ÓPTICA PURA Y APLICADA
www.sedoptica.es

Type: RESEARCH PAPER
Section: OPTICAL COMMUNICATIONS

Inverted U-shaped Frequency Reconfigurable Microstrip patch antenna for 5G communication systems

Lames Hasan[1], Mohammad Nassr[1], Mohammad Anbar[1],
Hamid Ali Abed Alasadi[2, 3*]

1. Communication Technology Engineering Department, Information and Communication Technology Engineerin College, Tartous University, Syria

2. Communication Engineering Department, IraqUniversity College, Basra, 61004, Iraq

3. Department of Computer Science, College of Education for Pure Sciences, University of Basrah, Basrah, Iraq

(*) E-mail:hamid.abed@uobasrah.edu.iq

Received: 25/05/2023 Accepted: 12/07/2023
DOI: 10.7149/OPA.56.3.51153

ABSTRACT:

An inverted "U" shape patch antenna has been proposed in this research. It is reconfigurable and operates with millimeter waves. Therefore, it is appropriate for 5G wireless networks. Three separate resistors—100, 500, and 750 ohms—that are integrated into the antenna's radiating element have been used to achieve frequency reconfigurability. The proposed antenna is (5mm x 3.2mm) rectangular patch. In this patch, a rectangular slot is made with dimensions (1mmx2.6mm). The proposed antenna is designed on Rogers RT5880 substrate with dielectric constant εr= 2.2 and loss tangent = 0.0009 and its thickness h=1.6mm. It produces three frequencies: 46.2 GHz, 50 GHz, and 50.8 GHz with return losses: -35dB, -25dB, -27dB and peak gains: 7.22dB, 7.15dB ,6.1dB respectively. The proposed antenna has been simulated using CST electromagnetic simulator.

Key words: Frequency reconfigurable, microstrip patch antenna, 5g communication, return loss, gain.

RESUMEN:

Only for Spanish speaking authors.

Palabras clave:

REFERENCES AND LINKS / REFERENCIAS Y ENLACES

[1] T. Khan, A. Alkhateeb and R. Heath, “*Millimeter Wave Energy Harvesting,” IEEE Transactions on Wireless Communications*," IEEE Transactions on Wireless Communications, Vol. 15, Issue.9, pp. 6048-6062, (2016).

[2] L. Hasan, M. Nasser, M. Anbar, M. Kolistratov and E. Vostorgina, *“High Gain, Wide Band 1*8 Microstrip Patch Antenna Array at 28GHz for 5G Communication*,” in IEEE (2022). M. Anbar, M. Nassr, L. Hasan, E. Vostorgina and M. Kolistratov, *"High Gain, Wide Band 1*8 Microstrip Patch Antenna Array at 28GHz for 5G Communication,"* 4th International Youth Conference on Radio Electronics, Electrical and Power Engineering (REEPE), Moscow, Russian Federation, 2022, pp. 1-5 (2022).

[3] E. Shepeleva, M. Makurin, A. Vilenskiy and S. Chernyshev, "*MM-wave Patch Antenna with Embedded Photoconductive Elements for 1-bit Phase Shifting,*" PhotonIcs & Electromagnetics Research Symposium - Spring (PIERS-Spring), Rome, Italy, pp. 578-581 (2019).

[4] K. Shereen, M. Khattak and M. Witjaksono,*" A brief review of frequency, radiation pattern, polarization, and compound reconfigurable antennas for 5G applications*," Journal of Computational Electronics, Vol.18 pp. 1065-1102, (2019).

[5] M.K. Shereen, M. I. Khattak and M.-Hasan,*" A frequency and radiation pattern combo-reconfigurable novel antenna for 5G applications and beyond*," Electronics, Vol. 9, pp.1-13, (2020).

[6] S. Bharadwaj, D. Sipal and D. Koul, "*A Compact Tri-Band Frequency Reconfigurable Antenna for LTE/Wi-Fi/ITS Application*," Progress In Electromagnetics Research M, Vol.91, pp. 59-67, (2020).

[7] W. A. Awan, *"Very small form factor with ultra wide band rectangular patch antenna for 5G applications,"* International Conference on Computing, Mathematics and Engineering Technologies (iCoMET), Sukkur, Pakistan, pp. 1-4 (2018).

[8] A. Ghaffar, X. J. Li, B. -C. Seet, W. A. Awan and N. Hussain, "*Compact Multiband Frequency Reconfigurable Antenna for 5G Communications,"* 29th International Telecommunication Networks and Applications Conference (ITNAC), Auckland, New Zealand, pp. 1-3 (2019).

[9] B. Alekhya, N. Murugan, B. Taraka, and N. Kartheek *"Millimeter-Wave Reconfigurable Antenna for 5G Wireless Communications,* "Progress in Electromagnetics Research Letters, Vol. 101, PP. 107-115, (2021).

[10] A. Ghaffar, X. J.Li, W.A. Awan, Hussain, *"A Compact Multiband Multi-Mode Frequency Reconfigurable Antenna for Portable devices,"* In Proceedings of the International Conference on UK-China Emerging Technologies (UCET), Glasgow, UK, pp. 1-4 (2020).

