BACKWARD-WAVE DIRECTIONAL COUPLER WITH TIGHT COUPLING AND BROAD BANDWIDTH USING ONE-DIMENSIONAL MUSHROOM STRUCTURE

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1. Introduction

Since double negative (DNG) materials were investigated theoretically [1] and experimentally [2] by V. G. Veselago and UCSD group, respectively, DNG materials have been researched by many groups. The analysis of physical phenomenon of DNG structure consisted of split ring resonators (SRRs) and periodic thin wire has been investigated intensively by many research groups [3-4]. However, this DNG structure has the disadvantage of narrow bandwidth to be utilized for practical RF devices. On the other hand, artificial transmission line composed of series capacitance and shunt inductance has been investigated to design the broadband RF devices [5-7]. For instance, backward-wave directional couplers having the characteristics of tight coupling and broad bandwidth were suggested to overcome the disadvantages of conventional coupler by University of Toronto group [8] and UCLA group [9], respectively. They have realized DNG transmission line by lumped elements and inter-digital capacitor and inductive stub.

The mushroom structure, proposed for high impedance surfaces as a reflector (e. g. low profile antenna) by D. Sievenpiper *et al*. in 1999 [10], can also be utilized for DNG transmission line [11]. The DNG characteristics of mushroom structure are induced by series capacitance by gap and shunt inductance by grounded wire. In this paper, we have proposed a new type of backward-wave directional coupler that has the characteristics of tight coupling and broad bandwidth using one-dimensional mushroom structure. The designed directional coupler consists of conventional microstrip line and one-dimensional mushroom as DNG transmission line.

2. One-dimensional mushroom structure as DNG transmission line

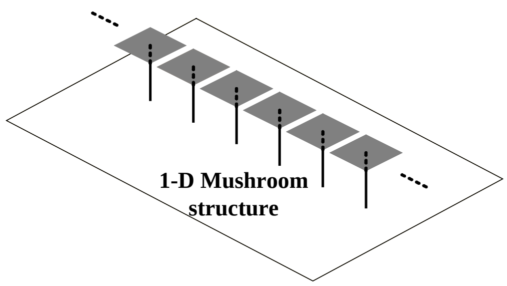

Figure 1. One-dimensional mushroom structure

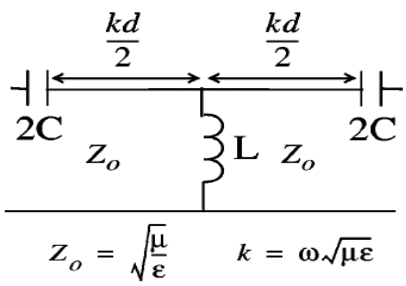

Figure 2. Equivalent circuit model of 1-D mushroom structures

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One-dimensional mushroom structure is composed of a patch separated by gap and a grounded wire, as depicted in Fig. 1. This mushroom structure can be implemented by microstrip line with gap and via hole. Fig. 2 shows an equivalent circuit model of one-dimensional mushroom structure. Series capacitance and shunt inductance are induced by gap and grounded wire, respectively. Denoted *k*, *d*, and Z_0 are the propagation constant of the interconnecting transmission lines, the unit-cell dimension, and characteristic impedance of host transmission line, respectively. We have simulated 10-unit cell one-dimensional mushroom structure using commercial software (Ansoft's HFSS) to obtain dispersion diagram. Length of gap and diameter of wire are 0.05mm and 0.3mm, respectively. Patch size of designed mushroom structure is 10mm×10mm. The utilized substrate is RT/Duroid 5880 with a relative dielectric constant ε_r of 2.2 and a thickness h of 1.57mm. As shown in Fig. 3, DNG region is between 2.4 and 4GHz and β_{DNG} is –124 (m^{-1}) at 3GHz.

