Full Wave Modeling of Miniature Antennas Embedded within 3D Finite Degenerate Band Edge Photonic Crystals

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Slow modes present in periodic multilayered structures (A. Figotin and I. Vitebskiy, Physical Review B, vol. 67, pp. 165210, 1-20, April 2003) are promising for high gain miniature antennas and arrays due to the large amplitude growth of the incoming wave at certain frequencies. Specifically, magnetic photonic (MPC) and degenerate band edge (DBE) crystals alleviate transmittance/matching and amplitude growth issues associated with the slow modes in regular band edge (RBE) crystals (G. Mumcu, K. Sertel, J. L. Volakis, A. Figotin, and I. Vitebsky, IEEE TAP, vol. 53, no. 12, pp. 4026-4034, Dec. 2005). Modeling of printed antennas embedded within finite thickness MPCs demonstrated that amplitude growth due to the slow modes translates into higher directivity (G. Mumcu, K. Sertel and J. L. Volakis, APS, 2005 IEEE, Washington, USA, vol. 2A, pp. 10-13). DBE crystals, simply obtained by removing the magnetic layer of the MPCs, allow for a better matching than RBE crystals due to the relatively flatter band edge (a decay rate of $\Delta\omega_d^{1/4}$ in contrast to $\Delta\omega_d^{1/2}$, $\Delta\omega_d$ being the difference between the band edge frequency and the frequency of operation). As a result, similar orders of field amplitude increase can be achieved using fewer layers as compared to RBE crystals resulting in a more compact structure. In a recent presentation (J. L. Volakis, G. Mumcu, and K. Sertel, ICEAA, 12–16 Sep. 2005, Torino, Italy) we demonstrated that printed dipoles in finite thickness DBE crystals also exhibit higher directivity. Specifically, significant narrowing of the antenna beamwidth (down to 10^0) is observed when a very short dipole antenna is placed inside the DBE crystal as compared to a simple dielectric layer of the same thickness.

Although the above studies demonstrated the performance of miniature dipoles embedded within finite thickness DBE crystals, they did not allow for an understanding of the performance in a three-dimensional (3D) setting (i.e. finite thickness and finite lateral extent). To determine the minimum crystal dimensions required to obtain desired directivity, it is important to characterize the effects of lateral truncation on the properties of antennas within DBE crystals. Towards this goal, here we consider miniature antennas placed within DBE crystals in a full 3D setting. Induced currents on the antenna and boundary of the DBE crystal is formulated via the Poggio–Miller–Chang–Harrington–Wu–Tsai (PMCHWT) surface integral equation employing the dyadic Green's functions for the uniaxial domains. Since the DBE crystal consists of many such layers with large uniaxial anisotropies (resulting in an electrically large structure), we specifically preferred the PMCHWT formulation over the volume integral and finite element boundary integral formulations. The resulting matrix system is solved iteratively by employing the Fast Fourier Transform multiplications arising from the symmetries of the geometry. We will present the analysis method along with the representative results for radiating and receiving elements placed within different size DBE crystals.