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A Review: Patch Antenna Design for 5G Wireless Communication

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Abstract:
Antennas play an indispensable role in radio engineering. The system between the electric currents flowing in the metal conduits and the radio waves flowing through space is constructed using a transmitter or receiver. A microstrip patch antenna was invented in 1953. They also became the area of interest to the researcher, as they raised the interest of the researcher owing to their good features, such as low profile, cheap to manufacture, light, and easy to install. Awareness began in 1970. Microstrip patch antennas are used in airplanes, spacecraft, satellites, and wireless communications. In recent communication devices, such as smartphones, Wi-Fi routers, and 5G mobile phones, the number of users has increased significantly in wireless communication and the application of microstrip patch antennas in communication devices. The large dimensions of antennas were eliminated by small antennas in the early days, as large antennas were used; however, as technology evolved, the size of antennas was reduced. In recent decades, researchers have focused on microstrip patch antennas to determine how to attain compact size and large bandwidth. This study provides a detailed analysis of the antenna designs and their different feeding methods and extended advanced research on the different types of antennas and their enhancement strategies to attain a small scale of the antenna to Sub-6 GHz to support 5G using simple antenna design techniques such as patch and ground slot-loading.
Key Terms: Patch antenna, Radio Communication, 5G communication.

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Introduction:
An antenna, according to the Institute of Electrical and Electronics Engineers, is "a device for transmitting or receiving radio waves." In other words, it is used for both transmitting and receiving electromagnetic waves[1][2].It has recently become a point of interest for researchers and engineers because the zone of communication devices, such as smartphones, radio sets, laptops with wireless access, and the Internet of Things, are growing in leaps and bounds, making it a serious issue with 4G LTE technology in terms of speed and big-detention of bandwidth-intensive video. This has changed to the 5th generation (5G) wireless communication. The primary goal of 5G is to provide a fleet transmission rate, tiny latency, tremendous traffic volume density, large signal bandwidth, better coverage, and prime quality of service with low battery consumption at a low cost [3]. The specifications of 5G are given in Table-1. 5G will accommodate users and operate in a vast array of frequencies. Various performance parameters of antennas are used to analyze the desirability of 5G. To facilitate the 5G, FCC sub-divided the frequency spectrum into three bands: high-band (millimeter wave), middle-band (sub-6 GHz), and lower-band (up to 1 GHz) [4][5]. The frequency bands of FR1 and FR2 in 5G are listed in Table-2 and Table-3. The 5G coverage of the low band was good. Millimeter-wave provides high data rates of more than 2 Gbps and huge capacity, and midband provides a combination of the two. The 5G wave spectrum is used to obtain ultra-fast data rates. Sub-6 GHz can be used in built-up and countryside regions in long-range with high data rates.

Table1: Specification of 5G [6], [7]

S.No.	Parameter	5G
1	Peak data rates	20 Gbps
2	Data traffic	50 Exabyte/month
3	Latency	<1ms
4	Available spectrum	30 GHz
5	Connectivity Density	1 million connection/K.m^2

Table2: Frequency Range 1(FR1) for 5G for below 6 GHz [8],[9]

Frequency (MHz)	Duplex Mode	Band	Common Name
2100,1900,1800	FDD, FDD, FDD	n1, n2, n3	IMT, PCS, DCS
850	FDD	n5	CLR
700	FDD	n7	IMT-E
900,700,800, 1900,700,700	FDD, FDD, FDD, FDD, FDD, SDL	n8, n12, n20, n25, n28, n29	Extended GSM, Lowers MH, Digital dividend, Extended PCS, APT, Lower SMH
2300,2300	FDD, TDD	n30, n40	WCS, S-band
2500,3500	TDD, TDD	n41, n48	BRS, CBRS
3700,3500,4700	TDD, TDD, TDD	n77, n78, n79	C-Band, C-Band, C-Band
1800	SUL	n80	Extended GSM,

Table3: Frequency range 2 (FR2) for 5G above 6 GHz

Frequency (GHz)	Band	Common Name
28	n257	LMDS
26	n258	K-band
39	n260	K-band
28	n261	Ka-band

