Design of a Broadband Cavity-Backed Multislot Antenna

Jing-yu Yang[1], Yan-ming Liu[1], Wen-jun Lu[1,2*] and Hong-bo Zhu[1]
1. Jiangsu Key Laboratory of Wireless Communications, Nanjing University of Posts & Telecommunications, Nanjing, China
2. State Key Laboratory of Millimeter Waves, Nanjing, China
*wjlu@njupt.edu.cn

***Abstract*-A novel cavity-backed microstrip-fed multislot antenna (CBMSA) for wideband application is proposed. The antenna is simply fed by a microstrip line terminated with a wide rectangular stub. By incorporating multi-slot configuration and backed cavity, unidirectional beam can be obtained within a broad bandwidth. The return loss, radiation pattern and gain over the antenna's operational bandwidth have been numerically and experimentally studied. It is shown that the impedance bandwidth of the antenna is from 5 to 10.3 GHz, which is about 69% (for $|S_{11}|$ lower than -10 dB). Good polarization purity with cross-polarization level lower than 18 dB and front-to-back ratio better than 12 dB are obtained. Hence, the antenna can be used in different broadband communication or identification systems.**

***Index Term*-Cavity-backed, multislot, slot antenna, microstrip-fed**

I. INTRODUCTION

Slot antennas have been studied since the 1940s [1]. As one kind of low-profile and cost-effective antennas, microstrip-fed narrow slot antennas have been initially studied theoretically and rigorously by employing full-wave numerical approaches [2]. However, the inherent narrow impedance bandwidth of such antennas restricts their applications. By using different feed structures [3-4] or modifying the shapes and numbers of the slots [5-6], various wideband slot antennas have been developed. In terms of these methods, impedance bandwidths varying from 30% to over 100% can be achieved.

With the improvement of the bandwidth and their intrinsic advantages, the slot antennas can be applied in broadband wireless systems. However, some applications, such as indoor base station or identification systems, require the antenna to have a unidirectional beam, and the aforementioned omnidirectional slot antennas should be modified to unidirectional ones. Usually, a slot antenna can be backed by a mental cavity to achieve unidirectional radiation. The cavity height of these cavity-backed slot (CBS) antennas is approximately one or three-quarter guide-wave lengths at the resonant frequency so that impedance matching is substantially preserved. Cavity-backed microstrip-fed slot antennas have been initially studied in [7]. Nevertheless, the measured bandwidth of this antenna is less than 10%. In order to increase the bandwidth of a CBS antenna, a bandwidth enhancement design with a via-hole above the slot has been proposed [8]. By introducing an additional resonance at high frequency band, a broadband design is obtained. However, the location of the via-hole is quite difficult to be determined. Another wideband slot antenna with a mesh cavity has been proposed [9] more recently. As is shown, the antenna has wide bandwidth, stable radiation pattern and low cross-polarization level. However, the antenna has a complicated structure and additional complexity may be introduced to its design, analysis and fabrication. To design a CBS antenna while retaining its simple structure and pretty good broadband performance is still an important and challenging task.

The objective of this paper is to propose a novel, broadband cavity-backed microstrip-fed multislot antenna with a simple structure. Two different narrow, rectangular slots are combined as one radiator and the antenna is fed by microstrip line terminated with a wide, rectangular patch. A metallic cavity is placed under the feed line to obtain unidirectional radiation pattern. The antenna is studied numerically first, and then, prototypes are fabricated and experimentally studied. Simulated and measured results are compared with each other and discussed in detail.

II. ANTENNA DESCRIPTION

The geometry of the proposed CBS antenna is shown in Fig. 1. It is seen that the cavity-backed slot antenna proposed here is based on the multislot antenna in [6]. The objective of the proposed design is to obtain unidirectional beam, wide bandwidth using a simple structure. In the proposed design, two different narrow, rectangular slot radiators are etched on the conductor ground plane. In order to obtain broadband impedance matching as well as simple feed structure, a fatter, open-circuit tuning stub is terminated at the end of the microstrip feed line. A metallic cavity with a height of 15mm is arranged at the side of the microstrip line so as to suppress the back-lobe. It is seen that proposed antenna has a simple structure. The characteristic impedance of the feed line is 50Ohm.

