A scheme to alter the resonant frequency of the microstrip patch antenna

J. L. Volakis and J. M. Jin

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Abstract

Simple schemes are presented for altering the resonant frequency of the rectangular patch antenna without a need to change its size. In particular, by placing a perturbance below the patch it is shown that as much as 20 percent increase and 30 percent decrease from the resonant frequency of the unperturbed patch can be achieved. The specific configurations considered in this letter include a cavity-backed, aperture-backed and a protrusion-backed patch, and for each case design curves are presented

Introduction

In many cases one is required to design a certain antenna or array which does not exceed given physical dimensions. Since the size of the antenna is typically determined by its operational frequency, restrictions on the physical dimensions of the antenna can present a challenge to the antenna designer. To facilitate the design process, in this letter we consider simple schemes to rather substantially lower or increase the operational frequency of the rectangular microstrip patch antenna without altering its aperture size. These include the placement of some perturbance (protrusion, depression or slot) in the cavity region below patch, a scheme well known to designers for controlling the cavity's resonant frequency [1], [2] or other antenna parameters [3]. However, because of a lack of available CAD tools to treat such perturbances, the approach does not appear to have been explored for altering the en sm

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frequency of the highly resonant microstrip antennas. Moreover, traditional applications of these frequency control methods dealt with small shifts in the resonant frequency.

Recently, a new analytical technique was developed for a characterization of microstrip antennas or arrays residing in a cavity that is recessed in a ground plane [4]. The technique is based on a hybrid version of the finite element method (FEM) where the mesh is terminated at the aperture of the patch via the exact boundary integral equation. Because of the FEM's geometrical adaptability perturbances or irregularities in the cavity's geometry, and material inhomogeneities in the substrate can be modeled without difficulty. Below we specifically consider the effect of three different cavity configurations on the resonant behavior of a given patch residing at the aperture of the cavity.

Antenna Geometry

Consider the reference geometry illustrated in Fig. 1. The configuration consists of a square 4.45cm $\times$ 4.45cm patch residing in a square cavity whose aperture size is 6.625cm $\times$ 6.625cm and depth is .05cm. The cavity is filled with a dielectric having a relative permittivity of $\epsilon_r = 2.17$ and we remark that its finite size has negligible effect on the resonance and input impedance of the patch.

With the goal of altering the resonant behavior of this patch we consider three modifications of the cavity. The xz and yz cross sections of these are illustrated in Fig. 2(a)–(c). They include a rectangular depression at the center of the original cavity, a second cavity which is aperture coupled to the original and a third configuration having a rectangular protrusion below the patch. In all cases the patch and aperture size is unchanged from the original antenna shown in Fig. 1.

The analysis of all four patch antennas depicted in Figs. 1 and 2 was accomplished via the hybrid finite element-boundary integral (FE-BI) method described in [4]. In accordance with this method the cavity region below the patch is formulated via the finite element method, which is readily adaptable to any cavity configuration with an appropriate choice of element shapes. For the particular cavity geometries at hand we employed rectangular bricks with edge-based shape functions which have zero divergence and are appropriate for modeling metallic corners. Because the FEM solves the wave equation, it yields a solution subject to the boundary conditions at the cavity walls and its aperture. For our case, the tangential field is set to zero at the interior cavity walls and at the aperture we enforce the field continuity between the interior and exterior fields. The last fields are expressed in terms of the radiation integral with the sources set equal to the tangential aperture fields. Consequently, the continuity condition on the aperture fields results in an integral equation which can be alternatively thought as a global mesh termination condition. In contrast to the usual absorbing boundary condition(s) which must also be enforced far from the radiating element, this approach is exact but involves a partially full submatrix. However, by solving the resulting (sparse) system via the biconjugate gradient method the need to generate the matrix is eliminated thus retaining the $O(N)$ storage requirement, which is typical in FEM solutions. As noted in [4] we have found this solution approach to be highly efficient with respect to the system size and convergence rate.

Numerical Results

Plots of the resonant frequency associated with the configurations in Figs. 2(a) and 2(b) to be referred to as cavity-backed or aperture-backed antennas, respectively, are given in Figs. 3 and 4. In Fig. 3, we depict the resonant frequency as a function of the second (bottom) cavity depth with the aperture at the interface of the two cavities fixed at 3.56cm $\times$ 3.56cm. The plot in Fig. 4 illustrate the effect of the aperture size on the resonant frequency with the bottom cavity depth kept at 0.3cm. From both figures, it is seen that by changing the aperture or depth of the bottom cavity one can decrease the patch's resonant frequency by as much as 30 percent. Consequently, one may construct a 30 percent smaller patch from the conventional one with the introduction of the second cavity. We have also verified that the RCS of the new antenna structure is nearly the same as that of the original, and thus the new design results in an overall reduction of the antenna's radar cross section (RCS). It should be noted though that when the aperture of the second cavity becomes larger than the patch size, there is minimal frequency shift and this is clearly shown in Fig. 4. The shift in the resonant frequency can be understood by resorting to a transmission line model of the patch antenna. In this case the inserted aperture below the patch can be represented by an equivalent reactance placed between the admittances representing the patch terminations.

