in Telecommunication Engineering in the year 1981. She joined MTRDC, DRDO in 1988. She is currently working as technical officer in development of compact mm wave TWT and carried out assembly and testing of the same to evaluate the design parameters.

Mr M. Vijaya Kumar received the BE in Electronics and Communication Engineering from Madras University in 1999 and MTech in Computational Science from IISc, Bangalore in 2016. He is currently working as Scientist in MTRDC Bangalore. His current research includes design and development of compact mmwave TWT for airborne and electronic warfare applications in Defence projects of DRDO.
In the present paper, he has performed all the design work, simulations and involved in all experimental evaluation of proposed MFS.