Design of Dual Mode AVA with Enhanced Radiation Characteristics

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Abstract

Dual mode antipodal Vivaldi antenna (AVA) with narrowband to wideband switching is proposed in this work. The antenna has the footprint of 60 mm x 40 mm x 1.6 mm and FR-4 substrate used for fabrication. The antenna exhibits 8.3 GHz bandwidth in wideband mode with a peak gain of 6.9 dBi and 1.6 GHz bandwidth in narrowband mode with a peak gain of 7 dBi. The simulations are performed using CST full wave simulator and the results are compared with the reference antenna of the same dimensions. PIN diodes are implemented to achieve the frequency switching. The working principle of the antenna is explained through simulation and verified through measurements.

1. Introduction

Rapid development in wireless communication demands the multifunctional antennas with cognitive functionalities. Reconfigurable antennas are the suitable candidate to the aforementioned problem via its notching characteristics. There are several reconfigurable antennas with several mechanisms are exploited in the open literature. Based upon the application, the re-configuration will be with respect to frequency, pattern or polarization. The reconfigurable mechanisms should not affect the radiation characteristics of the antenna and also the complexity. Ultra-wideband technology is recommended for applications like satellite networks, biomedical detection, microwave imaging, military and radar systems. Multifunctional characteristics can be obtained by incorporating multiple antennas or by re-configurable antennas. Vivaldi antennas are the one among the end fire antenna family and it has been explored in many ways in many applications. In our research, we have implemented antipodal Vivaldi antenna (AVA) to become a reconfigurable antenna with the help of PIN diodes.

Since Gibson unveiled the Vivaldi antenna in 1979, due to its benefits such as wide bandwidth, flat shape, relatively high directivity, radiation efficiency and simple to manufacture, it has gained more and more popularity in the field of science [1, 2]. The Vivaldi antenna is most commonly used for aircraft missiles, ships and other airborne applications. It is a standard UWB antenna, the bandwidth of the antenna is limited by its complicated feed setup and the width of the slot [3]. The AVA has low input impedance relative to the conventional Vivaldi antenna. So it can reliably match the characteristic impedance of 50 Ohm [4]. A Vivaldi antenna is a best option for UWB applications and it has strong end-of-fire radiation compared to the planar monopole antenna [5, 6]. Studies demonstrates that depending on the antenna size the lowest operating frequency is regulated and that the antenna size should be at least one half the wavelength, equivalent to the lowest operating frequency in free space, in order to receive effective radiation[7, 8]. In order to resolve the restriction, several techniques have been used and recorded to minimize the size of the Vivaldi antenna, the slotted edge has been used [9]. Adding a high-permittivity dielectric director will greatly increase antenna gain at various operating frequencies [10]. Improved radiation characteristics can be obtained by inserting slots to its boundary, it provides light weight and reduced structure [11]. Recently, the clustering of several networks in one antenna using antenna reconfiguration has gained a lot of coverage. In the antenna opening at different positions the PIN diodes and slots are inserted. This antenna is suitable for applications using UWB and narrow band switching

[12, 13]. At the receiver side, the interference level can be reduced by applying antenna reconfiguration and it can be used in cognitive radio applications [14, 15]. Frequency reconfiguration is typically accomplished by means of lumped elements, such as PIN diodes and MEMS switches, in a particular location to monitor the distribution of current [15–16]. The slot antenna's various designs are presented in [17, 18].The proposed dual mode antipodal Vivaldi antenna is designed by the introduction of rectangular slots to operate in ultra-wide band and two narrow bands [19].With the ground plane input change and placing a slot resonator on ground plane will provides a customized ultra wide band AVA [20]. By adding the lumped elements in the proposed miniaturized Vivaldi antenna will enhance impedance features [21]. A small wide band AVA is created by loading convex lens and director in an arc type radiator for high frequency performance enhancement [22].

