RECTENNA COMPOSED OF A CIRCULAR MICROSTRIP ANTENNA

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1. Introduction

"Rectenna", the Earth Station Terminal in the Solar Power Satellite (SPS) system converts the microwave power (2.45GHz) transmitted from SPS into the DC. The structure of the rectenna is divided roughly in two parts -- receiving antenna and rectifying circuit. One of big problems in the SPS system is reradiation of the harmonic waves generated by the rectifying diode. Therefore, the low-pass filter must be inserted between them in order to prevent the harmonics polluting radio communication environments.

The SPS baseline rectenna has been developed by Raytheon Company, and they have adopted a dipole antenna with ground plane as the receiving antenna [1]. Also, Gutmann et al. have investigated the possibility of using the Yagi-Uda antenna. However, all of the above-mentioned antennas are belong to the linear antenna and have the characteristics that higher resonance-harmonics of integer multiples of its dominant resonance frequency exist. These features are undesirable for suppression of higher harmonic reradiation.

We have proposed the use of a circular microstrip antenna (CMSA) as a competitor to the linear antenna for the rectenna in the SPS system [2], since the CMSA has no higher resonance-harmonics of integer multiples of the dominant resonance frequency.

This paper is concerned with the absorption efficiency of the rectenna composed of the CMSA. The efficiency is estimated explicitly using an infinite array model.

2. The Resonant Characteristics of a CMSA

The general geometry of the CMSA is shown in Fig.1. The microstrip antenna has many unique and attractive properties -- low in profile, light in weight, compact and conformable in structure, easy to fabricate, and to be integrated with solid-state devices. All of these features are desirable for the receiving antenna of the rectenna.

The resonant frequencies of the antenna correspond to eigen values. For the CMSA, its resonant angular frequency ω_r is given by the root of

$$Jn'(a\omega_r\sqrt{\varepsilon_r\varepsilon_0\mu_0})=0, \qquad (1)$$

where Jn(x) is the Bessel Function of n order, a is the effective radius of the CMSA, and ε_r is the relative dielectric constant of substrate. Solving this equation, the harmonic resonant frequencies are $1.66f_0$, $2.08f_0$, $2.9f_0$, $3.64f_0$, and so on, where f_0 is the dominant frequency. Therefore, it can be expected that there exists almost no higher harmonic reradiation from the CMSA. The experimental results showed that the insertion losses at $2f_0$ and $3f_0$ were 16.4dB and 7.2dB respectively [2].

3. Absorption Efficiency of the Rectenna of an Infinite CMSA Array

Generally, an infinite array model can apply approximately to the analysis of the large rectenna array. Although the edge effect cannot be evaluated under such approximation, we obtain very simple and usefull results.

Consider an infinite array of CMSA's shown in Fig.2. An angle θ is the direction of propagation of the incident plane wave and is restricted to the x-z plane. Polarization is parallel to the x-z plane. Using the Stark's method [3], we obtain the active admittance

$$Y=\sum_m\sum_n \frac{\pi^2 a^2}{Z_0 LxLy}\cdot\Big[\frac{k^2-hn^2}{k\gamma mn^*}\cdot\{J_0(\rho)+J_2(\rho)\cdot\cos 2\alpha\}^2 + \frac{k^2-\beta m^2}{k\gamma mn^*}\cdot\{J_2(\rho)\cdot\sin 2\alpha\}^2\Big], \quad \langle \text{ equation} \tag{2}$$

where $\rho=a\sqrt{\beta m^2+hn^2}$, $\alpha=\tan^{-1}(\beta m/hn)$,

k is the wave number of the incident wave, and βm, hn, and γmn are propagation constants of the (m,n)th space harmonic wave along x, y, and z respectively. These higher waves correspond to grating lobes.

When all higher waves are evanescent, the active conductance is expressed using eq.(2) as follows:

$$G=\frac{\pi^2 a^2}{Z_0 LxLy\cos\theta}\cdot\{J_0(\rho)-J_2(\rho)\}^2, \tag{3}$$

where $\rho=ka\sin\theta$.

The absorption efficiency of the infinite rectenna array is defined as a ratio of the maximum receiving power of one element to the incident power per an element [4]. Then the absorption efficiency is represented by

$$\eta=\frac{Ae}{LxLy\cos\theta}. \tag{4}$$

Ae represents the absorption cross section and is given by

$$Ae=\frac{Grad}{G}\cdot\frac{\lambda^2}{4\pi}\cdot D, \tag{5}$$

where Grad and D are the radiation conductance and the directivity of a single element respectively, and G the active conductance. Therefore, Ae is rearranged as follows:

$$Ae=\frac{\pi^2 a^2}{Z_0 G}\cdot\{J_0(\rho)-J_2(\rho)\}^2, \tag{6}$$

where $\rho=ka\sin\theta$.

