Multi-port Pattern diversity antenna for K and Ka-band application

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Abstract

A compact coplanar waveguide (CPW) fed reconfigurable antenna with pattern diversity using multi-port excitation is designed. The basic antenna consists of a circular patch of radius 2.5mm which is fed by four ports independently. By exciting the patch with each individual port, the direction of the radiation pattern changes by 90^0. With the use of CPW feed technique, a very wide impedance bandwidth of around 12GHz (21.65 – 33.87 GHz) covering the K-band and Ka-band is achieved. The proposed antenna can be used for different satellite communication applications like earth exploration, radio navigation and location, mobile satellite communications which comes under K-band and Ka-band. The measured return loss and pattern characteristic results are in good agreement with simulated ones.

1. Introduction

The concept of reconfigurable antennas was born to satisfy the increasing demands of wireless environment. The RF terminals used in such wireless communication systems must have multi-functional properties that adapt to system requirements such as frequency diversity, polarization diversity and radiation pattern selectivity. Reconfigurability sometimes makes the system intelligent. Smart systems such as Software Defined Radio (SDR), Cognitive Radio, adaptive multiple-input multiple-output communication systems use different reconfiguration schemes to adapt to changing system requirements like physical link conditions which improves the system performance by providing the robustness to varying channel conditions. These antennas provide cost effective solutions by incorporating multiple elements in a single physical device which reduces the total number of components used, thereby reducing the overall size of the system. The pattern reconfigurable antennas have the ability to dynamically change their radiation properties that adapt to the wireless channel characteristics. In a rich scattered wireless environment, an antenna that directs the main beam with increased gain to the desired coverage area while suppressing the unwanted beam in other directions, is required. This type of antennas mitigates the multi-path interference and allows higher rate of data transmission in a given band that enhances the spectral efficiency and improves the communication link performance because of the adaptive patterns it provides.

Many pattern diversity antennas have been designed in the past and many more are being done recently. A high gain beam switching antenna that can steer the beam to five different directions using four parasitic elements and one main radiating element for WiMAX applications is proposed [1]. Likewise, two parasitic elements and four switches are incorporated in UWB monopole antenna to get pattern diversity [2]. A new technique in which a parasitic structure (wire, loop or any shape) is rotated around a monopole to get rotated patterns [3]. An electro-active polymer actuator is used for rotation with a triangular parasitic element to get different beams. A CPW to slot line feed transition method is proposed to get pattern diversity [4]. Three different patterns are obtained with three feed modes; CPW, left slot line and right slot line. Dual-band reconfigurable frequency-selective reflectors (RFSR) are designed and applied to form a right-angle corner reflector antenna with reconfigurable patterns [5]. The concept of Yagi-Uda antenna is implemented on a planar patch to achieve beam steering by manipulating the status of the parasitic patches through switching mechanism to act as reflectors or directors [6]. Active Frequency Selective Surfaces (AFSS) are used to build a 360^0 beam steerable antenna with not only single and multi-beam configurations but also proportional beams are realizable with this continuous tuning capability [7].

The main aim of this paper is to achieve pattern diversity by using geometrically symmetrical shaped antenna with small size and less complexity. Very less literature is found on wide band pattern diversity antennas. Hence, we propose a very simple, compact and wide band pattern diversity antenna with four port excitations where the pattern changes its direction by 90^0 with each individual port exciting the main radiating patch. A coplanar waveguide (CPW) feed is used to excite the antenna. So far, pattern diversity antennas are designed with conventional microstrip feeding structures but this paper proposes CPW feed because of its many advantages such as; reduction in radiation loss, improved bandwidth, easy surface mounting of active and passive devices, reduced cross talk effects between adjacent lines because of ground plane between any two adjacent lines, simplified fabrication [8]. The configuration of the proposed antenna is briefly discussed in Section 2 and the simulated and measured results are presented in Section 3 and Section 4. The practical results are in good agreement with the simulated ones. Finally, the conclusions and useful applications are presented in Section 5.