This article outlines the design and implementation of dual mode antenna. Conventional AVA is implemented with a rectangular slots on its inner radiating structure and semi-circular slots on its outer radiating edges. To exhibit the dual mode characteristics, PIN diodes are implemented on the rectangular slits and the characteristics were studied. This paper is organized as follows. The antenna design with diode implementations are discussed in Sect. 2. Results and discussions are carried out in Sect. 3. Section 4 is the summary of our design and future potential.

2. Antenna Design

2.1 Antenna Geometry

The schematic of the proposed dual mode AVA is shown in Fig. 1. The antenna is printed on a 1.6 mm thick FR-4 substrate with a footprint of 60 mm × 40 mm. The exponential profiles are governed by the equations [1]–[3]. Antipodal Vivaldi antenna is an end fire radiator whose characteristics are governed by the inner exponential profile.

$$y = C_1 e^{Rx} + C_2 \tag{1}$$

$$C_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}} \tag{2}$$

$$C_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}} \tag{3}$$

Here C_1 and C_2 are constants. P(x_1,y_1) and P(x_2,y_2) are the starting point and ending point of the exponential profile respectively.

2.2 Selection of Antenna Geometry

Vivaldi antenna is the category of tapered slot antenna and it has highly directional radiation characteristics in end fire direction. The authors took the AVA with same foot print as the reference antenna and the performance metrics are compared. The antenna comprised of two radiating structures printed on the same substrate. Simple microstrip line is used as a feed to excite the radiation characteristics. In the real time implementation, the antenna is fed with the SMA and the characteristics were studied. The aperture width is chosen to avoid the grating lobes and it is responsible for the lower operating frequency of the AVA. The antennas surface current distribution is shown in Fig. 2.

It shows that the current distribution is dense at the inner exponential profile and it is forward in nature. This forward current is attributed to increase in directivity and gain of the antenna. If the current distribution is diverted away from the inner profile the radiation characteristics could be modified and it can be restored when a PIN diode is placed to bridge the slot. A small slit of 1 mm is placed on the inner profile of the antenna and it is not extended to its outer radiating edges. The placement of the slot on the tapering profile is made after several iterations. The implementation of slots make the aperture width as lower which resulted in increase of lower operating frequency. We termed the working of the antenna as narrowband mode. These slits are closed with PIN diodes to restore the current profile for its wideband mode. The outer edges has the small current distribution as shown in Fig. 2 and a semi-circular slot is placed on both sides of the radiating structure to improve the lower radiation characteristics. The antenna electrical length is increased and it resulted in lowering the lower operating frequency. This can be verified with the Fig. 3. It is evident from figure that the reference antenna is resonating from 4 GHz while the proposed antenna (when diode is ON) resonates from 3.7 GHz. Bandwidth improvement of 300 MHz is witnessed due to the implementation of semi-circular slots.

3. Result And Discussion

The fabricated antenna is shown in Figure 4. The reference antenna is also fabricated and is not shown. All the output parameters of the proposed AVA are compared to the reference antenna. The fabricated antenna is measured inside a chamber for its radiation characteristics.

Fieldfox handheld network analyzer (N9917A) is used for taking the measurements. The measured reflection coefficient of the proposed dual mode AVA is shown in Figure 5. The red color line response corresponds to the ON conditions of the diode. Both diodes are ON and the current distribution is towards the entire radiating structure and the antenna is operated in the wideband mode. The bandwidth is measured to be from 3.7 GHz to 12 GHz. When both diodes are OFF, the antenna works in narrow band mode and exhibits the bandwidth from 5 GHz. This is due to the diversion of current away from the radiating profile. The placement of the rectangular slit decides the resonance at the narrowband mode and it can be varied according to the need. Similarly, the length of the slot also influences the resonant frequency. In this work, the design parameters are optimized to have a resonance around 5 GHz. It is evident from Figure 5 that the measured results are in line with the simulated results and the small discrepancy in the high frequency is attributed to the diode biasing.

