

Review of Planar Slow Wave Structures for Travelling Wave Tube

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Abstract—Planar slow wave structures (SWS) are well-suited with micro fabrication technologies which have been known so far as alternative for circular helix- slow wave structures in traveling wave tube (TWT) for RF power amplification. Vacuum tube electronic devices with power ranges from few watts to kilo watts at THz frequency above 100GHz playing significant role for scientific, industrial and medical applications. While increasing operating frequencies size of helix becoming reduced and its use is restricted for maximum frequency ranges of up to 70GHz. In this paper an important focus on the present state of RF planar slow wave structures for high power traveling wave tubes have been reviewed and high frequency characteristics such as interaction impedance, dispersion characteristics are analyzed for different SWS's.

I. INTRODUCTION

DEVELOPMENT in traveling wave tube (TWT) - slow wave structures (SWS) are increased in recent years where high power miniaturized radiation sources in radio frequency structures are considered. Realization of device efficiency, output power and wide band width in high power millimetre wave range for specific applications such as radar, medical device and satellite communications have been increased widely and vacuum devices dominate solid state devices predominantly. Vacuum electronics amplifiers used for remote sensing, medical imaging, advanced materials spectroscopy, high resolving power radar, and high data rate communication applications and are required as low voltage compact light weight, high power at mm wave frequencies. Several approaches have been proposed to analyze travelling wave interaction. J. R. Pierce developed the classical small-signal theory which has a logical extension of the qualitative description of traveling wave interaction and numerous of the parameters well-defined by Pierce are currently part of the known vocabulary of the traveling wave tube industry. The analysis is divided as finding RF current

$$i_z = \frac{j\beta_e I_0}{2V_0(\beta_e - \beta)^2} E_z$$

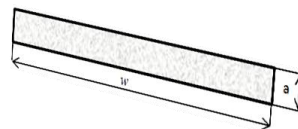
(The electronic equation) where I_0 - dc beam current, V_0 = dc beam voltage, $\beta_e = \omega/u_0$ is the propagation constant then analyzing slow wave circuit [7]. The propagation constants of the waves on the circuit and on the beam are found by combining the circuit equation with the electronic equation. Process additionally analyzed as beam velocity equal to cold circuit V_p (Phase velocity) and not to its conditions. As a final point, the results of circuit destruction and of space charge are considered.

The utilization of helix TWT is constrained up to a most extreme operating frequency of 70GHz while decrease in device size with increasing frequency [2]. Theoretical and simulation based analysis have been made for planar structures such as rectangular type which are well-suited with micro fabrication technology. Because planar structure interact with sheet beam comfortably where it is electroplated on a dielectric substrate [3-5].

II. PLANAR SLOW WAVE STRUCTURE

Vacuum tube devices at frequencies above 100GHz for applications in broad band communication and radar are very little in size and microelectronic innovation is required for fabrication. Conventional fabrication method is not possible for little size (radius in microns) of helix for a traveling wave tube. Folded waveguide (FWSWS) and coupled cavity slow wave structure (CCSWS) are RF structures for 95GHz TWT [2]. However both folded-wave guide and coupled-cavity SWS's are fundamentally shaped with planar structures and cylindrical electron beam is used for RF wave amplification. These two planar devices are difficult to manufacture and have low proficiency.

Geometry of sheet beam is having increased bandwidth, high beam current strength, reduced beam potential, decreased power densities and low potential gradients [9]. This type electron beam has many advantages compared with round-beam geometries.



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Fig. 1a. Sheet beam

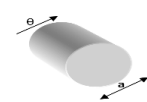


Fig. 1b. Round beam

Sheet beam: w —width and a - thickness, working frequency (f) of a design is oppositely proportional to its dimension shown in Fig.1a:

$$\text{beam current} \propto \text{width} \times \text{thickness} \times f^1$$

Where w is ignorable coordinate. The output power of a sheet beam wave tube is reducing merely linearly likewise a work about growing frequency, building it fitting for high frequency applications.

