ANALYSIS OF INPUT IMPEDANCE OF A SECTORAL CYLINDRICAL CAVITY-BACKED SLOT ANTENNA FED BY PROBE

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1. Introduction

A base station antenna for mobile communication system is generally designed to have omnidirectional pattern to cover the service area in a cell site. A typical antenna is a microstrip array (such as circular array) which suffers from the feeder loss [1]. Slot array antenna is of interest due to its high efficiency. The appropriate structure for arranging as the circular array is that of a sectoral cylindrical cavity-backed slot antenna. Some of research works related on sectoral cylindrical structure which is backed by slot array antenna have been published such as [2]-[3]. All of them considered only slot on the waveguide. For the slot on the cavity, the reflection at the shorted ends must be taken into account. In case of the structure fed by a probe, which is of particular important in practical, no information from previous works have been investigated. If the impedance characteristics of the antenna are well investigated, the design of that antenna will be achieved. Hence, study on impedance characteristics is significant and need to be carried out.

This paper presents the analysis of input impedance of a sectoral cylindrical cavity-backed slot antenna fed by probe. The method of moments plays a vital tool in determining the impedance characteristics. The numerical results of input impedance are illustrated and analyzed.

2. A Sectoral Cylindrical Cavity-Backed Slot Antenna Fed by Probe

The structure of a sectoral cylindrical cavity-backed slot antenna comprises of a narrow slot cut on an outer surface of the sectoral cylindrical cavity as shown in Fig. 1. The slot of the length l_s and the width w_s is aligned on z direction at which the center of this slot is oriented at (ρ_b, ϕ_s, z_s). The dimension of the cavity is made up from the concentric conducting circular cylindrical structure of the inner and outer radii of ρ_a and ρ_b, respectively. This structure is surrounded by the conducting surface at an angle ϕ_c and shorted at the both ends ($z = 0$ and $z = z_d$). This cavity wall is considered to be perfect electric conductor and the thickness is negligible. The cross section view of the antenna is illustrated as shown in Fig.2. The excitation probe is located at the center of the inner surface of the cavity ($\rho_a \le \rho_f \le \rho_b$, $\phi_f = \phi_c/2$, $z_f = z_d/2$). The length of the probe is l_f and it is assumed to be very thin so as to disregard the diameter.

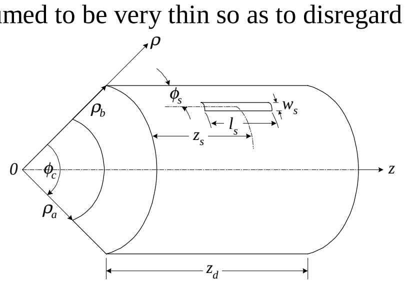

Fig.1 Geometry of the problem

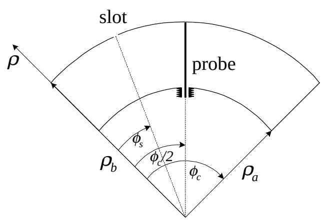

Fig.2 Cross section view

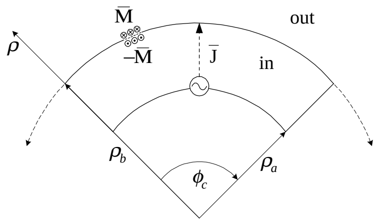

Fig.3 Equivalent analysis model

3. Antenna Analysis

The input impedance of a sectoral cylindrical cavity-backed slot antenna fed by probe will be analyzed by using method of moments. The integral equations of two unknown currents, viz., an electric current at the probe and a magnetic current sheet over slot, can be formulated based on the Field Equivalent Principle in addition to enforce the boundary conditions at the probe and the slot. Those boundary conditions are that the tangential magnetic fields are continuous through the slot aperture both inside and outside the cavity, and the delta gap source is considered at the bottom of the feed probe inside the cavity. The time convention $e^{j\omega t}$ is considered throughout this paper and omitted. The integral equations of the two unknown currents are

$$j\omega\varepsilon_o \iint_{S_s} \left\{ \overline{\overline{G}}{}^{in}_{HM}\left(\overline{R},\overline{R}'\right) + \overline{\overline{G}}{}^{out}_{HM}\left(\overline{R},\overline{R}'\right) \right\} \cdot \overline{M}\left(\overline{R}'\right) dS' + \int_{L_f} \overline{\overline{G}}{}^{in}_{HJ}\left(\overline{R},\overline{R}'\right) \cdot \overline{J}\left(\overline{R}'\right) dL' = 0 \tag{1}$$

