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Bandwidth-Enhanced Full-Metal Cavity-Backed Slot Antennas Based on Multimode Resonator

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***Abstract*-This paper presents some bandwidth-enhanced full-metal cavity-backed slot antennas based on multimode resonators. Multimode resonator is an effective method to design bandwidth-enhanced antenna. Fundamental cavity mode, high-order cavity mode, and slot mode are allocated together under proper perturbation. Besides, the full-metal cavity structure can obtain a high radiation efficiency.**

I. INTRODUCTION

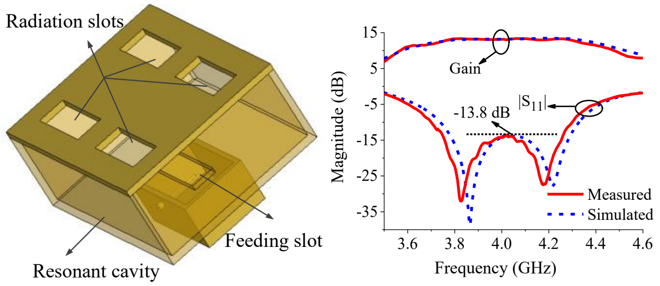
Cavity-backed slot antennas (CBSAs) [1]-[4] have been widely applied to wireless communication systems requiring high gain and high efficiency. Among them, the full-metal cavity-backed slot antennas [3]-[4] also own high power-handling capacity.

Multiple-mode resonator is a widely-used structure to improve the bandwidth with compact size, compared to conventional single-resonance antennas. This technique has been widely utilized to design wideband antennas, such as patch antennas [5]-[6], substrate integrated waveguide (SIW) cavity-backed slot antennas [7]-[8] and metal-cavity slot antennas [9]-[10]. In [6], TM_{01} and TM_{03} patch modes were used to obtain a wide bandwidth. In [8], the SIW modes were allocated into a same band to enhance the bandwidth by introducing shorting via, and two multimode wideband SIW slot antennas were designed. In [9]-[10], triple-mode waveguide slot antennas with enhanced bandwidth based on cavity mode and resonant-iris mode were proposed.

II. MULTIMODE ANTENNAS

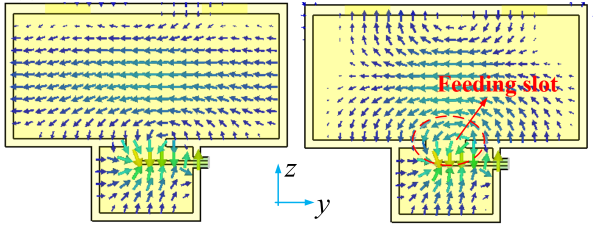
A. Dual-Resonance Slot Antenna Array

In [11], a dual-resonance slot antenna array was proposed, whose physical structure is given in Fig.1 (a). In this antenna, a quasi-TE_{101} cavity mode and a slot mode are utilized to design the dual-resonance antenna. The cavity mode is mainly affected by the cavity's size, and the slot's size also slightly affects the resonant frequency of this cavity mode. While the slot mode is mainly affected by the size of feeding slot. By properly modifying their sizes, these two modes can be allocated in a same band to improve the operating bandwidth. Fig.1 (b) shows the comparison of simulated and measured results, this antenna has a bandwidth of 15% with $|S_{11}| < -10$ dB, and the peak gain is about 13.4 dBi.



(a) (b)

Fig.1 (a) Geometry of proposed wideband cavity-backed 2×2 slot antenna array. (b) Simulated and measured results.



(a) (b)

Fig. 2 (a) E-field distribution of first resonant mode, (b) E-field distribution of second resonant mode.

To better understand these two modes, the electric field (E-field) distributions of them are provided in Fig. 2 (a) and (b), respectively. It can be observed that the first mode is a cavity mode, which is similar to the TE_{101} mode, called quasi-TE_{101} mode. While the second mode is a slot mode, as the electric field mainly distributes around the feeding slot.

B. Dual-Resonance Filtering Slot Antenna Array

In [12], a dual-resonance filtering slot antenna array was proposed, and its configuration is shown in Fig. 3 (a). In this antenna, the fundamental mode TE_{101} and high-order mode TE_{301} were chosen to form a dual-resonance band to improve the operating bandwidth. Besides, these two modes have high Q-factor, which can inherently produce a filtering performance.

