2024 IEEE International Symposium on Antennas and Propagation and INC/USNC-URSI Radio Science Meeting (AP-S/INC-USNC-URSI) | 979-8-3503-6990-8/24/$31.00 ©2024 IEEE | DOI: 10.1109/AP-S/INC-USNC-URSI52054.2024.10687176

Experimental Design of Liquid Crystal Based Intelligent Reflecting Surface For 5G Communications

Hiroyasu Sato(1), Hideo Fujikake (1), and Qiang Chen(2)
(1) Tohoku University, Graduate School of Engineering, Aoba-ku, Sendai 980-6579, Japan
(hiroyasu.sato.b1@tohoku.ac.jp)

***Abstract*— In this paper, design of Liquid Crystal based Intelligent Reflecting Surface (LC-IRS) for 5G communications of 40 GHz band is performed experimentally. It is found that not only the thickness of liquid crystal but also the thickness of sealing quartz grass substrate affects the reflection coefficient characteristics. Large phase change of 422 degree at the frequency of 39.7 GHz is obtained which enables the phase selection for arbitrary beam scanning direction.**

I. Introduction

In Intelligent Reflecting surface (IRS) technology for 5G communications, which electrically controls the direction of reflection, has been attracting attention in recent years. Among the IRS using diodes and MEMS are being researched as a typical phase control technology for realizing IRS, the liquid crystal-based IRS (LC-IRS) is expected for 5G and 6G communications based on the liquid crystal display technology. The phase is changed by controlling the dielectric constant of LCs to actively scan the direction of the reflected beam.

However, there are some challenges in designing a liquid crystal IRS. First, the dielectric constant distribution of liquid crystal is not homogeneous. The orientation distribution of the liquid crystal is determined by the low-frequency bias voltage applied to the liquid crystal, and inhomogeneous, anisotropic orientation distribution in the low-frequency band determines the inhomogeneous dielectric constant distribution of the liquid crystal in the millimeter wave band. Therefore, the full wave simulation requires approximations such as treating it as an isotropic medium. Furthermore, a cover substrate for sealing the liquid crystal will be affected to the reflection coefficient of LC-IRS and the dielectric constant and thickness of sealing substrate should be selected, appropriately.

In this paper, based on the above difficulties, design of Liquid Crystal based Intelligent Reflecting Surface (LC-IRS) for 5G communications of 40 GHz band is performed experimentally. The effects of thickness of sealing glass substrate and liquid crystal to the reflection coefficient have been investigated.

II. Developed LC-IRS and measurement setup

Figure 1 shows the developed LC-IRS and unit cell structure for one-dimensional beam scanning. Operating frequency is 40 GHz band. To perform one-dimensional beam scanning in E-plane, the reflect array (RA) elements in the vertical direction are connected by bias-lines and the reflection phase is controlled by applying different voltages to each vertical element. The structure of RA element consists of a three-element dipole to increase the amount of phase change.

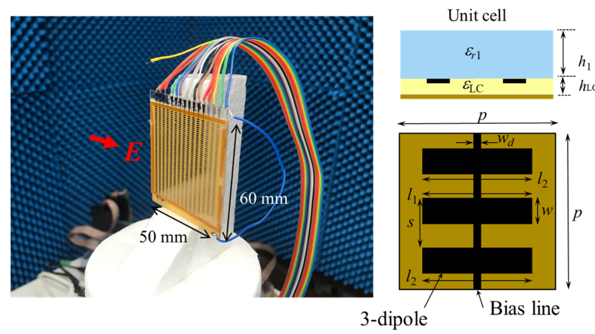

Figure 1. Structure of Intelligent Reflect Surface (IRS) using Liquid Crystals and it's prototype.

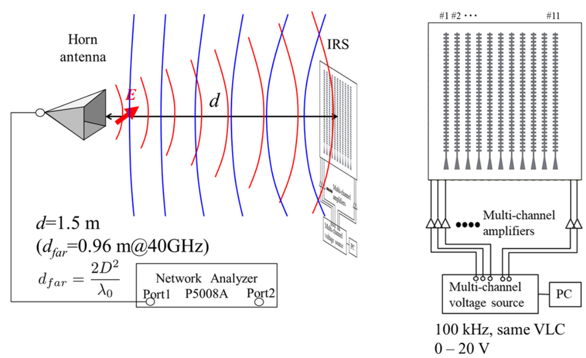

Figure 2. Measurement system of Reflection coefficient.

Figure 2 shows the measurement system of Reflection coefficient of LC-IRS. A horn antenna illuminates the IRS with a distance of 1.5 m which satisfy the far field condition and almost plane wave excitation will be realized. Horn antenna is connected to Keysight vector network analyzer P5008A and the reflection coefficient was measured. The same voltage is applied for each RA element and the voltage V_{LC} is changed from 0 V to 20 V by the multichannel voltage source with frequency of 100 kHz.

III. Results

Table 1 shows the parameters of LC-IRS for experimental evaluation. Developed liquid crystal of TD-1020XX [5] and a conventional E7 were used. Quartz glass with dielectric

Table 1. Parameter of LC-IRS for experimental evaluation.

