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Development of Novel and High Gain Microstrip Patch Antennas at Different Frequency Bands for 6G Applications

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Abstract—Wireless communications need antennas of different sizes, shapes, frequency-bands, bandwidths, and radiation patterns due to technical requirements, physical constraints, and FCC (Federal Communication Commission) regulations. For example, S-band antennas (2 GHz–4 GHz) are used in navigation, C-band antennas (4 GHz–8 GHz) used in Air-borne RADAR, X (8–12) band antennas used in Satellite communications, and millimeter wave (40 GHz and above) antennas used in autonomous vehicles. ultra-wideband (UWB) antennas of different frequency bands have also applications in different fields such as medical imaging, radar imaging, software defined radios, surveillance, and health monitoring of different equipment. Microstrip patch antennas of different gains, bandwidths, shapes, and radiation patterns will play a vital role in different wireless applications of future 6G systems. In this paper, we have discussed different novel designs of patch antennas at different frequency bands: V-shaped patch antenna @2.4 GHz, and hexagonal slotted half-circular patch antenna @4.29 GHz. We have designed antennas of different shapes for different frequencies since some applications require UWB; some applications require narrow band but higher gain; and some applications require different gain/radiation patterns at the same frequency. We have designed a patch antenna @2.4 GHz that can be used in Wi-Fi, and UWB patch @4.29 GHz with omnidirectional radiation pattern that can be used in energy harvesting or biomedical applications. In this paper, we have also discussed the prototype development and testing results of the novel hexagonal slotted half-circular patch antenna @4.29 GHz.

1. INTRODUCTION

Modern world is now mostly dependent on varieties of wireless communication technologies. Over the past several decades, wireless technology dependent applications have grown very rapidly, and they are now included in almost all smart devices. Antenna system (Tx and/or Rx) is one of the major components of a wireless communication link. It is obvious that we need antennas that are small, durable, can operate over a wide frequency range, and are efficient as wireless technology requires more sophisticated applications day by day. Microstrip patch antennas of different gains, bandwidths, shapes, and radiation patterns will play a vital role in different wireless applications of future 6g systems. Due to microstrip patch antennas' superior performance, durability, ease of manufacture, and widespread use, it is best suited in many modern communication technologies. Microstrip patch antenna has numerous benefits such as its light weight and simplicity of design, applications in many different sectors, including satellites, rockets, airplanes, military systems, vehicles, aircraft, and medicinal applications. Research on various kinds of microstrip patch antennas is entering a new phase of significant advancement as new wireless communication technologies take off.

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Although microstrip patch antennas are highly enticing for many transceiver system applications, their deployment in the majority of wideband wireless communication systems is limited by their small bandwidths. There are other requirements, including FCC guidelines and frequency allocation for different application areas. As a result, optimization of numerous independent antenna structures has lately gained attention in the field of microstrip antenna design. Power consumption of different wireless devices is also increasing. Therefore, a highly efficient antenna with less power loss is essential. It is a crucial task to develop a more efficient antenna structure for any specific application. Design methods of ultra-wideband antenna and circularly polarized monopole antenna have been discussed in [1, 2].

According to FCC regulation, frequency band of 76–77.5 GHz can be used in space research, radiolocation, radio astronomy, amateur satellite, broadcasting satellite, and some other amateur purposes. The range of 76–81 GHz frequency band has also been fixed for automotive uses by European Union in 2018 [3]. 77 GHz frequency can be applied to autonomous vehicle system with the help of microstrip patch for short-range radar and microstrip array for long-range radar [4]. We have designed a patch antenna at 77 GHz that can be used in the short-range radar of autonomous vehicles and a patch array at 77 GHz that can be used in the long-range radar of autonomous vehicles.

Frequency range of 2.39–2.45 GHz can be used for mobiles, radiolocations, and other fixed wireless applications. The presence of numerous internationally agreed standards for low-power communications, its global availability for industrial use, and the trade-off between power consumption and range that can be attained make the 2.4 GHz band industrially, scientifically, and medically the preferred choice for application [5]. As for higher coverage area and availability, 2.4 GHz is the most used Wi-Fi band. It can be used in Internet of Things (IoT), Internet of Industrial Things (IIoT), and Internet of Medical Things (IoMT) based applications. Given its accessibility, this frequency range can also be used for Reconfigurable Intelligent Surface (RIS) technology, which will be a significant advancement for the 6G communication system. A patch antenna at 2.4 GHz, which is novel in shape, efficiency, gain, directivity, and other parameters, has been discussed in this paper.

According to FCC, the 3.1–10.6 GHz frequency range with 500 MHz bandwidth can be used in UWB applications. Antennas of 3.02–11.17 GHz frequency range can be used in IoT, smart grid monitoring, mobile, fixed satellite, etc. Furthermore, using this UWB data spectrum results in faster response times and greater data throughput. We have designed and discussed a hexagonal slotted half-circular patch antenna at 4.29 GHz with an omnidirectional radiation pattern that can be used in energy harvesting or biomedical applications. In this paper, we have also discussed the prototype development and testing-results of the novel hexagonal slotted half-circular patch antenna at 4.29 GHz.

