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FORCED RESONANT TYPE SMALL CAVITY-BACKED SLOT ANTENNAS FOR ELECTROMAGNETIC POWER TRANSMISSION

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1. Introduction

The solar power satellite (SPS) concepts enable microwave energy to be beamed from space to Earth where it would be converted to electricity, and they are researches in progress [1]. For the microwave power transmission, cavity-backed slot antennas were proposed, of which the slot is normal to the feed post [2]. Therefore Microwave circuits are placed at the bottom of the cavity accounted for the ease of manufacturing (see Fig. 1(b)). This paper proposed an electrically small cavity-backed slot antenna, for the application of spacetenna, with a feed post and a parasitic post inserted parallel to the slot. This type of antenna might effectively excite the slot and forcibly resonate the cavity by adding external reactance to the parasitic post. Because of structural advantage of being small sized, microwave circuits can be attached to the lateral wall of the volume-reduced cavity (see Fig. 1(a)(c)).

The proposed antenna was analyzed by solving integral equations for the unknown electric current on each post and electric field in the slot with the employment of Galerkin's method of moments. The value of external reactance for forced resonance is discussed by deriving a determining equation, the current distribution on each post and the radiation patterns are considered. The analysis is in excellent agreement with the experiment for the input impedance.

2. Geometry of the spacetenna

Figure 1(a)(c) shows the geometry and coordinate system of a forced resonant type electrically small-sized cavity-backed slot antenna. The slot of length a, width b is in the infinite plane of perfect electric conductor at $z=0$ and is backed by a conducting rectangular cavity of depth c. A feed post (#1) of radius r is at $z=-s$, $x=d$ and the external reactance jX_{ext} is connected to a parasitic post (#2) at $z=-s$, $x=a/2$ to obtain forced resonance of the cavity antenna. Both posts are short ended. The element spacing of $L_x \times L_y$ which do not generate a grating lobe in beam scanning is chosen as $L_y \leq 0.67\lambda$ and $L_x \leq 0.78\lambda$. The shaded region of the lateral wall of the cavity shown in Fig.1 is reserved for microwave circuits.

3. Integral Equations

To derive integral equations, the antenna is divided into two regions as illustrated in Fig.1(a), a cavity (region I) and a half space (region II). Assuming the antenna is fed by a delta function generator of voltage V_1, we can obtain simultaneous integral equations for the unknown electric currents J_1 and

$\mathbb{J}_2$ on the feed post and parasitic post, respectively, and for the unknown aperture electric field $\mathbb{E}_a$ in the slot, as given by

$$\frac{1}{j\omega\varepsilon_0}\oiint_{S_1'}\overline{\mathbb{K}}^{I}_{11e}\cdot\mathbb{J}_1 dS_1' + \frac{1}{j\omega\varepsilon_0}\oiint_{S_2'}\overline{\mathbb{K}}^{I}_{12e}\cdot\mathbb{J}_2 dS_2' + \iint_{S_a'}\overline{\mathbb{K}}^{I}_{1m}\cdot[\hat{z}\times\mathbb{E}_a]dS_a' = -V_1\hat{y}\delta(y) \tag{1}$$

$$\frac{1}{j\omega\varepsilon_0}\oiint_{S_1'}\overline{\mathbb{K}}^{I}_{21e}\cdot\mathbb{J}_1 dS_1' + \frac{1}{j\omega\varepsilon_0}\oiint_{S_2'}\overline{\mathbb{K}}^{I}_{22e}\cdot\mathbb{J}_2 dS_2' + \iint_{S_a'}\overline{\mathbb{K}}^{I}_{2m}\cdot[\hat{z}\times\mathbb{E}_a]dS_a' = jX_{ext}\hat{y}I_2(0)\delta(y) \tag{2}$$

$$\hat{z}\times\{\oiint_{S_1'}\overline{\mathbb{K}}^{I}_{a1e}\cdot\mathbb{J}_1 dS_1' + \oiint_{S_2'}\overline{\mathbb{K}}^{I}_{a2e}\cdot\mathbb{J}_2 dS_2' + \frac{1}{j\omega\mu_0}\iint_{S_a'}\overline{\mathbb{K}}^{I}_{am}\cdot[\hat{z}\times\mathbb{E}_a]dS_a'\} = (-\hat{z})\times\frac{1}{j\omega\mu_0}\iint_{S_a'}\overline{\mathbb{K}}^{II}_{am}\cdot[-\hat{z}\times\mathbb{E}_a]dS_a' \tag{3}$$

where $\mathbb{K}$'s are kernels, $k_0=\omega\sqrt{\varepsilon_0\mu_0}$, and superscripts ***I, II*** and subscripts ***1, 2, a*** denote region I, region II, feed post, parasitic post, and aperture, respectively. And we assumed the time dependence exp($j\omega t$) and radius of the feed post considerably small compared with the wavelength.

To solve the simultaneous integral equations for the unknowns, the electric currents $\mathbb{J}_1$, $\mathbb{J}_2$ and the aperture electric field $\mathbb{E}_a$ are expanded in a series of sinusoidal basis functions. Substituting the assumed basis functions into (1) ~ (3) and employing Galerkin's method of moments, we obtain a set of linear equations for the unknown expansion coefficients.