2. Antenna Configuration

The geometry of the proposed antenna is shown in Fig. 1. The antenna is fabricated on a 1.6mm thick low cost FR4 substrate whose dielectric constant is 4.4 with loss tangent 0.02. The radius of basic circular patch is 2.5mm. The size of the antenna is 14mm×13.8mm×1.6mm which is very compact.

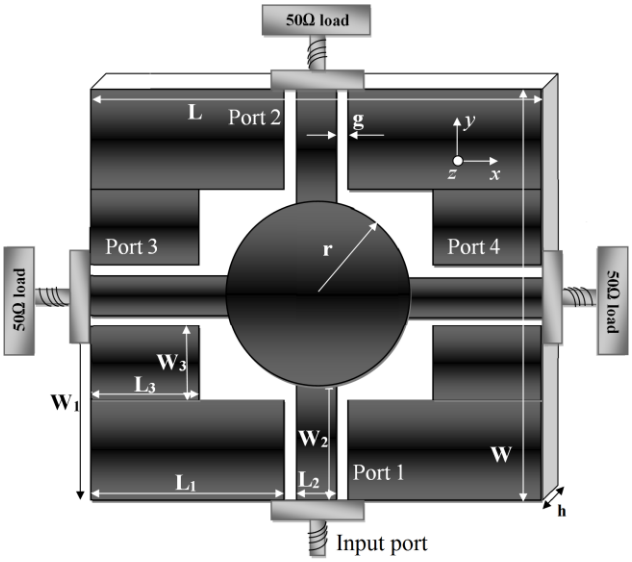


Figure 1: Geometry of the proposed pattern diversity antenna.

The signal is fed through the four ports, independently, which are placed at the four sides of the basic circular patch. When the patch is fed by one port, all the remaining ports are terminated by a 50Ω load for proper impedance match. The signal fed through each individual port changes the spatial current distribution on the radiating patch and thus changes the radiation pattern. The dimensions of the antenna are L=14mm, W=13.8mm, h=1.6mm, g=0.3mm, L_1=6.05mm, W_1=5.95mm, L_2=1.3mm, W_2=4.5mm, L_3=4mm, W_3=1.95mm, r=2.5mm.

3. Simulation Results and Discussions

The simulations are carried out in Ansoft HFSS software package which is based on Finite Element Method. Fig. 2 shows the reflection coefficients of the antenna fed by each port individually. The operating frequency of the antenna when it is fed through Port 1 is 26.7GHz with -10dB impedance bandwidth (BW) of 12.2GHz (46.8%), through Port 2 it has same frequency characteristics as the antenna fed through Port 1. Through Port 3 it is 27.5GHz with a BW of 11.15GHz (40.64%) and through Port 4 it has same frequency characteristics as the antenna fed through Port 3. The radiation characteristics of the basic circular patch are determined by the electric or magnetic current distributions on the radiating structure which in turn are responsible for changing frequency characteristics. Because of this relationship between the source currents and the resulting radiation, it is difficult to achieve pattern reconfigurability without having much changes in frequency characteristics. Hence there is a slight change in frequency in each operating mode.

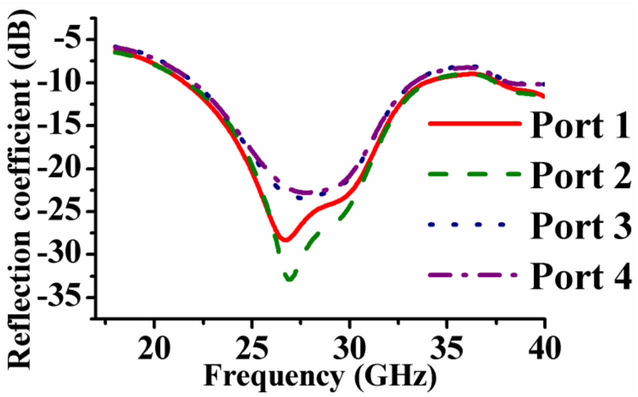


Figure 2: Reflection coefficients of proposed pattern diversity antenna.

