Design, Implementation and Experimental Comparison between Two Dual Polarized 2.4GHz Microstrip Patch Antennas

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***Abstract*—This paper presents the design and implementation of two dual polarized microstrip patch antennas for 2.4GHz In-band Full Duplex (IBFD) wireless applications. Both antennas use orthogonal feeding ports but differ in feeding structures. The performance of both implemented antennas has been compared by measuring the interport isolation (S_{12}) at required operating frequency around 2.4GHz. The implemented quarter wave microstrip fed antenna provides 43dB interport isolation while slot coupled version has 70dB isolation between transmit and receive ports at centre frequency. The slot coupled antenna provides more than 55dB interport isolation for 50MHz antenna`s 10 dB input impedance bandwidth.**

I. Introduction

The spectral efficiency of wireless communication systems can be doubled by transmitting and receiving simultaneously on the same carrier frequency which is called In-band full duplex (IBFD) wireless communication operation [1]. IBFD is one of the emerging technologies for next generation networks and is one potential candidate for 5G networks. In Band Full Duplex has also potential to coup with several issues in current wireless networks [2].

IBFD transceiver with shared antenna architecture use single antenna both for transmit and receive operation. The other option is to use two separate antennas (separate antenna architecture) for transmit and receive chains working at same radio frequency. A large amount of self interference (generated by coupling from its own transmitter) suppression at receiver is required for In-Band Full Duplex (IBFD) wireless operation. The self interference is normally suppressed at multiple stages across wireless transceiver [3-4]. A dual port, dual polarized microstrip patch antenna with high interport isolation along with self interference suppression at analog and digital stages, is required to realize simultaneous transmit and receive wireless operation at same frequency using single antenna.

Microstrip patch antennas with improved feeding techniques and orthogonally polarized for transmit and receive operation can effectively reduce mutual coupling between ports in order to achieve high interport isolation [4]. Such dual polarized antennas with improved feeding techniques may use external self interference cancellation mechanisms to achieve additional interport isolation. Normally, the external self interference cancellation techniques electronically process and combine sampled transmit and receive signals to suppress the self-interference [5]. Some stacked/multi layers microstrip patch antennas have also been implemented with good interport isolation performance [6].

In this work, two microstrip antennas with different feeding structures have been implemented and compared by measuring their interport isolation (S_{12}) to show the effect of feeding mechanism on interport isolation. The first antenna deploys two quarter wave microstrip feed lines for impedance matching and feeding patch antenna from orthogonal edges while in second antenna, one port is slot coupled instead of quarter wave feed line.

II. Dual Polarized Microstrip Fed Patch Antenna

The geometry of dual polarized 2.4GHz square microstrip patch fed with two quarter wave microstrip lines from two orthogonal edges is shown in Fig.1. The dimensions of antenna are kept identical in order to operate antenna at same transmit and receive frequencies. The antenna was simulated using Keysight Advanced Design System (ADS) Momentum software.

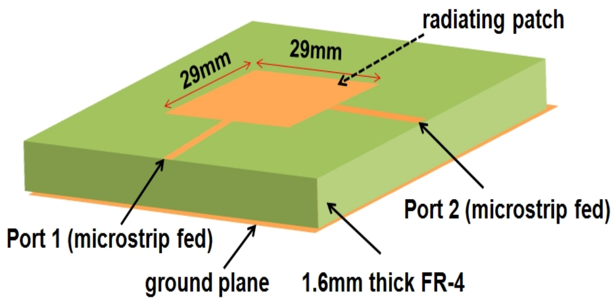


Fig. 1. Geometry of dual port microstrip patch antenna with both quarter wave microstrip fed ports

As reported in [7] and verified by simulation results in Fig.1, the maximum interport isolation for dual polarized microstrip patch antenna at required operating frequency is achieved when both perpendicular ports feed the antenna from the centre of respective edge. ADS Momentum simulation results in Fig.2 for different feeding locations of Port2 (d=0.5mm, 1mm and 1.5mm) on respective edge of antenna clearly demonstrate the effect of feeding point on interport isolation notch frequency. For example, with d=1.5mm the interport isolation is 44dB as compared to 40dB for d=0mm; however, the interport isolation notch frequency is also shifted from 2.4GHz to 2.64GHz.

