Progress In Electromagnetics Research Letters, Vol. 76, 91–96, 2018

Planar Cavity-Backed Self-Diplexing Antenna Using Two-Layered Structure

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Abstract—A design of a half-mode substrate integrated waveguide (HMSIW) cavity-backed self-diplexing antenna is proposed with a two-layer structure. The top layer comprises two HMSIW based cavities, and radiating patches are etched on the top-cladding of each cavity. The radiating patches are excited by two distinct printed microstrip lines on the backside of the bottom layer by using shorting-pins. The shorting-pin excites the corresponding cavity in its dominant mode, which resonates at two different frequencies in x-band. The simulated results demonstrate that the proposed design resonates at 8.20 GHz and 10.55 GHz with an isolation of higher than -25 dB between two excitations, which helps to introduce the self-diplexing phenomenon. Also, both resonant frequencies can be tuned independently by varying the dimensions of the corresponding cavity. Moreover, HMSIW cavity-backed structure and proposed feeding technique reduce the overall size of the antenna significantly, while it maintains high gain and unidirectional radiation characteristics for both operating frequencies.

1. INTRODUCTION

With the massive development of modern mobile and satellite communication systems, the dual-frequency antennas with high isolation at transceiver are in high demand. Recently, a model of the self-diplexing antenna was proposed in [1]. Implementing self-diplexing antenna reduces the complexity of the high-order diplexer network, which helps to reduce the size and cost of the overall RF (radio-frequency) front-end system. In the last decade, the state-of-the-art substrate integrated waveguide (SIW) technology has turned as a very promising technology, which facilitates the realization of conventional waveguide based circuits in their planar counterparts. An SIW technology has been adopted to realize a planar cavity-backed antenna, which incorporates the advantages of planar integration, low-cost and mass-productivity with high gain and unidirectional radiation characteristics [2, 3]. Numerous designs of dual-band antennas have been investigated in the literature [4, 5]. However, all these designs need a complex diplexer to isolate transmitted and received signals at the RF front end. In recent study, SIW based self-triplexing antenna is presented in [6] with the characteristics of intrinsically isolated input ports. However, this kind of structure feeding network engages a larger portion of the entire area covered by the antenna. Also, feeding network may deteriorate the electrical performance of such antennas.

In this letter, a design of the planar self-diplexing antenna with good isolation between input ports is demonstrated using a two-layer structure. The proposed design uses individual half-mode SIW (HMSIW) cavity-backed radiating patch for each operating frequency. The feeding network is designed at the backside of the other substrate which makes it compact and offers a shielding from parasitic radiations. On the other hand, HMSIW cavity based structure reduces backside radiation, thus, improving gain.

Received 16 March 2018, Accepted 16 April 2018, Scheduled 4 June 2018

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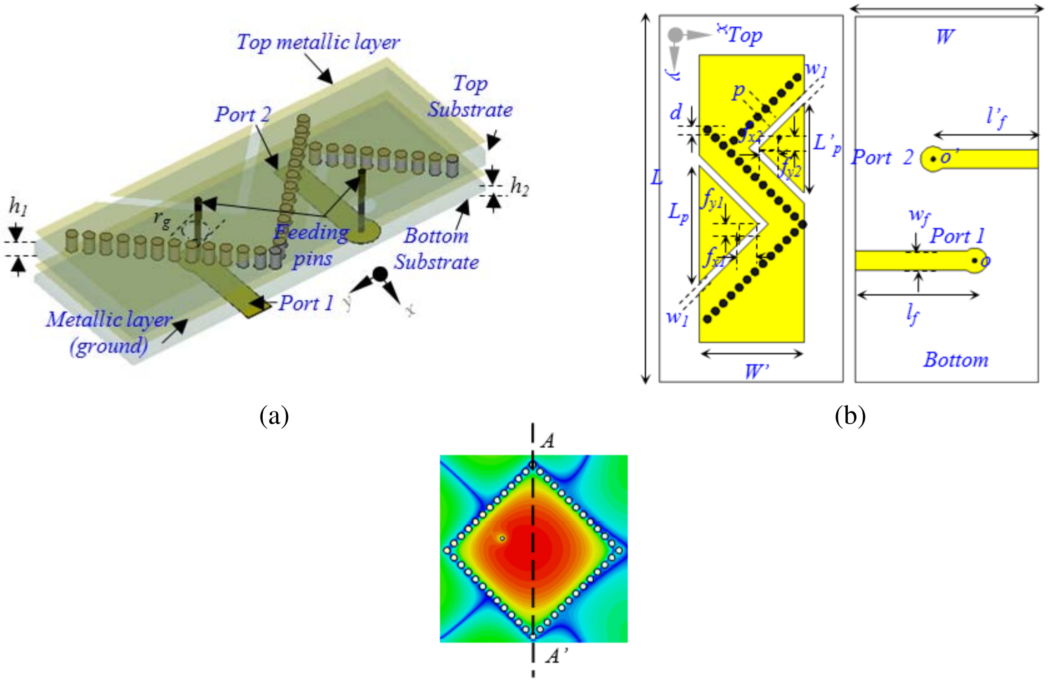


