Inductive Output Tube: A Promising Microwave Source for High Power Applications

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Abstract
This paper presents the overview of inductive output tube (IOT), a vacuum electron tube, which is now widely used for broadcast and scientific applications. The structure and operating principle of this device have been described. Its similarities and merits over other conventional tubes i.e. klystron and tetrode have been discussed. The current state of the art and major applications have been highlighted in this paper. Some simulation results of input cavity of an IOT using CST code, which is undergoing at CSIR-CEERI, Pilani, have been presented in detail.

Keywords
Inductive Output Tube; Klystrode; Microwave Tube; IOT; UHF Transmitter; Particle Accelerators

I. Introduction

IOT is a vacuum electron tube which amplifies RF power with very good efficiency. The structure of this device is similar to a klystron to some extent but it has some prominent differences in its operation. It is also named as "klystrode" signifying to have combined properties of klystron as well as tetrode. IOT is first proposed by Andrew Haeff in 1938 [1].

II. Structure and Operation

IOT has major components named as electron gun, input/output cavity, input/output coupler, collector and a focussing system shown in fig. 1 [2]. Pierce's type gridded electron gun is used for 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 electron beam is thus density modulated within the gun itself.

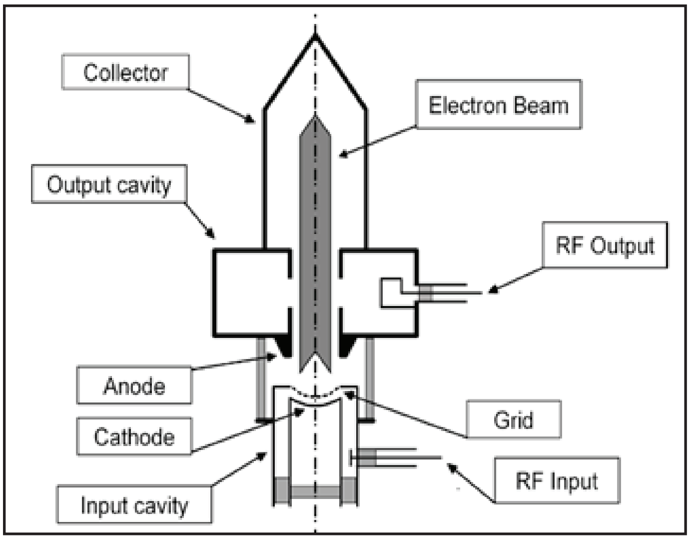

Fig. 1: Schematic of IOT

A structure similar to klystron cavity is adapted for IOT input cavity. However, in this case the inner wall of the cavity has to be connected between the cathode and grid - two electrodes which are both at a large negative potential. 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 very different from klystron operation. The modulated beam then passes into the klystron like RF output interaction region of the IOT. The conventional klystron has intermediate cavities which are stagger tuned to slightly different frequencies in order to do this. However IOT has no such intermediate cavities hence a double tuned output cavity system is employed to achieve high bandwidth. A standard 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 of traditional design of klystron either air cooled or liquid cooled depending on the power level involved [3-4].

III. Advantages Over Conventional Tubes

IOT has some salient features like high efficiency, moderate gain and bandwidth, high linearity, ease of tuning the input and output cavities, adequate lifetime and reliability of the device which makes it more preferable now-a-days in scientific application areas [4-5].

There are several advantages of this device over the conventional microwave tubes (specifically klystron and tetrode) [6]. IOT has higher conversion efficiency and lower operating cost per annum in TV transmitter application compared to klystron and tetrode. It is smaller in size, lighter in weight, has lower input drive power requirements, lower cooling requirements, lower magnetic field requirements and reduced collector size compared to klystron. It has higher gain, greater lifetime of tube (failure rate of 3 tetrodes for each IOT reported) than tetrode [7].

IV. Major Applications

IOT's are extensively used in TV services as UHF transmitters to amplify both audio and video signals. Its power gain, high efficiency and long life make it suitable for this application. This tube has been proving its capability and reliability in the field of broadcast applications.

Apart from this, IOT's are now well recognized for scientific applications too. They are used in a number of international high powered particle accelerators such as Diamond, CERN and LANSCE [8].

V. State of the Art

There are many qualified manufacturers for the development of IOT's for both broadcast and scientific applications. The IOT's which are latest and have the highest specification have been described in this section. Communications & Power Industries (CPI) have developed K290W (470-806 MHz, analog, 90 kW visual), K2D130W (digital, 130 kW peak) for broadcast applications and VKL-9130 (1.3 GHz, 30/90 kW power av./peak), VKP-9050 (500 MHz, 90 kW peak, 70% efficiency) for scientific applications.

Calabazas Creek Research, Inc. (CCR) has developed 350 MHz, 200 kW CW, multiple beam IOT for RF source for accelerators and colliders.

