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DESIGN OF A HIGH-GAIN CAVITY-BACKED SLOT ANTENNA WITH MUSHROOM CELLS AND BENT GROUND WALLS

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Abstract—This paper presents a cavity backed slot antenna design with high gain and relatively small size. The large ground plane of the original design is cut 75%. Mushroom cells, ground plane orientation, and bending edges in the ground plane have been employed to improve the antenna gain. A 19.25 dB maximum gain is obtained with an average gain of 18.2 dB in the entire operating band.

1. INTRODUCTION

High gain antennas have many applications in wireless communication systems as they produce focused and narrow beamwidth, which allow for more precise targeting of the signal. Therefore, various gain enhancement techniques for antennas have been studied in the past decades [1–21]. Specifically there are three important methods to achieve this purpose: (1) Using antenna array, (2) Adding superstrate, and (3) Using intrinsically high gain antenna.

For a very high gain, the array should contain a lot of elements if the gain of each element is not high, which not only increases the size of the array, but also decreases the efficiency of it [1–3]. Superstrates are also used for gain enhancement [4–7]. However, these antenna structures are either complicated or having thick profiles. In addition, a large superstrate size is usually required. Antennas like horn, Yagi-Uda and cavity backed slot can produce high gain. The horn is usually bulky, therefore an integrated horn antenna with fairly low profile at 60 GHz was presented in [8] that produces 14.4 dB gain. However, the antenna size is still large ($5.2\lambda \times 4\lambda$). The Yagi-Uda antenna was

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used excessively as a good candidate for high gain [9–11]. However, this antenna has limited gain up to 18 dB range, which can sometimes prove limiting in some remote applications.

Cavity-backed slot antennas are extensively used in satellite communications and airborne phased arrays [12–21], because of their unique features: (i) they can provide unidirectional radiation, (ii) mutual coupling between elements is relatively low, which is desirable in the design of phased arrays; and (iii) they can be readily mounted flush to the surface of a flying object. It was noted that the gain of a superstrate-covered cavity-backed slot antenna as described in [16–21] was between 9.8 and 16.7 dB.

In this paper, a simple backed slot antenna with regular one single-layer superstrate is introduced. The gain is improved by modifying the ground plane orientation, adding a small number of square mushroom cells to suppress side radiation, and bending the ground plane sides. The full-wave electromagnetic simulations and analysis for the presented antenna are performed using the commercial computer software package Ansoft High Frequency Structure Simulator (HFSS), which is based on the finite element method. The return loss and radiation patterns are also computed using a homemade FDTD program to verify the HFSS results and demonstrate the feasibility of the proposed configurations.

2. INITIAL ANTENNA GEOMETRY

Figure 1 shows the geometry of the initial antenna design, which is similar to the one in [21]. The antenna consists of a cavity of size $L \times W \times d$ (length $\times$ width $\times$ height) fed by coaxial cable, connected to a slotted ground plane of size $g \times g$. A $s \times s$ RT/Duriod superstrate of height t and $\varepsilon_r = 10.2$ is placed at distance h from the ground plane. The coaxial cable is feeding the cavity at the center of its wide face, at a distance u from the ground plane. The depth of the coaxial pin inside the cavity is p. All these parameters are depicted in Fig. 1. The dimensions in mm of the initial presented in Table 1 are the same as those in [21]. This design is called "Original Design" in this paper.

3. GAIN AND SIZE OPTIMIZATION

To validate the results, the design presented in [21] is modeled with HFSS and the return loss and radiation patterns are presented in Figs. 2 and 3, respectively. The obtained results are very close to the paper's results. The first step of optimizing this antenna is to decrease its ground plane size. Therefore, g is decreased from 200 to

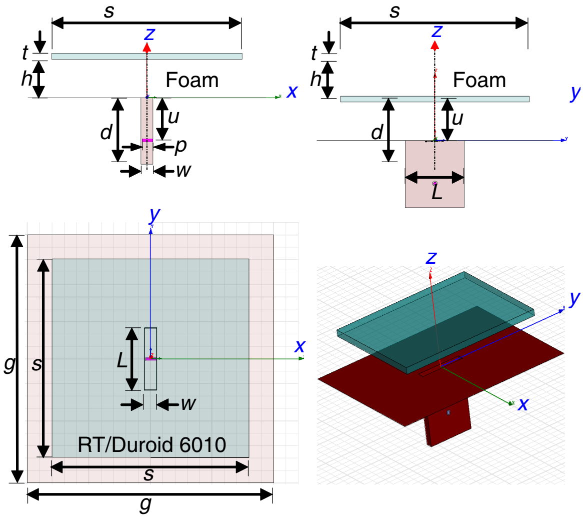

Figure 1. Antenna geometry and parameters.

