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A Polarization Diversity Substrate Integrated Waveguide fed Rectangular Dielectric Resonator Antenna

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***Abstract*—In this paper, a polarization diversity dielectric resonator antenna (DRA) is presented. In the proposed design, DRA is fed by using two narrow slots on the top wall of two adjacent substrate integrated waveguide structures, which shares a common row of metallic vias. The orientation of the slots are orthogonal to each other which generates two linear orthogonally polarized radiation pattern at same frequency to implement polarization diversity. The rectangular DRA is excited in higher order TE_{113} mode in order to obtain a DRA with larger dimension at 10 GHz. The measured impedance bandwidth (S_{11} <-10 dB) for *Port1* is 4.6% (9.34-9.78 GHz) and that for *Port2* is 8.4% (9.2-10.01 GHz). Over the operating bandwidth, the measured isolation between the two ports is better that 25 dB. The antenna is radiating in broadside direction with the peak gain of 6.1 dBi at *Port1* (horizontal polarization) and 5 dBi at *Port2* (vertical polarization). The envelope correlation coefficient (ECC) is also studied to evaluate the MIMO performance of diversity antenna. The measured result shows a good MIMO performance with envelope correlation coefficient (ECC) smaller than 0.003 over the entire spectrum.**

I. INTRODUCTION

The polarization diversity antenna has received attention due to their ability to improve the wireless link and overall system performance. Dual polarization operations are needed in many systems like polarimetric radar, synthetic aperture radar system to improve the target detection range [1], [2]. Moreover, polarization diversity is also needed in wireless communication applications to increase the channel capacity. Several works on dual polarized microstrip patch antennas have been reported in the past [3]-[6]. However, larger metallic losses in the patch antenna restricts them to be use in high frequency applications. On the other hand, dielectric resonator antenna (DRA) has been considered as a possible alternative of planar metallic antennas at high frequency due to several potential advantages such as light weight, small size, negligible conductor loss, no surface wave generation, relatively wider bandwidth etc [7]. Several dual polarized DRA have been reported in the past [8]-[14]. For instance, Huang *et. al.* [8] have demonstrated two possible ways to design dual polarized DRA. In [9], dual polarization is achieved by two methods: (a) using two narrow slots forming T-shaped configuration and (b) using hybrid CPW and slot feed mechanism. Input isolation better than 35 dB has been obtained over the band. A wideband dual polarized DRA using Hook- and 3-D J-shaped probe has been investigated by Chair *et. al.* [10]. Tang *et. al.* [11] have introduced balanced slot coupled feed to achieve high isolation and excellent polarization purity in dual polarized DRA. In [12], odd and even modes of CPW structure are utilized to achieve dual polarization using single aperture. A dual polarized two element thin dielectric resonator antenna for microwave imaging has been reported in [13]. Fang *et. al.* [14] have demonstrated theoretically and experimentally the three port cylindrical dielectric resonator antenna for polarization diversity. Most of these designs were below X-Band.

The dual polarization is related to the excitation of antenna using two orthogonal polarization and it is difficult to design dual polarized DRA at high frequency owing to its small space and stronger coupling between feeders. In this paper, a substrate integrated waveguide (SIW) fed dual polarized rectangular DRA is presented. In order to get DRA of larger dimension at 10 GHz, it is excited in its higher order TE_{113} mode instead of fundamental TE_{111} mode [15]. The horizontal and vertical polarization are achieved by exciting DRA with transverse and longitudinal slots, respectively. A prototype of proposed antenna is built and tested to verify the simulations using Ansoft HFSS.

II. ANTENNA DESIGN

Before embarking on the details of dual polarized antenna, initially a two adjacent substrate integrated waveguide (SIW) structure which shares a common row of metallic vias is designed to operate in X-band. Recently, SIW technology has become very popular among the researchers, which implements non planar waveguide circuits in planar form [16]. SIW

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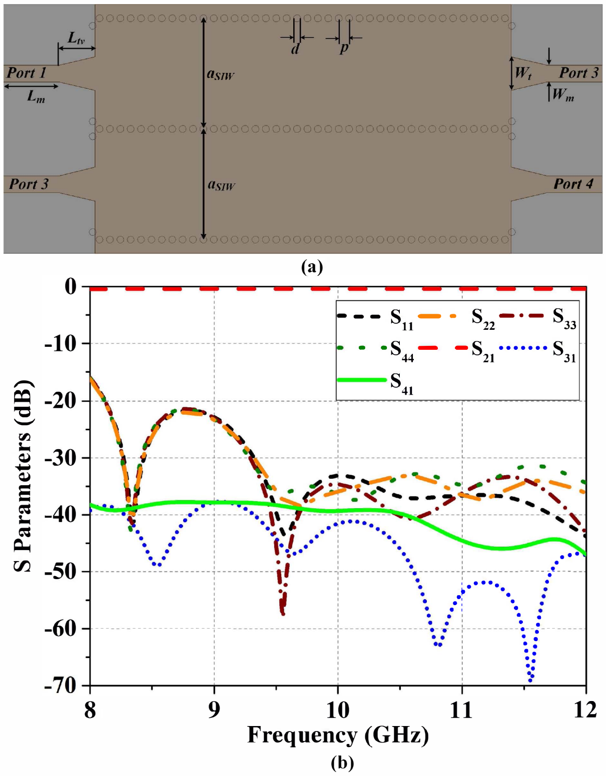

