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Design of Liquid Crystal Reflectarray Using Double-Layer Patch Elements

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Abstract— **Recently, the liquid crystal reflectarry (LC-RA) using liquid crystal as a dielectric substrate of a reflectarray is expected for beam steerable antennas. Dielectric constant of the liquid crystal changes by applying a bias voltage, the phase of reflection coefficient for each array elements and the scattering beam direction can be controlled. However, change of dielectric constant of the liquid crystal is limited in a range from 2 to 3, and it is not enough to change the phase of reflection coefficient up to 2π in the unit-cell analysis of periodic structure. In this paper, the liquid crystal reflectarray using double-layer patch elements is proposed to increase the phase-range of reflection coefficient and fundamental study of LC-RA is performed.**

Keywords-component; Reflectarray, Double layer structure, Liquid Crystal, Infinite periodic structure

I. Introduction

Recently, the beam steerable array antenna (BSAA) which can change beam directions according to communication environment is expected. For instance, BSAA is expected for a base station of the five generation communication system (5G). Currently, the frequency used for 4G systems is 800 MHz having relatively low propagation loss and the beam width of 60 degree is used for a base station with 6-sector configuration. In 5G, the frequency of 28 GHz band having high propagation loss, and a high gain and a beam steerable antenna for a 5G base station is required to communicate with moving terminals.

In order to change the beam direction continuously, a phased array antenna with a phase shifter in each element of the array is required [1][2]. Typically, a phased array antenna is quite expensive and the circuit configuration including phased shifter is complex. To realize low cost phased array antenna, a multi-bit phased shifter using SPDT switches is used, which provides discrete beam control due to discrete phase changes. On the other hand, the one-bit reflectarray using PIN diodes can be changed the beam direction continuously, however, compensation of phase is incomplete because of the 1 bit reflected phase change, and aperture efficiency is reduced [3][4].

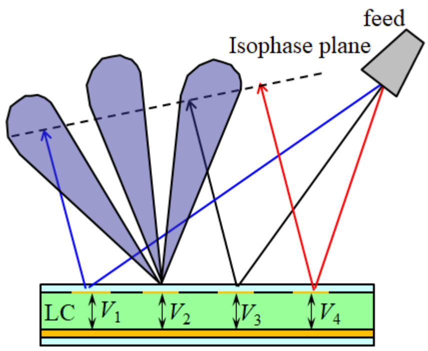

Figure 1. Conceptual diagram of liquid crystal reflectarray.

Recently, the liquid crystal reflectarray (LC-RA) using liquid crystal as a dielectric substrate of a reflectarray is studied for an beam steerable antenna [5]. The molecule of LC looks like rugby bowl and its polarization can be changed by applying bias voltage and anisotropy appears in the relative permittivity. The reflection coefficient of each array elements can be controlled, respectively, and the scattering beam direction of a reflectarray antenna can be controlled, continuously.

The conceptual diagram of liquid crystal reflectarray is shown in Figure 1. Compensating the phase of reflection coefficient of each array elements, the phase of the scattered waves becomes same in the desired direction. The phase change of the reflection coefficient should be more than 360 degree, however, change of dielectric constant of LC is limited in a range from 2 to 3, and it is difficult to obtain a large phase change. As a method to increase the phase change of a reflection coefficient for a unit cell of periodic structure, a reflectarray antenna having the patch elements with two layers has been reported [6]. In this paper, the liquid crystal reflectarray using double-layer patch elements (LC-RA-DLPE) is proposed to increase the phase-range of reflection coefficient and fundamental study of LC-RA is performed.

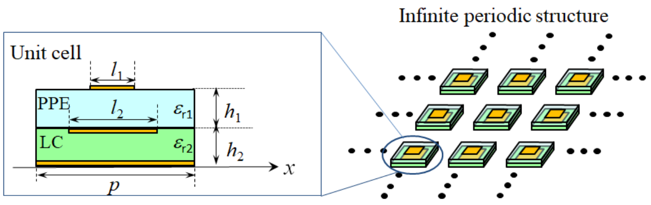

Figure 2. Analysis model.