and

$$\iint_{S_s} \overline{\overline{G}}{}^{in}_{EM}\left(\overline{R},\overline{R}'\right) \cdot \overline{M}\left(\overline{R}'\right) dS' + j\omega\mu_o \int_{L_f} \overline{\overline{G}}{}^{in}_{EJ}\left(\overline{R},\overline{R}'\right) \cdot \overline{J}\left(\overline{R}'\right) dL' = \delta\left(\overline{R}'\right) \tag{2}$$

where $\overline{M}(\overline{R}')$ and $\overline{J}(\overline{R}')$ denote the magnetic current over the slot and electric current along the probe. $\overline{\overline{G}}{}^{in,out}_{**}$ designate the dyadic Green's function of electric (E) and magnetic (H) types produced by electric (J) and magnetic (M) sources inside and outside the cavity, respectively. $\overline{R}'$ and $\overline{R}$ are the source and field point, respectively. The other notations have usual meanings.

Then, the unknown magnetic current sheet over the slot is expanded. The entire domain sinusoidal basis function is chosen as [4]

$$\overline{M}(\overline{R}') = b_s \hat{m}_s = \hat{\phi}\, b_s \frac{1}{w_s} \sin \zeta \frac{\pi}{l_s}\left(z' + z_s + \frac{l_s}{2} \right) \qquad , \zeta = 1,2,...N \tag{3}$$

The basis function on the feed probe is given by

$$\overline{J}(\overline{R}') = a_f\, \hat{j}_f = \hat{\rho}\, a_f\, , \tag{4}$$

where a_f and b_s are the coefficients of the electric current at the probe and the magnetic current over the slot, which must be determined, and ζ is either p for basis function or q for weighting function.

By using Galerkin's method of moments, the matrix of linear equation for unknown currents is

$$\begin{bmatrix} Y^{in}_{ss} + Y^{out}_{ss} & \alpha^{in}_{sf} \\ \beta^{in}_{fs} & Z^{in}_{ff} \end{bmatrix} \begin{bmatrix} b_s \\ a_f \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \tag{5}$$

where the reaction coefficients are written as follows [5]

$$Y^{in}_{ss} = j\omega\varepsilon_o \iint_{S_s} \iint_{S_s} \hat{m}_s \cdot \overline{\overline{G}}{}^{in}_{HM} \cdot \hat{m}_s dS' dS \tag{6}$$

$$Y^{out}_{ss} = j\omega\varepsilon_o \iint_{S_s} \iint_{S_s} \hat{m}_s \cdot \overline{\overline{G}}{}^{out}_{HM} \cdot \hat{m}_s dS' dS \tag{7}$$

$$\alpha^{in}_{sf} = \iint_{S_s} \int_{L_f} \hat{m}_s \cdot \overline{\overline{G}}{}^{in}_{HJ} \cdot \hat{j}_f dL' dS \tag{8}$$

$$\beta^{in}_{fs} = \int_{L_f} \iint_{S_s} \hat{j}_f \cdot \overline{\overline{G}}{}^{in}_{EM} \cdot \hat{m}_s dS' dL \tag{9}$$

and

$$Z^{in}_{ff} = j\omega\mu_o \int_{L_f} \int_{L_f} \hat{j}_f \cdot \overline{\overline{G}}{}^{in}_{EJ} \cdot \hat{j}_f dL' dL \tag{10}$$

The dyadic Green's functions inside and outside the sectoral cylindrical cavity for electric and magnetic fields due to the electric and magnetic current sources are derived to fulfill the requirement of the integral equations. The results of dyadic Green's functions inside the cavity can be expressed as

$$G^{in}_{HM,zz} = -\frac{1}{k^2 \rho_b}\delta(\rho-\rho')\delta(\phi-\phi')\delta(z-z') + 2j\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\frac{A_h k_h^2}{\sin(k_h z_d)} B_v(k_h\rho) B_v(k_h\rho')\cos(v\phi)\cos(v\phi')\begin{cases}\cos k_{gh}(z_d - z)\cos(k_{gh}z'), z > z' \\ \cos(k_{gh}z)\cos k_{gh}(z_d - z'), z < z'\end{cases} \tag{11}$$