The design and production of antibodies have been made easier over the years with the advent of microstrip patch antennas. It was first introduced in 1953. In the 1970s, a microstrip patch antenna was initially developed as an experimental antenna by Munson and Howell [10]. Microstrip Antennas If the radiating patch is on one side of a substrate and a ground plane is on the other, then such a patch is referred to as a Microstrip Antenna. [11], [12]. It provides superior performance results compared to traditional antennas because of the added advantages, including ease of fabrication, low fabrication cost, less complexity, and easy integration with integrated microwave circuits. However, it has some drawbacks, such as low gain and bandwidth. This can be compensated for with the help of a huge substrate that has lower values of dielectric constants.

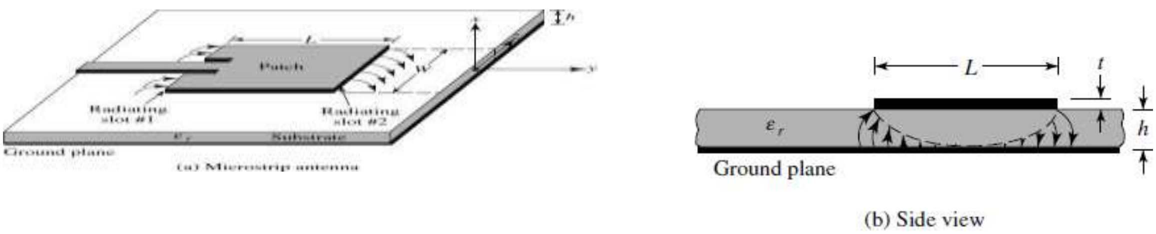


Fig.1. Microstrip antenna structure and its side view

The introduction of sub-6 GHz and the development of 5G are considered in Section 1. Section 2 considers the microstrip patch antenna design equation of the transmission line model and the different feeding techniques. Section 3 explains how the slot-loading method is used to obtain compact antenna sizes, and various review papers are discussed. Section 4 presents the conclusion.

1. Rectangular patch antenna design:

The design of the antenna shown in Fig.1 (a) is a very fine metallic strip lying a small portion of a wavelength over a plain of ground. The size of the rectangular patch antenna determines its frequency and input resistance. If the width of the antenna is too small, it becomes a microstrip line and does not function as a radiator. Typically, the length of the patch to the basic TM10 mode incitement is slightly less than the of the wavelength of the dielectric medium, that is, λ where is the wavelength in free space, because of free-space wavelength [11]. Fig.1 (b) illustrates a dielectric material (called substrate) that isolates the ground plane [12]. The gain of the patch antenna is between 5 and 6 dB and offers a 3-dB beam width between 70° and 90° [12][13]. The substrate material properties and patch size depend on the frequency at which the patch is used. The characteristics of the substrate material (different permittivity and loss tangents) can also be selected to improve the performance of the antenna. To achieve a high gain and reduce power losses, a substrate with a low relative permittivity and low loss tangent should be selected.

Table 4. shows the different substrate materials and their properties. The following equations [14][15] can be used to compute the design parameters of the patch.

Table 4. Properties of typical substrate materials [16]

Features	RO-4003	RO-4003	Fr4
Dielectric coefficient	2.2	3.4	4.4
Surface resistivity (Mohm)	2×10^5	4.2×10^9	3×10^7
Water absorption (percentage)	0.02	0.06	0.25
Peel strength (N/nm)	2	1.05	9
Loss tangent	0.0004	0,002	0.013
Tensile strength (MPa)	450	141	310
Breakdown voltage	60 kV	-	55 kV
Density (kg/m^3)	2200	1790	1850
Volume resistivity (M-Ohm.cm)	2×10^7	1700×10^7	8×10^7

The design parameters of the patch can be calculated by the following equations in [17][18].

