Substrate Integrated Waveguide Cavity Backed Mushroom Antenna With Broadband and High Gain

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Abstract—**This paper proposes a substrate integrated waveguide (SIW) cavity backed mushroom antenna with broadband and high gain. The proposed antenna with size 40mm×50mm consists of a 2×2 array mushroom unit cells, microstrip feeding line and a SIW back cavity. The following factors produce broadband: (1) Mushroom antenna is capable of exciting multiple resonances in a N-cell mushroom resonator. (2) The reduced quality factor due to mushroom antenna substrate. The following factors produce high gain: (1) The existence of the mushroom radiating gaps. (2) The SIW back cavity further improves antenna gain. The simulated bandwidth, peak gain are 70% (from 4.9GHz to 8.5GHz) and 9.9dBi, respectively. Compared with reference, the size is reduced by 44%, and the bandwidth is increased by 40%.**

Keywords— Substrate Integrated Waveguide, Mushroom antenna, Wide bandwidth.

I. INTRODUCTION

The cavity-backed antenna has the advantages of stable pattern, high gain and small backward radiation. Compared with the conventional metal cavities, the cavity-backed antenna based on SIW technique can effectively realize the miniaturization and improve the integration ability of antennas, and is gradually used in the cavity-backed antennas [1, 2]. As the antenna size decreases, the radiation efficiency, directivity coefficient and gain will be reduced. The mushroom structure is originally proposed by Sievenpiper et al. as an electromagnetic bandgap (EBG) structure to suppress unwanted surface waves within a certain frequency bandgap [3]. Sanada et al. demonstrated that this structure is essentially a composite right/left-handed (CRLH) TL, capable of exhibiting a negative refractive index [4]. In addition, compared with a complete rectangular patch antenna, owing to the existence of the radiating gaps between mushroom cells, the quality factor (Q) of the mushroom antenna decreases and radiation efficiency increases [5]. Then mushroom antenna has wider operation band and higher gain than conventional patch antenna. In the meantime, mushroom antenna has multi-resonance characteristic for wide operartion band (2N resonances in a N-cell mushroom resonator) [6]. So lots of research utilizing mushroom structure as radiator have be done[5,7,8,9], which achieve both wide bandwidth as well as high gain.

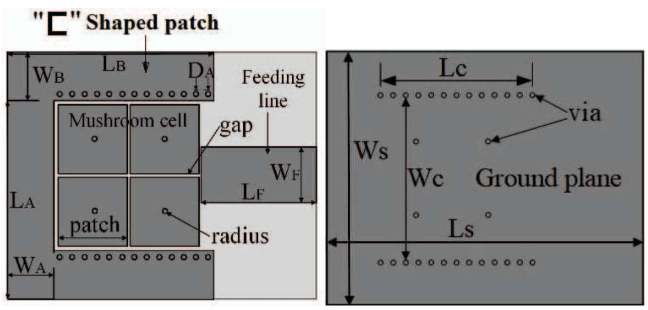
In this paper, an antenna with high gain, wide impedance matching bandwidth, low profile and high integration ability is developed by combining mushroom antenna and SIW cavity backed techniques. The proposed antenna consists of a mushroom radiator with 2×2 unit cells, microstrip feeding line and a SIW back cavity. The 2×2 mushroom unit cells act as radiator, and is fed by a microstrip line through gap coupling. A "⊏" shape patch, which is round the mushroom cells, is connected with the ground plane by vias to form SIW back cavity, which improves antenna gain by over 2 dBi. As a result, the proposed mushroom antenna with SIW back cavity has wide bandwidth 70% (from 4.9GHz to 8.5GHz) and peak gain 9.9 dBi. Compared with the mushroom antenna without back cavity, the SIW back cavity improves the gain by over 2 dBi.

II. DESIGN AND ANALYSIS OF THE PROPOSED ANTENNA

Fig.1 (a, b) are top and bottom side views of the proposed antenna, respectively, and related parameters are marked in the figure. The proposed antenna consists of a mushroom radiator with 2×2 unit cells, a feeding line and a SIW back cavity. The mushroom radiator, feeding line and the "⊏" shape patch are on the top side of the substrate, and the ground plane is on the bottom side. The mushroom with four unit cells acts as radiator, and is fed by the microstrip line through gap coupling. The "⊏" shape patch and the ground plane are connected by vias to form SIW back cavity in order to increase the antenna gain and impedance matching .

Fig. 2 shows the 3-D view of the mushroom structure and its equivalent circuit. The mushroom unit cell is a metal patch connected by a metal via to the ground plane. The equivalent circuit model of the mushroom structure is also presented in Fig. 2. The mutual capacitance formed by the adjacent mushroom caps introduces series capacitance C_L, while the metal via provides shunt inductance L_L. The distributed inductance of the patch introduces series inductance L_R, while the capacitance between the ground plane and the cap introduces shunt capacitance C_R.

