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A COMPACT ELECTRONICALLY RECONFIGURABLE DUAL FREQUENCY MICROSTRIP ANTENNA FOR L-BAND APPLICATIONS

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A novel design of a compact electronically reconfigurable dual frequency dual polarized single feed hexagonal slot loaded microstrip antenna in L-band is introduced in this paper. Pin diodes are used to switch the operating frequencies considerably, without much affecting the radiation characteristics and gain. The antenna can work with a frequency ratio varying in a wide range from 1.2 to 1.4. The proposed design has an added advantage of size reduction up to 72.21% and 46.84% for the two resonating frequencies, compared to standard rectangular patches. The design also gives considerable bandwidth of up to 2.82% and 2.42% for the two operating frequencies.

Keywords: Reconfigurable antenna; dual frequency; dual polarized; microstrip patch antenna; pin diode.

1. Introduction

Dual frequency multipolarization microstrip antennas have wide applications in satellite base communication, air route surveillance, GPS and mobile satellite personal communication systems [Huff *et al.*, 2003; Luxey *et al.*, 2000; Shynu *et al.*, 2004]. Recently wide attention has been attained by these types of antennas in satellite and mobile communication systems to obtain polarization diversity for good performance of reception and transmission or to integrate the receiving and transmitting functions into one antenna for reducing the antenna size [Fan & Yahya, 2002; Chen *et al.*, 2004]. Reconfigurable microstrip antennas can be used to cover these multiple functions with a single antenna aperture. This will increase antenna efficiency and signal processing speed while maintaining high degree of flexibility. All these applications need a compact reconfigurable microstrip antenna having better bandwidth and easy switching capabilities. In this paper we demonstrate a novel compact single feed electronically reconfigurable microstrip patch antenna with a switchable extended dual arm hexagonal slot for dual frequency operation and enhanced size reduction. Two pin diodes are embedded in the arms of the central hexagonal slot to switch the two resonant frequencies of the antenna, considerably, by changing the electrical length of the slot. Thus multiple frequencies are generated in a single antenna aperture by controlling the DC bias of the two pin diodes. Transmission lines are avoided in between the active components and the radiating element so that added noise and ohmic losses are suppressed and the resulting structure is more compact. The new design has the added advantage of high area reduction, better bandwidth and good matching for all operating frequencies compared to conventional microstrip patch antennas and offers a high flexibility in frequency tuning. Another attractive feature is that the antenna shows almost similar radiation patterns at all operating frequencies without much reduction in gain. The design has been successfully implemented and experimental results are presented.

2. Antenna Structure and Design

The geometry of the proposed reconfigurable microstrip patch antenna with dual arm hexagonal slot is illustrated in Fig. 1. A square microstrip patch antenna with side dimension L is fabricated on a substrate of thickness h and relative permittivity ϵ_r. A hexagonal slot of side parameters l_1 and l_2 with two identical slot arms of length l_a and width w_a, extending up to the edge of the square patch is placed at its center. Two surface mount pin diodes, D_1 and D_2 are positioned at the slot arms with distances x_1 and x_2 respectively from the hexagonal side. The positions of the diodes x_1 and x_2 can be suitably chosen to get the desired frequency ratio. Good DC isolation is obtained by embedding two smd capacitors C_1 and C_2 on the protruding slot arms as shown in the Fig. 1. DC bias voltage is applied to the patch through two chip inductors, which controls the pin diode states. The diodes are placed in such a way that one is forward biased and the other in reverse, at a time, so that

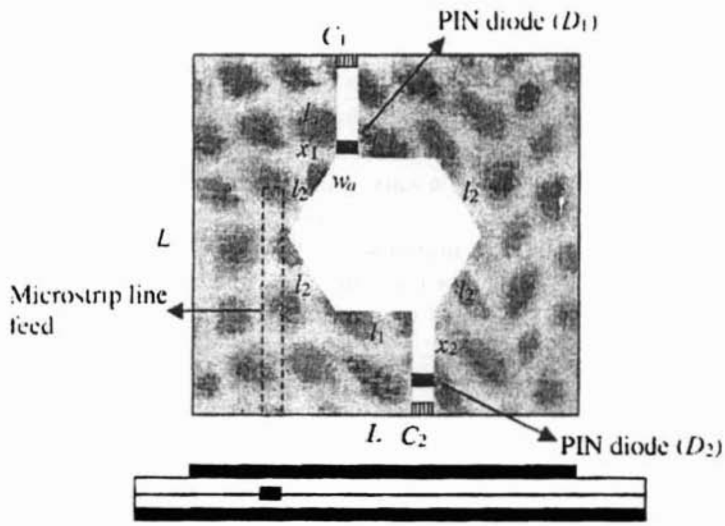

Fig. 1. Geometry of the proposed reconfigurable dual frequency antenna controlled by pin diodes. Antenna parameters are given in Fig. 2.

resonant frequency of the antenna can be selected by appropriately biasing the diodes. The antenna is electromagnetically coupled using a 50 ohm microstrip line as shown in Fig. 1.