As the original resonant frequencies of these two modes are quite different, proper perturbation should be introduced to make them close to each other. We firstly look at the field intensity distribution, as shown in Fig.3 (b). On one hand, a series inductance loading at point A (i.e., metal ridge, shown in Fig.3 (b)) can make TE_{301} and TE_{101} modes closer as this loading can cause lager frequency shift of TE_{301} mode. On the other hand, a parallel inductance loading at point B (i.e., metal

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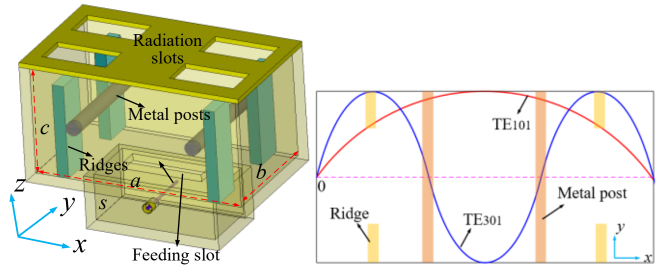
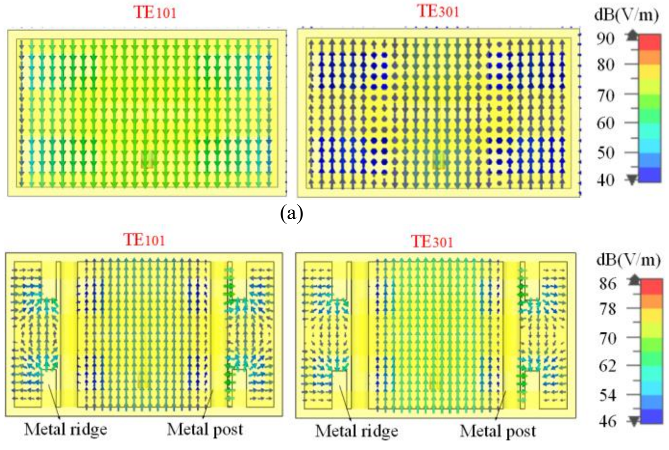


(a) (b)

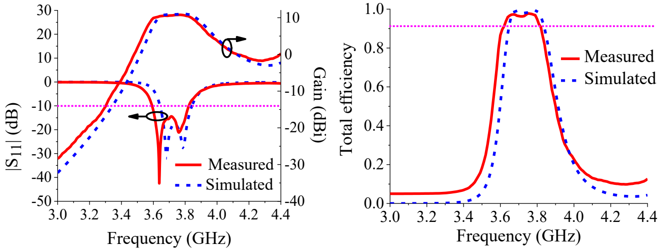
Fig.3 (a) Geometry of proposed wideband cavity-backed 2×2 slot antenna array. (b) Filed intensity distribution and positions of perturbation elements.



(a)

(b)

Fig.4 E-field distributions of TE_{101} and TE_{301} without and with metal ridges and metal posts.



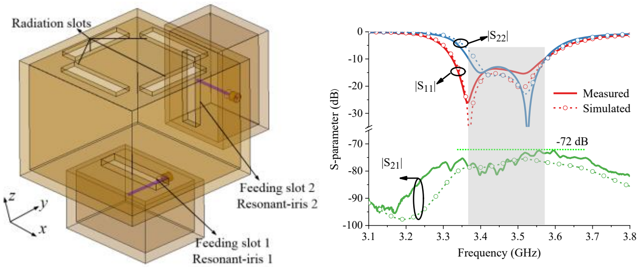
(a) (b)

Fig. 5 Measured and simulated results: (a) $|S_{11}|$ and realized gain; (b) Total efficiency.

post, shown in Fig.3 (b)) can make TE_{101} closer to TE_{301} as this loading only cause the frequency shift of TE_{101} mode.

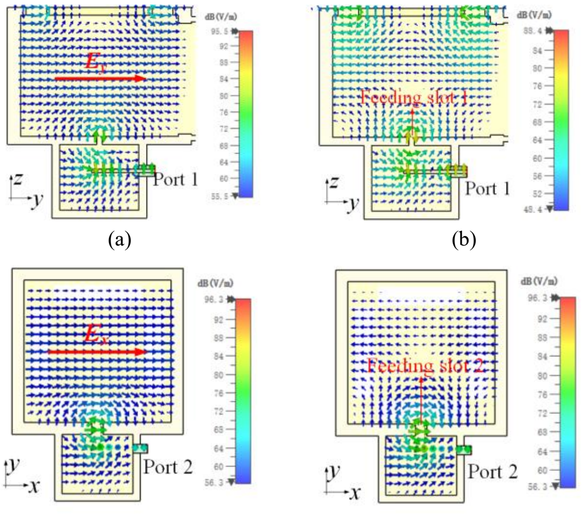
The E-field distributions of TE_{101} and TE_{301} modes are shown in Fig.4. Fig.4 (a) indicates that the TE_{101} and TE_{301} modes can be simultaneously excited under the proper placement of feeding slot and radiation slots. After the introduction of metal ridges and metal posts, these two mode have similar field distributions, as shown in Fig.4 (b), which indicates that they have similar resonant frequencies.

The comparison of simulated and measured results are shown in Fig. 5. The measured relative operating bandwidth ($|S_{11}| < -10$ dB) is about 6.2%. The measured total efficiency over the operating band is higher than 91% with a peak of 97%. Fig.6 also indicates that proposed slot antenna array has a good filtering performance.



(a) (b)

Fig.6 (a) Geometry of the proposed IBFD slot antenna. (b) Simulated and measured results.