Model	Parameters	1-1	1-2	1-3	1-4	1-5	1-9	1-10	1-11	1-12	1-13
Liquid Crystal	TD-10XX E7	TD 10XX	TD 10XX	TD 10XX	TD 10XX	TD 10XX	TD 10XX	E7	TD 10XX	TD 10XX	TD 10XX
Thickness of Quartz	h_1	0.3	0.3	0.3	0.3	0.2	0.7	0.7	1.0	1.3	1.6
Thickness of LC	h_{LC}	0.05	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1

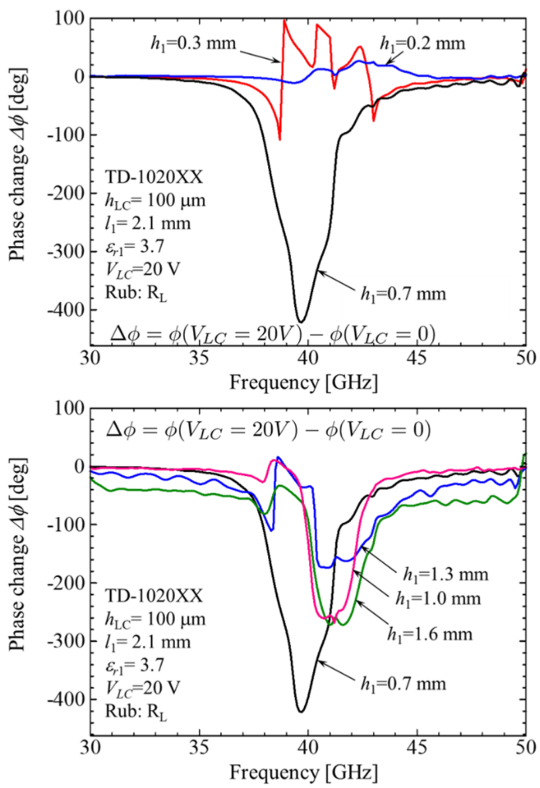

Figure 3. Measurement system of Reflection coefficient when thickness of sealing glass substrate changes.

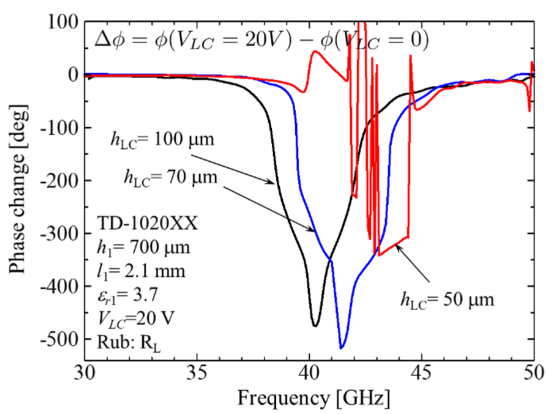

Figure 4. Measurement system of Reflection coefficient when thickness of liquid crystal TD-1020XX changes.

permittivity of 3.7, loss tangent of 0.005 was used as a sealing substrate of liquid crystal with changing the thickness from 0.2 mm to 1.6 mm. Also thickness of liquid crystal was changed from 50 μm to 200 μm.

Figure 3 shows the frequency characteristics of phase change $\Delta\phi$ denoted by the equation $\Delta\phi = \phi(V_{LC}{=}20V) - \phi(V_{LC}{=}0V)$ in the case when glass thickness h_1 of 0.2 mm, 0.3 mm, 0.7 mm, 1 mm, 1.3 mm and 1.6 mm. Large amount of phase change has been obtained only in the case of h_1=0.7 mm and the maximum phase change of 422 degree was observed at the frequency of 39.7 GHz. Frequency band of $\Delta\phi$ > 360 degrees were from 39.3 GHz to 40.2 GHz (500 MHz). On the other hand, in case of h_1=0.2 mm and 0.3 mm, quite small phase change was observed. Discontinuous curve can be considered that the trajectory of complex reflection coefficient as a function of frequencies has not been rotate the origin of complex-plane. In the case when h_1 is increased as 1 mm, 1.3 mm and 1.7 mm, maximum phase changes were decreased and peak frequency were shift around 41 GHz. Thus, it is found that there is optimum quartz glass thickness of around 100 μm for large amount of the phase changes.

Figure 4 shows the frequency characteristics of phase change $\Delta\phi$ in the case when thickness of liquid crystal TD-1020XX are of h_{LC} of 50 μm, 70 μm and 100 μm. Large amount of phase change has been observed except for 50 μm. In the case of 5G communications using frequency of 40 GHz band, it is considered that the thinner thickness of liquid crystal is around 50 μm and high frequency of over 100 GHz was selected in many papers [1-4] in order to use thin thickness with high agility.

IV. Conclusion

In this paper, the experimental design of Liquid Crystal based Intelligent Reflecting Surface (LC-IRS) for 5G communications of 40 GHz band is presented and large phase changes of over 360 degrees were achieved. Beam steering demonstration will be shown using developed 5G-LC-IRS.

Acknowledgment

This research was partly supported by the Ministry of Internal Affairs and Communications in Japan (JPJ000254).

References

[1] J. Yang et al., "Fully Electronically Phase Modulation of Millimeter-Wave via Comb Electrodes and Liquid Crystal," in IEEE Antennas and Wireless Propagation Letters, vol. 20, no. 3, pp. 342-345, March 2021.

[2] B. S. Ung et al., "Towards a rapid terahertz liquid crystal phase shifter: Terahertz in-plane and terahertz out-plane (TIP-TOP) switching," IEEE Trans. THz Sci. Techn., vol. 8, no. 2, pp. 209?214, Mar. 2018.

[3] S. Gao et al., "Tunable liquid crystal based phase shifter with a slot unit cell for reconfigurable reflectarrays in F-band," Appl. Sci., vol. 8, no. 12, Dec. 2018, Art. no. 2528.

[4] S. Sun et al., "Electronically tunable liquid-crystal-based F-band phase shifter," IEEE Access, vol. 8, pp. 151065-151071, 2020.

[5] X. Li, H. Sato, H. Fujikake and Q. Chen, "Development of Two-dimensional Steerable Reflectarray with Liquid Crystal for Reconfigurable Intelligent Surface Application," in IEEE Transactions on Antennas and Propagation, doi: 10.1109/TAP.2024.3354054.