[11] A. Yasir, N. Ojaroudi, I. Elfergani and R.A. Abd-Alhameed. "*A New Polarization-Reconfigurable Antenna for 5G Wireless Communications,"* ICST Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, Vol.263, pp. 431-437 (2019).

[12] M. Abbas *et al., "Millimeter Wave Frequency Reconfigurable Antenna for 5G WLAN,"* IEEE 21st International Multi-Topic Conference (INMIC), Karachi, Pakistan, pp. 1-6 (2018).

[13] S. F. Jilani, S. M. Abbas, K. P. Esselle and A. Alomainy, "*Millimeter-wave frequency reconfigurable T-shaped antenna for 5G networks,"* IEEE 11th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), Abu Dhabi, United Arab Emirates, pp. 100-102 (2015).

[14] M.Seelam, D. Jayasri, B. Naveena and A. Madhuri, *"Microstrip patch antenna designed using frequency reconfigurability for 5G applications,"* Journal of Engineering Science, Vol 11, Issue 6,pp. 904-907 (2020).

[15] K. Saraswat, A.R. Harish, *"Flexible dual-band dual-polarized CPW-fed monopole antenna with discrete-frequency reconfigurability,"* IET Micro. Antennas Propag, Vol.13, pp. 2057–2061 (2019).

[16] W. A. Awan, A. Ghaffar, N. Hussain and X. J. Li, *"A Frequency Reconfigurable Flexible Antenna for Multiple Mobile Applications,"* IEEE Asia-Pacific Microwave Conference (APMC), Singapore, pp. 813-815. (2019).

[17] S. Bharadwaj, D. Sipal, D. Yadav and S.K. Koul*, "A Compact Tri-Band Frequency Reconfigurable Antenna for LTE/Wi-Fi/ITS Application,"* Progress In Electromagnetics Research M, Vol. 91, pp. 59-67, (2020).

[18] A. Desai, R. Patel and T. Upadhyaya, *"Multiband inverted E and U shaped compact antenna for digital broadcasting, wireless, and sub 6GHZ 5G applications,"* International Journal of Electronics and Communications, Vol. 123, no.153296, (2020).

[19] S. Agarwal and P. Gupta,*" Millimeter-Wave Inverted U-Slot Antenna for 5G Applications."* Journal of Emerging Technologies and Innovative Research (JETIR), Vol. 6, Issue.6, pp. 676-680, (2019).

[20] A. Gupta, A. Kansal and P. Chawla, *"Design of a wearable MIMO antenna deployed with an inverted U-shaped ground stub for diversity performance enhancement,"* International Journal of Microwave and Wireless Technologies.Vol.13, Issue.1, pp. 76-86, (2021).

[21] P. Thanki and F. Raval, *"S shaped hexaband frequency reconfigurable antenna,"* International Journal of Sensors, Wireless Communications and Control, Vol. 11, No. 3, pp. 293–303, (2021).

[22] P.Thanki and F. Raval, *"Fork-shaped frequency and pattern reconfigurable antenna,"* International Journal of Communication Systems, Vol. 33, No. 17, pp. 1-11 (2020).

[23] P.Thanki, and F. Raval, *"I-Shaped Frequency and Pattern Reconfigurable Antenna for WiMAX and WLAN Applications,"* Progress in Electromagnetics Research Letters, Vol. 97, pp. 149-156, (2021).

[24] C. A. Balanis, "Antenna Theory, Analysis and Design," John Wiley & Sons Inc., 2nd Edition, (2005).

---

1. Introduction

Conventional antennas only cover one band. Therefore, electromagnetic range constraints and advances in telemetry innovation have accelerated the creation of multi-standard, multi-application devices. For this reason, having an antenna that may be flexible for a number of applications and reasonable concepts is crucial. Reconfigurable antennas have recently attracted a lot of interest due to their durability, adaptability to changing characteristics including polarization, radiation pattern, and frequency. Moreover, they have the ability to fulfill low framing requirements. Due to the rising demand for small, wearable technology, low-profile antennas with these characteristics have also caught the attention of researchers. As a result, adaptability is another essential requirement for modern applications in addition to reconfiguration [1]. Reconfigurable antennas are widely employed in multiband systems because they can change the dynamic range.

Devices which communicate using millimeter bands, must be equipped with low cost antennas which are easy to manufacture. These antennas must be designed to be integrated into portable devices. Therefore, micro-strip patch antennas are preferred because of the advantages they have over other types of antennas [2]. One of the most important requirements for 5G is that the antenna has a bandwidth of more than 1GHz [3]. Reconfigurable antenna technology allows gradual modification of antenna settings to accommodate changes in system demands. The radiation pattern, frequency, and polarization of an antenna are all reconfigurable parameters [4]. Radio frequency switches are used by frequency reconfigurable antennas to quickly switch between various frequencies. Radiation pattern reconfigurable Antennas have the ability to change their radiation pattern while still functioning at a fixed frequency. Antennas with polarization re-configurability can switch their polarization while keeping their radiation pattern and frequency unchanged. Hybrid reconfigurable antennas can change more than one feature at once such as the radiation pattern and polarization.

