Broadband Duplex–Filtenna Based on Low-Profile Metallic Cavity Packaging

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***Abstract*— An integrated method of broadband duplex–filtenna based on a 3-D metallic cavity structure is proposed in this paper. In our design, two broadband filtennas with different operation frequency bands share the same metallic cavity-backed resonator. The two operation bands are realized with fractional bandwidths (FBWs) of 24% and 18%. The whole total FBW of two bands achieves 57%, and there are radiated nulls at the transition band showing a good filtering property. By integrating these two filtennas, a duplex–filtenna is formed with unidirectional radiation property. The radiation gain of these two filtennas exhibits good filtering property. The filtenna gain frequency responses have two transmission zeros near the lower and upper cutoff frequencies of both lower and upper operation bands. To validate the proposed concept, one cavity-backed duplex–filtenna with low-profile metallic cavity is designed and fabricated. The measured results have verified the simulation results well, and the isolation between the two wideband channels exceeds 30 dB as predicted in theory.**

***Index Terms*— Duplex–filtenna, filtenna, transmission zeros, wide operation band.**

I. INTRODUCTION

IN THE rapidly developed wireless communication systems, the RF antennas and filters/duplexers have been considered as the key front-end components, and they are highly required to achieve the low-cost integration and high-power handling capability. Recently, the filters integrated with antennas have been receiving an increasing interest and concern as done in [1]–[13]. These integrated filtering antenna or filtennas in short can not only reduce the cost in fabrication, but also improve the desired performances, such as high radiation efficiency and reduced size, compared to the traditional antennas cascading with filters. For a filtenna, the antenna can contribute to the filtering performance for a faster roll-off in transition band. Thus, the filtenna can fully utilize the available frequency bandwidth of the frequency channel and avoid to interference with adjacent frequency channels. So far, a variety of filtennas have been mostly designed using the planar microstrip line [1]–[10] and substrate-integrated waveguide [11]–[13].

Meanwhile, integration of more RF front-end components has been recently becoming a research trend in microwave community. In this context, integration of duplexer and antenna was realized using the microstrip structure [14] and the LTCC technology [15]. The aforementioned works show excellent application of these planar circuit topologies [1]–[15], but it is not suitable for the application of metal cavity structure. The metallic cavity used for filter design has the high power capacity and low loss factor. It is why various metallic cavity filters and duplexers have been well explored for applications in base station of wireless communication systems. Consequently, it is necessary to put our concerns on how to integrate a metallic cavity filter with an antenna in a low-profile structure. In this paper, the filtenna-/duplex-antenna integrated method of low-profile metal cavity structure will be presented.

To construct the duplex antenna, a filtering antenna introducing the controllable transmission zeros at the transition band entails more study. The radiated nulls can improve the isolation of two operating channels. Moreover, as we know, the transmission zero at the transition band is presented in [1], [3], [6], and [9], but it is not discussed for flexible controlling except [9]. Meanwhile, it is unfortunate that narrowband duplex antennas are rarely discussed the radiation zeros [14], [15]. In this paper, the controllable radiated nulls will be introduced at the lower and upper transition bands.

The metallic 3-D cavity filter or duplexer has been well elaborated with mature technology [16]–[22]. In parallel, a cavity-backed antenna has been well developed to realize a unidirectional radiation pattern as reported in [23]–[28]. Moreover, a few wideband antennas with good performance were proposed in [27] and [28], and they are suitable for broadband design. However, the wideband cavity-backed antenna integrated with wideband metallic cavity filter/duplexer cannot be found in the reported literature.

