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Mathematical Model of Sever and Coupler for Folded-Waveguide TWT at W-band

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ABSTRACT

A wideband folded waveguide travelling-wave tube (TWT) amplifier has advantages of simple coupling structure and robust structure over conventional helix TWT. In millimeter wave bands sever are used to have good impedance matching especially in high-power tubes where efficiency is important. The common technique for suppressing the backward wave is through the use of one or more severs. In this paper mathematical model for a coupler and sever for the folded waveguide at W –band and numerical simulation is carried out using mat-lab.

Keywords — Folded-waveguide travelling-wave tube, couple, sever, Folded-waveguide slow wave structure.

I. INTRODUCTION

Folded waveguide slow wave structure (FW-SWS) is having advantages of broad bandwidth, easy fabrication from gigahertz to terahertz travelling wave tubes with micro fabrication technology [1] and is compact in size. For MMW helix and coupled cavity TWTs, it is difficult to design energy coupler for extremely wide band. It is often difficult to insert plungers for necessary adjustments required to obtain required characteristics. But for folded Waveguide TWT, owing to slow wave structure the propagating wave type in coupler is same as that in folded waveguide, therefore matching character is better and structure is simple. Folded waveguide slow wave structure (FW-SWS) is having advantages of broad bandwidth, easy to fabricate from Gigahertz to terahertz travelling wave tubes using micro fabrication technology and compact in size. In the analysis of travelling wave amplification, backward waves are found to exist. This wave can carry power reflected from the load or output side backward to the input. If there is any mismatch at the input, a portion of the signal will be reflected back again and result in Oscillation or severe variations in gain as a function of Frequency. Although the tube may be very well matched to the signal source and to the load, there will normally be reflections from the input and the output terminals because of the difficulty in making impedance transition from the RF structure. To control increase in gain, attenuators and severs are used in TWTS. Using these forward waves as well as the backward waves is attenuated. The loss in gain in the forward direction may be at least partially compensated by increase in the length of sever in the interaction region. Unfortunately, if a good impedance match is to be realized, the attenuator must be extended up to considerable length along the RF structure. On the other hand, by using attenuator not only the backward wave but also the forward wave is attenuated, as a result, the electric field of the circuit loses control of the bunching process and velocity spread in beam increases. The increase in beam velocity spread in the attenuation region results in less effective bunching after the attenuation causing reduction in efficiency. As a result, at high power and when efficiency is important, the attenuator is not a attractive solution. In high-power tubes where Efficiency is important the most common technique of suppressing the backward waves is through the use of one or more *sever*. *Sever* prevents the reflection from the load and the output terminal from reaching the input terminal. Although the forward growing wave on the input Section is lost at sever, the current and velocity modulation on the electron beam remains to carry the signal across the sever region for further amplification in the output section. As the beam drift across the sever region, bunching degrades and effects the final efficiency of the tube. As a result sever region should be as small as possible. Also, the amount of degrading in bunching depends on the intensity of bunching that occurs at the input section of the slow wave structure.

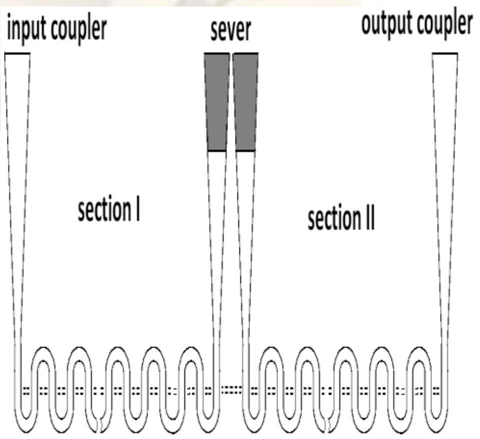

Fig. 1 Schematic of folded-waveguide with sever

The reflection coefficient at the output, at sever and at the input, along with the circuit attenuations must be taken into consideration in determining the practical gain. Because it is usually possible to keep the reflection coefficients at the sever termination less than those for the input and output. So severs are used in place of attenuator.

