The Design Method of Low-cross-polarization Reflectarray Antenna

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***Abstract*—This paper proposes a design method for a low-cross-polarization reflectarray antenna. In this paper, the mechanism of cross polarization is clarified and a design method for a reflectarray antenna with low-cross-polarization is shown. The validity of the design method is verified through simulations and measurements.**

I. INTRODUCTION

A reflectarray antenna[1] is composed of a flat reflector and a feed horn and it can sometimes be compared to an offset parabola antenna. In general, the efficiency and gain of a reflectarray antenna are lower than those of a parabola antenna. In addition, the bandwidth of a reflectarray antenna is narrower than that of a parabola antenna. On the other hand, the advantage of a reflectarray antenna is that its cross polarization component is lower than that of a parabola antenna because of the formers geometrical configuration. However, the cross polarization component tends to occur for various reasons.

In this paper, the mechanism of cross polarization of the reflectarray antenna is clarified and a design method for a reflectarray antenna with low-cross-polarization is shown. The validity of the design method is verified through simulations and measurements.

II. THE MECHANISM OF CROSS-POLARIZATION

There are two types of designs methods for a reflectarray antenna. The first one is a design that uses the incident angle subtended from the aperture side. The second one is a design that uses the incident angle subtended from the feed side. The difference results in different expressions of incident polarization against the TM and TE wave.

Fig.1 shows the polarization of the incident wave. As shown in Fig.1(a), the incident angle θ and ϕ of the incident wave measured from the aperture are constant on the flat reflector and are independent on the position of the resonant elements. Therefore, the incident polarization V and H are treated as the TM wave and TE wave, respectively. From Fig.1(b), the incident angle θ and ϕ of the incident wave measured from the feed horn are different on the flat reflector and are dependent on the position of the resonant elements. Therefore, the incident polarization V and H are expressed by the composition of the TE and TM-wave. In the case that the incident wave is composed of the TE and TM wave, the reflection coefficient of the cross polarization component (R_{cr}) can be shown as follows,

$$\begin{aligned} Rcr &= \cos\phi(\cos\phi R_{TE}^{TM} + \sin\phi R_{TE}^{TE}) \\ &\quad - \sin\phi(\cos\phi R_{TM}^{TM} + \sin\phi R_{TM}^{TE}) \end{aligned} \tag{1}$$

where R_{TB}^{TA} is the reflection coefficient of the TB polarization component for the incident wave of the TA polarization,R_{TM}^{TE} and R_{TE}^{TM} are the reflection coefficients of the cross polarization component resulting from the resonant elements.

In the case that the cross polarization component resulting from the resonant elements is 0, R_{TM}^{TE}=R_{TE}^{TM}=0. In addition, the reflection coefficients R_{TM}^{TM} and R_{TE}^{TE} can be expressed as $R_{TM}^{TM} = e^{\mathrm{j}\Phi_{TM}}$ and $R_{TE}^{TE} = e^{\mathrm{j}\Phi_{TE}}$, respectively because amplitude of the reflection coefficient is 1. In this case, Eq.(1) becomes as follows,

$$R_{cr} = \mathrm{j}e^{\mathrm{j}\frac{\Phi_{TM}+\Phi_{TE}}{2}} \sin 2\phi \sin\frac{\beta}{2} \tag{2}$$

where β=Φ_{TM}-Φ_{TE} is the difference of reflection phase between the TM and TE wave. Therefore, Eq.(2) becomes as follows,

$$|R_{cr}| = |\sin(2\phi)\sin(\frac{\beta}{2})| \tag{3}$$

With regard to the amplitude of the reflection coefficient, in the case of Fig.1(a), cross polarization is not generated because $\phi = 0[\mathrm{deg}]$ or $\phi = 90[\mathrm{deg}]$. On the other hand, in the case of Fig.1(b), if a difference in the reflection phase occurs between the TE and TM wave, then cross polarization is generated. For designing a low cross polarization reflectarray antenna, it is necessary to design the resonant elements using the incident angle measured from the feed horn and to reduce the difference of the reflection phase between the TM and TE wave.

III. DESIGN OF REFLECTARRAY ANTENNA

In the conventional design[2], evaluation parameters are provided for the phase error generated by unrealizable reflection phase region ($\Delta\phi_1$) and the phase error assuming 0.05 mm fabrication error ($\Delta\phi_2$).

In this paper, a new evaluation parameter $\Delta\phi_3$ is introduced to evaluate a cross polarization component that was not considered in the conventional design. From Eq.(3), the cross polarization component can be reduced by lowering the phase difference between the TE and TM wave. $\Delta\phi_3$ is defined as the maximum value of the phase difference obtained by changing the design parameters of the resonant elements.

