Design of Patch Type Meta-surface for Orthogonal Polarization Conversion

Yasuhiro TOMII, Toshikazu HORI, Mitoshi FUJIMOTO
Graduate School of Engineering, University of Fukui, 3-9-1, Bunkyo, Fukui, 910-8507 Japan
E-mail:tommy@wireless.fuis.u-fukui.ac.jp

***Abstract* - This paper proposes a meta-surface for orthogonal polarization conversion, and describes the design method of the meta-surface by using a patch type unit cell. It is clarified by the simulation results that the patch type meta-surface can realize orthogonal polarization conversion in the frequency bandwidth of 46.8%.**

***Index Terms* — Meta-surface, Polarization conversion, Orthogonal polarization.**

1. Introduction

A meta-surface is composed of Frequency Selective Surface (FSS) and the ground plane. It is an artificial surface that realizes distinctive characteristics. It can control the reflection coefficient and reflection phase. Therefore, it is expected to be used to control the propagation path and compose flat reflector that reflects an electromagnetic wave in an arbitrary direction. Further, realizing the polarization conversion has been considered by applying the property. Recently, the polarization function, which converts linear polarization to circular polarization, has been proposed by using the meta-surface [1][2]. However, orthogonal polarization function does not be studied. This paper proposes a meta-surface for orthogonal polarization conversion, and describes the design method of the meta-surface by using a patch type unit cell.

2. Mechanism of Orthogonal Polarization Conversion

Figure 1 shows the incident wave to the meta-surface and reflected waves. $\boldsymbol{E}^i_x$ and $\boldsymbol{E}^i_y$ are the incident electric field in the x and y directions, respectively. $\boldsymbol{E}^r_x$ and $\boldsymbol{E}^r_y$ are the reflection electric field in the x and y directions, respectively. The incident wave is polarized at 45° from the x axis, as shown in Fig.1. In this case, $|\boldsymbol{E}^i_x| = |\boldsymbol{E}^i_y|, |\angle\boldsymbol{E}^i_x - \angle\boldsymbol{E}^i_y| = 0°$. To convert the reflection wave to orthogonal polarization, the wave must be polarized at $\pi/2$ from the incident wave. In other words, the reflected wave must be polarized at the $3\pi/4$ from the x axis, as shown in Fig.1. In this case, $|\boldsymbol{E}^r_x| = |\boldsymbol{E}^r_y|, |\angle\boldsymbol{E}^r_x - \angle\boldsymbol{E}^r_y| = 180°$. When the following two conditions are satisfied, the orthogonal polarization conversion function is obtained.

$$|\boldsymbol{E}^r_x| = |\boldsymbol{E}^r_y| \quad (1)$$

$$|\angle\boldsymbol{E}^r_x - \angle\boldsymbol{E}^r_y| = 180° \quad (2)$$

3. Design Method by Using Patch Type Meta-surface

When the incident wave that is polarized at 45° enters to the square patches, the electric field characteristics in the x and y directions are the same amplitude and phase. That is, the condition (1) is satisfied, (2) is not satisfied. Therefore, rectangle patches are used. In this case, the electric field characteristics are different in the x and the y directions, and the reflection phase difference between $\boldsymbol{E}^r_x$ and $\boldsymbol{E}^r_y$ occurs. Therefore, when the incident wave that is polarized at 45° enters to the meta-surface using the rectangle patches, the condition (1) and (2) are satisfied. Then, the wave is reflected as an orthogonal polarization.

Fig.2 shows the reflection phase properties of patch type meta-surface. The solid and dotted lines show the phase of $\boldsymbol{E}^r_x$ and $\boldsymbol{E}^r_y$, respectively. When the frequency is with the reflection phase difference of 180° between the $\boldsymbol{E}^r_x$ and $\boldsymbol{E}^r_y$, the meta-surface can reflect an orthogonal polarization. The frequency with the reflection phase difference of 180° is defined as $f_{180°}$. It is normalized frequency when the reflection phase of $\boldsymbol{E}^r_y$ is 0°. Also, when the frequency is with the reflection phase difference from 160° to 200° between the $\boldsymbol{E}^r_x$ and $\boldsymbol{E}^r_y$, the meta-surface can reflect an orthogonal polarization.

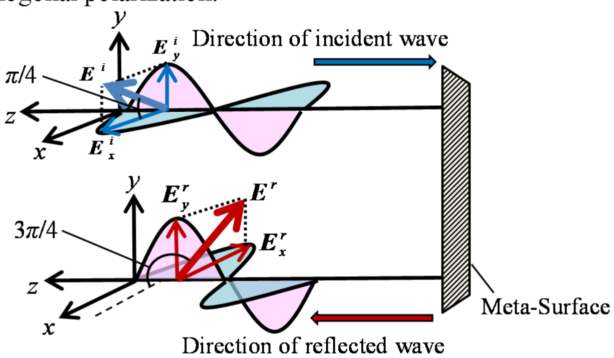

Fig.1. the incident wave to the meta-surface and reflected waves

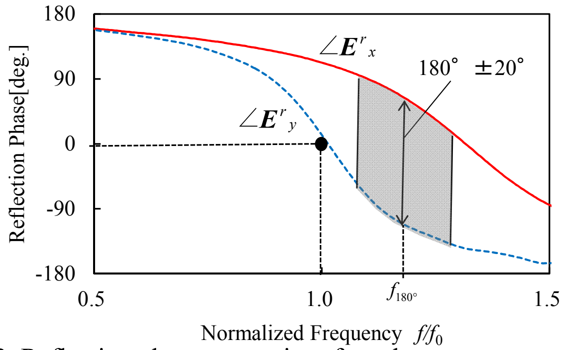

Fig.2. Reflection phase properties of patch type meta-surface

Fig.3 shows the meta-surface by using a patch type unit cell. It is composed of the FSS and the ground plane. Meta-surface consists of rectangle patches are used. Parameters are the width of the unit cell p_x, the length p_y, the width of the patch l_x, the length l_y, the distance between the patches and the ground plane h. In addition, we define the unit cell to patch ratio as $l_x / p_x = l_y / p_y = r$.