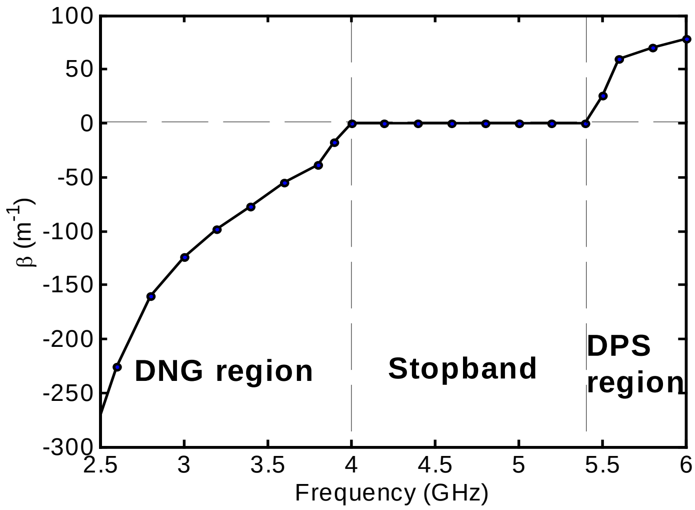
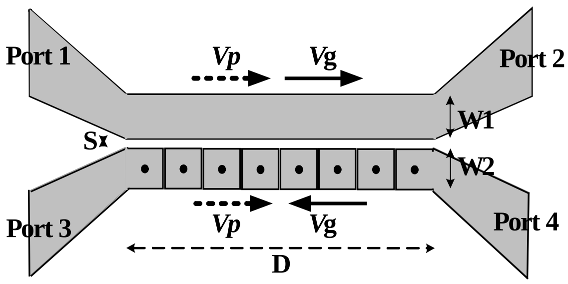
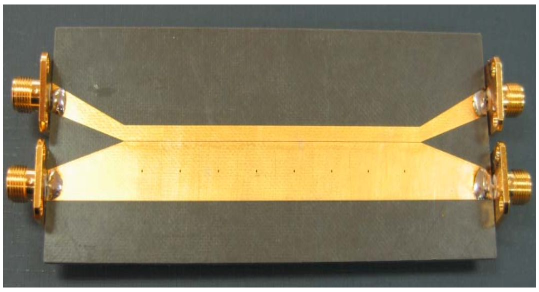


Figure 3. Full-wave simulated dispersion diagram of 1-D mushroom structure (Number of unit-cell=10, length of gap=0.05mm, diameter of wire=0.3mm, patch size=10mm×10mm, and dielectric constant and thickness of substrate=2.2 and 1.57mm, respectively)

3. Backward-wave directional coupler with tight coupling and broad bandwidth



(a)



(b)

Figure 4. The proposed directional coupler (a) Structure (b) Fabricated photograph

A structure of one-dimensional mushroom directional coupler for tight coupling and broad bandwidth is conceptually displayed in Fig. 4(a). The fabricated one-dimensional mushroom directional coupler is also shown in Fig. 4(b). If power is injected at port1, phase (propagation constant) and group (pointing vector) velocity direct toward port2. Because coupling between two lines occurs through transverse evanescent waves to same direction of phase velocity, phase and group velocity of the other coupled line propagate toward port4 and port3, respectively, due to the DNG property of the mushroom structure. As a result, backward coupling is accomplished in this type of directional coupler. In a case of conventional asymmetric coupler, maximum forward coupling is obtained when length of coupler (D) is satisfied with $\pi/|\beta_c - \beta_\pi|$. β_c and β_π are the propagation constants for the c and π modes, respectively [12]. In the case of very weak coupling between the two lines, β_c and β_π conceptually can be changed to β_{MS} (propagation constant of microstrip) and β_{DNG} (propagation constant of mushroom structure), respectively [9]. Therefore, maximum backward coupling occurs when D is $\pi/|\beta_{MS} + \beta_{DNG}|$ (β_{DNG} is negative sign in DNG region). We expect that D for maximum backward coupling of mixed microstrip and one-dimensional mushroom structure coupler is smaller than that for maximum forward coupling of conventional asymmetric coupler. In other words, new type of coupler has a property of tight coupling compared with conventional forward-wave coupler.