This paper is organized in the following way. Applications of patch antennas at different frequency bands are discussed in Section 2. The development process of a novel V-shaped patch antenna at 2.4 GHz is discussed in Section 3. The development process of a novel hexagonal slotted half-circular patch antenna at 4.29 GHz is discussed in Section 4.1. The prototype development and testing of a novel hexagonal slotted half-circular patch antenna at 4.29 GHz is discussed in Section 4.2. Finally, conclusion is made in Section 5.

2. APPLICATIONS OF PATCH ANTENNAS AT DIFFERENT FREQUENCY BANDS

For different wireless applications, microstrip patch antenna, without any doubt, is the most suitable and innovative antenna technology to date. Its success is a result of many well-known benefits. Although the idea of microstrip patch antennas was first put forth in 1953, Howell created the first useful microstrip patch antenna in 1970 [6].

In its most basic form, a microstrip patch antenna consists of a ground plane on one side of a dielectric substrate and a radiating patch on the other side [7, 8]. Microstrip patch antennas are in high demand because of the rising need for personal and mobile communications as well as the necessity for smaller and less expensive antennas. Microstrip antennas provide a number of advantages, including ease of fabrication utilizing printed circuit technology, thin, tiny size, and low volume. Along with its many benefits, it also has several drawbacks, such as deficient power, low efficiency, a high Q value, poor scan performance, spurious feed radiation, and narrow frequency band [9]. Microstrip patch antennas can be characterized through radiation pattern, gain, return loss (RL) bandwidth, efficiency, and polarization diversities. Design complexities of patch antenna increase with the miniaturization of antenna size. In most cases, patch antenna suffers from performance limitations. Effort in improving one parameter can result in other issues such as bandwidth limitations or shifting the frequency band. Patch antenna development of different methods is described in [9–15].

Microstrip patches come in a variety of forms and sizes, including triangular, triangular with slots, and rectangular ones. Rectangular patch antennas are the most widely utilized microstrip patch antennas. Antenna bandwidth can be increased by increasing the thickness of the substrate, but at the same time antenna efficiency is reduced as a result of higher power loss. This issue can be resolved by lowering the antenna's length; however, doing so reduces the impedance bandwidth and radiation efficiency. Various strategies, such as the use of high permittivity substrates, were adopted to increase the impedance bandwidth of antennas. In the ground plane of the microstrip patch antenna, different slots can be created to produce ultra-wideband. By including the capacitor/inductor, the microstrip patch antenna can achieve higher gain. Lens covering is an alternate method of boosting gain. Radiation from radiating elements is focused by lenses like elliptical, hemi-elliptical, and extended hemispherical lenses. Partial substrate removal on multi-layer dielectric substrate can also increase gain. The development of the microstrip patch antenna requires the employment of a more comprehensive and suitable methodology. The microstrip patch antenna's intended use and band designations are taken into account. IEEE has approved the conventional microwave band names; however despite this, other industries frequently utilize slightly differing band frequency restrictions. Table 1 displays the traditional IEEE standard band designation.

Table 1. IEEE standard band designation for Microwave.

Band Designation	**Frequency (GHz)**	**Wavelength (cm)**
L band	1–2	30–15
S band	2–4	15–7.5
C band	4–8	7.5–3.8
X band	8–12	3.8–2.5
K_u band	12–18	2.5–1.7
K band	18–27	1.7–1.1
K_a band	27–40	1.1–0.75
V band	40–75	0.75–0.40
W band	75–100	0.40–0.27
mmWave band	110–300	0.27–0.10

Ultra-wideband (UWB) is a radio technology that uses a low-energy state to provide short-range, high-bandwidth communications over a large chunk of the radio spectrum. Due to its low cost, high data resolution, and fast data transfer rate, UWB has become one of the most extensively utilized wireless communication systems. It has become more well known thanks to technology like ground penetrating radar, medical imaging systems, and others [16]. In the UWB frequency band, a band notch is created using a circular patch UWB antenna with slots. In the frequency range 5.1–5.9 GHz, a band notch is generated by inserting rectangular Split Ring Resonators (SRRs) on both sides of the patch [17].

IoT-enabled smart grid or microgrid, connected with smart wireless devices, such as smart antenna, enables utility companies to restore the power more quickly after a blackout [18]. In the event of a disturbance or blackout, IoT-enabled transformers and substations can automatically redirect power [18] within the shortest possible time. IoT-enabled sensors/smart antennas can also work as smart devices to investigate the condition of power equipment so that necessary maintenance and repair can be made before any occurrence of failure. Partial Discharge (PD) pulses from different faulty equipment are UWB in nature and may have different frequency spectra ranging up to several GHz [19–21]. These PD pulses can be captured through a properly designed patch antenna.

A symmetric and foldable printed UWB antenna is discussed in [22] in order to capture the UWB spectral signature of Partial Discharge (PD). This antenna is also matched in the ISM bands (434, 868, and 915 MHz), which is useful for multiplatform applications (S.A.W. interrogation, RFID, etc.) [23]. When a fault occurs in a high-voltage system, an electromagnetic (EM) wave is released, resulting in the PD phenomenon. The phase difference of different frequencies received by the antenna [24] and the direction of the EM wave emitted by the PD source can be utilized to locate the problem.