Figure 1. (a) Top view of two adjacent SIW structure (b) Simulated S-parameter response

is a good compromise between microstrip line and air filled metallic waveguide. Figure 1(a) depicts the top view of two adjacent SIW structure. The SIW is designed on RT/Duroid 5880 of dielectric constant 2.2 and thickness 0.787 mm. The SIW consist of two rows of metallic vias of diameter d and separated by a distance a_{SIW}. The two neighbouring vias are p distance apart. The diameter (d) and pitch (p) of the via holes are chosen following the design criteria as $d/p > 0.5$ and $d/\lambda_0 < 0.1$ to maintain minimum leakage of energy. The SIW width a_{SIW} is chosen for single mode TE_{10} operation and is excited by 50 Ω microstrip line [17]. The simulated response of two adjacent SIW structure is shown in Figure 1(b). From the figure, it is observed that throughout the X-band the return loss is better than 20 dB for all the ports with the maximum insertion loss of 0.48 dB. The port to port isolation is better than 35 dB over the entire band.

Since, SIW is a high Q device and DRA is low loss radiator, then SIW-DRA forms an excellent antenna system. SIW provides a compact, high Q and low profile feeding system and minimizes radiation loss and parasitic radiation. First systematic study on substrate integrated waveguide fed dielectric resonator antenna was carried out by Wahab *et. al.* [18]. Figure 2 shows the top view of proposed dual polarized SIW-DRA along with the fabricated structure. The proposed antenna comprises of two adjacent SIW structure, which share a common row of metallic vias. The DRA is excited by two narrow slots of different orientations *viz.* transverse (*Port1*)

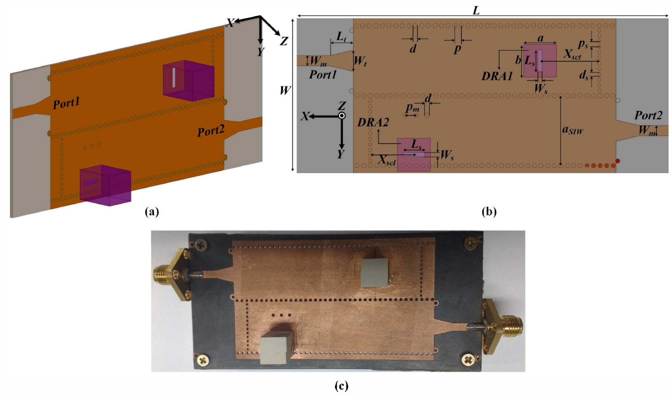

Figure 2. (a) 3D view of proposed antenna (b) Top view of proposed antenna (c) Fabricated prototype

and longitudinal (*Port2*) slot, respectively on the top wall of SIW. With reference to the coordinate system (see Figure 2a), the DRA fed by transverse slot will produce horizontal polarization whereas the DRA fed by longitudinal slot will produce vertical polarization. In the present design, the DRA is excited in its higher order TE_{113} mode instead of fundamental TE_{111} mode to obtain a larger DRA at 10 GHz. The dimensions of DRA are: a=b=7.5 mm and d=10.16 mm and is designed using RT/Duroid 6010 of ϵ_{rd}=10.2. The theoretical resonant frequency determined from dielectric waveguide model [15] for the said dimensions is 10 GHz which fairly agrees with the simulated value of 9.76 GHz when excited by transverse slot and 9.75 GHz when excited using longitudinal slot. The shift in the frequency is due to the fact that mathematical analysis considers infinite ground plane and did not take the slot effect into account. Initially, the transverse slot is placed $X_{sct} = \frac{\lambda_g}{2}$ apart from the shorting wall and the longitudinal slot is placed $X_{scl} = \frac{\lambda_g}{4}$ from the shorting wall (where λ_g is the wavelength in SIW). The slot position is further optimized by simulations using Ansoft HFSS in order to efficiently couple the energy to DRA. In the case of longitudinal slot excitation three extra vias are embedded in the SIW for the matching purpose [19].

