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INVESTIGATION OF AN ANTENNA SYSTEM COMPOSED OF SLOT AND WIRE ANTENNAS

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INTRODUCTION

This paper deals with the theoretical analysis of the mutual coupling between slot and wire antennas, and its experimental verification for an antenna system as shown in Fig. 1. The antenna system composed of the slot and the wire has been analyzed by King *et al.* [1], Butler *et al.* [2], and used practically by Clavin *et al.* [3]. It is obvious from these papers that the mutual coupling between the slot, that is, a magnetic current antenna, and the thin wire, that is, an electric current antenna is very strong. A concept of the mutual coupling between antennas is formulated clearly in the form of the mutual impedance and the mutual admittance for the electric and magnetic current antennas, respectively. However, a concept of the mutual coupling between the slot and the thin wire has not been grasped clearly as the above-mentioned quantities. This paper clarifies this concept in the form of a matrix representation by using the technique of reaction matching [4].

FORMULATION

Two sets of impressed fields $(\overline{E}^i_+,\overline{H}^i_+)$ and $(\overline{E}^i_-,\overline{H}^i_-)$ impinge on the antennas from regions z>0 and z<0, respectively, as shown in Fig. 1, where the region z>0 corresponds to the half space and z<0 another one, a waveguide, or a cavity. These fields induce an electric current $\overline{J}$ on the wire and magnetic currents $\overline{M}_+$ and $\overline{M}_-$ on the slot, which generate secondary electromagnetic fields $\overline{E}^s$ and $\overline{H}^s$, where subscripts + and - mean the regions z>0 and z<0, respectively. All these fields must satisfy Maxwell's equations in the space where they exist, and also the following boundary conditions:

$$[\ \overline{E}^s_+(\overline{J}) + \overline{E}^s_+(\overline{M}_+) + \overline{E}^i_+\ ]\times \hat{n} = 0\ , \qquad \text{on wire} \quad (1)$$

and

$$[\ \overline{H}^s_+(\overline{J}) + \overline{H}^s_+(\overline{M}_+) + \overline{H}^i_+\ ]\times \hat{z} = [\ \overline{H}^s_-(\overline{M}_-) + \overline{H}^i_-\ ]\times \hat{z}\ , \qquad \text{on slot} \quad (2)$$

where $\hat{n}$ and $\hat{z}$ are unit vectors normal to the surfaces of the wire and the slot, respectively. If the slot and the wire are thin enough, it may be quite all right to consider that the electric and magnetic currents have only axial components. The slot and the wire, then, are devided equally into N_s and N_w segments, respectively, for a piecewise-sinusoidal basic expansion [4], so that the slot and the dipole can be considered to be devided into (N_s-1) short slots and (N_w-1) short dipoles, whose current and aperture field distributions are sinusoidal, as shown in Fig. 2. Subsequently, "reacting" [4] any p-th short antenna with any q-th one in the slot and the wire, the following matrix representation is derived:

$$\begin{bmatrix} [\ Z_{mn}\ ] & [\ B_{mn'}\ ] \\ [\ C_{m'n}\ ] & [\ Y_{m'n'}\ ] \end{bmatrix} \begin{bmatrix} [\ I_n\ ] \\ [\ V_{n'}\ ] \end{bmatrix} = \begin{bmatrix} [\ V^i_m\ ] \\ [\ I^i_{m'}\ ] \end{bmatrix} \qquad (3)$$

where m and n for the short dipoles are integers from 1 through N_w-1, and m' and n' for the short slots from N_w through N_w+N_s-2.

Relations between elements of sub matrices and short antennas are given in Fig. 2. The sub matrices [Z_{mn}] and [$Y_{m'n'}$] are the generalized impedance and admittance matrices for the slot and the wire, respectively. [$B_{mn'}$] and [$C_{m'n}$] describe the interaction between the slot and the wire. $B_{mn'}$ can be termed the mutual coupling coefficient between the m-th electric short dipole and the n'-th magnetic one. $B_{mn'}=-C_{n'm}$ can be proved. [I_n] and [$V_{n'}$] are the unknown current and voltage vectors for the electric and magnetic short dipoles, respectively. [V_m^i] and [$I_{n'}^i$] are the given voltage and current vectors corresponding to the impressed fields. For coplanar antennas, Z_{mn} and $Y_{m'n'}$ of Eq. (3) are expressed in closed form involving sine and cosine integrals [4]. For some special cases, $B_{mn'}$ is also in closed form involving exponential integrals.