In recent years, the demand for power has grown, necessitating the usage of alternate energy sources. Fossil fuels are in short supply, expensive, and environmentally hazardous. Energy harvesting is a great way to store part of the electricity produced by radiation in today's environment. For small, wireless autonomous devices such as wearable electronics and wireless sensor networks, energy harvesting (also known as power harvesting, energy scavenging, or ambient power) is the capture and storage of energy from external sources (such as solar, thermal, wind, salinity gradients, and kinetic energy). Microstrip antennas are employed in energy harvesting because of their unique characteristics [25].

The use of millimeter wave RADAR under bad weather condition, such as rain or snow, is reported in [26]. RADAR technology can be used in vehicles for better road safety [27]. The use of 76–81 GHz band is mandatory for automotive applications in EU [3, 4]. Vehicular RADAR within the 76–81 GHz band requires antennas with high gain, wider beamwidth along the azimuth direction, and narrow beamwidth along the elevation direction [3, 4].

3. DEVELOPMENT OF HIGH GAIN V-SHAPED PATCH ANTENNA @2.4 GHZ

We have already designed a 2×4 array antenna [26] considering a rectangular tooth-shaped patch unit element and using Rogers RT Duroid 5880 substrate material (permittivity of 2.2). Rogers RT Duroid 5880 has a high melting point of 260°C, absorbs very little moisture, has a very low failure tangent (0.0009), is inexpensive and widely used in antenna construction. An inset feeding mechanism was chosen since it is relatively easier to achieve impedance matching with inset fed transmission line. We have reduced the mutual coupling effect further using the following approach.

Input impedance of the patch can be expressed by the following equation [9],

$$Z_{in} = \frac{1}{2\left(G_1 \pm G_{12}\right)} \tag{1}$$

In (1), mutual conductance (G_{12}) can be expressed as:

$$G_{12} = \frac{1}{\left|V_0\right|^2} \mathrm{Re} \iint_S E_1 \times H_2^{*} \cdot ds \tag{2}$$

It can be understood from (1) and (2) that the mutual coupling effect can be reduced if the impact of magnetic field H_2 at slot-2 is reduced. Transformed admittance of slot-2 can be expressed as [9]:

$$\tilde{Y}_2 = \tilde{G}_2 + j\tilde{B}_2 = \tilde{G}_1 - j\tilde{B}_1 \tag{3}$$

The total resonant input admittance, which becomes real, can be expressed as:

$$Y_{in} = Y_1 + \tilde{Y}_2 = 2G_1 \tag{4}$$

The total input impedance at resonance, which becomes real, can be expressed as:

$$Z_{in} = R_{in} = \frac{1}{2G_1} \tag{5}$$

We have compared the gain of our simulated array with those of other published works in Table 2 which indicates that our designed tooth-shaped patch array achieved higher gain with fewer antenna elements. It can be noted here that it is possible to reduce the manufacturing cost with fewer antenna elements.

The development process of a high gain patch antenna at 77 GHz has been described in [4] by the second and third authors. In this section, we have discussed the development process of a high gain V-shaped patch antenna at 2.4 GHz. The designed patch antenna is shown in Figure 3. Rogers RT Duroid 5880 (lossy) material was used as the substrate which has dielectric constant of $\varepsilon_r = 2.2$. Different designed parameters of the patch antenna are summarized in Table 3.

Figures 1(a) and 1(b) respectively show the front view and zoomed-in front view of the patch antenna. Figure 1(c) shows the ground plane of the antenna. As can be seen from Figures 1(a)–1(b), a

Table 2. Gain comparison of our simulation and other published works at 77 GHz.

Parameters	[28]	[29]	[30]	[31]	[32]
Center Frequency (GHz)	77.0	76.5	76.5	77	77
Array Dimension	2×4	1×10	8×7	2×8	5×4
Patch elements used	8	10	56	16	20
Gain (dBi)	18.0	16.56	19.78	15.8	18.7

Table 3. Summary of antenna parameters @2.4 GHz.

Parameters	**Values (in mm)**
L (Substrate Length)	98.76
W (Substrate width)	82.64
H (Thickness of the substrate)	1.6
PL (Patch length)	49.3
PW (Patch width)	41.32
ML (Length of Feedline)	20.66
MW (Width of Feedline)	4.89
InL (Inset Length (Lower))	15
InW (Inset Length (Lower))	1
IL (Inset Length (Upper))	10
IW (Inset Length (Upper))	0.35
GW (Ground slot width)	17
GL (Ground slot length)	45

V-shaped slot (with a width of $VW = 7\,\text{mm}$ and length of $VL = 5.5\,\text{mm}$) is created for better return loss and antenna gain. The feedline's width (MW) is chosen in such a way that the impedance matching stays close to 50. We have chosen the 2.4 GHz ISM frequency band for the design which corresponds to IEEE standard 802.15.6 [33]. Computer Simulation Technology (CST) studio software was used to simulate the antenna. In accordance with the reference point located below the -10 dB zone and the design requirements the return loss of the antenna at 2.4 GHz was -47.708 dB which can be visualized from the plot of Figure 2(a). The 10 dB return loss bandwidth was 35 MHz.

