A Self-Triplexing SIW Cavity-Backed Slot Antenna

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***Abstract*—In this letter, a new design of self-triplexing slot antenna using substrate integrated waveguide (SIW) technique is demonstrated for multiband communication systems. The proposed antenna operates at triple frequency bands (around 6.53, 7.65, and 9.09 GHz) simultaneously utilizing a slot inserted on the top of the SIW cavity and is excited by three separate microstrip lines. By properly optimizing the antenna parameters, an isolation of better than 19 dB is realized between any two input ports, which helps to achieve self-triplexing property. The proposed triplexing antenna preserves simplicity, compactness, and a planar configuration that makes it suitable for highly integrated handheld devices. To demonstrate the significance of the proposed work, the antenna is prototyped, and experimental results show a close agreement with simulations. Moreover, the proposed antenna exhibits the measured gain of 3.1, 4.7, and 3.9 dBi at resonant frequencies with stable radiation patterns.**

***Index Terms*—Cavity-backed slot antenna, isolation, self-triplexing antenna, substrate integrated waveguide (SIW).**

I. Introduction

In RECENT years, multifrequency antennas have been widely implemented in the modern wireless compact handheld and mobile devices. These devices are usually equipped with two or more transceivers with a multiantenna system for different applications. The multiband antennas are advantageous to achieve an extreme miniaturization of transceivers since it is quite complicated to integrate the multiantenna elements closely in compact systems [1], [2]. However, a frequency-selective element, such as higher order diplexer or triplexer, is needed to ease connectivity from multiple transmitter/receiver to the multiband antenna by providing a better isolation between them [3], [4]. Yet, these types of circuits increase the overall circuit complexity and limit the applications in the completely integrated systems.

Recently, the concept of self-diplexing antenna topologies is proposed with intrinsic isolation between the input ports [5], [6]. Such antenna topology reduces the mandatory complex decoupling network in general and diplexer in particular. Thus, this improves the compactness and efficiency of the overall RF front-end system.

However, there is a lingering uncertainty of self-diplexing antennas in practice, as the modern multiband communication systems need diversity for at least three operating frequencies. To the best of the authors' knowledge, only a few designs of antenna triplexer with three-port isolations are reported in the literature. In [7], an integrated antenna triplexer using a two-layered substrate is proposed, and good three-port isolations are achieved by the multimode excitation technique. Most recent self-triplexing antenna component using substrate integrated waveguide (SIW) technology is proposed in [8]. This prototype contains two SIW cavities and a couple of bow-tie-shaped slots, and has a capability to excite three different resonant modes simultaneously, while two microstrip lines and a coaxial probe feeding techniques are employed. However, a layered configuration or multicavity-based antennas increase the circuit size and complexity, and coaxial probe feed makes it unfit for a planar integration. Thus, these limitations confine the applications in compact handheld devices.

To this end, an SIW-based self-triplexing cavity-backed slot antenna is presented with simultaneous three-port isolations. This design uses a very simple feeding network of three different microstrip lines to excite three frequency bands around 6.53, 7.65, and 9.09 GHz. The antenna radiates into the free space through the slot on the top of the SIW cavity when excited by the corresponding feedline. Moreover, the design is prototyped with the help of printed circuit board procedure, and the experimental results reveal good agreement with simulations.

II. Configuration and Design Analysis

The geometrical configuration of the proposed self-triplexing antenna is presented in Fig. 1(a). The SIW cavity is realized using the chains of metallic vias in the substrate implementing the lateral walls of the cavity. The initial dimensions of the SIW can be estimated by its waveguide equivalence model presented in [9]. Apart from this, dimensions of the design are optimized such that it can be applied in the dominant TE_{110} mode within the frequency band of interest. A radiating slot is inserted on the top metal cladding as shown in Fig. 1(a). This slot divides the SIW cavity into three parts. Each part yields different resonant frequency when excited by three distinct 50 Ω microstrip lines, placed at the adjacent sides of the SIW cavity. The locations of the feedlines are adjusted such that proper impedance matching is achieved only at the desired frequency. To avoid mutual coupling of the incident power with adjacent ports, the width of the slot is kept quite wide.