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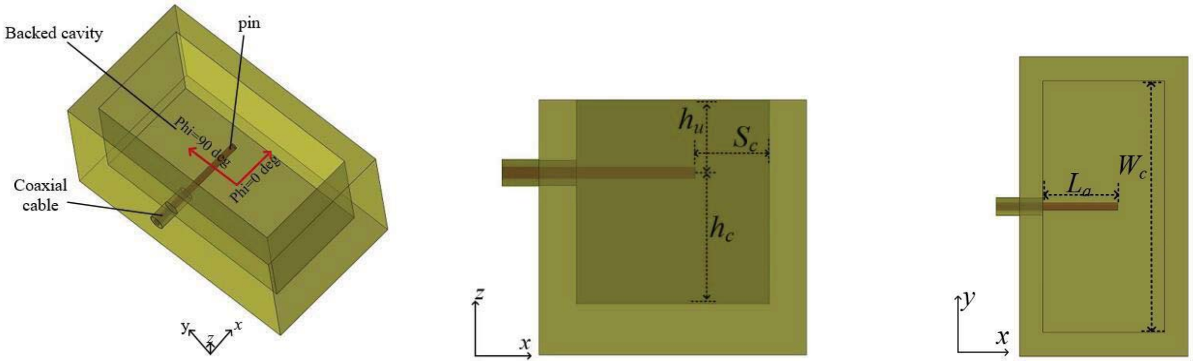
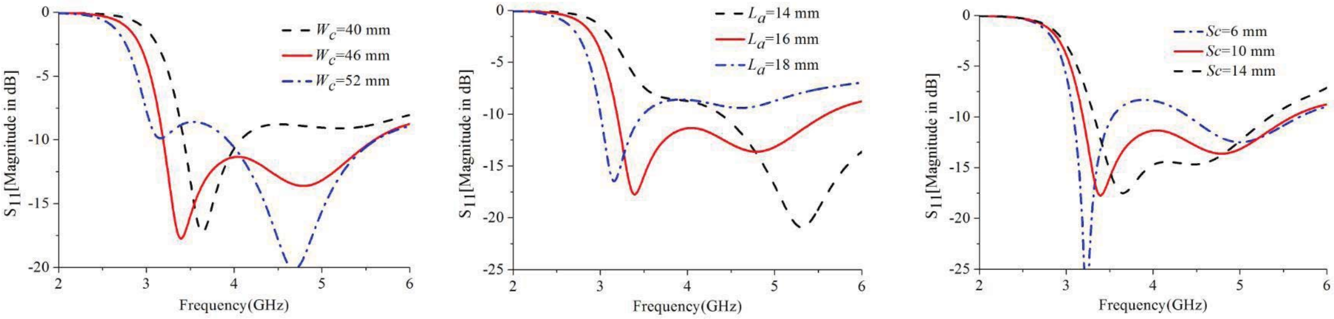


(a) (b) (c)

Fig. 1. Geometrical layout of the proposed cavity-backed antenna. (a) 3-D view. (b) Front view. (c). Top view.



(a) (b) (c)

Fig. 2. Simulated S_{11} magnitudes of the proposed cavity-backed antenna in Fig. 1 with respect to different dimensions. (a) W_c, when $L_a = 16$ mm and $S_c = 10$ mm. (b) L_a, when $W_c = 46$ mm and $S_c = 10$ mm. (c) S_c, when $W_c = 46$ mm and $L_a = 16$ mm.

In this paper, an air-filled low-profile metallic cavity-backed filtenna with controllable radiated nulls is proposed for broadband unidirectional radiation. Based on this filtenna, a wideband duplex–filtenna is further designed by sharing the upper and lower bands of the antenna with a single cavity-backed resonator.