Figure. 6 exhibit the gain of the proposed antenna for its narrowband and wideband. Gain of the antenna is computed using Friss transmission formula by inputting received power of the reference antenna, proposed antenna and gain of the reference antenna. Rectangular horn antenna is used as reference antenna for these computations. The wideband mode exhibits good impedance matching between 3.7 GHz to 12 GHz and in narrowband mode the matching is between 4.1 GHz to 5.7 GHz. The negative values in the table are attributed to the notched characteristics of the narrowband mode. Radiation characteristics of the antenna are given in Figure 7. From Figure, it is evident that the directional characteristics of the antenna are preserved for both cases viz. reference and the proposed antenna respectively. Also, the cross polarization of the antenna is well below the Co polarization. The radiation pattern shown here are taken only for the sample on 5 GHz. The directional characteristics are preserved and the main beam is located in 0 degree for both cases of Figure 7 (a) and 7 (b). In 7b, the back lobe is higher compared with the reference antenna which is due to backward current on the radiating profile. Still, the antenna exhibit uncompromised gain in the entire bandwidth.

Conclusion

This paper describes the design and implementation of dual mode AVA with enhanced radiation characteristics. PIN diodes are utilized to obtain the switching between narrow band and wideband. The antenna exhibits a peak gain of 6.9 dBi in the wideband and 7 dBi in the narrowband. Also, the modified radiating fins provide 300 MHz additional bandwidth in the lower bandwidth. Wideband mode antenna exhibits a bandwidth of 8.3 GHz (3.7 GHz – 12 GHz) and 1.6 GHz (4.1 GHz – 5.7 GHz) in narrowband operating mode. PIN diodes are biased properly and ensured that it is not influencing the characteristics of the antenna. In future, the work will be extended for continuous re-configurability using Varactor diode.

Declarations

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*Conflicts of interest/Competing interests

Not applicable

*Availability of data and material

Not applicable

*Code availability

Not applicable

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Figures

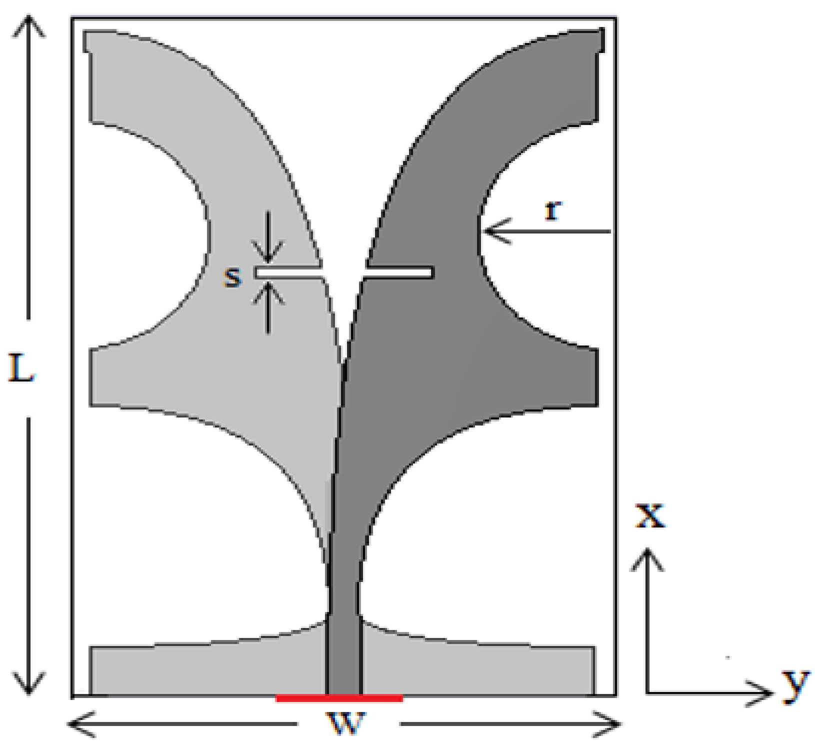

Figure 1

Schematic of the proposed dual mode Antipodal Vivaldi Antenna. The dimensions are L =60 mm, W = 40 mm, s = 1mm and r = 10 mm.