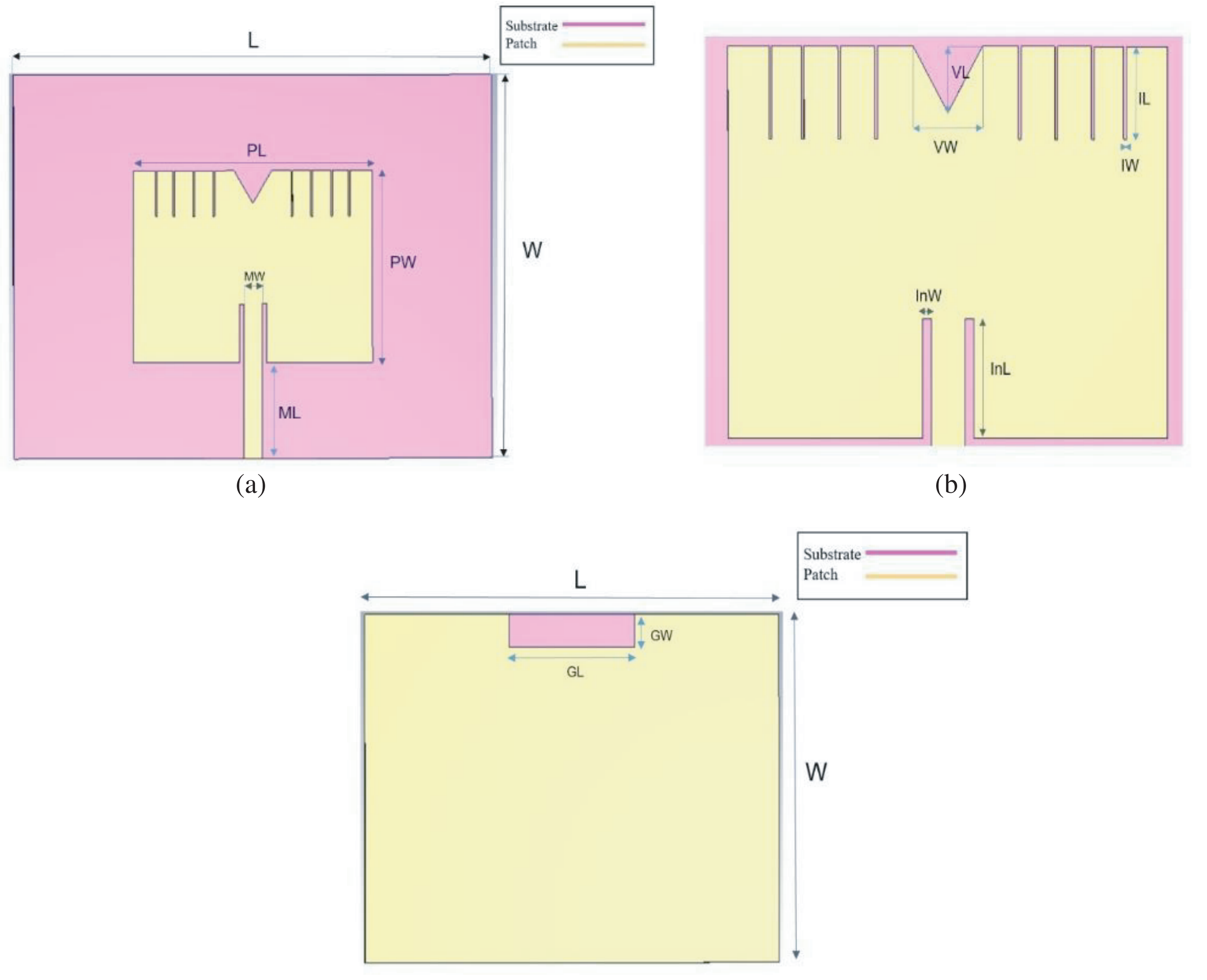
Figure 2(b) shows the radiation pattern of the antenna in 2D polar plot. Figure 2(c) and Figure 2(d) respectively show the 3D plots of antenna directivity and gain. Maximum directivity and gain of the antenna are 7.98 dB and 7.24 dB, respectively. It can be seen from Figure 3 that most of the current is concentrated along the sides of the patch antenna. A summary of the simulation results is shown in Table 4 which also summarizes the radiation parameters of patch antennas at 2.4 GHz which were published by other authors. Our simulation results indicate the superiority of the designed V-shaped patch antenna.

A novel design is achieved by creating slots on the radiating patch which is made of annealed copper. Also by adding slots, the impedance and surface area are reduced. The effective length and width of the patch vary as a result of a slot's reduced effective field.

Adding more slots on the patch the antenna reduces the gain though it significantly improves return loss. To maintain balance between them we have added a V-shaped slot on the upper side of the patch

Table 4. Comparison of simulation results of patch antenna along with other published results @2.4 GHz.

