FORCED RESONANT TYPE CUTOFF CAVITY-BACKED SLOT ANTENNAS LOADED WITH REACTANCE ON APERTURE

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1. Introduction

The solar power satellite 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)). Previously, work has been done on the analysis of the forced resonant type cutoff cavity-backed slot antenna with external loaded reactance [3], [4]. This paper propose an electrically small cavity-backed slot antenna loaded with two parallel wires on the aperture, 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 two parallel wires on the aperture as a external reactance. 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 [5]. The current distribution on each post and the radiation patterns are considered.

There are generally two different loading methods to obtain the forced resonance of the antenna using reactance elements. One is the perfect matching which requires two reactance elements since we need two degrees of freedom to obtain forced resonance. The other is the partial matching which requires only one reactance element. In case of the partial matching, input impedance should be equal to the input resistance of the antenna, which implies that the input reactance of the antenna should be zero by loading a reactance element. It is found, from the numerical results in Section 3, that we can obtain nearly perfect impedance matching with one reactance element loaded on the aperture. Therefore, the case of the partial matching is dealt in this paper, which can reduce redundancy and has more simple structure than the case of perfect matching.

2. Theoretical Analysis

Figure 1(a) and (c) show the geometry and coordinate system of a forced resonant type electrically small-sized cavity-backed slot antenna loaded with two parallel wires on the aperture. 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 two parallel wires of length l as a external reactance is connected to the nearside of a parasitic post (#2) at $z=-s$, $x=a/2$ to obtain forced resonance of the cutoff cavity antenna. Both posts are short ended to the wall of the cavity. The cavity dimensions are chosen such that the cross section of the cavity $a \times b$ corresponds to the cutoff condition for the waveguide of the same cross section when the cavity is empty. For this reason we name it cutoff cavity. The element spacing of $L_x \times L_y$ which do not generate a grating lobe in beam scanning is chosen as $L_y \le 0.67\lambda$ and $L_x \le 0.78\lambda$ [2]. The shaded region of the lateral wall of the cavity shown in Fig.1 is reserved for microwave circuits.

To derive integral equations, the antenna is divided into two regions, 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 $\boldsymbol{J_1}$ and $\boldsymbol{J}_2$ on the feed post and parasitic post, respectively, and for the unknown aperture electric field E_a in the slot, as given by

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

$$\frac{1}{j\omega\varepsilon_0}\oiint_{S_1'} \overline{\boldsymbol{K}}^I_{21e}\cdot \boldsymbol{J}_1 dS_1' + \frac{1}{j\omega\varepsilon_0}\oiint_{S_2'} \overline{\boldsymbol{K}}^I_{22e}\cdot \boldsymbol{J}_2 dS_2' + \iint_{S_a'} \overline{\boldsymbol{K}}^I_{2m}\cdot[\hat{z}\times \boldsymbol{E}_a]dS_a' = 0 \quad (2)$$

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

where $\overline{\boldsymbol{K}}$'s are kernels, $k_0 = \omega\sqrt{\varepsilon_0\mu_0}$, and $I_L = V_L / jX$ is the current at loading position for the *x* and *y* direction. The superscripts ***I, II*** denote region I and region II, subscripts ***1, 2,*** and ***a*** represent 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 $\boldsymbol{J_1}$, $\boldsymbol{J}_2$ and the aperture electric field 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.

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

$$\mathrm{Im}\{Z_{in}(d,h,jX)\} = 0 \quad (4)$$

Since the open-circuited transmission line with characteristic impedance Z_c and length l constitutes the external reactance, the expression for the value of reactance can be expressed as $jX = -jZ_c\cot(k_0 l)$. A perfect impedance matching at the feed point might be obtained by controlling the input resistance.

3. Numerical results and discussion

Figure 2 shows the input impedance characteristics dependent on the length of external reactance loaded on the aperture when the fixed $d = 0.1\lambda$ and $h = 0.2\lambda$. As shown in Fig. 2, the length of $l \cong 0.16\lambda$ is resonated at the frequency of 2.45 GHz as a series resonance. And the length of $l \cong 0.34\lambda$ is also resonated at 2.45 GHz as a parallel resonance. It is found that the cutoff cavity antenna can be resonated at the given frequencies at two independent fixed lengths of the external reactance. To match the antenna's input impedance Z_{in} to the characteristic impedance $50\ \Omega$ of the feed line, the selection of loading position and determination of the length of reactance element should be made simultaneously. As the results, the feed post should be placed at $h = 0.1971\lambda$ for the input impedance to be matched perfectly as a series resonance when the characteristic impedance of the feed line is $50\ \Omega$. The length of loading reactance in this case would be $l = 0.15695\lambda\ (X = -312.20\ \Omega)$. And the feed post should be located at $h = 0.1920\lambda$ for the input impedance to be matched perfectly as a parallel resonance when the characteristic impedance of the feed line is $50\ \Omega$. The length of loading reactance in this case would be $l = 0.34427\lambda\ (X = 317.43\ \Omega)$.

Figure 3 represents the current distribution on each post when the external reactance $X = -312.20\ \Omega\ (l = 0.15695\lambda)$ is loaded on the aperture. As shown in Fig. 3, the currents on the posts for the series resonance are almost uniform of *20* mA but much larger resonant current flows on the parasitic post for the parallel resonance. In this paper, we discussed the case of a series resonance since the length of the reactance becomes larger when a parallel resonance occurs.