Round beam: a - diameter, working frequency of a device is inversely relative to square of dimension (a) shown in Fig.1b:

$$\text{beam current} \propto a^2 \times f^{-2}$$

Where θ is ignorable coordinate. Quadratically the output power of a round beam twt is decreasing with rising frequency which makes it a reduced amount of capable for applications with high frequency. Furthermore sheet beam geometry is characteristically suitable to planer micro production machinery for vacuum devices

III. RECTANGULAR HELIX SWS

For wide band, small voltage and high power millimetre wave traveling wave tube the rectangular helix slow wave structure was developed [1] which is suitable for micro fabrication technology.

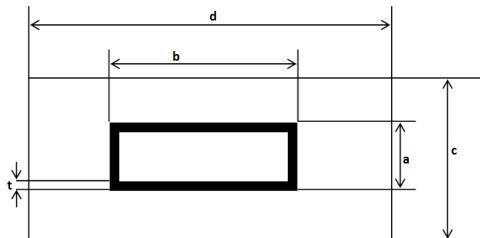


Fig. 2 Dimensional parameters of rectangular Helix SWS

High frequency characteristics such as dispersion characteristics, interaction impedance and reflection characteristics have been analyzed for conventional circular helix, rectangular structures. Only cross sectional shapes of both structures are different and all others parameters such as period, the circumference, width and thickness of metal strips are kept same dimensional. Interaction between wave and electron beam of rectangular structure was gained by using particle in cell code in simulation tool CST particle studio. In rectangular helix, the dispersion characteristics are similar to

circular helix with similar cross sectional perimeter and interaction impedance are considerably bigger. For a set cross sectional scale the rectangular helix may contain the choice of dissimilar aspect ratio (b/a) which is not the case in circular helix structures.

The helical structures dispersion relation and interaction impedances were examined under the regular limit conditions by [1] where it is observed that the phase velocity of shown slow wave structure rises from the circular to the rectangular type in series and sharp response of dispersion curve of the square helix and rectangular helix. But the interaction impedance of the rectangular helix is bigger than circular helix. It has been investigated and analyzed [1] that the rectangular type slow wave structure is appropriate with the overall consideration of high frequency characteristics and fabrication process

Based on simulations performed by [1], the scattering characteristics of the squared helix are alike to that of one's circular helix with all the same cross sectional boundary, while the interaction impedance is better than the matching circular helix slow wave structure.

IV. PLANAR SWS FOR W- BAND TWT

A new planar slow wave structure TWT [2] was proposed working at 92GHz according to metamaterial despite the fact that operates using a cylindrical electron beam which significantly simplifies the fabrication and magnetic focus of only 0.35 T. These planar SWS have been realized by two diamond structures originating at two rounded micro strip zigzag line shown as Fig. 3a which is infused with a metallic protection. The metallic protection is a waveguide over two rectangular channels within the dielectric substrates Fig. 3b.

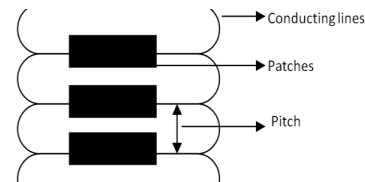


Fig.3a.Top view of planar SWS

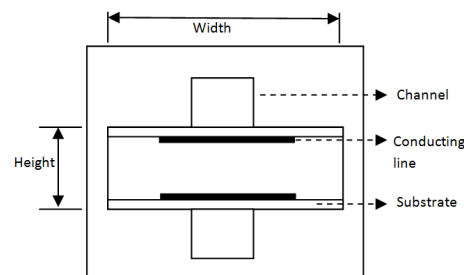


Fig.3b. Front cross section of planar SWS

Wave- beam interaction in this planar structure was performed by an electron beam of cylindrical shape travels alongside the fundamental axis of SWS. The diameter of the electron beam appropriated as 0.16 mm

V. FOLDED WAVE GUIDE SLOW-WAVE STRUCTURE

RF sws design for W band traveling wave tube has been projected [7] where SWS design was carried by electromagnetic simulation code CST-MWS and GdfidL for W-band FWTWT. Fig.4a and 4b are showing unit cell and complete FWSWS.