(a) (b)

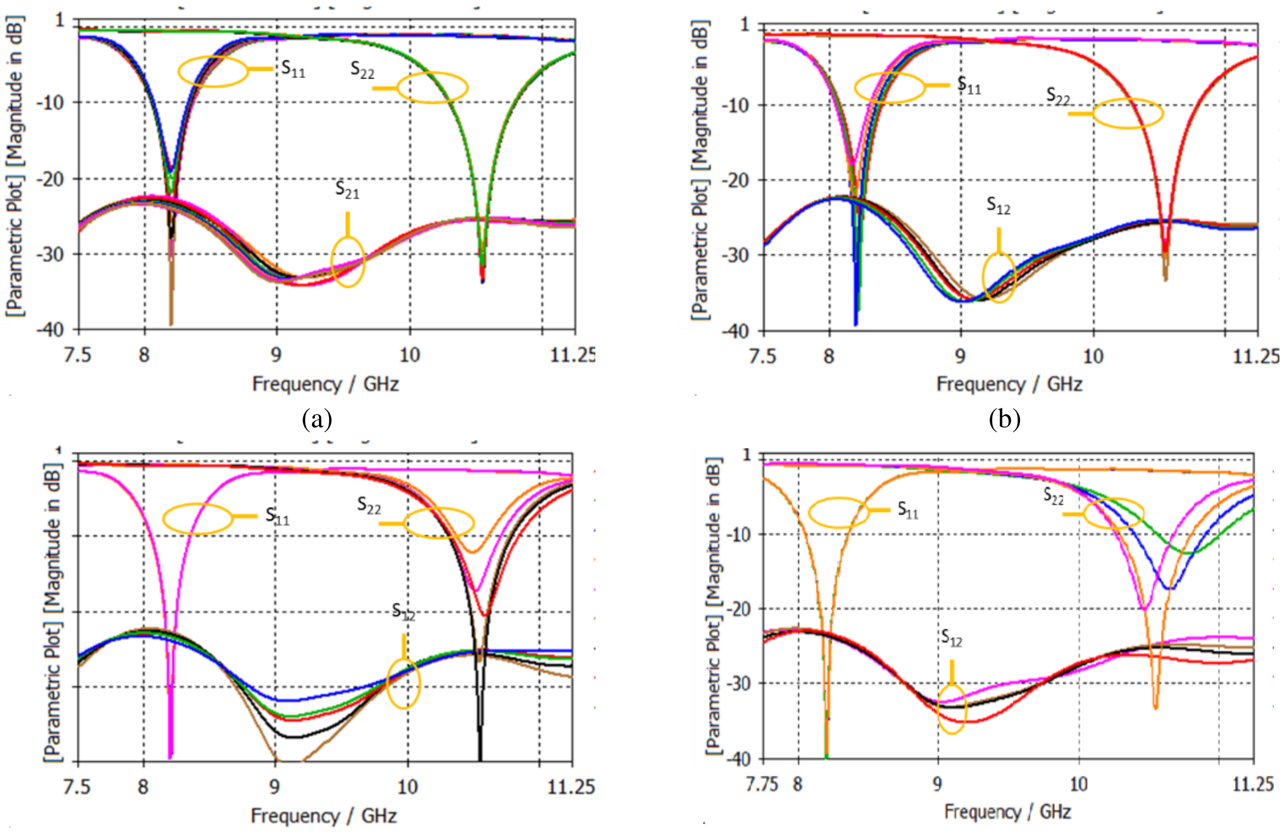
(c)

Figure 1. Proposed design: (a) Perspective view. (b) Top and bottom view, and (c) E-field distribution in SIW cavity. ($W = 22\,\text{mm}$, $L = 45\,\text{mm}$, $L_p = 14.9\,\text{mm}$, $L'_p = 11.2\,\text{mm}$, $l'_f = 15.1\,\text{mm}$, $l_f = 13.3\,\text{mm}$, $w_f = 2.4\,\text{mm}$, $r_g = 2.4\,\text{mm}$, $w_1 = 0.95\,\text{mm}$, $p = 1.5\,\text{mm}$, $d = 1\,\text{mm}$).