From eqs.(4) and (6), we obtain the absorption efficiency

$$\eta=\frac{\pi^2 a^2}{Z_0 G L_x L_y \cos\theta}\cdot\{J_0(\rho)-J_2(\rho)\}^2. \qquad (7)$$

The substitution of eq.(3) into eq.(7) shows that the absorption efficiency η is 100%. This means that the infinite rectenna array can absorb the incident power perfectly under the condition of no grating lobes.

Fig.3 shows the absorption efficiency vs. element spacing in the case of a square lattice ($L_x=L_y=L$). When the grating lobe generates, the efficiency becomes zero since all of the incident power flow along x-y plane or in the direction of propagation of the grating lobe. This phenomenon cannot be observed for an infinite array of dipoles with ground plane where the cancellation occurs between dipoles and their images [3].

This discussion can be extended to the case of the CMSA with losses. When we consider the ohmic and the dielectric losses of the CMSA, the active conductance is rewritten as follows:

$$G'=G+Gcu+Gdiel. \qquad (8)$$

Both the ohmic and the dielectric losses of the CMSA are affected by the thickness of the dielectric substrate. Fig.4 shows the absorption efficiency under the existence of losses, where the relative dielectric constant of the substrate is 2.6 and $\tan\delta$ 2.2×10^{-3}.

4. Conclusion

This paper showed that the absorption efficiency of the infinite rectenna array composed of the CMSA was 100%. The rusults indicate the possibility of realization of the very thin rectenna which uses the CMSA as the receiving antenna.

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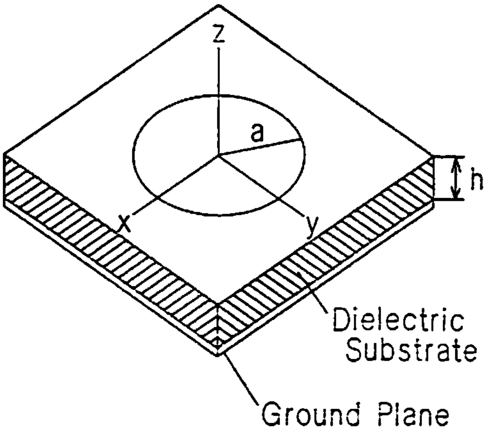

Fig.1. Circular microstrip antenna.

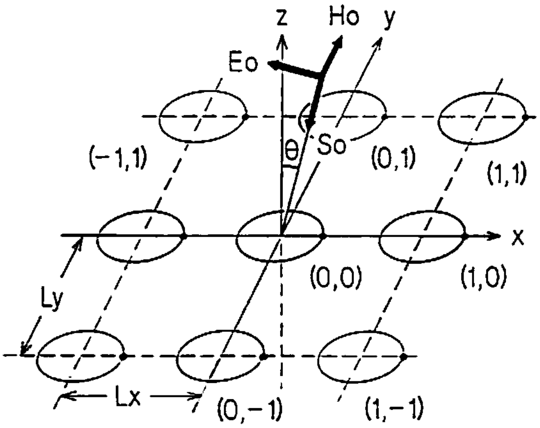

Fig.2. Geometry of an infinite CMSA array.

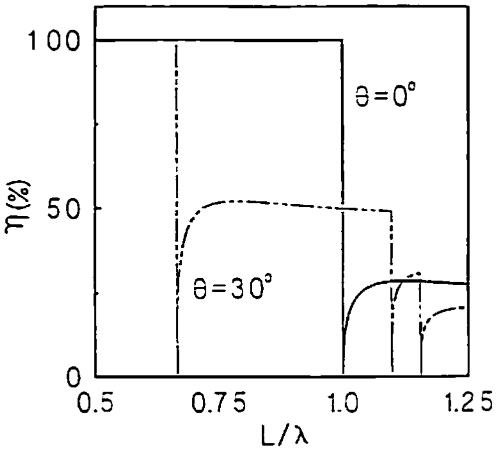

Fig.3. Absorption efficiency vs. element spacing where parameter is the incident angle θ ($Lx=Ly=L$).

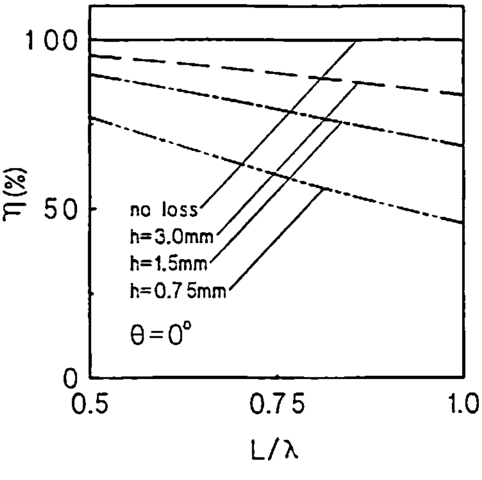

Fig.4. Absorption efficiency vs. element spacing where the CMSA possesses the ohmic and dielectric losses.