The resonant frequency of the third antenna (protrusion-backed) depicted in Fig. 2(c) is plotted in Fig. 5 as a function of the protrusion's height. For these calculations the xy cross section of the protrusion was fixed to be 3.56cm $\times$ 3.56cm. Not surprisingly, the protrusion increases the resonant frequency of the original patch almost linearly and up to 20 percent as the protrusion height is increased. As expected, when the protrusion's cross section extends beyond the patch, there is minimal shift in the resonant frequency of the reference patch having a substrate thickness equal to the distance between the patch and protrusion.

Unfortunately, the bandwidth of the cavity-backed and aperture-backed configurations was not altered although some differences were observed in the actual values of the input impedance as shown in Fig. 6. To increase the patch's bandwidth one could, of course, resort to standard approaches such as those reported in [5],[6]. Some bandwidth increase is observed for the protrusion-backed antenna but this is attributed to the larger substrate thickness below the patch's edges.

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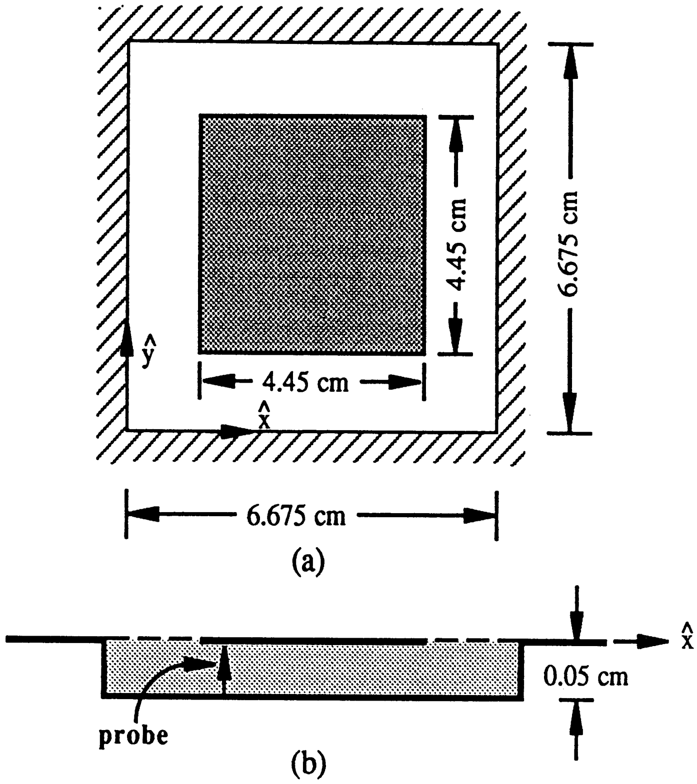
Figure 6. Patch input impedance with the modified cavity configuration: (a) cavity-backed with $d = 0.3$cm, (b) unperturbed antenna shown in Fig. 1, (c) protrusion-backed with $h = 0.3$cm. For (a) and (b) the probe feed was placed at the diagonal of the patch and 0.315cm from the nearest corner. For (c), the feed was placed at the diagonal of the patch and a distance of 1.259cm from the nearest corner.