2. DESIGN ANALYSIS: DESIGN AND PRINCIPLE

As shown in Fig. 1, the proposed design is realized using a two-layer stacked structure. Two HMSIW based planar cavities are realized on the top substrate, and a triangular patch is etched on the upper metallic plate of each cavity for radiation. Each radiating patch is excited by $50\,\Omega$ microstrip line by using shorting-pins. The lateral walls of the planar cavities (HMSIW) are shaped by implementing metalized via-arrays. The diameter of via (d) and pitch distance (p) is chosen such that it follows the essential conditions as given in [4]. The feedlines are printed on the backside of the bottom layer. As shown in the perspective view (Fig. 1(a)), the design utilizes a common ground plane for cavities and feedlines inserted between two dielectric substrates. The radiating patches backed with the individual cavity help to introduce high isolation between the input ports. Thus, the proposed design is very suitable for realizing the self-diplexing mechanism. Both top and bottom layers are designed on an RT/Duroid 5880 substrate with dielectric constant of 2.2 and thickness of 1.57 and 0.787 mm, respectively.

The design procedure begins with the determination of SIW cavity dimensions by using the empirical relation between the SIW and metallic waveguide operating at its dominant mode (TE_{110}) [5]. The electric-field distribution of the conventional SIW cavity applied in TE_{110} mode is plotted in Fig. 1(c). When an SIW cavity is split along A-A′ (i.e., perfect magnetic wall [7]), the HMSIW cavity is realized while preserving half of the electric-field distribution of its dominant mode. Thus, the HMSIW is capable to reduce the size up to 50% of the original. In the proposed design, two distinct HMSIW cavities are used that operate at a corresponding dominant mode. Thus, the design provides flexibility to tune each resonant frequency without affecting the other by adjusting the dimensions of the cavity and radiating patch. Moreover, the feeding network for the proposed diplexer is designed at the backside of the bottom substrate while maintaining planar integrability. Such a feeding topology reduces overall size occupied by design significantly. In addition, it offers an extra shielding from parasitic radiation effects of the feeding network, which will enhance the radiation performance in terms of gain and bandwidth [8]. The location of the feeding point on the radiator plays a critical role for impedance matching. The effect of feeding point at o (*Port 1*) and o' (*Port 2*) is analyzed by shifting it along x-axis and y-axis in Fig. 2. Finally, locations of feeding points o and o' are adjusted such that maximum impedance matching is achieved at the desired frequency. The optimized parameters values are as $f_{x1} = 2.5\,\mathrm{mm}$, $f_{y1} = 1.2\,\mathrm{mm}$, $f_{x2} = 2.5\,\mathrm{mm}$, and f_{y2}, 1.35 mm.



(a) (b)

(c) (d)

Figure 2. Effect on S-parameters with the variation of feeding location at *Port 1* and *Port 2*: (a) by changing parameter f_{x1}, from 2.2–3.0 mm, (b) by changing parameter f_{y1}, from 1.74–2.14 mm, (c) by changing parameter f_{x2}, from 1.7–2.8 mm, and (d) by changing parameter f_{y2}, from 0.95–1.55 mm.

3. EXPERIMENTAL VERIFICATION

The proposed design is prototyped by using a low-cost printed-circuit-board procedure and experimentally tested. The fabricated sample of the design is depicted in Fig. 3. Both layers are fabricated on an RT/Duroid 5880 substrate, and nylon screws are used for their alignment. The proposed design is optimized by using CST tool, and optimized parameters are presented in Fig. 1(b). To validate the concept, the measured responses are compared with simulated counterparts in terms of S-parameters, gain and radiation patterns. As shown in Fig. 4, the simulated and measured resonant frequencies are at 8.20 and 8.12 GHz, respectively, when input *Port 1* is excited and *Port 2* terminated with matched load, and likewise 11.55 and 11.47 GHz, respectively, when input *Port 2* is excited and *Port 1* matched with terminated load. The measured values of isolation between *Port 1* and *Port 2* are −22.2 and −25.17 dB at the frequencies of 8.12 and 11.47 GHz, respectively. A comparison of the simulated and measured gain characteristics is plotted in Fig. 5. The measured gain values at lower and higher resonant frequencies of the antenna are 4.0 and 4.3 dBi, respectively. It can be observed from Fig. 3 that the gain at lower frequency band approaches 0 dBi when *Port 2* is excited. Likewise, when input *Port 1* is excited, the gain at higher frequency is very low, which demonstrates the self-diplexing phenomenon of the proposed design. Figs. 4 and 5 show that the experimented and simulated responses agreed well with each other. However, a small deviation is observed, which may be attributed to fabrication tolerances.

