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Triple-Band Co-Polarized QMSIW In-Band Full Duplex (IBFD) Antenna

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Abstract

A compact co-linearly polarized triple band quarter mode substrate integrated waveguide (QMSIW) antenna with high isolation for in-band full-duplex (IBFD) applications is presented in this paper. The triple band radiation characteristics of the IBFD antenna is achieved by the simultaneous excitation of two hybrid TE130/310 modes and TE330 mode of the QMSIW cavities. The designed antenna exhibits a co-linearly polarized radiations at 9.11, 9.73 and 11.20 GHz. The transmitting (Tx) and receiving (Rx) antennas have identical polarization and nearly similar radiation characteristics. Moreover, it also exhibits high isolation more than 40 dB between the transmitting and receiving ports.

1. Introduction

Due to several inherent characteristics such as simultaneous transmission and reception capability by the same carrier frequency and double spectral efficiency compared to the half-duplex systems, full-duplex systems receive much more attention nowadays [1]-[3]. In full-duplex systems, both the transmitting and receiving antennas operate at the same frequency. High isolation is one of the essential requirements for the full-duplex systems. Polarization and pattern diversities are commonly used to obtain high isolation between the transmitting and receiving antennas of the full-duplex systems [4]-[8]. For high spectral efficiency, the transmitting and receiving antennas must have the same polarization. Nowadays, several co-polarized full-duplex antennas have been investigated in the literature [9]-[15]. In [9]-[12], the shorted TM1\2,0 microstrip patch antennas (MPAs) are used as radiating elements for In-Band Full Duplex (IBFD) systems. In [9], shorted microstrip patch antennas utilizes defected ground structure (DGS) to increase the isolation. In [10], a co-linearly polarized microstrip antenna with 4.6 % FBW is loaded with fence strip resonator to reduce the mutual coupling between the transmitting and receiving antennas. In [11], high port-to-port isolation is achieved using field confinement and ground perturbation techniques. However, most of these antennas radiates only at single band. To efficiently utilize the available spectrum, multiband antennas are preferred over the single band

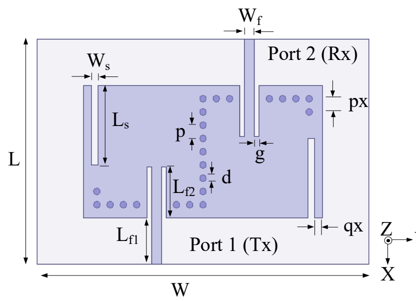

Figure 1. Triple band IBFD antenna [$L = 20$, $W = 36$, $L_{f1} = 7$, $L_{f2} = 7.75$, $W_f = 1.48$, $g=0.7$, $L_s = 12$, $W_s = 1$, $px = 2$, $qx = 1.2$, $p = 2$, $d = 1$ (in mm)].

antennas. Different technologies have been explored for the design of multiband antennas. Due to the inherent advantages such as low profile, lower cost, lower losses, high gain, high power handling capability, size miniaturization and uniplanar characteristics, the substrate integrated waveguide (SIW) is the most promising technology in the recent years [16]. Half mode SIW (HMSIW) and quarter mode SIW (QMSIW) are widely used for size miniaturization [17], [18]. These miniaturized version of SIWs utilizes the concept of magnetic wall for the bifurcation of SIW cavities. Several QMSIW multiplexing antennas are reported in the literature [19]-[21]. In all these reported antennas, one port can transmit only one frequency at a time. However, transmitting multiple-frequencies with single port is essential for compact multiband communication systems.

In this paper, a compact triple band co-linearly polarized QMSIW antenna for IBFD applications is investigated. The antenna is realized using two QMSIW cavities which shares a common via side wall leading to the compact size. The antenna utilizes two hybrid $TE_{130/310}$ modes and TE_{330} mode of the QMSIW cavities for the realization of triple band characteristics. The simple and unique placement of QMSIW cavities maintain low mutual coupling between the transmitting and receiving antennas without using any decoupling mechanism. Due to the confinement of the E-field within the QMSIW cavities, high isolation at all the three operating bands is obtained. The designed structure is fabricated and its characteristics are measured for demonstration.