The slot divides the SIW cavity into three subcavities that can be considered as a combination of one half-mode (HM) and two quarter-mode (QM) SIW cavities/resonators, as illustrated in Fig. 1(b). The fundamental resonant frequency of HM/QMSIW cavity resonator is estimated by following the guidelines suggested in [10]. The proposed antenna is designed and analyzed

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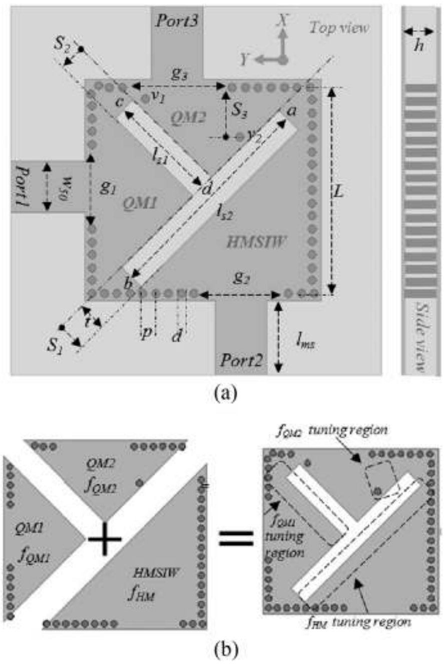

Fig. 1. (a) Proposed design. (b) Analytical model: a combination of one half-mode (HMSIW) and quarter-mode (QMSIW) resonator in single antenna element, yielding three different resonant frequencies ($L = 19.27$, $S_1 = 2.5$, $S_2 = 2.5$, $S_3 = 4.5$, $g_1 = 7$, $g_2 = 8$, $g_3 = 9$, $l_{s1} = 10.3$, $l_{s2} = 20.7$, $l_{ms} = 6.9$, $w_{50} = 4.78$, $p = 1.25$, $d = 0.8$, $h = 1.57$). All dimensions are in millimeters.

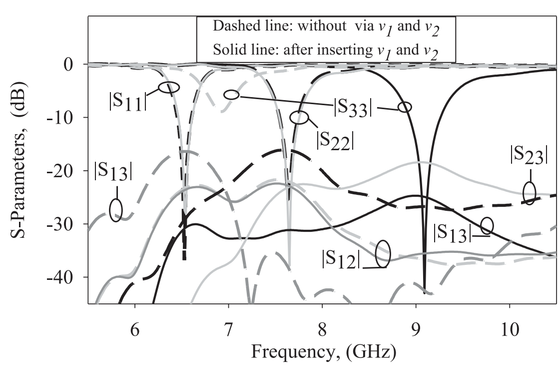

Fig. 2. S-parameters with and without inserting via "v_1" and "v_2".

using CST Microwave Studio. The optimized antenna parameters are symbolized in Fig. 1(a). The proposed design exhibits three resonant frequencies of 6.53, 7.65, and 9.09 GHz with isolations better than 19 dB among the input ports. This is good enough to realize self-triplexing property. The middle frequency band around 7.65 GHz is obtained due to HMSIW cavity resonance (f_{HM}) and radiates along "*ab*" [see Fig. 1(a)] when *Port2* is excited. On the other hand, the lower frequency band (f_{QM1}) around 6.65 GHz is obtained due to the resonance of *QM1* resonator and it radiates along the aperture "*bdc*" when *Port1* is excited. Similarly, the higher frequency band (f_{QM2}) around 9 GHz is obtained due to *QM2* resonator when *Port3* is excited. Additionally, two shorting vias v_1 and v_2 are inserted to improve the port isolations [11]. The effect of these vias on the S-parameters is shown Fig. 2. It can be clearly seen that the vias "v_1" and "v_2" improve the isolation level of S_{13} and S_{23}

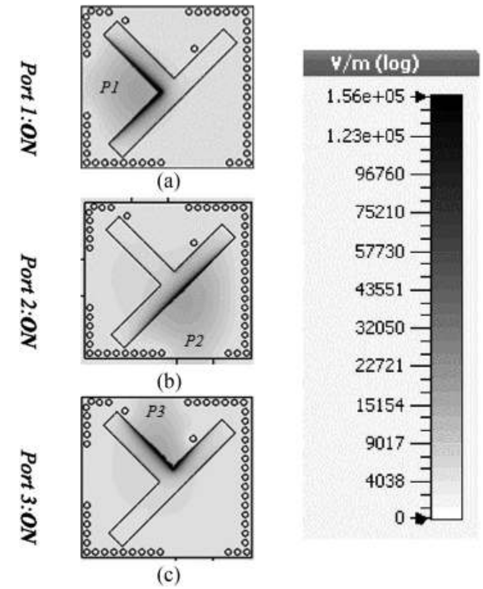

Fig. 3. Electric field distribution at resonant frequencies of (a) 6.53, (b) 7.65, and (c) 9.01 GHz (when one port is ON, others are OFF).

significantly without affecting cavity resonances except f_{QM2}. Moreover, via "v_2" is found useful to shift the f_{QM2} of *QM2* resonator toward the higher frequency for the triple frequency operation.