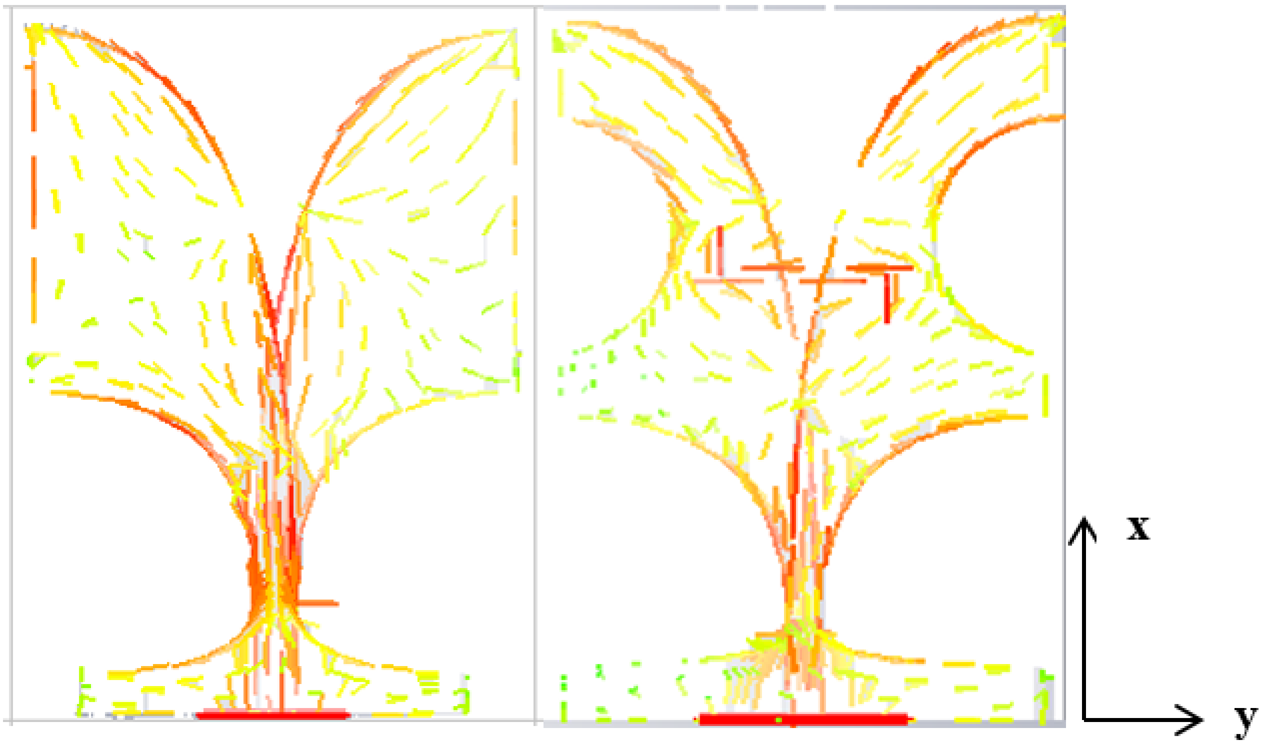

Figure 2

Surface current distribution taken at 5 GHz for (a) reference antenna (b) proposed antenna

