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Spatial Filter with Multilayered FSS for Wideband Orthogonal Polarization Conversion

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Abstract **– This paper proposes the spatial filter with multilayered FSS(Frequency Selective Surface) for wideband orthogonal polarization conversion such as converting vertical polarization to horizontal polarization. It is indicated that FSS with LPF(Low-Pass Filter) and HPF(High-Pass Filter) in orthogonal direction realizes wideband orthogonal polarization conversion. Furthermore, it is shown that the optimal number of layers of the FSS is four, and maximum value of relative bandwidth is 40.2%.**

Index Terms **— FSS, Polarization Conversion, Orthogonal Polarization**

1. Introduction

FSS is composed of metallic elements arranged periodically at narrow intervals. And, it can transmit or reflect electromagnetic waves of a specific frequency[1]. The transmission and reflection phases of the electromagnetic waves are controlled by selecting filtering characteristics of FSS. Therefore, the polarization conversion has been proposed by using this feature[2][3]. However, transmission type orthogonal polarization conversion which has been proposed is narrow band.

This paper proposes the spatial filter with multilayered FSS for wideband orthogonal polarization conversion.

2. Conditions of transmission type orthogonal polarization conversion and realization by FSS

Fig. 1 shows the concept of the transmission type orthogonal polarization conversion. The incident wave $\boldsymbol{E}^i$ is obliquely polarized at $\Phi=\pi/4$, and the electric field component in x-direction and y-direction are $\boldsymbol{E}^i_x$, $\boldsymbol{E}^i_y$ respectively. In addition, $\boldsymbol{E}^i_x$ and $\boldsymbol{E}^i_y$ that transmitted through the spatial filter is represented as $\boldsymbol{E}^t_x$ and $\boldsymbol{E}^t_y$. When $\boldsymbol{E}^i_x$ and $\boldsymbol{E}^i_y$ are assumed to be equal amplitude and equal phase, conditions of the orthogonal polarization conversion is $\boldsymbol{E}^t_x$ and $\boldsymbol{E}^t_y$ are equal amplitude and phase difference π. By satisfying those conditions, the transmission wave $\boldsymbol{E}^t$ becomes oblique polarization of $\Phi=3\pi/4$. As a result, $\boldsymbol{E}^i$ and $\boldsymbol{E}^t$ are orthogonal.

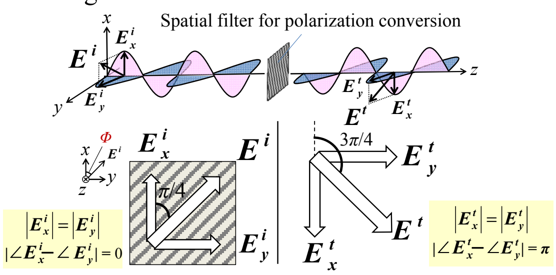


Fig. 1. Spatial filter for polarization conversion

Fig. 2 shows incident wave to the FSS and transmission wave. Here, it is considered that FSS which has different impedance in the x-direction and y-direction. Oblique polarization of $\Phi=\pi/4$ is incident to this FSS. In this case, the incident wave operates differently in the x-direction and y-direction component, and phase difference π is realized in between both directions. For this reason, spatial filter using FSS realizes orthogonal polarization conversion. The conventional transmission type FSS is loop-slot type as shown in Fig. 2, and it has band-pass filter characteristics. Loop-slot type FSS realizes orthogonal polarization conversion, but its limit of relative bandwidth is 9.5%.

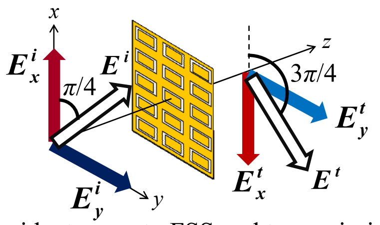
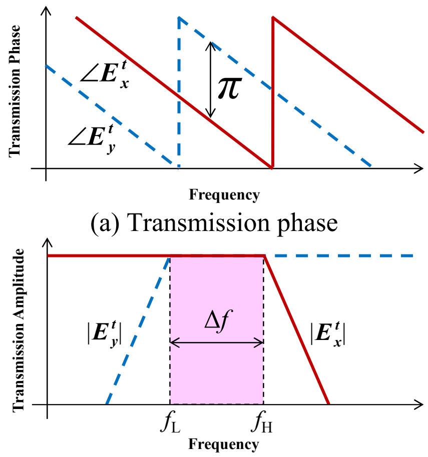


Fig. 2. Incident wave to FSS and transmission wave

3. Spatial filter characteristics for wideband orthogonal polarization conversion

Fig. 3 shows the spatial filter characteristics for wideband orthogonal polarization conversion. As shown in Fig. 3(a) and (b), it is considered that spatial filter characteristics which is LPF in x-direction and HPF in y-direction. Those characteristics are largely different in each of the phase shift, and each of the transmission band overlaps in wideband. For this reason, those characteristics are considered to be suitable for polarization conversion.