English Electric Valve Company Ltd. (e2v) manufactures IOTD3130W (77 kW vision + 7.7 kW aural) analog and

IOTD3130W (135 kW peak) digital for UHF TV transmitters.
L3 communications produces IOTD85T and IOTD130T high efficiency tubes operating in the UHF-TV frequency range of 470-810 MHz. These amplifiers are designed for digital transmitters requiring up to 30 kW average/130 kW peak output in 8VSB digital service or up to 70+7 kW in common mode service [9-12].
The European spallation source (ESS), an accelerator division in Sweden, is developing the most powerful linac that has been ever built. This linac requires 150 individual high power RF sources including (352 MHz/704 MHz, 2.8/1.5 MW peak) klystrons, (704 MHz, 1.2 MW) IOTs, and (352 MHz, 400 kW peak) tetrodes. The responsibility of procuring this IOT is being taken by ESS in collaboration with CERN [13].

VI. Ongoing Activities on IOT in CSIR-CEERI, Pilani

The study of design aspects of an IOT (specifically, 500 MHz, 90 kW) is going on at CSIR-CEERI Pilani as the research topic for the first author's Ph.D thesis. The IOT with similar specifications has been developed by CPI for particle accelerator applications. Our aim is to learn the technological aspects of its design and to validate our approach.
As mentioned earlier, IOT has only two resonant cavities- one input and one output cavity. The input cavity structure is somewhat different from the klystron cavity because the velocity modulation has to 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 is very small in the range of 0.3 mm, the design of the cavity should be such that the required field profile (E and H) is obtained within this gap 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.
The paper presents the simulation results of input cavity carried out in CST software. The cavity structure shown in fig. 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. Here, the cavity dimensions are optimized to get the required resonant frequency and field profiles. The other parameters namely unloaded Q ≅ 3368 and R/Q ≅140Ω are calculated from CST. The fabrication of this cavity is in progress. Fig. 2 shows the cut plane view and fig. 3 provides the information about the resonant frequency and E field profile.

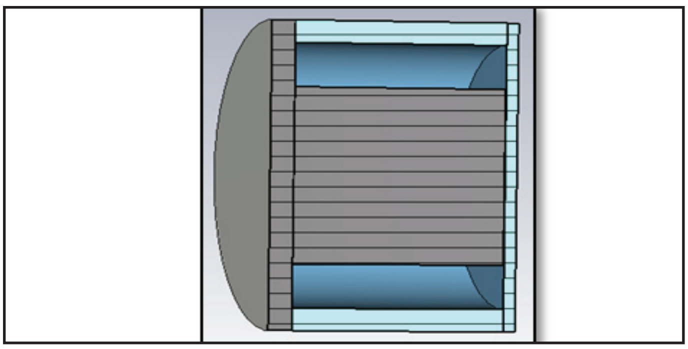

Fig. 2: Cutting Plane View of the Input Cavity

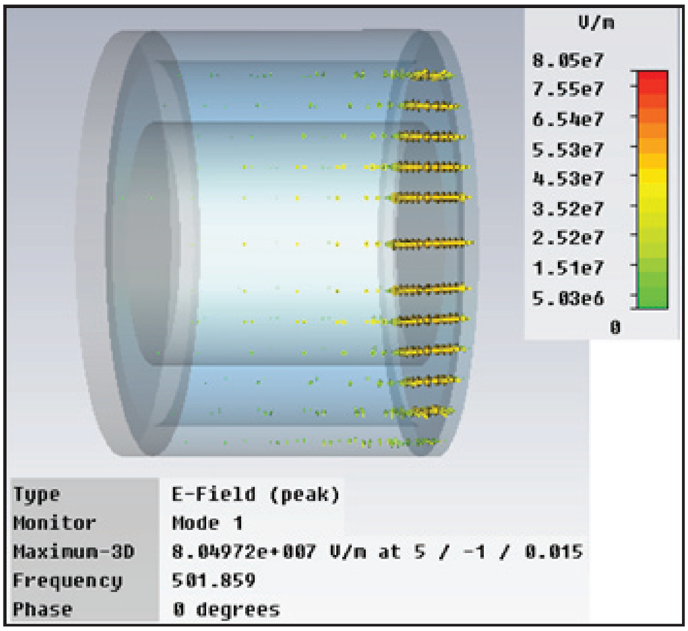

Fig. 3: Input Cavity Structure in CST

VII. Conclusion

IOT's have the potential of competing with the conventional available vacuum tubes. Firstly recognized as a useful device in television transmitters, IOT's are now preferred in various other fields like particle accelerators also. At present, it is desired to produce more IOT's at higher frequencies to meet the requirements of industrial applications. A variety of IOT's like higher order mode (HOM) IOT, multi-beam (MB) IOT, wide-band (WB) IOT etc have been developed and a lot more are in demand for future accelerators applications. So, IOT's has an emerging future ahead.
The eigen-mode analysis of input cavity has been done at CSIR-CEERI using CST software. After the fabrication, the cold testing of the cavity will be done by network analyzer to validate the simulated and measured results.

VIII. Acknowledgement

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