The fundamental resonant frequency of the conventional unslotted square patch is 1.884 GHz. By loading the hexagonal slot alone the operating frequency can be lowered to 1.74 GHz, results in greater area reduction. The extended slot arms splits the fundamental resonant frequency of the square microstrip patch with hexagon alone, into two separate resonant modes, TM_{10} and TM_{01} with orthogonal polarization planes. Thus the central hexagonal slot with the two slot arms considerably increases the effective lengths of the two excited resonant modes, TM_{10} and TM_{01}, and the excited patch surface current densities are perturbed in such a way that these two modes can be excited for dual frequency operation with a single feed. The length of the slot arms determines the frequency ratio of the two operating frequencies and a constant frequency ratio will be maintained for same slot arm lengths. Thus desired frequency reconfiguration can be readily achieved by switching the two slots with different lengths, by embedding the pin diodes.

When the pin diode is on, it essentially behaves as equivalent short circuit, thus driving the currents on the patch directly through it, reducing the effective length of the slot. Since D_1 and D_2 are placed at x_1 and x_2, to achieve different slot lengths, dual frequency generation is accomplished by different frequency ratios, depending on which diode is forward biased. When both diodes are off, the currents have to flow through the capacitors C_1 and C_2, with an increased current path, resulting in the shifting of resonant frequencies towards lower frequency region with another frequency ratio. The advantage of this design is that the pin diodes can be placed at any position of the two slot arms for different x_1 and x_2 values, without much affecting the good return loss characteristics and bandwidth, for a single feed position. This property of the design gives more flexibility in frequency tuning where frequency ratio varies in a wider range 1.2 to 1.4.

3. Experimental Results

The proposed reconfigurable antenna is tested using a HP 8510C Vector Network Analyzer. When the protruding slot arms are absent, the antenna shows a single resonant frequency at 1.74 GHz, much lower (144 MHz) than the fundamental resonant frequency (1.884 GHz) of the unslotted square patch antenna. Thus the hexagonal slot of side parameters l_1 and l_2 placed at its center reduces the fundamental resonant frequency of the patch from 1.884 GHz to 1.74 GHz, giving enhanced size reduction.

When both diodes, D_1 and D_2 are off, the antenna resonates at 1.21 GHz and 1.675 GHz with a frequency ratio 1.3845. By turning on the diode D_1, positioned at $x_1 = 0$ mm, the first resonant frequency shifts 150 MHz and second by 5 MHz giving excitations at 1.36 GHz and 1.67 GHz with a much lower frequency ratio 1.2279. Also by keeping D_2 on, positioned at $x_2 = 8$ mm, the operating frequency ratio can be brought to 1.29, where the antenna resonates at 1.295 GHz and 1.675 GHz. In all these three diode states the antenna has a good matching below -10 dB at a single feed position. Figure 2 shows the measured return loss (S11) of the antenna with dimensions $L = 4$ cm, $l_1 = l_2 = 0.8$ cm, $x_1 = 0$ cm, $x_2 = 0.8$ cm, $w_a = 0.1$ cm, $h = 0.16$ cm and $\epsilon_r = 3.98$.

The new design provides a maximum area reduction of 72.21% for the first resonant frequency and 46.84% for the second resonant frequency, compared to standard rectangular

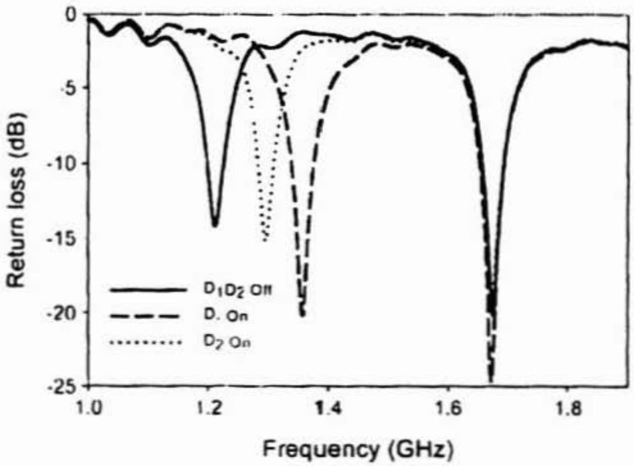

Fig. 2. Measured return loss (S_{11}) of the antenna for the three pin diode states. ($L = 4$ cm, $l_1 = l_2 = 0.8$ cm, $x_1 = 0$ cm, $x_2 = 0.8$ cm, $w_a = 0.1$ cm, $h = 0.16$ cm and $\epsilon_r = 3.98$).

patches, which proves the compactness of the proposed design, suitable for the early mentioned applications in L-band. Moreover, bandwidths up to 2.82% and 2.42% respectively have been obtained in the two modes, in all the three diode states.