DISCUSSIONS

Solving Eq. (3), the voltage and (electric) current distributions for the slot and the wire, respectively, can be determined. Input impedance and admittance can be evaluated by a ratio of the voltage and the current at feeding points of the antennas. Fig. 3 shows calculated results of the input impedance of the slot. As shown in Fig. 3, the antenna system is the same model appeared in [3], where the slot with two parastic monopoles is center-fed, although the slot here is backed by the shallow rectangular cavity. In the computation, the slot is devided into 12 segments and each monopole 6 ones. It is obvious from Fig. 3 that experimental values shown by small circles in the figure agree well with the calculated results.

Radiation fields and power gain patterns can be evaluated by the electric and magnetic current distributions on the antennas. The dashed lines of Fig. 4 show the calculated radiation patterns, where the cavity-backed slot on an infinite ground plane is center-fed and the dipole is parastic. In the computation, both the slot and the wire are devided into 10 segments. It is evident from Fig. 4 that the parastic dipole functions not only as a director but also as a reflector. This fact is also predictable from [1]. The measurement was done for the slot on a finite square ground plane. Measured results are given by the full lines of Fig.4 . The dashed lines (calculated values) do not agree well with the full lines (experimental ones), especially in Fig. 4 (a). This is because that the radiation patterns are influenced strongly by the finiteness of the ground plane. The radiation patterns calculated for the infinite ground plane can be corrected by using the induced current method [5]. That is, at first step, the current distribution on the finite ground plane is determined by the improved induced current method [5]. A radiation pattern is, then, approximated by a sum of the radiation from the slot and dipole antennas, which does not contain contributions from their images, and the radiation from the induced current on the finite ground plane. The radiation patterns corrected by this approximation process are shown by the small circles in Fig. 4. They agree well with the experimental curves.

CONCLUSION

The antenna system composed of the slot and wire antennas has been analyzed theoretically. The detailed comparison of the experimental and calculated values has clarified the validity of the theory. The concept of the mutual coupling between the slot and the wire has been grasped clearly as both mutual impedance and admittance in the conventional antenna theory.

REFERENCES

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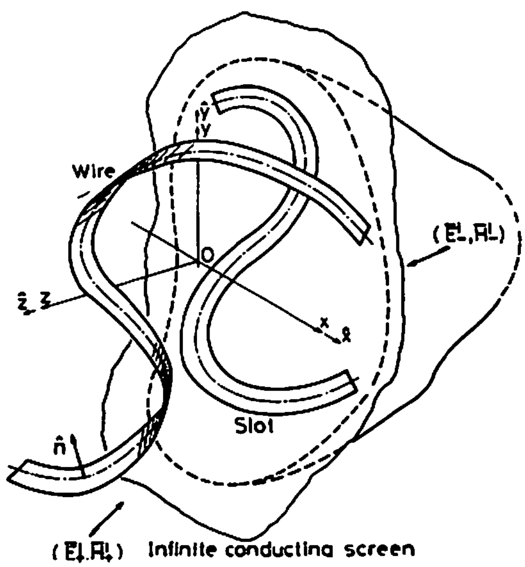


Fig. 1. An antenna system composed of slot and wire antennas.

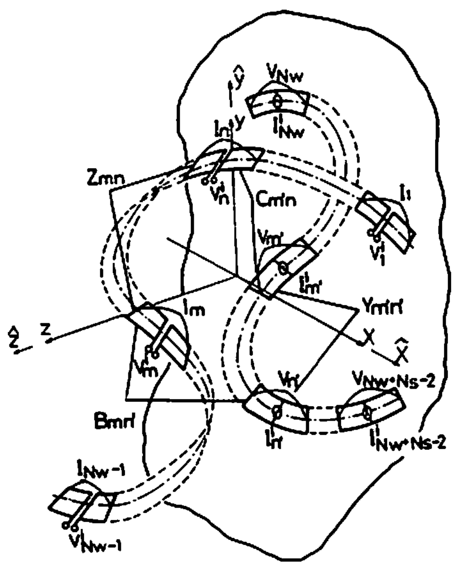


Fig. 2. Relations between elements of matrices and short dipoles.