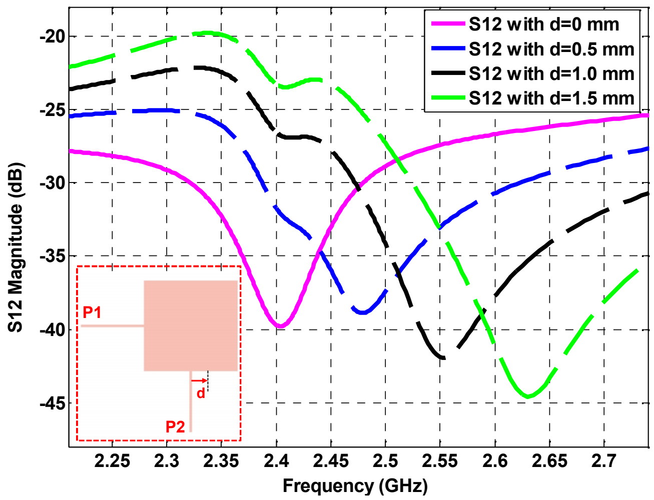
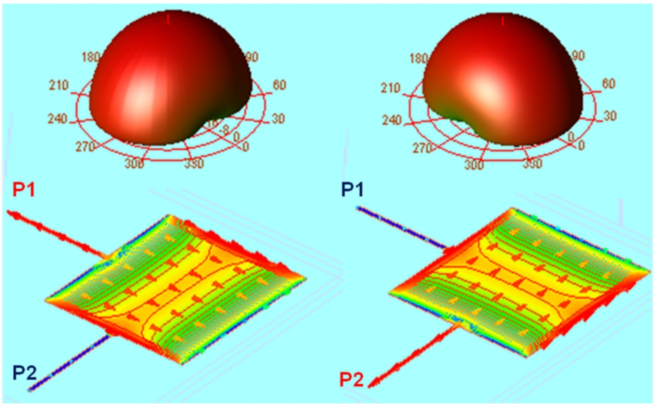


Fig. 2. Interport isolation vs feeding location from respective antenna edge

The simulated radiation characteristics of dual polarized microstrip patch antenna fed through quarter wave length impedance transformer microstrip transmission lines are shown in Fig.3 for each port excitation while the other port is terminated with 50 ohms.



(a) Port 1 excitation (b) Port 2 excitation

Fig. 3. Simulated Radiation characteristics of dual polarized antenna for each port excitation

The proposed antenna is clearly dual polarized (orthogonal polarization) as it is linear vertical polarized for excitation from one port and linear horizontal polarized for other port excitation as shown in Fig.3.The simulated gain is 4.1dBi for each port excitation. The antenna transmits and receives with orthogonal polarization and it effectively provides propagation domain isolation between transmit and receive RF signals.

The antenna was implemented on 1.6mm thick FR-4 substrate (ε = 4.4, tangent loss =.02).The implemented antenna is shown in Fig.4. One port is to transmit RF signal and other is used to receive radio signal.

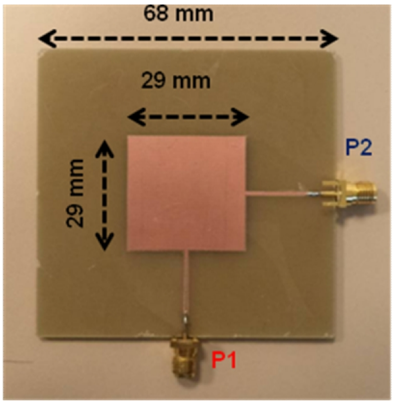


Fig. 4. Dual polarized 2.4GHz patch antenna implemented on 1.6mm thick FR-4 substrate

E5062A RF Network Analyzer was used for S_{11} and S_{22} measurements for port 1 and port 2 respectively and isolation (S_{12}) between the two ports. SOLT calibration for network was performed using Keysight 85032E calibration kit. As shown in Fig.5, the measured return loss (S_{11}, S_{22}) and interport isolation (S_{12}) are around 20dB and 43dB respectively at centre frequency. The interport isolation is better than 35dB for 50MHz antenna's 10dB input impedance bandwidth. The simulated and measured results are in close agreement with each other.

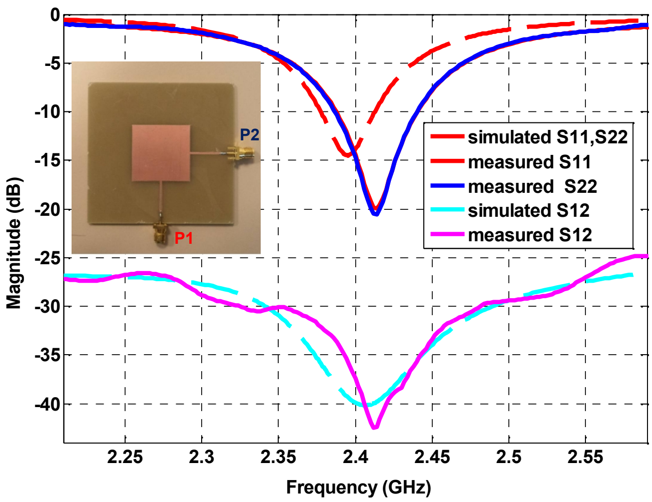


Fig. 5. Simulated and measured S11, S22 and S12 parameters for dual polarized microstrip fed microstrip patch antenna