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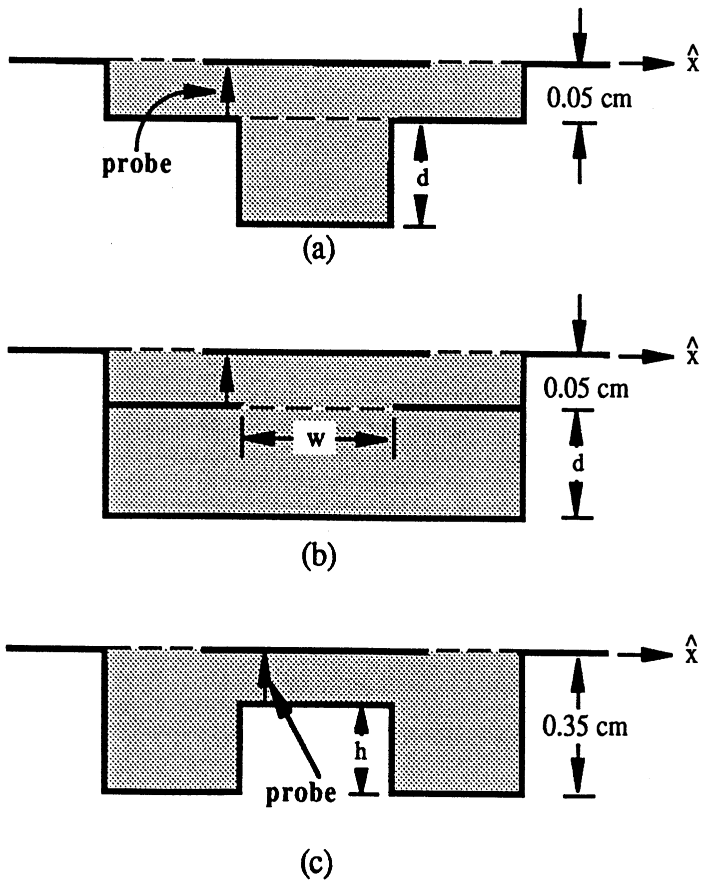

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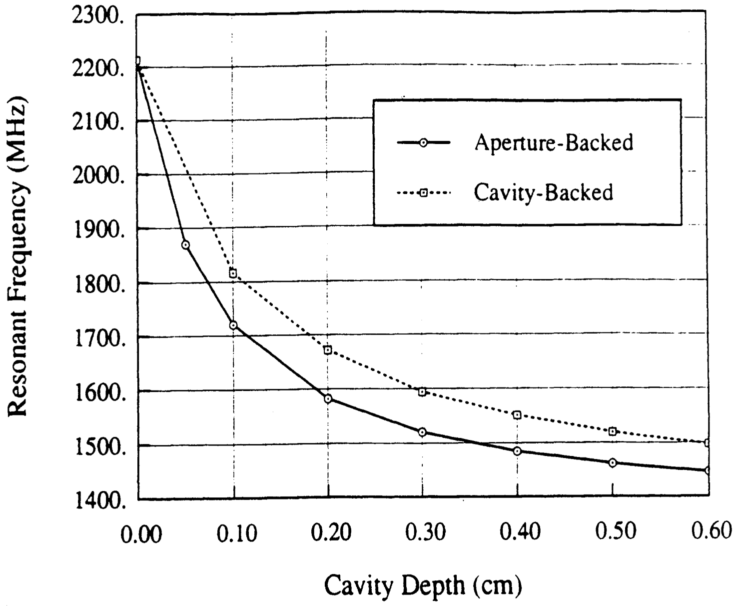

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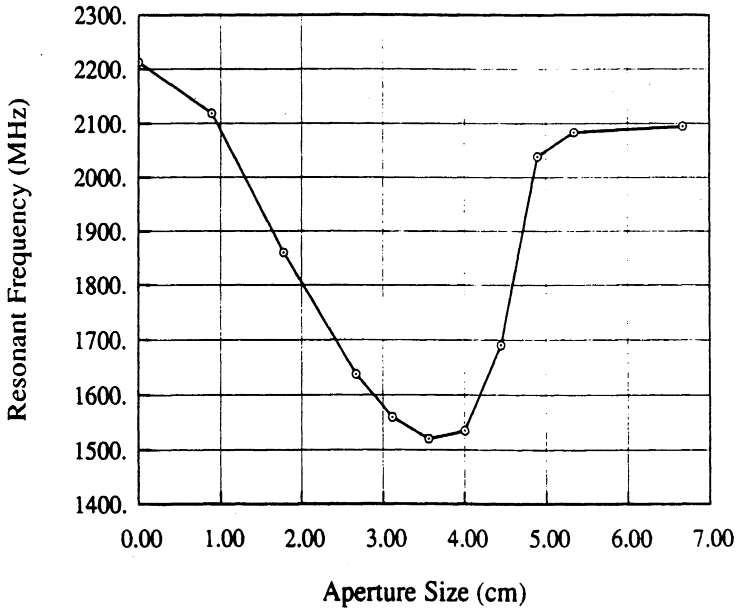

