OPTIMIZATION OF REFLECTION AND TRANSMISSION CHARACTERISTICS OF A WAVEGUIDE WINDOW

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ABSTRACT

Waveguide windows are known to be major components of transmission lines used with high-pressure or vacuum applicators, particle accelerators, and microwave plasma devices [1-5]. The function of the window is to provide vacuum/gas isolation of the source from the cavity while transmitting microwaves with minimum attenuation. It essentially consists of a dielectric plate surrounded by a metal frame and sandwiched between special flanges so that the cross-sectional dimensions of the plate are larger than the corresponding waveguide dimensions. In practice, to reduce reflections of a single window, the latter is matched by an additional inductive or capacitive iris [2]; when dealing with a double window, the mutual orientation of the two dielectric plates is chosen the way that the total reflection is minimized [3].

Known theoretical characterizations of the waveguide window include the approaches based on substantial idealizations of the problem and exploitation of transmission-line equations [1, 3, 4] as well as more adequate considerations supported by advanced numerical techniques – finite elements (code ANSYS) [5] and finite integration (code MAFIA) [2]. However, neither validation, nor estimation of accuracy of these models has been given. Moreover, the entire structure of a waveguide window has never been optimized in terms of the low power reflections.

This paper, for the first time, presents an accurate numerical analysis of reflections and transmissions of a double window, demonstrates a possibility of detection, identification, and visualization of trapped (ghost) modes [6], and generates a series of optimized geometries guaranteeing fairly low reflection and high transmission. The structure has been analyzed with the use of 3D conformal FDTD method (code *QuickWave-3D*) [7] and optimized by the artificial neural network procedure outlined in our earlier paper [8].

FDTD Model

A fully parameterized FDTD model has been developed for a rectangular waveguide and two rectangular dielectric plates. In order to verify the model, the latter was applied to two double windows manufactured by the Ferrite Company, Inc., i.e., to the structures with the Quartz and Teflon plates in the 94 × 48 mm waveguide; it was assumed that the plates were situated in the center of the waveguide section of the 240 mm length. The non-uniform mesh was built from 4 mm cells in air and 1.5/2 mm cells in Quartz/Teflon and contained 328,950 and 224,400 cells respectively. Dielectric constants were taken as 3.8 (Quartz) and 2.06 (Teflon). The frequency responses of the reflection coefficient were measured and computed in the range of $2.35 < f < 2.55$ GHz and found to be in sufficiently close agreement.

Sensitivity Analysis and Trapped Modes

The model has been applied to the WR340 Quartz double window to study sensitivity of reflections to different geometrical parameters. It turned out that the most dramatic changes in the frequency response of the reflection coefficient occur with simultaneous variation of thicknesses of both dielectric plates while variation of one plate's thickness or the distance between the plates affects primarily the position of the window resonance. Changes in the cross-sectional dimensions of the plate produce quite different effects: variation of the height may lead to a dramatic shift of the resonant frequency and strong deformation of the resonant characteristics, while variation of the width influences primarily the resonance's depth.

The performed full-wave analysis has been also extended to the trapped modes which may exist in the vicinity of the dielectric plates. With a wideband pulse excitation, the resonances of those modes have been found (at the frequencies not necessarily coinciding with the operating frequency of the dominant waveguide mode) for particular configurations of the window. With subsequently applied sinusoidal excitation at the resonant frequencies of the trapped modes, their structures have been completely restored. For example, when increasing the width of one of the plates, we have detected the modes identified as the TE_{20} and TE_{30} ones. Since the fields of the trapped modes decay exponentially on either side of the plate and no energy travels away, they may be responsible for breaking transmission characteristics (which in the absence of the trapped modes would be satisfactory) and even for a physical destruction of the window. Therefore, the developed model has proven its high value for practical design.

Optimization

The knowledge accumulated at the stage of analysis of the waveguide window was used for formulating the related optimization problem. It has been aimed on minimization of reflections in the $2.4 < f < 2.5$ GHz range while requiring the absence of the trapped resonances on the corresponding transmission characteristic. The design parameters in optimization processes included the plates' thicknesses, cross-sectional dimensions, and the distance between them.

The configuration of the window has been optimized with the use of the neural network procedure [8]. While arbitrary (non-optimized) configurations are typically resonant, the obtained optimal frequency responses turned out to possess quite flat characteristics. The 7-parameter optimization has provided the geometry generating less than 1% power reflection, but quicker "partial" optimization turned out to be fruitful as well (less than 4%). A series of optimal configurations has been generated for the Quartz plates in WR430 and WR975.

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