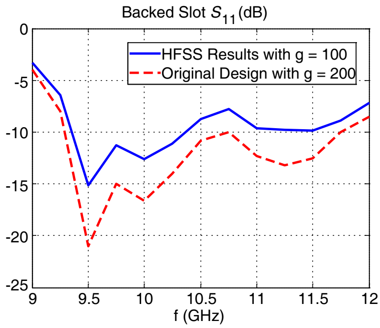

Figure 2. Return loss of the original design ($g = 200$ mm) and the small one ($g = 100$ mm).

Table 1. Original antenna dimensions (mm).

L	**W**	**d**	**u**	**p**
25	5	18	8	4.5
G	**s**	**t**	**h**	
200	80	2.54	16	

100 mm (75% less). The return loss of the small antenna is depicted in Fig. 2, which shows that cutting the ground plane resulted in higher reflections.

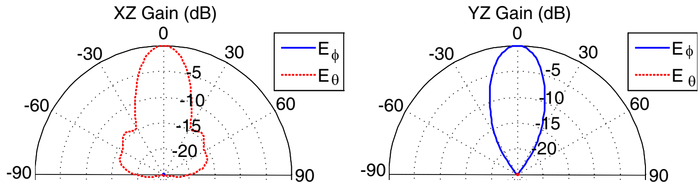

Figure 3. Radiation patterns of the original design [21].

The antenna parameters are studied for their effect on the gain. It is found that a maximum gain of 17.1 dB is obtained when $g = 80$ mm, and $h = 15$ mm but it happens at higher frequency (10.25 GHz). A circular superstrate replaced the square to be more symmetrical around the slot. It is also 21% less in size than the square one. Next, $10 \times 10\,\mathrm{mm}^2$ mushroom cells, separated by 2 mm, with different configurations are added to suppress side radiation. The ground plane is rotated by 45° to allow more space for more cells at the x and y directions. The mushroom cells are well known in the design of electromagnetic band gap structures (EBG). When the cell size is $w_{\mathrm{EBG}} \times w_{\mathrm{EBG}}$, the distance between the cells is d_{EBG}, and the height is h_{EBG}, the LC circuit that describes this EBG structure can be approximated by the following formulas [22]:

$$C = \frac{2w_{EBG}\varepsilon_0}{\pi}\cosh^{-1}\left(\frac{w_{EBG}+d_{EBG}}{g_{EBG}}\right), \quad \text{and} \quad L = \mu_0 h_{EBG}.$$

The resonance frequency for this structure is $\omega_0 = 1/\sqrt{LC}$, and its bandwidth is $\sqrt{L/C}/\eta$. Where η is the free space intrinsic impedance.

It is noticed that the more the number of cells in the x direction (direction of the antenna polarization), the better the obtained gain. Therefore, the cells in y direction are removed to simplify the design. By adding and optimizing the locations of the mushroom cells, the gain is improved to 18.75 dB at 10.25, for the design shown in Fig. 4 (with straight ground plane), compared to 16.7 dB at 9.5 GHz in [21], with 75% less size. It should be noticed that the new ground size which is $100 \times 100\,\mathrm{mm}^2$ in the final design is (3.4λ). Although it is much smaller than the original design, it is large enough to prevent any negative effect on its gain when placing this antenna on metallic surface.

To further increase the gain, the edges of the ground plane are bent, parallel to the H-field direction in the slot (in the areas that do not have mushroom cells) to focus the radiation in the direction of the main lobe. The bending angle and the length of the bent part are optimized to improve the gain, with a minimum effect on the antenna return loss level and impedance bandwidth. The maximum gain is obtained for angle = 31°. This design provides a 19.25 dB gain at 10.25 GHz and an 18.85 dB gain at 10 GHz. In the antenna operating band, the average gain is 18.2 dB, and the average increase in the gain over the one in [21] is 3.84 dB, as shown in Fig. 5. At the same time, the proposed design is 75% less in size than the Original Design.