Basically, these vias (v_1 and v_2) introduce a difference in the magnitude and phase of the electric field distribution on the opposite side of the radiating slot. Due to this mechanism, the slot radiates into the free space with the negligible transmission of incident wave to the other ports. This property improves the input port isolations and helps to achieve the self-triplexing phenomenon. Evidently, the electric field distribution of the three resonant frequencies is shown in Fig. 3. It can be clearly observed that the antenna radiates maximum through the aforementioned aperture without significant transmission of the input wave to the other ports.

The proposed design offers a flexibility to tune all the three resonant frequencies. A parametric study of the concerned parameters is investigated in Figs. 4–6. The variation of S-parameters with change in the parameter "S_1" is shown in Fig. 4. As the value of "S_1" increases, the effective radiating aperture area of the HMSIW cavity gets reduced and the resonant frequency (f_{HM}) shifts toward the higher frequency. Thus, f_{HM} can be tuned within the frequency range of 7.29–8.14 GHz by varying the parameter S_1 from 1.7 to 3.5 mm. Similarly, Fig. 5 shows that the frequency of f_{QM1} can be tuned within the frequency range of 6.25–6.88 GHz by varying the parameter S_2 from 1.6 to 3.6 mm. On the other hand, Fig. 6 shows that the frequency of f_{QM2} at higher band can be tuned within the range of 8.74–9.75 GHz, by changing the location (S_3) of the loaded shorting pin "v_2" from 4.22 to 5.20 mm. Thus, each resonant frequency is tuned over a large frequency span without impacting the other resonances. The tuning region for individual resonant frequency is highlighted in Fig. 1(b). It can be clearly observed that each parameter greatly influences the isolation

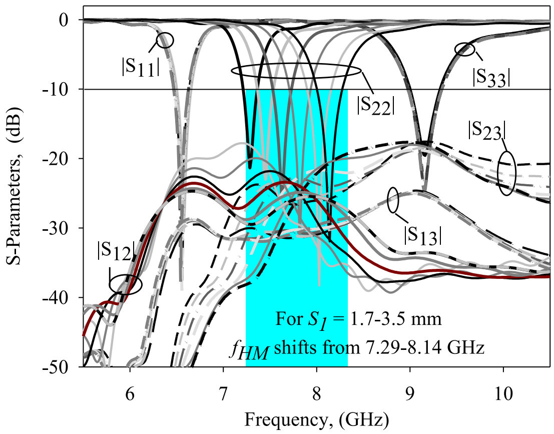

Fig. 4. Variation of S-parameters with change in parameter "S_1" from 1.7 to 3.5 mm.

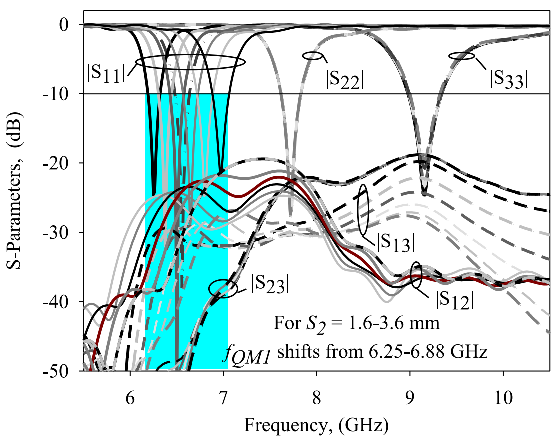

Fig. 5. Variation of S-parameters with change in parameter "S_2" from 1.6 to 3.6 mm.