$$G^{in}_{HJ,z\rho} = -2j\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\frac{A_h k_h^2 k v}{\rho_b' \sin(k_{gh} z_d)} B_v(k_h\rho) B_v(k_h\rho')\cos(v\phi)\sin(v\phi')\begin{cases}\sin k_{gh}(z_d - z)\cos(k_{gh}z'), z > z' \\ \sin(k_{gh}z)\cos k_{gh}(z_d - z'), z < z'\end{cases} \tag{12}$$

$$G^{in}_{EM,\rho z} = -2j\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\frac{A_h k_h^2 k v}{\rho_b \sin(k_{gh} z_d)} B_v(k_h\rho) B_v(k_h\rho')\sin(v\phi)\cos(v\phi')\begin{cases}\cos k_{gh}(z_d - z)\sin(k_{gh}z'), z > z' \\ \cos(k_{gh}z)\sin k_{gh}(z_d - z'), z < z'\end{cases} \tag{13}$$

$$G^{in}_{EJ,\rho\rho} = -\frac{1}{k^2\rho_a}\delta(\rho-\rho')\delta(\phi-\phi')\delta(z-z') + 2j\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\left[\frac{A_h v^2}{\rho_b\rho_b'\sin(k_{gh}z_d)}B_v(k_h\rho)B_v(k_h\rho')\sin(v\phi)\sin(v\phi')\begin{Bmatrix}\sin k_{gh}(z_d-z)\sin(k_{gh}z')\\ \sin(k_{gh}z)\sin k_{gh}(z_d-z')\end{Bmatrix}\right.$$
$$\left. + \frac{A_e k_{ge}^2}{k^2\sin(k_{ge}z_d)}\frac{\partial B_v(k_e\rho)}{\partial\rho}\frac{\partial B_v(k_e\rho')}{\partial\rho'}\sin(v\phi)\sin(v\phi')\begin{Bmatrix}\sin k_{ge}(z_d-z)\sin(k_{ge}z')\\ \sin(k_{ge}z)\sin k_{ge}(z_d-z')\end{Bmatrix}\right], \begin{matrix} z>z' \\ z<z'\end{matrix} \quad (14)$$

where $B_v(k_\xi\rho) = J_v'(k_\xi\rho_a)Y_v(k_\xi\rho) - Y_v'(k_\xi\rho_a)J_v(k_\xi\rho)\Big|_{\rho=\rho'=\rho_b}$ and $A_\xi = -j\frac{(2-\delta_o)}{2\phi_c k_\xi^{\,2} I_\xi k_{g\xi}}$.

The normalization factor, I_e and I_h are given by

$$I_e = \frac{1}{2k_e^{\,2}}\left[\rho^2\frac{\partial B_v(k_e\rho)}{\partial\rho}\right]_{\rho_a}^{\rho_b} \quad (15)$$

$$I_h = \frac{1}{2k_h^{\,2}}\left\{(k_h^{\,2}\rho^2 - v^2)[B_v(k_h\rho)]^2\right\}_{\rho_a}^{\rho_b} \quad (16)$$

where $v = m\pi/\phi_c$, $k = 2\pi/\lambda$, $k_{gh} = \sqrt{k^2 - k_h^2}$, $k_{ge} = \sqrt{k^2 - k_e^2}$, h_{mn} are the roots of $B_v'(k_h\rho) = 0$, and e_{mn} are roots of $B_v(k_e\rho) = 0$ and ξ is either e or h corresponding to E and H modes, respectively.

The dyadic Green's function outside the cavity is derived and can be written as

$$G^{out}_{HM,zz} = -\frac{1}{2\pi^2\rho_b}\sum_{m=0}^{\infty}\frac{1}{1+\delta_o}\cos m(\phi-\phi')\int_{\Gamma}\frac{1}{k_k}\frac{H_m^{(2)}(k_k\rho_b)}{H_m'^{(2)}(k_k\rho_b)}e^{-jt|z-z'|}dt \quad (17)$$

where $k_k = \begin{cases}\sqrt{k^2-t^2} & ,k \ge t\\ -j\sqrt{t^2-k^2} & ,k<t\end{cases}$ and $\delta_o = \begin{cases}1, m=0\\ 0, m\neq 0\end{cases}$

By solving (5) and back substitution to (3) and (4) the unknown currents are achieved and then, the input impedance at the feed probe can be readily determined from the voltage to the current ratio at that probe.