II. DESIGN OF LINEAR TAPERD WAVE-GUIDE.

Consider a tapered waveguide of length 'L' which connects two uniform waveguide of impedance of 'Z_O' and 'Z_1' as shown in Fig.2. Let 'X' be the distance from the end of taper where impedance is 'Z_O' and assume that impedance in the taper is the function of 'X' such that Z (0) = Z_O and Z (L) = Z_1 with partitioning interval $0 \le X \le L$, divided into equal 'N' sub intervals. Now we replace the taper with N uniform waveguides, each having length of '$\Delta X = L/N$' let the impedance of the n^{th} segment be $Z_n = Z(X_n)$ as per reference [11]

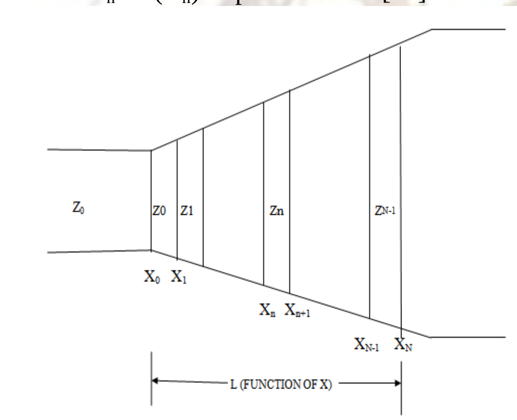

Fig.2 Tapered waveguide.

Total reflection coefficient is now a function of 'N' small reflections from the discontinuities at X_0, X_1, X_2…………..X_N. If 'N' is large the reflection at each discontinuity is very small. The reflection coefficient as per reference [11] is given in equation (1)

$\tau = \tau_1 \exp(-2 * \gamma_0 * \Delta x) \quad + \tau_2 \exp(-2 * \gamma_0 * \Delta x - 2 * \gamma_0 * \Delta x) + \ldots\ldots + \tau_N \exp(-2 \sum_{M=0}^{N-1} \gamma_M * \Delta x).$

$$\tau = \sum_{n=1}^{N} \tau_n \exp(-2 \sum_{M=0}^{N-1} \gamma_M * \Delta x) \qquad (1)$$

Where γ_N is the propagation constant in the nth segment

$$\tau_n = \frac{z_n - z_{n-1}}{z_n + z_{n-1}} \qquad (2)$$

Substituting the equation (2) in the equation (1) we get

$$\tau = \sum_{n=1}^{N} \left[\frac{z_n - z_{n-1}}{z_n + z_{n-1}}\right] * \exp(-2 \sum_{M=0}^{N-1} \gamma_M * \Delta x) \qquad (3)$$

In the above equation if 'N' discontinues approaches infinity summation becomes integral as shown in equation (4)

$$\tau = \int_0^L \left(\frac{Z'(x)}{2\, z(x)} * \exp(-2 \int_0^X \gamma(t)dt).\right) dx \qquad (4)$$

Integrating equation (4) we approach to

$$\tau = \frac{-1}{4\gamma_1}\left(\frac{d}{dx}(\log(Z))_1 \exp(-2 \int_0^L \gamma dx\right) + 14\gamma 0(ddx\log Z0-120Lddx(ddx\log zx*0L\exp-2*0x\gamma tdt.dx)$$
(5)

From the general equation (5) we can derive the particular type of taper for waveguide applications as follows

$$\tau = \frac{1}{4\gamma_0}\left(\frac{d}{dx}(\log(Z))_0 \quad \frac{-1}{4\gamma_1}\left(\frac{d}{dx}(\log(Z))_1 \exp(-2 \int_0^L \gamma dx\right) + \int_0^L \frac{d}{dx}\left(\frac{d}{dx}(\log(z(x))\right) * \int_0^L \exp\left(-2 * \int_0^x \gamma(t)dt\right).dx\right) \qquad (6)$$

Equation (6) is the generalized expression depending upon the parameters of attenuator like length etc. The above equation can be modified, if 'γ' which not a function of 'x' is as

$$\tau = \frac{1}{4\gamma_L} * \log\left(\frac{Z_1}{Z_0}\right) * (1 - \exp(-2 * \gamma * L)) \qquad (7)$$

Fig.3 shows a linear taper of the length 'L' of dielectric constant 'K' which Connects a rectangular waveguide of impedance Z_O and Z_1 with a taper section 'a' and 'b' which are the linear function of 'x'.