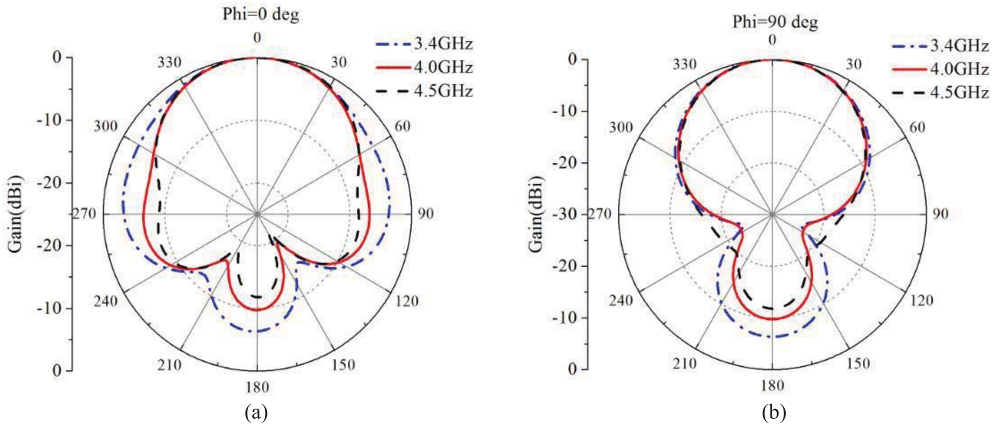
II. CAVITY-BACKED FILTENNA

A. Cavity-Backed Antenna

To achieve the broadband filtenna, a cavity-backed antenna is proposed for broadband and unidirectional radiation. The layout of the proposed antenna is shown in Fig. 1. The parametric studies on W_c, L_a, and S_c are numerically executed. Variation of return loss against the varied W_c, L_a, and S_c is presented in Fig. 2(a)–(c), respectively. The curves in Fig. 2 are extracted by the fixed parameters of $h_u = 10$ mm and $h_c = 18$ mm. Herein, h_u value is not sensitive to the performance of the antenna, and the h_c is set as about a quarter-wavelength of operating frequency. As shown in Fig. 2, the cavity-backed antenna is a resonant antenna and it has two resonant modes within the operation band. Furthermore, the two modes can be shifted to higher frequency as W_c, L_a, and S_c decrease. Meanwhile, as S_c or L_a decreases, the coupling between two modes is enlarged so as to make the two resonant modes separated apart. Due to the contribution of these two resonant modes, the proposed cavity-backed antenna can hold a wideband performance for radiation. Next, a set of optimized antenna dimensions are chosen as $h_u = 10$ mm, $h_c = 18$ mm, $W_c = 46$ mm, $L_a = 16$ mm, and $S_c = 10$ mm. Three radiation patterns at 3.4, 4, and 4.5 GHz are derived as depicted in Fig. 3(a) and (b) in their E-plane and H-plane, respectively. As can be seen in Fig. 3, a unidirectional radiation pattern property is satisfactorily realized. The 3-dB beamwidth becomes stable with respect to the frequency, and the back lobe is reduced as the frequency increases, due to the electrically large ground plane in higher frequency.

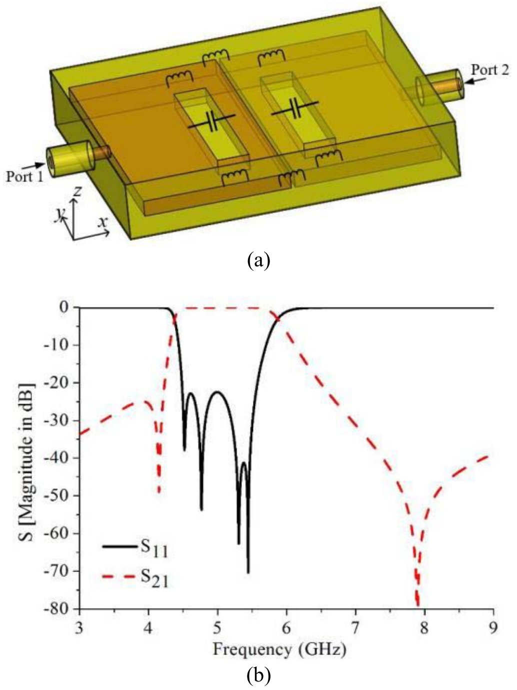
B. Integration of Filter and Antenna

A fourth-order wideband metal cavity bandpass filter is designed herein to feed the antenna, and its geometry is shown in Fig. 4. A slot-cut metal plane is inserted into rectangular cavity, and the slot cut can generate the transmission zeros for the mixed coupling. As shown in Fig. 4(a), the slot-cut structure can be equivalent to the parallel capacitance and inductance model corresponding to the electric and magnetic coupling (mixed coupling). The two shorter slots generate the transmission zero at upper stopband, whereas the longer slot at the center generates the transmission zero at lower stopband, as clearly shown in Fig. 4(b). In Fig. 5, a small section of 50-Ω coaxial cable is utilized to connect the filter and the antenna. The center of the coaxial cable is inserted into the cavity for broadband radiation. The filter and antenna are co-designed as the filtenna to achieve good impedance matching and wideband radiation performance. As such,



(a) (b)

Fig. 3. Normalized simulated radiation patterns of the proposed cavity-backed antenna in Fig. 1. (a) $\Pi = 0^\circ$. (2) $\Pi = 90^\circ$.



(a)

(b)

Fig. 4. Cavity filtering circuit. (a) Structure. (b) Simulated scattering parameter.

