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Efficient Design of Filters Based on Metallic and Dielectric Periodic Structures in SIW Technology

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We propose a self-contained, rigorous and numerically fast full-wave formalism, capable of efficiently analyzing the spectral responses of Substrate Integrated Waveguides (SIWs) (for both real and complex waveguide modes) [1], and waveguide-based passive circuits (*i.e.* filters), which relies on 2-D periodic structure models. It is applicable to the analysis of a wide class of periodic and EBG-based waveguides [2,3] and filters operating from mm-wave, via THz up to optical frequencies. When the wall's elements – *i.e.* the circular rods – are comprised of perfectly electric conductors (PECs), we can expect a field confinement effect related to the cutoff waveguide phenomena. When the gap width h-2r (h is the period of the grating and r is the radius of the rods) between two adjacent PEC cylinders satisfies the condition $h-2r < \lambda_0 / (4\varepsilon_b)^{1/2}$ (λ_0 is the wavelength in free space and ε_b is the background relative dielectric permittivity), the wave propagation across each layer of arrays will be cutoff. Due to this cutoff effect in the array of PEC cylinders, the wave field is effectively confined in the guiding region even for a single layer. At much higher frequencies, however, the metals lose their properties and the dielectric materials start to play an important role. The phenomenon of field confinement in the guiding region in the case of dielectric rods is still an open research issue. For dielectric rods, the confinement is primarily governed by the Bragg reflection in a periodic structure. As a result, good confinement of the field can be achieved at the expense of a larger transversal extent of the device. Our proposed full-wave formalism can very efficiently calculate the S-parameters of SIWs and filters in a self-contained manner for various configurations with both metallic and dielectric materials as wall elements (about 0.01 second per frequency on a 3.8 GHz Intel Core i7 CPU with 32 GB RAM).

Having available such an efficient forward solver, we next investigate the optimization problem, namely, how to choose the structural parameters in order to achieve the desired filter characteristics within a very short amount of computation time [4]. For the computer-guided filter design considered here, we are relying on a breeder Genetic Algorithm (GA), which has already proven to be highly efficient in tracking down high-quality solutions in the framework of numerical structural optimization, *e.g.* in dense integrated optics [5]. Our optimized results for some particular filters' (iris filters with simpler geometry) are in excellent agreement with results found in the literature. However, our method is considerably faster and can analyze SIW filters with much more complex geometries/topologies.

References

[1] V. Jandieri, P. Baccarelli, G. Valerio and G. Schettini, "1-D periodic lattice sums for complex and leaky waves in 2-D structures using higher-order Ewald formulation," *IEEE Trans. Antennas Propag.,* vol. 67, no. 4, pp. 2364-2378, 2019.

[2] K. Yasumoto, (ed.), *Electromagnetic Theory and Applications for Photonic Crystals*, Ch. 3, Boca Raton, FL, USA: CRC Press, 2005.

[3] V. Jandieri, H. Maeda, K. Yasumoto and D. Erni, "Analysis of post-wall waveguides and circuits using a model of two-dimensional photonic crystals," *Prog. Electromagn. Res. M (PIER M)*, vol. 56, pp. 91-100, 2017.

[4] J. Nagar and D. Werner, "Multiobjective optimization for electromagnetics and optics," *IEEE Antennas Propag. Mag.*, vol. 60, no. 6, pp. 58-71, 2018.

[5] D. Erni, D. Wiesmann, M. Spühler, S. Hunziker, E. Moreno, B. Oswald, J. Fröhlich and C. Hafner, "Application of evolutionary optimization algorithms in computational optics," *ACES Journal: Special Issue on Genetic Algorithms*, vol. 15, pp. 43-60, 2000.

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