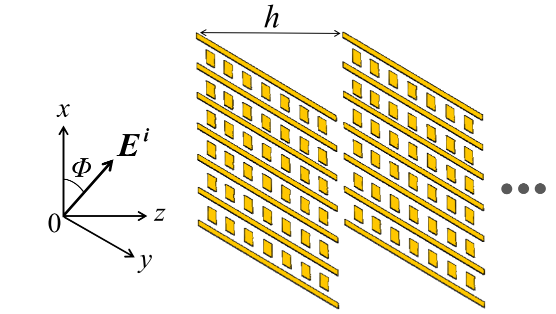


(b) Transmission amplitude

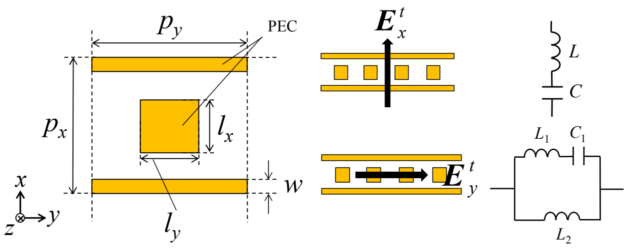
Fig. 3. Spatial filter characteristics which is required for FSS

4. Configuration of FSS for wideband characteristics

Fig. 4 shows the structure of FSS. Fig. 4(a) shows Bird's-eye view of FSS, and Fig. 4(b) shows unit cell of FSS and its equivalent circuit model. Unit cell of FSS has the structure in which places the patch between the grid. In x-direction, inductance L and capacitance C are connected in series. In y-direction, a series of inductance L_1 and capacitance C_1 is connected with inductance L_2 in parallel. In the operating band, x-direction and y-direction characteristics close to LPF and HPF respectively by adjusting the parameters. In order to obtain wide transmission bandwidth and the transmission phase difference, FSS is multilayer structure. p_x, p_y is x-direction and y-direction of the unit cell size. l_x, l_y is the patch size. w is the grid width. h is the interlayer distance of the FSS. λ_0 is the wavelength of the wave of the design frequency f_0.



(a) Bird's-eye view



(b) Unit cell of FSS and equivalent circuit model

Fig. 4. Structure of FSS

5. Band characteristics of wideband FSS

Fig. 5 shows an example of spatial filter characteristics of the orthogonal polarization conversion FSS. Here, solid line is $\angle E^t_x$, dotted line is $\angle E^t_y$, ○ is $|E^t_x|$, △ is $|E^t_y|$. At this time, FSS is three layers structure, and the parameters are p_x=0.41λ_0, p_y=0.29λ_0, l_x=0.26λ_0, l_y=0.15λ_0, w=0.02λ_0, h=0.25λ_0. Frequency band Δf is the bandwidth of the polarization conversion loss is 1.0dB or less. From the figure, the characteristics are LPF and HPF in orthogonal direction, and each of the transmission band overlaps at the edges. In addition, it can be seen that the slope of each of the phase characteristics in this band are similar, and the phase difference π is maintained. Therefore, the important thing for wideband polarization conversion is the characteristics having transmission band of $|E^t_x|$ and $|E^t_y|$ overlaps at the edges in wideband. This structure realizes the wideband orthogonal polarization conversion of relative bandwidth 18.1% when the three layers structure.

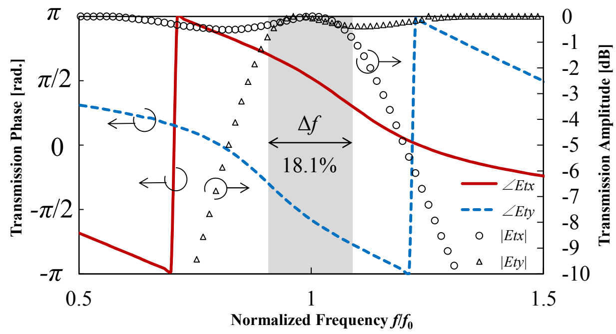


Fig. 5. Spatial filter characteristics of three layers FSS

Fig. 6 shows the relationship between the number of layers of the FSS and the maximum relative bandwidth and the thickness of FSS. Solid line is the maximum relative bandwidth, and dotted line is the thickness of FSS. Here, the maximum value of relative bandwidth of the polarization conversion loss less than 1dB is defined as the maximum relative bandwidth. It is shown that maximum relative bandwidth 40.2% is obtained by four layers structure. In addition, if the number of layers is five or more, the relative bandwidth is reduced by the fluctuation of the transmission amplitude. On the other hand, the increase amount of the thickness of the FSS becomes smaller with the number of layers increases.

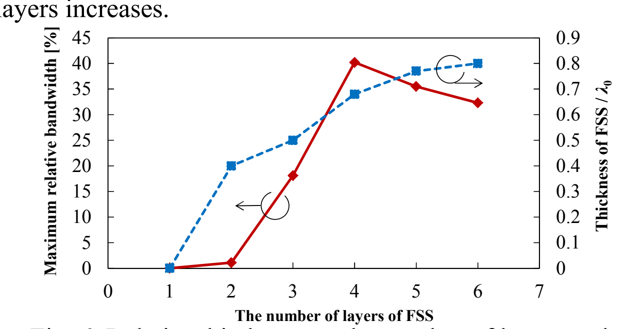


Fig. 6. Relationship between the number of layers and maximum relative bandwidth and thickness of FSS

6. Conclusion

In this paper, wideband spatial filter with multilayered FSS for orthogonal polarization conversion was proposed. First, it was shown that the characteristics which have LPF and HPF in orthogonal direction realize the wideband orthogonal polarization conversion. Then, the structure of the FSS which could satisfy the wideband spatial filter characteristics was shown. Moreover, it was indicated to be obtained maximum relative bandwidth of 40.2% when using four layers structure FSS.

References

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