2D Distributed Meta-Structures with Negative Refractive Properties

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The transmission line (TL) approach of left-handed (LH) or negative refractive index (NRI) metamaterials has lead to broadband and low-loss structures, whereas resonant-type configurations, such as the split ring resonators (SRRs) [1] and metal wires structure experimentally demonstrated by R. A. Shelby et al. [2], are intrinsically very lossy and narrow-band. C. Caloz et al., have successfully demonstrated a distributed one-dimensional (1D) microstrip line configuration [3] and characterized its dispersion relation by developing a new circuital theory of composite left/right-handed (CLRH) model, which takes into account the effects of parasitic series inductances and shunt capacitances [4]. In addition, a lumped-element 2D-NRI-TL has been proposed by G. V. Eleftheriades [5] et al. and demonstrated to exhibit focusing properties due to negative refraction when interfaced with a conventional material [6].

In this paper, 2D *distributed* periodic TL structures with LH fundamental mode are proposed. The unit cell is composed of a square mushroom-shaped structure on a ground plane [7] with 45°-rotated square metal caps just below the mushroom (see the inset in Fig.1). The dispersion diagram of the unit cell computed by the FEM is shown in Fig.1. The mushroom structure provides a shunt inductance to the ground and series capacitances to adjacent unit cells. The caps dramatically enhance the series capacitance and, as a result, contribute to drastic enhancement of the left-handedness of the TL in terms of negative slope in the ω-β diagram and LH bandwidth. This structure is *open* and the fundamental LH mode consequently couples with the surface wave (TM) mode at low frequencies.

A closed version of the distributed 2D-TL can be realized by combining symmetrically two open structures in a parallel-plate waveguide configuration with the mushrooms in the center. This structure can have a pure CRLH fundamental mode, which is characterized by left-handedness below a transition frequency ω_0, where $\beta = 0$, and right-handedness above, as shown in the dispersion diagram in Fig.1. The frequency ω_0 corresponds to the Γ-axis of the dispersion diagram where *perfect effectiveness* is achieved: $period/\lambda_g = 0$. It is essential to note that there is no gap between the LH and RH ranges; the ω_0-point is therefore associated with a non-zero group velocity and the structure can be quasi-lossless at this point. The transition frequency is given as $\omega_0 = (\omega_L \omega_R)^{-1/2}$, where $\omega_L = (L_L C_L)^{-1/2}$ and $\omega_R = (L_R C_R)^{-1/2}$, L_L and C_L are the inductance and capacitance of the LH unit cell and L_R and C_R are the parasitic inductance and a capacitance, respectively [3].

Both the open and closed LH distributed structures described here can exhibit *negative refraction* effects in their effective frequency range when interfaced with conventional right-handed (RH) structures. This has been confirmed by full-wave simulations, which revealed unique phenomena such as the existence of *focusing and surface plasmons*. In the case of the open structure, a parallel-plate waveguide was used as the RH medium; in the case of the closed structure, the RH medium was a strip line structure. These effects have also been observed in sandwiched RH/LH/RH configurations analogous to the "superlens" presented in [6].

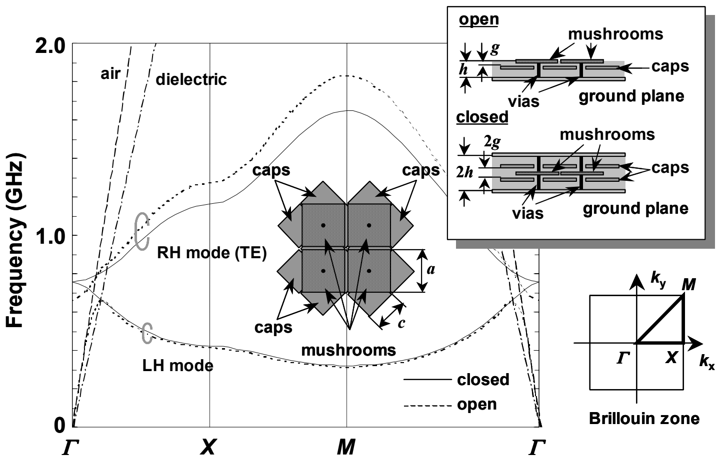

Fig.1 Dispersion diagram. a = 32.6mm, c = 16.1mm, h = 1.697mm. g = 0.127mm. The period of structure is 33.0mm, the permittivity of the substrate is ε_r = 2.2, and the diameter of the via is 0.4mm.

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