III. Results and Discussions

To validate the dual polarized design, a prototype is built and tested. The optimum dimensions are: a=7.5 mm, b =7.5 mm, h=10.16 mm, a_{SIW}=16 mm, p=1.5 mm, d=1 mm, X_sct= 13.5mm, X_{scl}= 10mm, p_s=1.3 mm, d_s= 0.8 mm, p_m=2 mm, L_s=5 mm, W_s=1 mm,W_m=2.4 mm, W_t=4.9 mm, L_t=5.2 mm. The simulated and measured scattering parameter response of the proposed antenna is shown in Figure 3. It is observed that, simulated resonant frequency of the two polarization is almost same i.e. 9.76 GHz whereas the measured resonant frequency is 9.5 GHz for both the polarization state. The simulated and measured impedance bandwidth (for S_{11} <-10 dB) for *Port1* (horizontal polarization) is 4.8% (9.5-9.97 GHz) and 4.6% (9.34-9.78 GHz), respectively. For the *Port2* (vertical polarization), the simulated and measured impedance bandwidth is 9.8% (9.35-10.32 GHz) and 8.4% (9.2-10.01 GHz),

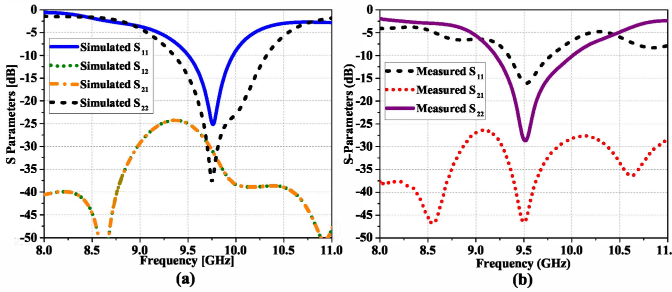

Figure 3. (a) Simulated (b) Measured S-parameter response of the proposed antenna

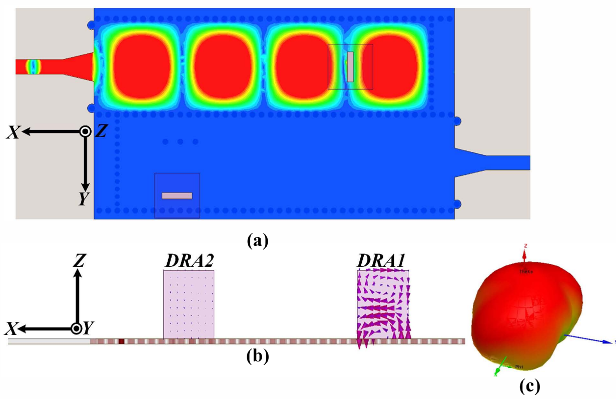

Figure 4. (a) Electric field distribution in SIW when *Port1* is excited (b) Vector electric field distribution in DRA (c) 3D radiation patten

respectively. It is found that, over the operating bandwidth the simulated and measured isolation between the ports is better than 24.4 dB and 25 dB, respectively. A little deviation are not unusual in DRA measurement and can be attributed to fabrication tolerances and the inevitable air gap that exists between DR and feeding structure.

Figure 4 shows the electric field distribution in SIW and DRA when *Port1* is excited and *Port2* is terminated with matched load. It is observed that the *DRA1* is excited by transverse slot in TE_{113} mode generating linear horizontal polarization. Figure 5 shows the electric field distribution in SIW and DRA when *Port2* is excited and *Port1* is terminated with matched load. It is found that the *DRA2* is now excited by longitudinal slot in TE_{113} mode generating linear vertical polarization. The three dimensional radiation pattern of the proposed antenna is shown in Figure 4(c) and Figure 5(c). With the reference to figure, it is noticed that the pattern exhibits change of polarization of the antenna with change of excitation port without much variation in the radiation pattern. This confirms the polarization diversity nature of the antenna.

The simulated and measured normalized radiation pattern in depicted in Figure 6. The proposed antenna radiates in broadside direction with the cross polar level below 15 dB at both the ports along the broadside direction. The proposed antenna achieves a peak gain of 6.1 dBi when excited at *Port1* and 5 dBi when excited at *Port2*.