In this paper, we have designed backward-wave directional coupler using the one-dimensional mushroom structure mentioned in the section2. The β_{DNG} and β_{MS} are –124 (m^{-1}) and 84.5 (m^{-1}) at 3GHz, respectively. As considered condition of maximum backward coupling, a length of coupler (D) is obtained to 80mm (needs to 8-unitcell mushroom structure in the coupled line). And then, separation between microstrip and one-dimensional mushroom (S) is selected as 0.1mm.

The S-parameters of the coupler, which are obtained by simulation and measurement using Ansoft's HFSS and HP 8510C Vector Network Analyzer, are presented in Fig. 5(a) and Fig. 5(b). As shown in Fig. 5(a) and 5(b), measured results show good agreement with simulated results. Despite of a relative

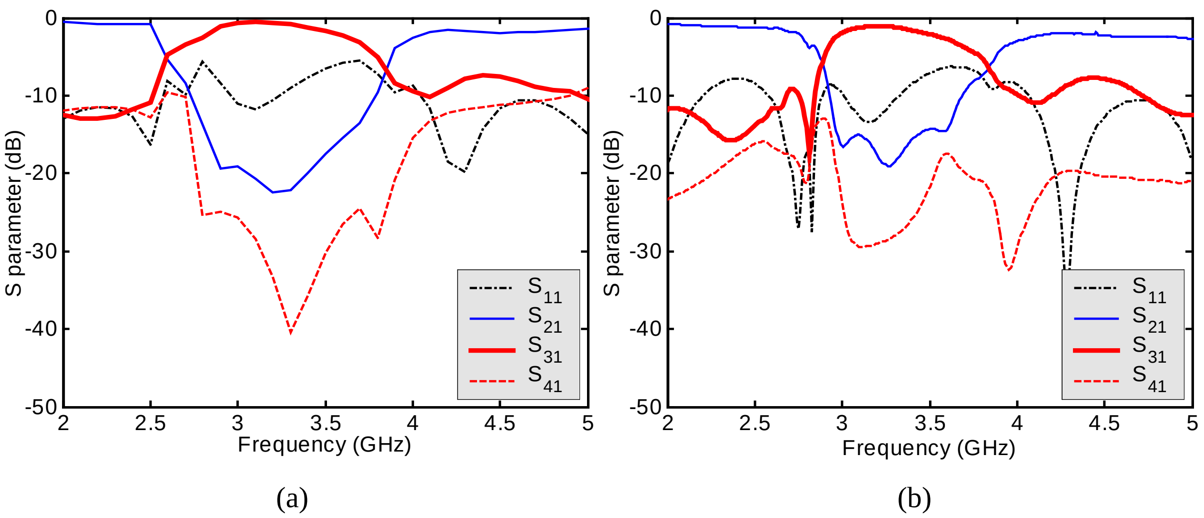


Figure 5. S-parameters of the designed directional coupler (a) Full-wave simulation (b) Measurement (Operation frequency=3GHz, number of unit-cell=8, S=0.1mm, D=80mm, W1=2.655mm, and patch size (W2)=10mm×10mm)

wide separation between two lines, coupling coefficient of proposed coupler is achieved to be around –1dB from 2.9 to 3.7GHz. Isolation is below –25dB in a coupling range.

4. Conclusion

A new type of backward-wave directional coupler with tight coupling and broad bandwidth composed of conventional microstrip and one-dimensional mushroom structure characterized with DNG transmission line has been proposed. Tight coupling is broadly achieved to be about –1dB near operation frequency (bandwidth of 30%). Moreover, high directivity of ~ 30dB has been obtained in the coupling frequency range.

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