4. Forced resonant condition and determining equation for reactance value

The input impedance of the cavity-backed slot antenna in Fig.1(a) can be controlled by adjusting external reactance value. Consequently a forced resonance can be obtained. The resonant condition at the feed point is given by

$$\mathrm{Im}\{Z_{in}(y_{ij}, jX_{ext})\} = 0 \tag{4}$$

where Z_{in} is the input impedance of the antenna, and Im denotes the imaginary part. We represent the input impedance as (5) by treating the antenna as a two-port network with the applied voltage at port 1 and the reactance element at port 2 using admittance parameters $y_{ij}(i,j=1,2)$.

$$Z_{in} = \frac{y_{22}+(1/jX_{ext})}{y_{11}[y_{22}+(1/jX_{ext})]-y_{12}^2} \tag{5}$$

Substituting (5) into (4), we obtain a determining equation for forced resonant reactance, as given by

$$X_{ext} = \frac{2y_{11}^I}{(-E\pm D)} \tag{6a}$$

$$kt = \tan^{-1}\left(\frac{2y_{11}^I}{Z_0(-E\pm D)}\right) \tag{6b}$$

where, $D=\sqrt{E^2-4y_{11}^I G}$, $E=(y_{12}^I)^2-2y_{22}^I y_{11}^I-(y_{12}^R)^2$, $G=y_{11}^I(y_{22}^R)^2+y_{11}^I(y_{22}^I)^2-2y_{22}^R y_{12}^R y_{12}^I-y_{22}^I(y_{12}^I)^2$ $+y_{22}^I(y_{12}^R)^2$, and y_{ij}^R and y_{ij}^I denote the real part and imaginary part of y_{ij}, respectively. Since the short-circuited transmission line with characteristic impedance Z_0 and length t constitutes the external reactance, the expression for the value of reactance, $jX_{ext}=jZ_0\tan(kt)$, should be put into the matching condition mentioned in Eq. (4) to obtain the expression for the length of the reactance for forced resonance as in Eq. (6b). In the Eqs. (6), a positive and a negative sign of D in the denominator give rise to a series and a parallel resonance, respectively. The enforcement of reactance obtained from Eqs. (6) makes the imaginary part zero resulting in resonance of the cavity. Also a perfect impedance matching at the feed point might be obtained by controlling the input resistance. The input resistance is dependent on the position of the feed post.

5. Numerical results and discussion

Figure 2 shows the external reactance value that satisfies the resonance condition (4), which is calculated from the Eqs. (6). By enforcing the calculated reactance value at the parasitic post, we can realize the forced resonance of the antenna. The length t_l of the external reactance that determines the reactance value as shown in Fig. 2 is for the positive sign of D in Eqs. (6) and for the series resonance. In this paper, we discussed the case of a series resonance since the input resistance of the antenna becomes larger when a parallel resonance occurs.

Figure 3 describes the input impedance characteristics dependent on the position of the feed post when the external reactance in Fig. 2 is loaded at the parasitic post. As shown in Fig. 3, the feed post should be placed at $d = 0.0455\lambda$ for the input impedance to be matched perfectly when the characteristic impedance of the feed line is 50Ω. The loading reactance value in this case would be $X_{ext} = 677.4\,\Omega$ as shown in Fig. 2. Figure 4 and Figure 5 represent the current distribution on each post and the radiation pattern of the antenna in resonance.

Figure 4 shows that the current on the feed post is almost uniform of 20 mA but much larger resonant current flows on the parasitic post. The main beam of the antenna faces the front side of the slot as shown in Fig. 5. To reduce the cross polarization appearing in H-plane, either the slot width should be decreased or both the feed and parasitic post should be moved to the far inside of the cavity from the aperture. The frequency characteristics of both the calculated and measured input impedances show good agreement within 6 %.

6. Conclusions

We proposed a forced resonant type spacetenna that has a feed post and a parasitic post in an electrically small-sized cavity, and suggested the use of external reactance to obtain a forced resonance. The structural advantages are that the cavity might be downsized and microwave circuits can be attached to the lateral wall of the volume-reduced cavity. Expanding the proposed spacetenna element to an array is still remained and this deserves as a future work.

