An Approach for Bandwidth and Gain Enhancement of 0.22THz RF Amplifier

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***Abstract*— In this paper, a scheme for bandwidth and gain enhancement of 0.220THz traveling wave tube amplifier (TWTA) is presented. A two-section staggered double vane (SDV) slow wave structure (SWS) loaded with two period Bragg reflector at both the ends is analyzed in this paper. The attenuator section that separates the input and output section comprises of a six pitch long rectangular waveguide loaded with lossy material on top and bottom walls. Velocity taper is provided at all transitions for improved impedance match. The dispersion characteristics were computed through Eigen mode analysis in Microwave studio module of Computer Simulation Technology (CST) and the results were validated using Ansys's High Frequency Software Simulator (HFSS). 15dB transmission and reflection loss across a bandwidth of 45GHz from 0.205-0.250THz is provided by the design optimized attenuator while separating the input and output sections. Through particle in cell (PIC) simulations in CST Particle studio, beam wave interaction between input RF signal and a sheet electron beam is studied. The proposed TWTA yields 22dB gain across the bandwidth of 32GHz ranging from 0.218-0.250 THz range for a beam current of 30mA fed at an operating voltage of 19kV.**

Keywords—staggered double vane, traveling wave tube amplifier, slow wave structure, Bragg reflector, and attenuator.

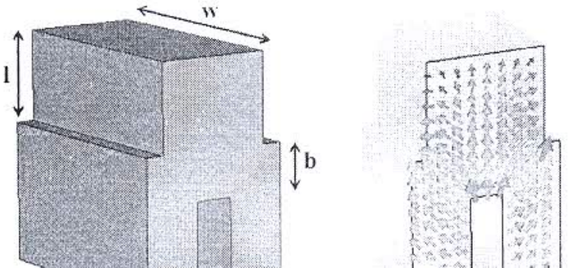
I. INTRODUCTION

Recent advances in high-data-rate and deep space communications, precise imaging, diagnostics, sensing and radars [1-3] have created an increasing demand in devices operational at sub-millimetre frequencies. Vacuum microelectronic devices (VMED) are the apt solution to the demands as they are able to deliver high power output across wider bandwidths. Although the conventional traveling wave tubes are feasible to fabricate and deliver wider bandwidths at microwave frequencies, their dispersive nature reduces bandwidth and their small sizes increase complexity in fabrication at millimetre and sub-millimetre wave frequencies. In order to provide much wider bandwidth, higher gain, low loss and better heat dissipation with ease of fabrication, a recourse in design of traveling wave tube amplifiers were made to opt for planar SWS such as folded connected in series or in parallel in order to achieve larger power gain. The attenuator section of predominant designs incorporate multiple small lossy materials with varying heights placed in successive cells of the SWS [3-6] spanning over 8 pitches along the axis. In order to deliver better attenuation in reduced length, single lossy material spanning over multiple pitches along axial distance was presented in [7]. Also, Bragg reflectors [8, 9] are conventionally used in optical systems and millimetre wave backward wave oscillators in order to prevent leakage of RF signal into collector and electron gun. In [10], stability analysis of single cell Bragg reflector in TWT for G band was presented.

In this paper, we present a scheme for bandwidth and gain enhancement of SDVSWS at 0.22 THz applications. In Section II, a unit cell of the SWS is studied and the dispersion characteristics are discussed. Section III discusses the transient analysis results of the SWS that incorporates two cell Bragg reflectors for enhanced bandwidth and the attenuator section. Section III also presents the results of PIC simulations in which the SWS successfully yields a gain of 22dB in the band ranging from 0.218-0.250 THz.

II. DISPERSION CHARACTERISTICS

The dispersion characteristics are obtained by analysing a unit cell of the periodic structure. A unit-cell of the SDV SWS is displayed in Fig. 1(a). Table 1 briefs the relative dimensions of the unit cell, namely the width of the vane (w), beam tunnel thickness (b) and vane height (l) with respect to one axial pitch distance of the unit cell. Fig. 1(b) displays the field distribution of the E field at 0.22 THz in the cutting plane view.



