RF Design of Input Cavity Structure of a Low Frequency, High Average Power IOT

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Abstract— Inductive Output Tube (IOT) is a vacuum electron tube capable of amplifying RF power with very good efficiency. IOT has been extensively used in TV services as UHF transmitters to amplify both audio and video signals. Its moderate power gain, high efficiency and long life make it suitable for this application. Besides that, this tube has been proving its capability and reliability in scientific areas like in high energy particle accelerators and fusion plasma heating purposes. The paper will present the RF design of input cavity of a low frequency (~ 350 MHz) IOT carried out at CSIR-CEERI. It is an important component of the device. The simulation of the cavity has been carried out in CST and MAGIC2D codes. The CAD drawings have been prepared and the cavity structure has been fabricated. The details of design approach using CAD tools shall be presented in this paper.

1. INTRODUCTION

The IOT was invented in 1938 by AV Haeff but it took long time to recognize the ability and potential of this device. The tube came in prominence when it was used in UHF transmitters where its performance impressed the microwave researchers [1]. The structure of the device is similar to any other linear beam tube, like klystron, having some major differences in its operation. The input RF cavity, being an important part of the device, has to be designed with many technical constraints. The velocity modulation occurs in the interaction gap of the cavity which is placed onto the gun part.

The major components of IOT are electron gun, input/output cavities, input/output couplers, focussing magnet and collector, as shown in Figure 1. Pierce's type gridded electron gun is used for electron beam generation. The RF input signal is applied between cathode and a grid which is positioned close to and in front of the cathode.

The inner wall of the cavity is connected between the cathode and grid — the two electrodes both of which are at a large negative potentials. Further, it is necessary to maintain the outer wall of the cavity and its tuning mechanism at ground potential. The method used to form bunches is somewhat different from the conventional linear beam tubes. The modulated beam passes into the RF output interaction region of the IOT. The device has no intermediate cavities. An output coupler connects the cavity to the output feeder system. The electron beam is focused using a suitable magnetic focussing system. The spent electron beam is dissipated in a copper collector either air cooled or liquid cooled depending on the power level involved [2–4].

IOTs are widely used in TV services as UHF transmitters to amplify both audio and video signals. It has average power gain, very high efficiency and sufficient long life which make it suitable for this application. Apart from this, IOT's significance has now being recognized for scientific applications too. They are used as RF source in a number of international high energy particle accelerators such as Diamond, CERN and LANSCE [5].

2. DESIGN APPROACH AND RESULTS

IOT has only two resonant cavities- one input and one output cavity. The velocity modulation will occur in the input cavity where the nose cone gap is the distance between the cathode and grid. The cavity should be smartly positioned so that the cathode-grid gap plays the role of cavity drift gap and contributes to the interaction between electron beam (emitting from the electron gun) and the input RF signal (applied at the cathode-grid gap). As the cathode-grid distance is very small in the range of 0.3 mm, the design of the cavity should be such that the required field pattern (E and H) could be obtained within the cavity for proper modulation. One key issue is that the cavity operates in grounded mode and in this case, the inner wall of the cavity is connected to the cathode and grid, having high negative potential, hence proper isolation of the input circuit is mandatory for its successful operation.

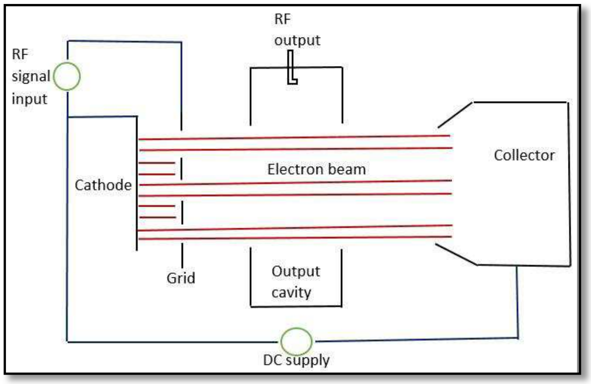

Figure 1: Schematic of IOT.

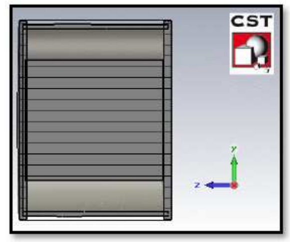

Figure 2: Structure of input cavity.

The paper presents the simulation results of a 350 MHz input cavity carried out in CST and MAGIC PIC software. The cavity structure shown in Figure 2 is chosen for properly placing the cavity onto the cathode-grid gap. The inner conductor, shorted at one end and open at other end (which makes the cathode-grid gap), acts as cathode which is emitting electron beam from its face and the outer conductor dimensions (diameter and length) are the deciding factor of the desired resonance of input RF signal in the cavity. The design is so chosen because in this structure, E field peaks at the gap and B field maximises at the short end which is the desirable field profiles for coupling the input power to this cavity.

