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Dispersion Control of a Helix Slow-Wave Structure by I-shaped Metamaterial Loading for Wideband Traveling-Wave Tubes

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Abstract

A simple metamaterial loading scheme for a helical slow-wave structure (SWS) has been proposed in lieu of a conventional anisotropic loading — metal vane loading scheme. The proposed structure consists of a helix in a metal envelope supported by three rectangular dielectric rods. Left handed material property (epsilon-negative) of these support rods have been achieved by printing I-shaped metal-strip on both of radial faces of each rod. The structure has been simulated on CST and shows better control on dispersion and higher interaction impedance compared to conventional anisotropically loaded helix SWS.

1. Introduction

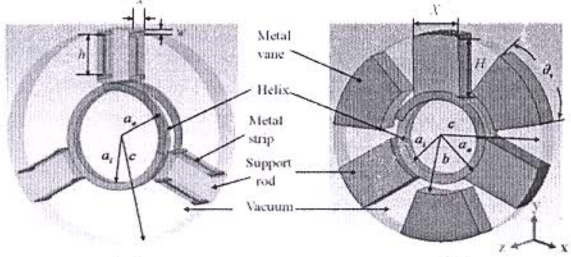
Non-resonant helix SWS is almost dispersion free which can further be improved by suitably loading the helix and hence finds potential application in helix traveling-wave tubes (TWTs) for wideband applications. However, TWTs for electronic warfare (EW) systems, namely, ECM, ECCM, etc. demand ultra wideband TWTs with improved performances and that can be achieved if the SWS exhibits flat-to-negative dispersion characteristics. Such dispersion characteristics are achieved by suitably loading the helix anisotropically [1], [2] or inhomogenously [3] and or by loading with left handed metamaterials [4], [5].

However, flat-to-negative dispersion characteristics of helix SWS over a wide frequency range is achieved by loading the helix SWS anisotropically— realized by providing radial inward metal vanes from the outer metal jacket (metal envelope). But realization of vane loaded anisotropic structure is considerably complex than inhomogeneous loading. This motivated authors to achieve flat-to-negative dispersion using metamaterial loaded helix SWS without using metal vanes which further enhances harmonic contents in the RF performance of a TWT.

Cold analysis, namely, dispersion and interaction impedance characteristics of helix SWS, supported with double-negative MTM rectangular support geometry — realized by printing metallic split-ring resonators(SRRs) and metallic strips on radial faces of rectangular support rods have been reported in [5]. But printing of SRRs and or metallic strips on the faces of dielectric supports have certain limitations due to dimensional limitations of the latter. In this paper, authors have proposed a novel and simple helix SWS assisted by I-shaped metal-strips on rectangular support rods to achieve epsilon-negative MTM [6] (section 2)and the SWS exhibits flat-to-negative dispersion characteristics with higher interaction impedance. CST-Frequency domain solver have been used to extract the constitutive parameters of the I-shaped MTM structure and subsequently CST-Eigen mode solver [7] has been used to get the dispersion and interaction impedance characteristics of the proposed structure (section 3). The proposed structure exhibits flat-to-negative dispersion characteristics with higher interaction impedance replacing complex conventional anisotropic loading scheme.

2. Proposed Structure

The proposed structure comprises a helix in a metal envelope supported by rectangular dielectric rods each printed with I-shaped metal-strip printed on both of its radial faces exhibiting epsilon-negative MTM(Fig. 1(a)). Figure 1 (b) represents its counterpart and depicts anisotropic wedge-shaped metal vane loaded structure. The relevant dimensions of both these structures are given in the caption to Fig. 1.



(a) (b)

Fig. 1. CST models of a single-turn helix in a metal envelope (a) with rectangular dielectric helix-support rods assisted by I-shaped metal-strip epsilon-negative MTM (proposed structure) and (b) with rectangular dielectric helix-support rods and wedge-shaped metallic vanes, the latter projecting inward from the envelope (structure for comparison) [1]. [a_i = 0.65 mm, a_0 = 0.75 mm, pitch = 0.61 mm, helix width = 0.2 mm, relative permittivity of support rod ε_r = 6.5 (BeO), X = 0.45 mm, H = 0.75 mm, h = 0.12 mm, x = 0.61 mm, w = 0.05 mm, c = 1.5 mm, b = 0.9, θ_v = 60°].

3. Results

Both proposed and conventional SWSs (Fig. 1) have been simulated in CST [7] to obtain both dispersion characteristics (phase velocity (v_p/c) versus frequency) and interaction impedance (K) characteristics (Fig. 2). Negative dispersion has been achieved using the proposed epsilon-negative MTM assisted structure with higher values of K (Fig. 1(a)) than those obtained in the conventional vane-loaded helix SWS (Fig. 1(b)), which is an alternative to complex conventional anisotropic loading to achieve flat-to-negative dispersion with enhanced K to improve device performances without affecting other design parameters and can find potential application for ultra wideband applications in EW systems.

