Analysis of the Dispersion Characteristics of Gyro-TWT with Axially Periodic Dielectric and Metal Loading

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***Abstract - A*n axially periodic dielectric and metal loading structure showed advantage of facility and widening Gyro-TWT's bandwidth by controlling the dispersion of the waveguide.The field matching technique was used to analyse the axially periodic structure and yielded the dispersion relations.The dispersion characteristics was ploted with the help of dispersion equation and Floquet's theorem,and converged results were obtained using numerical approach.It shows that the dielectric disk axial thickness,permittivity and periodicity and disk-hole radius quite effectively shaped the structure dispersion.The disk-hole radius was more effective than the disc-periodicity in controlling the structure dispersion. The thickness or permittivity of dielectric discs controlled the passband frequencies and hence helped attain operating frequencies of a Gyro-TWT.**

I. INTRODUCTION AND BACKGROUND

THE Gyrotron travaling wave amplifier(Gyro-TWT) is one of the gyrotron amplifier which features a fast-wave structure for high-power and broad-band interaction. A variety of beam-wave interaction structures were employed to widen Gyro-TWT's bandwidth[1-4].As an important slow-wave structure,periodic structures were proved thire important practicability for widening device bandwidth.An axially periodic dielectric and metal loading structure(Figure 1.) showed advantage of facility and widening Gyro-TWT's bandwidth by controlling the dispersion of the waveguide.

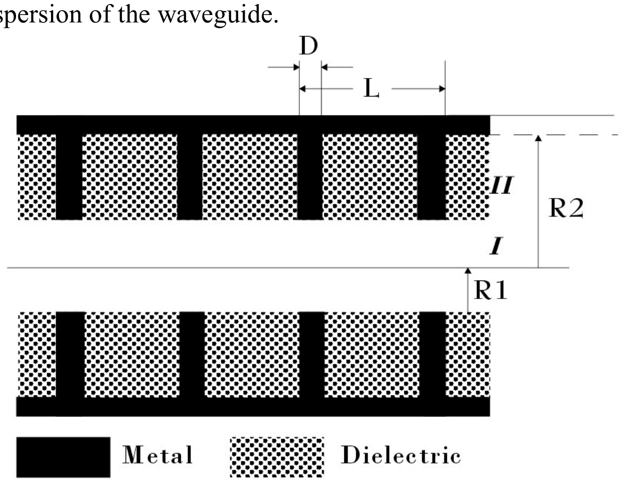

Figure 1. Axially periodic dielectric and metal loading structure.

II. Theoretics and Analytical Approach

It's an essential approach to accurately predict the propagation characteristics of axially periodic dielectric and metal loading structure for designing a high gain and wideband beam-wave ineraction system. Several techniques have been used to reach this goal.The field matching technique was used to analyse the structure and attained the dispersion relations which involve a nonlinear determinant equation,resolve the equation numerically, converged results were obtained and the dispersion characteristics were ploted,consequently, dispersion characteristics had been optimized by suitably choose the structure parameters.

The periodic structure is analyzed in the fast-wave regime and the effect of the finite thickness of discs is included.The analysis is carried out for TE modes. Further, considering nonazimuthally varying modes(Here,TE_{01} and TE_{02} mode) ,the relevant field expressions for regions I and II may be written, in the cylindrical system of coordinates(r, θ ,z) as

$$H_z^I = \sum_{n=-\infty}^{+\infty} F_n^I J_0\{\gamma_n^I R\}\exp(j(\omega t-\beta_n^I z)) \tag{1}$$

$$E_\theta^I = j\omega\mu_0 \sum_{n=-\infty}^{+\infty} \frac{1}{\gamma_n^I} F_n^I J_0^{'}\{\gamma_n^I R\}\exp(j(\omega t-\beta_n^I z)) \tag{2}$$

$$H_z^{II} = \sum_{m=1}^{+\infty} G_m^{II} Z_0\{\gamma_m^{II} R\}\exp(j\omega t)\sin(\beta_m^{II} z) \tag{3}$$

$$E_\theta^{II} = j\omega\mu_0 \sum_{m=1}^{+\infty} \frac{1}{\gamma_m^{II}} G_m^{II} Z_0^{'}\{\gamma_m^{II} R\}\exp(j\omega t)\sin(\beta_m^{II} z) \tag{4}$$

where

$$Z_0(\gamma_m^{II} R) = \frac{Y_0^{'}(\gamma_m^{II} R2) J_0(\gamma_m^{II} R) - J_0^{'}(\gamma_m^{II} R2) Y_0(\gamma_m^{II} R)}{Y_0^{'}(\gamma_m^{II} R2)}$$

$$Z_0^{'}(\gamma_m^{II} R) = \frac{Y_0^{'}(\gamma_m^{II} R2) J_0^{'}(\gamma_m^{II} R) - J_0^{'}(\gamma_m^{II} R2) Y_0^{'}(\gamma_m^{II} R)}{Y_0^{'}(\gamma_m^{II} R2)}$$

The superscripts I and II refer to the disc-free region I and the disc-occupied region II, respectively (Figure. 1). The subscript n represents the space-harmonic number referring to region I, and the subscript m represents the modal harmonic number referring to region II. F_n^I and G_m^{II} are the field constants.J_0,Y_0 are the zeroth order Bessel functions of the first and second kinds, respectively. $\gamma_n^I = [\varepsilon_r^I k^2 - (\beta_n^I)^2]^{1/2}$ represents the radial propagation constant referring to the disc-free region: $0 \le R < R1$, 0 < z < L (region I), and $\gamma_m^{II} = [\varepsilon_r^{II} k^2 - (\beta_m^{II})^2]^{1/2}$ represents the radial

