Radiation pattern of reconfigurable antenna design for portable device applications

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ABSTRACT. *In wireless communication, the high performance handsets are blooming in the market. Multiple applications are incorporated in these portable devices. In this regard, antenna plays a very important role in handling these multiple functions simultaneously. Radiation pattern is one of the important parameter of antenna. This paper presents, radiation pattern of a compact reconfigurable meander micro strip patch antenna, suitable for portable devices. Here, effect of cover on radiation pattern is also displayed. The reconfigurable antenna radiation pattern also compared with the traditional antenna radiation pattern for conclusion. The antenna is designed and tested at 2.4GHz (ISM band) having 130MHz bandwidth. HFSS (High Frequency Structure Simulator) is used to design and simulate the antenna. Proposed antenna changes its polarization (horizontal/ vertical) as per necessity using PIN diodes. The radiation pattern is measured in the laboratory using antenna measurement system. The results focus on the fact that polarization reconfiguration is better performance than the frequency reconfiguration technique in antenna in portable device.*

RÉSUMÉ. *Dans la communication sans fil, les portables de hautes performances sont en plein essor dans le marché. De nombreuses applications sont intégrées dans les appareils portables. À cet égard, l'antenne joue un rôle très important dans la gestion simultanée de ces multiples fonctions. Le diagramme de rayonnement est l'un des paramètres importants de l'antenne. Cet article présente le diagramme de rayonnement d'une antenne en micro-ruban en méandre reconfigurable et compacte, adapté aux appareils portables. Ici, l'effet de la couverture sur le diagramme de rayonnement est également affiché. Le diagramme de rayonnement d'antenne reconfigurable a également été comparé au diagramme de rayonnement d'antenne traditionnel pour une conclusion. L'antenne est conçue et testée à 2,4 GHz (bande ISM) avec une largeur de bande de 130 MHz. HFSS (Simulateur de Structure à haute Fréquence) est utilisé pour concevoir et simuler l'antenne. L'antenne proposée utilise des diodes PIN pour modifier sa polarisation (horizontale/verticale) selon les besoins. Le diagramme de rayonnement est mesuré en laboratoire à l'aide d'un système de mesure d'antenne. Les* *résultats se concentrent sur le fait que la reconfiguration de polarisation offre de meilleures performances que la technique de reconfiguration de fréquence dans une antenne d'un dispositif portable.*

KEYWORDS: *reconfigurable antenna, radiation pattern, portable device.*

MOTS-CLÉS: *antenne reconfigurable, diagramme de rayonnement, appareil portable.*

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1. Introduction

Today, wireless technology is the main areas of research in the world of communication systems and communication system study is incomplete without an understanding of the fabrication and operation of antennas. This is the main reason for fabricating antenna. The area of antenna study is a huge and vast, so, grasping the fundamentals, two pronged approach by dividing the process into steps as follows are adopted. One is the design and optimization of antenna– mechanical/geometric structures, in particular, the orientation and shape of the radiators, the feeding network, as well as loading. This conventional approach most often employed in antenna design. Top-loaded dipole antennas, Inverted-F antennas, and slotted planar antennas all fall into this category. The use of non-conducting material - Antennas loaded with high-permittivity or ferrite dielectric materials (for instance, ceramics) are examples of this type of technology, as is the dielectric resonant antenna. The application of special fabrication processes - The fabrication of low-temperature co-fired ceramics printed circuit boards has made co-planar and multiple-layer microstrip patch antennas popular. Such technologies are conducive to the mass production of miniaturized antennas at low cost. The portable mobile devices will include - mobile phone handsets; RFID tags; laptops with embedded wireless local area network (WLAN) access points; medical devices for microwave thermal therapy; sensor installed on or above the human body; and ultra-wideband (UWB) based high-data-rate wireless connectors such as the wireless USB dongle. All of these portable mobile devices are widely used. The antennas used in them have become a bottleneck in the miniaturization of portable devices in terms of performance, size, and cost. The increasing design challenges have made the antenna design for portable devices much more critical than before.