The antenna is simulated by using *Zeland's* IE3D based on method of moments (MoM). After a few simulation, an initial antenna with parameters as shown in Table 1 is designed on a dielectric substrate with low relative permittivity ε_r=2.2, loss tanδ of 0.0008 and thickness h=0.8mm.

This work was supported in part by the National Natural Science Foundation of China (61001079), Program for New Century Excellent Talents in University (NCET) of Ministry of Education, Basic Research Program of Jiangsu Province (BK2011027) and Research Project of State Key Laboratory of Millimeter Waves (K201202).

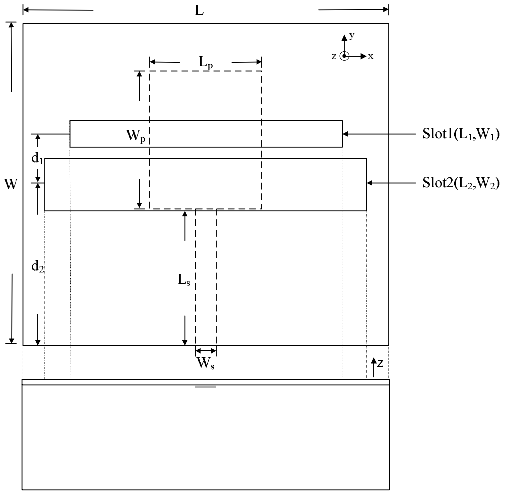


Fig. 1 Geometry of the proposed antenna

TABLE 1
PARAMETERS OF THE INITIAL ANTENNA

Length of cavity	L	52mm
Wide of cavity	W	46mm
Depth of cavity	H	15mm
Length of solt1	L_1	39mm
Wide of slot1	W_1	4mm
Length of slot2	L_2	46mm
Wide of slot2	W_2	7.5mm
Stub length	L_p	16.4mm
Stub width	W_p	19.7mm
Feed line length	L_s	2.8mm
Feed line width	W_s	29.3mm
Distance from slot1 to slot2	d_1	7.25mm
Distance from slot2 to feed point	d_2	22.57mm

Sensitive dimension parameters will be studied first so that an optimal antenna can be obtained. In the numerical simulation, only one parameter is varied, whereas the others are kept constant. All simulations are performed by employing *Zeland's* IE3D.

As described in Fig. 1, a microstrip line width step exists at the junction of the microstrip feed line and the tuning stub. Such a discontinuity will affect the results in the slot coupled structure. The relative position between the junction and the lower edge of slot2 can be defined as a sensitive parameter named α, which is given by

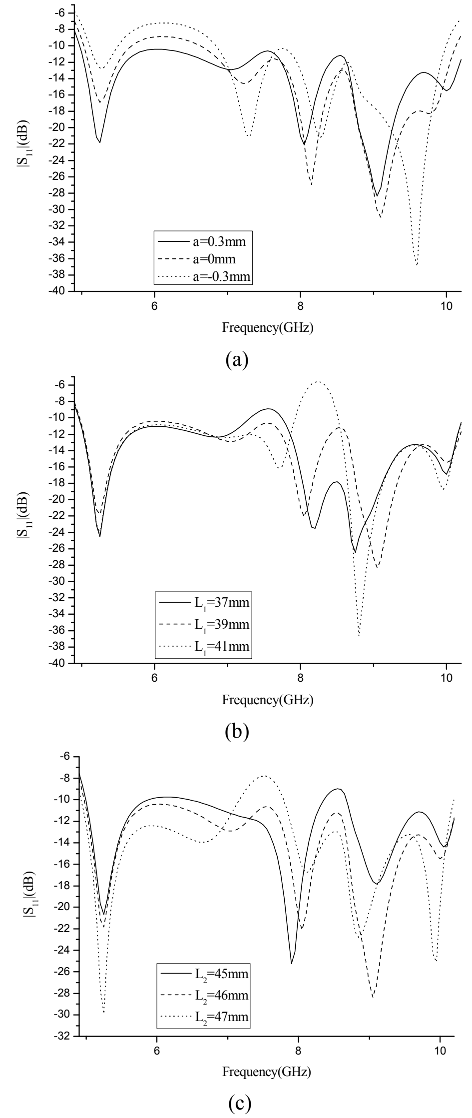
$$\alpha = d_2 - W_2/2 - L_s \tag{1}$$

The effect of varying α on the input performance is plotted in Fig. 2(a). It can be seen that the frequency of all resonances are quite sensitive to α. Even α varies within a relatively small range, the return loss of the antenna will change greatly. It is seen that an optimal value of α is 0.3mm.

