Dispersion Engineering for Slow-wave Structures using Quad Coupled Transmission Lines

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Engineered metamaterials have shown great promise due to their unique RF properties. They find applications in antenna miniaturization, phase-shifters and in high-power microwave applications. For these metamaterials to show specific properties, a certain $\omega - k$ relation needs to be engineered. Commonly used regular band edge (RBE) structures find application for wave-confining and other slow-wave applications, but are inherently narrow band. For wideband design, the dispersion curves usually require introduction of higher order modes, often requiring magnetic anisotropy (to achieve MPC modes). Adding such magnetic layers can cause the structures to become bulky and unusable for most microwave applications. Alternatively, these metamaterials can be implemented using a printed line, where exotic dispersion properties are generated due to coupling of non-identical transmissions lines.

In this work, we present the theory of such coupled transmission structures, where dispersion properties can be engineered using two or more coupled transmission lines. As obvious, the lines are made of periodic structure, where each period contains coupled and uncoupled regions of the line. Specifically, upto four non-identical transmission-line modes will be considered to obtain a forth order Degenerate Band Edge (DBE) and Magnetic photonic crystal (MPC)-like modes in the engineered structure. One of the key findings of the theory is to determine the coupling parameters, K_1, K_2, K_3 essential to generate the dispersion curves leading to the different applications. The parameters K_1 to K_4 represent the coupling between the modes, needed to obtain the desired metamaterial response. Notably such transmission lines can generate unique properties that are absent in nature.