STUDY OF SIMPLE SINGLE LAYER PATCH ARRAY ANTENNAS FOR ETS-VIII APPLICATION

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1. Introduction

Engineering Test Satellite-VIII (ETS-VIII) is a National Space Development Agency's (NASDA) geostationary satellite, planed to be launched in 2004 [1]. ETS-VIII will conduct orbital experiments on mobile satellite communications, enabling people to communicate using hand-held terminals in the S-band frequency. Various proposals of antennas for ETS-VIII application have been made. Nevertheless, all of them focused only on the high speed transmission data (2 Mbps) for video, requiring a minimum gain of 12 dBi at low elevation angle [2-3]. In this research, their counterpart, i.e. the low speed transmission data (a few hundred kbps) for audio, is investigated. In this case, the desired minimum gain at low elevation angle is 6 dBi.

In the present paper, simple antennas constituted from one to eight patches are numerically simulated and their performances compared by use of numerical simulations based on the method of moment. The elements that compose the arrays are square patches with two truncated corners. The beam is switched by feeding all of the patches with the same amplitude and phase but by adding 180° to the phase of any one of them.

2. Composition of the studied antennas and specifications

2.1 Composition

Fig. 1 shows, as an example, the typical composition of the four patches array antenna operating at 2.6 GHz, seeing that all the elements are the same. In order to induce a circular polarization, each single-fed patch has two opposite corners truncated [4-5]. Precisely, the size of a patch is $a = b = 38.6$ mm, the truncated corner is $c = 3.0$ mm and the feeding source is located at $\rho = 11.0$ mm from the edge. In the case of two patches, the distance between adjacent elements leading to the best results is $d = 15.0$ mm. For three patches, it is $d = 2.0$ mm and for the other cases, $d = 0.0$ mm.

The feeding method explained in [6] was used in order to realize the beam switching. Practically, all the patches are fed simultaneously with the same amplitude and phase but a phase difference of 180° is applied to any one of them. In this case, a 90°-deflection of the direction of the maximum radiation from the patch that is fed out of phase is observed in the conical-cut plane. In [7], various kinds of substrates used to fabricate array antennas for mobile satellite communication that are easy to get and relatively not expensive have been investigated. From this study, it has been revealed that the value of the relative permittivity that is satisfactory is $\varepsilon_r = 2.17$. Therefore, this value was used for the following simulations.

2.2 Specifications

The targeted gain and axial ratio are more than 6 dBi and less than 3 dB, respectively. In this paper, Ω_{res} is the solid angle for which the results satisfy these specifications (dark area in Fig. 2) and Ω_{inv} is the investigated solid angle (grey area in Fig. 2). The former is delimited by φ_{b1} and φ_{b2} in azimuth and by θ_{b1} and θ_{b2} in elevation, the latter is contained between φ_1 and φ_2 in azimuth and between θ_1 and θ_2 in elevation.

The satellite is a geostationary one, the elevation angle is 48°±10° (i.e. $\theta_1 = 32^\circ \leq \theta \leq \theta_2 = 52^\circ$, where θ represents the angle from the z-axis to the x-axis). The polarization should be a left hand circular polarization. Furthermore, in terms of azimuth, each beam should cover $|\varphi_1 - \varphi_2| = 360°$, 180°, 120°, 90°, 72°, 60° or 45°, with an increase in the number of patches. The operating frequency is 2.6 GHz.

2.3 Definition of the coverage

In this paper, a measure (called "coverage"), which indicates how much the previously defined specifications expressed in terms of solid angle are satisfied, is employed. From Fig. 2, the dark area becomes small in the direction of high elevation angle. In addition, the investigated solid angle Ω_{inv} can be written as

$$\Omega_{inv} = \int_{\theta_1}^{\theta_2} \int_{\varphi_1}^{\varphi_2} \sin\theta \, d\theta \, d\varphi \, . \tag{1}$$

Then the calculation used to determine the coverage is given by

$$Coverage\ [\%] = \frac{\Omega_{res}}{\Omega_{inv}} \times 100 \tag{2}$$

with Ω_{res} defined as in Sec. 2.2. If $\varphi_{b1} = \varphi_1$, $\varphi_{b2} = \varphi_2$, $\theta_{b1} = \theta_1$ and $\theta_{b2} = \theta_2$, the coverage reaches 100%. φ_1 and φ_2 depend on the number of patches considered and on the patch that is fed out of phase. Typically, in the case of four patches array with patch #4 fed out of phase, φ_1 = 45° and φ_2 = 135°. Thus, $|\varphi_1 - \varphi_2| = 90°$ as illustrated in Fig. 2.