III. DUAL POLARIZED SLOT COUPLED PATCH ANTENNA

The interport isolation of orthogonally fed patch antenna can be improved significantly if one port is slot/aperture coupled instead of feeding with quarter wave microstrip feed line. The slot coupled port excites the antenna through a small aperture in the ground plane. The shape of coupling slot greatly affects the amount of coupling from feed line to radiating element and the rectangular slot has better coupling efficiency as compared to circular coupling slot for a given area of aperture [8]. Such structure consists of two substrate layers as shown in Fig.6. The top substrate layer has radiating element on upper side. The second substrate has ground plane with rectangular coupling slot on top side and 50 ohms microstrip feed line on its lower part. The length of slot determines the amount of coupling and level of back radiation. The coupling level also depends upon the width of slot but it is less sensitive as compared to its dependency on slot length and the maximum amount of coupling is achieved when the feed line is placed perpendicular to centre of coupling slot [9].The width of feed line define its impedance and also effects the coupling level between feed line and radiating patch.

In our implemented structure, both substrate layers are comprised of 1.6mm thick FR-4 substrate (ε = 4.4, tangent loss =.02) as shown in Fig.6.The optimized dimensions for both radiating element and feeding structures are also shown in Fig.6.

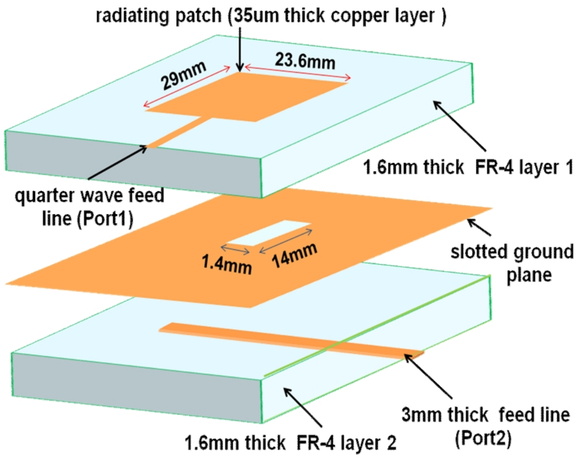
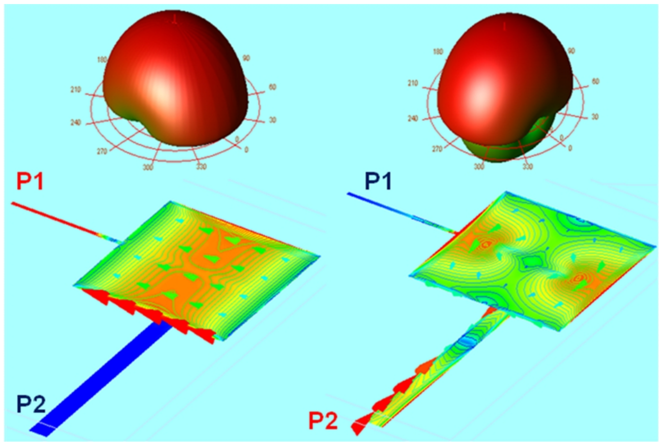


Fig. 6. Geometry of dual port microstrip patch antenna with one microstrip fed port and other port is slot coupled

The slot/aperture coupled microstrip patch antenna provides improved input impedance bandwidth as compared to single layer microstrip fed patch antennas [10-11].This improvement results from tuning stub which is used to tune the reactance of aperture coupled antenna (which is mainly resulted from thick substrates) to achieve optimum input matching [9].

The dual polarized slot coupled antenna with optimized dimensions as shown in Fig.6 was simulated using Keysight Advanced Design System (ADS) Momentum software. The simulations were performed with infinite slot ground plane.

The simulated radiation characteristics of dual polarized microstrip patch antenna are shown in Fig.7 for each port excitation with the other port terminated with 50 ohms. Port1 feeds the antenna though quarter wave microstrip transmission line but port 2 is slot coupled and excites the radiating element by electromagnetic coupling through slot in ground plane. The back side radiations are clearly visible in Fig.7 (b) when slot coupled port is used to excite the radiating element. The antenna is clearly dual polarized (orthogonal polarization) when fed from two orthogonal edges as shown in Fig.7.



(a) Port 1 excitation (b) Port 2 excitation

Fig. 7. Simulated Radiation characteristics of slot coupled microstrip patch antenna for each port excitation

The simulated E-plane gain patterns (for $\Phi = 0^0$ and $\Phi = 90^0$) for dual polarized microstrip patch antenna operating at 2.4GHz frequency are shown in Fig.8. The simulated gain is 4.1dBi for microstrip fed port and 3.85dBi for slot coupled port as shown in Fig.8.