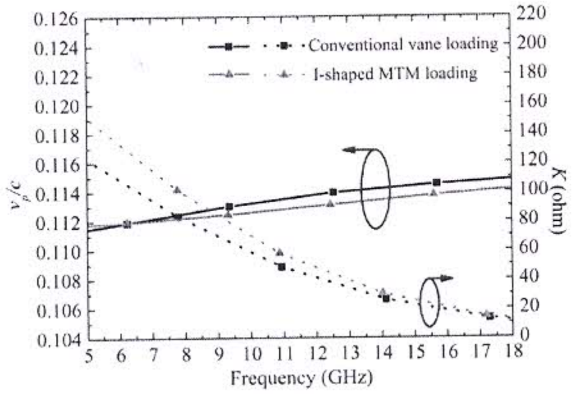


Fig. 2. Variation of v_p/c (solid line) and K (dotted line) with frequency of proposed model (Fig. 1(a) and conventional vane-loaded structure (Fig. 1(b)) [h = 0.12 mm, x = 0.61 mm, w = 0.05 mm].

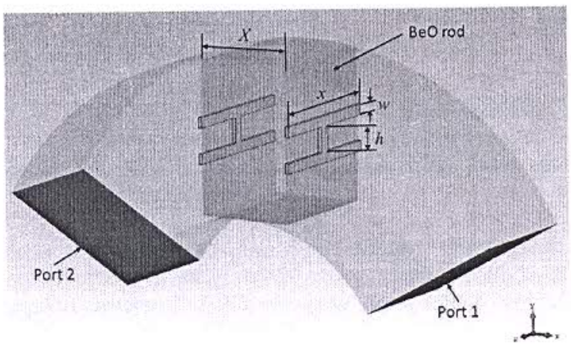


Fig. 3. Unit cell of proposed I-shaped MTM printed on both the radial faces of the rectangular BeO support rod (dimensions are given in the caption of Fig. 1).

The curvature angle of the unit cell (Fig. 3) is 120°, because the unit cell is periodic in the azimuthal direction (three unit cell, Fig. 1(a)). The constitutive parameters of the I-shaped MTM unit cell (Fig. 3) have been obtain using post-processing of CST-Frequency domain solver considering an incident wave has electric and magnetic field directed z-axis and y-axis, respectively, (Fig. 4(a)) and vice versa (Fig. 4(b)).

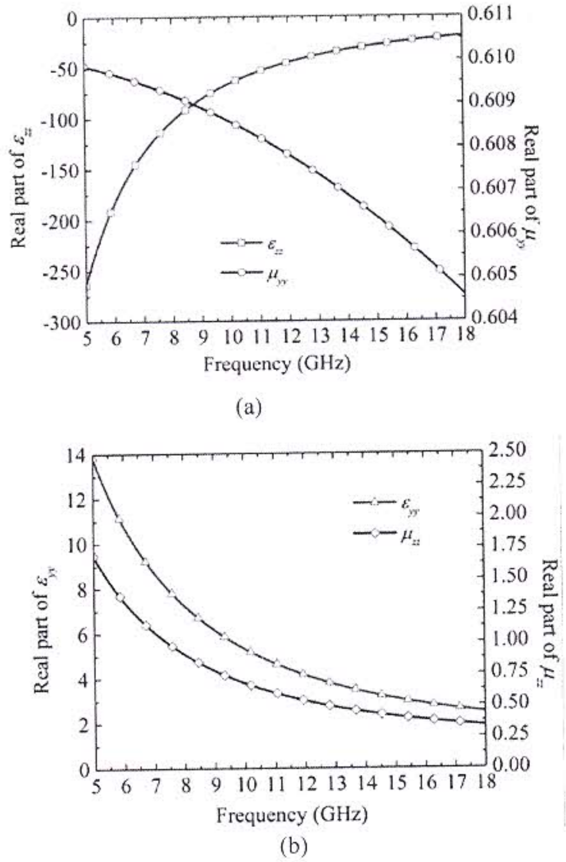


Fig. 4. Extracted relative permittivity and permeability of I-shaped MTM unit cell (Fig. 3).

Further, one can achieve positive, flat and negative dispersion by appropriately choosing the physical dimensions of the epsilon-negative MTM-loaded structure (Fig. 3) (Table 1).

Table 1: Nature of dispersion vis-à-vis I-shaped MTM dimensions

Dimensions of I-shaped MTM (mm)			Type of dispersion
h	x	w	
0.30	0.50	0.05	Positive
0.49	0.46	0.05	Flat
0.55	0.50	0.05	Negative

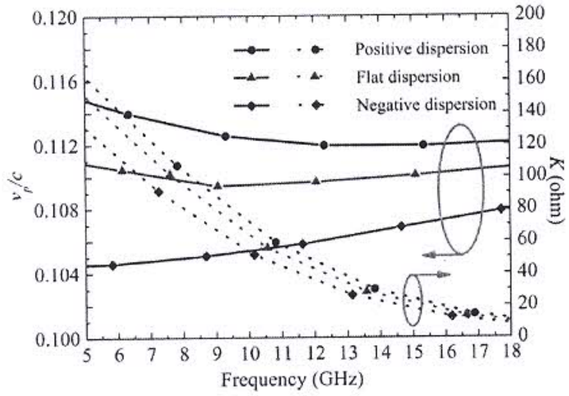


Fig. 5. Effect of dimensions of I-shaped MTM (Table 1) on v_p/c and K.

4. Acknowledgements

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5. References

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