The lengths of the slots also affect the antenna's performance significantly. Fig. 2(b) shows the effect of the length of slot1 on the antenna's return loss. It can be seen that the lowest and the highest resonances are not sensitive to the value of L_1. However, it is seen that the coupling between the two resonances at 8-9GHz band can be flexibly controlled by modifying L_1.

Fig. 2(c) demonstrates the tendency of the antenna's return loss when varying the length of slot2. It shows that the lowest resonant frequency is also not sensitive to L_2. Meanwhile, three other resonances at higher frequency band are sensitive to L_2. As L_2 increases, the second resonant frequency is increases, and the third and fourth resonant frequencies decreases. It is seen that the variations of L_1 and L_2 have opposite effect on the coupling between two resonances at 8-9GHz. Thus, L_1 and L_2 can be simultaneously used to finely tune the return loss at high frequency band. From Fig. 2(b) and (c), an optimal combination should be L_1=39mm and L_2=46mm.

The study of the influence of three most sensitive parameters on the antenna's return loss has been done. These results are useful in optimizing the dimension parameters of the fabricated prototypes.



(a)

(b)

(c)

Fig. 2 $|S_{11}|$ versus parameters: (a) α (b) L_1 and (c) L_2

III. NUMERICAL AND EXPERIMENTAL RESULTS

Based on numerical results discussed in Section□, prototypes are fabricated on a dielectric substrate with low relative permittivity ε_r=2.2, loss tanδ of 0.0008 and thickness h=0.8mm. The photograph of a fabricated prototype is shown in Fig. 3. The fabricated antenna is measured with *Agilent's*

8720ET vector network analyzer (VNA) first and then measured in an anechoic chamber by using *NSI's* NSI-800F-10x far-field antenna measurement system.

The simulated and measured return loss of the proposed antenna in Table 1 are plotted and compared with each other in Fig. 4. It is observed that the measurement result is in good agreement with the simulation one. The measured 10 dB return loss bandwidth is about 5.3 GHz (5.0-10.3 GHz) which is about 69%. The slight deviations between the measured and simulated results may be due to the non-ideal materials and fabrication errors. The cavity is copper with the thickness of 0.5 mm in reality, while in the simulation, it is assumed to be made from zero-thickness perfect electrical conductor (PEC).

The radiation patterns of the antenna at 6GHz, 7GHz and 9.7GHz in both E-plane (z-y plane) and H-plane (z-x plane), are measured by using NSI-800F-10x far-field antenna measurement system in an anechoic chamber and displayed in Fig. 5. The difference between the simulated and measured results is mainly introduced by the asymmetric factors introduced in the fabrication process, as well as the antenna mounting and aligning errors. It is observed that relatively stable unidirectional radiation patterns are achieved within the operational frequency band. The cross-polarization level in the H-plane is about 18 dB below the co-polarization one. The measured front-to-back ratio (f/b) ranges between 12 and 20 dB within the whole frequency range.

Moreover, the peak gain of the antenna is also measured in a chamber, as plotted in Fig. 6. The gain of the proposed antenna is from 4.5 to 8.6 dBi which is relatively constant over the whole frequency band. It also can be observed the measured gain is lower than the simulated at the whole frequency band. The difference between the measured and simulated results is caused by material loss and measurement errors, as well as the undesired reflections in the cavity excited by the parasitic cavity modes.