Antenna having rectangle shape and rectangle shape with semi circle at top offered -18dB Return loss, -15.7dB to -31.4dB Insertion loss, -25dB Isolation and Omni directional radiation pattern using Varactor diodes and PIN diodes as switch for frequency reconfiguration (Husseini *et al*., 2013). In ref. (Munir and Ludihargi, 2013) a simple circular microstrip patch antenna with insertion loss of 1.87dB and 200MHz bandwidth is noted. S. Singh *et al*. (2013) presented Reconfigurable circular patch antenna having -10dB return loss and 1GHz Bandwidth using PIN diodes for polarization reconfiguration. A meander antenna with 0 to -5dB return loss, -30dB to -20dB Insertion loss, 2:1 SWR, Gain of the order of 1.1dBi, 95MHz and Omni directional radiation pattern using copper link for switching purpose for polarization reconfigurable antenna is obtained here (Raman *et al*., 2013). Helix antenna with-10dB to -14dB Return loss, 6.2dB gain, 10% of resonance frequency and isotropic radiation pattern with polarization reconfiguration is studied (Alaa *et al*., 2014). In this paper, Meander shaped dipole antenna used which offers -15dB Return loss, 2.21dBi Gain and 9.95% Bandwidth is noted. To achieve these parameters PIN diode for switching is used. Polarization and Frequency reconfiguration is shown here (Husna *et al*., 2014). L shaped antenna with -28dB to -30dB Return loss, 25dB Isolation, 3dB Insertion loss and 196MHz Bandwidth is obtained in ref. (Sodre *et al*., 2014). Dipole antenna divided into slots for frequency variation and offers -20dB Return loss, Gain of 2.82 to 4.11dBi and Radiation pattern same as Dipole antenna. Using PIN diode slot size changed to get Frequency Reconfiguration (Borakhade and Pokle, 2015). E shaped antenna shifting is carried out using Photo conductive switches. With this technique Return loss of -15dB, 12.5dB Gain and Omni directional Radiation pattern is obtained (Kang and Juang). Rectangle antenna with Return loss -7dB, Insertion loss 0.7dB, Gain 8.1dBi and 850MHz Bandwidth is reported in ref. (Adami *et al*., 2018). Pentagon Antenna for frequency reconfiguration is used here. Return loss of -15.8dB and -18.5dB, SWR between 1.06 to 1.26, Gain of 2.14dBi, 290MHz and 370MHz and Omni directional radiation pattern is reported in ref. (Sahu, 2015) with help of Loop and Beam steering antenna is used for Beam variation using PIN diode. Return loss under 6dB, SWR less than 3, Gain between 5.9 to 6.6dBi, Bandwidth of 130MHz and Omni directional radiation pattern is obtained in (Takacs *et al*., 2015). In this paper polarization reconfiguration is obtained using square shaped antenna and PIN diode for switching purpose. Return loss -18.69dB, Insertion loss -14dB, SWR 1.03, Gain 6.5dB, Bandwidth of 32.5MHz and Isotropic radiation pattern is reported (Trong *et al*., 2015). Helix antenna with -6.2dB Return loss, 5.9dBi Gain and 123MHz Bandwidth is reported in (Cai *et al*., 2016). Polarization shifting from circular polarization to linear polarization with Varactor diode (Switch) and using Square shaped antenna is reported here. In this work -9.8dB Return loss, Gain 7.3dB, 40%Bandwidth and Omni directional radiation pattern is obtained (Chatterjee and Parui, 2016). Polarization reconfiguration is obtained using Slotted circle in this paper. PIN diodes are used for polarization diversity. In this paper Return loss of -10dB, Gain of 2.5dBic, Bandwidth 19.8% and Conical shaped Omni directional radiation pattern is reported (Gao *et al*., 2016). Monopole antenna with Return loss < -10dB, Gain 12.5dBi, Insertion loss <-5dB, Bandwidth -10dB (38%) and Omni directional radiation pattern is noted (Heydari *et al*., 2017). Polarization variation with the help of Triangle connected in circular shape is done here. The return loss >-10dB, Isolation >20dB, large Bandwidth of 400MHz and Omni directional radiation pattern is reported. The reconfiguration is obtained by changing feeding technique to antenna (Bharathi *et al*., 2017). Frequency Reconfiguration of circular patch antenna and PIN diodes for switching is used. Return loss -5dB, SWR <2, Gain 16dBi, Omni directional radiation pattern and Bandwidth 1.2GHz is obtained using this technique. Polarization and frequency reconfiguration using single Square patch antenna is obtained in this paper. 6 PIN diodes are used for this purpose. Return loss <-10dB, Gain 6.3dBi, 60MHz Bandwidth and Omni directional radiation pattern is obtained in ref. (Kadam and Kulkarni, 2015).