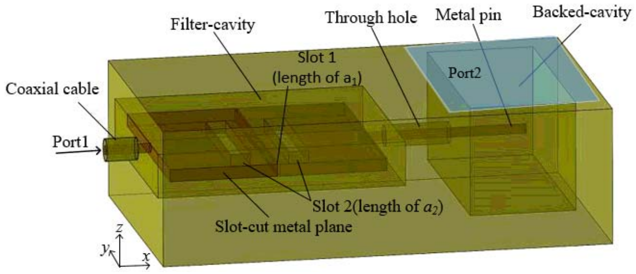


Fig. 5. Geometrical structure of the proposed cavity-backed filtenna.

a cavity-backed filtenna can be formed, and its geometry is displayed in Fig. 5.

As mentioned above in [1]–[11], the total number of resonant modes in this filtenna is equal to the number of resonant modes in filter plus the number of resonant modes in antenna. To further discuss how these modes affect the filtenna's performance, a waveguide port is put on the aperture of the backed cavity of the antenna, as shown in Fig. 5. The $|S_{21}|$ variation of the resonant modes is numerically extracted under the weak coupling, and it is depicted in Fig. 6. Since a small length of the excitation pin L_a is chosen, the first resonant mode of the cavity-backed antenna is used to construct the passband, as shown in Fig. 2. Thus, five resonant modes are observed in total from this filtenna. Moreover, resonant frequencies of the last four modes are shifted to lower frequency as L_a is enlarged, thus providing a way to control the fractional bandwidth (FBW) of the operation band.

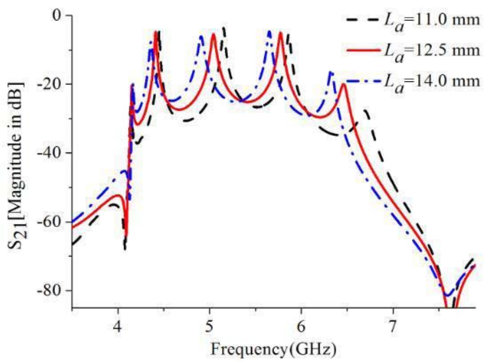
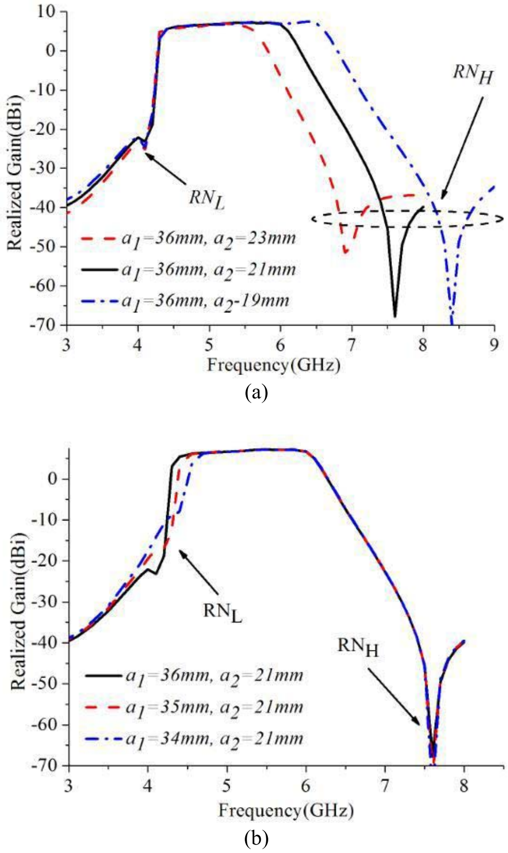


Fig. 6. Resonant frequencies of a few modes in the proposed filtenna versus L_a.

The radiated nulls can be controlled by the slot cuts, which are presented as slot 1 and slot 2 in Fig. 5, and the length of slots are signed as a_1 and a_2, respectively. The slot cut can be treated as the mixed coupling. In detail, the slot is a capacitive coupling and the edge metal plane of the slot is an inductive coupling, as shown in Fig. 4(a). As the length of slot is enlarged, the capacitive and inductive coupling increase, which results in the transmission null shifting to lower frequency. In this structure, the slot 1 controls the radiated null at low transition (RN_L) and the slot 2 controls the radiated null at high transition (RN_H), which shows in Fig. 7.

Based on the discussion above, the integration method of filtenna has been elaborated. Now, let us move to discuss the



(a)

(b)

Fig. 7. Simulated realized gain of filtenna against varied length of slots. (a) a_2. (b) a_1.