Using reconfigurable antennas is another intriguing and fascinating way to address the most recent advancements in wireless communication networks [5]. The reconfigurable antenna offers flexibility in architecture once it has provided agile frequency. Flexibility is achieved by utilizing a specific operating system and cognitive radios to handle operations involving multiple services, multiple standards, and multiple bands that can be extended and reconfigured. Moreover, reconfiguration allows efficient power consumption and usage [6].

In this work, frequency re-configurable antenna with inverted "U" shape for 5G communication systems, has been proposed. The rest of this research has been organized as follows. Section 2 presents literature review and related works which deal with the same topic. Section 3 discusses different methods of frequency switching in antennas. Section 4 includes detailed explanation of design stages of the proposed antenna. In section 5, all the obtained simulation results have been included and discussed. Conclusions of the research have been presented in section 6.

2. Literature Review

The idea of reconfigurable antenna was developed as an alternative to the idea of having different antennas for different working frequencies. Due to its adaptability and capability, reconfigurable antennas have grown to be very popular in wireless communication systems. An internal mechanism is built into the structure of theses antennas to change their frequencies, polarization, and radiation pattern. This internal mechanism can be any tunable material [7-9]. This approach is primarily used to achieve antennas with feasible and strong performance in order to fulfill changing operational requirements such as gain, return loss, or Voltage Standing Wave Ratio (VSWR) [10]. Micro-strip patch antennas are the most popular basic antennas to achieve re-configurability due to their advanced properties such as ease of fabrication, sturdy design and lightweight [11]. Due to its importance, many researchers studied this topic using different methods. The research in [12] compared and contrasted various reconfigurable antenna designs for 5G. Each of these designs operates at a resonant frequency of 60GHz. Ground planes and radiating patches of the suggested antenna designs are with different sizes. The substrate is called Roger-RT5850 with different thicknesses as well as a loss tangent of 0.0009 and a relative permittivity of 2.2. Micro-strip line feeding and Ground Coplanar Waveguide (GCPW) feeding are the two methods used to supply the antenna. The research in [13] described a frequency-reconfigurable T-shaped coplanar waveguide (CPW) fed millimeter-wave antenna for 5G networks. The suggested antenna is intended for use with wireless systems and applications that are body-centric and person-to-person. In [14] a millimeter wave "Y" shaped patch antenna was proposed where frequency re-configurability is achieved by using an RF diode. In [15] a flexible discrete-frequency reconfigurable dual-band dual-polarized CPW-fed monopole antenna was described. That antenna was constructed on a transparent and flexible substrate. The suggested antenna configuration was also expanded to enable discrete frequency re-configurability. To enable higher band re-configurability, two p-i-n diodes were placed into the monopole. The antenna can cover 28.2 to 30.7 GHz frequencies. A simple structure with an arrow-shaped radiator and matching stub frequency reconfigurable antenna to cover a 5G sub-6 GHz band was presented in [16]. In [17], a slotted structured antenna with reconfigurable frequency was introduced. The antenna has two slots in the main radiator and a single ring slot on the ground plane, loaded with two pin diodes switches.

Wide bandwidth features of inverted U-shaped antennas are well known [18]. There have been a number of researches on inverted U-shaped structures that demonstrate their viability for multiband, wideband, and ultra-wideband applications [19–20]. It is such an important research idea to include inverted U-shaped structure in Millimeter Wave (MMW) frequencies.

The millimeter waves band antenna proposed in this research has an inverted "U" shape. Frequency re-configurability is accomplished by varying some resistors. These resistors alter the voltage value which in turn alters the current distribution resulting in frequency modification. Good matching, return loss, VSWR, and gain for each resistance value define the suggested design.

3. Switching Methods

RF-switches are used by frequency reconfigurable antennas to switch between different frequencies as needed. Cognitive radio systems and satellite applications are just two examples of frequency reconfigurable antenna applications [21]. The required methods to achieve frequency reconfigurable antennas are:

- Varying the Patch Size: By analysing the total size of patches, this technique may easily obtain the appropriate operating frequency. One of the disadvantages of this method is its complex biasing circuit and antenna design, however. As the patch size changes, it mostly affects the antenna's return loss, reflection coefficient, surface current, and gain, while VSWR is least affected [21].
- Reconfigurable Matching Network (Stub Tuner): This design provides a straightforward antenna geometry but only a little amount of frequency reconfiguration. It has a significant impact on VSWR and return loss [21].
- Varying value of the Current Flow: For preventing antenna short circuit, capacitor, inductor, and PIN diode must be added correctly to the biasing circuit. Additionally, a little slot between switches needs to be added to the antenna to allow for various configuration states. The operating frequency and antenna performance will also be impacted by the antenna's shifting structure. The return loss, reflection coefficient, and radiation pattern are all negatively impacted [22].
- Mechanically configurable using Meta: Surface Mechanically reconfigurable antennas fall under this category of approach, where the antenna structures' (meta-surface) moving pieces are used to change the frequency. The difficulty of the fabrication process to ensure the moveable part can be mounted to the antenna and be moved at the same time was a downside of such designs. All the parameters are affected [22].
- Changing Slot Length: The radiation efficiency is affected by slot size variations. The return loss and radiated gains are affected, as well as the transmission line's qualities [23].
- Varying Lumped Elements' Values: The most efficient method for frequency exchanging is changing the values of lumped elements because all changes can be tested in software prior to manufacture. Additionally, no need to change the patch size or do any other actions that would change the shape of the final antenna. These bundled characteristics are affordable, portable, and easily accessible on the market. Therefore, this method has been adopted and used in this work [23].