Fig. 3 shows the 3D plots of the radiation patterns of the antenna operating in four different modes. It is observed that when the antenna feed is changed from Port 1 to Port 3, Port 3 to Port 2, Port 2 to Port 4 and again to Port 1, the radiation pattern changes by 90^0 each time. It is observed from Fig. 2 and Fig. 3 that frequency characteristics are maintained while changing the radiating characteristics when the antenna is fed through different ports individually which satisfies the principle of pattern reconfigurability.

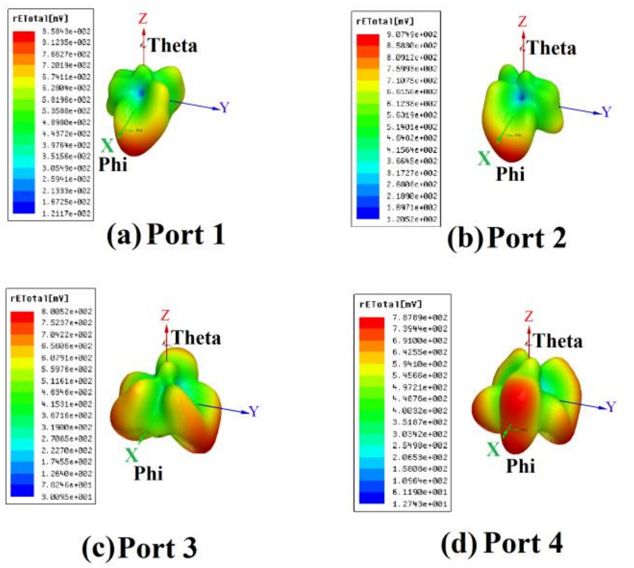


Figure 3: 3D radiation pattern of the proposed pattern diversity antenna at (a) 26.7GHz (b) 26.9GHz (c) 27.49GHz (d) 27.45GHz.

The transmission coefficients of the antenna when fed through Port 1 are shown in Fig. 4. It is known that $S_{ij}=S_{ji}$ and here in this case $S_{12}=S_{34}$. Also, $S_{31}=S_{41}=S_{32}=S_{42}$. We can say that, when the antenna is fed through any one port there is more chance of the signal getting leaked in the adjacent ports. The correlation between the ports 1 and 2 is calculated by equation (1). It is known that, $\rho_{ij} = \rho_{ji}$, and also in this case $\rho_{31} = \rho_{41}$. Fig. 5 shows the Envelope Correlation Coefficients (ECCs) obtained from the simulated S-parameters.

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

The ECC for ρ_{21} is <0.07 and for ρ_{31} is <0.06 which satisfies the low correlation criteria of ECC<0.5. Hence the designed antenna has a very good diversity performance.

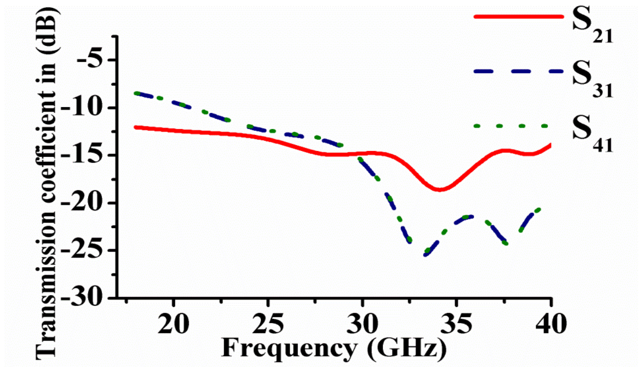


Figure 4: Transmission coefficients of the proposed pattern diversity antenna when it is fed through Port 1.