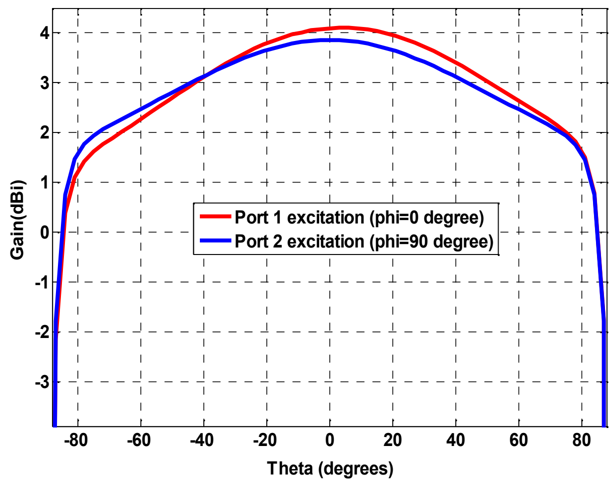
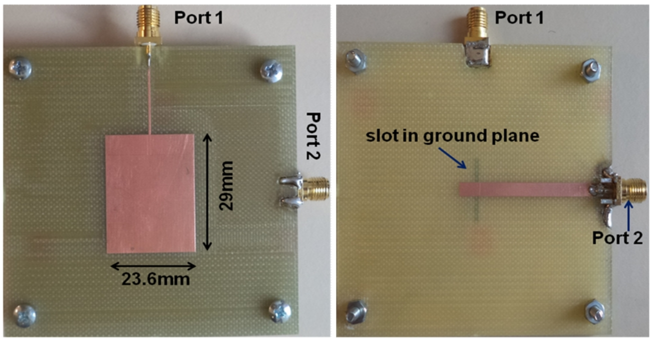


Fig. 8. Simulated 2D gain pattern for dual polarized slot coupled microstrip antenna at 2.4GHz

The implemented dual port, dual polarized antenna is shown in Fig.9 where the microstrip feed line under the ground plane is clearly shown in Fig.9(b).The ground plane with rectangular aperture is sandwiched between two 1.6 mm thick FR-4 substrate layers.



(a) Top Side (b) Back side

Fig. 9. Constructed dual port,dual polarized slot coupled patch antenna

The simulated and measured S_{11},S_{22} and S_{12} results for proposed and implemented dual polarized slot coupled antenna are shown in Fig.10.The quarter wave microstrip fed (port 1) has 50MHz and slot coupled port (port2) has 100MHz input 10dB bandwidth. Thus, slot coupled port has better impedance bandwidth as compared to microstrip fed port. The implemented antenna structure provides better than 55dB interport isolation for 50MHz antenna's 10dB bandwidth. Thus, slot coupled microstrip patch antenna provides better inter-port isolation performance as compared to quarter wave microstrip fed patch antenna. There is a good agreement between simulated and measured results except the amount of interport isolation. The measured and simulated interport isolation results differ because the implemented antenna has finite slotted ground plane while the simulation results were obtained with infinite slotted ground plane.

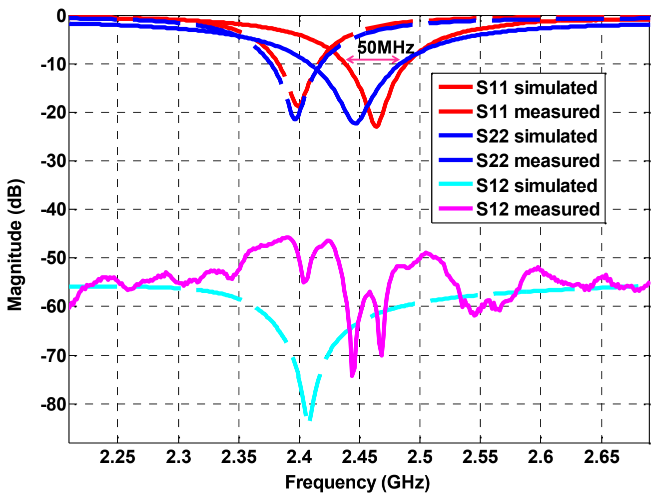


Fig. 10. Simulated and measured S11, S22 and S12 parameters for dual polarized slot coupled microstrip patch antenna

IV. CONCLUSION

The feeding structure plays a critical role in interport isolation (S_{12}) performance of dual port, dual polarized microstrip patch antenna. Two dual port, dual polarized microstrip patch antennas with different feeding structures have been designed and implemented for 2.4GHz operating frequency and their interport isolation performance (S_{12}) has been compared. The implemented microstrip patch antenna with one slot coupled port and other microstrip fed port, has almost 20dB better interport isolation performance for 50MHz antenna's 10dB input bandwidth as compared to that fed through quarter wave microstrip feed lines. The slot coupled port also provides better input impedance as compared to microstrip coupled port.

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