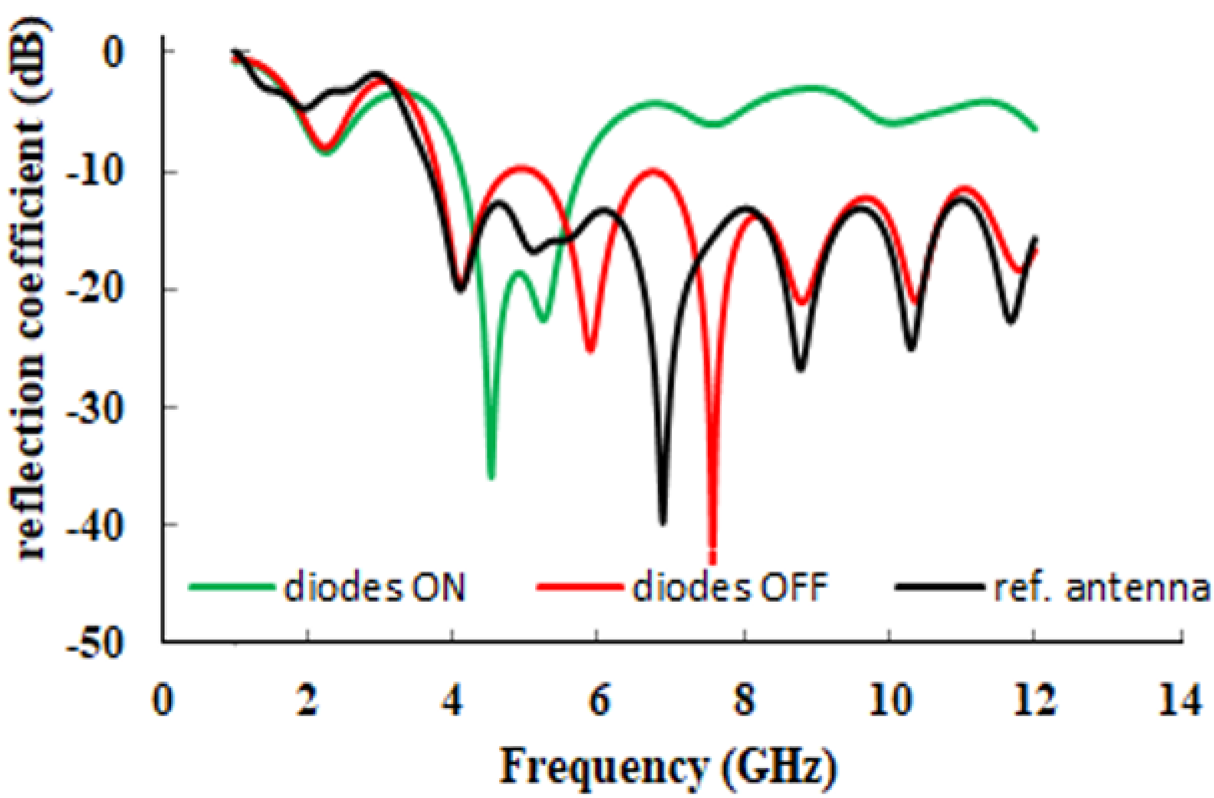

Figure 3

Simulated S11 of the proposed antenna against reference antenna.