a) Height of the patch

$$h=\frac{0.3c}{2f\sqrt{\epsilon_r}} \quad (1)$$

Where $C = 3 \times 10^8$ m/s, ϵ_r = dielectric constant of the substrate

b) Width (W) of the patch

$$w = \frac{c}{2f}\sqrt{\left(\frac{2}{\epsilon_{r+1}}\right)} \quad (2)$$

W= the width is in millimeter (mm)

c) Effective dielectric constant (ϵ_{reff})

The effective dielectric constant is a factor that must be considered when designing a rectangular patch antenna. When the radiating patch waves travel in the direction of the ground plane, they travel through the air, and owing to the fringing effect, some of the waves escape the substrate. The value of the dielectric materials differs for different media. The effective dielectric constant must be computed because the electromagnetic wave is traveling. The effective dielectric constant can be calculated using the following equation:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \quad (3)$$

Where, ϵ_{reff}= Effective dielectric constant, h= height of the patch, and w=width of the patch

d) Patch length

e) Length expansion is the extra length at the end of the patch owing to the fringing field along its width. The length expansion was calculated using the following equation:

$$L = 0.412\frac{[\epsilon_{reff}+0.3][\frac{h}{w}+0.264]}{[\epsilon_{reff}-0.258][\frac{h}{w}+0.8]} \quad (4)$$

Where ΔL is the patch length expansion, w and h are the width and height of the patch, respectively, and is the effective dielectric constant of the substrate.

f) Effective patch length (Leff)

The effective path length was calculated using the following formula:

$$L_{eff} = \frac{c}{2f\sqrt{\epsilon_{reff}}} \quad (5)$$

Where ϵ_{reff}= Effective dielectric constant

g) Actual length (L) of the patch

$$L = L_{eff} - 2L \quad (6)$$

Where Leff= Effective patch length

h) The ground plane dimensions

$$L_g = L + 6h \quad (7)$$

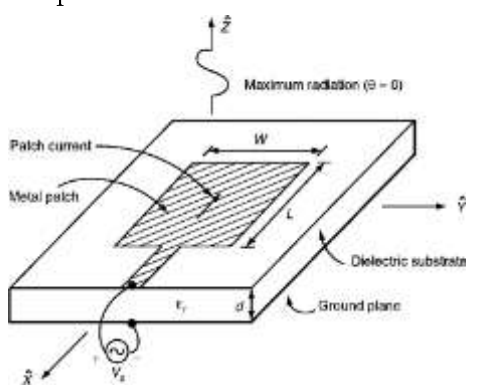
$$W_g = W + 6h \quad (8)$$

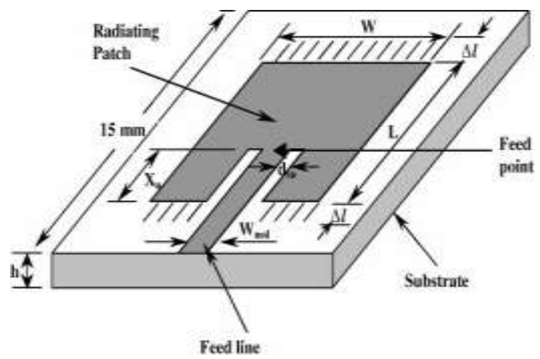
Where W is the patch antenna's width and L is the patch antenna's length.

2. 1 Feeding techniques of Microstrip patch antenna

Feeding methods improve various antenna qualities, such as bandwidth, radiation pattern, gain, impedance, and polarization. These electromagnetic waves are guided through a feed that runs between the source and the bottom of the patch. Part of this energy escapes into space at the border of the patch. Feeding can be divided into two types: contacting and non-contacting. The power of the input radio frequency is directly supplied to the patch by an attached section, such as a microstrip line, in the contacting technique. In the non-contacting method, which is an indirect method, electromagnetic field coupling transfers power in the mid-plane of the microstrip line and the patch that is radiating. Coaxial feed, microstrip line, aperture, and proximity coupling methods are popular feeding methods used in microstrip patch antennas. An outline of each feeding method is provided in this section.