A number of factors affect antenna performance in hand held i.e. portable computing devices in wireless communication. Antenna performance is defined or accounted by many parameters. Above survey shows that the researchers have considered parameters like return loss, gain, impedance, isolation, insertion loss, radiation pattern and SWR for evaluating their antenna. But the effect of cover is also important for measuring parameters as all portable devices are now a day integrates antenna inside the box. Due to this it is important to study the effect of different covers on antenna performance and also on the radiation pattern of antenna which is important parameter for evaluation. The aim of this paper is to test and compare the radiation pattern of reconfigurable antenna. Here frequency and polarization reconfiguration is used for evaluation purpose. In the laboratory, initially measure radiation pattern of polarization and frequency reconfigurable antenna without any cover. In next step plastic, paper and cloth are used as cover for both antennas. By changing the cover of antenna, radiation pattern is measured in laboratory with the help of antenna measurement kit. The objective of this process is to find the effect of cover on radiation pattern of reconfigurable antenna and also observe the effect on radiation pattern due to change in reconfiguration parameter from frequency to polarization.

2. Méthodologies

Different levels (Figure 1) to test the radiation pattern of reconfigurable antenna are;

Level 1: Basic antenna shapes – rectangle, square, circle and monopole antenna (Meander shaped) are simulated by using Simulation software – HFSS.

Level 2: All listed patch antennas are fabricated on FR4 substrate and tested on antenna trainer kit.

Level 3: Effect of cloth, paper and plastic cover is tested on performance of antenna.

Level 4: Polarization reconfigurable meander antenna is simulated using HFSS.

Level 5: Polarization reconfigurable antenna is fabricated and initially tested without PIN diode for switching between antenna.

Level 6: Reconfigurable antenna with PIN diodes is fabricated and Raspberry PI for switching PIN diodes is used. This whole structure is used in walkie-talkie system and tested in outdoor environment.

Level 7: All fabricated antenna are tested with cloth, paper and plastic for finding effect of cover on antenna performance in the laboratory.

3. Antenna design

Table1 shows the parameters of Meander antenna. Number of meander sections can be calculated using Eq. 1.

$$A = \frac{Z_0}{L}\sqrt{\frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{S}{\varepsilon_r}\right)} \tag{1}$$

where, *A*= Number of folds.

