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A NOVEL CIRCULAR PATCH ANTENNA WITH RECONFIGURABLE FREQUENCY FOR WiMAX AND LTE NETWORKS

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Abstract: *Modern communication devices are design to support several services and functionality with improved performance. This requires several components integrated on a single device and subsequently the overall system becomes bulky with degraded performance. To address the problems, reconfigurable antennas are employed to improve the performance. A frequency reconfigurable circular patch antenna was designed and simulated. Frequency reconfiguration was achieved by creating a slot on the ground plane with three PIN diodes as switching devices. Six different reconfigured frequencies were obtained. The frequency F6 at 2.1 GHz and F8 at 1.8 GHz have potential application for broadband wireless communication in WiMAX (Worldwide interoperability for Microwave access) and LTE (Long Term-Evolution) networks respectively. The reflector introduced at the back of the antenna to further enhance the antennas gain by 7.80 at 1.8 GHz. Also, peak efficiency of 93.7% was obtained at 2.10 GHz. A directional radiation pattern obtained further justified its broadband applications.*

Key words: Antenna, Reconfigurable, PIN diodes, Frequency and, LTE.

1 Introduction

Antenna is an electromagnetic device that is designed to receive or transmit electromagnetic waves. They are essential components in various communication systems, including radio, television, and mobile phones (Swain and Sharma, 2023). Antennas convert electrical signals into radio waves and vice versa, allowing for wireless communication over long distances(Kumar*, Khandekar and Tupe-Waghmare, 2019). They come in different shapes and sizes, each designed for specific frequencies and applications. Several antennas can be installed on a single device each providing a specific function and service. The most widely used for portable communications devices are microstrip patch antennas (Bala, Rahim and Murad, 2012). These antennas offer various advantages of low profile, compact, lightweight and ease of integration with active elements (Boukarkar *et al.*, 2018).

It is worth noting that as communication devices are becoming smaller due to miniaturization, so is the need to have a compact antenna of smaller footprint that support several applications (Li *et al.*, 2024). This give rise a reconfigurable antenna where a desirable property of antenna such as frequency, bandwidth, directivity, patterns and polarization can be reconfigured (Singh, Basu and Koul, 2020). In this research work, a frequency reconfigurable antenna is presented for an applications on a smart phones and computers with smaller footprint and multiband operations (Bala, Rahim and Murad, 2014), (Subhi, Jamal and Al-gburi, 2025).

Reconfigurable antennas are antennas that are capable of modifying their operating frequencies by reducing or enlarging the dimension (the size) of the patch, either physically or electrically by using devices such as Radio Frequency (RF) switches, impedance loading or tuneable materials (Majid *et al.*, 2014; Salazar-Cerreno *et al.*, 2020)

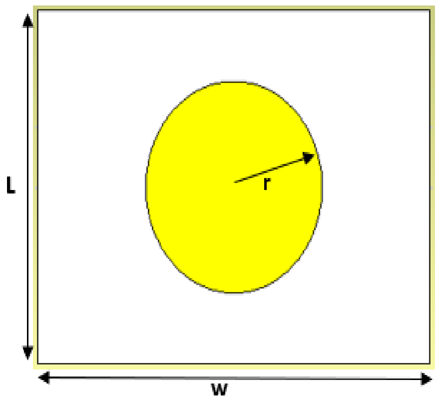
In (Zhao and Riaz, 2018), a novel microstrip feed line based dual-band frequency reconfigurable multiple-input multiple-output (MIMO) patch slot antenna was presented. The antenna has planar structure and comprises of four symmetrically placed rectangular patches. A dual hexagonal-shaped defected ground structure (DGS) was uses as ground plane. Varactor diodes were integrated within the feed line to achieve the frequency reconfigurable. This antenna reconfigured its frequencies in the lower band. In (Singh, Basu and Koul, 2020), a nearly square patch was designed with two small stubs that are connected at the bottom corners of the patch, which are separated by a PIN diodes. As the PIN diodes states changes, the stubs are either connected or separated from the main patch. The antenna is fed by a quarter-wave transformer. Three frequencies are reconfigured in this design. The biasing of this antenna become complex. A fluidically loaded microstrip patch antenna on a multi-layered substrate was presented In (Singh and Saavedra, 2021). The resonator is a square patch loaded at all the corners with short circuited long stubs of length $\lambda_g/4$. An arrangement of fluidic channels was presented by moulding Polydimethylsiloxane (PDMS) with 3D printed mould is incorporated beneath each stub. By injecting or withdrawing distilled water into the channels, variable loads are realized and the frequency is reconfigured. The antenna has complexity in its design and frequencies reconfigured have a little variation. In (Sumana, Sundarsingh and Priyadharshini, 2021), planar antenna with narrow and ultra-wide (UWB) bands was designed. Its ground plane made of nickel-titamin with shape memory alloy (SMA) is also presented. The antenna operates at flat condition with frequency of 1.16GHz. Upon bending the SMA ground plane at an angle of 200° with a transformation temperature of 66°C. The same antenna in (Johnson *et al.*, 2020)operates over 3.4GHz to 10.2GHz UBW range, this is due to the SMA phase transformation via resistive heating and cooling. The antenna has no sources of heat; hence, it is difficult for the SMA to bend. In (Johnson *et al.*, 2020), the patch antenna with concept enable by adhesive polyimide tape was designed. The antenna can switch from a conventional patch to monopole-like antenna with minimal actuation complexity. The antenna reconfigured its frequency form 2.1GHz to 2.4GHz. The antenna has a complexity in reconfigure its frequency because no active components used in order to increase or reduce the size of the patch.