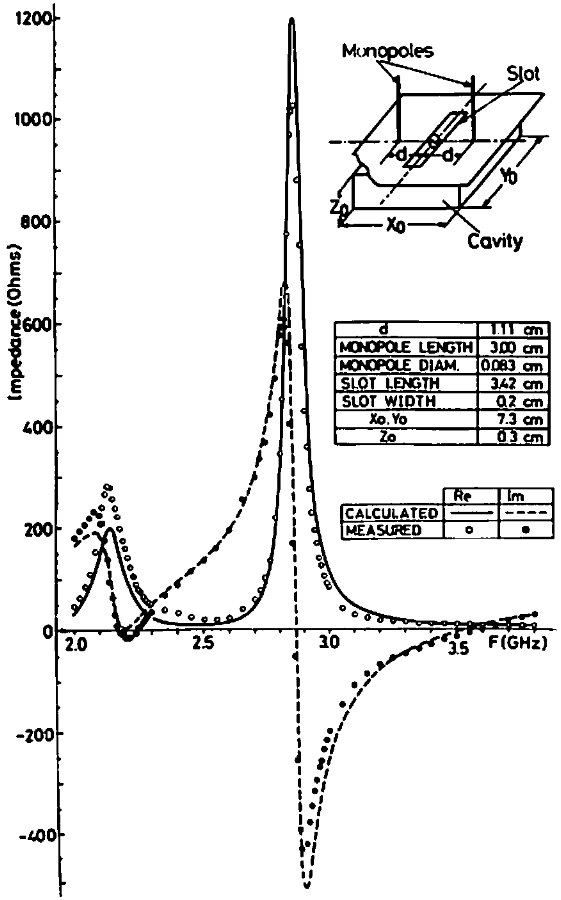


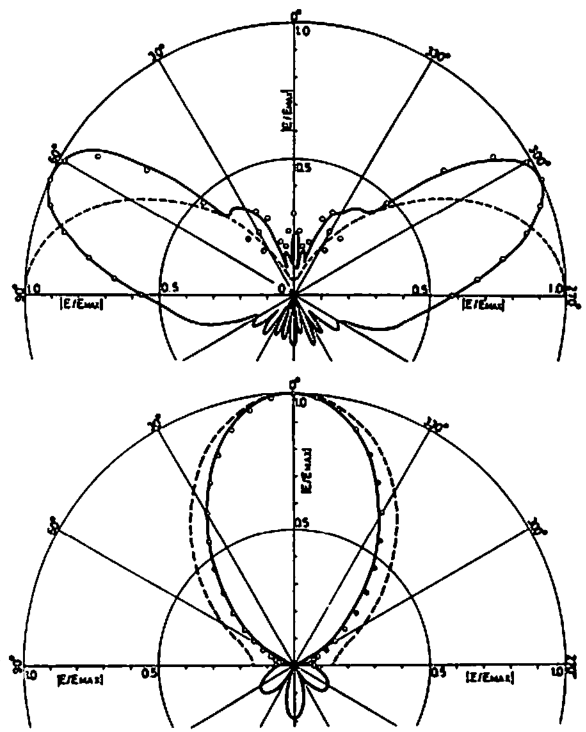
Fig. 3. Impedance of a slot-monopole antenna system.

(a)

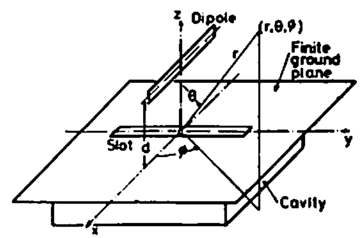
Model A
-a dipole as
a reflector-
(50 cm square
ground plane)

(b)

Model B
-a dipole as
a director-
(15 cm square
ground plane)



Ground plane	Measured	Calculated
Infinite	———	------
Finite	═══	o



	MODEL A	MODEL B
CENTER FREQ.	3.0 GHz	2.2 GHz
d	2.50 cm	1.36 cm
DIPOLE LENGTH	5.00 cm	6.14 cm
DIPOLE DIAM.	0.083 cm	
SLOT LENGTH	6.84 cm	
SLOT WIDTH	0.20 cm	
CAVITY VOLUME	7.3x7.3x0.3 cm^3	

Fig. 4. E-plane radiation patterns of slot-dipole antenna systems.