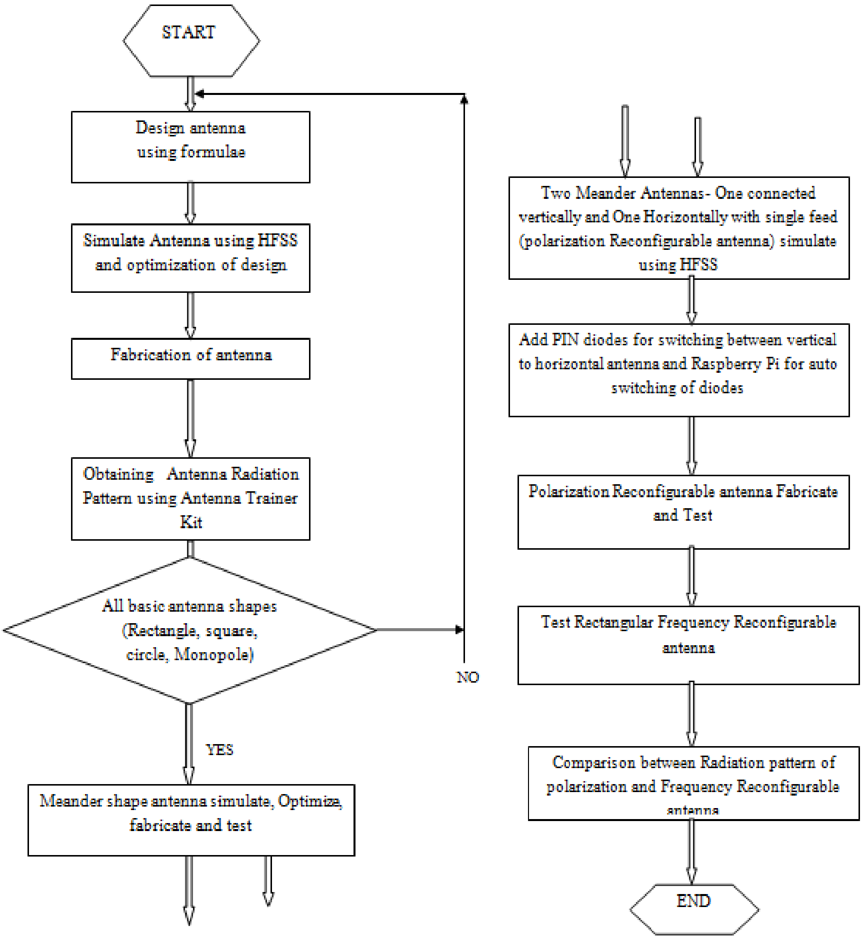


Figure 1. Methodology

The antenna is designed, simulated, optimized and results are verified using HFSS. The optimized parameters used to fabricate antenna as shown in Figure 2 with FR4 as a dielectric and Tin plating used for tracks. The basic need of portable device antenna is antenna should be small size. The proposed antenna design is a miniature in size with performance stability. This is achieved by co axial feed along with capacitive de coupling structure. 6PF/16V NPO SMD capacitor connected to give good ESR (Equivalent Series Resistance) at microwave frequency. Another requirement of portable device antenna is Bandwidth. Portable device has a limited bandwidth. In many applications, bandwidth up to 25MHz is observed and focus is given on increasing their band efficiency but not bandwidth. The designed antenna satisfies existing channel Bandwidth (130MHz) requirement. Along with these parameters, Impedance, far field requirement and constraints i.e. in which device antenna is placed, (the adjacent devices and circuitry) antenna performance should not degrade due to vicinity of other components. As the direction of signal coming to antenna is not fixed, the radiation pattern of antenna should be omni directional whereas for point to point communication, directional pattern with high directivity is preferred. In case of portable computing devices, omni directional radiation pattern is expected which is obtained from the designed antenna. In portable devices, co axial feed is not feasible to antenna because as per size the feed itself is bigger which can deteriorate signal due to coaxial pin reactance and losses that are taking place in the cable. So inset fed arraignment is done. As PCB mountable compact feed, it gives good performance whereas if feed size is large, performance gets deteriorated. Thus antenna co axial feed can be easily converted into inset feed to achieve high performance.

Table 1. Parameters of meander antenna

Parameter	Dimension
Height (h)	1.6mm
Width(w)	38.03mm
Free space wavelength($\lambda=L$)	125mm
Guided wavelength (λ_g)	61.53mm
Operating Frequency(fr)	2,4GHz
Characteristics Impedance (Zo)	50Ω
Fold bend/ Vertical height (S)	7mm

As the proposed antenna is a reconfigurable antenna (Figure 3), two antennas are used (one horizontal and another vertical antenna) as shown in Figure 3. and isolation between two antennas is a critical issue. The designed antenna is for portable device, so isolation between closely spaced PCB tracks is also important. To achieve this isolation artificial magnetic conductor surrounded at ground is also fabricated and tested. This technique also helps to provide efficient radiation only on dominant mode and reduce the power of higher order modes (The mode of the proposed antenna is quasi TEM).

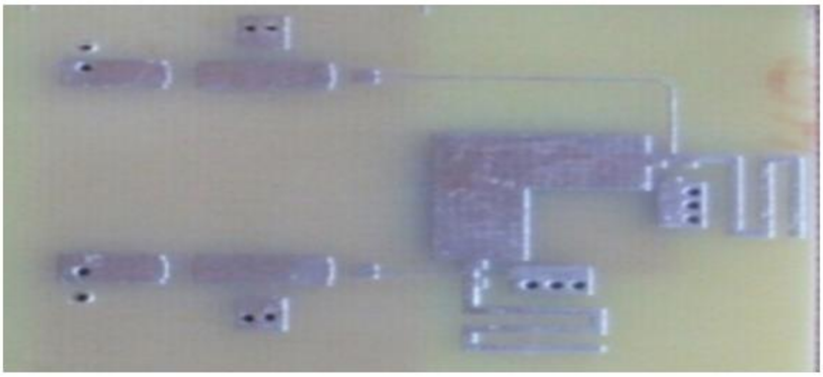
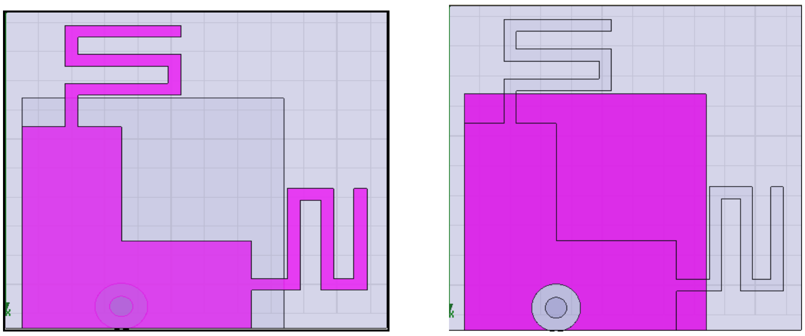


