Design of Self-Quadruplexing Quadruple Band SIW Antenna with High Isolation

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Abstract. A new and compact self-quadruplexing Substrate Integrated Waveguide (SIW) cavity-fed patch antenna with quad-band operation is designed and reported in this paper. The designed antenna comprises four planar ports, a modified H-shaped slot, and a Substrate Integrated Waveguide (SIW) cavity. Initially, the rectangular slot is designed and altered its location to provide isolation (>22 dB) between any two ports. This slot is modified into H-shape, producing four patches facing four separate ports and radiating at four distinct frequencies (4.25, 6.09, 8.27, and 10.12 GHz) with minimum isolations exceeding 30.10dB. To achieve isolation of the port apply the center-off and provide isolation between two ports which is improved to ≥36.8 dB. The proposed model is compact and accessible. It is useful for portable devices.

Keywords: Substrate Integrated Waveguide (SIW) cavity · Quadruplexing antenna · Isolation

1 Introduction

Modern Wireless communication systems must integrate distinct components into a single platform and facilitate multi-band operations, given the trend toward downsizing [1]. Because of their large diameters, numerous antenna radiators must be installed on a single platform. More antennas are required to integrate on one platform to get these specifications. This issue can be avoided by sharing a single antenna with numerous feeding ports to function toward various frequencies or bands, this will eventually result in an inferior physical size [2]. Different methods, including element stacking and aperture segmentation, are presented in [3, 4] respectively. While aperture segmentation weakens the inherent isolation between any two ports, the stacking method expands complication and antenna footprint [5]. Defective ground construction [6] and Wilkinson power divider [7] have been employed to maintain good isolation. However, they demand more space and have significant back radiation.

Due to their high isolation, low loss, small size, and simple circuit integration, the Substrate Integrated Waveguide (SIW) supported antennas have recently attracted attention [6–9]. To ensure better port isolation this method can be applied to self-multiplexing (SM) antennas [10–14]. These antennas reduce the complete size of the RF component because they don't need an external multiplexing network.

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A self- diplexing antenna typically requires two feed lines at two various frequency bands. The self-triplexing antenna's ability to operate at multi-frequencies or bands has also been demonstrated [10–14]. For instance, in triple-band antennas T-shaped slots [14] with multi ports and dual-layer printed circuit boards [13] based on SIW have been employed. For compact applications in tri-band operation, rectangular and circular half-mode SIW cavities are presented [11]. A novel hybrid coupling strategy has been applied in recent research [12, 13], although it necessitates the use of at least one feed probe and two cavities are employed. This restricts antenna and restricts its use in planar portable devices. The design of all planar-fed SIW is an efficient small self-triplexing antenna that increases port isolations. It is quite extremely preferable even though the recently expressed self- triplexing antennas [10–15] reach maximum isolation of about 25 dB. Compared to the former the designed self-quadruplexing antenna achieved maximum isolation is about $>$ 33dB.

A compact self-quadruplexing planar-fed SIW cavity-based antenna design is presented in this paper. The proposed model operates at various frequencies of 4.25 GHz, 6.09 GHz, 8.27 GHz, and 10.12 GHz. The proposed design uses four planar microstrip feeding ports and provides superior isolation ($\geq$ 36.8 dB) with a steady gain in all bands. The proposed antenna structure was designed and analyzed with ANYSIS High-Frequency Structure Simulator (HFSS).

2 Design Procedure for the Proposed SIW Antenna

The proposed antenna layout and dimensions are displayed in Fig. 1. In Fig. 2, shows three distinct stages of the designed model. The RT/Duroid 5870 substrate with relative permittivity Er $= 2.33$, $tan\delta = 0.0012$, and thickness $(ls) = 0.787$ mm is used to produce a SIW cavity ($L \times W$). The SIW cavity resonates at a frequency (f_{mn0}) that can be calculated as below formula [7].

$$f_{mn0} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{L_{eff}}\right)^2 + \left(\frac{n\pi}{W_{eff}}\right)^2} \tag{1}$$

Here $m = 1, 2\ldots$and $n = 1, 2\ldots.$are the half wavelength variations where μ is relative permeability, and Er is the relative permittivity of the given substrate. Where (L_{eff}) and (W_{eff}) are the effective length and width of the SIW cavity can be found by following the below expressions [7].

$$L_{eff} = L - 1.08\frac{d^2}{p} + 0.1\frac{d^2}{L} \tag{2}$$

$$W_{eff} = W - 1.08\frac{d^2}{p} + 0.1\frac{d^2}{W} \tag{3}$$

In order to gain the lowest possible leakage energy, the pitch, and diameter of the via are selected such that $0.5 \leq d \leq 0.1\lambda_0$ (where λ_0 is the free-space wavelength at the resonant frequency-loss. The leaky SIW technique and low-loss substrate obtain unidirectional radiation characteristics [10–15]. To excite the cavity, four planar microstrip