In this paper, a circular patch antenna with frequency reconfigurability features is proposed. A circular patch was designed with a slot at its ground plane. Three PIN diodes were used to modify the size of the ground plane of the antenna in order to obtain various frequency bands knowing fully that resonant frequencies are dependent of the antenna sizes. Eight configurations are obtained by proper switching combinations of F1, F2 and F3 switches. This antenna has a simple structure and also has applications in WLAN and future generation. Section 2 discusses the design methodology and approach; section 3 discusses the simulated results and analysis while section 4 concludes the paper with references.

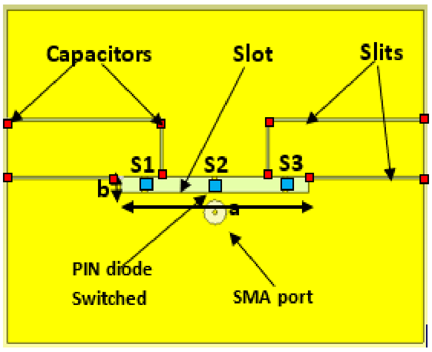
2 ANTENNA DESIGN

The geometry of the proposed antenna is shown in Figure 1. The antenna is design on Flame retardant-4 (FR4) substrate with permittivity of 4.3, tangential loss of 0.0019 and thickness of 1.6 mm. A top circular patch of radius r acted as the antennas main radiating element while a full ground plane is employed at the bottom of the substrate. The antenna is fed via coaxial probe technique. To reconfigure the frequencies, a slot is etched on the ground plane which is divided into three segments. Each segment bears a PIN diode for biasing the slot. Slits were also etched on the ground plane to act as biasing lines but however the slits introduce RF wave discontinuities on the ground plane. Therefore, to ensure the RF wave continuity is sustained on the ground plane, 10 capacitors were installed within the slits to provide RF wave passage and block direct current blocking during biasing.
The antenna's dimension is W = 80mm by L = 60 mm, the radius r of the circular patch is 18 mm, the radiating slot on the ground plane has the dimension of a = 36 mm and b = 2.45 mm, the slits is 0.3 mm provides DC blocking and acted as biasing lines. Three BAR50-02V- PIN diodes are used as switches installed at different locations on the slots for reconfiguration and capacitors value of 100 pF on the slits provides DC blocking on the ground plane. The antenna is simulated using Computer Simulation Technology (CST)®software.

To achieve the frequency reconfigurability, three PIN diodes was installed on the slot. As the PIN diodes state changes to either ON or OFF, the frequency will be shifted. All the simulation results are obtained by using computer simulation technology (CST) software.



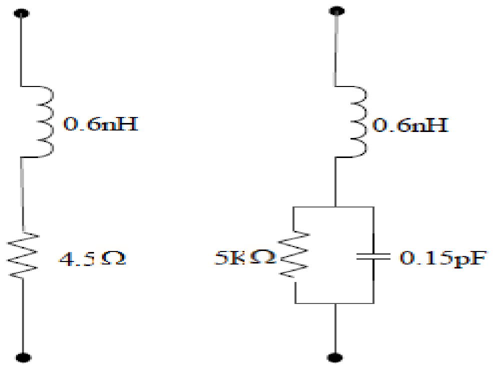
(a)



(b)

Figure 1: Geometry of the proposed antenna: (a) Front view (b) Back view

The RF PIN diode employed in the proposed antenna's equivalent circuit model is shown in Figure 2 for both forward bias (switch on) and reverse bias (switch off) conditions (Jabire *et al.*, 2024).