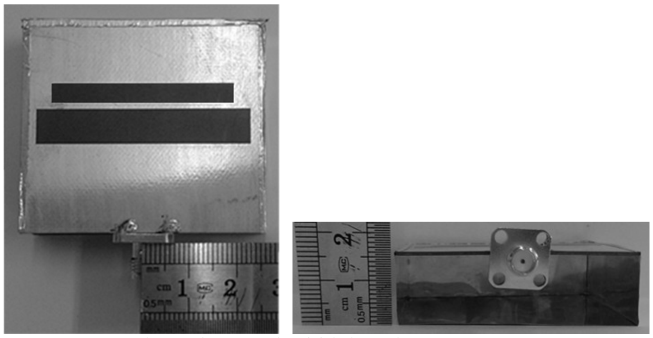


Fig. 3 Photograph of fabricated prototypes

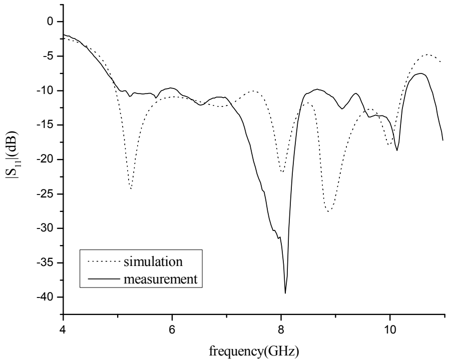
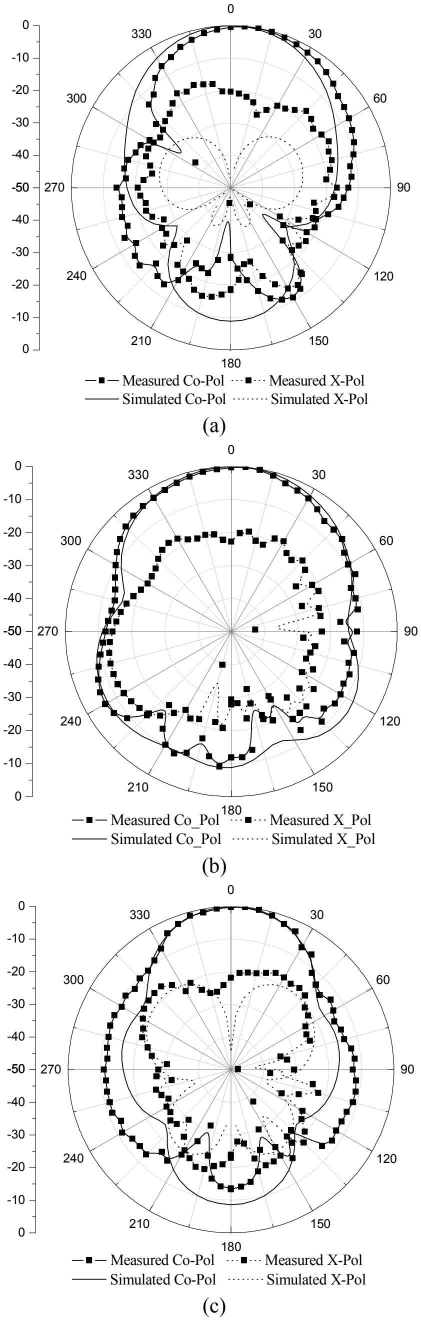


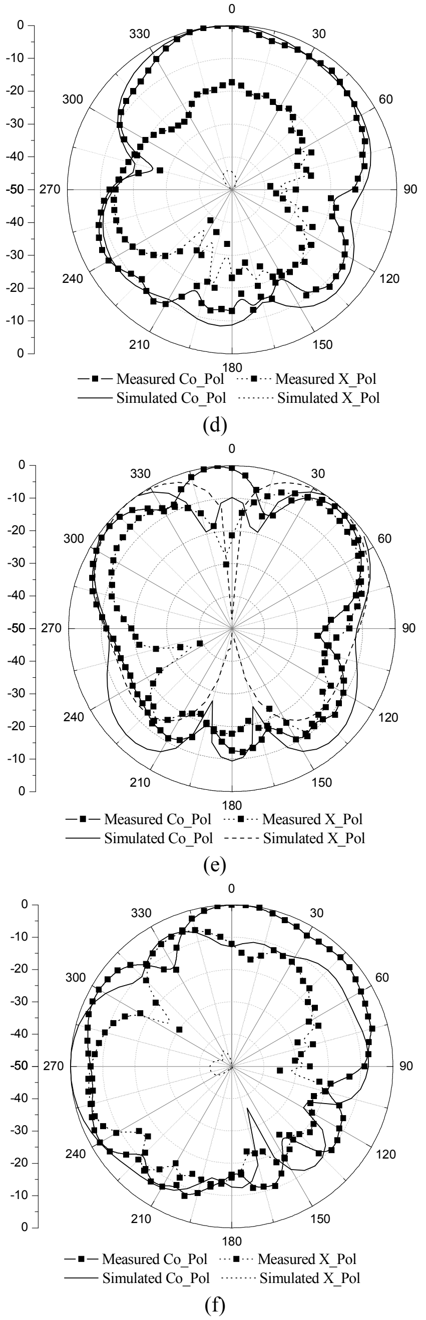
Fig. 4 Measured and simulated return loss