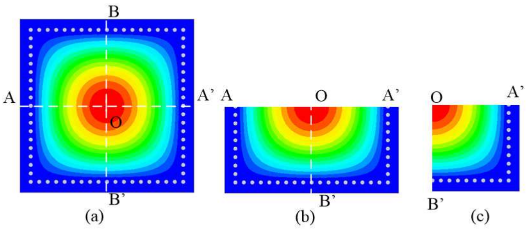

Figure 2. E-field distribution for TE_{110} mode (a) FMSIW (b) HMSIW (c) QMSIW

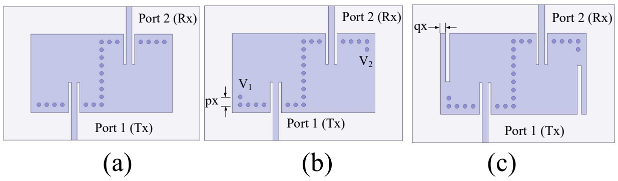

Figure 3. Different Stages (a) Stage-I (b) Stage-II (c) Stage-III

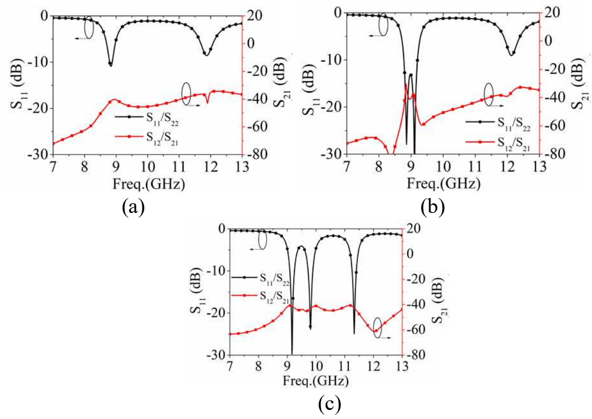

Figure 4. S-parameters of the different stages (a) Stage-I (b) Stage-II (c) Stage-III

2. Antenna Configuration

Figure 1 shows the proposed low-profile triple band co-linearly polarized QMSIW antenna for IBFD applications. The IBFD antenna is designed on 0.508 mm thick RT/Duroid 5880 substrate with dielectric constant 2.2 having overall volume of 36×20×0.508 mm^3. It consists of two QMSIW cavities placed side by side sharing the same row of metallic vias as one of their side walls. It is inset-fed by two microstrip feedlines through two ports designated as Port1 (Tx Port) and Port2 (Rx Port). These ports are orientated 180° apart as shown in Figure 1. A via and an open-ended rectangular slot are inserted at one of the open-ended edges of each QMSIW cavity for mode perturbation and better impedance match. The dimensions of the QMSIW cavities are chosen in such a way that all the operating frequencies lies in the X-band. The dimensions of the proposed IBFD antenna are provided in caption of Figure 1. The IBFD antenna is designed using ANSYS HFSS v22.

The presented triple-band IBFD antenna comprises of a pair of QMSIW cavity resonators, which acts as a basic antenna element. The QMSIW cavity resonator emerges from full-mode substrate integrated waveguide (FMSIW)

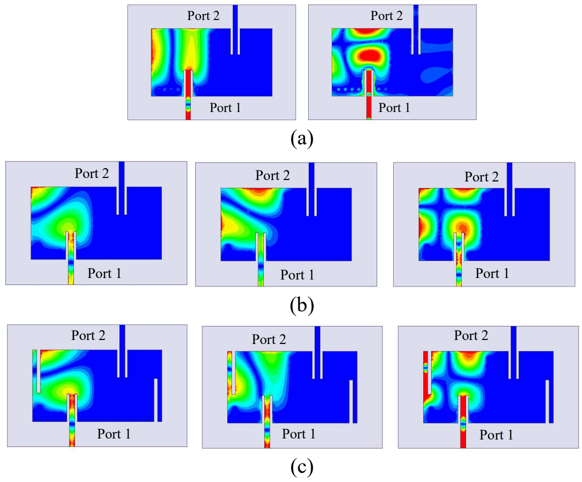

Figure 5. (a) E-field at 8.84 GHz and 11.84 GHz in Stage-I (b) E-field at 8.27, 9.11 and 12.13 GHz in Stage-II (c) E-field at 9.16 GHz, 9.81 GHz and 11.33 GHz in Stage-III

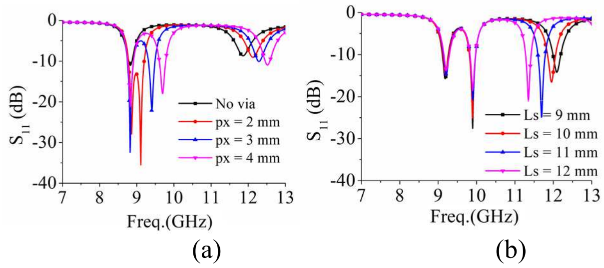

Figure 6. (a) S_{11} of Stage-II for different values of px, (b) S_{11} of Stage-III for different values of Ls

and half-mode SIW (HMSIW) cavity resonators as shown in Figure 2. HMSIW cavity can be created by bisecting the FMSIW cavity along the symmetrical plane AA' by applying the magnetic wall concept. By further bisecting the HMSIW cavity along the symmetrical plane OB', a QMSIW cavity can be obtained [18]. A square QMSIW cavity supports only TE_{mn0} modes, where m and n can have only odd values. The dominant mode in square QMSIW cavity is TE_{110} mode while the higher order modes are TE_{130}, TE_{310}, TE_{330}, TE_{350}, TE_{530}, etc.