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propagation constant referring to the disc-occupied region: $R1 \le R < R2$, $0 < z <$ (L-D) (region II). k is the free-space propagation constant. ε_r^I and ε_r^{II} are the relative permittivities of regions I and II, respectively.In this paper, no dielectric loaded is considered in disk-free region(regions I), namely, ε_r^I = 1. β_n^I is the axial phase propagation constant referring to nth space harmonics in region I, which may be related to the fundamental axial phase propagation constant β_0^I with the help of Floquet's theorem as $\beta_n^I = \beta_0^I + 2n\pi / L$ .And $\beta_m^{II} = m\pi/(L-D)$ is the axial phase propagation constant referring to the mth modal harmonic in region II that supports standing waves such that the distance between two consecutive metal discs becomes equal to an integral multiple of half wavelength.

The dispersion relation of the disc-loaded circular waveguide was obtained with the help of the field expressions (1)–(4) and the following boundary conditions: at R=R1:

$$H_z^I = H_z^{II} (0 < z < (L-D)) \quad (5)$$

$$E_\theta^I = \begin{cases} E_\theta^{II}, (0 < z < (L-D)) \\ 0, ((L-D) < z < L) \end{cases} \quad (6)$$

with an appropriate interpretation of the radial propagation constants γ_n^I and γ_m^{II}, the following dispersion relation was yielded:

$$\det \left| A(n,m) J_0(\gamma_n^I R1) Z_0'(\gamma_m^{II} R1) - Z_0(\gamma_m^{II} R1) J_0'(\gamma_n^I R1) \right| = 0 \quad (7)$$

where

$$A(n,m) = \{\gamma_n^I \beta_m^{II} [1-(-1)^m \exp(-j\beta_0^I L)]\}\{\gamma_m^{II} [\beta_m^{II} - \exp(-j\beta_0^I L)(\beta_m^{II} \cos(\beta_m^{II} L) + j\beta_n^I \sin(\beta_m^{II} L))]\}^{-1}$$

III. RESULTS

In dispersion relation (7), the radial propagation constant γ_n^I and the axial propagation constant β_n^I are each expressed in terms of the fundamental space harmonic component β_0^I as: $\gamma_n^I = [\varepsilon_r^I k^2 - (\beta_n^I)^2]^{1/2}$ and $\beta_n^I = \beta_0^I + 2n\pi / L$,and then, determinant equation (7) can be numerically resolved by truncate the determinant to the order of 7 × 7 (corresponding to n=0, ±1, ±2, ±3 and m=1, 2, 3, 4, 5 ,6, 7), and converged results were obtained.

With the help of dispersion relation (7) of the disc-loaded cylindrical waveguide, the dispersion characteristics was ploted(Figure 2.) and has been used here to study the effect of the structure parameters.

For a axially periodic dielectric and metal loading structure without a coaxial dielectric rod insert(ε_r^I = 1), the variation of relative permittivity of the dielectricn discs ε_r^{II} causes a change in the frequency range of the passband. A comparison between the modes TE_{01} and TE_{02} is carried out to study the control of the shape of the dispersion characteristics.

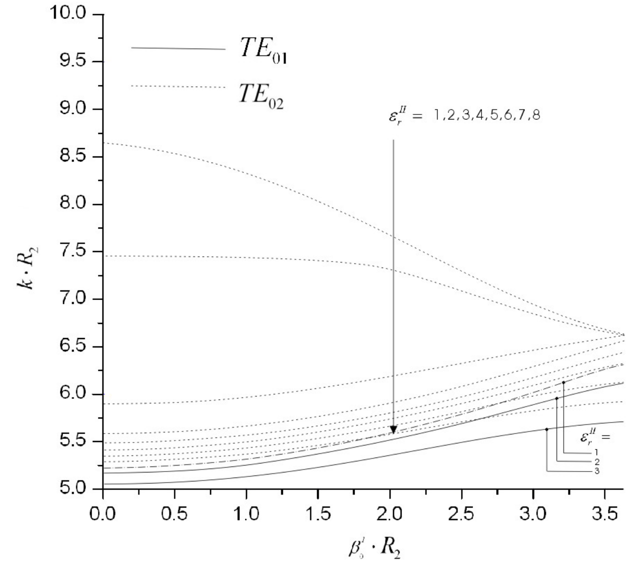

Figure 2. Dispersion characteristics of a circular waveguide with axially periodic dielectric and metal loading

For the TE_{01} mode, the passband decreases with the increase of ε_r^{II}.For the TE_{02} mode, the passband first decreases and then increases with the increase of ε_r^{II} . Also, the shape of the dispersion characteristics of the structure, for both the modes TE_{01} and TE_{02}, changes with the value of ε_r^{II} .

The dielectric disk axial thickness,permittivity and periodicity and disk-hole radius quite effectively shaped the structure dispersion.The disk-hole radius was more effective than the disc-periodicity in controlling the structure dispersion.The thickness or permittivity of dielectric discs controlled the passband frequencies and hence helped attain operating frequencies of a Gyro-TWT.

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