4. Proposed Antenna Design

After well analysis and study of different antennas designed for the same purpose, a new design has been proposed. The proposed antenna mainly contains ground plane and radiating element in its design. The radiating element is made of material composed of copper with thickness t=0.035mm. It is designed on Rogers RT5880 substrate with dielectric constant εr= 2.2 and loss tangent = 0.0009. The proposed model is showing huge band width of almost 10GHz.

Access to the patch antenna, which has an inverted U shape, is done through a 50 Ω microstrip line. A rectangular patch antenna(3.2mmx5mm) has been used as the radiating element. In this rectangular patch antenna, a rectangular slot has been made with the dimensions (1mmx2.6mm).

Additionally, different resistors with different values have been in the experiments. These resistors are placed between the two gaps of the proposed antenna in order to provide frequency modulation. This thing allows switching between various frequencies and consequently the use in variety of applications. Three different values of resistors have been used, 100, 500, 750 ohms. During simulation experiments, each value of these resistors has been used in different case. For example, two resistors of the value 100 ohms have been placed in the gaps of the antenna. The same explanation is applied on the other two values.

Dimensions of the patch (length and width) can be calculated using equations (1), (2), (3) and (4) respectively. [24].

$$W = \frac{c}{2\,f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{\lambda}{2}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$L = L_{eff} - 2\Delta L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{2}$$

$$\Delta L = 0.412h\frac{\left(\varepsilon_{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12\frac{h}{W}}} \tag{4}$$

Ground plane dimensions are calculated using equations (5) and (6) [24]:

$$L_g = 6h + L \tag{5}$$

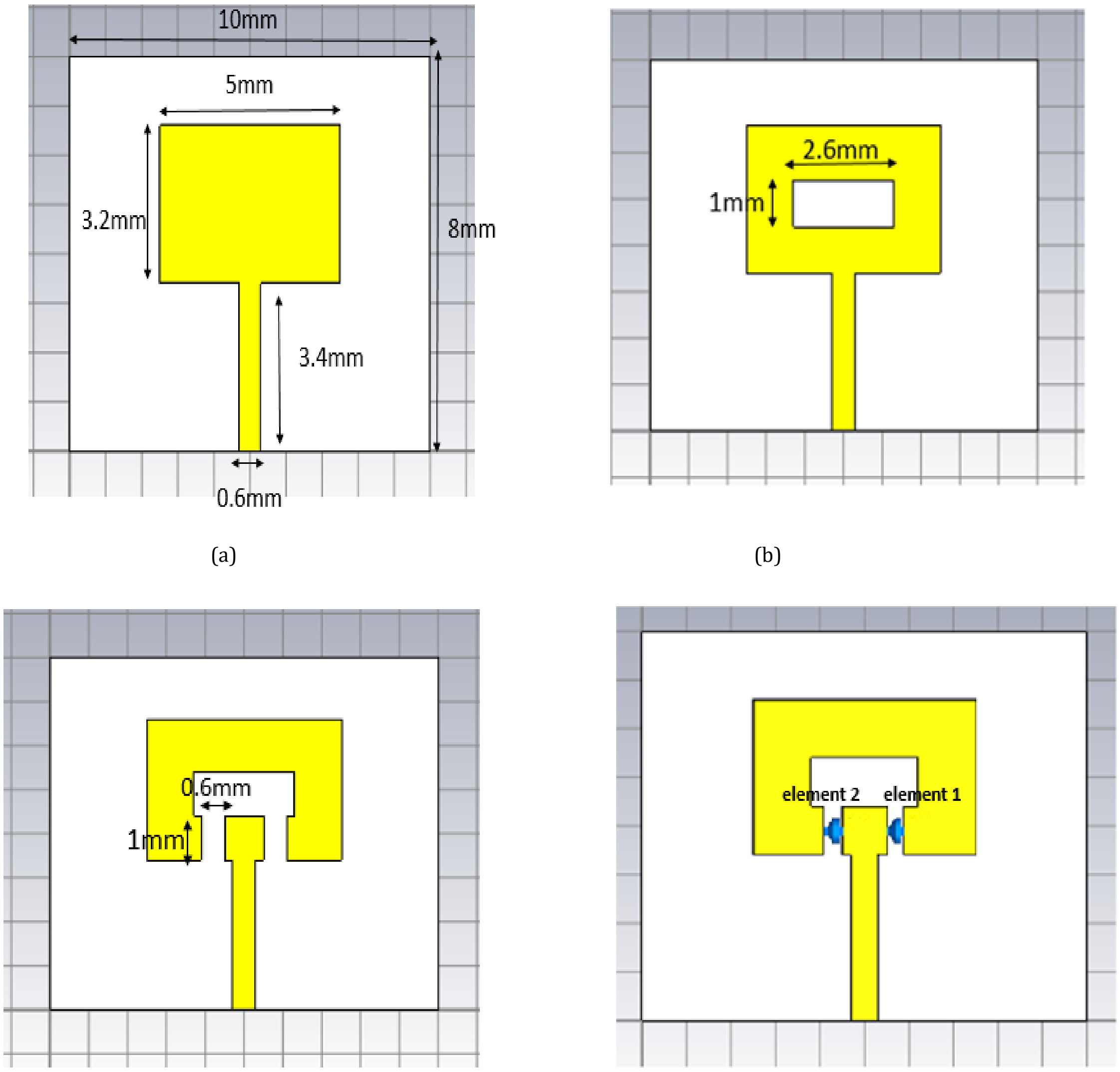
$$W_g = 6h + W \tag{6}$$

W: width of the patch antenna
L: length of the patch antenna
f_r: frequency of resonance
λ: the wavelength
c: speed of light
ε_r: constant related to dielectric of the substrate
L_{eff}: effective length
ΔL: the extended length of an antenna
h: thickness of the substrate
ε_{eff}: effective constant related to dielectric of the substrate
Lg : ground plane length
Wg: ground plane width

Based on these equations, the proposed antenna has been designed as shown in Figure 1 according to the four stages shown. In stage (a), a rectangular patch antenna was designed and fed using a 50 Ω transmission line. In stage (b), a rectangular slot was created with appropriate dimensions in order to improve the bandwidth. In stage (c), gaps were created between the patch antenna and the transmission line in order to improve the return loss and the introduction of variable resistors into the design. In stage (d), two variable resistors were placed between the two gaps.

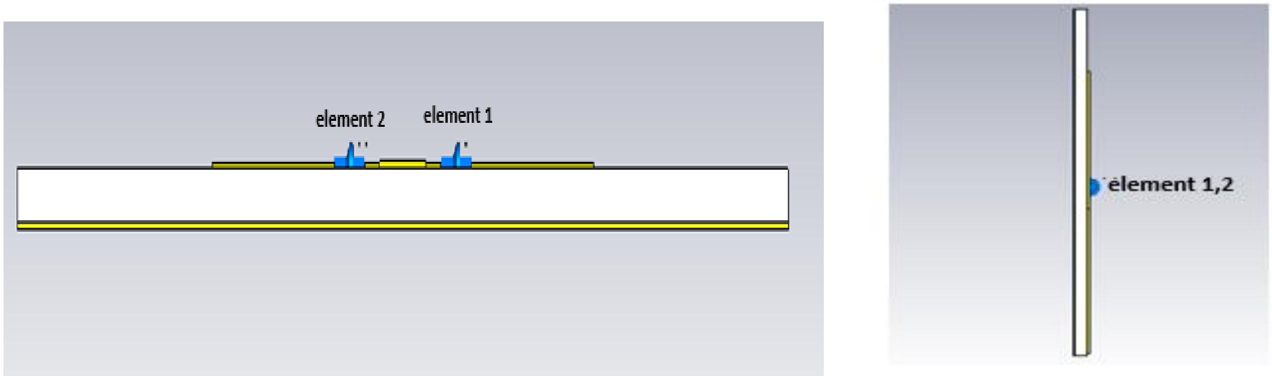
Lumped resistors in the patches can cause a reduction in the radiation efficiency of the antenna due to the additional losses introduced by the resistors. This is because the resistors dissipate some of the power that is supposed to be radiated by the antenna. The amount of power dissipated by the resistors depends on their resistance value and the frequency at which the antenna is operating. Analysing the antenna's radiation pattern, impedance matching, and efficiency. By varying the resistance value of the lumped resistors, one could observe the effect on the antenna's performance and determine the optimal resistance value that balances the trade-off between impedance matching and radiation efficiency. So, we choose resistors to have a high enough value to avoid affecting the wave matching and efficiency of the antenna.

Figure 1: (e) and (f) show side views of the proposed antenna.



(a) (b)

(c) (d)



(e) (f)

Figure1: proposed antenna design stages (from a to d), (e) and (f) are side views of the designed antenna

5. Results and Discussion

Simulation results of return loss, VSWR and gain are presented using CST electromagnetic simulator.

5.a. Return Loss (S11):

return loss, measured in dB, is the power loss resulting from reflections which occur in the standing waves at the interface between the transmission line and the antenna. Figure 2 shows return losses for stages of designing the proposed antenna shown in Figure 1 respectively (a, b, c). In the first stage, resonance frequency is 48GHz, S11=-17dB and BW=2GHz as shown by the blue dotted line in Figure 2. Resonance frequency in the second stage is 53GHz, S11=-30dB and BW=5GHz as depicted by the red solid line in Figure 2. In the third stage, resonance frequency is 56GHz, S11=-23dB and BW=6GHz as illustrated by the black dashed line in Figure 2.

