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Benefits of Multimodal Transfer-Matrix Approach for Analyzing General Periodic Problems

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The broad application of periodic structures has been driving the development of efficient methods for studying them. Bloch analysis is key to provide the required knowledge on how the electromagnetic waves interact with the structure. The resulting dispersion diagram informs us of the dispersion level, anisotropy, the forward/backward and slow/fast nature of modes, etc. Nowadays, the most common practice to obtain this knowledge is to use commercial full-wave simulators applicable to the most general problems. Meanwhile, ad-hoc methods like equivalent circuits and mode-matching have proven to be more efficient in certain specific cases. However, there are several factors that often complicate the Bloch analysis and limit the applicability of the aforementioned methods, among them the complex nature of modal solutions, the arbitrary geometry and inhomogeneous materials, as well as the electrical size of the problem. Here, we demonstrate that the multimodal transfer-matrix approach (MMTMA) offers a hybrid solution that combines the benefits of both full-wave simulation packages and in-house algorithms, providing high computational efficiency, good accuracy, and extra physical insights into more general periodic problems.

We have used the MMTMA to study a variety of one-/two-/-three-dimensional (1-/2-/3-D) bound/open structures. One interesting feature of the MMTMA is the accurate evaluation of imaginary parts of the wavenumbers associated with evanescent/complex modes in bound structures, radiation in open problems, and large dissipation losses, features that cannot easily be obtained by commercial eigenmode solvers like CST. For instance, we accurately found relevant complex modal solutions and tracked the transition between them in a bound 1-D mushroom-like transmission line and in a 2-D glide-symmetric holey all-metal metasurface. Also, we efficiently computed radiation losses in the design of a leaky-wave antenna based on the 1-D gap waveguide [1]. Recently, we successfully applied MMTMA to the evaluation of the radiation losses in a 2-D open problem with a grounded dielectric slab etched by a holey iris in its top cladding. In a 2-D metasurface with printed meandered microstrip lines, we obtained the dielectric losses that were readily calculated when performing the dispersion analysis. This is particularly useful since other perturbation-based approaches employed in commercial simulators are known to be inaccurate in evaluating high losses. Another appealing asset of MMTMA is the capability of fast calculation of the isofrequency contours, which are of capital importance to examining the level of isotropy in 2-/3-D problems. In one of our last works, we generalized the MMTMA to 3-D problems and applied it to a 3-D double-wire-mesh metamaterial. The efficient evaluation of contour maps is enabled by our proposed linearization technique that converts the non-linear eigenvalue problem in 2-/3-D cases to a linear one and hence avoids the need for zero-searching algorithms in the complex plane [2].

References

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[2] F. Giusti, Q. Chen, F. Mesa, M. Albani, O. Quevedo-Teruel, “EEfficient Bloch Analysis of General Periodic Structures with a Linearized Multimodal Transfer-Matrix Approach," *IEEE Transactions on Antennas and Propagation*, 2022.