The proposed antenna is made on a substrate with dielectric constant 2.2, thickness 5mm, and size 40mm×50mm. The design was done by high frequency structure simulator (HFSS) 15.0, and the optimized geometry parameters are as follows: W_S=40mm, L_S=50mm, L_A=32mm, W_A=5mm,L_B=34mm, W_B=8mm, D_A=2mm, radius=0.5mm, gap=0.4mm, patch=11mm, L_F=18.82mm, W_F=11mm, Lc=24mm, Wc=26.4mm.



(a) Top view (b) Bottom view
Fig.1 Geometry of the proposed antenna.

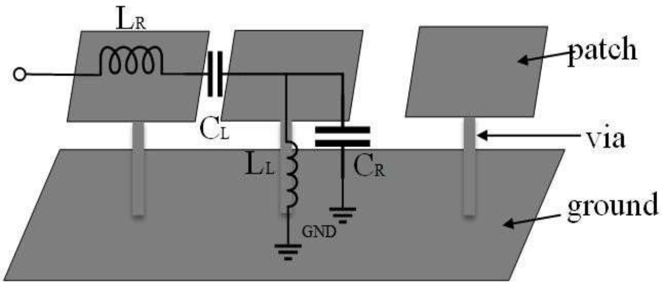


Fig. 2 The mushroom schematic and its equivalent circuit model.

The SIW structure is introduced for enhancement of antenna gain and impedance matching. The SIW design in this antenna is already explicated in previous paragraphs. In this SIW design TE modes are allowed to preserve as currents caused by TE waves will not be cut by the gaps between vias [10].The eigenmode frequencies in SIW resonant cavity can be calculated as follows

$$f_{mn} = \frac{1}{2\sqrt{\epsilon\mu}}\sqrt{\left(\frac{m}{L_{eff}}\right)^2 + \left(\frac{n}{W_{eff}}\right)^2} \quad (1)$$

$$L_{eff} = L_c - 1.08\frac{d^2}{D_A} + 0.1\frac{d^2}{L_c} \quad (2)$$

$$W_{eff} = W_c + 0.1\frac{d^2}{W_c} \quad (3)$$

Here ε and μ are the permittivity and permeability of the substrate, d is the diameter of SIW cavity hole, m and n are the numbers corresponding to the patterns of standing waves along x- and y-axis directions, L_{eff} and W_{eff} represent the effective length and width of SIW cavity, respectively.

Substitute the values of these parameters into equations above, the resonant frequency of TE_{110} mode is calculated as near 5.8GHz. However, this is under the circumstance without other components taken into consideration, when SIW is integrated in an existed structure, the interactions between each other may cause a little frequency shift. Electric field vectors distribution at 5.8 is obtained by HFSS simulation as Figure.3 illustrates, which is approximately in agreement with the assumption.

III. Simulated Results

Fig. 4 (a, b) are the mushroom antenna with/without SIW back cavity, respectively. Fig. 5 shows the real and imaginary parts of impedance of two antennas. Compared with antenna without SIW back cavity, the impedance real part for the proposed antenna has small ripple in the low frequency band after the SIW structure is introduced, and impedance real parts close to 50 Ohm are obtained in a wide band from 4.9GHz to 8.5GHz. The S_{11} in Fig. 6 also indicates that the SIW back cavity greatly improves the impedance matching in the lower frequency band, especially in frequencies near 6GHz, which can be explained by the effect of SIW TE_{110} resonance as aforementioned .

Fig. 7 shows the gains of the antennas in Fig. 4. The mushroom antenna without back cavity has high average gain about 6.4dBi. After SIW back cavity is introduced, the antenna gain is further enhanced in most of the operation band, and peak gain 9.9dBi is obtained. Fig. 8 is the far field radiation pattern at 5.2Ghz in E-Plane. The proposed antenna has more convergent beam than antenna b without SIW structure, and back radiation is also obviously reduced. Compared with reference [8], the size is reduced by 44%, and the bandwidth is increased by 40%.