Microstrip Line Feed





(a) (b)Fig.2. (a) Microstrip Antenna using Microstrip Line. (b) Microstrip Antenna using inset fed

A conducting strip [19] is attached to the side of the patch antenna. This grouping provides a planar construction. In most cases, the conducting element is narrower than the patch antenna. Owing to these drawbacks, it is possible to form large arrays with edge-fed patches. The radiation of the feed line is a source of insufficiency, leading to cross-polar plane growth. This was achieved by controlling the inset positions, as shown in Fig. (b). To achieve proper impedance matching without the need for additional matching components, a cut into the patch may also be applied to the patch in the feed position. This is attained by appropriately managing the position of the inset. This feeding technique is simple because of the simplicity of fabrication and modeling and matching of good impedance.

a) Coaxial Probe Feed

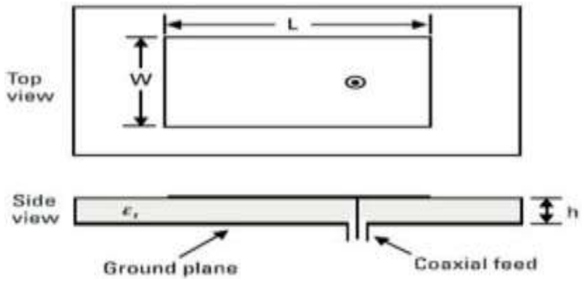


Fig.3. Coaxial Probe Feed

The coaxial Probe Feed method is easy to assemble and generates less spurious radiation. The outer conductor of the coaxial connector was connected to the ground plane. However, the inner side of the coaxial cable is stretched over the dielectric and attached to the radiating part of the antenna. The great advantage of these methods is that they can be positioned at any preferred location on the inner part of the patch to properly match the input impedance. However, its major weaknesses are that it provides a lower bandwidth and inadequate radiation. This feeding arrangement creates an asymmetrical arrangement that is not entirely planar. For thick substrates, as the coaxial feed length increases, it provides unwanted radiation, causing the input impedance to be more inductive.

b) Proximity Coupled (Electromagnetically) Microstrip Feed Technique

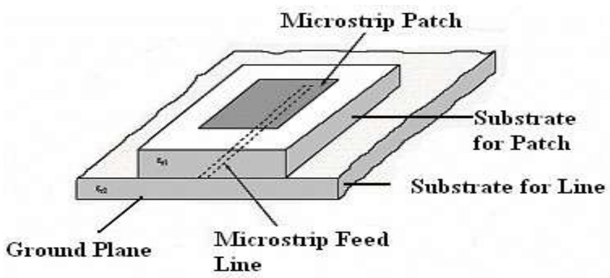


Fig.4. Microstrip Antenna fed by Aperture Coupled Microstrip Feed

This arrangement demonstrates a non-contact feeding method. Proximity-coupled feed methods are also known as electromagnetic coupling methods. It used two dielectric substrates, the feeding line was laid through the center of each substrate of the two levels, and the radiating patch was on the higher of the two levels, as shown in Fig.4. This method involves the use of two dielectric layers. A radiating patch is used in one of the layers, and the ground layer on the back is produced on the lower layer. [19]. Using the common ground plane, the two dielectric substrates are isolated from each other. A slot aperture on the common ground plane is used to provide an electromagnetic connection between the patch and microstrip line on the bottom substrate. Through an adequate choice of the slot dimensions, the performance parameters can be improved. The radiation from the open part of the feed line does not affect the radiation pattern of the patch owing to the shielding effect of the ground structure. [18].

c) Aperture Coupled Microstrip Feed

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In this feeding method [14], a hole or slot is cut in the ground surface to connect the radiating patch and feed line. The size of the opening in the ground plane affects the coupling variation. This will change the results of the performance parameterization, such as bandwidths and return losses. The coupling slot is typically located in the middle of the patch. The uniform configuration improved the cross-polarization. The aperture can be resonant or not. Choosing two different substrate materials for the two layers can improve the performance parameters.

