Analysis of Discontinuities of Double Negative (DNG) Slab Waveguide Sandwiched between Two Conventional Slab Waveguides

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In 1968 [V.G. Veselago, *Soviet Phys. Uspekhi* **10**, 509, (1968)], Veselago theoretically investigated plane wave propagation in double negative (DNG) material whose permittivity and permeability were assumed to be simultaneously negative, and predicted that electromagnetic plane waves in such medium would propagate in a direction opposite to that of the flow of energy. The direction of the Poynting vector is antiparallel to the direction of phase velocity, contrary to the case of plane wave propagation in conventional simple media. Recently, renewed interests to DNG media appears. Ziolkowski [R.W. Ziolkowski and E. Heyman, *Physical Review E* **64**, 056625, (2001)] investigated the propagation of electromagnetic waves in DNG media from analytical, numerical and experimental point of view. Engheta [N. Engheta, *Digest of URSI-USNC National Radio Science Meeting*, 66, Boulder, (2002)] proposed the DNG waveguide and analyzed the dispersion diagram of DNG slab waveguide and found that the portion of the guided mode inside the slab has the Poynting vector antiparallel to the direction of phase flow of the mode and the portion of guided mode outside the slab has the Poynting vector parallel with phase flow. If a conventional slab waveguide is put next to a DNG slab waveguide, one can have the "anti-directional coupling" [A. Alu and N. Engheta, *2002 IEEE-Nanotechnology Conference*, Washington DC, 233, (2002)].

In this paper, we use the mode-matching method to analyze the discontinuity structure of a DNG waveguide sandwiched between two dielectric slab waveguides as shown in the Figure below. The field representations in the transverse direction and the scattering characteristics of discontinuities in the longitudinal direction are derived. Four cases with different height of the waveguide are considered and the results are discussed. For case 1, when all the modes in the DNG waveguide are cutoff, the percentage power of the transmitted TM_0 mode is 0. For case 2, if the guided mode in the DNG waveguide is at the critical point, the reflection of TM_0 mode and the backward radiation are the majority components except for the resonant points. At those resonant points, TM_0 mode has no reflection and most of the power becomes the transmitted TM_0 and forward radiation. For case 3, when the DNG waveguide is in the special region, there are oscillations in the reflected and transmitted power because of the coupling of the special two modes. The reflection of TM_0 mode is much smaller and the transmission takes the majority component. For case 4, when only one TM mode exists in the DNG waveguide, this mode is almost matched with the TM_0 mode in the dielectric waveguide. For this case, the reflected TM_0 and TM_1 mode, the transmitted TM_1, backward radiation and forward radiation are all very small. The transmitted TM_0 is the majority component.