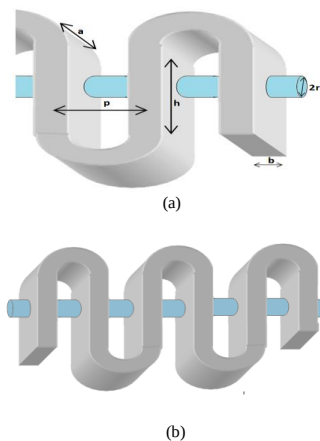


Fig. 4 (a)Unit cell of FWSWS, (b)FWSWS

Dispersion results found through simulation codes. Large signal analysis was done on CST particle studio and large signal analysis code SUNRAY 1D. This device services an E plane curved bending equilateral waveguide as a SWS circuit, as shown in Fig. 4b. A cylindrical electron emit is transported over the small-scale holes within the broad side of waveguide which interacts using the external electrical field of a propagating, principal TE₁₀-mode.

The input parameters such as broad side dimensions (a), narrow wall dimension (b), height (h), pitch (p), beam tunnel radius (r) got from simple formulas shown in Fig. 5a and input dimensional parameters were optimized through repetitions. Input parameters for circuit length of 55mm for affordable gain and electron beam of 35mA at 16kV with boundary 125um were set and results obtained at the output section with the effect of pitch tapering was calculated that advanced the gain to just about 24 dB. Advantages of FWTWT are robust structure, high-power capability, easier coupling over alternative structures like asymmetrical corrugated waveguides, its derivatives, simpler to fabricate than traditional CC-TWT circuits.

VI. BROADBAND PLANAR RF STRUCTURE

A planar staggered double vane rectangular waveguide SWS has been developed using a simplified analytical approach to get a broadband 0.22 THz 100W TWT [8]. The formation is intended for an electron beam of voltage 20kV and current 50mA which is integrally well-matched for sheet beam process.

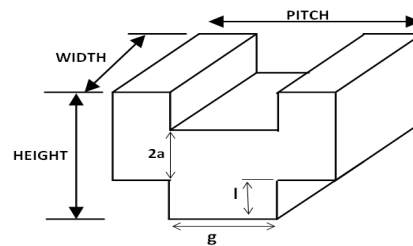


Fig. 5. Unit cell of SWS

Parameters of shown rectangular wave guide are

- P - Pitch
- d - Staggering factor
- g - Gap among two vanes
- t - Thickness
- l - Vane height
- 2a - Beam tunnel height
- h - Total height
- w - Width

The approached wave guide SWS is really a forward principal structure. First leading space harmonic of phase shift/pitch changing from 2π to 3π is selected for amplification process. Though the interaction impedance of better space harmonic is usually a smaller amount however it delivers broader working bandwidth.

The dispersion characteristic of analytical method and the simulated dispersion characteristic of the structure matches well within 5% and it has been revealed that pitch, vane height are most important parameters. For efficient beam-wave interaction half period staggering of multiply vanes within the SWS delivers high impedance, wider transmission capacity and strong in proportion RF electric field. The approached structure has high interaction impedance and large bandwidth of more than 50GHz.

VII. CONCLUSION

All types of planar slow wave structures discussed in this paper are having some merits over circular helix SWSs and are broadly designed and analysed by scientists and researchers for micro fabrication using semiconductor technology. Major advantage of planar slow wave structures is easy realization with typical 3D analysis. Folded waveguide SWS has exposed hopeful results at millimeter and sub millimeter frequency range. Since solid state devices are not able to provide enough transmit power at millimeter frequency

ranges vacuum devices will play an important role for 5G communications. All planar structures reviewed above are providing acceptable ranges of gain and bandwidth at maximum operating frequency ranges traveling wave tube upon planar RF slow wave structure, sheet beam is wished at tera hertz frequency ranges since planar structure is appropriate to dream up the use of MEMS tools and sheet beam is having more advanced beam current capacity.

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