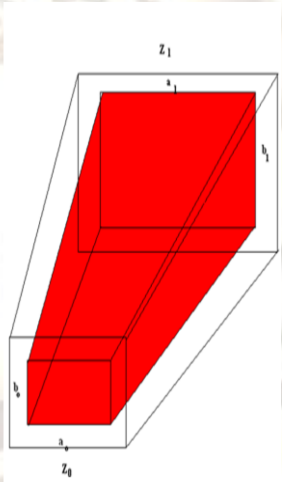

Fig.3. Sever for FW-TWT

The integrated characteristics impedance defined on voltage and current basis is given in equation (8)

$$Z = \frac{\pi\eta_0}{2} * \left(\frac{b}{a * \sqrt{k - \left(\frac{\lambda}{2*a}\right)^2}}\right)$$
(8)

$$\gamma = \frac{i2\pi}{\lambda_g}$$
(9)

$$\gamma = \frac{i2\pi}{\lambda} * \left(\sqrt{k - \left(\frac{\lambda}{2*a}\right)^2}\right)$$
(10)

Now,

$$\frac{d}{dx}(\log(Z)) = \frac{1}{L}\left[\left[\frac{b_1-b_0}{b}\right]-\left[\frac{a_1-a_0}{a}\right]\left[\frac{k}{\left[k-\left(\frac{\lambda}{2a}\right)^2\right]}\right]\right]$$

(11)

$$\exp\left[-2\int_0^L \gamma\, dx\right] = Z \quad \exp\left[-4\pi i\int_0^L \frac{dx}{\lambda_g}\right]$$

(12)

Hence,

$-2\int_0^L \gamma\ dx = -4\,\pi i\int_0^L \frac{dx}{\lambda_g}$, We have already derived the equation of the reflection coefficient of linear taper as

$$\tau = \left[\frac{i}{8\pi\left(\frac{L}{\lambda}\right)}\right] * [k_1\exp(-i4\pi l) - k_0]$$

(13)

$$k_1 = \left[\frac{\left[\frac{b_1-b_0}{b_1}\right]-\left[\frac{a_1-a_0}{a_1}\right]\left[\frac{k}{\left[k-\left(\frac{\lambda}{2a_1}\right)^2\right]}\right]}{\sqrt{k-\left(\frac{\lambda}{2a_1}\right)^2}}\right] \qquad (14)$$

$$k_0 = \left[\frac{\left[\frac{b_1-b_0}{b_0}\right]-\left[\frac{a_1-a_0}{a_0}\right]\left[\frac{k}{\left[k-\left(\frac{\lambda}{2a_0}\right)^2\right]}\right]}{\sqrt{k-\left(\frac{\lambda}{2a_0}\right)^2}}\right] \qquad (15)$$

$$l = \frac{1}{\lambda}\int_0^L \sqrt{K-\left(\frac{\lambda}{2a}\right)^2}\, dx$$

(16)

$$|\tau| = \frac{1}{\frac{L}{\lambda}}\left(\sqrt{\frac{k_1^{\,2}+(k_0)^2}{64\pi^2\left(\frac{L}{\lambda}\right)^2} - \frac{k_0k_1(\cos(4\pi l))^2}{32\pi^2\left(\frac{L}{\lambda}\right)^2}}\right)^{\frac{1}{2}} \qquad (17)$$

$$\text{VSWR} = \frac{1+|\tau|}{1-|\tau|} \qquad (18)$$

$$l = \frac{L}{(a_1-a_0)*2}\left(\frac{2a_1}{\lambda_{g1}}-\frac{2a_0}{\lambda_{g0}}+\left(\frac{\sin^{-1}\frac{\lambda}{2a_1K}-\sin^{-1}\frac{\lambda}{2a_0K}}{K}\right)\right)$$