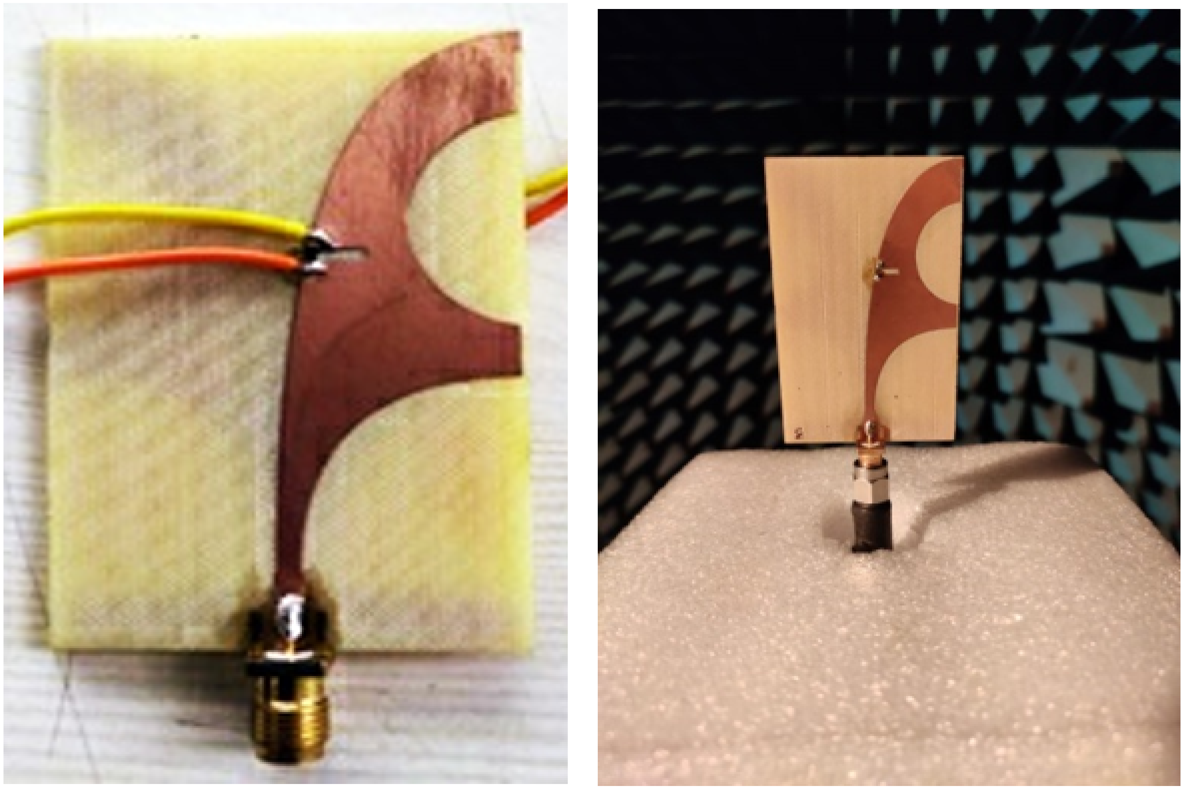

Figure 4

Fabricated antenna along with chamber measurement setup.