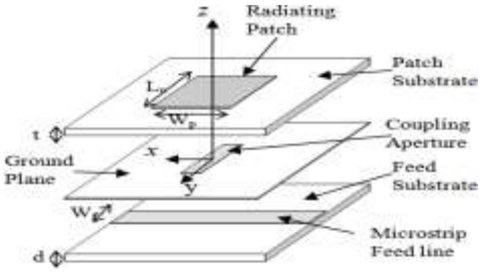

Fig.5. Coupled Microstrip Feed method

Table5: A comparison table between different methods of feeding [20]

Feature	Microstrip feed line method	Co-axial Feed method	Proximity coupled feed method	Aperture coupled feed line method
Bandwidth achieved	2-3%	2-3%	3-5%	3-5%
Impedance matching	Convenient	Convenient	Difficult	Difficult
Ease of fabrication	Convenient	Difficult	Difficult	Difficult
Reliability	Better	Poor	Good	Good
Spurious feed radiation	More	More	Minimum	Less
Modeling	Tough	Facile	Facile	Facile

2. Review of Compact Microstrip patch antenna for sub 6Ghz

Every day, communication technologies improve. The tools used in these technologies are becoming smaller. Manufacturers use different methods to increase the bandwidth without increasing the size. These include the Stacked Shorted Patch, Shorted Patch, Slotted Ground Plane, and Slot-Loading methods. This study examines how the slot-loading and slotted ground plane techniques can be used to miniaturize antennas.

a.) The slot-loading method makes the system more compact. The current path length on the patch increases when a slot is used on the patch. This increases the bandwidth and decreases the size. The antenna structure measured 20 × 30 × 1.5. The designed antenna structure has three slots on the patch, which are arranged on a steeped rectangular radiating part with three slots and a broken ground plane. Printing was performed on both sides of the FR4 dielectric substrate. This structure uses slots that connect to the ground plane to obtain a good gain, efficiency, and a wide range of frequencies, from 3.15 to
5.55 GHz, and an omnidirectional pattern to cover sub-6 GHz, WLAN, Wi-Fi, and LTE bands [21].

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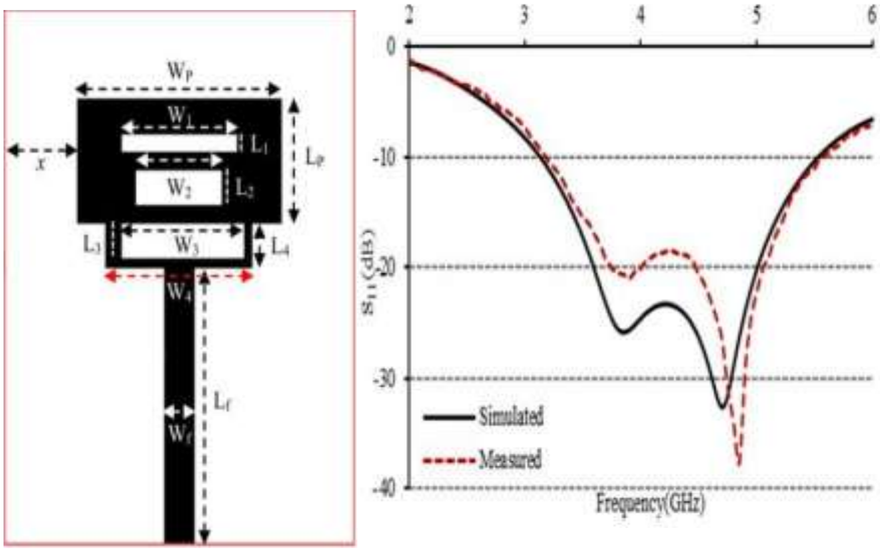
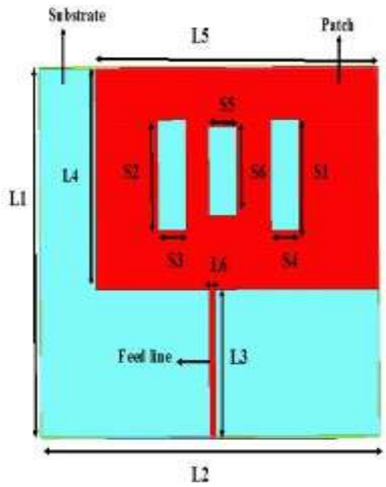