For choosing the initial dimensions of the cavity, there are some limitations and considerations. Within the inner conductor of the cavity, in actual, cathode has to be placed. Therefore, the inner conductor has to be of sufficient diameter so that the cathode will be inserted in it properly. Hence, the inner conductor's diameter's estimation is taken from the cathode diameter (which is already simulated according to the beam parameters). The outer conductor's diameter is optimized through various iterations to get the resonance of the desired frequency in the cavity. The critical dimension is the cathode-grid gap. The gap is taken so small (~ 0.3 mm) to have only 1–2 percent of the RF cycle being interacted with the electron beam so that proper and efficient velocity modulation takes place for sufficient bunching of the electrons. On the other hand, decreasing the gap distance below the specified value will cause breakdown issues. Therefore, this gap is chosen within safe limits to properly serve its purpose of modulation in the cavity.

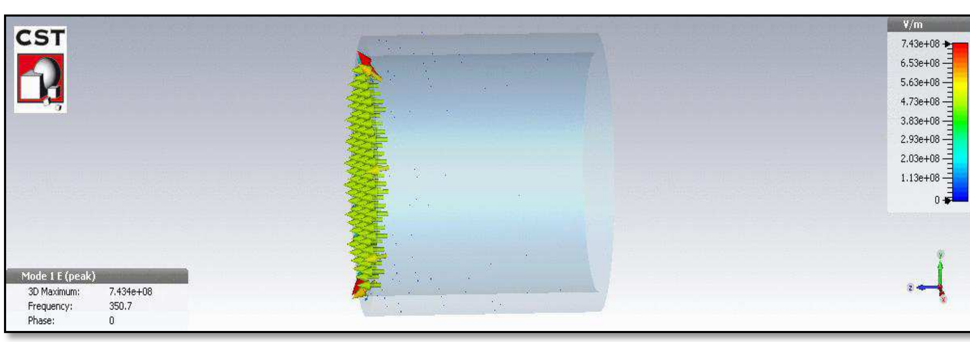

Figure 3: Resonant frequency @ 0.3 mm gap.

The cavity structure is similar to a radial cavity whose inductance, capacitance and resonant frequency can be estimated from the following equations [6]

$$L = \frac{\mu l}{2\pi} \ln(b/a) \tag{1}$$

$$C = \epsilon_0 \left[\frac{\pi a^2}{d} - 4a \ln\left(0.765/\sqrt{\{l^2 + (b-a)^2\}}\right) \right] \tag{2}$$

$$f_r = \frac{c}{2\pi\sqrt{\epsilon_r}\sqrt{\left\{ al \left[\frac{a}{2d} - \frac{2}{l} \ln\left(\frac{0.765}{\sqrt{[l^2+(b-a)^2]}} \right) \right] \ln\left(\frac{b}{a}\right) \right\}}} \tag{3}$$

where L is the inductance produced in the cavity wall, μ is the permeability, C is the capacitance in the cavity gap, ϵ_0 is the permittivity of free space, f_r is the resonant frequency, ϵ_r is the relative permittivity of the material of the cavity, a and b are radius of inner and outer conductor respectively, d is the cathode-grid gap, l is the height of the cavity and $c = 3 \times 10^8$ m/s is the velocity of light in vacuum.

Figures 3 and 4 provide the information about the resonant frequency and E field pattern obtained in CST and MAGIC respectively. Based on the results obtained, the input cavity has been fabricated as shown in Figure 5. The cold test measurements are planned for validating the simulation results. The experimental results will also be presented in the talk.

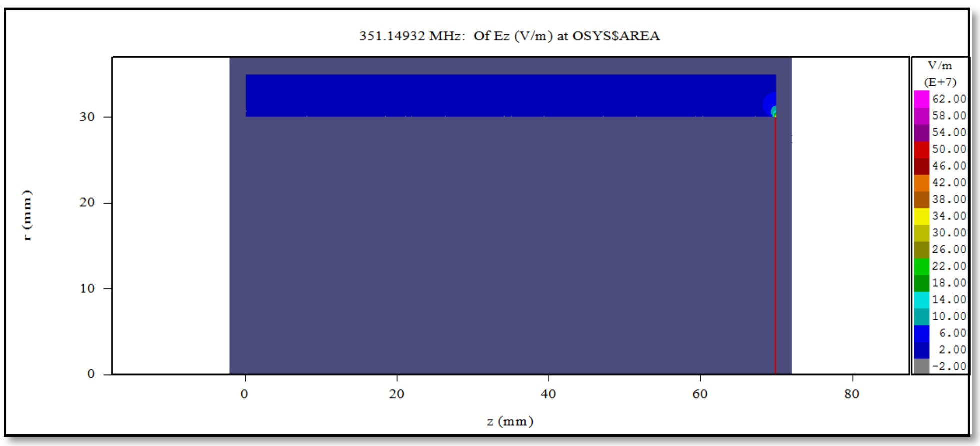

Figure 4: Resonant frequency in MAGIC code.

Figure 5: Fabricated input cavity.

3. CONCLUSION

IOTs are now widely recognized as a useful vacuum tube for various microwave applications. The results of input cavity of an IOT under development at CSIR-CEERI are presented in this paper. The eigen-mode analysis of the cavity has been done in CST as well as MAGIC codes and is fabricated in the CEERI workshop. From simulations, it can be concluded that the cavity structure presented in the paper will be suitable for generating resonance of the RF input signal in an IOT. The design adopted is also suitable for putting it onto the electron gun structure which is necessary for the velocity modulation of the electron beam.

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