Where,

$$\frac{\lambda}{\sqrt{K-\left(\frac{\lambda}{2a_1}\right)^2}} = \lambda_{g0}\ ,\ \frac{\lambda}{\sqrt{K-\left(\frac{\lambda}{2a_0}\right)^2}} = \lambda_{g1}$$

(19)

Where,

K is the dielectric constant.

a_1 is the broad wall dimension of rectangular tapered waveguide.

a_2 is the broad wall dimension of rectangular folded waveguide slow wave structure.

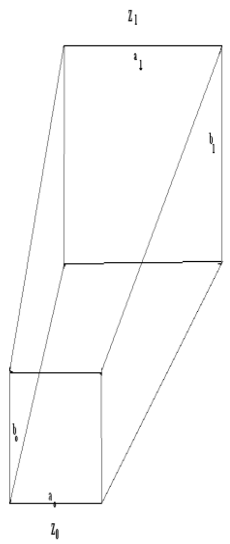

Fig .4 Coupler structure for FW-TWT.

In the equation (13), (14), (15), (16) and (19) put K=1 then we get the VSWR for coupler.

III. Results

The VSWR plot for sever shown in Fig. 4 for FW-TWT (equation (18)) has been simulated at W-band frequency with dielectric constant of 10.

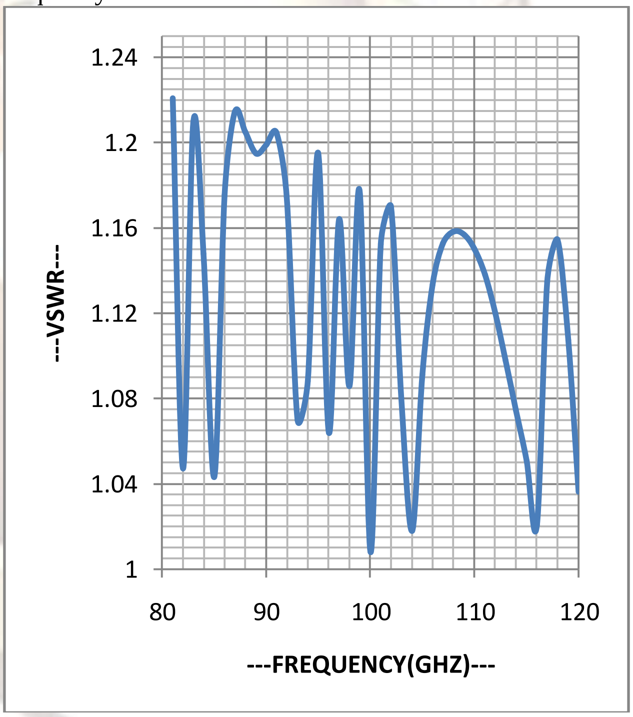