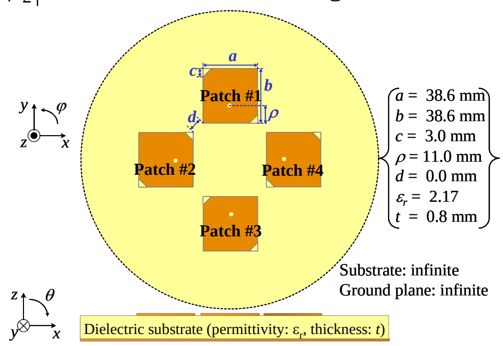

Fig. 1 Example of composition for the four patches array antenna

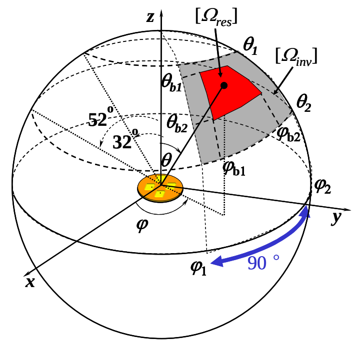

Fig. 2 Coverage (four patches)

3. Results and discussion

The simulations were performed using the software Ensemble version 8 from Ansoft, based on the method of moment. The dielectric substrate and the ground plane considered are infinite, owing to the limitation of the software. Various performances of the arrays are plotted hereafter. One patch is considered as well for comparison.

3.1 Coverage of gain

Fig. 3 shows at 2.6 GHz the variation of performances (coverage of gain and minimum gain at θ = 32°, 42° and 52°) with the number of patches. From this figure, the best performances are obtained when the number of patches is five or six. In this case, the coverage of gain is 97.7% and the minimum gain is 5.0 dBi for the former and the coverage of gain is 98.0% and the minimum gain is 4.9 dBi for the latter. In addition, as the minimum does not reach 6 dBi at low elevation angle, the coverage is less than 100%. It can be seen that the performances become good with an increase in the number of patches for θ = 32° and 42° but not at θ = 52°. This phenomenon can be explained from the viewpoint of the direction of maximum radiation as well as the beamwidth, as described hereafter.

In Fig. 4, the maximum gain and the direction of maximum radiation are plotted at 2.6 GHz. From this figure, the maximum gain increases logically as the number of patches increases. In addition, the direction of maximum radiation that should ideally be centered on θ = 42°, decreases from four patches or more. This phenomenon might be due to the attenuation of the mutual coupling effects between non-adjacent patches.

Fig. 5 presents various beamwidths in both elevation and conical-cut planes at 2.6 GHz. The horizontal beamwidth (HB) calculated for θ = 32°, 42° or 52° and the vertical beamwidth (VB) calculated in the direction of minimum gain (i.e. $\varphi = \varphi_1$ or φ_2) are defined as

$$HB[\%] = \frac{|\varphi_{b1} - \varphi_{b2}|}{|\varphi_1 - \varphi_2|} \times 100 \qquad (3) \qquad \text{and} \qquad VB[\%] = \frac{|\theta_{b1} - \theta_{b2}|}{|\theta_1 - \theta_2|} \times 100, \qquad (4)$$

where φ_{b2}, φ_{b1}, θ_{b2} and θ_{b1} have been previously defined. In addition, $|\theta_1 - \theta_2|$ is always equal to 20°.

From this figure, when the antenna is constituted of four patches or more for θ = 32° and 42° in the conical-cut plane, a beamwidth of 100% or more is reached. This means the gain is higher than 6 dBi on 100% of the beam or more when the antenna is constituted of four patches or more. When θ = 52° is considered, the larger beamwidths are obtained for five and six patches. When it comes to the elevation plane, the best performances are obtained for six elements.