The transmission characteristics are measured using HP8510C Vector Network Analyzer interfaced to a S310C Automatic Antenna Position Controller and an IBM PC. The designed reconfigurable antenna is kept in the transmitting mode and a wide band standard horn is used as receiver. RF signal and a DC voltage source are applied to the reconfigurable antenna in the transmitting mode and the power received by the wide band horn, in the vertical plane is stored as a function of frequency for a particular PIN diode state. The transmitting antenna is then rotated 90° to record the received power as a function of frequency in the horizontal plane. The analysis of the recorded data in both the planes reveals that the two resonant frequencies are in orthogonal polarization planes. The experiment is carried out for all the three PIN diode states and it is found that the polarization of the two operating frequencies is essentially same in all the diode states, Fig. 3.

Gain measurements are carried out using the gain comparison method with standard circular patches fabricated in the dielectric substrate of $\epsilon_r = 3.98$. For the first resonant frequency the gain is found to be 3.63 dBi and 3.57 dBi respectively, when D_1 and D_2 are on. In the case of second resonant frequency it is 5.6 dBi and 5.4 dBi when D_1 and D_2 are on respectively. When both the diodes are off, the measured gain for first resonant frequency is 3.38 dBi and that of second resonant frequency is 5.07 dBi.

The radiation patterns are measured for three diode states and plotted in Fig. 4. All the patterns show similar broadside radiation characteristics without any distortion even after the diodes are turned ON, which is highly desirable for frequency reconfigurable antennas. Although the maximum radiation direction shows some slight variations, the power difference between them in all the diode states are below 0.4 dB. The measured 3 dB beam width for the two resonant frequencies in different PIN diode states are shown in Table 1. Table 2 lists the variation of maximum radiation direction in degrees, for the two operating frequencies in different diode states.

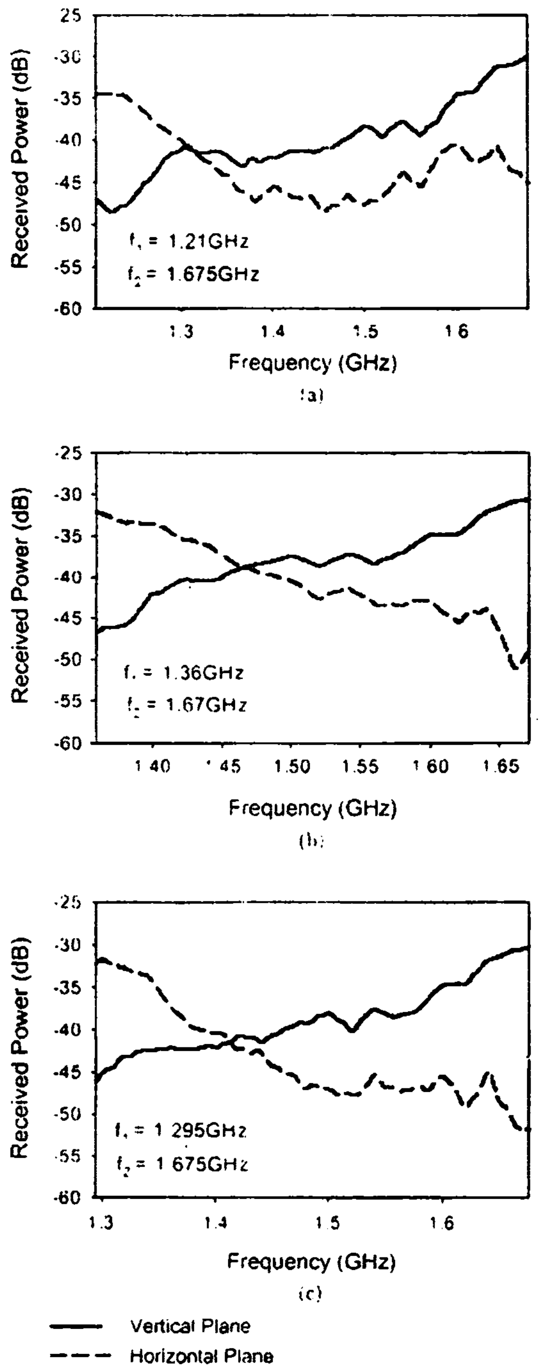

Fig. 3. Variation of received power with frequency for the two orthogonal polarization planes for all the three pin diode states. (a) D_1 and D_2 off. (b) D_1 on (c) D_2 on.