(a) (b)

Fig.6. (a) Antenna structure, and b) Return loss of the antenna vs. frequency [21]

A different review paper on slot-loaded microstrip antennas was examined [22]. The results show that using three slots on the patch makes it small and provides a wide bandwidth. The antenna was 50 × 30 in size. The antenna was fabricated on a Rogers 5880 substrate, which was 1.57 mm thick and had a permittivity of 2.2. The antenna operates at two frequencies: 3 and 3.3 GHz. At 3 GHz, the antenna gain is 4.7 dB, and at 3.05 GHz, the reflection coefficient is -22 dB, and at 3.3 GHz, it is -16 dB.



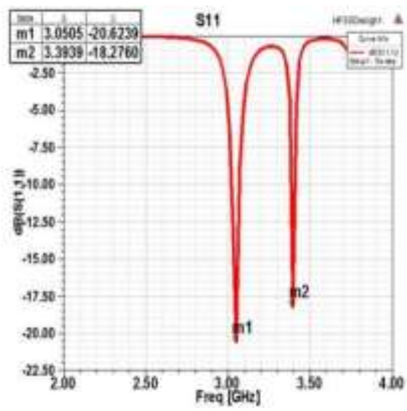
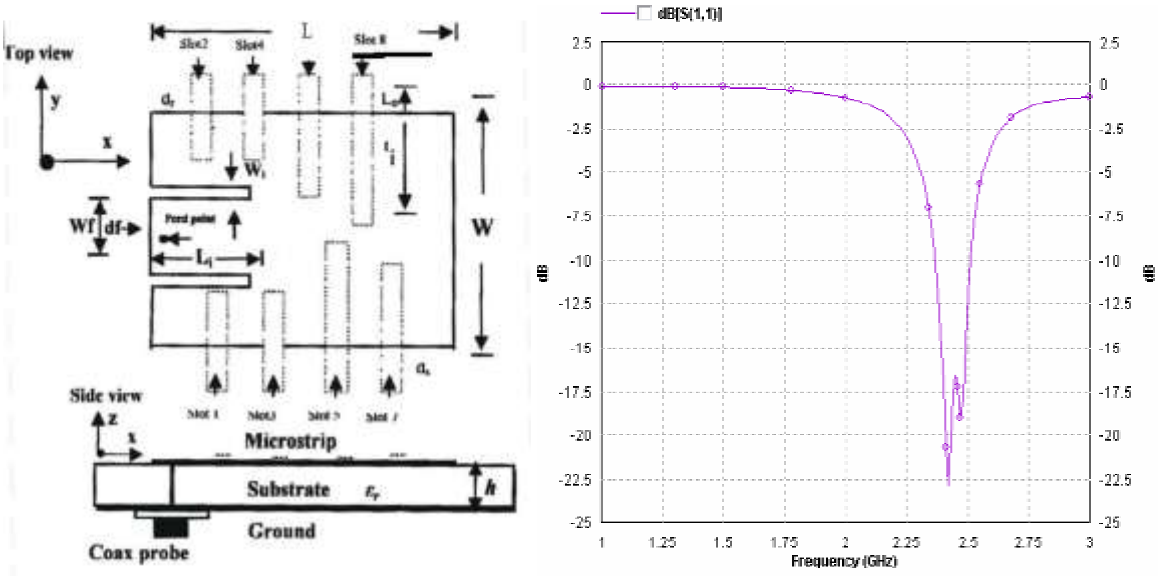


Fig.7. (a) antenna Structure, **Fig.7** b) The return loss of the antenna vs. frequency [22]

In another study, four slots in the ground plane were used to enlarge the excited plane current in the ground plane. This enhances the antenna performance and reduces its size [23].