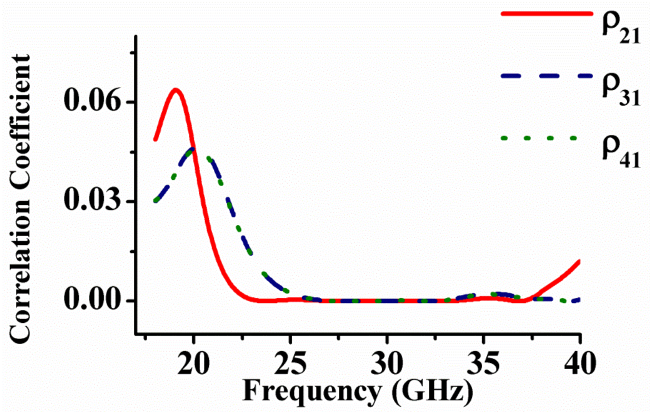


Figure 5: ECC of the proposed antenna when fed through Port 1.

4. Measured Results

The proposed pattern diversity antenna is fabricated on a low cost FR4 substrate with dielectric constant 4.4 and thickness 1.6mm and tested in order to validate the simulated results. The photograph of the prototype antenna used for the measurement is shown in Fig. 6. All the return loss measurements were taken using Agilent E8363C PNA Series Microwave Network Analyzer, which operates in the frequency range 10 MHz to 40 GHz.

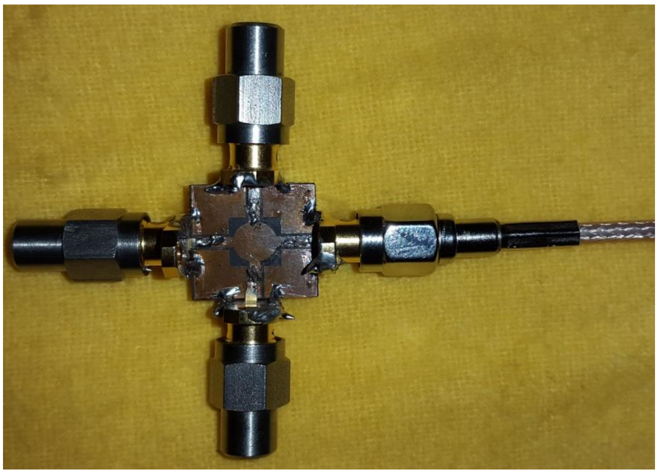
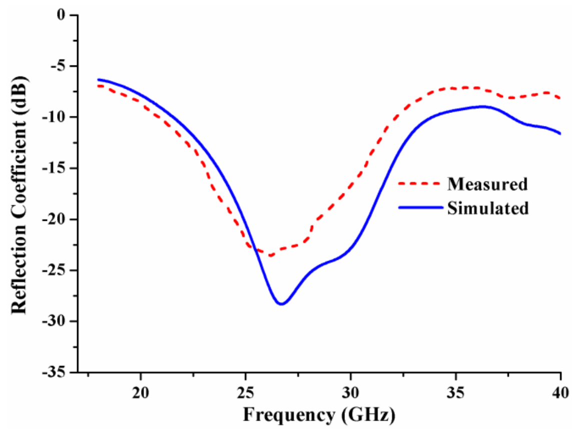
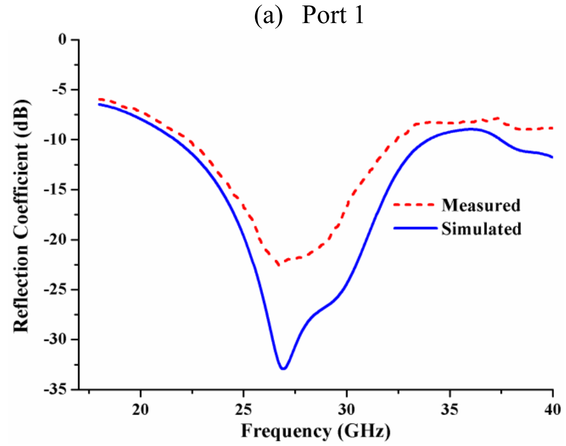


Figure 6: Fabricated prototype of the proposed antenna with pattern diversity.