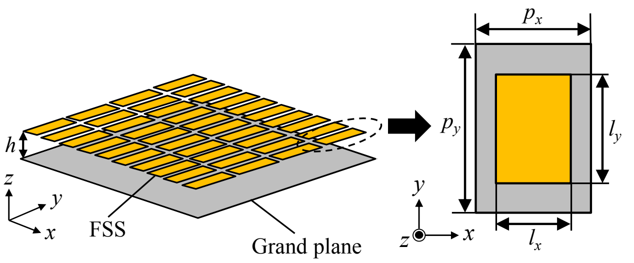

Fig.3. Structure of proposed patch type meta-surface

4. Orthogonal Polarization Conversion Characteristics of Patch Type Meta-surface

Fig.4 shows the relationship between the patch size ratio r and the frequency bandwidth. In this case, the distance between the patches and the ground plane $h = 0.075\lambda_0$. As the aspect ratio of the unit cell p_y/p_x increases, the maximum frequency bandwidth and the patch size ratio r become large. Gradually, the maximum frequency bandwidth converges when p_y/p_x is more than 5.0.

Fig.5 shows the relationship between the patch size ratio r and the distance between the patches and the ground plane h. The patch type meta-surface can realize orthogonal polarization conversion in the frequency bandwidth of 46.8% when the $p_y/p_x = 5.0$, $r = 0.74$, and $h = 0.075\lambda_0$.

Fig.6 shows the relationship between the aspect ratio of the unit cell p_y/p_x and the maximum frequency bandwidth. The maximum frequency bandwidth converges when p_y/p_x is more than 5.0. Therefore, patch type meta-surface is optimal when p_y/p_x is 5.0.

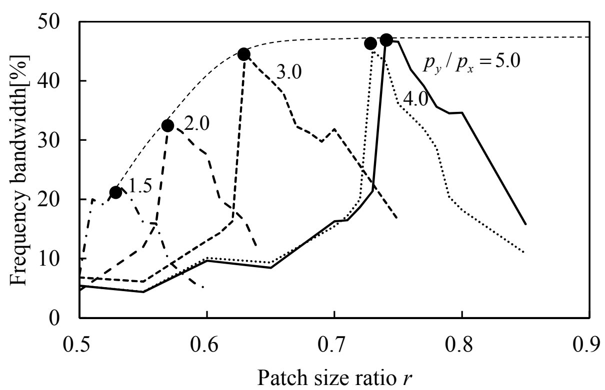

Fig.4. Relationship between the patch size ratio r and the frequency bandwidth

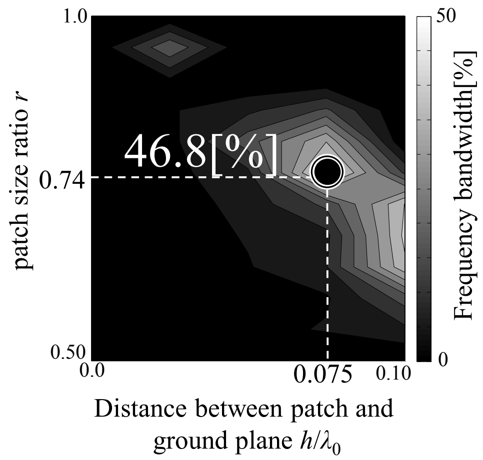

Fig.5. Relationship between the patch size ratio r andthe distance between the patches and the ground plane h

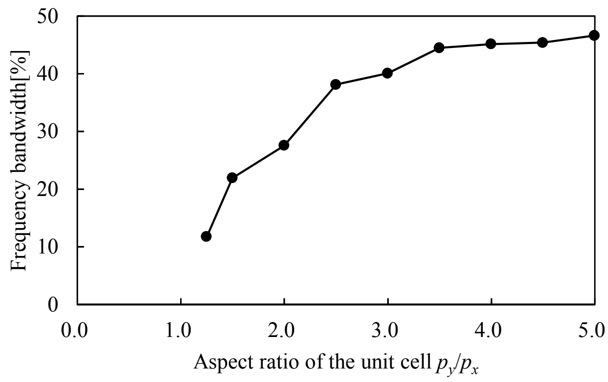

Fig.6. Relationship between the aspect ratio p_y/p_x and the maximum frequency bandwidth

5. Conclusion

The meta-surface for orthogonal polarization conversion was proposed, and the design method of the meta-surface by using a rectangle patches was shown. When the distance between the patches and the ground plane h was the same, as the aspect ratio of the unit cell p_y/p_x increased, the maximum frequency bandwidth and the patch size ratio r became large. The maximum frequency bandwidth converged when p_y/p_x was more than 5.0. It was clarified by the simulation resulted that the patch type meta-surface could realize orthogonal polarization conversion in the frequency bandwidth of 46.8%.

References

[1] Y. Kawakami, et al., “Low-profile design of meta-Surface by considering filtering characteristic of FSS,” Proc. iWAT2010, Lisbon, Portugal, PS2.27, Mar. 2010.

[2] M. Kamiya, R. Kuse, T. Hori, and M. Fujimoto, “Frequency bandwidth of patch type meta-surface with polarization conversion function,” Proc. APCAP2015, Bali, Indonesia, TP-28, July 2015.