Figure 2. Fabricated antenna structure

Figure 3. Reconfigurable antenna with Raspberry Pi

Another need of reconfigurable antenna is to carry fast switching between antennas to match high frequency signal. The PIN diode (HSMP3864) is used for switching purpose. The operating frequency of this diode is 3.4GHz, 100nS switching time (Current and Capacitance between two plates will decide switching time). For testing purpose, and to observe the switching signal on DSO for analysis, the cycle period 100 Sec is adjusted in the program and later it can be changed to achieve high switching speed. Initially reconfigurable antenna is fabricated with gap and to switch between two antennas copper strip used where switching is carried out manually. In later step, PIN diode is connected in the gap and auto switching is done. Two separate PIN diodes are used for the purpose and for switching purpose, required square wave obtained from Raspberry Pi as shown in Figure 3. Python is used to program the board. In future when the overall system is transferred to SoC (System on chip) antenna, Raspberry can give a better solution.



(a) Front View (Actual Antenna) (b) Back View (Ground Plane)

Figure 4. Geometry of proposed antenna

The overall dimensions of antenna are such that the whole space is utilized properly as shown in Figure 4. Initially no gap is added at the point of feed and antenna is simulated. In further step, RF switches (PIN diodes) are added for reconfiguration purpose, which can be fitted in the top right corner, on the same PCB in the fabrication process. The length and width of substrate is 0.30λ and at 2.4GHz (λ = 76mm) i.e. the size of the substrate is selected as 23mm × 23mm. The feed line strip has width of 6mm. The overall length of monopole antenna is 30.76mm and 2 folds are used to fit it into given size of board as shown in Figure 4(a). The other side of Board contains 10mm × 10mm ground plane as shown in Figure 4(b).

4. Results and discussion

4.1. Numerical simulation

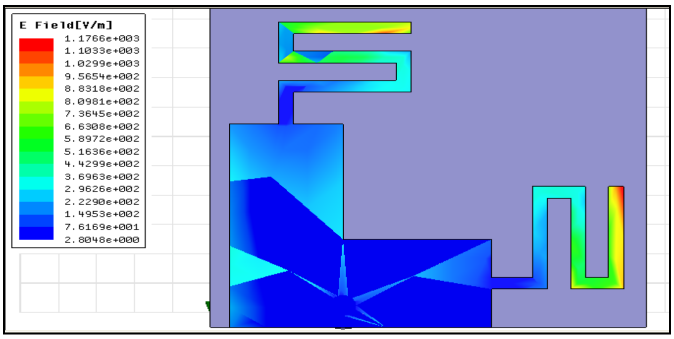


Figure 5. Field plot

Figure 6. Radiation pattern

The Figure 5 shows the field strength in the antenna when feed is applied. The Figure 4 indicates that the antenna radiates exactly at 2.4GHz with sufficient current flow through out length of antenna when no switch present feed point and vertical as well as horizontal antenna. Both antenna behaves as if a single antenna and contribute equally in radiation. Figure 6 shows radiation pattern of proposed antenna using HFSS. Radiation pattern of proposed antenna indicates two major lobes along Y axis covering horizontal plane and minor lobes absent as shown in Figure 6. The aim of work is to study the radiation pattern of the reconfigurable antenna and observe the effect of reconfiguration as well as cover on the radiation pattern. Cloth, plastic and paper is used to cover antenna. The AMS-A ANTENNA MEASUREMENT SYSTEM is used to measure radiation pattern. The maximum operating frequency of Antenna Trainer Kit is 3GHz and uniform +5dBm power input is applied to antenna from the kit. The arrangement of measurement system is as shown Figure 7.