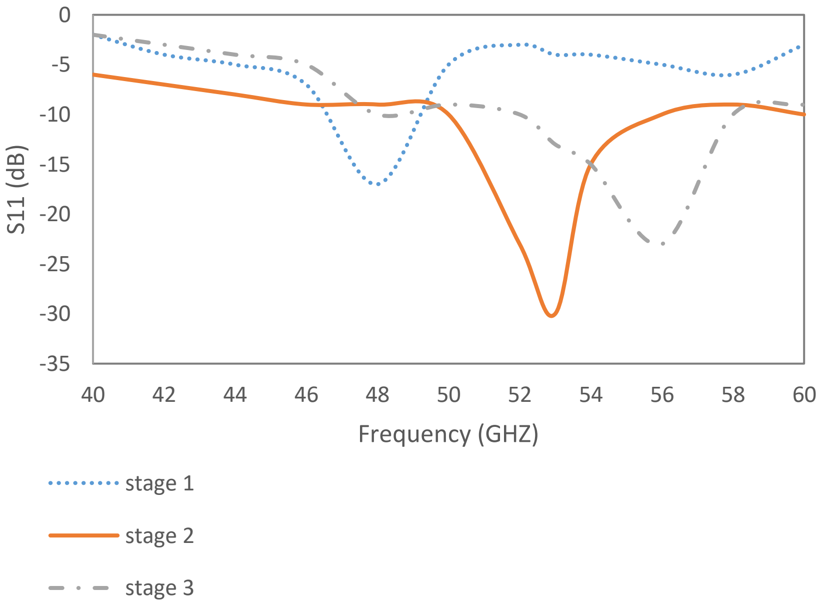


Figure 2: Return loss of various design stages

The resistance value is responsible for altering the voltage and current distributions. Frequency reconfiguration within 46.2-50.8GHz range is achieved by adjusting the resistance of variable resistors. By adjusting the values of the variable resistors, impedance matching of the antenna is shown in Figure 3. It demonstrates that as the resistance varies between 100 and 750 ohms, the resonant frequency shifts upwards. The antenna has maximum return loss (S11=-35) at a resistance of 100 ohms. At this resistance, a greater proportion of the input power is transformed into radiation. The bandwidth is 8GHz as the blue dotted line shows in Figure 3. For the resistance 500 Ω, value of S11 is -25dB, and the bandwidth is 10GHz as illustrated by the red solid line in Figure 3. black dashed line in Figure 3 shows that the return loss for the resistance 750Ω is S11=-27dB, and the bandwidth is 5GHz. This result meets the requirements of 5G systems. Also, the big value of bandwidth defined as the frequency band when S11<-10 dB, helps in defending the obstacles imposed by waves which propagate in millimetre ranges.

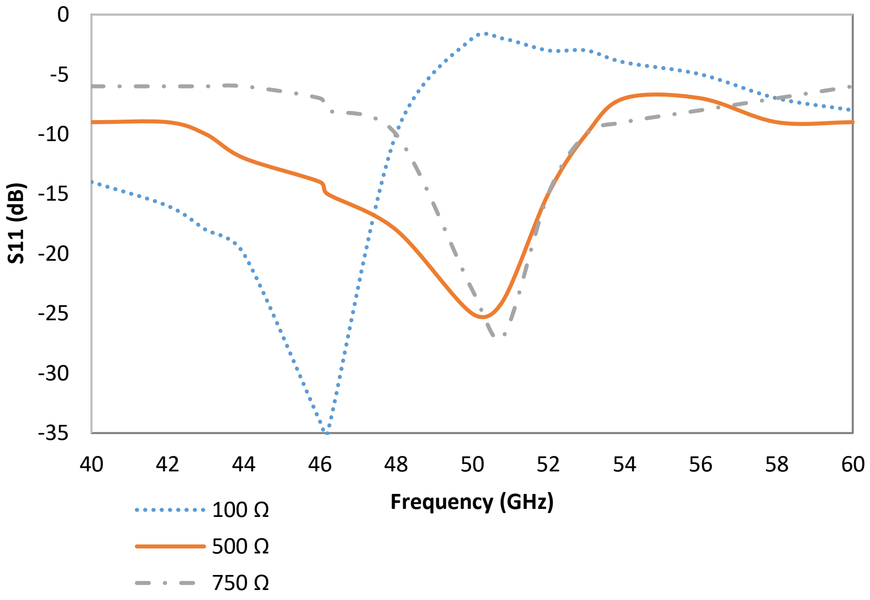


Figure 3: Return loss of all resistors cases

5.b. Voltage Standing Wave Ratio (VSWR):

due to the mismatch in impedance between the transmission line and the antenna input, part of the signal is reflected back. This part is referred to as the input to reflected signal ratio. VSWR is positive quantity and varies between 1 and 2. When VSWR decreases, more power is transmitted to the antenna and the antenna matches the transmission line better. VSWR experimental graphs for various resistor values are displayed in Figure 4. In comparison to all other resistance values, VSWR for 100 ohms is 1.01 as shown by the blue dotted line in Figure 4 which represents the lowest value. The ideal value of VSWR is almost reached at 100 ohms. Value of VSWR, for the 500Ω resistance, is 1.14 as shown by the red solid line in Figure 4 while it is 1.22 for the 750Ω resistance as depicted by the black dashed line in Figure 4. The obtained results reveal that all values of VSWR meet the required condition (VSWR ≤ 2). This value is the required value for achieving an acceptable and good antenna matching.