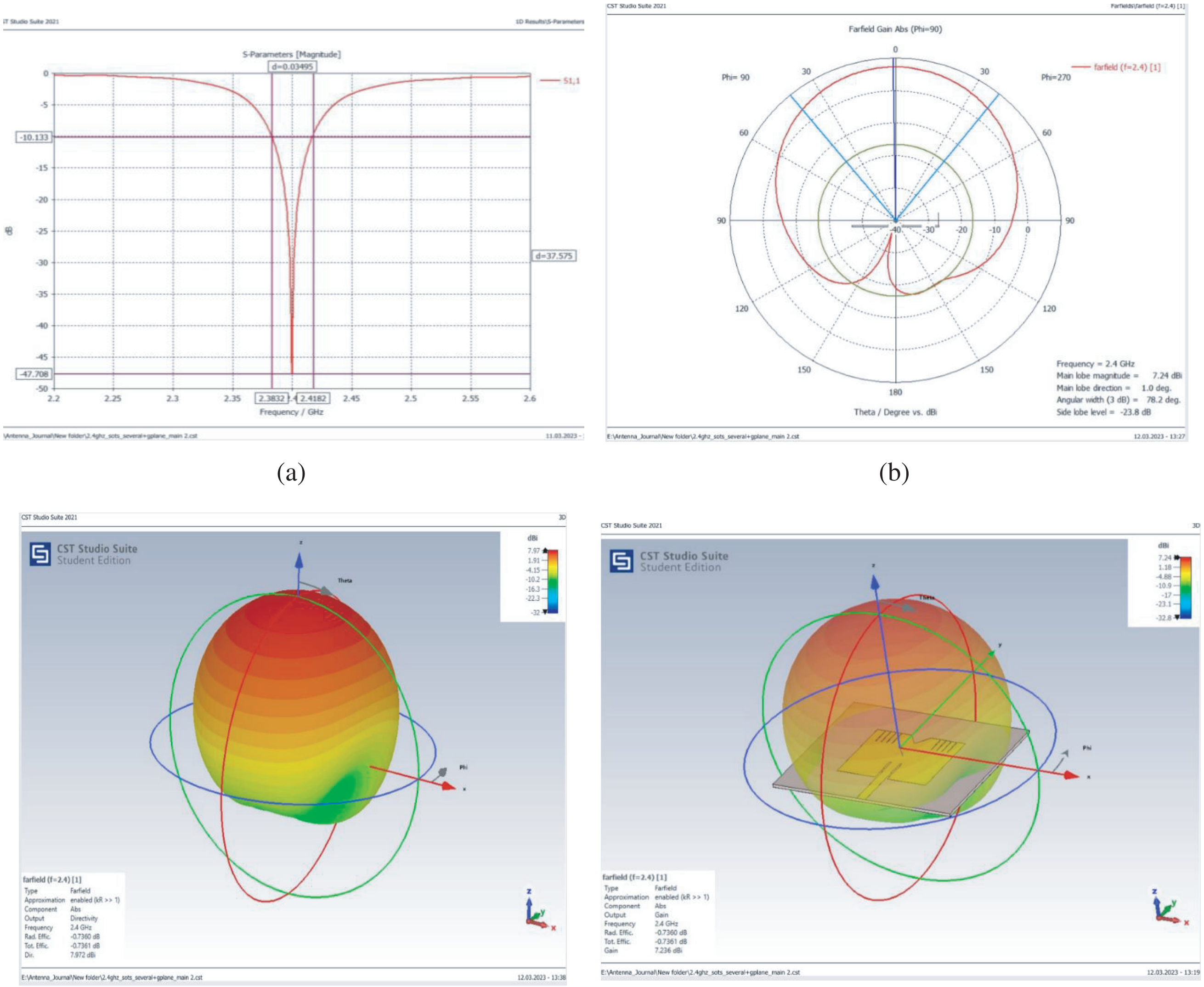
Ref.	Frequency (GHz)	Return Loss (dB)	Directivity (dB)	Gain (dB)
[34]	2.4	−39.008	N/A	4.685
[35]	2.39	−30.86	6.035	N/A
[36]	2.4	−39.008	6.287	4.685
[37]	2.4	−23	7.22	4.2
[38]	2.4	−40	5.19	3.75
[39]	2.4	−36.57	6.285	4.65
[40]	2.4	−29.5	N/A	5.5
Our designed V-shaped antenna	2.4	−47.708	7.98	7.24



(a) (b)

(c)

Figure 1. V-shaped microstrip patch antenna @2.4 GHz. (a) Front view. (b) Zoomed in front view. (c) Ground plane.