References

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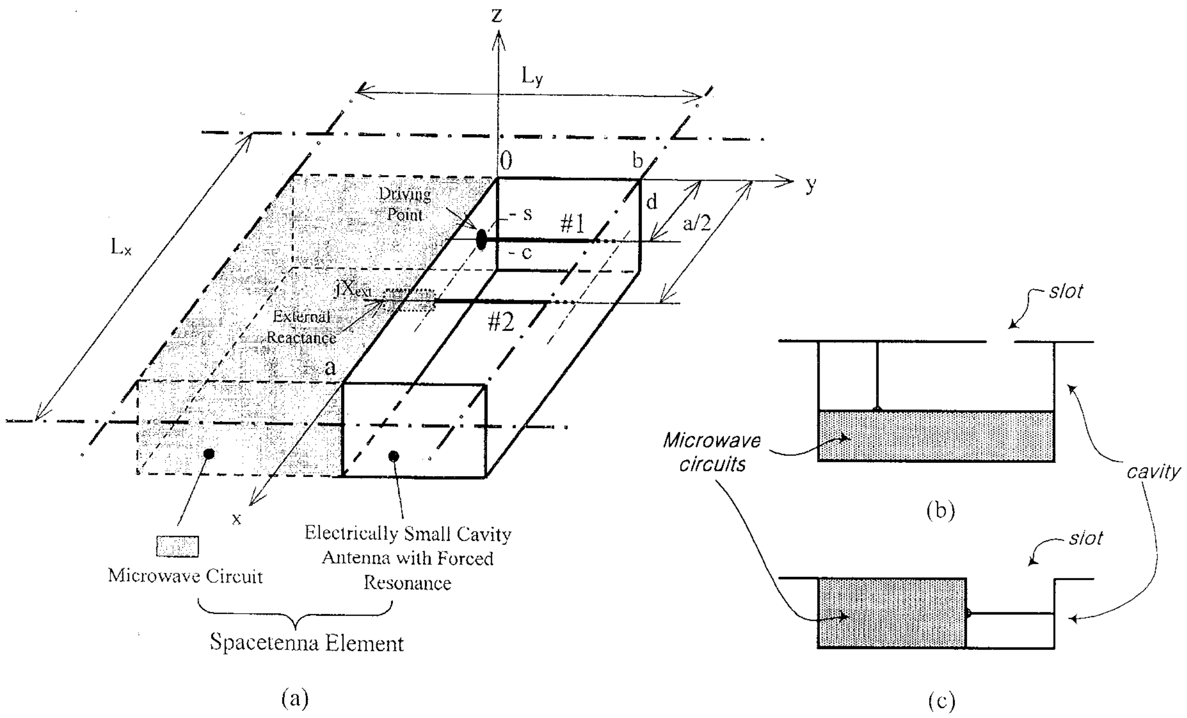

Fig. 1. Geometry and coordinate system of the antenna

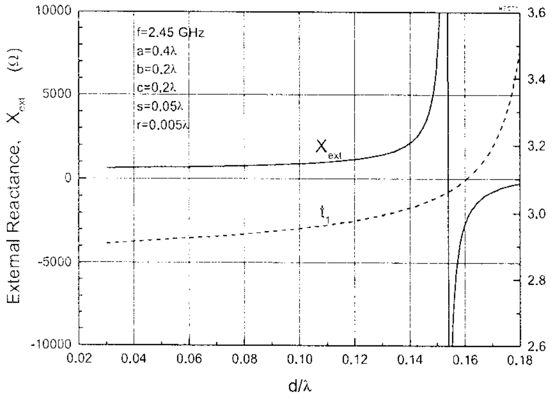

Fig. 2. Resonant external reactance value and length. vs. feed post position.

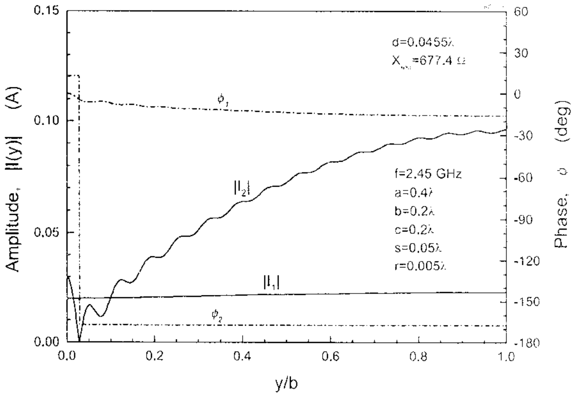

Fig. 4. Currents on the posts in resonance.

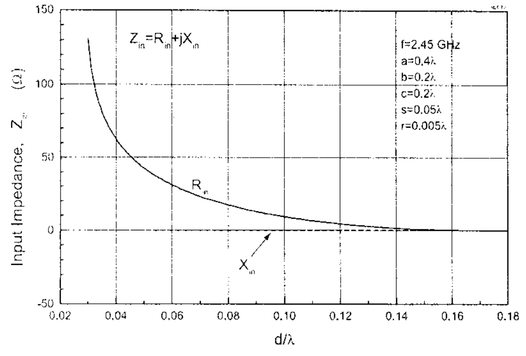

Fig. 3. Resonant input impedance vs. feed post position.

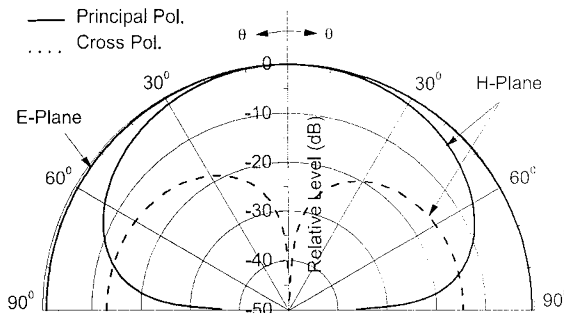

Fig. 5. Radiation Patterns in resonance.