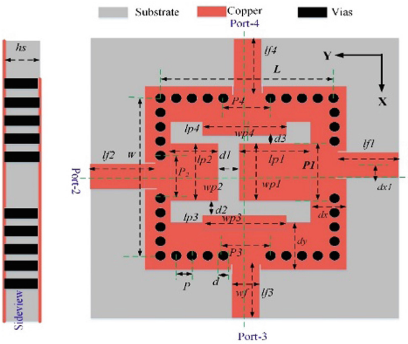


Fig. 1. Design of proposed quad-band antenna. ($L = W = 22$, $ls = 0.787$, $p = 1$, $d = 1$, $wf = 2.33$, $dx = 3.8$, $dy = 5.7$, $dx_1 = 2$) all dimensions are in millimeters.

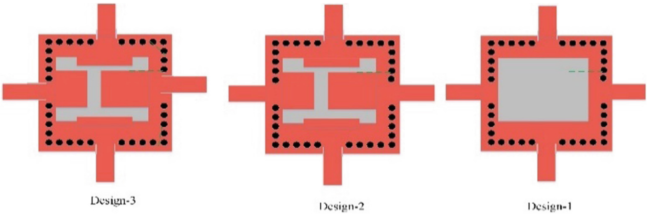


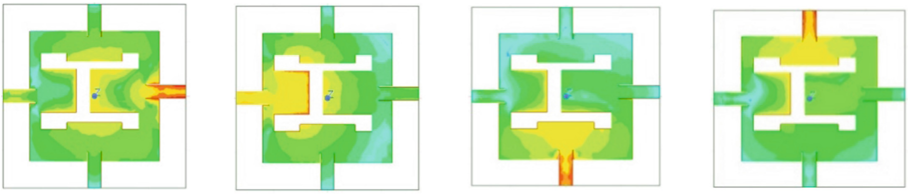
Fig. 2. Design stages for proposed model (Design-3).

feeds with a width (ω_f= 2.33 mm) are placed in four directions. A modified H-shaped slot is used to disturb the cavity, which increases capacitive loading and the resonant frequency decreases to below the operating frequency. By reducing the resonance frequency, high compactness can be achieved. Figure 3 displays the E-field distributions of the disturbed square resonator. It supports TE110 at 4.25 GHz (excited with Port1) and 6.09 GHz (excited with Port2), as can be seen, with the highest intensities at the corner slot that are facing Port1 and Port2, individually. Additionally, TE210 can be observed at 8.27 GHz (excited with Port3) and Port4 is excited at 10.12 GHz, the slot edges that face Port3 have the largest field concentration at this frequency. The S- parameter responses of the designed model is shown in Fig. 4.

1. $f_1 = 4.25$, $f_2 = 6.09$, $f_3 = 8.27$ and $f_4 = 10.12$ GHz are the four frequencies at which the antenna operates.
2. For all four bands respectively, peak gains of 3, 3.3, 3.9, and 4.1dBi are attained.

2.1 Design of SIW Cavity with Single Slot

In the first design, the rectangular slot ($0.24\ \lambda_g \times 0.21\ \lambda_g$) is created. The cavity's center (i.e., at $dx = 4.9$ mm and $dy = 3.1$ mm), as illustrated in Fig. 2. The dx is fixed at 4.9mm, and the minimal isolation of one and other ports increases. It reveals that all isolations—aside from |S31|—are higher than 28.2dB. The area of the rectangular slot



(a) (b) (c) (d)

Fig. 3. E – Field distribution of the proposed model at (a) 4.25 GHz, (b) 6.09 GHz, (c) 8.27 GHz, and (d) 10.12 GHz.