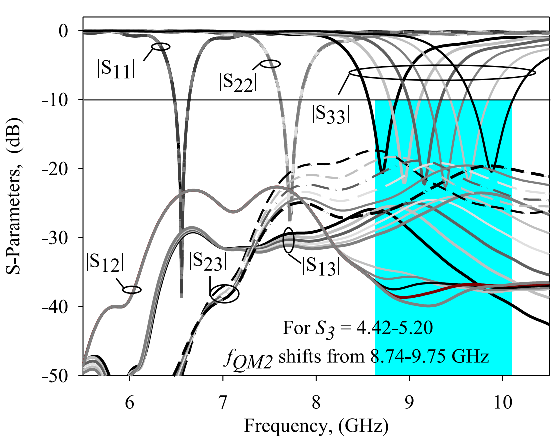

Fig. 6. Variation of S-parameters with change in parameter "S_3" from 4.42 to 5.20 mm.

levels. Therefore, these are optimized in order to maintain the isolation level.

III. Experimental Validations

The proposed self-triplexing antenna is prototyped on a single layer of Rogers RT Duroid 5880 substrate with a thickness

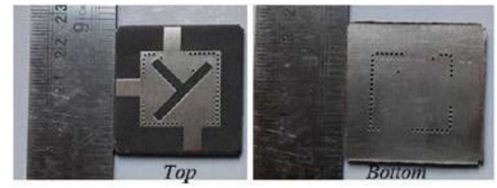

Fig. 7. Photograph of the fabricated triplexer antenna.

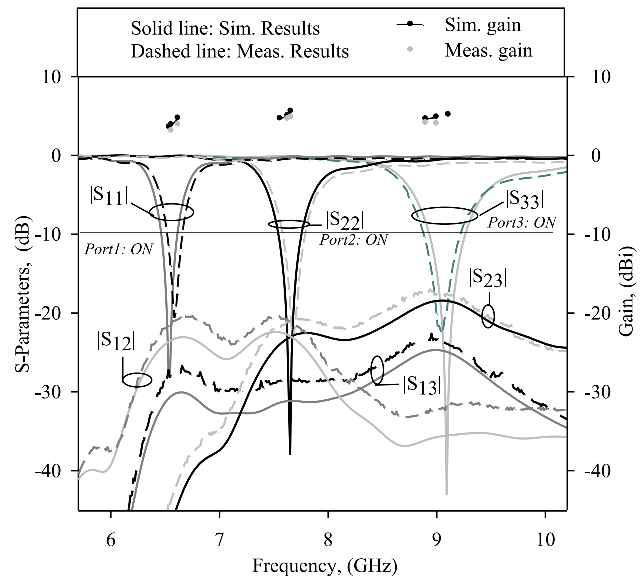

Fig. 8. Simulated and measured results: S-parameters and gain.

of 1.575 mm, dielectric constant of 2.2, and tangent loss of 0.0009. A photograph of the prototyped antenna is displayed in Fig. 7. To validate our proposal, the measured responses are compared with the simulations in terms of S-parameters, gain, and radiation patterns. Fig. 8 shows the respective simulated and measured resonant frequencies of 6.53 and 6.60 GHz when *Port1* is ON and others are terminated with matched load. On the other hand, the simulated and measured resonant frequencies of 7.65 and 7.70 GHz are obtained, respectively, when *Port2* is ON and remaining is terminated with matched load. Similarly, 9.09 and 9 GHz are obtained, respectively, when *Port3* is ON and remaining is terminated with matched load. The overall measured port isolations are greater than 18.1 dB at the operating frequencies. The respective measured gain values at resonant frequencies are 3.1, 4.7, and 3.9 dBi. Moreover, the measured results show good agreement with the simulations.

The simulated and measured radiation patterns at two principle cut-planes $\phi = 0°$ (*yz plane*) and $\phi = 90°$ (*xz plane*) at the frequencies of 6.6, 7.7, and 9.0 GHz are plotted in Fig. 9. All patterns are stable and unidirectional with measured front-to-back ratio of greater than 21, 13.2, and 15 dB, respectively. Also, the measured cross-polar level of the three resonant frequencies is better than –17, –11.2, and –12.3 dB, respectively, in the direction of maximum radiation. The overall size of the proposed design including feeding network is 34.5 mm × 29.1 mm × 1.57 mm.