(a) (b)

Figure 2: The equivalent circuits for PIN Diodes: (a) Forward Biased (ON switch) (b) Reversed Biased (OFF switch) (Jabire *et al.*, 2024).

To reconfigured the frequency of the antenna, switches S1, S2 and S3 were activated which represented by 1 and deactivated which represented by 0 state. Therefore, for 3 states of the diode eight configurations are obtain as shown in table 1.

Table 1: Switch Configurations

Configurations	Diode States			Resonance Frequency (GHz)
	S1	S2	S3	
F1	0	0	0	-
F2	0	0	1	1.64
F3	0	1	0	1.92
F4	0	1	1	2.00
F5	1	0	0	1.64
F6	1	0	1	2.10
F7	1	1	0	2.00
F8	1	1	1	1.80

3 Result Discussions

In this section, the simulated results of the proposed antenna is analyzed and discussed. Figure 3 shows the simulated reflection coefficients of the proposed antenna at different switch configurations (F1-F8). As observed, six different frequency bands are obtained from eight configurations as tabulated in Table 2. It can be observed that configurations F2 is the same as F5 and configuration F4 is the same as F7. This is as result of symmetrical nature of the resonating slot. From the above result, F1 is when all the switches are in OFF state (000), F2 is when switch S3 is ON and S1, S2 are OFF (001), F3 is when only S2 is ON (010), F4 is when S2 and S3 are ON while S1 is OFF (011), F5 is when only S1 is ON (100), F6 is when S1 and S3 are ON while S2 is OFF (101), F7 is when S1 and S2 are ON while S3 is OFF (110) and final F8 is when all the three switches are ON.

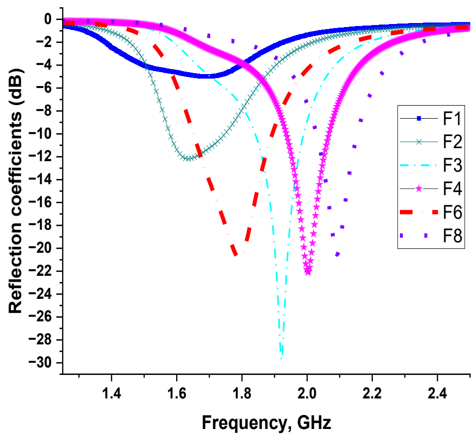


Figure 3: Simulated result of the antenna.

The antenna did not resonate at frequency F1 but radiates some of its energy (> -6dB) due to larger size of the slot at back. This accounts for escapes of EM wave through the slots. However, the antenna resonates at different frequencies due to proper combinations of switches as shown in Table 1 with magnitude of return loss less than -10dB. Figure 4 shows the simulated gains and efficiency of the proposed antenna. The antenna gain improves by the introduction of a reflection put behind the ground plane with the space of λ/4 from the ground plane were λ is the wavelength at 1.8 GHz for LTE applications. The reflector reflects back the surface waves that escaped through the slot thereby improve the overall antennas directivity. The antennas gain improves from 5.29 dB to 7. 83 dB at 1.8 GHz representing (48%) with an efficiency of 84.5 %. Table 2 shows the gains and efficiencies of the antenna at various frequencies. The current distribution of the proposed antenna is presented in Figure 5. The figure 5 clearly depicts high current concentrations along the slots and the slits showing the parts of the antenna actively responsible for frequency reconfiguration.

Table 2: Gains and efficiencies at different frequencies

Configurations	Resonance Frequency (GHz)	Gains (dB)		Eff (%)
		With reflector	Without reflector	
F1	-	-	-	-
F2	1.64	6.73	6.64	80.6
F3	1.92	7.91	5.57	86.3
F4	2.00	7.84	5.76	93.1
F5	1.64	6.73	6.64	80.6
F6	2.10	7.76	5.71	93.7
F7	2.00	7.84	5.76	93.1
F8	1.80	7.80	5.20	94.2

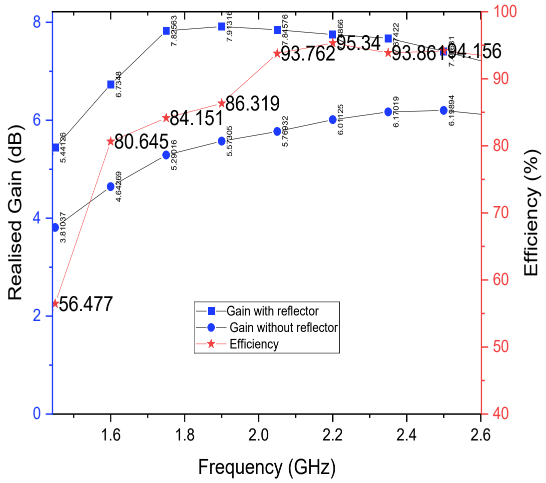


Figure 4: Simulated Gains and Efficiency of the antenna.

