Modeling of Dielectric Multilayers through Coupled-Mode Theory

S. Ceccuzzi, F. Guerra*, and G. Schettini
Engineering Dept., “Roma Tre” University, Italy; e-mail: silvio.ceccuzzi@enea.it; fed.guerra4@stud.uniroma3.it; giuseppe.schettini@uniroma3.it

A multilayer made of two periodically alternating dielectric materials exhibits a frequency range, called band gap, where wave propagation along layer normal is forbidden. This phenomenon places the multilayer in the class of Electromagnetic Band Gap (EBG) structures, more precisely in the subset of one-dimensional EBGs, for which much effort has been spent during last decades in tailoring enhanced spectral responses for specific applications. Numerous configurations have been proposed, relying for instance on multiple defects, three or more materials, exotic shapes, variable periodicity, or inhomogeneous layers. EBGs have been simulated with several types of analytical, semi-analytical, and numerical approaches such as transmission line theory, Fourier modal method, time domain techniques, and finite element method (FEM) codes, just to cite a few.

This paper addresses the wave propagation inside the multilayer through a simple and effective electromagnetic model based on the coupled mode theory [1]. The expression of the coupling coefficient, ruling the energy transfer between forward and backward waves inside the multilayer, has been derived allowing us to describe the physical behavior of the periodic medium in the form of a system of coupled differential equations. The latter can be analytically solved for the standard multilayer configuration, providing an extremely fast design tool. Computation time is much shorter than FEM codes even when the system of differential equations is solved numerically. An in-house code based on such model has been developed and successfully validated against the full-wave solver of a commercial code, as shown in Figure 1. The coupled-mode theory relies on some physical approximations, whose range of validity has been tested over a large set of multilayer parameters, performing a systematic study of error statistics.

Once checking model reliability, the code has been applied to study alternative multilayer configurations. Tool capability goes indeed beyond the prediction of classical multilayers: the code can handle any permittivity profile that can be expanded in Fourier series, allowing for a significant flexibility in conceiving, analyzing and designing the periodic medium as well as for a deeper insight into its physical mechanisms. Some examples in this sense will be given.

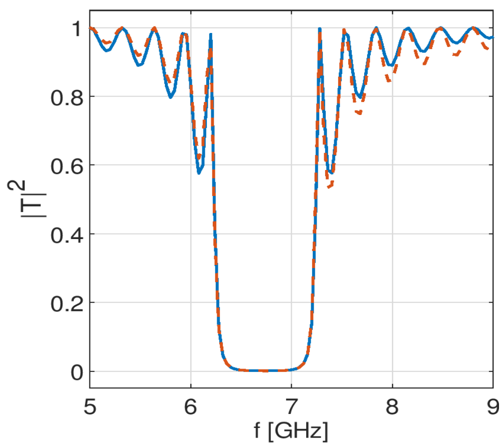

Figure 1. Comparison of transmissivity vs. frequency of a multilayer computed with a full-wave software (blue solid line) and with the coupled-mode theory (red dashed line).

References

[1] A. Yariv, "Coupled-mode theory for guided-wave optics," *IEEE Journal of Quantum Electronics* **9**, 9, September 1973, pp. 919-933, doi:10.1109/JQE.1973.1077767.