A High Performance ε-μ Meta-Material Designed Utilizing Resonant Transmission Line Inclusions

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In recent years there have been significant amount of research in the area of functional meta-materials. The aim of meta-material development is to propose novel periodic configurations of available materials for achieving new media with desired figures of merit. Different material properties such as Double Negative (DNG), Double Positive (DPS), Epsilon Negative (ENG), and Mu Negative (MNG) parameters have been investigated and many novel applications for them in the areas of RF and optical systems have been proposed.

However, most of the designs are still in the stage of theory and there is a big challenge to integrate them in real applications. The building block unit cells of so far designed meta-materials are constructed of metallic loop circuits and in order to obtain a desired magnetic property the structures must operate near their resonance. This generates two problems, one is narrow permeability bandwidth, and the other is significant conduction loss in metallic loops. Therefore, the meta-material development utilizing resonant loop circuits are kind of impractical.

The objective in this paper is to present a new meta-material design with enhanced characteristics. This will be achieved with the use of periodic array of metallo-dielectric resonant transmission line sectors. The metallic sections are basically parallel strip transmission lines loaded with high permittivity dielectrics. Their physical size in fact is small fraction of wavelength in free space ($<\lambda_0/15$). At resonance short circuit transmission lines represent parallel LC circuits providing magnetic property. Compared to the loop circuit configuration, the metalo-dielectric inclusions occupy more volume and the magnetic property is accomplished using quarter-wavelength short-circuit lines. Therefore, an efficient permeability with higher bandwidth and less loss tangent is achieved.

To comprehensively characterize the complex periodic structure a Finite Difference Time Domain (FDTD) technique with Periodic Boundary Conditions/Perfectly Matched Layered walls is applied. The transmission amplitude and phase for a plane wave propagating through the meta-material are obtained and the results are successfully compared with the performance of an equivalent medium with $\varepsilon_{eff}-\mu_{eff}$ constitutive parameters. The effective parameters are theoretically obtained using a circuit-model transmission line approach.

In this work, we will also investigate the possibility of design of high performance μ materials with the use of all metal or all dielectric optimized configurations. To accomplish this the FDTD is integrated with a Genetic Algorithm (GA) optimization method to optimize building block unit cell of the periodic meta-material for achieving required permeability at a frequency of interest.