Since we do not have enough tools to fabricate this design, especially that the vias are 0.5 mm height with 0.5 mm radius, another

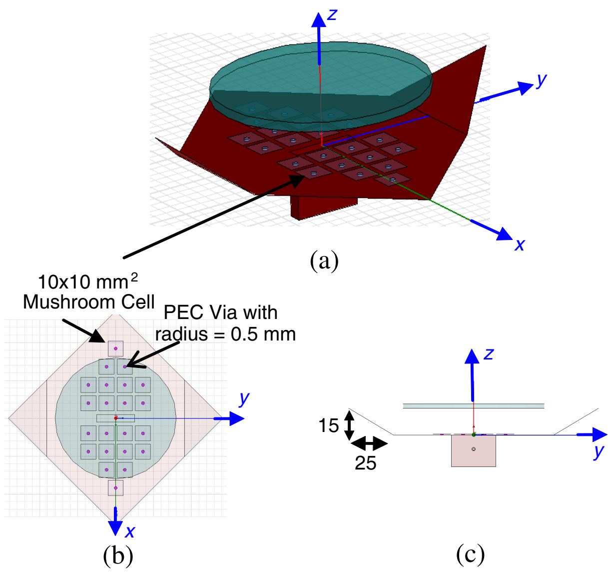

Figure 4. Optimized Design: (a) 3D Geometry. (b) Top view and (c) front view.

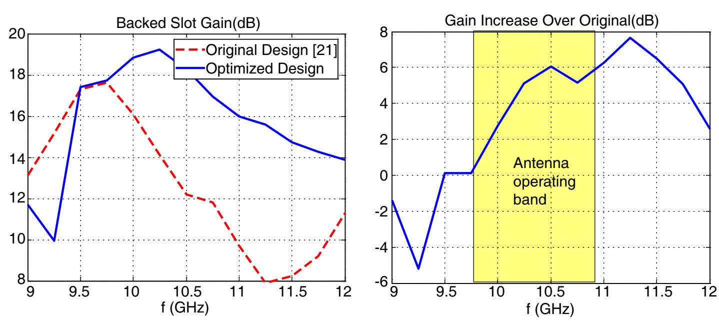

Figure 5. Computed gain using HFSS of the final design compared to the initial one.

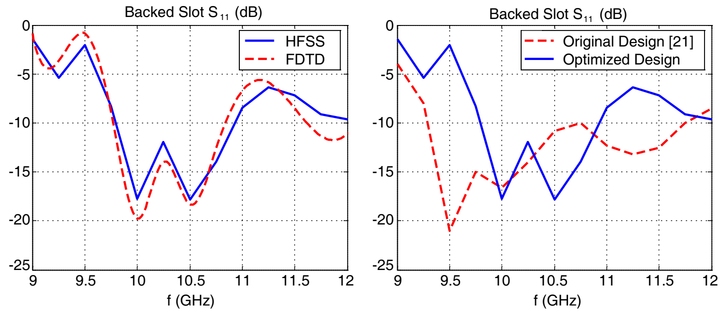

Figure 6. Return Loss for the final design compared to the initial one.

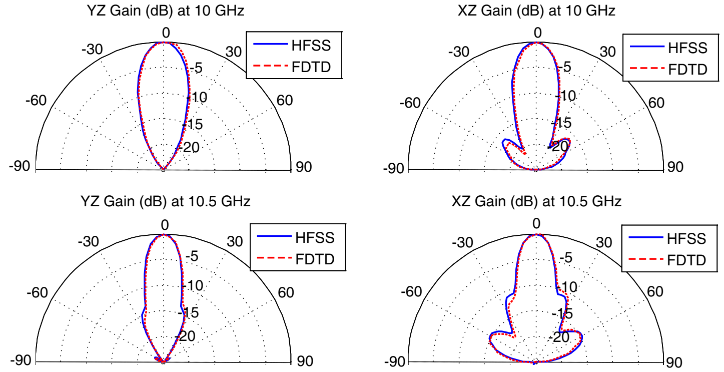

Figure 7. Radiation patterns of the final design.

simulation tool is used for more verification of the HFSS results. A homemade FDTD program is used to model the proposed antenna. Stair case is used to model the bent parts in the ground plane. The computed return loss and radiation patterns using HFSS and FDTD are shown in Figs. 6 and 7, respectively, with good agreement between them. Fig. 6 shows that the price paid to increase the gain, as described before and in Fig. 5, is that the antenna provides a 10.9% bandwidth from 9.77 to 10.9 GHz, which is less than the one in [21]. However, this bandwidth is still good and acceptable for many applications.

4. CONCLUSIONS

A cavity backed slot antenna is presented for high gain applications. The antenna ground plane is reduced by 75% to decrease the overall antenna size. To compensate for the gain drop due to ground decrement, mushroom cells are added to suppress the side radiations, and the ground plane edges are bent to focus the radiation in the main direction. The final design provides a 19.25 dB maximum gain with acceptable bandwidth. The average gain improvement over the original antenna in the operating band is 3.84 dB.

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