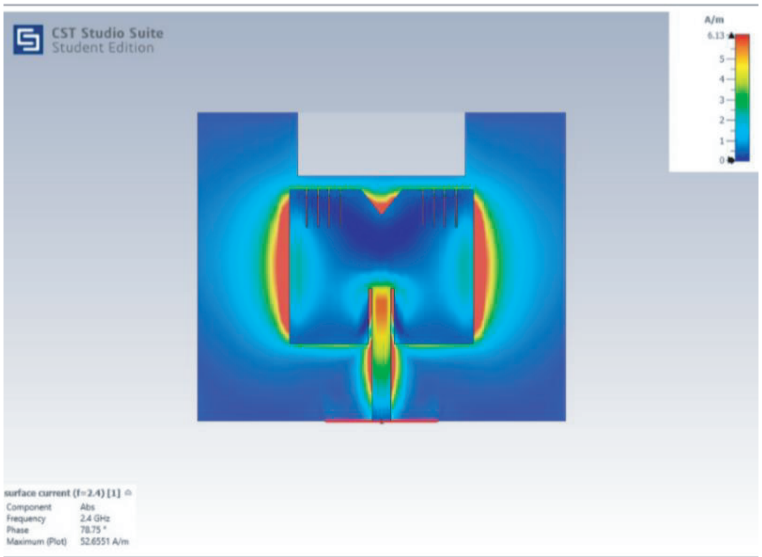
(a) (b)

(c) (d)

Figure 2. Return loss and gain of the developed V-shaped patch antenna @2.4 GHz. (a) Return loss. (b) 2D gain (polar plot). (c) 3D directivity. (d) 3D gain.

as shown in Figures 1(a)–1(b). Slots can be introduced on the ground plane of the antenna to change the fundamental resonant frequency of the patch. The efficiency of the designed antenna was around 90.84%.

The novel V-shaped antenna at 2.4 GHz, discussed in this paper, can be utilized in a range of different applications, including medical implants, wearable sensors, remote health monitoring, and smart healthcare systems. Also, sports, IoT-based applications, telecommunications, etc. can be major fields for the use of this antenna. Another substantial field can be Reconfigurable Intelligent Surface (RIS) based multiple-input multiple-output (MIMO) communications of 6G. An effective and adaptable method of managing electromagnetic waves is made possible by the antenna when it is integrated with RIS structures. By incorporating RIS, it is possible to enhance wireless communications, manage reflected waves for radar and sensing, and improve indoor communication due to increased efficiency through RIS-based communications. The development of numerous wearables and medical devices appears to be a promising field for RIS-based wireless communications.



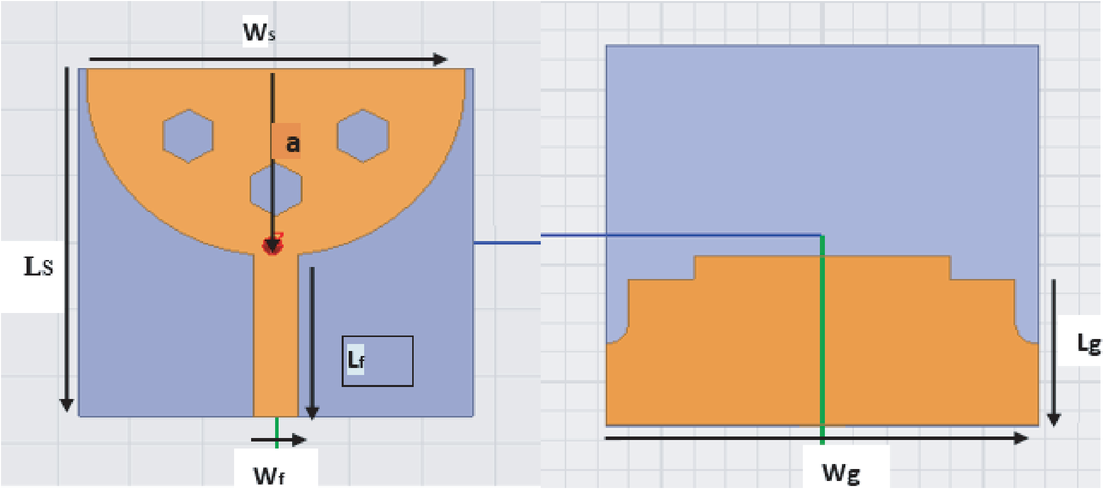
surface current (f=2.4) [1]
Component Abs
Frequency 2.4 GHz
Phase 78.75 °
Maximum (Plot) 52.6551 A/m

Figure 3. The current distribution of V-shaped patch antenna @2.4 GHz.

4. DEVELOPMENT OF HEXAGONAL SLOTTED HALF-CIRCULAR PATCH ANTENNA @4.29 GHZ

4.1. Design of Patch Antenna at 4.29 GHz

In Section 3, we have discussed the development of patch antennas at 2.4 GHz. In this section, we have discussed the development process of a novel half-circular slotted UWB at 4.29 GHz which is shown in Figure 4. The design parameters of the antenna are summarized in Table 5. The designed patch antenna can achieve −10 dB return loss bandwidth within the range of 3.39 GHz–10.93 GHz (Figure 5). We have achieved better return loss bandwidth by adding slots (Figure 4(b)) on the ground [41]. The power loss lowers as the return loss improves, making an antenna more efficient. Minimum simulated return loss was −42.19 dB at 4.29 GHz, and the gain of the patch was 3.21 dB. Directivity and gain of



(a) (b)

Figure 4. Top view and the bottom view of the patch antenna @4.29 GHz. (a) Top view of the patch antenna. (b) Bottom view of the patch antenna.

Table 5. Optimized dimensions of designed antenna.