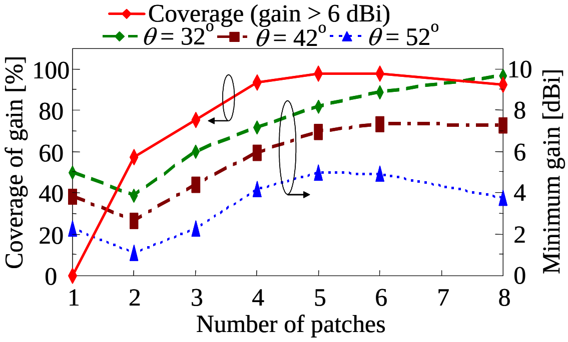

Fig. 3 Variation of the coverage of gain and the minimum gain

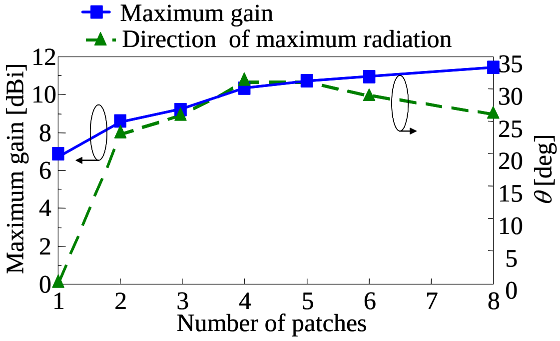

Fig. 4 Maximum gain and direction of maximum radiation

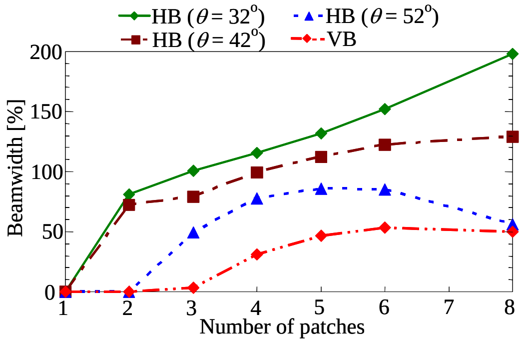

Fig. 5 Beamwidth in the elevation and the conical-cut planes

From Figs. 4 and 5, the reasons why the coverage of gain does not reach 100% could be understood. One of the reasons is due to the shift of the direction of maximum radiation from the ideal one (θ = 42°) as shown in Fig. 4. The other reason comes from the narrowness of the beam at low elevation angle as shown in Fig. 5.

3.2 Coverage of axial ratio

In Fig. 6, the variation of coverage of axial ratio is shown for the three different values of axial ratios less than 1 dB, 2 dB and 3 dB. From this graph, the coverage of axial ratio less than 3 dB is always of 100%. However, if the axial ratios less than 1 dB and 2 dB are taken into account, the best coverage is obtained for six patches.

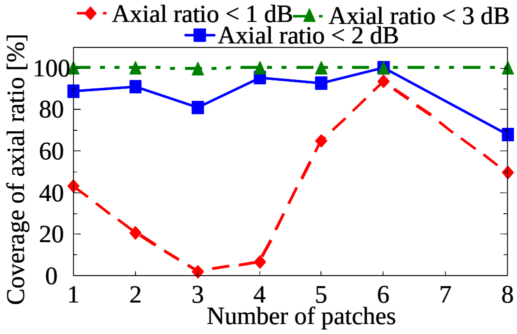

Fig. 6 Variation of the coverage of axial ratio

3.3 Performances of the six patches array antenna

From Secs. 3.1 and 3.2, it has been shown that the best performances are obtained for array antennas composed of five or six patches. Therefore, to illustrate the discussions of these sections, the typical radiation characteristics of the six patches array antenna at low elevation angle in the conical-cut plane are shown next.

From Fig. 7, the axial ratio is always contained under 3 dB on the whole azimuthal range of interest (dark area). Thus, 100% in terms of coverage of axial ratio is obtained as shown in Fig. 6. Concerning the gain, it is more than 8 dBi in the direction of maximum radiation, but the minimum gain is 4.9 dBi because the beam becomes narrow at low elevation angle.

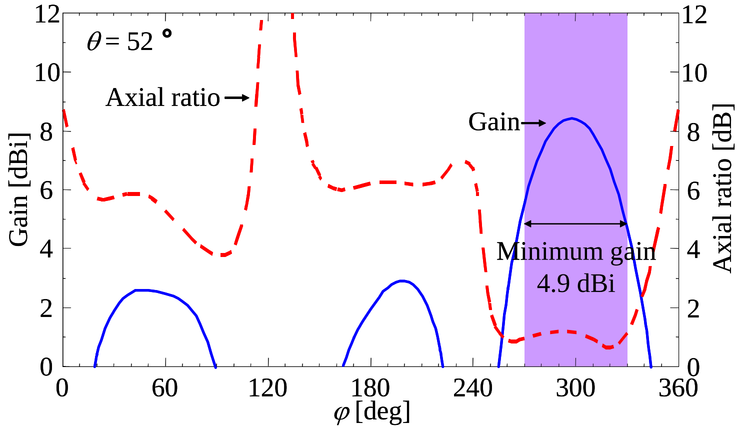

Fig. 7 Radiation characteristics in the conical-cut plane (θ = 52°)

4. Conclusion

In this paper, simple array antennas for ETS-VIII application operating at 2.6 GHz have been numerically investigated. Various characteristics have been presented to determine the optimized number of patches that leads to the best performances. From the coverage of gain and axial ratio, it has been shown that the five or six patches array antennas give better results. Then, the minimum gain, the direction of maximum radiation and the beamwidth helped understand why the coverage cannot reach exactly 100% in the case of the five or six patches array antennas. Finally, the typical radiation characteristics of the six patches array antenna at low elevation angle have been presented.

From this paper, when analyzing antennas constituted of one to eight patches, it has been revealed that the performances do not inevitably become good as the number of elements increases. It is then natural to think that the performances would not become better if the number of patches is more than eight. Therefore, it is planed in the next step to add parasitic elements to increase the gain at low elevation angle. Numerical simulations and measurements will also be performed using a finite ground plane.

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