(a) (b)

Fig.8. (a)Antenna structure, and (b) Return loss of the antenna vs. frequency [23]

b.) Compactness and wide bandwidth are achieved by cutting a polygon with six segments and a polygon slot with 18 segments. The antenna is modest in size but has a 700 MHz bandwidth. For wireless applications, the antenna may cover the 5G NR sub-6 GHz n77 and n78 bands. [24].

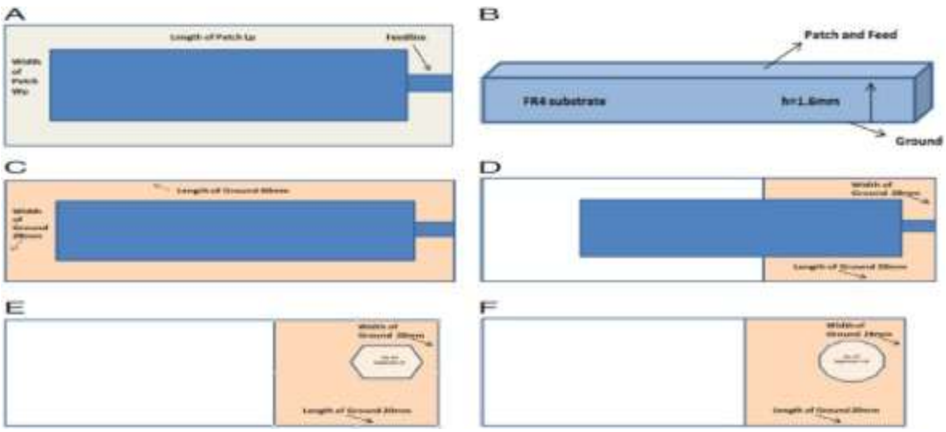


Fig.9 (a) Antenna structure

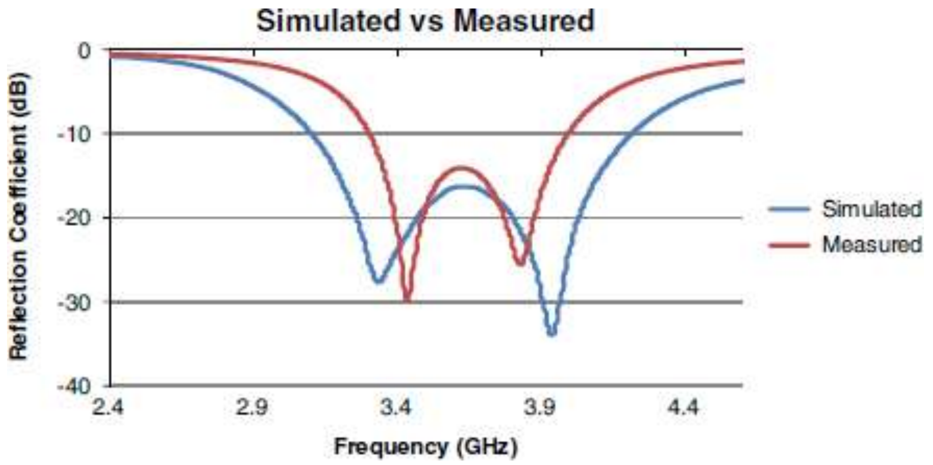


Fig.9 (b) Return loss of the antenna vs. frequency [24]

c.) A T-slot was used to load the patch in another study antenna. This improves the radiation properties of the antenna. The T-slot adds impedance to the design, which, when placed appropriately, provides the antenna with its radiation properties. The ground structure of the antenna has certain C-slot structures. Microstrip patch antennas for ISM band applications use slotted ground planes. The antenna is designed for wireless communications below 6 GHz and resonates at 4.96 GHz [25].