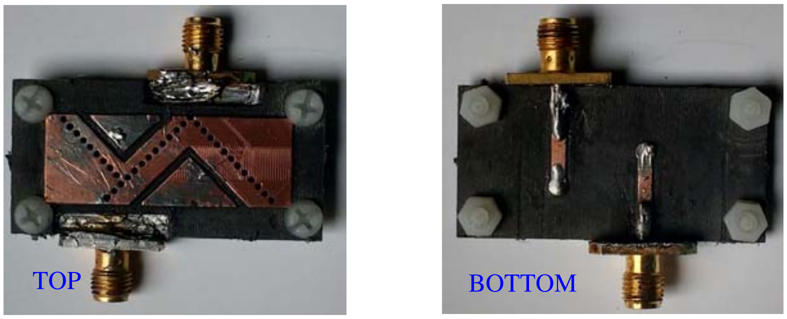


Figure 3. Fabricated prototype.

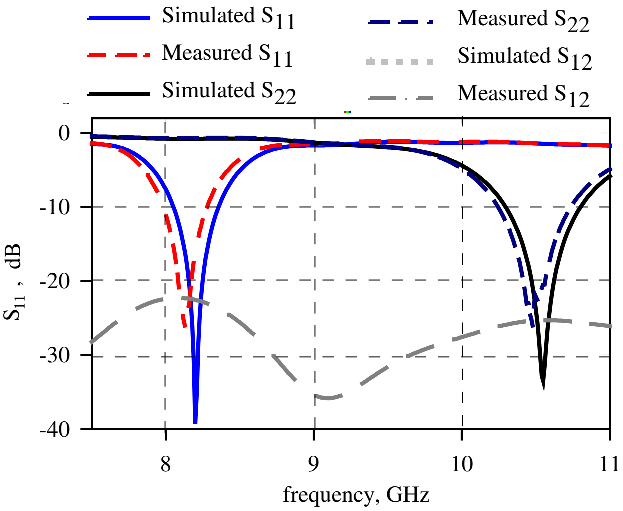


Figure 4. Comparison between simulated and measured S-Parameter (Case 1: *Port 1* is ON; Case 2: *Port 2* is ON).

