

Analyse dispersive des guides d'ondes pour les antennes à ondes de fuite *Dispersive Analysis of Waveguides for Leaky-Wave Antennas*

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Résumé

Cet article présente une étude du comportement dispersif de guides d'ondes à plaques parallèles présentant une symétrie de glissement, perturbés par l'ouverture de fentes sur l'une des plaques, ce qui permet le rayonnement d'un mode à onde de fuite. Les caractéristiques de rayonnement de ce mode peuvent être prédites en calculant la partie réelle (constante de phase) et la partie imaginaire (constante d'atténuation) du nombre d'onde complexe associé à l'onde de fuite. Une méthode des moments périodique est utilisée pour effectuer ce calcul, et nous nous concentrons ici sur une étude paramétrique de l'atténuation dans la bande interdite ouverte. Nous effectuons une comparaison entre des guides d'ondes avec et sans symétrie de glissement, mettant en évidence des niveaux d'atténuation et des largeurs de bande interdite différents.

Abstract

This paper presents an investigation of dispersive behaviour of glide-symmetric parallel-plate waveguides perturbed with the opening of slots on one plate of the waveguide, allowing for radiation of a leaky-wave mode, whose radiation features can be predicted by computing the real part (phase constant) and imaginary part (attenuation constant) of the leaky-wave complex wavenumber. A periodic method-of moment is employed to perform this calculation, and we focus here on a parametric study of the attenuation in the open stopband. We perform a comparison between glide- and non-glide symmetric waveguides, finding different levels of attenuation and stopband bandwidth.

1 Introduction

Current and next-generation wireless communications are pushing to a wider use of millimeter waves in order to grant connections with wider bandwidth and therefore higher data rates. At these frequencies all-metal structures can reduce losses and enable compact designs. Metallic glide-symmetric (GS) metasurfaces, i.e. metasurfaces invariant under a translation and a mirror reflection, have already proved to lead to non-dispersive designs and higher tolerance manufacturing. This paper studies the effect of introducing slots on the top plate of an all metal glide-symmetric (GS) parallel-plate waveguide (PPW) to explore the possible conversion of stopband modes into radiating leaky-wave modes. A periodic Method-of-Moment (MoM) is employed to rigorously analyse the dispersion and attenuation characteristics, comparing GS and non-GS structures, and offering new insights for designing low-attenuation leaky-wave antennas.

2 Approach for modal analysis

For the modal analysis of periodic open waveguides, a numerical code based on an efficient periodic MoM formulation, which rigorously accounts for both the periodic structure and the open radiation conditions by simulating a single unit cell.[1], is introduced to study the dispersive behaviour of all-metal 1-D periodic waveguide. The problem is formulated by an Electric-Field Integral Equation (EFIE) including a periodic kernel rigorously enforcing Floquet boundary conditions on the boundaries $x=0, p$ of the unit cell in Fig. 1(b). In the case of a TM^x polarization, the EFIE is

$$\hat{\mathbf{n}} \times \int_C \left(1 + \frac{1}{k^2} \nabla \nabla\right) \mathbf{J}(\mathbf{r}') G_p(\mathbf{r}, \mathbf{r}'; k_x, \omega) d\mathbf{r}' = \mathbf{0} \quad (1)$$

where $\mathbf{J}(\mathbf{r}')$ is the modal current flowing on the metallic line C and $\hat{\mathbf{n}}$ is the normal vector to C . G_p is the periodic Green's function of the bidimensional space with periodicity along the x direction. It depends on \mathbf{r} and \mathbf{r}' , the

source and the observation points on C respectively, on the Floquet wavenumber $k_x = \beta - j\alpha$ and on the angular frequency ω . In a modal analysis, sources are absent and the right-hand side of (1) is null: we compute $k_x(\omega)$ such that $\mathbf{J} \neq 0$ exists.

The EFIE (1) can be transformed into matrix form

$$[\mathbf{Z}][\mathbf{J}] = \mathbf{0} \quad (2)$$

where the entries Z_{mn} of the system matrix are

$$Z_{mn} = \int_C \mathbf{\Lambda}_m(\mathbf{r}) \cdot \int_C \mathbf{\Lambda}_n(\mathbf{r}') G_p(\mathbf{r}, \mathbf{r}'; k_x, \omega) d\mathbf{r}' d\mathbf{r} + \frac{1}{k^2} \int_C \nabla \cdot \mathbf{\Lambda}_m(\mathbf{r}) \int_C \nabla' \cdot \mathbf{\Lambda}_n(\mathbf{r}') G_p(\mathbf{r}, \mathbf{r}'; k_x, \omega) d\mathbf{r}' d\mathbf{r} \quad (3)$$

The propagation waveguide $k_x(\omega)$ corresponds to complex zeros of the determinant of the system matrix, which are found in the complex plane by means of an iterative method based on type II Padé approximation [2]

Figs 1(a) and (b) show the structure under analysis. Fig. 1(c) presents the dispersive behaviour (phase β and attenuation α constants of the fundamental Floquet mode) of an open GS structure with a slot on the upper metallic plate. The results demonstrate good agreement with those obtained using the multi-modal transmission matrix method (MMTMM) [3], an approximate method for the extraction of wavenumbers of Floquet modes from the simulation of a truncated cascade of cells. With this MoM, two key geometrical operations are investigated described in the following subsections.