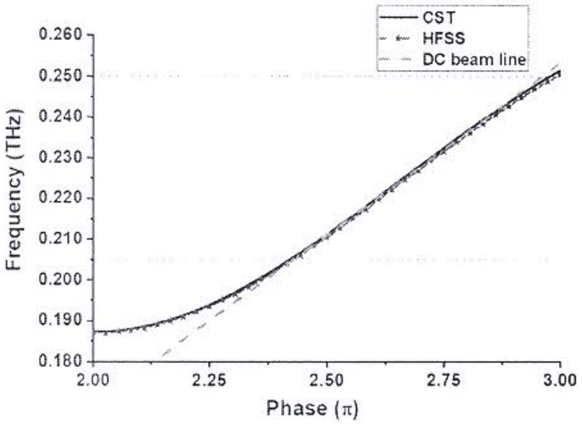


Fig. 2. Dispersion characteristics computed using CST MWS, HFSS and 19 kV DC Beam line

Using CST-MWS and HFSS, Eigen mode analysis was performed on the unit cell. Periodic boundary conditions were applied for the planes normal to the axis; at the transverse planes, the electric boundary conditions were applied. The Eigen mode analysis results in the dispersion characteristics of the unit cell of the SWS and are plotted in Fig. 2. A 19 kV DC beam line passes along the dispersion plots from 205-250 GHz. The RF signal in the 45GHz bandwidth when fed through the proposed SWS would be able to effectively interact with the 19kV electron beam.

III. TRANSIENT ANALYSIS

Fig. 3 displays the TWTA consisting of two sections of SWS – input and output sections. The proposed SWS comprises of periodically placed unit cells along the axial direction. The RF signal in each section traveling towards the other, is shorted out by the attenuator, thereby isolating input and output sections. At the other ends of the two sections, identical ports are designed in order to couple the externally fed RF signal into the TWTA and to couple the amplified RF signal to the respective external circuitries.

In optical systems and backward wave oscillators (BWO), Bragg reflectors [8, 9] are more widely used on either ends of the devices, to prevent the leak of RF signal. In order to provide much better impedance match at the input port across wider bandwidth and to prevent the RF signal coupling to electron gun and collector through beam tunnel, a two cell Bragg reflector is used at each ends of the TWTA. In the input section shown in Fig. 4, the RF signal is fed through an H plane bent rectangular waveguide with a two section Bragg reflector. As shown in Fig. 4, a velocity taper of 3.5 pitch distance is provided adjacent to the H plane bend for further reducing the impedance mismatch between the input port and the SWS, delivering the necessary phase velocity taper at the waveguide transition.

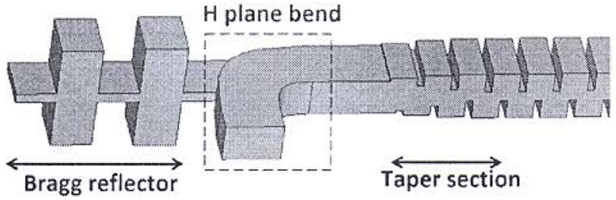


Fig. 4. Bragg reflector loaded input section with H plane bent input port.

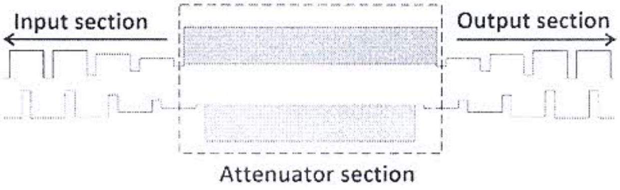
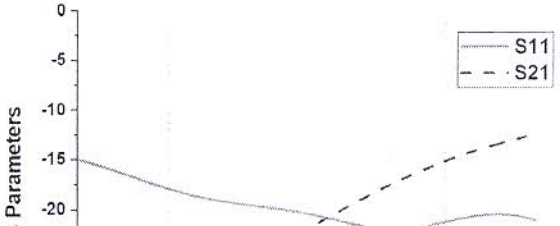


Fig. 5. Attenuator section separating input and output sections

With 30mA of beam current, a sheet electron beam is guided through the SWS at 19kV potential at the entrance plane. A 0.3T magnetic focussing system is employed in order to keep the beam focussed along the axis of the SWS.