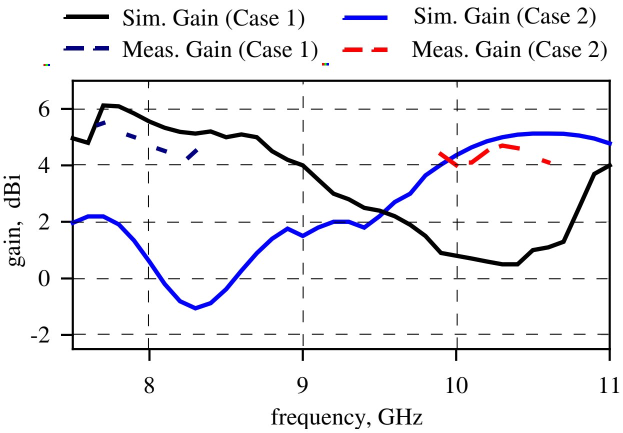
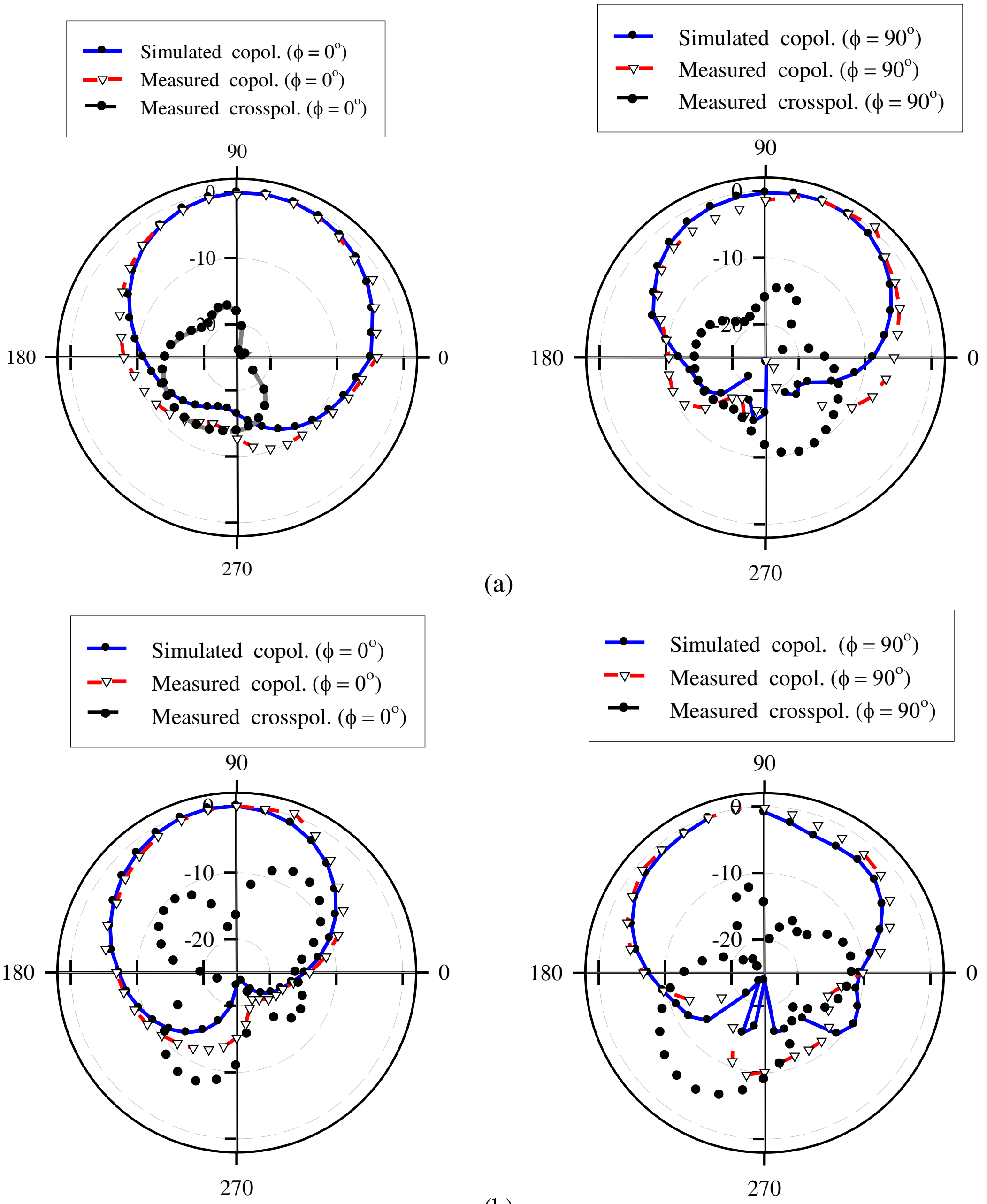


Figure 5. Comparison between simulated and measured gain parameter (Case 1: *Port 1* is ON; Case 2: *Port 2* is ON).

Figure 6 presents radiation profiles at two principle cut planes of $\phi = 0°$ (yz-plane) and $\phi = 90°$ (xz-plane) at the lower and higher resonant frequencies when the corresponding port is excited. Once again, it can be observed that the measured and simulated responses agree well with each other. Also, the radiation patterns are stable and unidirectional at both operating frequencies due to the HMSIW backing cavity structure. The proposed design functions as a self-diplexing antenna with unidirectional gain along with high gain and good isolation between the input ports. It was noted that each resonant frequency can be tuned without affecting the other by varying the cavity and patch dimensions (not shown here). Also, it owns a simple, compact and planar configuration which can be rescaled for any desired frequency making it a promising candidate for a practical application operating in x-band (8–12 GHz).



(a)

(b)

Figure 6. Radiation patterns: At (a) 8.20 GHz and (b) 10.55 GHz.

4. CONCLUSION

A planar cavity-backed self-diplexing antenna using a two-layer stacked structure is presented in this letter. The antenna uses two HMSIW cavity-backed patches, which radiate at corresponding resonant frequencies. The two-layered structure improves impedance bandwidth and gain at both resonant frequencies as well as miniaturizes the feeding network. The experimental results show that the antenna resonates 8.12 and 10.47 GHz with the gains of 4.0 and 4.3 dBi, respectively. The proposed design exhibits an isolation of higher than −22 dB between the feeding ports, which makes it suitable for self-diplexing functionality. Moreover, this design is reasonably compact and simple, easy to redesign for any frequency.

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