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Tunable Dielectric Resonator-Based Left-Handed Leaky Wave Antenna

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1. Introduction

Recently, left-handed (LH) metamaterials have been achieved by arranging an array of TE resonant dielectric resonators (DRs) in a cut-off parallel plate waveguide [1], [2]. Since negative permittivity is provided by the TE cut-off background, the DRs only need to generate the required negative permeability in order to realize a LH metamaterial. This configuration provides a more flexible choice in structural parameters and uses a non-metallic resonant structure for achieving negative permeability that can be scaled to terahertz frequencies and beyond.

One of the unique features of a LH metamaterial-based leaky wave antenna is that it can scan from back-fire to end-fire simply by changing the operational frequency. To overcome this frequency-dependent feature, an electrically-controlled tunable leaky wave antenna has been proposed [3]; the dispersion curve can be shifted by varying the bias voltage of the varactor diodes in each unit-cell.

In contrast to the frequency and electrically controlled leaky wave antenna, this paper presents a mechanically controlled leaky wave antenna suitable for DR-based LH transmission lines. The dispersion curve is shifted when the boundary condition on the other side of the radiation aperture changes. A 15-cell leaky wave antenna is designed with the proposed structure and the radiation patterns are measured to confirm the capability of mechanical tunability for the maximum beam direction.

2. Dispersion Diagram

The geometry of the proposed 1-D LH transmission line is shown in Fig. 1. It is composed of a parallel-plate waveguide loaded with a 1-D array of disc-type DRs. The DR array is located at a distance, s, away from the nearest side wall of the parallel plates. Another metal plate that is parallel to the side walls of parallel plates is inserted inside the waveguide at a distance, g, away from the DRs for tuning the dispersion characteristics. The various parameters used in the calculation are as follows; the dielectric constant, height, and diameter of DRs are $\varepsilon_{DR} = 38$, h = 2.03 mm, and a = 5.10 mm, respectively. A dielectric material with a dielectric constant of $\varepsilon_{BG} = 2.2$ is used as the host medium for filling the parallel plates. The distance of the parallel plates is d = 5 mm, and the length of the unit cell p = 6 mm.

The dispersion diagram is numerically obtained for the unit-cell under periodic boundary conditions in the longitudinal direction, and is shown in Fig. 2. The finite-element method (FEM) is used for the simulation. When the distance g becomes smaller, the frequency at $\beta = 0$ shifts to a higher frequency. The dispersion curve can be tuned due to the proximity of the metal plate. Furthermore, the stop band above the cut-off frequency can be shifted to a higher frequency band. In the case of g = 1.0 mm at 11.1 GHz, the phase constants β with/without the metal plate are 121.7 rad/m and 69.7 rad/m, respectively.

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3. Tunable Leaky Wave Antenna

The configuration for the simulation of the 15-cell leaky wave antenna is illustrated in Fig. 3. The width and height of the rectangular waveguides for feeding are 4 mm and 5 mm, respectively. The feed waveguide is filled with a substrate with dielectric constant of 10.2.

In the experimental setup, a commercial DR (Murata product: DRD0510203M00A01T) was employed as the disc-type DR to be inserted in the parallel plates. An RT/Duroid 5880 substrate with dielectric constant of 2.2 was used as the host medium between the cut-off parallel plates. An RT/Duroid 6010 substrate with dielectric constant of 10.2 was chosen as a high dielectric constant rod inserted in a 4 mm x 5 mm cross-sectional rectangular waveguide.

In Fig. 4, the simulated and measured transmission characteristics of the 15-cell structure are shown. As seen in Fig. 4(a), the measured passband without the metal plate appears from 10.5 GHz to 11.2 GHz, as predicted in the numerical simulation and the dispersion diagram of Fig. 2. The simulated and measured insertion losses are significant in the radiation region within the passband from 10.8 GHz to 11.2 GHz. As seen in Fig. 4(b), the large insertion loss of measurement is confirmed in the radiation region within the passband. The main reasons for this discrepancy are the air gaps between the background and the metal plate and the contact condition between the parallel plate and the inserted metal plate.

In Figs. 5 and 6, the simulated and measured E-plane radiation patterns at 11.0 GHz and 11.1 GHz are shown, respectively. The radiation beam angle ϕ has been measured from broadside toward the backward direction, as shown in Fig. 3(b). The measured results are in good agreement with the simulated results at 11.0 GHz, and the maximum radiation angle with/without the metal plate is 44 deg. and 36 deg., respectively. At 11.1 GHz, the measured maximum radiation angle and beamwidth are different from the numerical results. This difference can be explained by referring to Fig. 4(b); the magnitude of S_{21} at 11.1 GHz is much smaller in comparison to the value at 11.0 GHz. This low transmission coefficient at 11.1 GHz means that not all the 15-cells are excited, resulting in a smaller radiation aperture. From the results of Fig. 5 and Fig. 6, the mechanically controlled tuning of the radiation angle is verified.