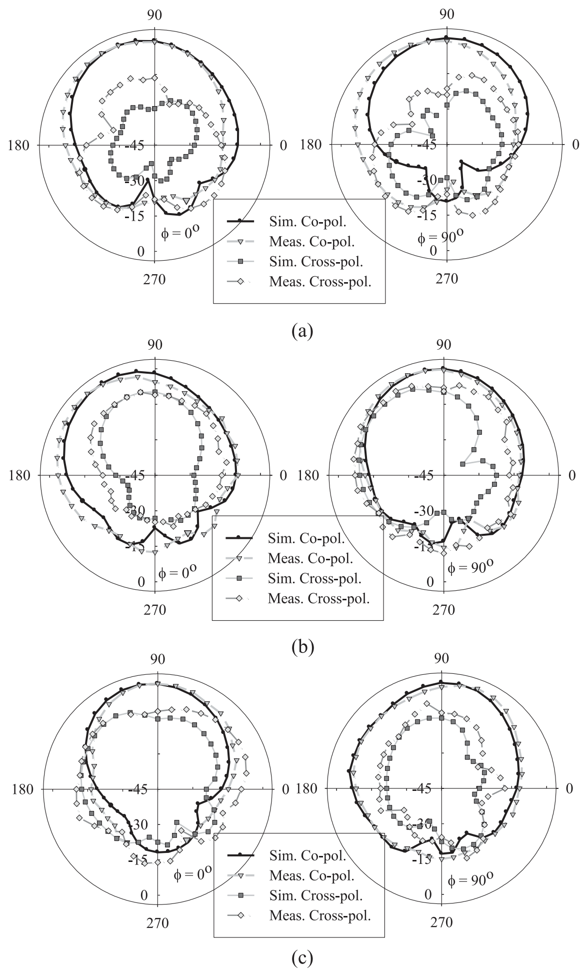

Fig. 9. Simulated and measured radiation patterns at frequencies of (a) 6.6, (b) 7.7, and (c) 9.0 GHz (when one port is ON, others are OFF).

TABLE I
PERFORMANCE COMPARISON OF THE PROPOSED ANTENNA WITH OTHER DESIGNS

Properties		Proposed Work $f_1 = 6.5$, $f_2 = 7.6$, $f_3 = 9$ GHz	[6] $f_1 = 9$, f_2=11.2 GHz	[7] $f_1 = 0.8$, $f_2 = 1.6$, $f_3 = 2.4$ GHz	[8] $f_1 = 7.8$, $f_2 = 9.4$, $f_3 = 9.8$ GHz
Thickness (*h*) (mm)		1.57	0.78	1.52, 1.52	0.78
No. of Layers		Single	Single	Two	Single
Gain (dBi)	f_1	3.68	4.3	0.85	7.2
	f_2	4.76	4.2	4.0	7.2
	f_3	4.54	--	4.23	7.0
Isolation (dB)	$\|S_{12}\|$	>21.3	>22	>29	>22.5
	$\|S_{13}\|$	>18.1	--	>19	>22.5
	$\|S_{23}\|$	>24.1	--	>20	>22.5
*Size (including feeding network)		$0.7\lambda_o \times 0.6\lambda_o$	$0.5\lambda_o \times 1.3\lambda_o$ (approx.)	$0.53\lambda_o \times 0.36\lambda_o$	$0.9\lambda_o \times 0.8\lambda_o$
Radiation Pattern		Unidirectional	Unidirectional	Bidirectional	Unidirectional
Component-Type		Ant. Triplexer	Ant. Diplexer	Ant. Triplexer	Ant. Triplexer

* λ_o is the wavelength at the lowest resonant frequency

Moreover, the proposed design possesses a simple and planar topology that is suitable to realize a compact and integrated system. To highlight the contribution of the proposed work, a comparative study with the previously reported works is tabulated in Table I. It can be observed that the proposed design owns relatively smaller circuitry in size with good radiation performance.

IV. CONCLUSION

A novel and small SIW cavity-backed self-triplexing slot antenna is proposed. A radiating slot on the top of the SIW cavity divides it into three parts and produces three different resonant frequencies when excited separately by microstrip lines. The proposed antenna element can be considered as an integration of one HM and two QM resonators. Due to this novel topology, the antenna achieves a small circuitry size with a measured three-port isolation of better than 18.4 dB. Moreover, the overall circuitry size including a feeding network of the proposed component is $0.7\lambda_o \times 0.6\lambda_o \times 0.03\lambda_o$. This makes it a more viable option for practical applications.

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