The modes of the QMSIW cavity are chosen in such a way that their resonant frequencies lie in the X-band. Hence, TE_{130}, TE_{310}, TE_{330} modes are selected in this work for the design of IBFD antenna. The different stages of the designed IBFD antenna is shown in Figure 3 and their corresponding S-parameters are plotted in Figure 4. Stage I of the proposed IBFD antenna is realized with the utilization of two QMSIW cavities placed back to back sharing an array of vias as common side wall. These QMSIW cavities are inset fed through a pair of microstrip lines as shown in Figure 3(a). The antenna in Stage-I resonates at 8.84 GHz and 11.84 GHz through TE_{130} mode and TE_{330} mode, respectively [Figure 4(a)]. However, there is not proper matching at these frequencies. Here, the array of vias i.e. common side wall acts an electric wall which inherently provides low mutual coupling between the Tx and Rx ports. The E-field

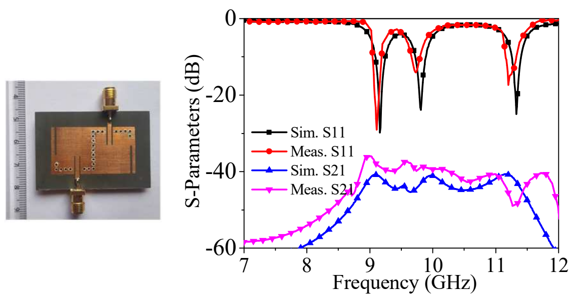

Figure 7. Simulated and measured S-parameters of designed IBFD antenna (Fabricated Prototype)

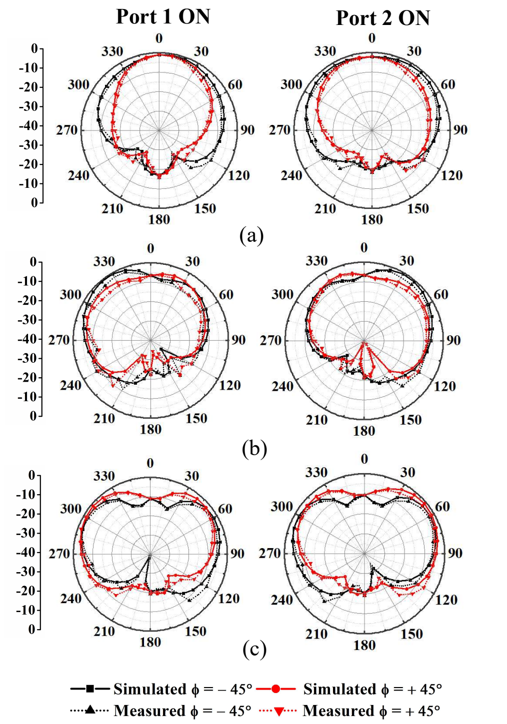

Figure 8. Radiation pattern of the designed IBFD antenna at (a) 1st band (b) 2nd band (c) 3rd band

distribution at these resonant frequencies are plotted in Figure 5 (a). These frequencies can be tuned by properly choosing the dimensions of the QMSIW cavities.

Figure 3 (b) shows the Stage-II of the proposed IBFD antenna. The vias V_1 and V_2 are inserted near one of the open-ended edges of the QMSIW cavities. The introduction of via V_1 perturbs the degenerate TE_{130} and TE_{310} modes of QMSIW cavity resulting in the bifurcation of frequencies [Figure 5(b)]. This bifurcation leads to the generation of two hybrid TE_{130}/TE_{310} modes named as Hybrid1 TE_{130}/TE_{310} and Hybrid2 TE_{130}/TE_{310} modes [22]. The combination of these hybrid modes not only improves impedance matching but also results in an increase in the impedance bandwidth [Figure 4(b)].

Further, to verify the role of via V_1, a parametric study is carried out by varying its position and their corresponding results are plotted in Figure 6 (a). As the value of px increases, i.e. via V_1 moves upward, it will strongly perturb the electric fields of Hybrid2 TE_{130}/TE_{310} mode, while the electric fields of Hybrid1 TE_{130}/TE_{310} mode will be minimally perturbed [Figure 5 (b)]. This upward movement of via results in shifting of the resonant frequency of Hybrid2 TE_{130}/TE_{310} mode to higher value that in-turn leads to dual band operation. Moreover, the upward movement of via V_1 also perturb the E-fields of TE_{330} mode in the similar manner as that of Hybrid2 TE_{130}/TE_{310} mode.