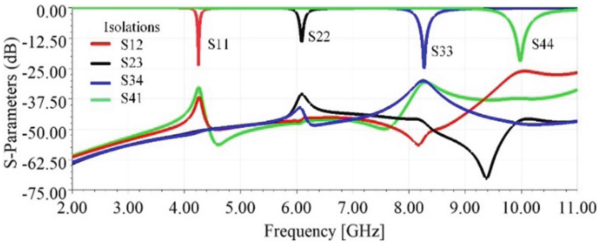


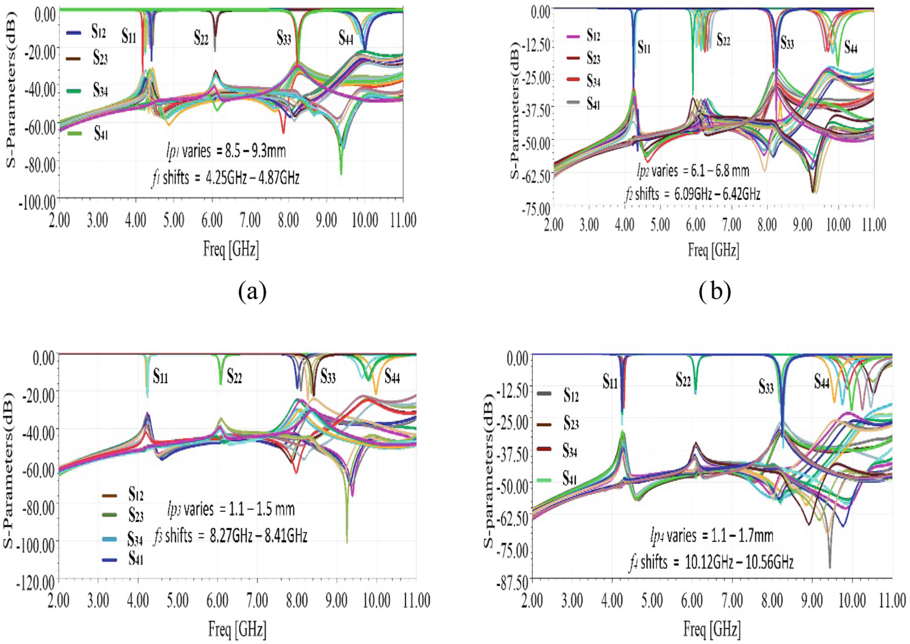
Fig. 4. S- Parameters performance of proposed design

is modified into the x-axis from the center. So the offset space dx (4.9 mm $\leq dx \leq$ 6.1 mm) to obtain a satisfactory level of isolation between all ports. In a similar way the y-direction, it is varying dy from (3.1 mm $\leq dy \leq$ 4.4 mm). Therefore, isolations of all the ports are increased to greater than 31.22dB. Finally, the space $dx = 5.9$ mm and $dy = 3.7$ mm, which is fixed and increases the reflection coefficient from all four ports.

2.2 Design of Modified SIW Cavity Slot

Four patches of varying lengths are constructed based on the previously optimized slot location, with lp_1 facing P1, lp_2 facing Port2, lp_3 facing Port3, and lp_4 facing P4 respectively. This allows the radiator to transmit at four separate frequencies. The slot outline now resembles an altered H-appearance slot with vertical and horizontal components. It enables port1 and port2 to be orthogonal to port3 and port4 (along with their associated patches) (and its patch).

The parametric studies are conducted and shown in Fig. 5 to explain independent frequency tuning. This demonstrates how altering the patch lengths ($lp_1/lp_2/lp_3/lp_4$) can adjust the resonance frequencies for the antenna. The variations in $lp_1/lp_2/lp_3/lp_4$ have a direct impact on slot widths (d1/d2) and slot location, and hence, isolation as well. Accordingly, it is observed that in order to maintain good isolation when varying $lp_1/lp_2/lp_3/lp_4$, the vertical slot width (d1) and horizontal slot width (d2) should both be kept at or above 1.5 and 0.5 mm, respectively. In Table 1, all adjustable frequency ranges are displayed in relation to their respective patch lengths.



(a) (b)

(c) (d)

Fig. 5. S- Parameter performance of resonant path for (a) *lp1, (*b) *lp2,* (c) *lp3,* and (d) *lp4.*

Table 1. Tuneable operating frequencies at all ports.

Tuning Frequency (GHz)	Variable Range (mm)
$4.25 \leq f_1 \leq 4.87$	$8.5 \leq lp_1 \leq 9.3$
$6.09 \leq f_2 \leq 6.42$	$6.1 \leq lp_2 \leq 6.8$
$8.27 \leq f_3 \leq 8.41$	$1.1 \leq lp_3 \leq 1.5$
$10.12 \leq f_4 \leq 10.56$	$1.1 \leq lp_4 \leq 1.7$

3 Design of Slot Modified and Off-Centered Port 1 in the SIW Cavity

Figure 5 shows the minimum isolations between any two ports. It shows that all the isolations are higher than 31.22dB. This is because ports port1 and port2 are aligned increasing coupling. Port1 is therefore slightly offset in the horizontal direction (d×1) in order to break the symmetry (moved from the center toward the edge). The trade-off between |S12| and |S23| (or |S34| and |S41) can be seen in Fig. 5. For the sake of brevity, the port2 results are not considered when dx1 is increased above 2 mm from the x-axis. So to achieve improved isolations |S12| (>33.8 dB), |S23| (>35.4 dB), |S34| (>35.2 dB) and |S41| (>35.80.2 dB), it is possible to fix dx1 at 2 mm from x-axis. Thus, a goal to maintain all isolations at or above 31.22 dB is satisfied. The radiation patterns of various frequencies and angles are shown in Fig. 6.