Figure 4(a) and (b) show the radiation pattern of the cavity-backed slot antenna in series resonance. The main beam of the antenna faces the front side of the slot as shown in Fig. 4. To reduce the cross polarization appearing in E- and 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.

4. Conclusions

We have described a forced resonant type cutoff cavity-backed slot antenna that has a feed post and a parasitic post in an electrically small-sized cavity, and suggested the use of external reactance on the aperture to obtain a forced resonance. The basic characteristics are investigated using the method of moments. It is found that we can obtain nearly perfect impedance matching with one reactance element loaded on the aperture. 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.

References

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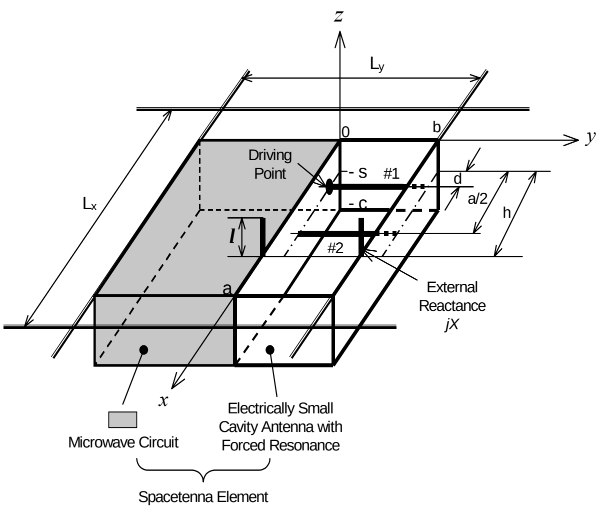
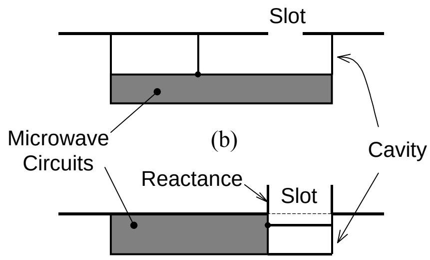


(a)



(b)

(c)

Fig. 1. Geometry and coordinate system of the cavity-backed antenna

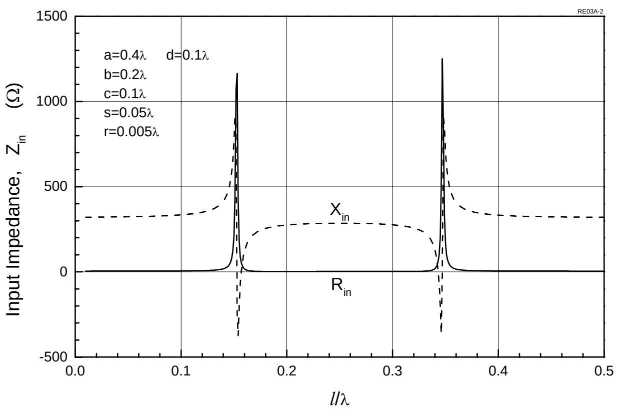


Fig. 2. Input impedance vs. the length of external reactance.

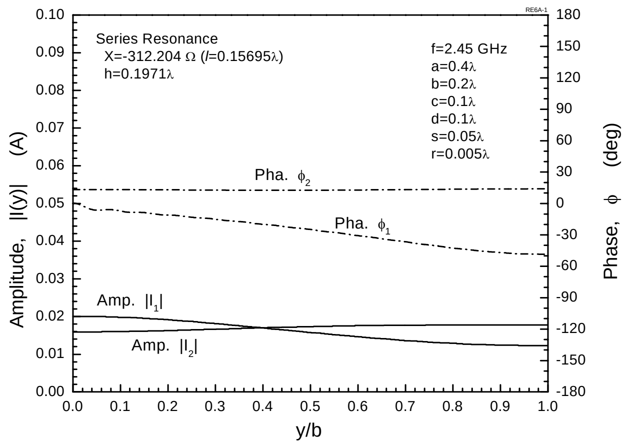
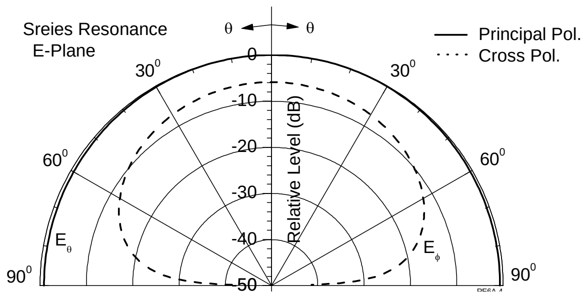
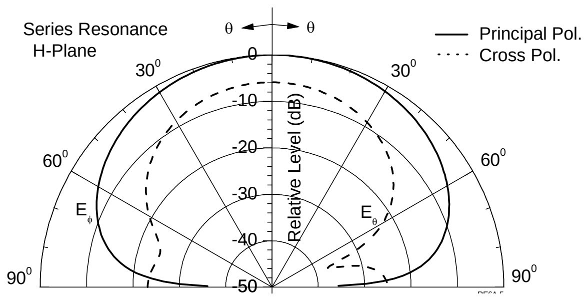


Fig. 3. Current distributions on the posts



(a) E-Plane



(b) H-Plane

Fig. 4. Radiation Patterns in resonance.