4. Conclusion

The 1-D mechanically tunable left-handed leaky wave antenna has been proposed which is composed of a parallel plate waveguide and dielectric resonators. The dispersion curve can be tuned by changing the metal plate position near the DRs. The cut-off frequency becomes 11.24 GHz and 11.14 GHz with/without the metal plate, respectively. The mechanically tunable leaky wave antenna was designed and fabricated with 15-unit cells. Tuning for maximum beam direction by adjusting the metal plate position was confirmed.

Acknowledgments

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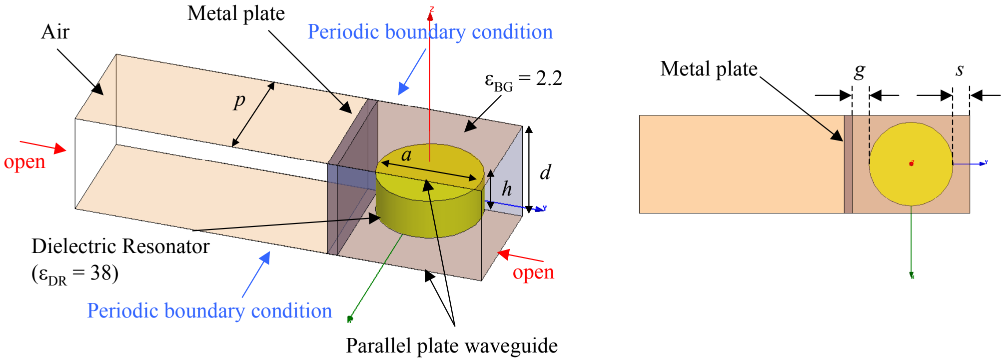


(a) (b)

Figure 1: Geometry of unit-cell of 1-D DR-based LH structure with metal plate. (a) Perspective view. (b) Top view.

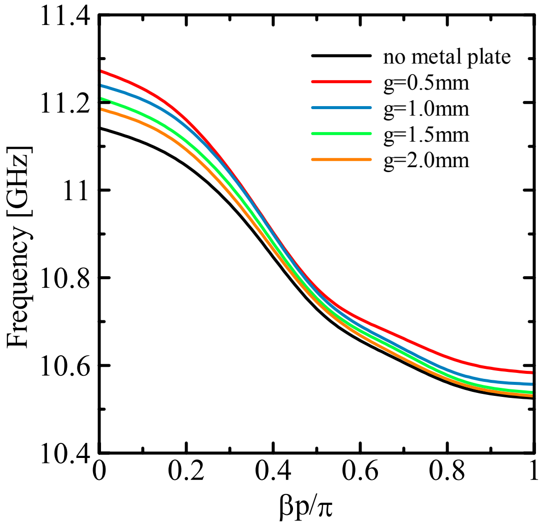
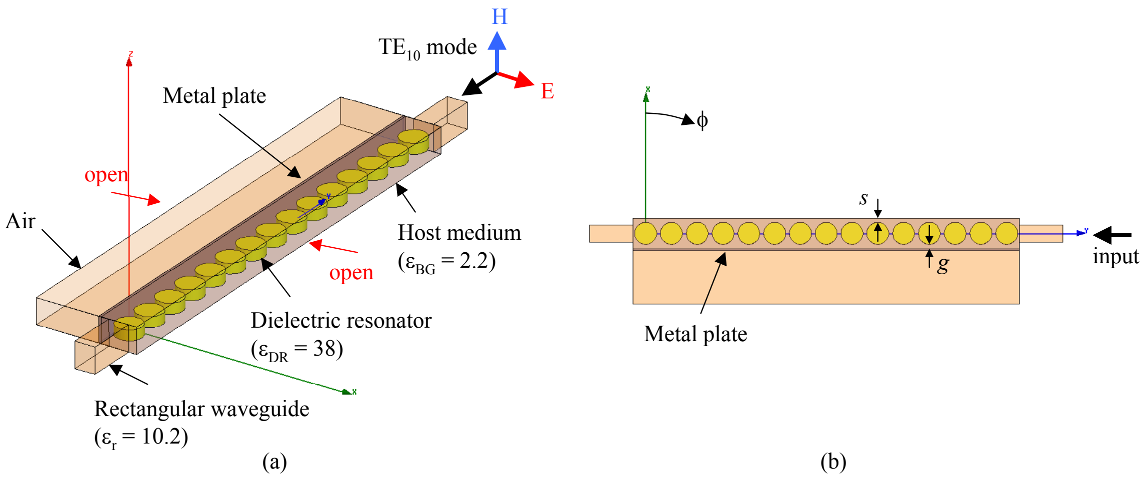
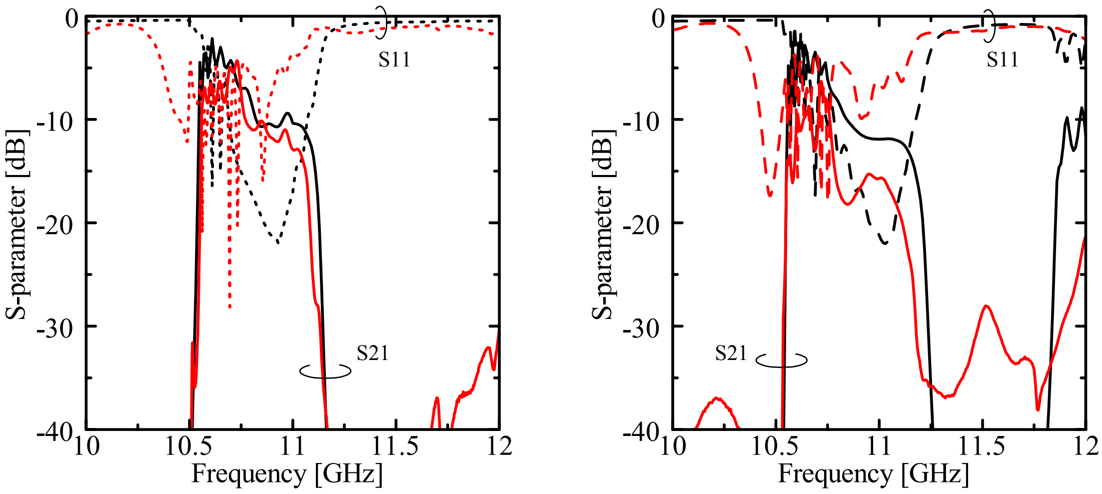