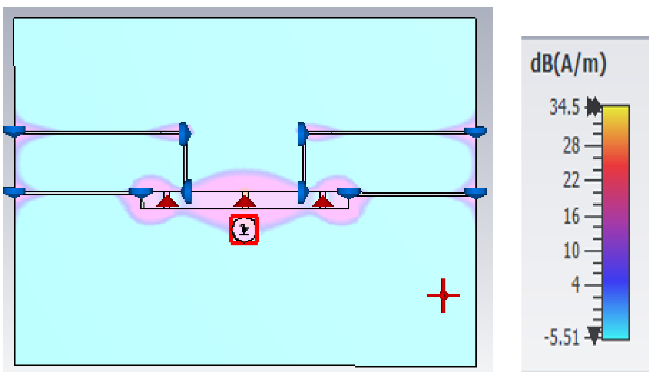


Figure 5: Current distribution of the proposed antenna

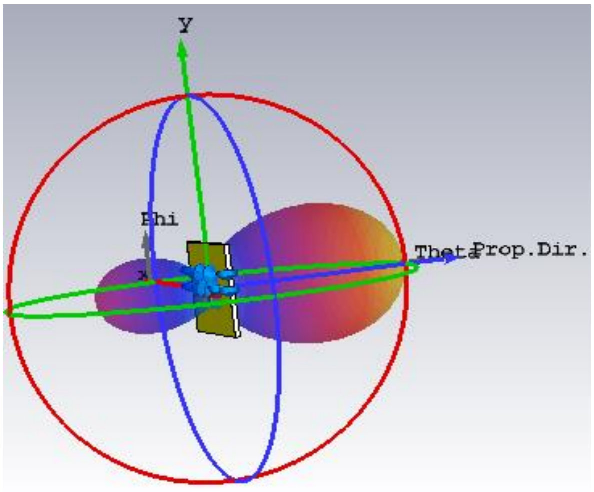


Figure 6: 3D Radiation Pattern

Directional radiation pattern of the antenna is shown in Figure 6. The main lobe points to the direction of propagation while the back lobe is a results of surface waves passing through the slots. The effect of back lobe can be mitigated by the introduction of reflector to send back the escaped surface waves and consequently improving the antennas gain. The E-plane and H-planes are shown in Figure 7 at 1.8 GHz. A directional e-field and Omni-directional radiation pattern is obtained for E-field and H-field respectively.

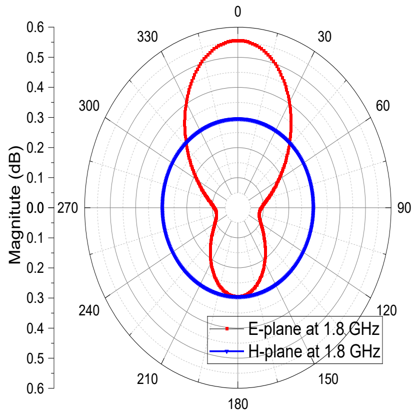


Figure 7: Simulated Radiation Pattern in E-plane and H-Plane

Table 3 shows the results comparison between some existing researches with the current research for validation.

Table 3: *Result validation.*

References	Frequency band (GHz)	Maximum Gain (dBi)
(Ghosh and Das, 2022)	2.35-5.22	3.04
(Cao, 2022)	2.38-7.40	4.20
(Zhang *et al.*, 2024)	2.15-3.84	4.22
This work	1.64-210	7.8

4 Conclusion

A frequency reconfigurable circular patch antenna was designed and simulated. Frequency reconfiguration was achieved a slot on the ground plane with three PIN diodes as switching device. Six different reconfigured frequencies were obtained. The frequency F6 at 2.1 GHz and F8 at 1.8 GHz have potential application for broadband wireless communication in Wimax (Worldwide interoperability for Microwave access) and LTE (Long Term-Evolution) networks respectively. All the return losses of the frequencies are less than -10dB which indicates that the antenna has a good impedance matching. The reflector introduced at the back of the antenna further enhanced the antennas gain by 48% at 1.8 GHz and has no effect on the complexity and size of the antenna. Also, peak efficiency of 93.7% was obtained at 2.10 GHz. A directional radiation pattern obtained further justified its broadband applications.

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