Fig.2, shows the evaluation parameters vs the thickness l of the dielectric substrate (incident angle θ=0$\sim$65$[\mathrm{deg}]$) when the resonant elements ring patch type is used. In this figure, the solid line indicates the maximum values of $\Delta\phi_1$ and $\Delta\phi_2$ that correspond with the phase error and the broken line indicates the maximum value of $\Delta\phi_3$ that corresponds with the cross polarization component.

From Fig. 2, a thickness of l=2.4mm of the dielectric substrate shows the least evaluation values. However, considering the availability of the dielectric substrate, the thickness l of the dielectric substrate was selected to be 1.6mm.

IV. REFLECTARRAY ANTENNA

Table 1 shows the design parameters.

Fig.3, shows the analyzed and measured radiation patterns. As shown in the figure, the measured beam-width coincides well with the analyzed result. The measured cross polarization levels were about -27 dB and the difference between the analyzed and measured was about 6.0 dB.

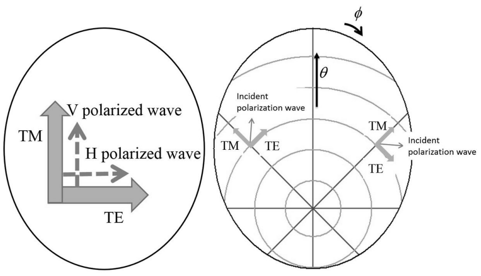
Fig.4, shows the frequency characteristics of the measured cross polarization levels compared with the parabola antenna. In this figure, the cross polarization levels of the reflectarray antenna are marked by black circles and those of the parabola antenna are marked by black triangles. As shown in the figure, the cross polarization levels of the reflectarray antenna were about 8 dB lower than those of the parabola antenna at wide frequency band.

V. CONCLUSION

In this paper, the mechanism of cross polarization was clarified and a design method for a reflectarray antenna with low cross polarization was proposed. The measured cross polarization levels of the proposed reflectaray antenna was about -27 dB and lower than those of the parabola antenna at wide frequency band. Therefore, the proposed reflectarray antenna is better than a parabola antenna with regard to cross polarization levels.

TABLE I. DESIGN PARAMETERS

Frequency f	12.5GHz
Relative permittivity ϵ_r	3.45
Thickness l of dielectric substrate	1.6mm
Period of elements d	8.4mm
Gradient of mirror surface θ_d	30.7deg
Ring width w	0.8mm
Ring radius r	0.6-3.7mm



(a) Aperture side (b) Feed horn side

Fig. 1. The explanation of TE and TM-wave

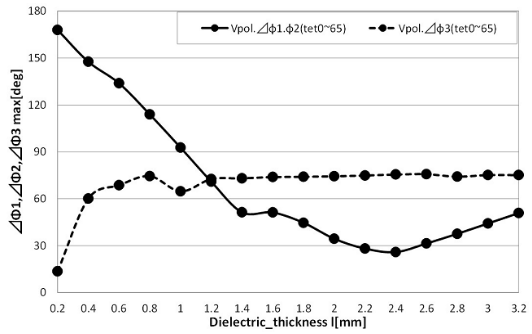


Fig. 2. Evaluation parameters vs. thickness l of the dielectric substrate

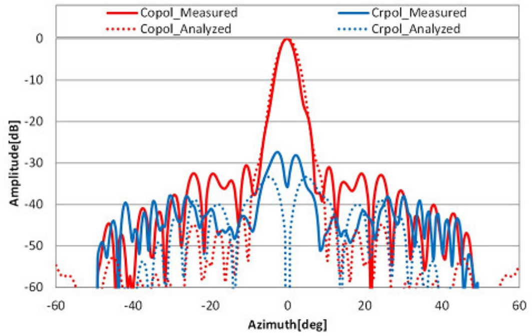


Fig. 3. Measured radiation pattern (12.5GHz)

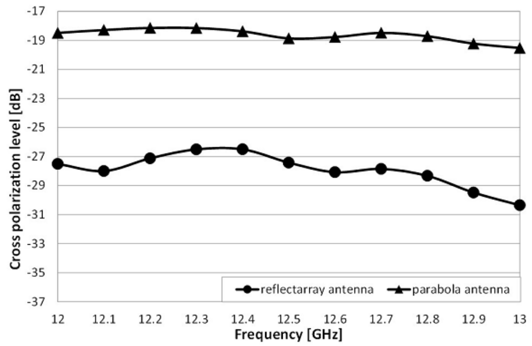


Fig. 4. Cross porarization levels

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