(a) (b)

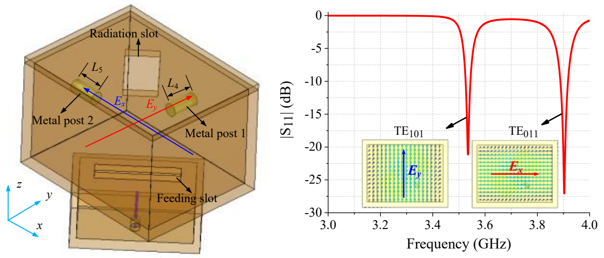
(c) (d)

Fig. 7 E-field distributions: (a) TE_{101} mode; (b) Slot mode by feeding slot 1; (c) TE_{011} mode; (d) Slot mode by feeding slot 2.

C. Dual-Resonance In-Band Full-Duplex Slot Antenna

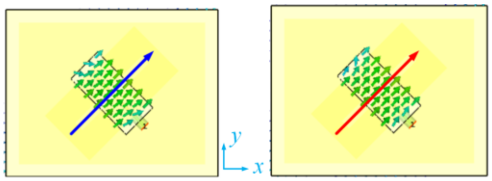
Fig.6 (a) shows the configuration of the dual-resonance in-band full-duplex (IBFD) slot antenna [13]. In this antenna, each channel operates at a cavity mode and a slot mode. Channel 1 operates at TE_{101} mode and a slot mode produced by feeding slot 1. While channel 2 operates at TE_{011} mode and a resonant-iris mode produced by feeding slot 2. Fig.6 (b) shows the comparison of simulated and measured S-parameter of proposed IBFD slot antenna. We see that the overlapping operating bandwidth is about 6.2%, and the isolation over the operating band is higher than 72 dB. Such high isolation is obtained by properly placing the two feeding structures, which can largely reduce the coupling between the two channels.

The E-field distributions at the four frequencies of this dual-resonance duplex antenna are shown in Fig. 7. It can be seen that the first resonant mode of channel 1 and channel 2 are the TE_{101} and TE_{011} modes, respectively. While the second modes of channel 1 and channel 2 are the slot modes produced by the two feeding slots. The cavity modes are mainly affected by the size of the resonant cavity, while the slot modes are mainly affected by the size of feeding slots. By properly modifying their sizes, similar frequencies can be achieved for all four modes, and then a bandwidth-enhanced IBFD antenna is obtained.



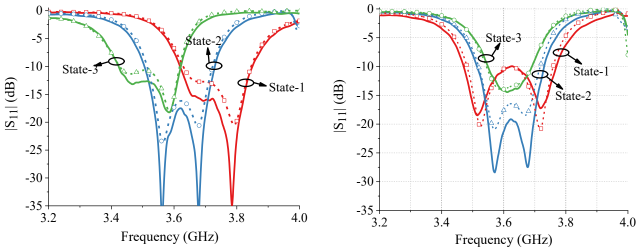
(a) (b)

Fig.8 Reconfigurable dual-resonance slot antenna. (a) 3-D view; (b) Simulated $|S_{11}|$ and the electric field of two modes.



(a) (b)

Fig.9 E-field distribution on the radiation slot: (a) TE_{101} mode; (b) TE_{011} mode.



(a) (b)

Fig. 10 Comparison of simulation and measurement under different operation states: (a) For frequency reconfiguration; (b) For bandwidth reconfiguration. Solid line: measured results; Dashed line with symbol: simulated results.

D. Reconfigurable Dual-Resonance Slot Antenna

In [14], a reconfigurable slot antenna was reported, and its physical structure is given in Fig.8 (a). Two cavity modes TE_{101} and TE_{011} were firstly utilized to design a dual-resonance slot antenna. The metal post can affect the magnetic field of the cavity mode, and then produce an inductance loading, which can cause the desired frequency shift. Besides, the cavity mode is only affected by the metal post parallel to its electric field, but not affected by the metal post perpendicular to its electric field. Thus, the modes TE_{101} and TE_{011} with orthogonal field distribution can be individually tuned by the metal post along y-axis and x-axis, respectively.

The rotated feeding slot can simultaneously excite TE_{101} and TE_{011} modes. Although these two modes have orthogonal field, they can only radiate through the same rotated radiation slot. The electric field distribution on the radiation slot, shown in Fig.9, indicates that these two orthogonal modes have same E-field distribution for radiation, which means that they have same radiation property including the polarization.

As the two modes can be individually tuned, tunable operating frequency and tunable bandwidth can be realized by properly modifying the two metal posts. The simulated and measured results are shown in Fig.10, the good agreement between them have well validated the proposed design concept.

III. CONCLUSION

This paper presents four cavity-backed slot antennas using multimode resonator, including dual-resonance slot antenna array, dual-resonance filtering slot antenna array, dual-resonance IBFD slot antenna, and dual-resonance reconfigurable slot antenna. The multimode structure can improve the operating bandwidth and maintain a simple antenna's structure. Besides, the utilization of full-metal cavity can produce a high radiation efficiency.

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