4. Numerical Results of Input Impedance

Input impedance of a sectoral cylindrical cavity-backed slot antenna fed by probe is investigated for various frequencies are illustrated in Fig.4 and Fig.5 for different cavity sizes. It is obvious that these two graphs are in the same trending i.e., the higher the frequency the lower the resistance and the higher the reactance. In addition, the smaller height yields the lower values of both the resistance and reactance than the larger ones.

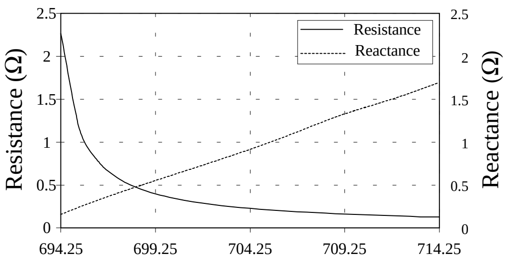

Fig.4 Input impedance vs frequency (ρ_a=1.08 m, ρ_b=1.12 m and ϕ_c=30°)

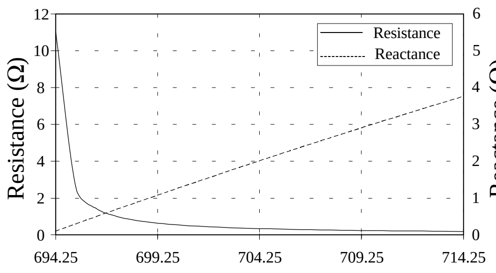

Fig.5 Input impedance vs frequency (ρ_a=0.88 m, ρ_b=1.00 m and ϕ_c=30°)

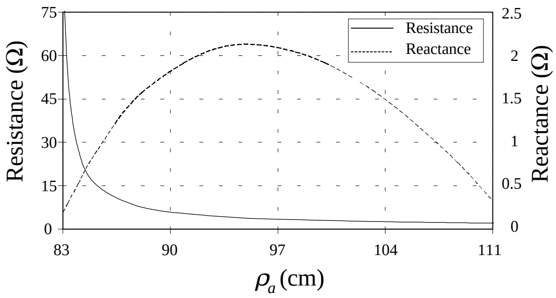

Fig.6 Input impedance for various radii
(ρ_b=*1.12* m and ϕ_c=*30°*)

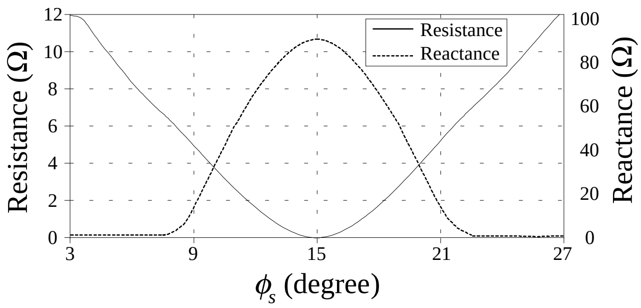

Fig.7 Input impedance for various angles of slot
(ρ_a=*0.88* m, ρ_b=*1.00* m and ϕ_c=*30°*)

Fig.6 shows the input impedance for various inner cylindrical radii when the outer radius is fixed at *1.12* m. It is apparent that the impedance varied as the cavity radius. From this graph, the radius of the cavity for the optimum matching conduction can be determined.

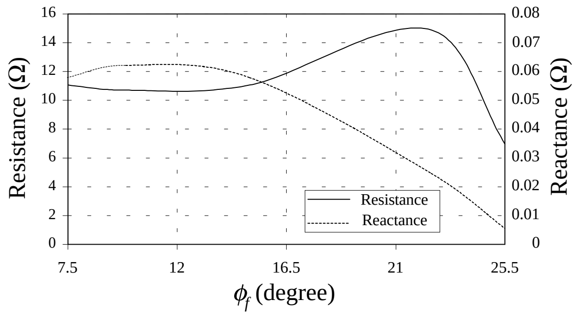

Fig.8 Input impedance for various angles of probe
(ρ_a=*0.88* m, ρ_b=*1.00* m and ϕ_c=*30°*)

Figs.7 and 8 illustrate the input impedance for various angles of slot and probe. It is found that the impedance depends on both the positions of the slot and the probe. The design of the antenna parameters for the optimum condition can be done straightforwardly from this method of analysis.

5. Conclusions

This paper presents the analysis of input impedance of a sectoral cylindrical cavity-backed slot antenna fed by the probe. This structure is proposed to be the element of the antenna array for the mobile communications. The method of analysis is straightforward and general. The demonstrations of the input impedance are carried out for various antenna parameters. The experimental results are under investigation.

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