II. THE STRUCTURE OF LC-RA-DLPE

Figure 2 shows the analysis model of the unit cell of the infinite periodic structure of RC-RA-DLPE. The design frequency is 12 GHz. The unite cell is square periodic structure and the pitch in the *x*-, *y*-direction is *p*. Where *p* is 14 mm, which is slightly longer than the half-wavelength 12.5 mm at 12 GHz. The length of one side of the lower square patch of the unit cell is l_2, and the length of one side of the upper square patch is $l_1 = a * l_2$ where the coefficient *a* is the scale factor. The thickness of the dielectric substrate is h_1, h_2, and the relative permittivity is ε_{r1}, ε_{r2}.

Infinite periodic structure analysis was performed to analyze the reflection phase of the unit cell of a reflectarray. In this paper, the finite element method (HFSS) was used. As one of the features of infinite periodic structure analysis, the interelement coupling of each array element is included. This feature is an effective method when the coupling between elements is significant, such as a reflectarray. By appropriately setting the boundary conditions including the periodical boundary condition using Floquet's theorem, it is possible to analyze the scattering characteristics of the unit cell in a form that includes inter-element coupling.

III. ANALYTICAL EXAMINATION

In this chapter, the result of infinite periodic structure analysis for two cases, when A. the relative permittivity of two layers is changed, B. the relative permittivity of the upper layer is fixed and the relative permittivity of the lower layer is changed is described.

A. The relative permittivity of two layers changed

Figure 3 shows the phase of reflection coefficient with changing patch length l_2. The analyses were performed in two ways: the dielectric substance is vacuum (relative permittivity $\varepsilon_{r1} = \varepsilon_{r2} = 1$) and LC (relative permittivity $\varepsilon_{r1} = \varepsilon_{r2} = 2.9$). In both cases, the thickness of substrates are $h_1 = h_2 = 3$ mm. From Figure 3, it was confirmed that the width of phase change increased by two layers in two substances. Also it can be observed that the rate of phase change versus the change of structure increases because the effective wavelength becomes short as the relative dielectric constant of the substrate increases.

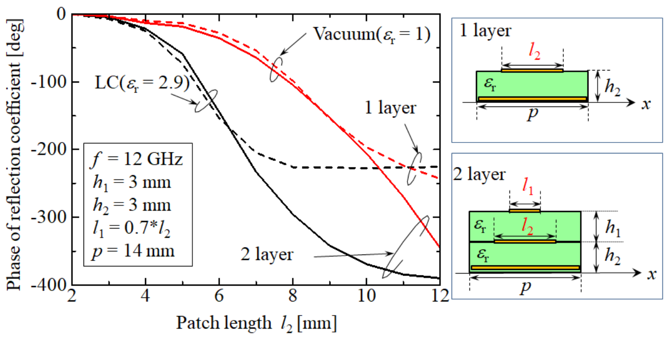

Figure 3. Phase of reflection coefficient with changing patch length l_2.

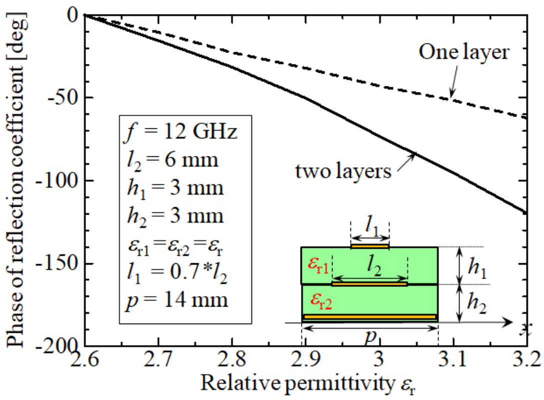

Figure 4.
Phase of reflection coefficient with changing relative permittivity of two substrates.

Fig. 4 shows the phase of reflection coefficient with changing relative permittivity of two substrates when l_2 = 6 mm. *a* = 0.7, thickness $h_1 = h_2 = 3$ mm. From Figure 4, the change of the relative permittivity in a range from 2.6 to 3.2 resulted in a phase change of the reflection coefficient about 120 degree, which was smaller than the structural change.

B. The relative permittivity of lower layer changed

Figure 5 shows the phase of reflection coefficient with changing patch length l_2. The analyses of several thickness LC-RA-DLPEs was performed. Comparing with Figure 4, it was confirmed that the thinner the liquid crystal layer, the greater the phase change of the reflection coefficient.