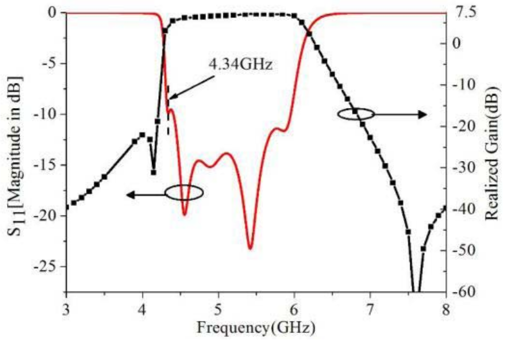
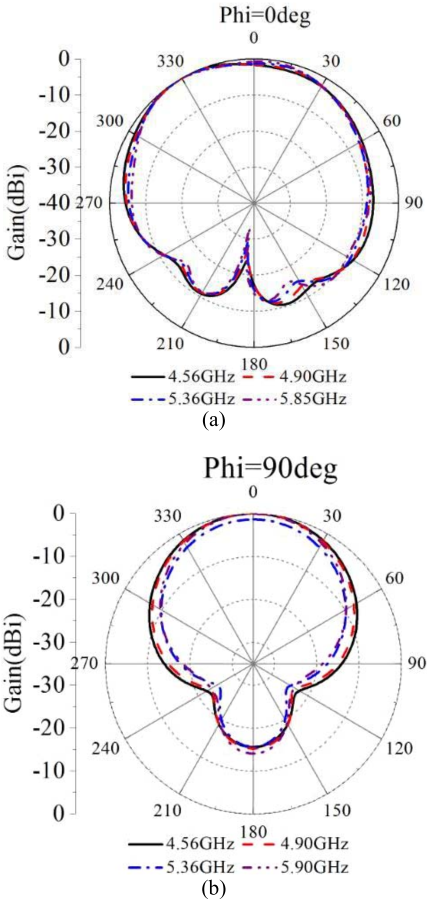


Fig. 8. Simulated $|S_{11}|$ and realized gain of the proposed filtenna.



(a)

(b)

Fig. 9. Normalized radiation patterns of the proposed filtenna. (a) H-plane. (b) E-plane.

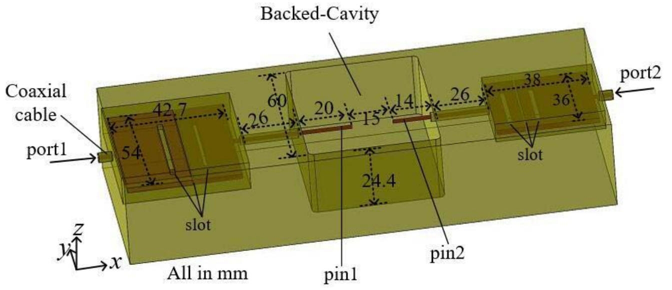
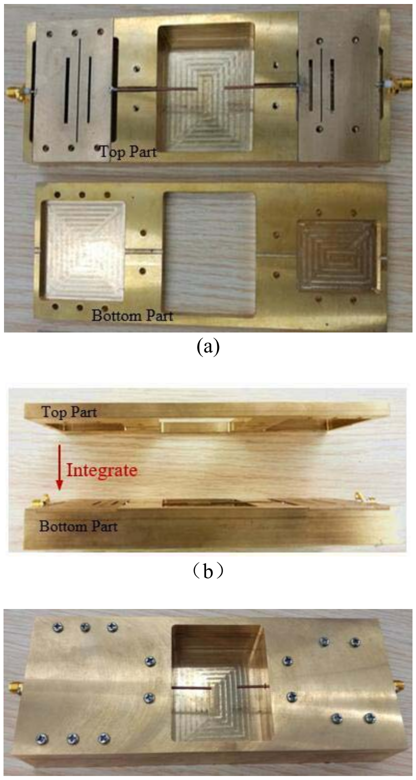


Fig. 10. Geometrical structure of the proposed duplex–filtenna.

transmission coefficient $|S_{11}|$, radiation patterns, and gains of the proposed filtenna. Fig. 8 presents its $|S_{11}|$ as a function of frequency; it exhibits the emergence of five resonant modes as predicted in Section II. Its radiation gain is shown in Fig. 8 to show its filtering performance of the filtenna. As two transmission zeros are produced at the lower and upper stopbands, good frequency selectivity is exhibited. The curve of the realized gain as a function of frequency is very flat within the passband, where the gain is constantly equal to 7.2 dBi. Next, the designed filtenna has an FBW of 31.5% under the 10-dB definition and central frequency at 5.1 GHz. The radiation patterns in the E-plane and H-plane at three frequencies, i.e., 4.56, 4.90, and 5.85 GHz are shown in Fig. 9. The 3-dB beamwidth is found to be 92°–110° and 63°–76° in the E-plane and H-plane, respectively. Moreover, the radiation patterns in both E-plane and H-plane are quite stable over a wide frequency band.