Parameters	Symbol	Dimension (mm)
Substrate Width	W_s	27
Substrate Length	L_s	26
Patch Radius	a	13
Thickness	h	1.6
Ground Width	W_g	27
Ground Length	L_g	11.5
Feed Line Width	W_f	3
Feed Line length	L_f	13

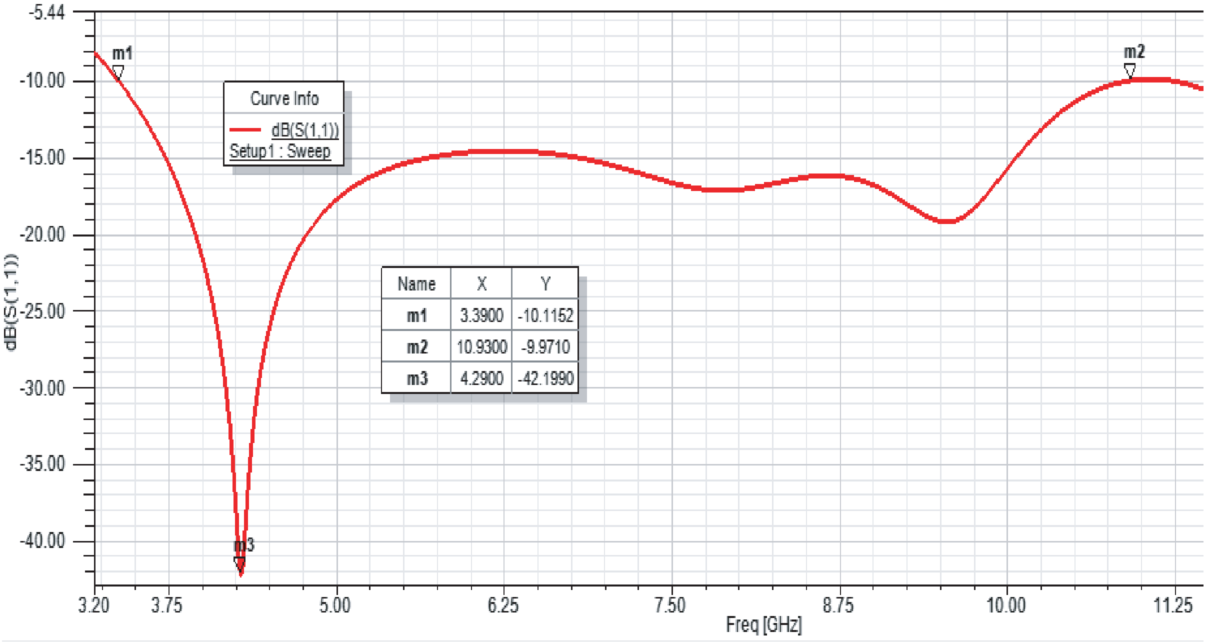
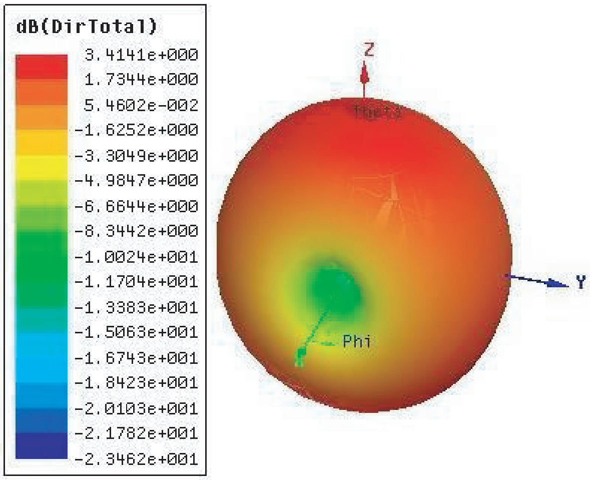


Figure 5. Return loss plot of the patch antenna @4.29 GHz.

the patch antenna are plotted in Figures 6(a) and 6(b), respectively. Radiation efficiency of the antenna was 94.13% at 4.29 GHz. From the design and return loss plot we have found the following values —

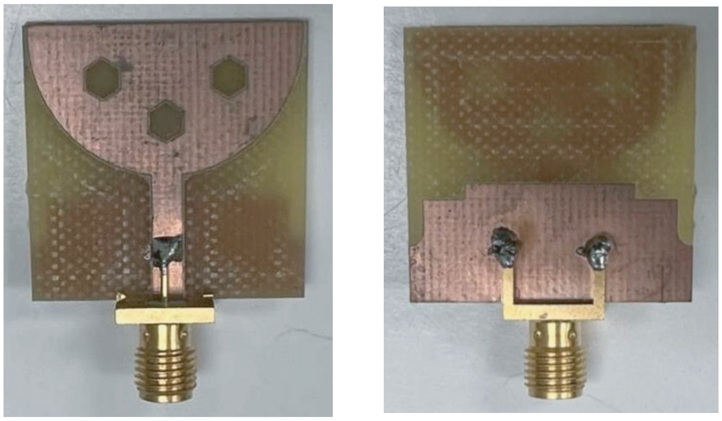
Lower cutoff frequency, $f_1 = 3.39\,\text{GHz}$
Upper Cutoff frequency, $f_2 = 10.93\,\text{GHz}$
Centre frequency, $f_c = 4.29\,\text{GHz}$
$\text{FBW} = \frac{f_2 - f_1}{f_C} \times 100\%$ [9]
$\text{FBW} = \frac{10.93-3.39}{4.29} \times 100\%$
$\text{FBW} = 175.75\%$