The attenuator section of conventional TWTAs consists of finely cut lossy dielectrics of varying heights placed in subsequent unit cells that provide a tapered profile [1-2]. The cutting of the lossy dielectric into precise small pieces increases the cost of the SWS drastically. In order to provide sufficient attenuation to the RF signal, filling successive cells would require a minimum of 8-10 pitches axially [1] which increases the SWS length. In this work, we propose an attenuator section comprising of a rectangular waveguide loaded with two dielectrics placed on its opposite walls as shown in Fig. 5. The length of the attenuator section is reduced to 6 pitches, and the lossy dielectric design is optimised along with the waveguide dimensions to provide a minimum reflection loss (S11) and transmission loss (S21) of 15dB each. Fig. 6 displays the S parameters of the attenuator section for the 0.208-0.248 THz range. On both sides of the attenuator, a taper is provided along the axis in the input and output sections for velocity tapering.



The transient analysis results of the TWTA are presented in Fig. 7. The previous reported results of conventional designs neglected to mitigate the loss of RF signal to the beam tunnel in the electron gun and collector ends. In current approach, the use of dual cell Bragg reflectors at the input and output sections reduce the loss of RF signal into the beam tunnel, thereby providing an improved -10dB bandwidth of 32GHz ranging from 0.218-0.250 THz. The minimal attenuation at ports effectively helps in increasing the gain in the intended operational bandwidth.

The PIC simulations were performed on the Bragg reflector loaded 65 mm long SDVSWS at multiple frequencies ranging from 0.218-0.250 THz. A 19kV electron beam of 30mA current was employed with 0.3T focusing system. The resultant gains obtained are plotted in Fig 8. It can be observed that the gain is consistently greater than 22dB across the bandwidth (3dB) and gain per mm is above 0.37.

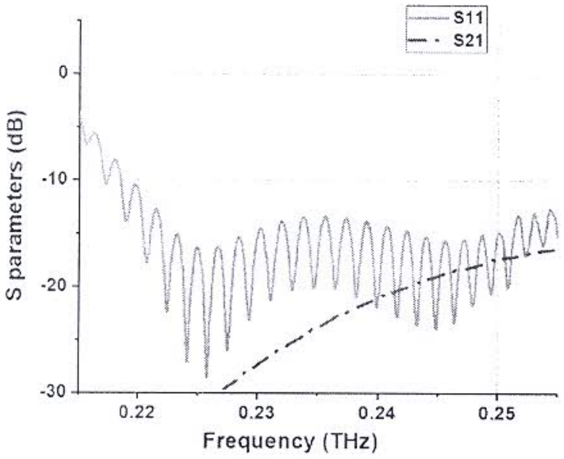


Fig. 7. Scattering parameters of the complete SWS.

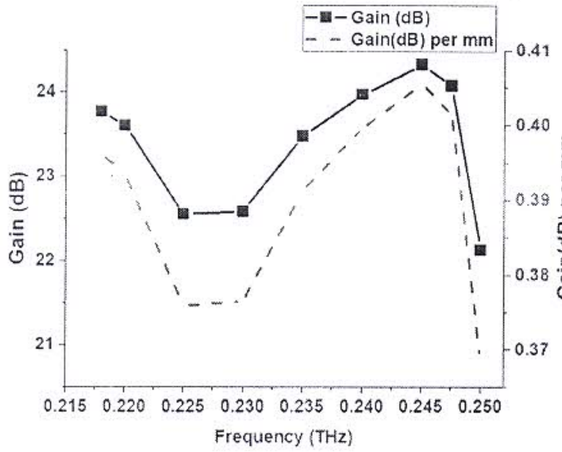


Fig. 8. PIC simulation results of Gain (dB) and gain per mm.

CONCLUSION

This paper successfully provided a scheme to enhance the gain and the bandwidth of staggered double vane slow wave structure. The designed SWS yields 22dB gain at minimal axial distance across the bandwidth of 0.218-0.25THz. The magnitude of achieved gain across the 32GHz band in such short length of SWS was achievable due to the precise tuning of the unit cell of the SWS, the attenuator and the two cell Bragg reflectors at the input and output sections. Further increase in gain is achievable by increasing the beam wave interactions through addition of SDV unit cells in both input and output sections.

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