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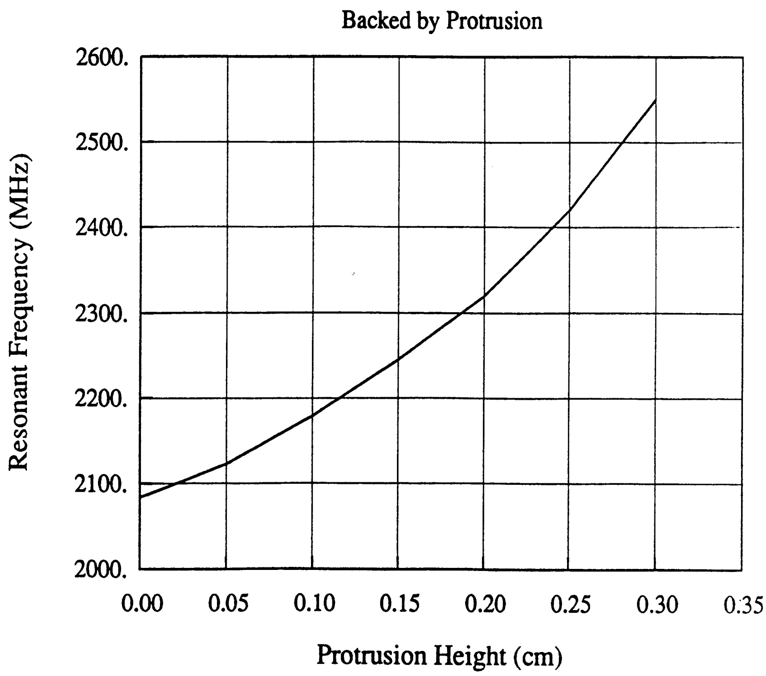
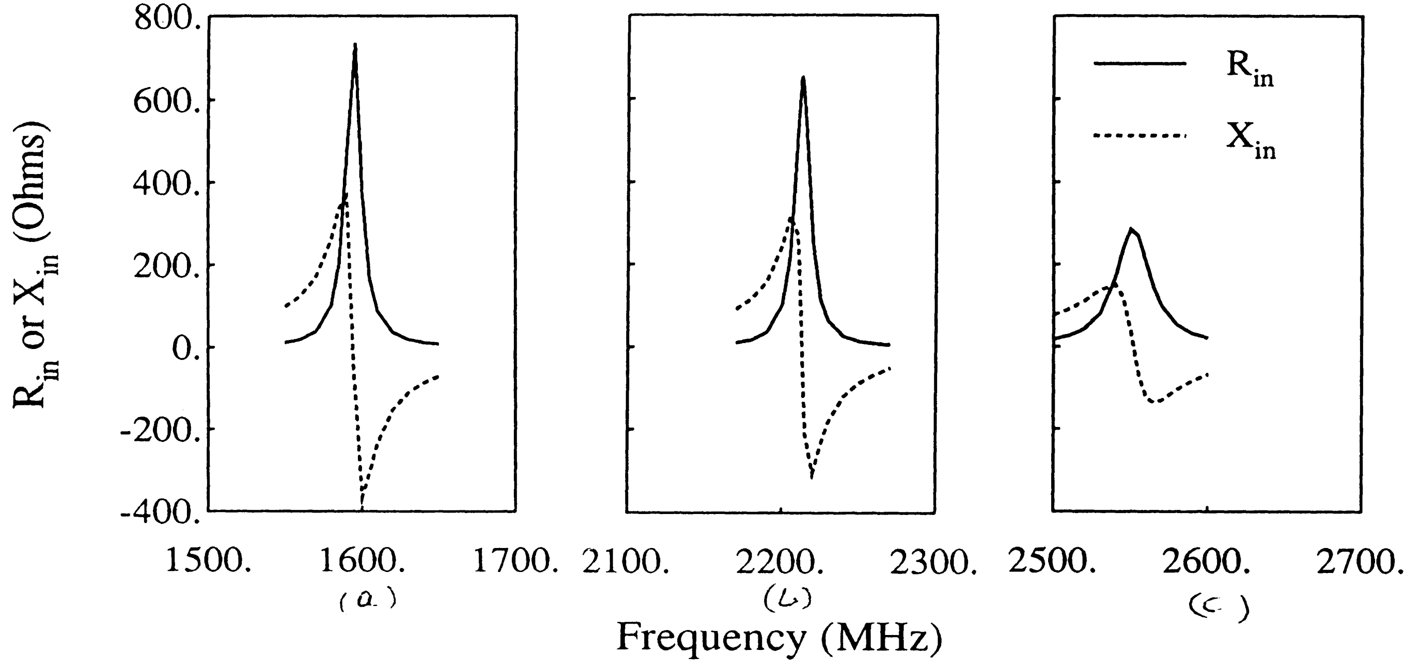


Figure 5. Resonant frequency of the protrusion-backed patch as a function of the protrusion's height h. The protrusion's xy cross section was kept at 3.56cm × 3.56cm.



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