For measurement purpose, the Wire Dipole antenna (isotropic antenna) is used as a transmitter and proposed antenna used as a receiver as shown in Figure 7 (Figure 7). The dipole antenna is adjusted to length 24cm to operate at 2λ. The radiation pattern is obtained by rotating receiving antenna from 0° to 360° in steps of 1.8°. The frequency of transmitter is adjusted to 2.4GHz manually. The power input to dipole antenna is given as +5dBm and by rotating receiving antenna in 360°, the power output is recorded. Readings are uploaded to PC by using RS232 cable and the polar plot is generated by software designed for the measurement system kit.

There are basically three reasons, due to which deterioration in radiation pattern takes place.

Due to the objects in Near Field- Here, the person who is carrying experiment may come in between or other instruments like CPU, Monitor etc.

Secondary sources in Near Field- Here, the objects which are present in the near field may absorb the radiation transmitted by dipole or they may reflect it to receiver antenna.

Antenna cables which are parts of setup come into picture. The cables connected between receiving antenna and receiver unit has its own impedance and length. The impedance is a function of frequency. When the signal travels from receiving antenna to receiver, it may get attenuated and deteriorate the pattern.

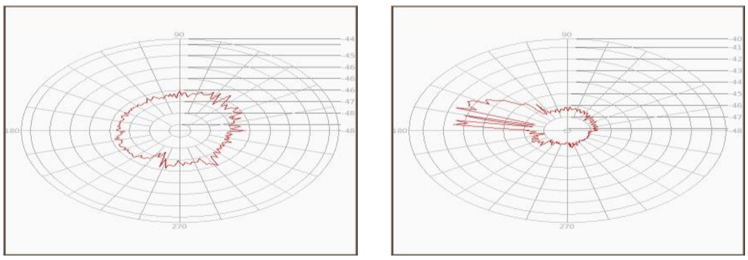
4.2. Experimental Analysis

4.2.1. Radiation pattern of antenna without polarization Reconfiguration

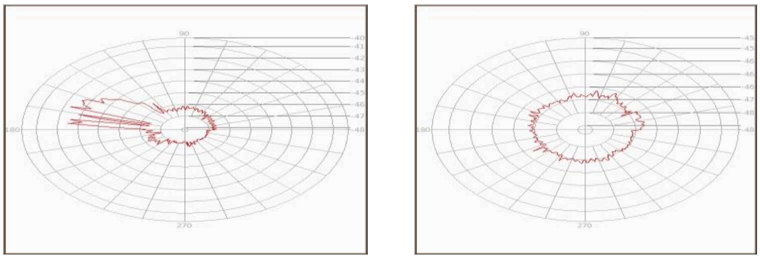
The average signal strength is -44dBm.The two antennas are arranged in LoS (Line of Site) Communication. But when it starts rotating, the other objects which are present in near field region reflects signal and this reflected signal gets added with the signal fall on receiving antenna in that particular direction and due to that pattern changes.

Figure 7. Antenna measurement system

The four radiation pattern shown in Figure. 8 indicates that the antenna gives omni directional radiation pattern. Figure 8(a) shows radiation pattern of antenna without any cover on antenna. But when covers are applied to antenna, the pattern gets changed. It is observed that with cloth and paper as a cover, in the radiation pattern as shown in Figure 8(b) and Figure 8(c), the minor lobes are increasing significantly and it can be due to the secondary source present in the near field region whereas very less effect of plastic cover on radiation pattern of antenna as shown in Figure 8(d).