Stage-III of the proposed antenna is obtained by inserting a rectangular slot near one of the radiating open-ended edges of the QMSIW cavity as shown in Figure 3(c). The rectangular slot provides capacitive loading which in turn perturbs hybrid TE_{130}/TE_{310} modes and TE_{330} mode of the QMSIW cavity as shown in Figure 5(c). This perturbation improves the impedance matching of all the three operating bands. As the length L_s of the slot increases, the resonant frequency of TE_{330} mode shifts to lower value, while the resonant frequencies of hybrid TE_{130}/TE_{310} modes remains unaltered [Figure 6 (b)]. The S-parameters of the proposed IBFD antenna is plotted in Figure 4 (c). The IBFD antenna radiates at 9.16 GHz, 9.81 GHz and 11.33 GHz.

The high isolation between the transmitting and receiving ports is accomplished by strategical placement of QMSIW cavities that ensures the confinement of the E-field within the cavities. These QMSIW cavities share a common via wall which is also responsible for compact size and high isolation. Thus, the designed IBFD antenna exhibits an isolation better than 40 dB at all the three operating bands without using any decoupling mechanism as depicted in Figure 4 (c) and Figure 5 (c).

3. Results and Discussion

A prototype of the designed IBFD antenna is fabricated and its characteristics are measured to verify the present design approach. Figure 7 shows the photograph of the fabricated prototype. The overall footprint of the designed IBFD antenna is $1.52\lambda_0 \times 1.03\lambda_0 \times 0.015\lambda_0$, where λ_0 is the wavelength operating frequency of the first band. The S-parameters of the fabricated IBFD antenna prototype are measured using Agilent 5071C VNA and radiation patterns are characterized in the anechoic chamber and they have good agreement with each other. The simulated and measured S-parameters are plotted in Figure 7. The simulated operating frequencies of the IBFD antenna are 9.16 (9.08-9.25), 9.81 (9.71-9.90) and 11.33 (11.25-11.41) GHz, while the corresponding measured values are 9.11 (9.04-9.19), 9.73 (9.65-9.80) and 11.20 (11.15-11.35) GHz, respectively. The port-to-port isolation is better than 40 dB in simulation and 35 dB in measurements over all the operating bands.

The simulated and measured 2D far-field normalized radiation pattern in the planes of $\phi = \pm 45°$ of the designed IBFD antenna are shown in Figure 8. It can be observed that the measured radiation pattern agrees well with the simulated ones the measured radiation pattern agrees well

TABLE I
COMPARISON WITH OTHER REPORTED IBFD ANTENNAS

Ref	Ant. Footprint ($\lambda_0\times\lambda_0$)	No. of Bands	Pol.	f_0 (GHz)	Iso. (dB)
[9]	0.73×0.77	1	Co-LP	2.46	>25
[10]	0.25×0.25	1	Co-LP	2.44	>20
[11]	1.024×0.841	1	Co-LP	5.9	> 60
[12]	0.75×1.57	1	Co-LP	5.9	>35
[13]	0.63×0.63	1	Co-LP	6.29	>25
[7]	0.90×0.90	2	DP	2.45/5.25	>40
[8]	0.83×0.70	2	DP	2.45/5.25	>40
Prop.	1.52×1.03	3	Co-LP	9.11/9.73/11.20	>35

LP: Linearly Polarized, DP: Dual Polarized,

with the simulated ones. The radiation pattern under port 1 excitation (Tx port) is similar to that of the radiation pattern under port 2 excitation (Rx port), that verifies the identical radiation characteristics for transmitter and receiver ports. The simulated peak gains are 4.8, 6.8 and 4.65 dBi at the corresponding operating frequencies, while the measured peak gains are 4.68, 6.61 and 4.45 dBi. The measured radiation efficiency is over 80% for all the operating bands. Table I presents a comparison of the proposed antenna with other reported IBFD antennas to demonstrate the best part of our design. It is clear from the table that the designed co-polarized IBFD antenna operates at three frequency bands along with high isolation between the ports.

4. Conclusion

In this work, a compact and simple triple band co-polarized IBFD antenna is presented. The antenna is designed on the same substrate using two identical QMSIW cavities sharing a via side wall. The triple band is obtained with the utilization of two hybrid TE_{130}/TE_{310} and TE_{330} modes of QMSIW cavity excited simultaneously. The designed antenna radiates at 9.11, 9.73 and 11.20 GHz with the realized peak gains of 4.68, 6.61 and 4.45 dBi. To the best of authors' knowledge, the proposed IBFD antenna offers low profile, simple, compact size, ease of integration with planar circuits, triple band characteristics, co-polarized radiations with high Tx-Rx isolation without usage of any decoupling mechanism. The aforementioned characteristics of the proposed IBFD antenna have an application in military communication systems.

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