III. CAVITY-BACKED DUPLEX–FILTENNA

Based on the filtenna proposed in Section III, the duplex–filtenna will be designed in this section. To do it, the two channels of the filtenna share a common backed cavity, and two metal pins from different ports are inserted into the common backed cavity for excitation of the resonant modes in cavity-backed filtenna. As shown in Fig. 10, the proposed duplex–filtenna shares the common backed cavity, and the distance of two inserted pins is 15 mm, which is less than the 1/4 wavelength of channel 1 (22 mm) and channel 2 (16 mm) resulting from the filtering characteristic.



(a)

（b）

(c)

Fig. 11. Photographs of the fabricated cavity-backed duplex–filtenna. (a) Top and bottom parts. (b) Integration of two parts. (c) Whole structure.

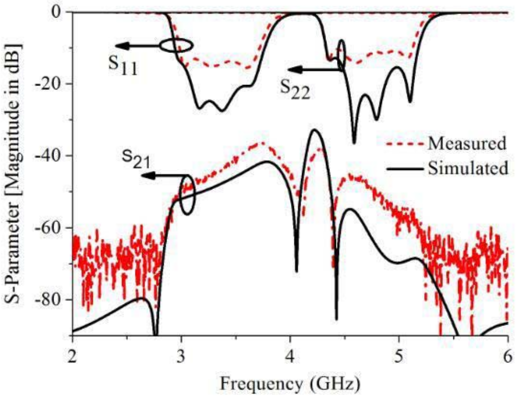
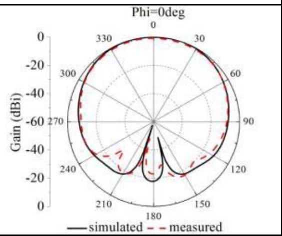
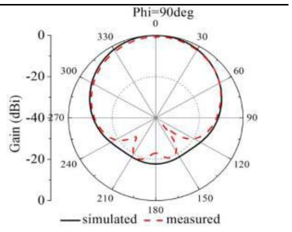
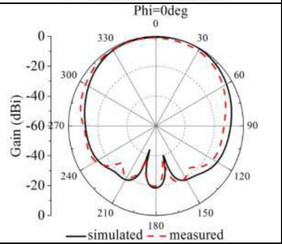
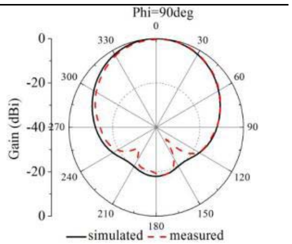
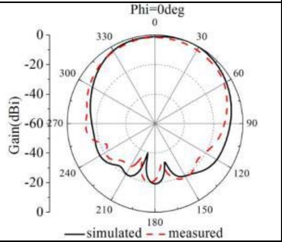
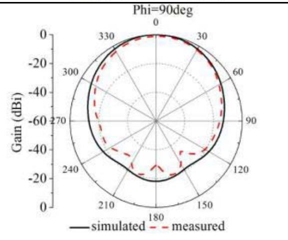
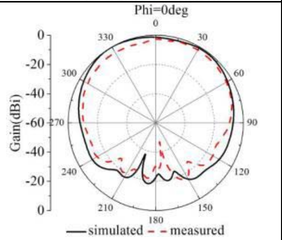
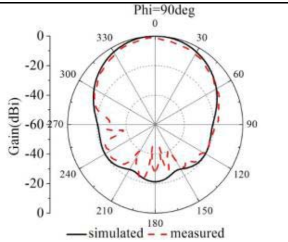
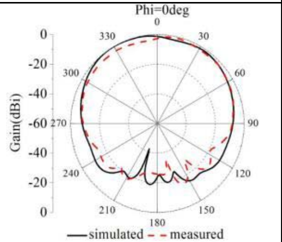
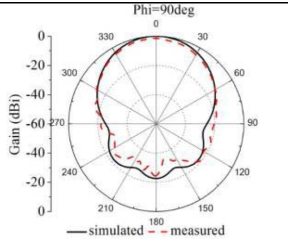
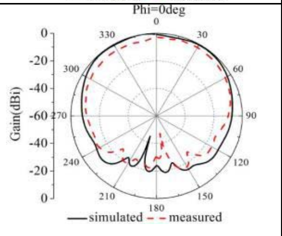
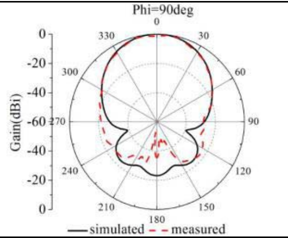


Fig. 12. Simulated and measured S-parameters of the proposed duplex-filtenna.