It can be noticed from Figure 6 that the designed patch antenna can produce an omnidirectional radiation pattern. A UWB omnidirectional antenna ensures that RF energy can be evenly sent or received in all directions across the operating frequency range. This is significant for applications requiring a broad frequency range and signal reception or transmission in all directions [42], such as wireless communication, radar systems, and medical imaging [16].



(a) (b)

Figure 6. Directivity and Gain of the patch antenna @4.29 GHz. (a) Directivity (3.41 dB). (b) Gain (3.21 dB).



(a) (b)

Figure 7. Top view and the bottom view of the prototype patch antenna. (a) Top view of the prototype antenna. (b) Bottom view of the prototype antenna.

4.2. Development and Measurement of Prototype Patch Antenna

We have developed and tested the prototype of the patch antenna described in Section 4.1. Figure 7 shows the prototype of the hexagonal slotted half-circular patch antenna. Figure 8 shows the measured return loss of the prototype. Minimum return loss was −18.73 dB at 4.1 GHz. Calculated fractional bandwidth of the prototype antenna was 146.34%. Some results of the simulated and measured antenna performances are summarized in Table 6.

It can be observed from Table 6, Figure 5, and Figure 8 that the measured data of the prototype well conforms to the simulated results. It is noteworthy to mention here that the simulation model is mainly a mathematical-based model [27], and some factors/errors of measured data are not incorporated in the simulation. Some reasons behind the difference between measured and simulated data are as follows —

- Material properties of the prototype,
- Fabrication tolerances,
- Environmental factors,
- Accuracy of the simulation model.

Table 6. Comparison table of simulated and measured performance of hexagonal slotted half-circular patch antenna.

Parameters	Simulated Results	Measured Results
Fractional Bandwidth	175.75%	146.34%
VSWR	1.0156	1.2617
Return loss in dB	−42.19 @4.29 GHz	−18.73 @4.1 GHz
Efficiency	94.13%	-

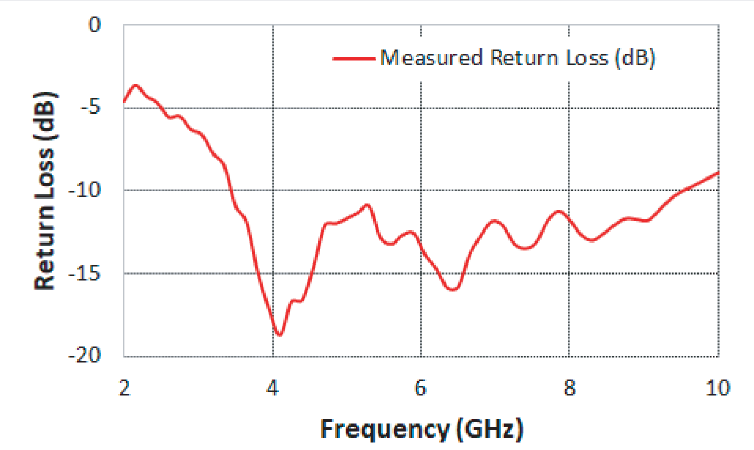


Figure 8. Measured return loss of the hexagonal slotted half-circular patch antenna.

5. CONCLUSION

Nowadays, it is difficult to imagine a single day without wireless communications. Wireless communication and antenna technology are complementary to each other. Antennas have versatile applications ranging from cell phones to astronomy. Though 5G is the latest communication technology, there are scopes of improvements in 5G. Improved or new technologies will be implemented in future 6G communication systems. Areas of improvement in 6G are cell capacity, coverage area, device density, energy efficiency, spectrum uses, latency, location accuracy, and user experiences. Patch antennas at different frequency bands will play a vital role in future 6G communications. In this paper, the development processes of novel patch antennas at different frequency bands (i.e., 77 GHz, 2.4 GHz, and 4.29 GHz) are discussed. The prototype development and testing of a patch antenna at 4.29 GHz is also discussed in this paper. Developed patch antennas, discussed in the paper, showed improved return losses and radiation efficiencies. In the case of 2.4 GHz V-shaped patch element, we have achieved 7.24 dB gain and −47.71 dB return loss. In the case of 4.29 GHz half-circular hexagonal slotted patch we have achieved 146.34 % fractional bandwidth and −18.73 dB return loss bandwidth from the experimental data. Developed patch antennas at different frequency bands, discussed in this paper, will have different applications in 6G such as IoT, IIoT, MoIT, vehicular RADAR, energy harvesting, and smart grid applications. For example, patch antenna at 77 GHz can be used in autonomous vehicle; patch antenna at 2.4 GHz can be used in WLAN; and patch antenna at 4.29 GHz can use in energy harvesting.

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