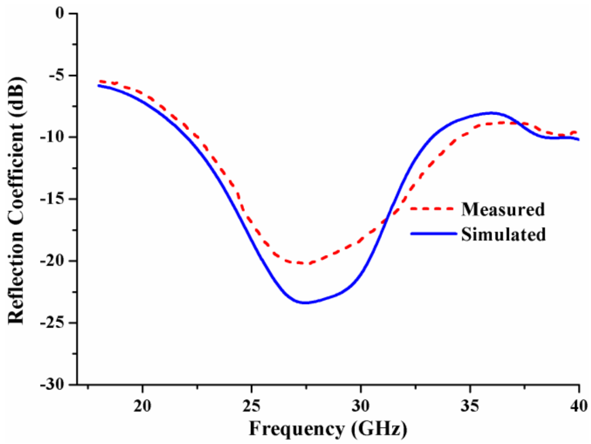
The simulated and measured reflection coefficients S_{11} of the proposed reconfigurable antenna for all the operating modes are shown in Fig. 7. The reasons for the difference between simulated and measured results are due to minor fabrication inaccuracies, dielectric imperfections, and SMA connector solder losses (i.e., while testing, SMA connector can be treated as the extension of the ground which creates some impedance mismatch at the CPW feed). The measured and simulated results are tabulated in Table 1.



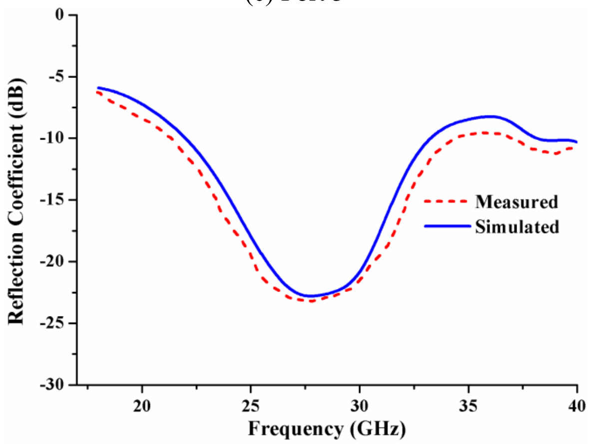
(a) Port 1



(b) Port 2



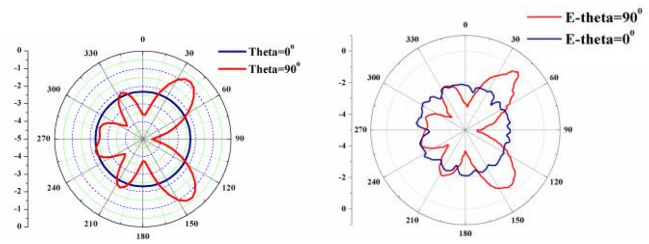
(c) Port 3



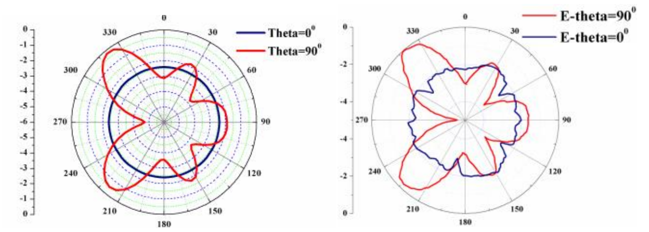
(d) Port 4

Figure 7: Simulated and Measured Reflection coefficients of proposed reconfigurable antenna when fed through different ports

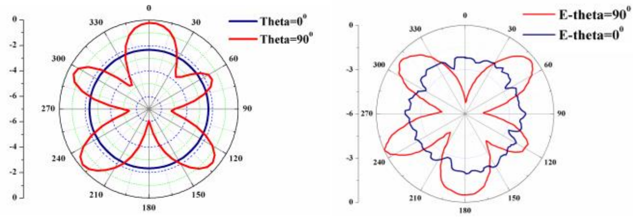
The simulated and measured 2D polar cuts in azimuth and elevation planes depicting both co-polarization and cross-polarization for each port are shown in Fig. 8 and Fig. 9.



