Design and Analysis of Folded Waveguides- A Potential Interaction Structure in TWT at High Frequencies

Sudhamani HS, Jyothi Balakrishnan, Reddy S U M

I. INTRODUCTION

There has been a spurt in the growth of multimedia SATCOM services in the last few years. These systems need sources of high average power at millimeter wave frequencies (30 – 300 GHz). The conventional slow wave structures, such as helix and coupled cavity, are difficult to fabricate at these frequencies. The Helix structure becomes very small and fragile. The fabrication of the coupled cavity structure maintaining the required tolerances, becomes a challenging task. Deviations during the assembly of the individual cavities are also large. The cumulative error adversely affects the performance of the device. The Folded Waveguide Structure is one of the promising structures at millimeter and sub millimeter frequencies. This is because it is a rugged structure and can be fabricated using micromachining techniques on a block of metal. This structure can withstand high average as well as peak powers. The input and output couplers are also simple to design (waveguide input and waveguide output). The simplicity of the device has led to a lot of research in folded waveguide structures at sub mm wave frequencies.

In this paper, the design of a FWG structure at 220GHz is presented. An analysis of the structure with circular beam hole and various configurations of a square beam hole has been done. The dispersion and interaction impedance of the folded waveguide with different beamhole configurations has been compared and presented.

II. DESIGN OF FOLDED WAVEGUIDE STRUCTURE:

The schematic diagram of the serpentine waveguide slow wave structure is shown in Fig.1 below. The FWG structure has i. a rectangular waveguide circular E-plane bend (clockwise), ii. Waveguide straight section, iii. Circular E-plane bend, bent in the anticlockwise direction and iv. a straight section. The structure repeats resulting in the multiple folding of the rectangular waveguide, giving rise to the serpentine structure. The phase velocity of the waveguide is greater than the velocity of light. The effective phase velocity of the waveguide is slowed down, by increasing the path length by waveguide folding. This is done to facilitate the interaction of the wave with the electron beam. The wave velocity is slowed down by the factor pitch/leff, where pitch is defined as the length between successive beam crossings. The length leff is the total path that the electromagnetic wave traverses along the folded waveguide between the beam crossings.

Fig 1: (a) Schematic of folded guide structure (b) Cross section of waveguide with beam hole (c) CST model of FWG

In Fig.1, ‘a’ represents the broadside dimension of the waveguide, ‘b’ is the narrow dimension of the waveguide, ‘lₕ’ is the straight portion of the waveguide, ‘r’ is the mean radius of the circular E-bend, ‘r-b/2 is the inner radius of the E-bend, r+b/2 is the outer radius of the E-bend, and ‘rₑ’ is the beam hole radius. The waveguide serpentine structure which has a smooth circular E-bend is used to reduce the reflections and improve VSWR. Pitch ‘p’ is chosen such that there is a synchronization and thus proper interaction between the electron beam and the wave. It may be noted that a phase reversal of the TE₁₀ electric field occurs at the waveguide bend.

II A. Design Equations:

i. The FWG is designed for fₑ = 220 GHz, where fₑ is the center frequency of operation of the TWT.

ii. The ratio of operating frequency to cut-off frequency is assumed to be fₑ/ωₑₜₑₐ₉ = 1.25. Hence ωₑₜₑₐ₉ is determined. The dimension ‘a’ of waveguide is determined from ωₑₜₑₐ₉.

iii. The dimension b = 0.15a.
iv. The phase shift between the beam crossings $\Theta \equiv 1.5\pi$. (can vary from $\pi$ to $2\pi$

II B. Calculations
i. The effective phase velocity $v_{\text{p eff}} = \frac{p}{l_{\text{eff}}} v_{\text{ph}}$, where $v_{\text{ph}}$ is the velocity of the rectangular waveguide, and $l_{\text{eff}}$ is the effective length of the folded waveguide.

a. $l_{\text{eff}} = 0.5l_{\text{st}} + l_{\text{ebend}} + 0.5l_{\text{st}}$

ii. $u_0 = 5.9313 \times 10^5 \sqrt{V_c}$ m/s is the velocity of the beam and is decided by the beam voltage $V_c$ in volts.

iii. The condition for synchronization is $v_{\text{p eff}} = u_0$

iv. The Pitch $p$ is evaluated using $u_0 = \frac{\omega}{\beta_e} = \frac{\omega}{\Theta/p}$

v. The mean radius of the circular E bend is chosen as half of the pitch ‘p’. The effective length of E bend can be obtained and the length of the straight portion of the waveguide can also be determined.

III. SIMULATION USING CST STUDIO

CST Microwave Studio (MWS) is a specialized tool for the solution of 3D electromagnetic equations in high frequency problems. One period of the structure is modeled in Eigen mode solver and the Eigen frequencies are determined. The phase shifts and thus the dispersion characteristics are obtained. $V_p/cis$ calculated from this data. The interaction impedance is a parameter which determines the interaction between the beam and the wave. It depends on the strength of on-axis electric field available for the interaction. As the structure is periodic, the total electric field represents the sum of all space harmonics as per the Floquet’s theorem. The first forward space harmonic ($m=1$) component is the one which contributes to the interaction impedance. This component is determined by Fourier analysis. Simulations were carried out for different beam-hole configurations and the results are given in Fig 2a and Fig 2b.

Using CST Studio, Folded Waveguide has been modeled with circular and square beam hole configurations. The dimensional data is as per the reference [2].

IV. CONCLUSIONS

A study of the graphs, show that the dispersion characteristics have no dependence on the shape of the beam hole. However, the interaction impedance varies with the shape of the beam hole. R/C is chosen as parameter (R/C = 0.8, 0.88, 0.9) to see the variation in the characteristics for comparison with the circular beam hole. The interaction impedance of FWG with circular hole (diameter C) and the square hole (side R=0.88C) are same. It is observed that at R=0.88C, the area of the circle is approximately the same as that of the square.

BIBLIOGRAPHY