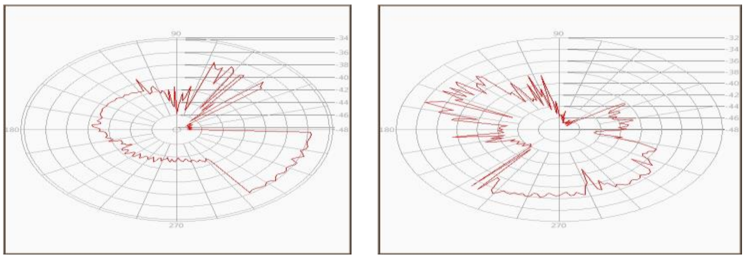
(a) (b)



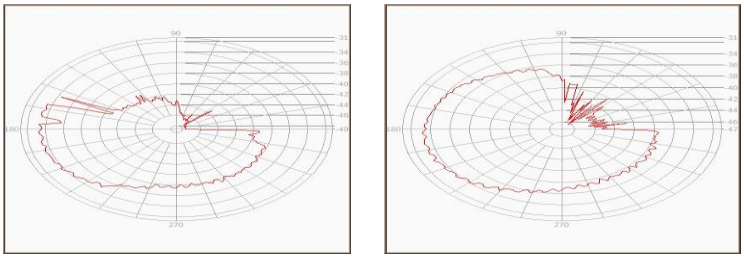
(c) (d)

Figure 8. Radiation pattern of reconfigurable antenna with both PIN diodes ON a. without cover b. with cloth cover c. paper cover. d. with plastic cover

4.2.2. Radiation pattern of Polarization Reconfigurable antenna when horizontal antenna is functioning



(a) (b)



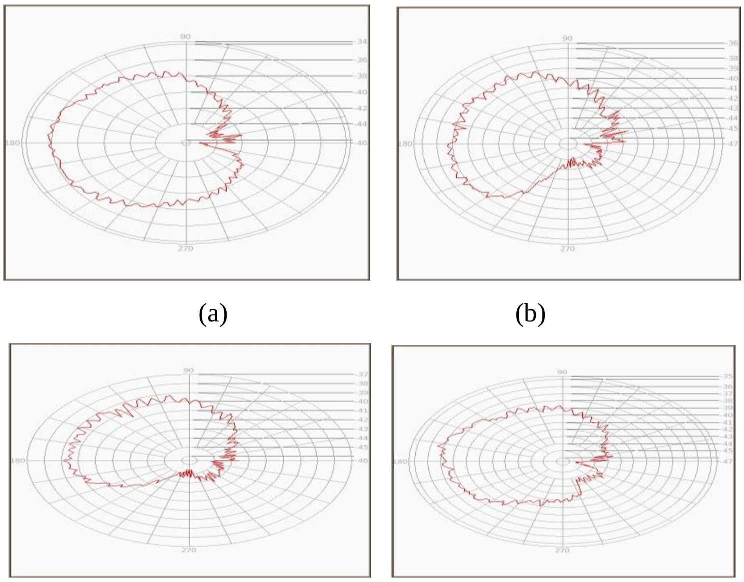
(c) (d)

Figure 9. Radiation pattern of horizontal antenna a. without any cover b. with cloth cover c. with paper cover d. with paper cover

The Figure 9 shows the radiation pattern of horizontal antenna (only one antenna switched ON) which is more deteriorated due to secondary source. This is due to the polarization of transmitter and receiver did not match (i.e. XDP level considered.) because of which minor lobes increased more than previous arrangement. More glitches are observed in Figure 7(b) and Figure 7(c). Open area site test is one of the reason of the same. From Figure 9, it is observed that the vertical antenna with plastic cover gives better results. With plastic cover the shift in null is less.

Effect of PIN diode: When PIN diodes are ON, forward resistance of diode decreases and signal strength in antenna increases whereas when diode is OFF resistance increases and signal strength decreases. But, when both diodes are ON, the symmetrical antennas work together. So, XDP level increases and no addition of two signals takes place and radiation pattern deteriorates due to reduction in overall strength.

4.2.4. Radiation pattern of vertical antenna



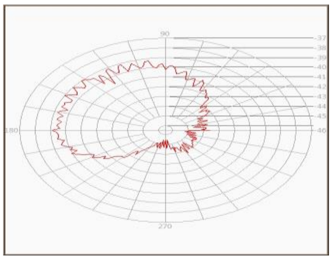
(a) (b)

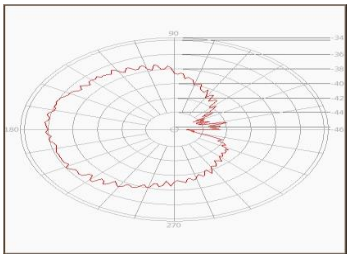
(c) (d)

Figure 10. Radiation pattern of vertical antenna a. without any cover b. with cloth cover c. with paper cover d. with plastic cover