Next, in order to evaluate the MIMO performance of the diver-

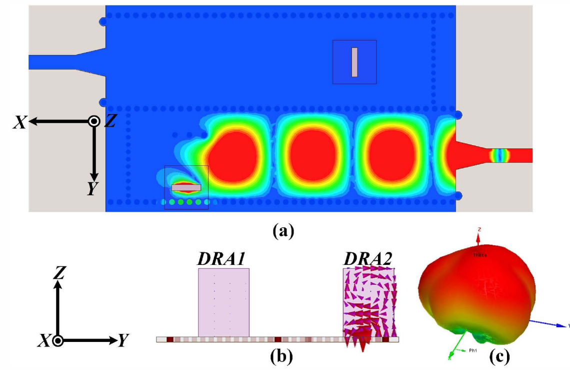

Figure 5. (a) Electric field distribution in SIW when *Port2* is excited (b) Vector electric field distribution in DRA (c) 3D radiation patten

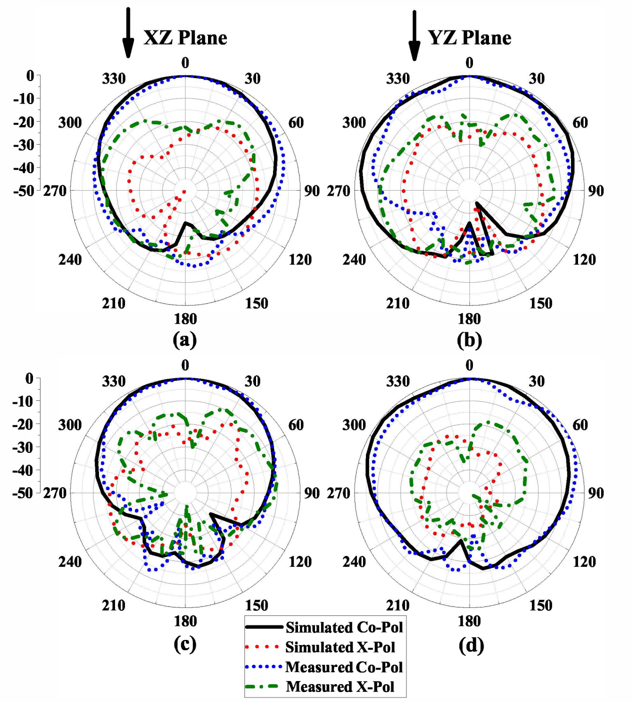

Figure 6. Simulated and measured normalized radiation pattern (a) *Port1* XZ-Plane (b) *Port1* YZ Plane (c) *Port2* XZ-Plane (d) *Port2* YZ-Plane

sity antenna, the envelope correlation is studied. A broadband calculation of envelope correlation coefficient (ECC) can be calculate using S-Parameters of the antenna, assuming the antenna elements are well matched and lossless [20], [21] as:

$$\rho_{e,12} = \frac{|S_{11}^{*}S_{12} + S_{12}^{*}S_{22}|^2}{(1-(|S_{11}|^2+|S_{21}|^2))(1-(|S_{22}|^2+|S_{12}|^2))} \quad (1)$$

Figure 7 depicts the simulated and measured envelope correlation of the diversity antenna, and they reasonably agrees with each other. It is observes that across the entire band the ECC is smaller than 0.003, satisfying the low-EC criteria (ECC<0.3) [20] for MIMO system.

IV. Conclusion

A polarization diversity rectangular dielectric resonator antenna has been presented. The proposed antenna is excited

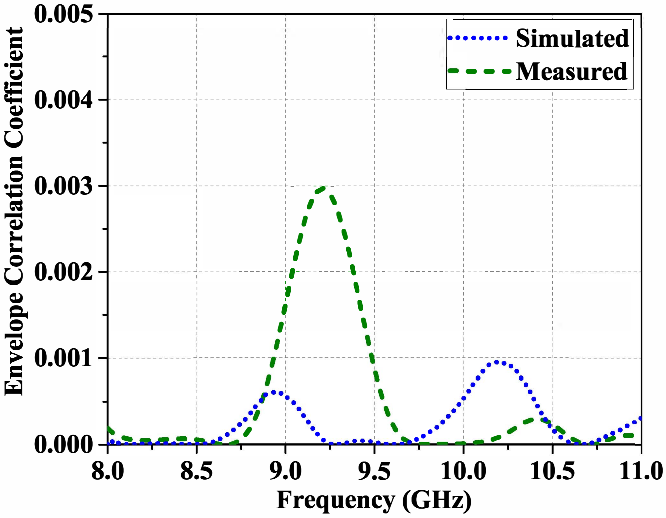

Figure 7. Simulated and measured envelope correlation coefficient (ECC)

using narrow slots of different orientations on the top wall of substrate integrated waveguide. The measured impedance bandwidth (for S_{11} <-10 dB) for *Port1* (horizontal polarization) is 4.6% (9.34-9.78 GHz) and for *Port2* (vertical polarization) is 8.4% (9.2-10.01 GHz). It has been found that, across the entire bandwidth the measured isolation between the two ports is better than 25 dB. The antenna radiates maximum in the broadside direction with the cross polar level below 15 dB along the broadside direction. Moreover, the proposed diversity antenna shows a good MIMO performance with envelope correlation smaller than 0.003 throughout the spectrum. The present antenna can be extended to dual polarized array for MIMO applications.

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