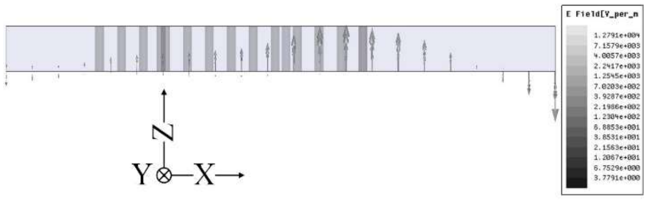


Fig.3 Electric field vector of SIW cavity at TE_{110} mode

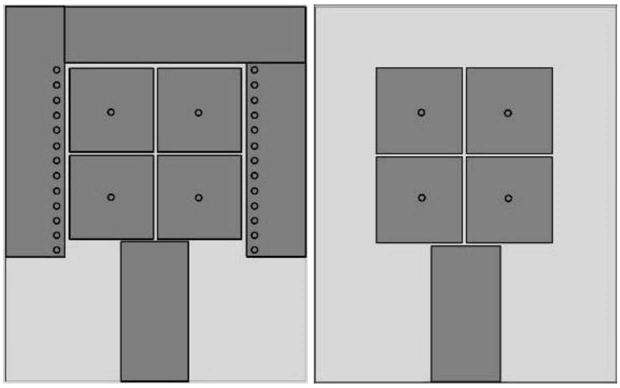

(a) (b)

Fig.4 Mushroom CRLH TL antenna with (a) / without (b) SIW back cavity.

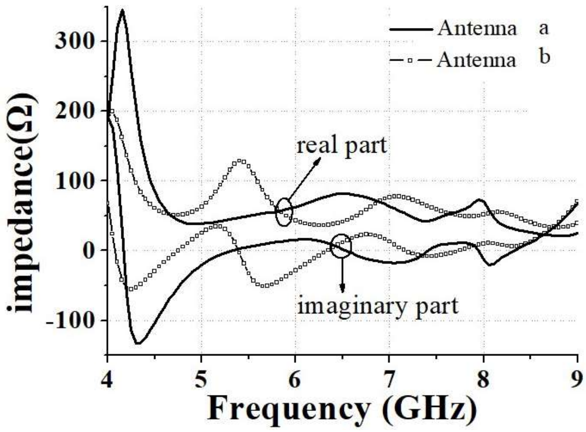


Fig. 5 Impedance curves of Antenna (a) and (b)

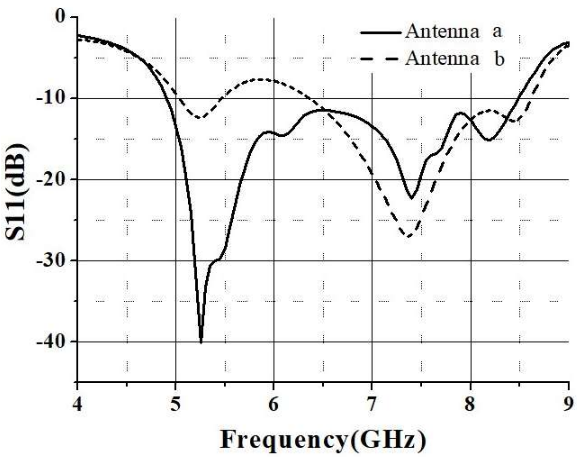


Fig. 6 Reflection Coefficient of Antenna (a) and (b)

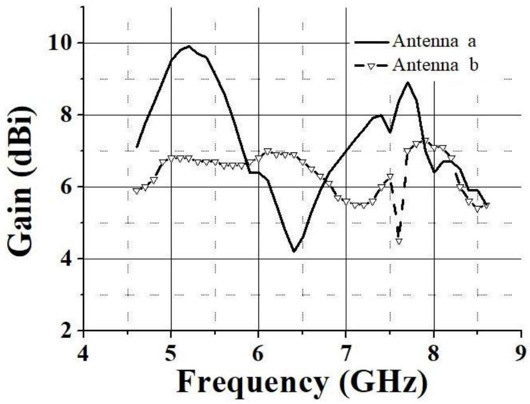
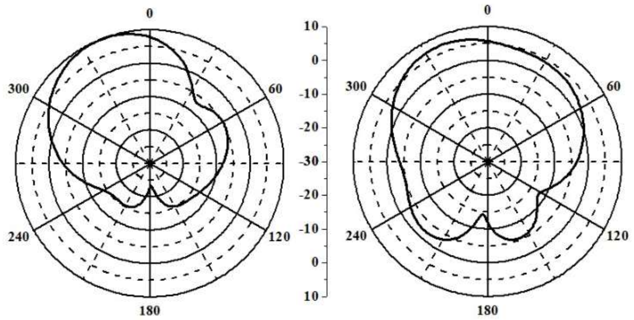


Fig. 7 Gain Results of Antenna (a) and (b)



(a) (b)

Fig. 8 E-Plane Radiation Pattern: for Antenna (a) and (b)

IV. Conclusion

In this letter, a mushroom antenna with substrate integrated waveguide structure is developed. By introducing SIW, both impedance matching and gain results of the antenna are improved. The developed antenna has wide impedance bandwidth of 70% from 4.9GHz to 8.5GHz and peak gain of 9.9dBi.

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