Figure 2: Dispersion diagram when the distance g is varied.



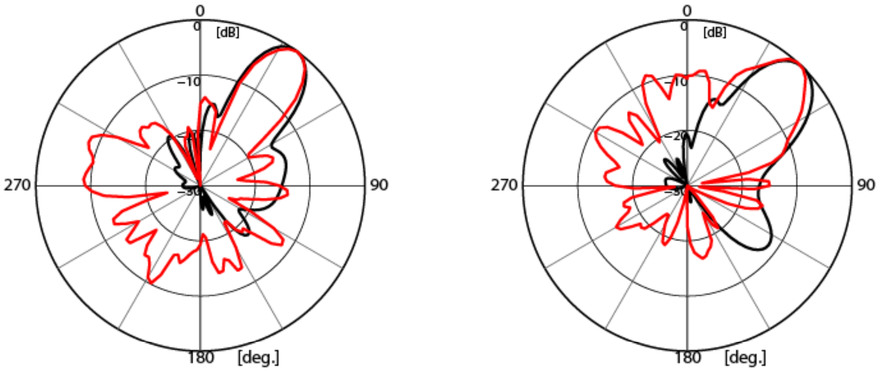
(a) (b)

Figure 3: Geometry of 15-cell DR-based LH leaky wave antenna with metal plate. (a) Perspective view. (b) Top view.



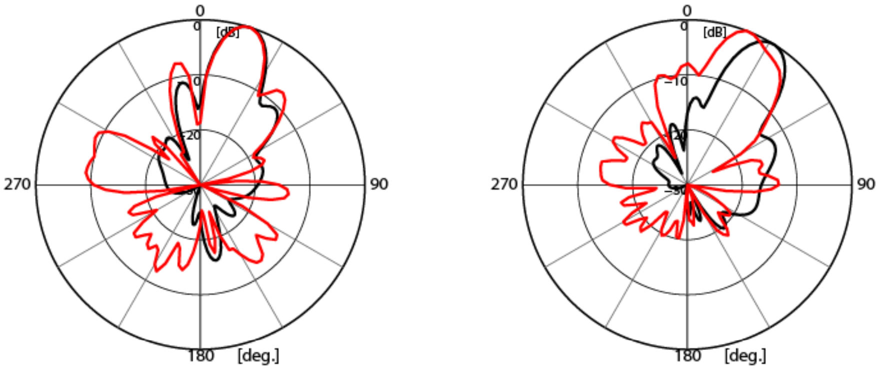
(a) (b)

Figure 4: S-parameter characteristics. Black and red lines show simulated and measured results, respectively. (a) without metal plate. (b) with metal plate (g = 1.0 mm).



(a) (b)

Figure 5: Radiation patterns at 11.0 GHz. Black and red lines show simulated and measured results, respectively. (a) without metal plate. (b) with metal plate (g = 1.0 mm).



(a) (b)

Figure 6: Radiation patterns at 11.1 GHz. Black and red lines show simulated and measured results, respectively. (a) without metal plate. (b) with metal plate (g = 1.0 mm).