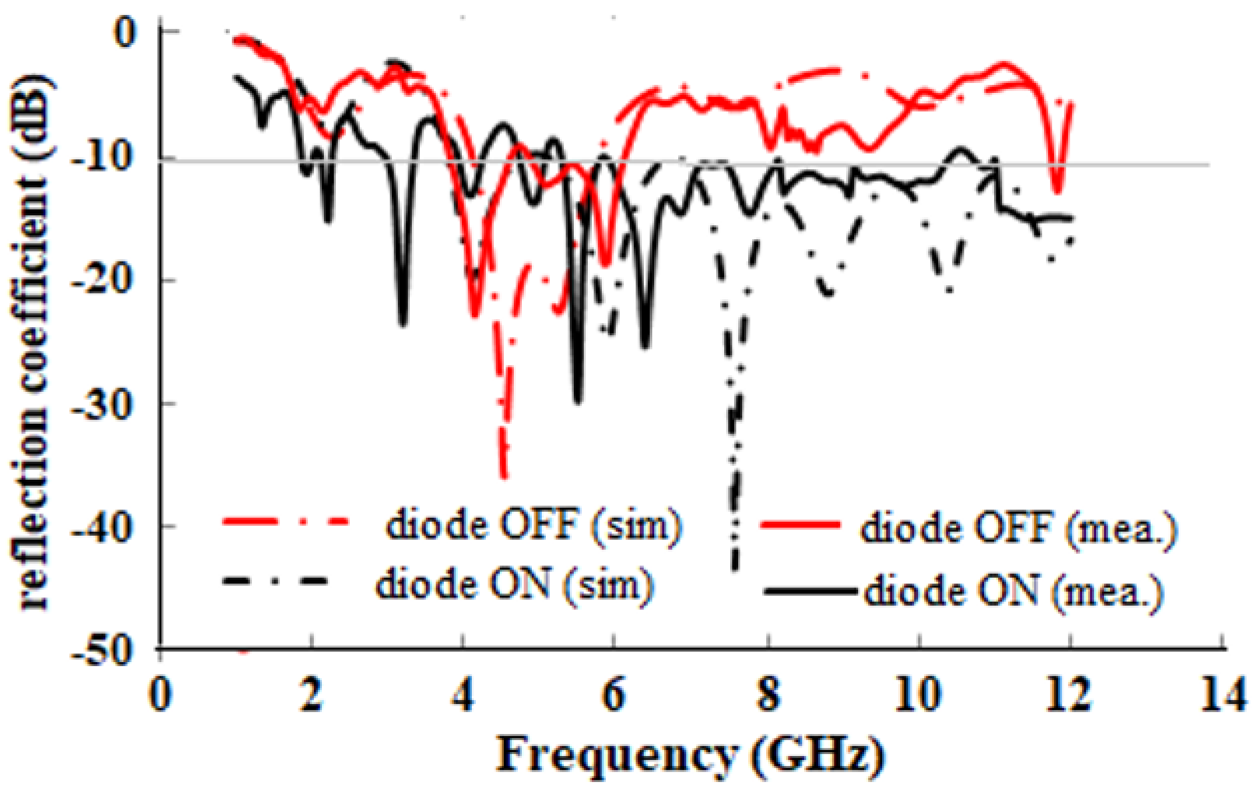

Figure 5

Measured S11 of the proposed antenna when the diodes are ON and OFF.