(a)

(b)

(c)



(d)

(e)

(f)

Fig. 5 Measured and simulated radiation pattern of the proposed antenna
(a) H-plane pattern at 6 GHz
(b) E-plane pattern at 6 GHz
(c) H-plane pattern at 7 GHz
(d) E-plane pattern at 7 GHz
(e) H-plane pattern at 9.7 GHz
(f) E-plane pattern at 9.7 GHz

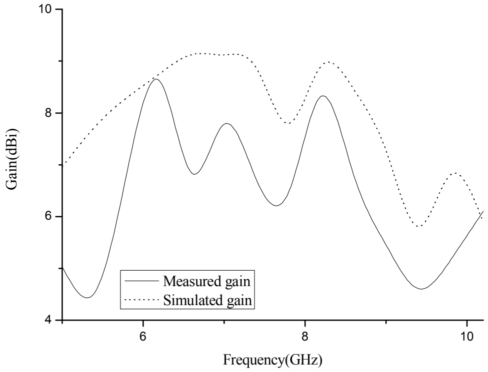


Fig. 6 Measured and simulated gain of the antenna

IV. CONCLUSION

A simple broadband cavity-backed slot antenna has been presented and experimentally studied. Multislot configuration introduces multiple resonances with close frequencies and an operation bandwidth of more than 69% can be achieved. Stable unidirectional beam with good polarization purity is obtained across the bandwidth, with front-to-back ratio better than 12 dB, cross-polarization level lower than 18 dB and maximum gain of 8.6 dB. The antenna has a simple structure and can be easily designed and fabricated. The operation bandwidth of the antenna covers the C and X band, so it can be applied to 5GHz-WLAN (i.e., 5.15-5.35 GHz), 5GHz-RFID (i.e., 5.725-5.875 GHz) and European standard UWB systems (i.e., 6-8.5 GHz). On the other hand, the antenna is also suitable for indoor base station applications after scaling-in-large to L and S band.

REFERENCES

[1] H. G. Booker, “Slot aerials and their relation to complementary wire aerials”, *J IEE*, vol. 26, pp. 620–626, 1946.

[2] D. M. Pozar, “Reciprocity method of analysis for printed slots and slot coupled microstrip antennas,” *IEEE Trans Antennas Propagat*, vol. 34, pp. 1439–1446, 1986.

[3] Y. Yoshimura, “A microstrip line slot antenna,” *IEEE Trans. Microwave Theory and Techniques*, vol. 20, pp. 760-762, 1972.

[4] N. Behada and K. Sarabandi, “A multiresonant single-element wideband slot antenna,” *IEEE Antenna and Wireless Propagat Letters*, pp. 5–8, 2004.

[5] Y. W. Jang, “Broadband cross-shaped microstrip-fed slot antenna,” *Elec-tron Lett,* vol. 36, pp. 2056–2057, 2000.

[6] W. J. Lui, C. H. Cheng and H. B. Zhu, “A novel broadband multislot antenna fed by microstrip line,” *Microwave and Optical Technology Letters*, vol. 45, pp. 55-57, 2005.

[7] S. Tokumaru and H. Takahashi, “Cavity backed two slots antennas,” *Antennas and Propagation Society International Symposium*, vol. 14, pp. 383-386, 1976.

[8] S. Yun, D. Y. Kim and S. Nam, “Bandwidth enhancement of cavity-backed slot antenna using a via-hole above the slot,” *IEEE Antenna and Wireless Propagat Letters*, vol. 1, pp. 98-101, 2012.

[9] C. R. Medeiros, E. B. Lima, J. R. Costa and C. A. Fernandes, “Wideband slot antenna for WLAN access points,” *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 79-82, 2010.