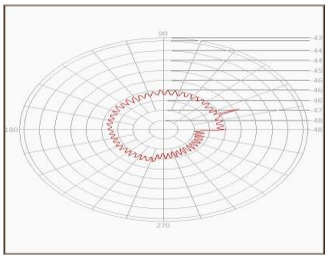
4.2.5. Radiation pattern of without frequency reconfigurable antenna:

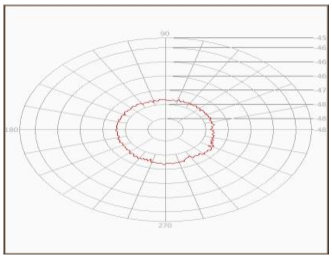
Figure 10 (a) and Figure 10 (b) shows the radiation pattern of Vertical Antenna. Radiation pattern of vertical antenna without cover is shown in Figure 10(b), Radiation pattern of Vertical antenna with cloth cover is shown in Figure 10 (c), with paper cover shown in Figure 10(d), with plastic cover. Without Frequency Reconfigurable antenna, with E shape is used to evaluate the effect on radiation pattern. From Figure 11 it is observed that the isotropic radiation pattern is obtained with less effect of cover.





(a) (b)



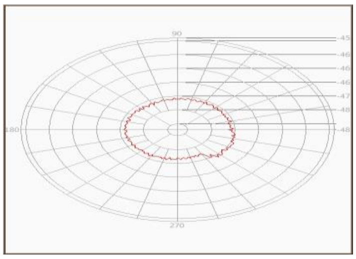


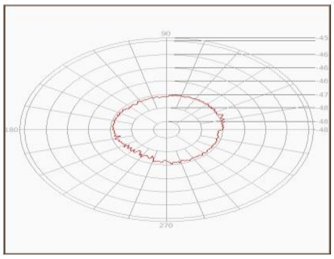
(c) (d)

Figure 11. Radiation pattern of e shaped antenna a. without cover b. with cloth cover c. with paper cover d. with plastic cover

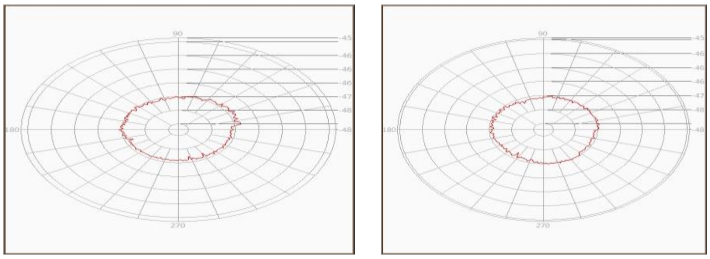
4.2.6. Radiation pattern of frequency reconfigurable antenna

The Figure 12 shows E shaped antenna with frequency reconfiguration. The radiation pattern is almost same for all cases. In Figure 12 (c) shift in null is observed. Overall signal strength is reduced and reaches up-to -48dBm.





(a) (b)



(c) (d)

Figure 12. Radiation pattern of frequency reconfigurable e shaped antenna a. without cover b. with cloth cover c. paper cover d. with plastic cover

5. Conclusion

In this paper, in case of frequency reconfiguration, radiation pattern is less affected. But if the signal is suffering from noise at a particular frequency, then one has to shift to lower band because lower band is more immune to noise. Polarization reconfiguration is suggested than frequency reconfiguration as the antenna for portable device is suffered from noise and strength of signal (Generally it is weak). If noise has to be avoided, then frequency band has to be shifted but then lower band is already crowed. Whereas polarization reconfiguration employs shift from vertical to horizontal or vice versa which result to overcome both problems at same frequency. Even in WiFi module and other wireless devices polarization change is suggested to improve the performance. Frequency reconfiguration utility is less useful than polarization reconfiguration. That is why when noise is more polarization plane change is best. Frequency reconfiguration change band is not allowed. In a particular band polarization reconfiguration is allowed. No money for polarization is charged. But if one needs to shift from 1 band to other, he has to pay the service provider. In wireless communication, 802.11, 802.11a, 802.11.b, 802.11g, and 802.11n protocol, polarization change allowed. Thus, it is observed that the plastic cover is better for antenna to avoid deterioration in radiation pattern.

Conflict of interest: The authors declare that there is no conflict of interests regarding the publication of this paper.

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