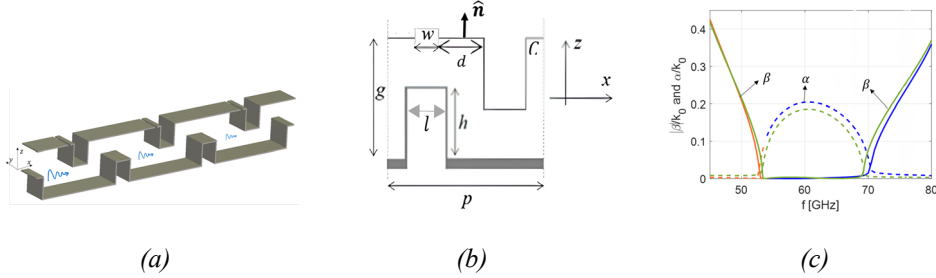


Figure 1: Geometry of the GS structure under analysis. (a) 3D view. (b) Later view. (c) Dispersive behaviour of the structure in (a) MMTMM (green lines), MoM (orange and blue lines)

3 Analysis of symmetric configurations and radiation slots

In this section, we investigate the influence of various structural parameters on the dispersive behaviour of the open waveguide. The introduction of slots breaks the original symmetry, thereby disrupting the glide symmetry effect [4]. To assess the impact of this disruption, we first compare the dispersive behaviours of the LWAs based on glide- and conventional nonglide-symmetric structure to investigate the influence of the background waveguide. Following this, we further analyse how introducing a second slot and modifying the corrugation shape in the structure of Fig. 1(a) can optimize the dispersive performance.

3.1 Study of mirroring and translation

The effects of the two operations of GS structure-mirroring and translation-are examined. Three configurations are compared: a slotted GS structure and two non-GS structures, where only one plate is corrugated with a slot—

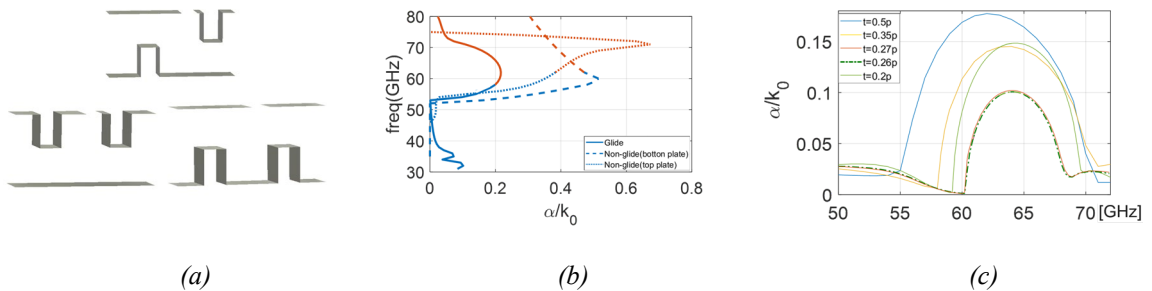


Figure 2 (a) Unit cell of the slotted GS and non-GS structure (b) Normalized attenuation constant of the structures in (a). (c) Normalized attenuation constant of quasi-glide symmetric structures with different translation, t is the distance between two adjacent corrugations.

either on the corrugated or on the flat plate, as shown in Fig. 2(a). Results in Fig. 2(b) show that the mirroring operation significantly reduces the attenuation constant and the frequency bandwidth of the stopband at $\beta = 0$. Moreover, by varying the distance t between upper and lower corrugations while keeping the period constant, an optimal value ($t = 0.26p$) is identified at which attenuation is minimized, as depicted in Fig. 2(c). These insights can be useful as a starting point to design leaky-wave antennas with open-stopband suppression.

3.2 Study with the radiation slots

We further investigate the influence of introducing a second slot and modifying the corrugation shape. A two-slot configuration, where the slots are placed asymmetrically[5], is found to lower the attenuation as the slot spacing increases, as shown in Fig. 3(b). Additionally, replacing a rectangular corrugation with a trapezoidal one, as shown in Fig. 3(c), and fine-tuning its dimensions further reduces the maximum normalized attenuation constant to 0.0234, thereby dividing by almost a factor 10 the attenuation in the original GS structure of Fig. 2(a).

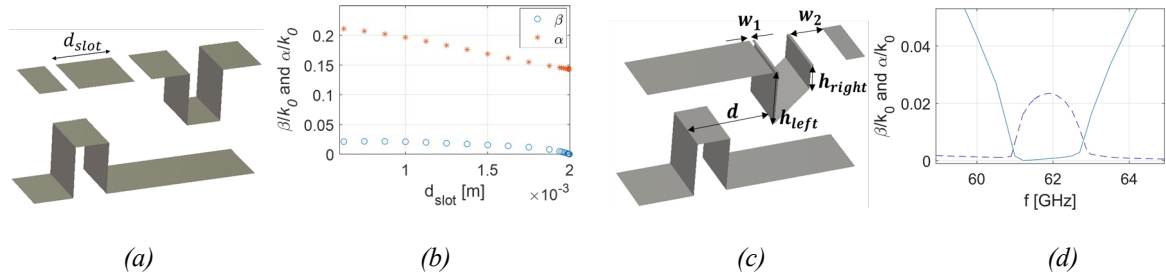


Figure 3 (a) GS unit cell with two slots (b) Wavenumber at 60 GHz with different distance between slots (c) Unit cell with a trapezoidal corrugation on the top plate. (d) Dispersive behaviour with optimized geometrical parameters.

4 Conclusion

This study analysed the stopband of periodic double-corrugated all-metal waveguides, examining the impact of slot and corrugation geometry on attenuation constants. An *ad-hoc* periodic MoM approach lead to rigorous dispersion analyses. Results show that a simple optimization of the slot and corrugation position and shape can significantly reduce the attenuation in the open stopband, thus selecting structures candidates for directive broadside radiation. In the full paper a complete design leading to an open stopband suppression will be discussed.

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