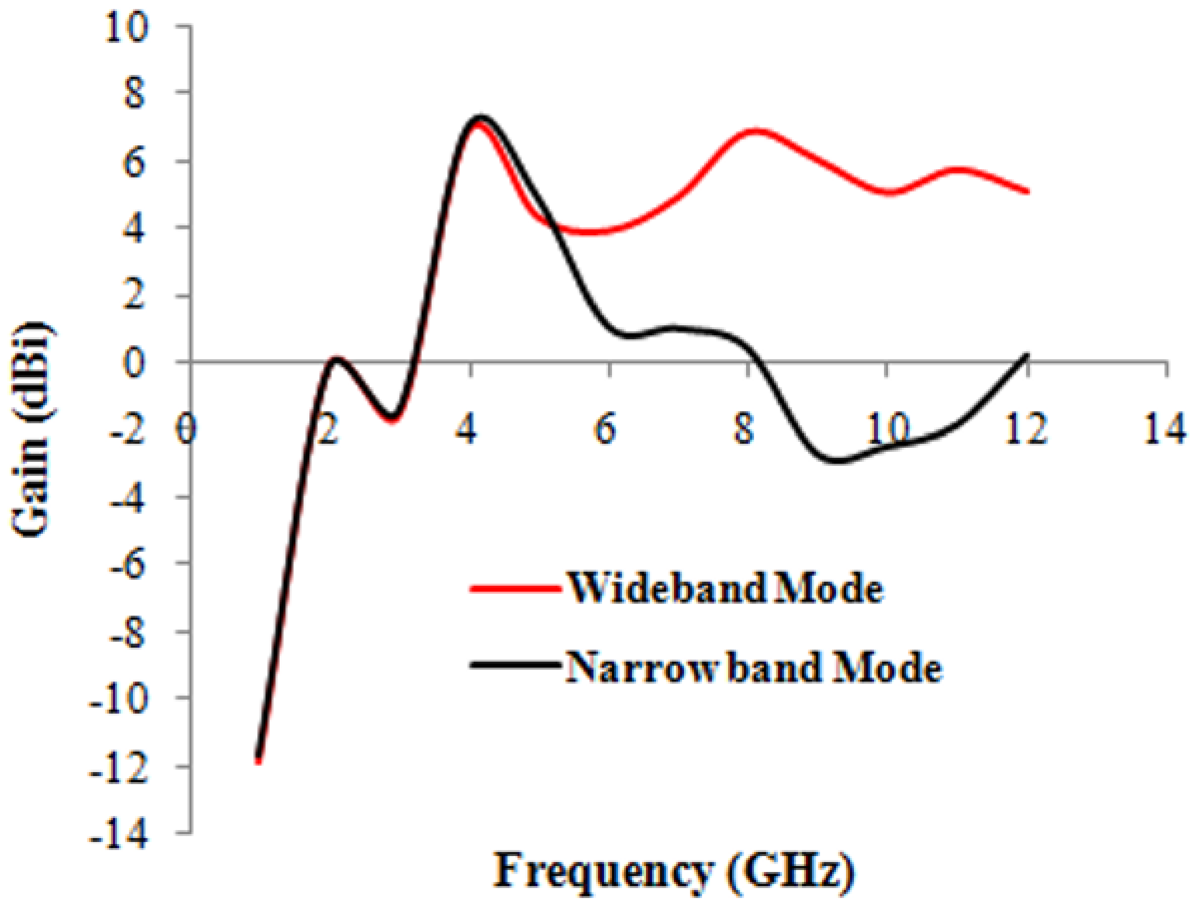

Figure 6

Calculated gain of the proposed antenna.

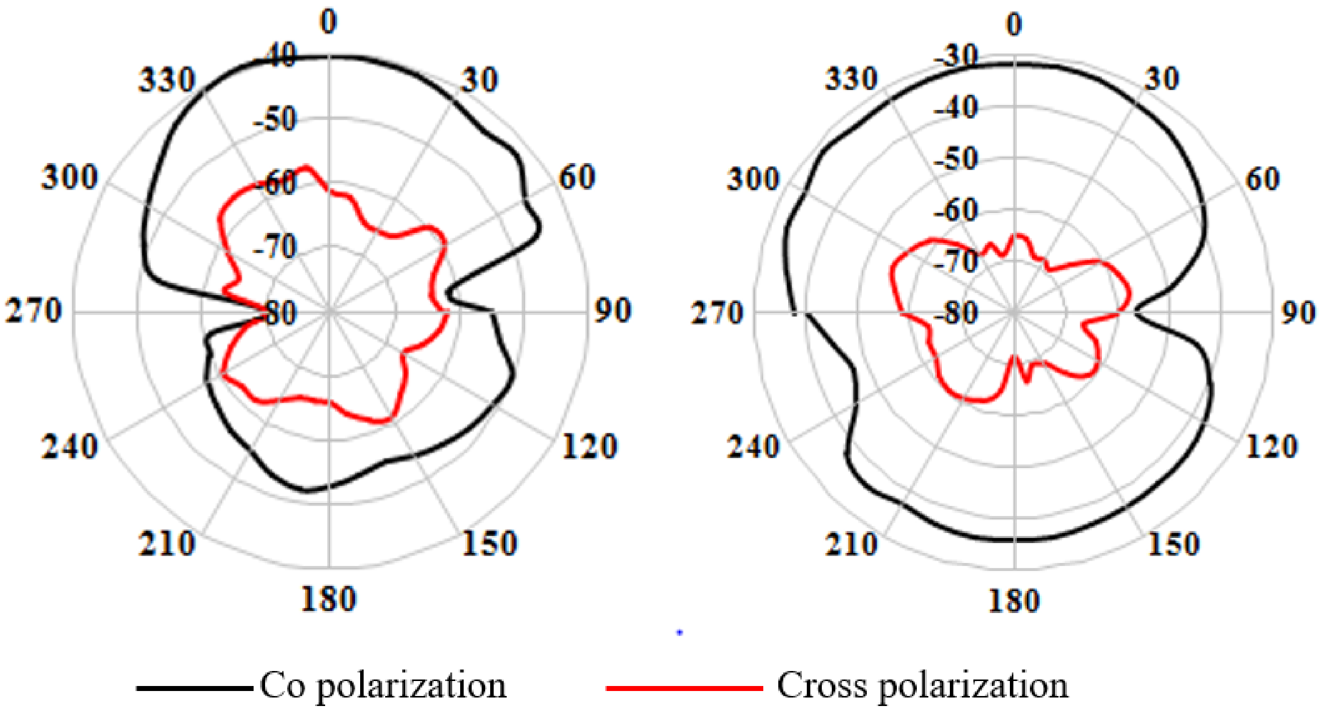

Figure 7

Measured radiation pattern (E- plane) of the antenna at 5 GHz (a) Reference antenna (b) Proposed (diodes OFF)