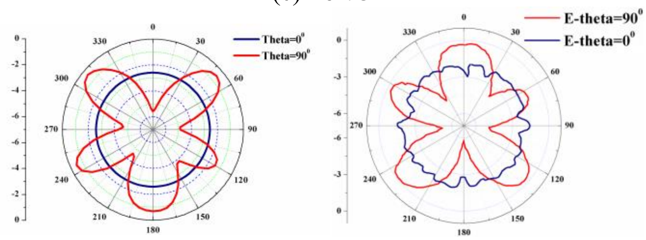
(a) Port 1



(b) Port 2

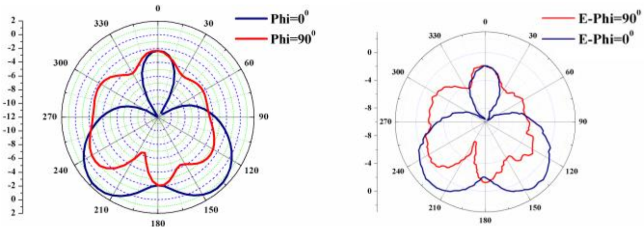


(c) Port 3

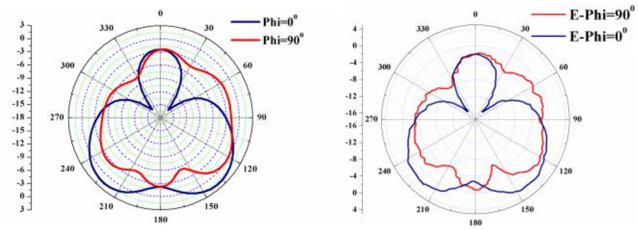


(d) Port 4

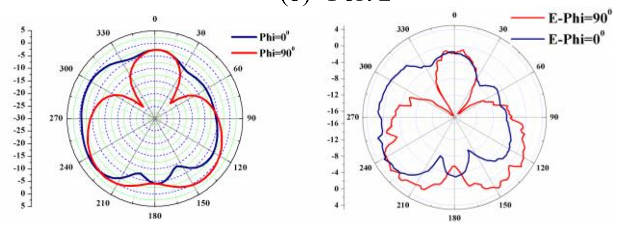
Figure 8: Simulated (Left side) Measured (Right side) 2D Radiation patterns of the pattern diversity antenna in Elevation plane with excitations at different ports at (a) 26.7GHz (b) 26.9GHz (c) 27.49GHz (d) 27.45GHz.



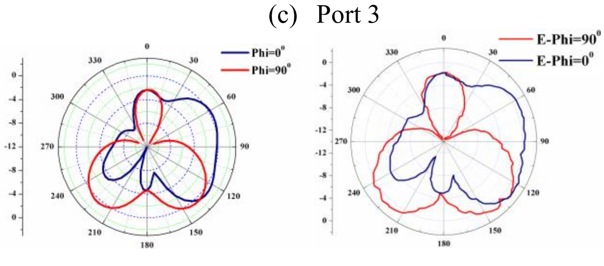
(a) Port 1



(b) Port 2



(c) Port 3



(d) Port 3

Figure 9: Simulated (Left side) Measured (Right side) 2D Radiation patterns of the pattern diversity antenna in Elevation plane with excitations at different ports at (a) 26.7GHz (b) 26.9GHz (c) 27.49GHz (d) 27.45GHz.

It is observed from Fig. 7 that frequency characteristics are maintained while changing the radiating characteristics when the antenna is fed through different ports individually which satisfies the principle of pattern reconfigurability.

5. Conclusions

A very simple and compact pattern diversity antenna using CPW feed is designed using four ports and analyzed in this paper. A very wide impedance bandwidth of around 12GHz is achieved by the use of CPW feeding technique. The antenna is capable of rotating its radiation pattern by 90^0 with each port excitation without having major changes in frequency characteristics. A very good return loss and very low ECC of 0.06 is obtained between four ports which can be used in different MIMO applications. Due to its compact dimension and high isolation between the different ports and wide bandwidth, the proposed antenna is suitable for mobile satellite communication applications operated under K- and Ka-band.

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