TABLE I

NORMALIZED RADIATION PATTERNS OF THE PROPOSED DUPLEX–FILTENNA

Freq. (GHz)	E-plane	H-plane
3		
3.3		
3.55		
4.36		
4.7		
5.08		

In order to validate the proposed idea, a low-profile duplex filtenna is fabricated by using brass. Its photographs are shown in Fig. 11. Fig. 11(a) shows the lower-half and upper-half photographs of the duplex–filtenna before installation. Fig. 11(b) indicates the integration of the lower half and upper half of duplex–filtenna. Fig. 11(c) shows the external photograph after installation of the duplex–filtenna. Fig. 12 depicts the measured and simulation results of the proposed duplex–filtenna. They are reasonably matched with each other. The S-parameter results show the duplex–filtenna has the wide FBW of 24% under $|S_{11}| < -10$ dB at center frequency of 3.4 GHz and 18% at center frequency of 4.7 GHz for channel 1 and channel 2, respectively. Between these two channels, there is a transition stopband of 6% with the channel-to-channel isolation better than 30 dB. Fig. 13 shows the simulated and measured radiation gains in these two channels. The designed duplex–filtenna shows a good filtering performance in both lower and upper channels as expected. The measured gain is 6–8 dBi with two transmission zeros at both lower and upper stopbands for both of channels.

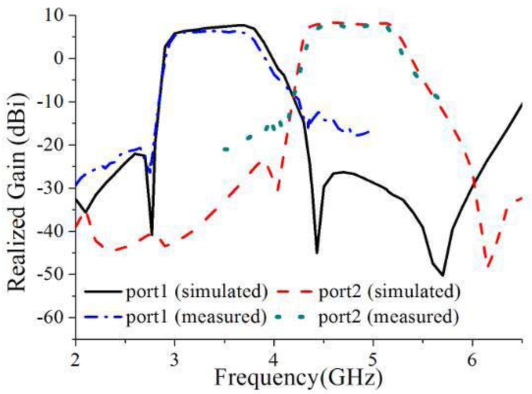


Fig. 13. Simulated and measured antenna gain of the proposed duplex-filtenna.

The measured radiation patterns of the proposed duplex–filtenna are extensively demonstrated in Table I, where the operation frequencies of 3, 3.3, and 3.55 GHz are chosen for excitation at port 1, while 4.36, 4.7, and 5.08 GHz are chosen for excitation at port 2. As can be seen in two sets of figures in Table I, a unidirectional radiation property is well confirmed in experiment. The 3-dB FBW in the E-plane is found to be 84°–100° and 113°–121° within the operation band of channel 1 and channel 2, respectively, while the 3-dB FBW in the H-plane is 83°–87° and 56°–60° within the operation band of channel 1 and channel 2, respectively.

IV. CONCLUSION

In this paper, a low-profile cavity-backed antenna has been proposed to design and explore the broadband filtenna and duplex–filtenna with a unidirectional radiation. The overall circuit structure of the duplex–filtenna is fabricated using brass to verify the proposed concept in experiment. Our derived results illustrate that the proposed duplex–filtenna has the FBW of 24% under $|S_{11}| < -10$ dB at the center frequency of 3.4 GHz and 18% at the center frequency of 4.7 GHZ over the whole operation band with overall FBW of 57%. The measured S-parameter, realized radiation gains, and radiation patterns are found in good agreement with the simulation results. Moreover, the designed duplex–filtenna shows an excellent filtering performance with radiation zeros at both lower and upper stopbands of two channels, and a stable radiation pattern within the desired wide operation frequency band.

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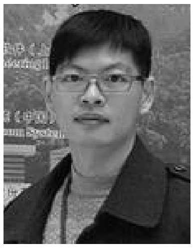

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