The measured radiation patterns at various frequencies with respect angles ($\phi = 0°$ and $\phi = 90°$) are shown in Fig. 6. In the ($\phi = 0^o$) plane the X-polarization and Co-polarization with various frequencies are $\geq$ 21dB and in ($\phi = 90^o$) plane $\geq$ 18 dB. The reported model achieved high isolation and is useful in X-band applications compared to the recently designed antenna. The proposed quad-band is more compact and achieved high isolations.

4 Conclusion

A compact self-quadruplexing quadruple band with improved isolation cavity-backed Substrate Integrated Substrate (SIW) antenna capability is presented. The simulated gain for the antennas at 4.25 GHz, 6.09 GHz, 8.27 GHz, and 10.12 GHz) and achieved gain values are 3, 3.3, 3.9, and 4.1dBi) respectively. The radiation patterns at various frequencies and angles are simulated. The layout makes it simple to tune individual frequencies using a unique variable. The position of the ports used to improve isolations ($\geq$ 36.8 dB) among the ports. Therefore compared to the most recent designs, the projected design is compact and has a higher level of isolation. It finds applications in mobile and portable devices.

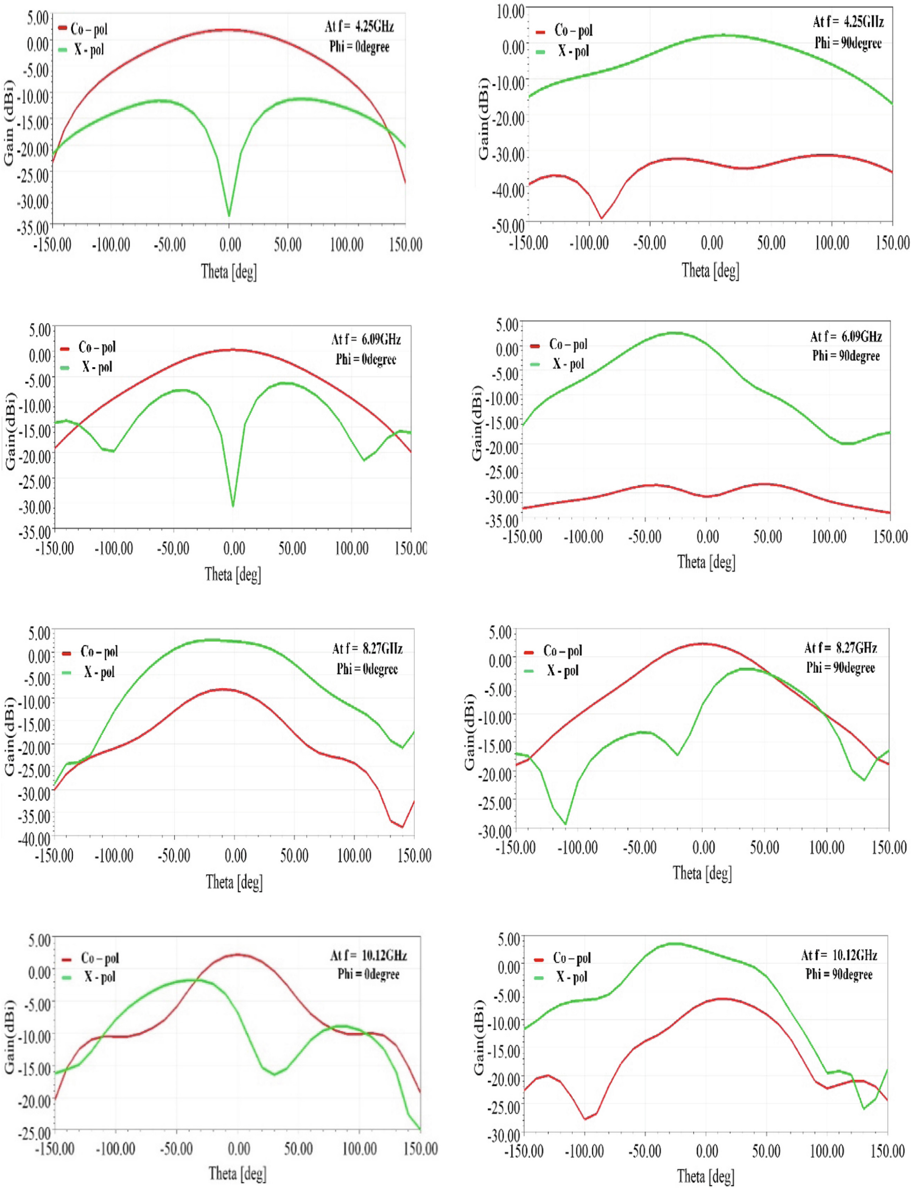


Fig. 6. Radiation patterns at various frequencies and angles.

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