Fig .4 VSWR vs. Frequency

The VSWR plot of Coupler for FW-TWT at W-band frequency shown in Fig. 5

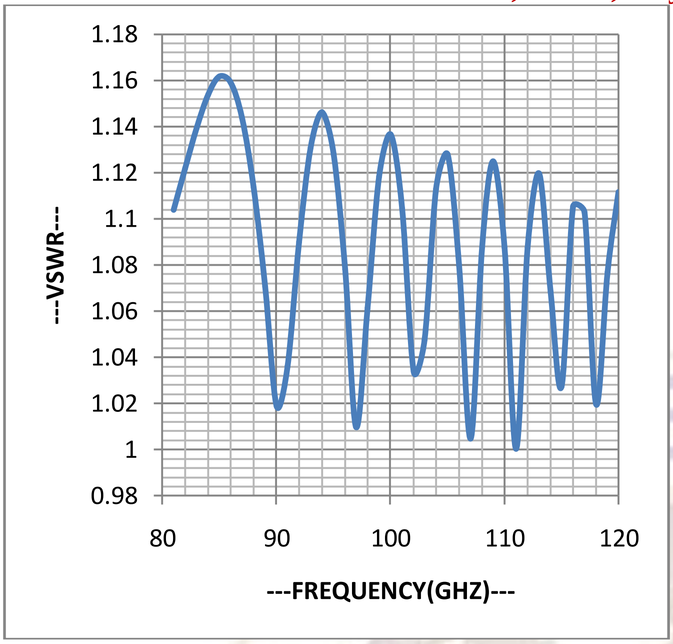

Fig .5 VSWR vs. Frequency

The VSWR plot (as the function of the tapered length) of sever for FW-TWT at 95GHz shown in Fig.6

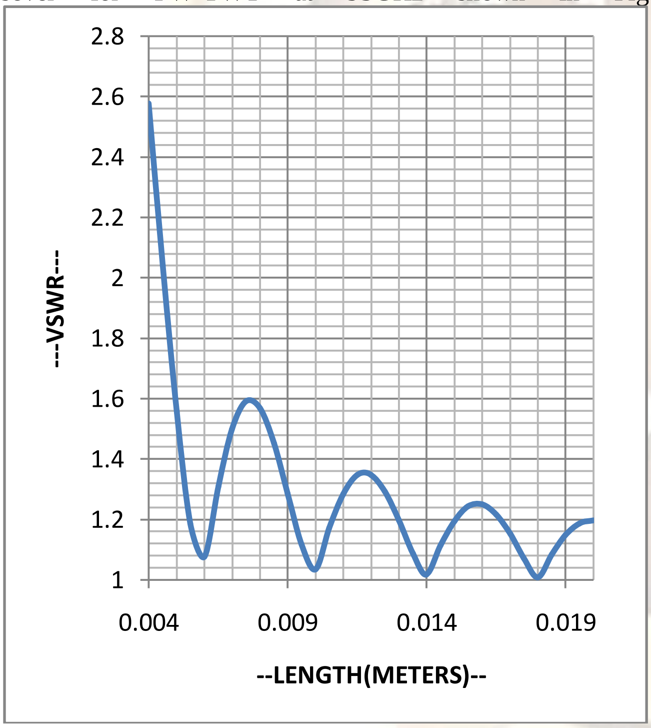

Fig.6 VSWR vs. Tapered Length.

The VSWR plot of coupler for FW-TWT at 95GHz shown in Fig.7

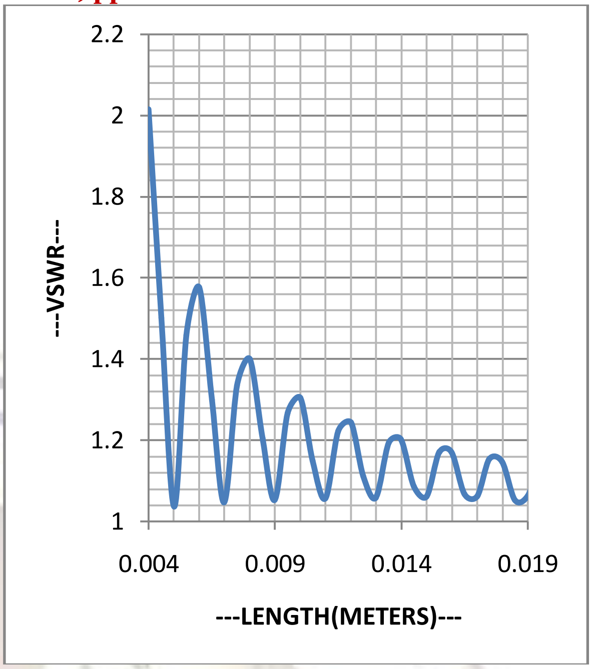

Fig.7 VSWR vs. Tapered Length

IV. Conclusion

The average value of VSWR at W-band for sever is 1.2 and for the coupler is 1.08. VSWR for both coupler and sever decreases as the tapered length increases.

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