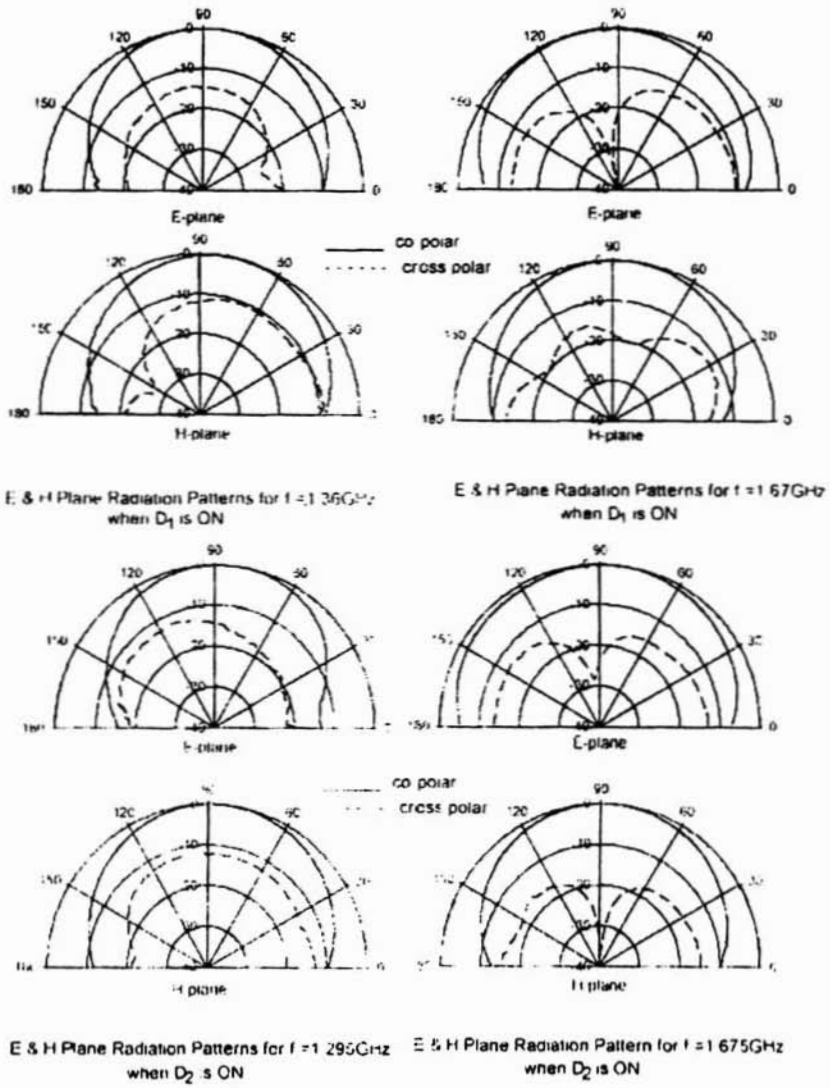

Fig. 4. Measured E and H plane radiation patterns of the proposed antenna in different pin diode states (Antenna parameters given in Fig. 2).

Table 1. Measured beam width in degrees for first and second resonant frequencies for all PIN-diode states.

	First resonant frequency, f_1			Second resonant frequency, f_2		
	D_1 ON	D_2 ON	D_1 & D_2 OFF	D_1 ON	D_2 ON	D_1 & D_2 OFF
E-Plane	82°	76°	98°	112°	130°	156°
H-Plane	84°	84°	88°	86°	86°	102°

Table 2. Maximum radiation direction in degrees for first and second resonant frequencies for all PIN-diode states.

	First resonant frequency, f_1			Second resonant frequency, f_2		
	D_1 ON	D_2 ON	D_1 & D_2 OFF	D_1 ON	D_2 ON	D_1 & D_2 OFF
E-Plane	83°	83°	91°	98°	87°	98°
H-Plane	77°	85°	87°	84°	85°	95°

4. Conclusion

A novel electronically reconfigurable dual frequency, dual polarized microstrip patch antenna suitable for compact *L*-band operation is reported in this paper. The antenna uses a highly simplified circuitry of pin diodes, without any transmission lines, for switching the operating frequencies. The frequency ratio of the antenna varies in a wide range of 1.2 to 1.4 with a good bandwidth of 2.82% and 2.42% for the two resonant modes. The added advantage of the antenna is that its high size reduction of 72.21% and 46.84% for the two operating frequencies compared to standard rectangular patch, without much reduction in gain.

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