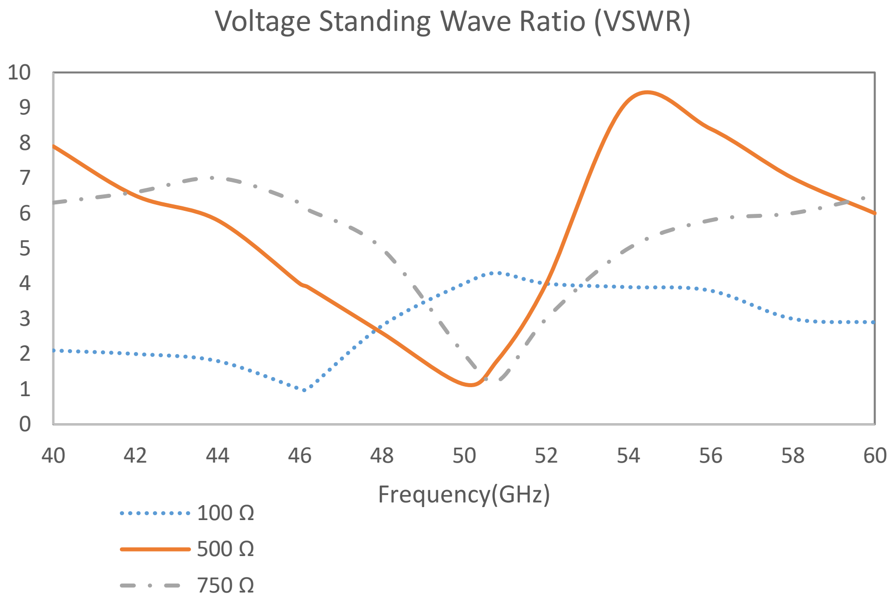
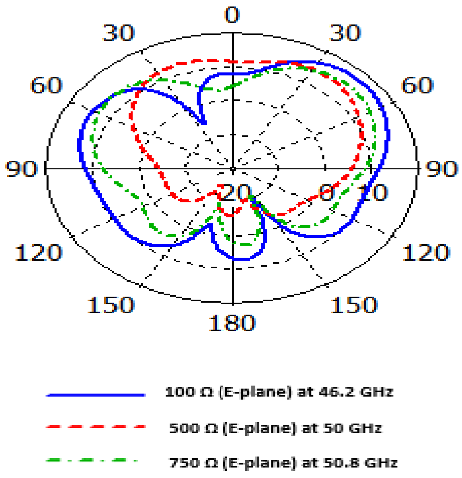


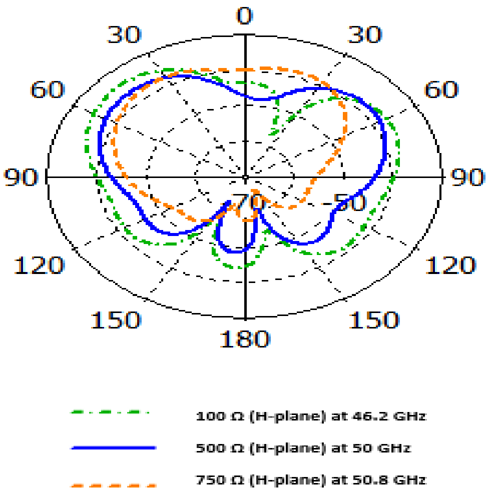
Figure 4: VSWR for all resistors values

5.c. Radiation Pattern:

Antenna radiation pattern is a measurement of an antenna power or radiation distribution. Figure 5 shows 2D radiation patterns in E-plane where in antenna design, the E plane refers to the plane that contains the electric field vector of an electromagnetic wave. In other words, it is the plane perpendicular to the direction of propagation of the wave, where the electric field component of the wave is strongest, and H-plane where in antenna design, the H plane refers to the plane that contains the magnetic field vector of an electromagnetic wave. it is perpendicular to the direction of propagation of the wave and is where the magnetic field component of the wave is strongest for resistor values. An antenna gain is the indication of how well an antenna transforms energy into radio waves in a certain direction. Gain radiation patterns of the proposed antenna design in this research are depicted in Figure 6. Resistor values have been varied from 100 to 750 ohms. The largest gain value (7.22 dB) has been obtained at 100Ω as shown in Figure 6(a). Gain value at 500Ω is 7.15dB as illustrated in Figure 6(b). For the resistance 750Ω, gain value is 6.1dB as shown in Figure 6(c). The obtained results are good values for a reconfigurable micro-strip patch antenna designed to work in 5G communication networks because it meets the needs of 5G networks.