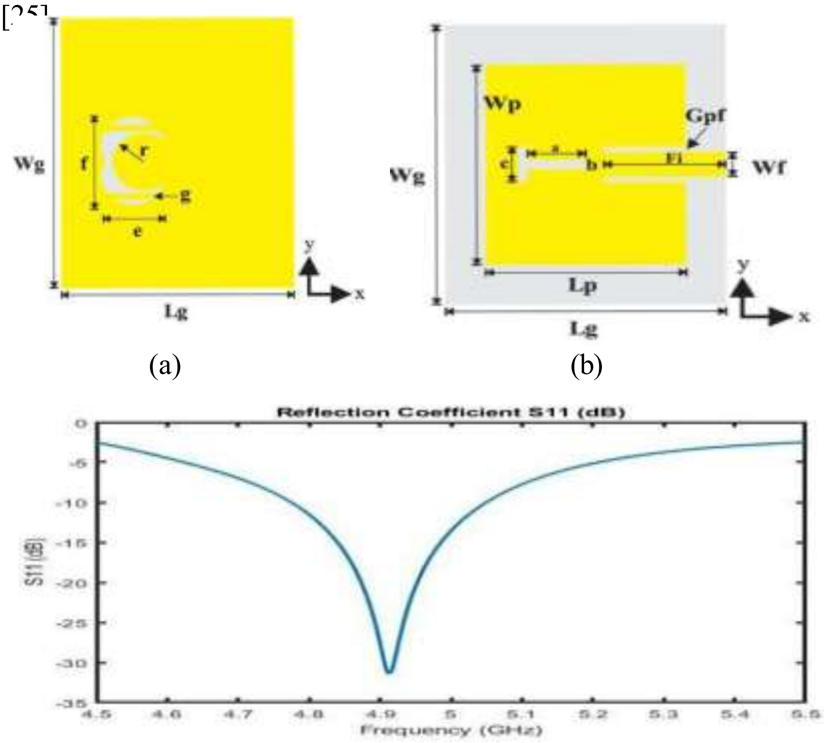


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Fig.10. (a) Top view Antenna (b) Ground plane of Antenna (c)Reflection coefficient (S11) of the antenna [25]

In another study [26], a slotted hexagonal microstrip patch antenna was studied. The antenna is small because a hexagonal patch is cut, and circular holes are loaded between the patches. The antenna resonates at a frequency of 3.5 GHz, and its results include a reflection coefficient of -42.18 dB and a good bandwidth of 550 MHz, which is applicable for sub -6 GHz wireless communication.

(a) (b)**Fig.11.** (a)Antenna structure (b) Return loss of the antenna vs. frequency [26]

Table 6: Comparison analysis of different types of antennas for sub-6 GHz applications

Ref	MPA Configu ration	Feeding mechanism	Mate rial	Permittivi ty	Freq.	Gain (dbi)	Retu rn loss	Applica ti on
[26]	Slotted hexagon al patch antenna	Microstrip line	Fr4	4.4	3.5	3.93	-42.18	Wireless applicat io n
[27]	Bus shaped Microstr ip patch antenna	Inset feed	PET	3	5.3	5.9	-26.76	Wireless applicat io n
[28]	Compac t Microstr ip patch antenna	Coaxial feed	RT-duroid	2.33	3.5	6	-24.51	WiMax
[29]	Microstr ip Patch array	Microstrip line	Rogers Duroid RT-5880	2.2	3.8	13.2	NA	WiMax and UAV applicat io ns
[30]	Multiba nd inverted E and U-shaped compact antenna	Microstrip line	Fr4	4.4	0.77, 1.43, 2.13, 3.48, 3.84, 5.17, and 6	1.1, 1.3, 1.1, 1.6, 1.7, 1.8, and 2.2	-20.2, -14.5, -11.5, -15.5, -16.2, -10.5,	Digital Broadcast ing, Medical telemetry, WLAN, WiMAX, Sub 6 GHz 5G

							-16.2	
[31]	Microstrip patch antenna	Microstrip line	Rogers RT-5880 Substrate	2.2	NA	NA	−18.2 dB	WiMax

4. CONCLUSIONS

A study of antennas that operate below 6 GHz for 5G communication has been completed. Researchers are more interested in the appearance and performance of antennas. It was found that the shape and location of the slots on the patch or ground can affect the gain, bandwidth, and radiation losses. To make 5G antennas smaller, a new method for loading them onto the patch or ground was used. This lowers the resonance frequency and reduces the antenna size..

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