Figure 6 shows the phase of reflection coefficient with changing relative permittivity of lower layer substrates as the liquid crystal. From Figure 5, it was confirmed that the width of phase change of up to 350 degrees was obtained by changing the relative permittivity from 2.6 to 3.2.

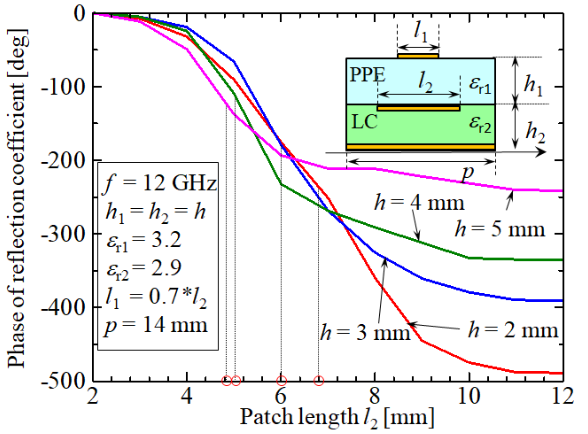

Figure 5.
Phase of reflection coefficient with changing patch length l_2. Cases with thickness h =2, 3, 4 and 5 mm.

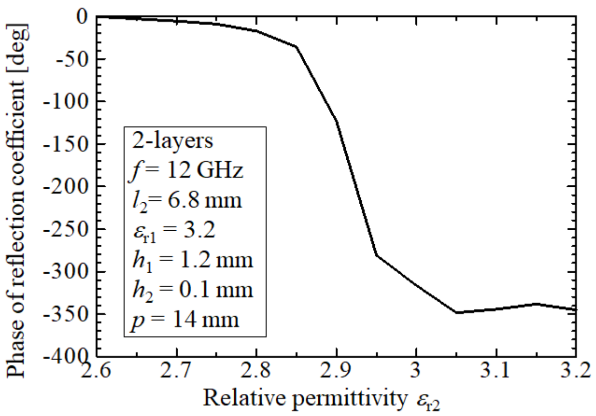

Figure 6. Phase of reflection coefficient with changing relative permittivity of lower layer substrate.

IV. Conclusion

The liquid crystal reflectarray using double-layer patch elements is proposed to increase the phase-range of reflection coefficient. The phase change of the reflection coefficient of the unit cell was analyzed using the infinite periodic structure analysis. It was confirmed that the width of phase change of the reflection coefficient can be improved by using two layers. It was also shown that the width of phase change increases as the thickness of liquid crystal layer decreases, and the phase change of about 2π was achieved with the limited change of the relative permittivity in a range from 2.6 to 3.2.

References

[1] M. Smith and Y. Guo, “A comparison of methods for randomizing phase quantization errors in phased arrays”, IEEE Trans. Antenna Propagation, Vol.31, No.6, pp.821828, Nov. 1983

[2] W. Jiang, Y. Guo, T. Liu, W. Shen, and W. Cao, “Comparison of random phasing methods for reducing beam pointing errors in phased array”, IEEE Trans. Antenna Propagation, Vol.51, No.4, pp.782787, April 2003

[3] E. Carrasc, M. Barba, and José A. Encinar, “X-Band Reflectarray Antenna With Switching-Beam Using PIN Diodes and Gathered Elements”, IEEE Trans. on Antennas and Propagation, Vol.60, N.12, Dec 2012

[4] H. Zhang, X. Chen, Z. Wang, Y. Ge, and J. Pu, “A 1-Bit Electronically Reconfigurable Reflectarray Antenna in X Band”, Digital Object Identifier 10.1109/ACCESS.2019.2918231

[5] S. Bildik, S. Dieter, W Menzel et al..,"Reconfigurable Folded Reflectarray Antenna Based Upon Liquid Crystal Technology", IEEE Transaction on Antenna and Propagation, Vol.63, No.1, Jan 201

[6] Jose A Encinar, “Design Of Two-layer Printed Refrectarrays Using Patches Of Variable Size”, IEEE Trans. Antennas Propagation, Vol.49, No.10, Oct 2009