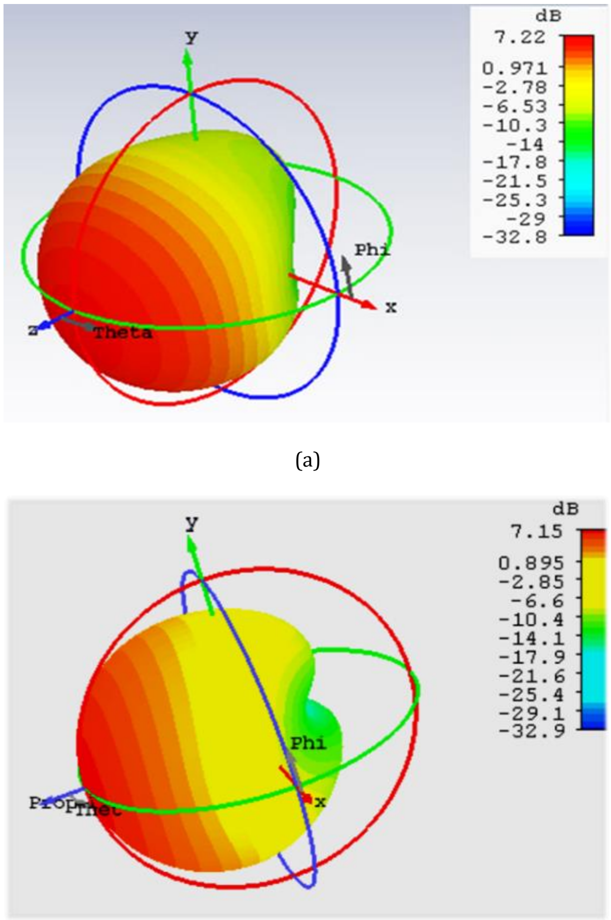


(a)



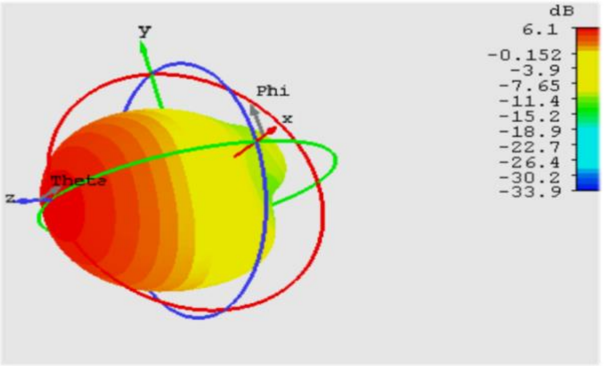
(b)

Figure 5: 2D radiation patterns in E-plane and H-plane for resistor values



(a)

(b)



(c)

Figure 6: The proposed antenna gains for resistor values: (a)100Ω, (b)500Ω, (c)750Ω at the resonance frequencies 46.2GHz, 50GHz, 50.8GHz respectively.

From the results presented by CST simulator, it is evident that using three resistors allows for switching between three different frequencies depending on the desired application. Based on the simulation results summarized in Table 1, we can conclude that by using three resistors, frequency reconfigurability between three different frequencies can be achieved with a simple microstrip patch antenna. Each produced frequency is suitable for a specific application, with 46.2GHz, 50GHz and 50.8GHz frequencies being suitable for radar, satellite communications, and the next generation telecom network (5G), which plays a major role in powering the enormous number of Internet of Things (IoT) devices.

Different results can be obtained under various conditions, such as using a different type of substrates, designing the antenna differently, or using different values for resistors. Each case yields different results that are suitable for specific applications.

Performance of the proposed antenna has been compared with other antennas of different shapes as clear in table 1.

Table 1: comparison between the proposed antenna and other antennas of different shapes.

Ref No.	Shape	Size (mm^2)	Resistance (ohm)	Frequency (GHz)	BW Info. (start freq.-end freq.)	BW (GHz)	S11 (dB)	VSWR	Gain (dB)	Directivity (dBi)
[13]	T-shaped	6.4 x 1.55	100	24.5	23.6 GHz-27.4 GHz	3.8	-40.34	1.1	5	6.1
			500	25.8	23 GHz-27 GHz	4	-24.1	1.21	4.5	5.5
			750	26.3	25.3 GHz-28.3 GHz	3	-11.8	1.4	3	5
[14]	Y-shaped	1.95 x 4.2	100	44	42.5 GHz-46.7 GHz	4.2	-22.9	1.16	8.4	10.3
			500	47	45 GHz-51 GHz	6	-22.1	1.35	4.3	5.2
			750	51	50 GHz-53.5 GHz	3.5	-13.6	1.6	4.1	5.6
Proposed	Invert U-shaped	5 x 3.2	100	46.2	40GHz -48 GHz	8	-35	1.01	7.22	9.3
			500	50	43 GHz - 53 GHz	10	-25	1.14	7.15	9
			750	50.8	48 GHz - 53 GHz	5	-27	1.22	6.1	8.4

6. Conclusions

The proposed antenna is simple compact antenna with small size. It is easy to manufacture and has a small form factor which makes it compatible with the integration of miniature circuits. The proposed antenna is frequency reconfigurable antenna which is suitable for millimeter wave applications such as radar systems, 5G wireless networks, and satellite crosslink. The copper inverted "U" slotted pattern that makes up the proposed antenna has two resistors added to it in the space between the 50 micro-strip feed and the inverted "U" lines. The experimental results of the three resistor values have yielded three distinct frequencies which are 46.2GHz, 50GHz, and 50.8GHz respectively. The proposed antenna exhibits good results in terms of all radiation properties. This thing makes it suitable for various applications in the millimeter wave range.

It must be mentioned that the proposed antenna has not been manufactured yet due to different reasons which can't be mentioned in this research. Therefore, the experimental results obtained in this research are the results obtained using simulation. It is important to say that the used simulator is good simulator where many researches have been used it for performing their experiments on different designs of antennas.